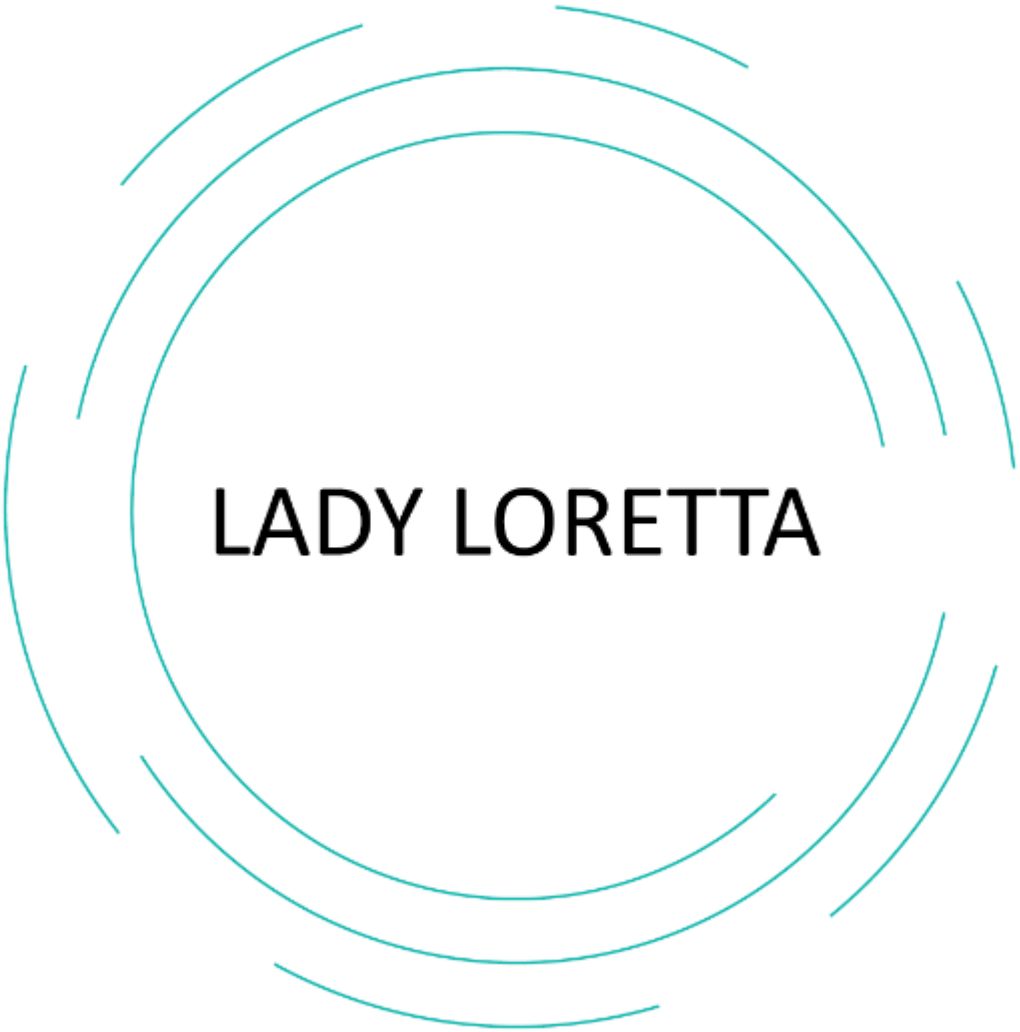
LADY LORETTA
A GLENCORE Company



Z-LLM-HSEC-PLN-Progressive Rehabilitation and Closure Plan

Cover Page

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1. INTRODUCTION

1.1. SCOPE AND OBJECTIVES

This Progressive Rehabilitation and Closure Plan (PRCP) has been developed for the Lady Loretta Mine (LLM). LLM is owned and operated by Noranda Pacific Pty Ltd, a subsidiary of Glencore plc (Glencore). The PRCP has been developed to meet the specific requirements of the *Progressive Rehabilitation and Closure Plan Transition Notice* (the PRCP Transition Notice) issued by the Queensland Department of Environment and Science (DES) on 18 September 2020, as well as requirements outlined in the LLM Environmental Authority EPML00982013 (the EA) and the *Progressive Rehabilitation and Closure Plans Guideline* (DES, 2021).

This PRCP comprises two main components:

- **Rehabilitation Planning** – Description of site characteristics and surroundings, regulatory requirements, stakeholders, post-mining land use, rehabilitation goals, rehabilitation methodology, site closure design risk assessment and monitoring program, and
- **PRCP Schedule** – Schedule of progressive rehabilitation activities and milestones.

The purpose of this PRCP is to provide details of the activities and resources required for the progressive rehabilitation, decommissioning and closure of all components of LLM during operations, closure and post-closure of LLM.

1.2. LEGAL AND OTHER REQUIREMENTS

1.2.1 Mineral Resources Act 1989

Resource activities are regulated through a "resource authority" under the *Mineral Resources Act 1989* (MR Act). This provides resource companies with the right to enter land and undertake the approved activity. The MR Act applies to mining leases and informs the requirement for surrender.

1.2.2 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 land within the relevant mining tenure be rehabilitated to support a suitable Post-Mining Land Use (PMLU) or managed as a Non-Use Management Area (NUMA). Any disturbed land must also be identified as a PMLU. Sections 126C and 126D stipulate the requirements for PRCPs and 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 PRCP. The EP Act also prescribes the requirements for surrendering an EA, including the preparation of final rehabilitation reports and post-mining management reports.

1.2.3 Land Outcome Document

Correspondence was received by DES on 11 January 2019, stipulating that the Post Mine Land Use Plan (PMLUP) for Environmental Authority (EA) EPML00982013, submitted to DES on 24 August 2018 has been accepted as a land outcome document (LOD). Various components of the LOD are proposed to be transitioned into this PRCP. This includes the domains and corresponding preliminary potential end land uses and various completion criteria

considered relevant at the time of developing this PRCP. The rehabilitation management methodologies primarily remain unchanged for various mine domains, including: water dams, infrastructure, Run of Mine (ROM), paste plant and batch plant area, roads, underground openings and exploration areas. Progressive rehabilitation efforts have meant various stockpiles no longer exist, e.g. LMD Stockpile and the cover material stockpile near the waste disposal trench. The proposed rehabilitation management methodologies for the waste rock emplacement (WRE) have subsequently been advanced and improvements made since the PMLUP development, with an alternative WRE landform and cover system design. LLM rehabilitation monitoring program as stipulated in the PMLUP has fundamentally remained unchanged, noting recent improvements made subject to key learnings from ongoing rehabilitation monitoring efforts. The knowledge gaps as stipulated in the PMLUP aimed to strengthen closure planning at LLM have been addressed through ongoing investigations and closure planning studies, resulting in various advancements to closure planning design.

1.2.4 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 an EA holder fails to meet their environmental and rehabilitation obligations. This act also amended the EP Act to require mining companies to develop PRCPs.

1.2.5 Guideline: Progressive Rehabilitation and Closure Plans

This guideline, prepared by the DES, contains information to assist applicants in developing a PRCP as part of a site-specific EA application for a new mining activity. The guideline also provides information to assist existing EA holders transition their mining activity to the PRCP framework. The administering authority must consider this guideline when making a decision about a PRCP schedule under section 176A of the EP Act.

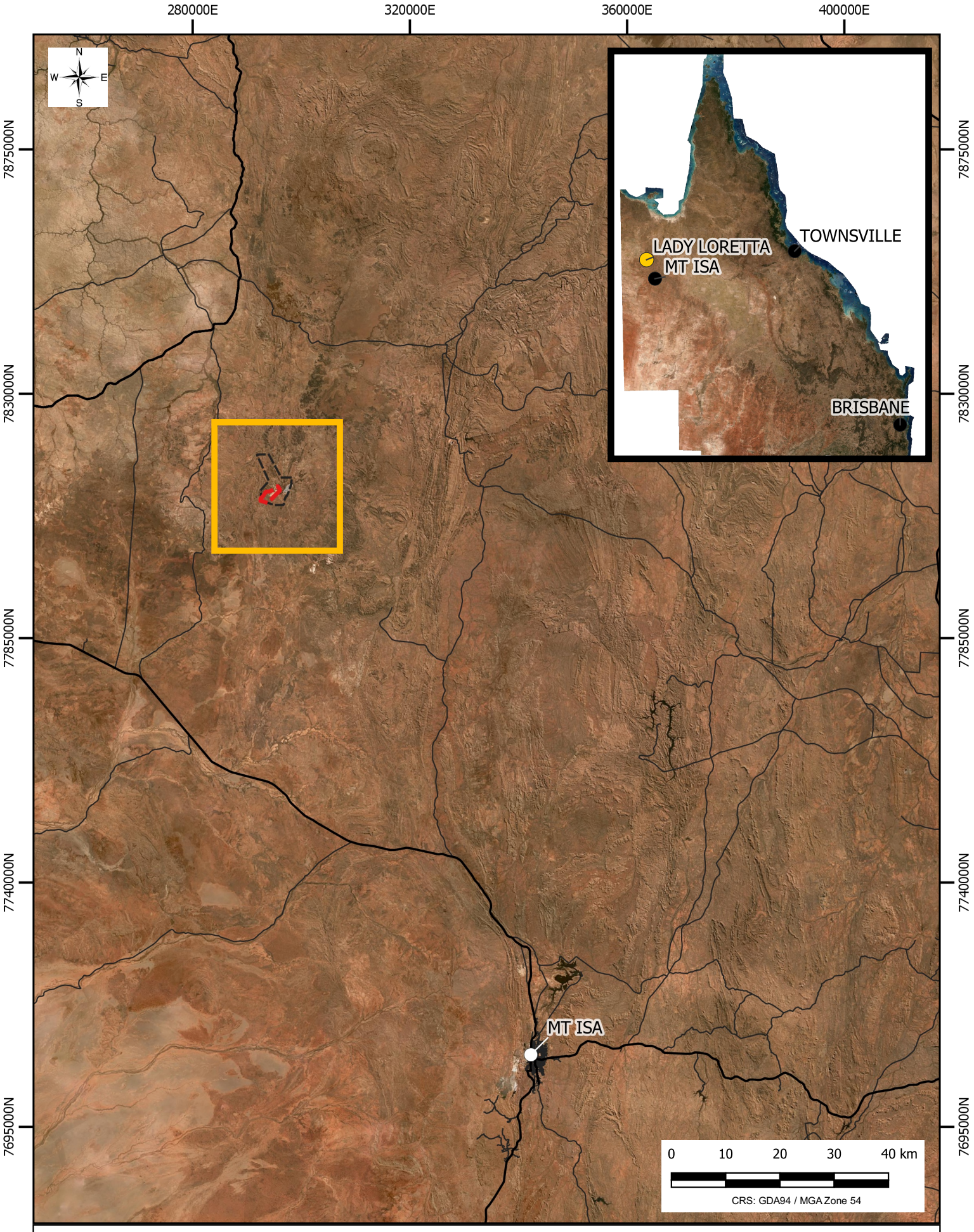
2. BACKGROUND INFORMATION

2.1. PROJECT DESCRIPTION

LLM (the Site) is located approximately 140 kilometres (km) north north-west of Mount Isa in north-west Queensland within the Mount Isa City Council (MICC) local government area. Mining Lease (ML) 5568 occupies approximately 2,783 Hectares (Ha) and was granted in 1984. Of this, approximately 140 Ha has been disturbed by mining activity. Immediately to the west of the Site is the Lady Annie Copper Mine (Mining Lease 90179), which is operated by a subsidiary of Austral Resources Limited.

Access to the Site is via a 53 km, unsealed road that connects LLM with the Barkly Highway.

A locality plan is presented in Figure 1.



LEGEND

- WATERCOURSE
- ROADS
- STATE CONTROLLED ROADS
- LADY ANNIE LEASE BOUNDARY
- LADY LORETTA MINE LEASE

NORANDA PACIFIC PTY LIMITED

LADY LORETTA MINE
LOCATION PLAN

FIGURE 001

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2.1.1 Tenure

LLM operates an underground zinc, lead and silver mine on ML5568.

Land tenure details are shown in Table 1 and Figure 2.

Table 1: Current Tenement Details

Lease	Lease Area (Ha)	Expiry Date	Background Landholder	Lot/Plan
ML5568	2,783	21 January 2026	Noranda Pacific	Lot 1 (Crown Plan UN6) County Undilla Parrish Burburgate

2.1.2 Surrounding Landholdings

The entirety of ML5568 is surrounded by the Thorntonia Station pastoral lease. The nearest inhabited dwellings are:

- Thorntonia Station, 33 km to the north north-west,
- Carlton Hills Station, 54 km to the south-east,
- Capricorn Copper Mine accommodation camp (located in previous township of Mount Gordon), 35km to the east,
- Lady Annie Camp, 17 km to the south-east, and
- Koolamara Station, 19 km to the south-east.

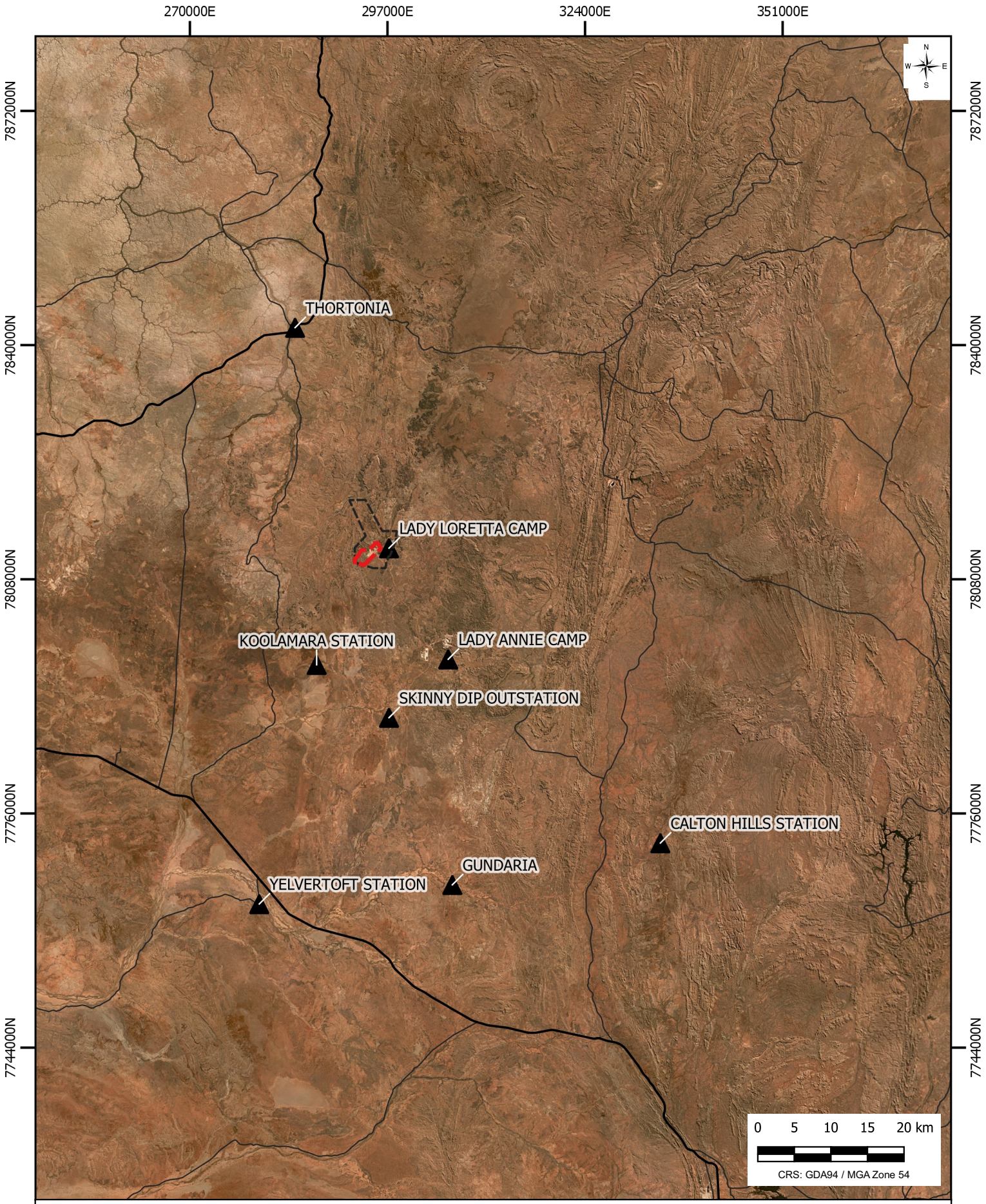
Additional neighbouring landholdings are: Skinny Dip Outstation, Gundaria, and Yelvertoft. Station locations are shown in Figure 2.

2.1.2.1. Traditional Owners and Cultural Heritage

LLM currently engages with both the Kalkadoon Community Pty Ltd (Kalkadoon) and Indjilandji/Myuma Pty Ltd.

An archaeological survey of LLM and immediate surrounds was undertaken in 1981 by Hill, with more recent assessments undertaken in 1998 and 1999 by Dr Luke Goodwin and Ian McNiven. LLM operates in accordance with the existing Commercial in Confidence Cultural Heritage Management Plan (CHMP). The CHMP is made between the Kalkadoon claimants and Noranda Pacific. Cultural heritage matters are dealt with in accordance with the arrangement of the CHMP.

A European Heritage Investigation undertaken in 2000 (Heritage Management Consultants Pty Ltd; cited in Xstrata Zinc, 2012) reported exploration activities at the LLM deposit over the past 30 years involving construction of a variety of features (e.g. access tracks and drill pads). These sites were not considered significant to the European heritage of the region due to the relatively recent age a.



LEGEND

- RESIDENCES
- LADY LORETTA MINE LEASE
- LADY ANNIE LEASE BOUNDARY
- ROADS
- STATE CONTROLLED ROADS

NORANDA PACIFIC PTY LIMITED

LADY LORETTA MINE
MINING TENURE

FIGURE 002

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2.1.3 Site History

A summary of the operations and key timeline events of LLM are outlined below:

1968: Placer Prospecting Pty Ltd and Triako Mines NL discover lead, zinc and silver mineralisation.

1987: Exploration activities begin with a 468 m deep concrete lined exploration shaft and exploratory drive constructed. Waste rock from the exploration was stockpiled in what is now known as the LMD stockpile.

1988: 6,500 t of ore was extracted for metallurgical testing, which was conducted off site. The ROM pad was built, along with basic infrastructure.

1996: Bulka Minerals Pty Ltd acquires LLM and its lease area.

1998: Bulka Mineral Pty Ltd enter a joint venture with Noranda Pacific Pty Ltd, owned by Mount Isa Mines Pty Ltd (MIM).

1996 – 2010: No mining activities were conducted over this time, however a Feasibility Study was completed. MIM was acquired by Xstrata plc in 2003.

2011: EA MIN101458310 was granted and mining activities commenced in October 2011.

2012: Amendments to the EA to include additional dams and biodiversity offset conditions to address State environmental offsets under the EP Act.

2013: Glencore plc acquires Xstrata plc. EA amendments lead to another EA issued by the DES, EPML00982013.

2015 – 2017: Works are temporarily suspended, with LLM entering care and maintenance.

2018: Mining activities resume in the first quarter under contractor Redpath Australia, who were awarded the LLM mining contract from Glencore in December 2017.

2.1.4 Mine Development

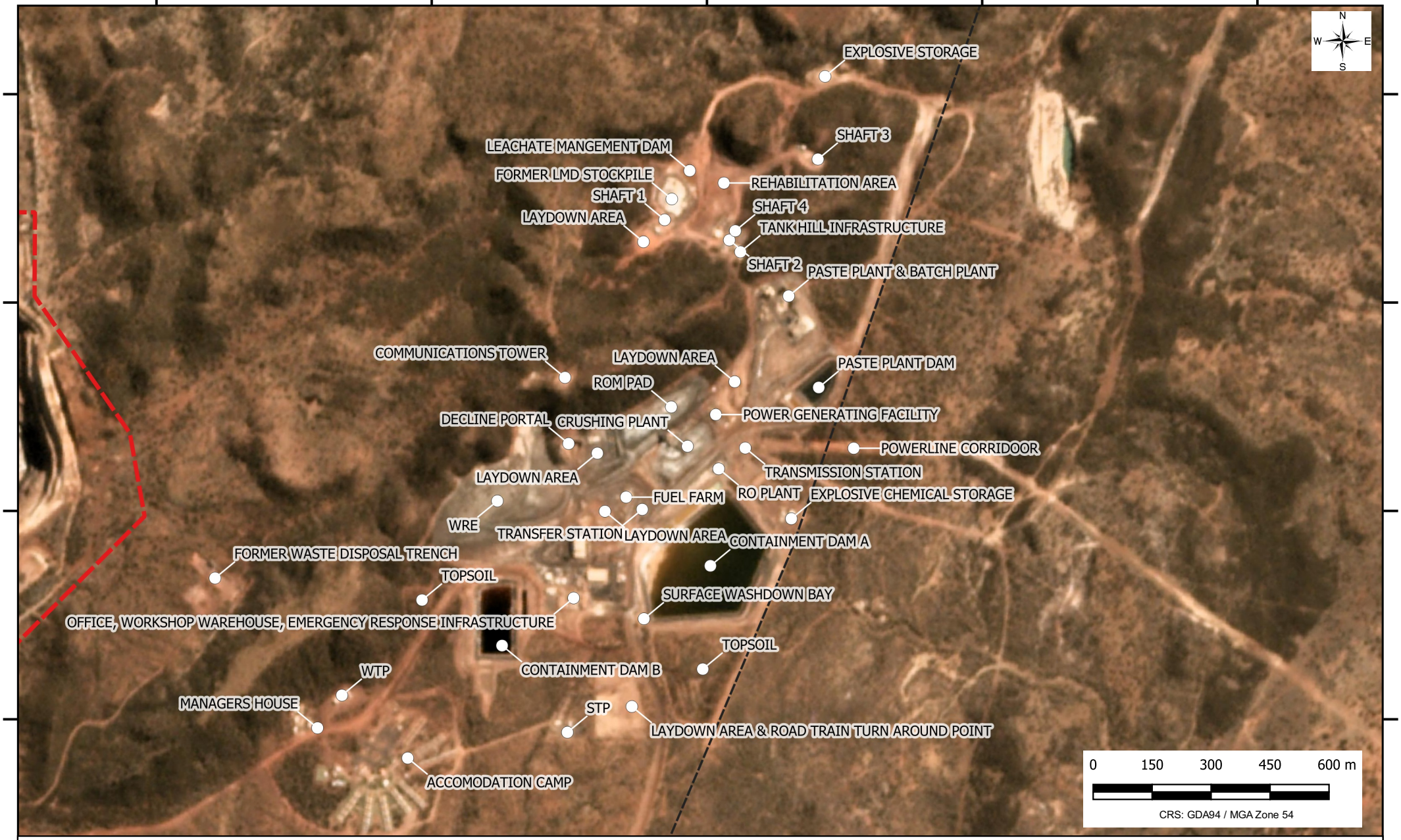
Development at the Site has centred on an underground mine from which zinc-lead ore is extracted. The underground workings have been developed to 500 m below surface and include more than 30 km of development drives. These provide access to the various stopes for drill and blast and material haulage activities. Sub-level open stoping is used as the primary mining method. Cemented paste-fill is used to backfill extracted stopes to improve safety and overall recovery of ore. Run-of-mine (ROM) ore is brought to the surface with trucks for crushing. Crushed ore is exported from the Site and transported to Mount Isa for further processing. Tailings from the Mount Isa process are back-loaded to the Site for reuse in paste preparation.

Associated development at the Site includes the following surface infrastructure:

- Access tracks and haul roads,
- Accommodation camp and Manager's houses,
- Ore stockpiles and primary crushing facilities,
- Paste-fill plant and batch plant,
- ROM Pad,
- Underground openings including access portal, decline and four ventilation shafts,
- WRE and topsoil stockpiles,
- Water management infrastructure including four regulated dams,
- Workshop, warehouse, bathhouse, administration and vehicle wash bays,

- Explosive chemical storage yard and explosive storage,
- Ventilation equipment,
- Utilities including: fuel farms, power station, transmission station, sewage treatment plant (STP), water treatment plants (WTPs),
- Waste transfer station,
- Laydown areas,
- Communications tower,
- Waste disposal trench,
- Emergency response training ground, and
- Airstrip.

A layout of the Site including the location of major infrastructure is provided in Figure 3.



LEGEND

- LADY LORETTA MINE LEASE
- LADY ANNIE LEASE BOUNDARY
- SITE FEATURES

NORANDA PACIFIC PTY LIMITED

LADY LORETTA MINE
SITE LAYOUT

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FIGURE 003

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2.1.5 Environmentally Relevant Activities

DES, under EA EPML00982013, granted approval for underground mining activities for zinc, lead and silver on ML5568. The current EA took effect from 4 December 2018.

Activities that will, or have the potential to, release contaminants into the environment which may cause environmental harm are defined as environmentally relevant activities (ERAs) in the EP Act and are regulated by conditions documented in the EA.

Table 2 summarises the ERAs authorised by the EA.

Table 2: Environmentally Relevant Activities

ERA Number	Description
Schedule 2A, 09	Mining activity involving drilling, costeaning, pitting or carrying out geological surveys causing significant disturbance
Schedule 2A, 10	Investigating the potential development of a mineral resource by large bulk sampling or constructing an exploratory shaft, adit or open pit
Schedule 2A, 17	Mining copper ore
Schedule 2A, 18	Mining lead, silver or zinc separately or in any combination
Ancillary 07 – Chemical manufacturing, 3	Manufacturing, in a year, a total of 200t or more of any of the following, (d) explosives
Ancillary 08 – Chemical storage, 2	Storing 50t or more of chemicals of dangerous goods class 6, division 6.1 under subsection (1)(b)
Ancillary 15 – Fuel burning	Using fuel burning equipment that is capable of burning at least 500kg of fuel in an hour
Ancillary 16 – Extraction and screening, 3	Screening, in a year, the following quantity of material, I more than 1,000,000t
Ancillary –0 - Waste disposal, 2	Operating a facility for disposing of, in a year, the following quantity of waste mentioned in subsection (1)(b), (a) 50t to 2000t
Ancillary –1 - Waste incineration and thermal treatment, 2	Incinerating or thermally treating, in a year, the following quantity of general waste, (a) less than 5000t
Ancillary –3 - Sewage treatment, 1	Operating sewage treatment works, other than no release works, with a total daily peak design capacity of, (b-i) more than 100 but not more than 1500EP if treated effluent is discharged from the works to an infiltration trench or through an irrigation scheme

2.2. PROJECT ACTIVITIES

2.2.1 Life of Asset Strategy

LLM is operated pursuant to a Life of Asset (LoA) Plan made up of five programs. The programs operate in parallel with an overall objective of maximising the economic and social value of the mineral resources located at the Site. The programs that comprise the LLM LoA are:

- Resource Development,
- Capital Development,
- Asset Management,

- Mining Operations, and
- Decommissioning and Rehabilitation.

The specific duration of each of the programs that comprise the LoA are characterised by key Life of Mine (LoM) milestones that are described in Table 3.

Table 3: LoA Key Dates

LoM Milestone	LoM Plan	Context
Grant of Exploration Permit	1967 Actual	LLM Exploration Permit was granted under the MR Act in 1967. Lead-zinc-silver mineralised was first discovered at LLM in 1968.
Grant of Mining Leases	1984 Actual	The lease was originally granted as ML 8052 in 1984. It was renumbered following the passing of the MR Act.
Grant of Environmental Authority	2011 Actual	The EA MIN101458310 authorises the operator of LLM to undertake various ERAs including mining activities pursuant to the EP Act.
Commencement of Mining Operations	2011 Actual	The first campaign of mining commenced in October 2011. Low commodity prices caused the site to be placed in care and maintenance in October 2015. The current campaign commenced in March 2018.
Completion of Mining Operations	2025 Plan	The current LoA is for the current campaign of mining to be completed in 2025. Approximately 100,000 tonnes of ore reserves (proven) will remain unmined.
End of Commercial Proposition	2032 Plan	End of Commercial Proposition represents the point where the LLM Owner determines that additional investment into the Resource Development and Capital Development programs at LLM is no longer commercially viable.
End of Decommissioning Works	2035 Plan	End of Decommissioning Works represents the point where the Decommissioning and Rehabilitation program has reached practical completion. For the purposes of this PRCP, End of Decommissioning Works is scheduled to occur three years after End of Commercial Proposition.
Conversion of Regulated Dams to Erosion and Sediment Control (ESC) Facilities	2044 Plan	Decommissioning of the regulated dams will commence once underground dewatering ceases, all inventories of mine-affected waters have been removed and rehabilitation of disturbed areas has been completed. A series of ESC facilities will be constructed in the footprint of the regulated dams to capture adjacent sediment.
Surrender of the Environmental Authority	2060 Plan	Surrender of the EA can only occur after all decommissioning and rehabilitation works have been undertaken and suitable vegetation has been established on the disturbance area. LLM will be required to demonstrate that the rehabilitation success criteria have been achieved. For the purposes of this PRCP, a demonstration period of 25 years has been adopted.

2.2.2 Resource Development Program

The objective of the Resource Development program is to identify zones of mineralisation at the LLM that may be suitable for classification as an Ore Reserve.

Development of the Mineral Resources at the Site commenced in 1968 when prospectors first identified mineralisation. Since that time, LLM and its antecedents have undertaken multiple campaigns of work to improve the level of understanding of the Mineral Resources present. These have included field investigation, geo-physical survey, materials sampling and analytical testing, data processing and numerical modelling. The Mineral Resources are classified as either inferred, indicated or measured where the classification represents the level of confidence or understanding of the geological characteristics. Increasing this level of understanding is a complex activity that requires significant investment and commercial risk.

The component of a Mineral Resource that can be economically mined is referred to as an Ore Reserve. Determination of an Ore Reserve is a similarly complex undertaking that considers the risks, costs and benefits associated with extracting the ore-body and converting it into saleable products. These risks, costs and benefits are all subject to change and reflect external factors including global commodity markets. As a consequence, Ore Reserves are dynamic and a subjected to periodic review.

The Resource Development program has been in continuous effect since mineralisation was first identified in 1968. Site-based work is generally completed on a campaign basis and includes drilling, down-hole and geophysical survey. These campaigns generate significant data sets that are then analysed and interpreted remotely.

Both Mineral Resources and Ore Reserves have been declared for the Site. These are reviewed annually based on the latest available data.

The Resource Development program will continue following the completion of the current mining campaign. Mineralisation associated with the Lady Loretta orebody is extensive and highly prospective. The Resource Development program will be concluded when End of Commercial Proposition is called.

2.2.3 Capital Development Program

The Capital Development program is concerned with the construction and commissioning of the fixed plant and infrastructure required to support economic extraction of zinc and lead bearing ores at the Site.

The Capital Development program commenced in 1987 with the installation of the exploration shaft and associated facilities located at what is now known as the legacy mine area.

A major campaign of Capital Development occurred in 2011 and 2012 following Grant of the Environmental Authority. These works included:

- Mine access road,
- Initial mine development including box-cut, access decline, development drives and ore handling,
- Initial mine infrastructure package including ventilation system, high-voltage distribution, mine dewatering network,
- Initial surface fixed plant package including crushing circuit, paste plant and weighbridge,
- Initial surface facilities including administration complex, warehouse, workshops, accommodation camp, and
- Initial surface infrastructure package including power generation and distribution, fuel storage, raw water supply, potable water and sewage systems.

Since that time the Capital Development program has added to the portfolio of assets at the Site. Ongoing investment via the Capital Development program is essential to maintain the commercial viability of LLM. For example, to convert existing mineral resources to an ore reserve, suitable access and ventilation and other services would have to be installed to support a mining campaign.

The current LoA Plan requires that the Capital Development program will be concluded at the End of Commercial Proposition.

2.2.4 Asset Management Program

The Asset Management program is concerned with maintaining the various assets that comprise the LLM in good order and good standing. The program is concerned with:

- Physical assets including mobile and fixed plant, buildings, roads and ancillary infrastructure, and
- Non-physical assets including the mining leases, the environmental authority, and stakeholder obligations.

The Asset Management program was first activated in 1987 when the first fixed plant was installed at the Site. Since that time, the scope and scale of the program has been extended to match the growth of the LLM asset package.

The current LoA Plan requires that the Asset Management program remains in effect until the EA is surrendered.

Key activity types to be undertaken pursuant to the Asset Management program are discussed in the following sections.

2.2.4.1. Asset Protection

Asset protection is concerned with ensuring that the assets are not degraded by unauthorised activities such as theft, vandalism, or improper use. Asset protection is also concerned with ensuring that unauthorised persons are excluded from the Site and therefore not exposed to critical hazards.

2.2.4.2. Plant Maintenance

A key requirement of the Asset Management program is that mobile and fixed plant as well as infrastructure is maintained in a condition suitable to support the objectives of the LoA Plan.

Plant maintenance activities include:

- Routine inspection of fixed plant and infrastructure to confirm condition, operational and regulatory requirements,
- Routine activation of systems and sub-systems to maintain operability, and
- Scheduled and breakdown maintenance of systems and sub-systems.

The level of plant maintenance undertaken at the Site is a reflection of the scale, extent and utilisation of the asset portfolio. Although at a peak during active mining operations, this aspect of the Asset Management program will remain active through until Surrender of the EA.

2.2.4.3. Water Management

Water management activities at the Site are undertaken as a component of the Asset Management program. As described in Section 3.1.5.3**,** the Water Management System (WMS) has been implemented to:

- Provide a supply of water to the Site,
- Contain and manage mine affected waters that are unsuitable for release to the receiving environment, and
- Discharge excess waters including non-mine affected runoff from the Site.

Effective implementation and operation of the WMS is a key control in managing compliance risk and ensuring protection of the receiving environment at the Site. Execution of the Decommissioning and Rehabilitation program will act to mitigate and eventually diminish these risks. As a result, the manner in which the WMS is operated will evolve to reflect the prevailing risk profile of the Site. For the purposes of this PRCP, the WMS will transition through the following modes of operation:

- Operational water management,

- Transitional water management, and
- Passive water management.

2.2.4.3.1. Operational water management

The WMS is currently operated under the operational settings with a focus on supporting dewatering of the active mining area and ensuring that mine-affected waters are not released to the receiving environment. The WMS will continue to be managed pursuant to the operational settings until the following conditions have been met:

- Dewatering of the underground workings has been discontinued,
- Water quality monitoring demonstrates that surface runoff and seepage from the disturbance area is no longer mine-affected, and
- All inventories of mine-affected waters have been removed from the surface storages.

2.2.4.3.2. Transitional water management

Water management under the transitional settings will be concerned primarily with erosion and sediment control (ESC). Under the transitional settings, potential sources of contamination will have been eliminated or mitigated via engineered cover systems and/or relocation or removal of potential contaminant sources. The most significant driver of surface runoff quality will be sediment and turbidity as the water drains off disturbed areas and those recently reworked.

To manage this risk, surface runoff from the Site will be directed to ESC facilities prior to release to the receiving environment. The ESC facilities will be monitored and maintained to ensure their effective operation during this period.

2.2.4.3.3. Passive water management

As the revegetation on the disturbance area matures, the requirement for the ESC facilities will diminish and the quality of the surface runoff will be suitable for direct release to the environment. At that time, the ESC facilities will be reprofiled so that they are free-draining, and water management will become entirely passive.

2.2.4.4. Land Management

Another key objective of the Asset Management program is to ensure that the land on which the LLM is located is appropriately managed. This includes control of invasive weeds and feral animals as well as appropriate use of fire in the local landscape. Land management activities are undertaken each year generally on a campaign basis.

2.2.4.5. Stakeholder Engagement

Stakeholder engagement is also a component of the Asset Management program. LLM will continue to engage with key stakeholders regarding the development, operation and rehabilitation of the Site right up until Surrender of the EA.

2.2.4.6. Compliance Monitoring

A primary obligation of the EA is that as the operator of the Site, LLM must undertake compliance monitoring to demonstrate compliance with the specific requirements of the EA. In addition, LLM must also collect suitable monitoring data to demonstrate that the works undertaken pursuant to the Decommissioning and Rehabilitation program have been effective and that the success criteria can be reasonably met.

The obligations to undertake compliance monitoring will remain in effect until the EA is surrendered. Specific requirements to undertake monitoring and maintenance of the Site following implementation of the Decommissioning and Rehabilitation program is provided in Section 3.14**.**

2.2.5 Mining Operations Program

The Mining Operations program is concerned with the economic extraction of zinc and lead bearing ores at the Site. The first campaign of mining occurred between 2011 and 2015. Low commodity prices caused the site to be placed in care and maintenance in October 2015. The current campaign commenced in 2018 and is scheduled for completion in 2025.

Mining operations undertaken at the Site have utilised underground mining methods to extract zinc and lead ores. Extracted stopes are typically back-filled with cemented paste fill to improve stability and increase resource utilisation. This mining strategy requires that suitable accesses to the orebody are available via haulage drives, draw-points and ventilation passages. Establishment of these accesses occurs as a component of the Capital Development program.

The Mining Operations program is facilitated by the Resource Development, Capital Development and Asset Management programs. For Mining Operations to be undertaken, suitable quantities of Ore Reserve must have been defined, and the requisite access, plant, systems and services available to allow mining to proceed at an acceptable cost.

As a result, the Mining Operations program is under constant review to ensure the commercial viability of LLM. Extensions of the Mining Operations program beyond the current campaign will be evaluated, however, for the purposes of this PRCP, extraction is due to be completed in 2025.

At the conclusion of the current mining campaign, at least three stopes will remain unmined. Stopes 950-280L and 950-980J have been declared probable while stope 1150-835L has been declared a proven ore reserve by a competent person pursuant to the JORC Code (https://www.jorc.org/). These are estimated to contain approximately 37,000 tonnes (t) of zinc and lead bearing ore.

The months leading up to the end of the current mining campaign will include preparations for the non-operations period. These preparations will include progressive draw-down and removal of:

- coarse ore and crushed ore stockpiles including deep-cleaning of the crushing and radial stacking circuits,
- pastefill input stockpile, binder inventories and deep-cleaning of the paste plant, and
- diesel fuel inventory.

2.2.6 End of Commercial Proposition

As described in the preceding section, the current campaign of mining operations is scheduled for completion in 2025. Conclusion of the current campaign will not result in draw-down of the entire ore reserve. The predicted mineral resource and ore reserve inventory for the LLM at the completion of the current campaign of mining is presented in **Table 4**

Table 4: Predicted Resources and Reserves at Completion of Current Campaign

Lady Loretta		Tonnes (KT)	Zinc Grade (%)	Lead Grade (%)
Mineral Resources	Measured	2,280	11.65	3.3
	Indicated	1,342	10.81	2.03
	Inferred	846	8.18	2.72
	Total	**4,468**	**10.74**	**2.81**
Ore Reserves	Proven	3.2	7.93	1.21
	Probable	33.4	10.38	1.75
	Total	**36.6**	**10.16**	**1.71**

Completion of the current mining campaign will not constitute the End of Commercial Proposition. Similarly, it would not trigger the curtailment of the other LoA programs. Further investment via the Resource Development program would seek to extend the Ore Reserve. At the same time, continued investment in the Asset Management program will maintain the plant, infrastructure and systems in an operable condition to support future mining campaigns.

Continuation of the LoA programs is not without cost and cannot be justified without a reasonable expectation of return on investment. End of Commercial Proposition represents the point where the asset owner can no longer support additional investment in the LoA.

For the purposes of this PRCP, End of Commercial Proposition is scheduled for 2032.

2.2.7 Decommissioning and Rehabilitation Program

The Decommissioning and Rehabilitation Program is concerned with mitigating the long-term risks presented by the implementation of the Resource Development, Capital Development and Mining Operations programs.

The objective of the Decommissioning and Rehabilitation program is to support transition to the Post Mining Land Uses and eventual surrender of EPML00982013 and relinquishment of ML 5568.

Planning and technical elements of this program commenced prior to grant of the EA in 2011 and have been reviewed and refined to reflect the Mining Operations and Capital Development programs. Site works packages have been completed on a campaign basis since 2018 and have included termination and rehabilitation of resource definition drill collars, rehabilitation of the waste disposal trench, removal of the legacy mine waste rock landform, and recontouring and revegetation of some of the disturbance area in the vicinity of the legacy mine area.

Pursuant to section 126D of the EP Act, land disturbed by mining is considered available for rehabilitation unless:

(a) The land is being used for operating infrastructure or machinery for mining, including, for example, a dam or water storage facility, or

(b) The land is identified in the proposed PRCP schedule or the application of an EA for relevant activities to which the schedule relates as containing a probable or proved ore reserve that is to be mined within 10 years after the land would otherwise have become available for rehabilitation, or

(ba) The land is required for the mining of a probable or proven ore reserve mentioned in (b), or

(c) The land contains permanent infrastructure identified in the proposed PRCP schedule as remaining on the land for a PMLU.

Progressive rehabilitation will continue to occur when areas become available, alongside the Resource Development, Capital Development, Mining Operations and Asset Management Programs. This PRCP details the activities and schedule attributable to the Decommissioning and Rehabilitation program.

2.2.7.1. Progressive Decommissioning

Ongoing development of the Site causes some of the previously installed infrastructure to become surplus to requirements or redundant. Under these circumstances, specific infrastructure becomes available for decommissioning and progressive rehabilitation. Opportunities for progressive rehabilitation are identified and resourced as an outcome of the business planning process. Being an underground operation, opportunities for progressive rehabilitation at the Site are limited. This notwithstanding, some recent examples of progressive rehabilitation are discussed in the following sections.

2.2.7.1.1. Legacy Mine Disturbance

Much of the initial development at the Site occurred in and in the vicinity of the sinking of Shaft 1 in the 1980s. Associated infrastructure including a workshop, offices, laydown areas and gravel borrows were developed in the nearby vicinity. Additional staging areas were established to support the sinking of Shafts 2, 3 and 4 as well as the tank farm and ventilation stations.

LLM commenced decommissioning and rehabilitating these areas in 2019 with excavation and removal of mineralised material, placement of inert fill in excavations, recontouring, construction of clean water diversion drains, diversion berms and associated rock erosion protections, growth media application and ripping and seeding works (Engeny, 2020). To date, approximately 1 Ha of this legacy mine disturbance area has been rehabilitated including revegetation.

The sinking of Shaft 1 also yielded mineralised waste rock that was stored in an emplacement area known as the LMD Stockpile. Surface runoff and seepage from the emplacement was mine-affected and was collected in a regulated dam (Leachate Management Dam; LMD) for interim storage and management. The LMD Stockpile was reclaimed and removed to the main WRE in 2021 as a risk reduction measure.

2.2.7.1.2. Exploration Disturbance and Access Tracks

Development of the Site has included in excess of 240 mineral drill-holes developed as a component of the Resource Development program. These disturbances present various long-term risks including drill holes acting as pit-fall traps for livestock and wildlife and disturbance areas presenting opportunities for invasive weeds to establish. Drill-holes are installed to gather geological data. They are typically maintained in an open state to allow for follow up investigations which may include hole extension or down-hole survey. In most circumstances, all useful data is extracted from a drill-hole within two to three years of installation and then they may be available for rehabilitation.

Drill holes are decommissioned and rehabilitated by cutting the collars below ground level and inserting plugs. The drill pads, sumps and access tracks are then reprofiled to conform with local terrain before being revegetated. To date, more than 200 drill-holes have been decommissioned and rehabilitated. LLM maintains a register that details the status of all drill-holes that have been installed at the Site.

2.2.7.1.3. Waste Trench

LLM operated a relatively small landfill at a site known as the waste disposal trench. The waste disposal trench received non-regulated waste streams generated at the Site. No chemicals, putrescible or other type of regulated waste has reportedly been placed in the waste disposal trench. Solid waste material was removed from the waste disposal trench in August 2020 to prepare the site for backfill with the adjacent bund and stockpiled cover material. A review of the landfill inventory undertaken prior to rehabilitation works describe the waste materials as poly pipe, plastics (chairs, reels, pallets), concrete fragments, scrap car parts, metal framework, empty fire extinguisher cases contained in IBCs and metal crates, cardboard, wooden pallets and tree cuttings. The waste disposal trench was decommissioned and rehabilitated in 2020. Works included backfilling, recontouring and installation of ESC facilities. Revegetation works were completed on the disturbance area in late 2021.

3. PRCP – REHABILITATION PLANNING

3.1. PROJECT PLANNING

3.1.1 Baseline Information

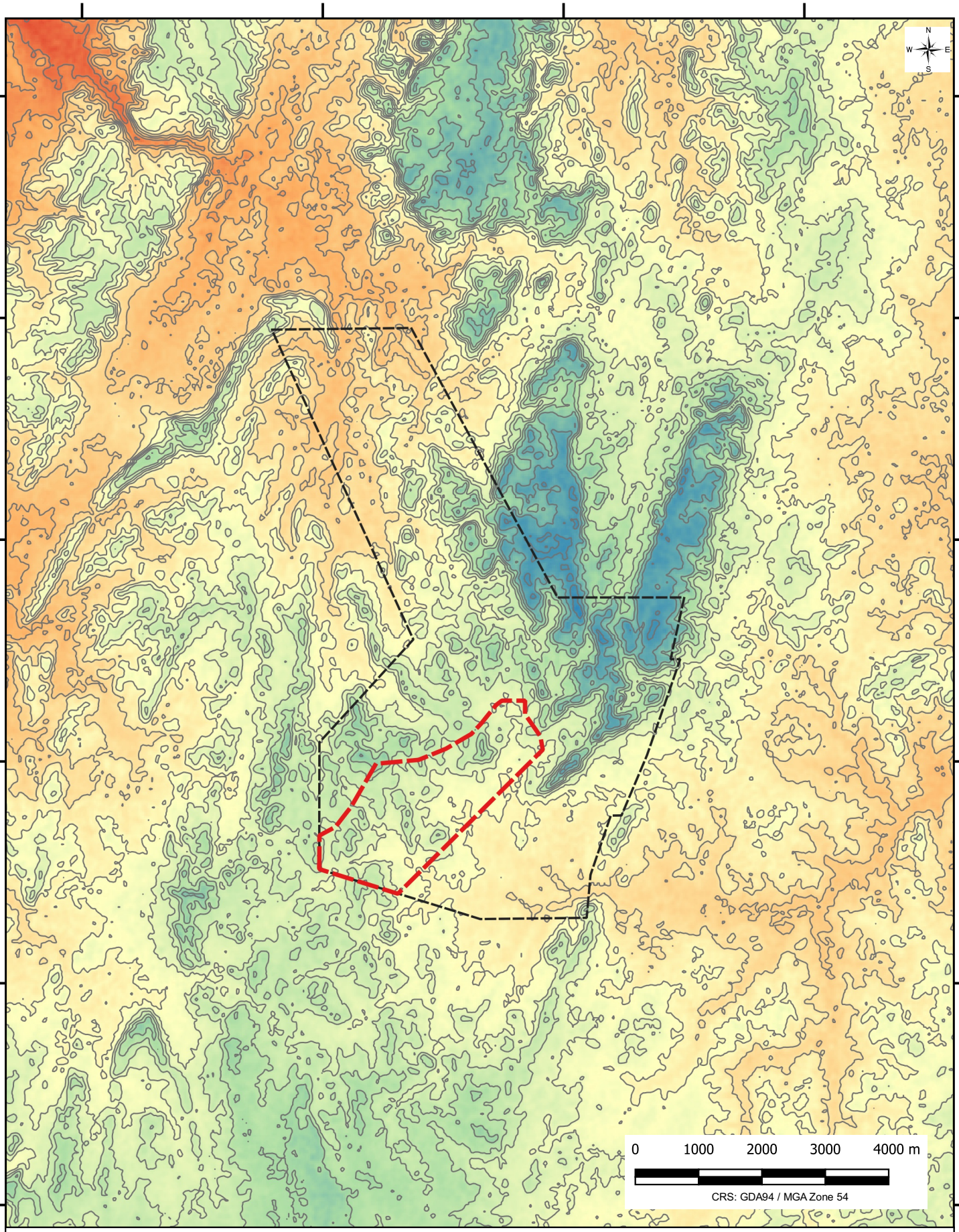
3.1.1.1. Topography

Topography of the mine is dominated by the “Big Syncline”. The eastern limb of this syncline forms the main ridgeline at LLM. The ridgeline is orientated in a north-east to south-west direction. Elevations across the mine vary from approximately 380 m Australian Height Datum (AHD) to 320 m AHD.

Most of the mine infrastructure is located on the edge of a ridgeline, occupying levels between 325 m and 335 m AHD at typically low gradients, less than 3% slope. The steepest gradients found at LLM are approximately 40% to 50% on the hill slopes of the Big Syncline.

To the east, south-east and north-east of LLM the topography flattens and is dominated by undulating plains with occasional lower hills and ridgelines (Noranda Pacific, 2000).

Regional topography is shown in Figure 4**.**



LEGEND

- LADY LORETTA MINE LEASE
- LADY ANNIE LEASE BOUNDARY
- 10m CONTOURS

ELEVATION (RL m)

- 245
- 283
- 322
- 360
- 398

NORANDA PACIFIC PTY LIMITED

LADY LORETTA MINE
TOPOGRAPHY

FIGURE 004

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3.1.1.2. Climate

The area experiences a semi-arid climate with distinct wet and dry seasons. The wet season is generally from December to March and is characterised by heavy rainfall in short bursts. The dry season spans April to October with little to no rainfall during this season.

Climate data from 1960 to 2018 derived from rainfall records from the Lady Annie Mine Gauge (029172), Carlton Hills Station Gauge (029118) and Flora Downs Station Gauge (037055) was obtained from the Bureau of Meteorology (BoM) SILO data drill (SLR, 2021).

The average rainfall and evaporation data are presented in Figure 5.

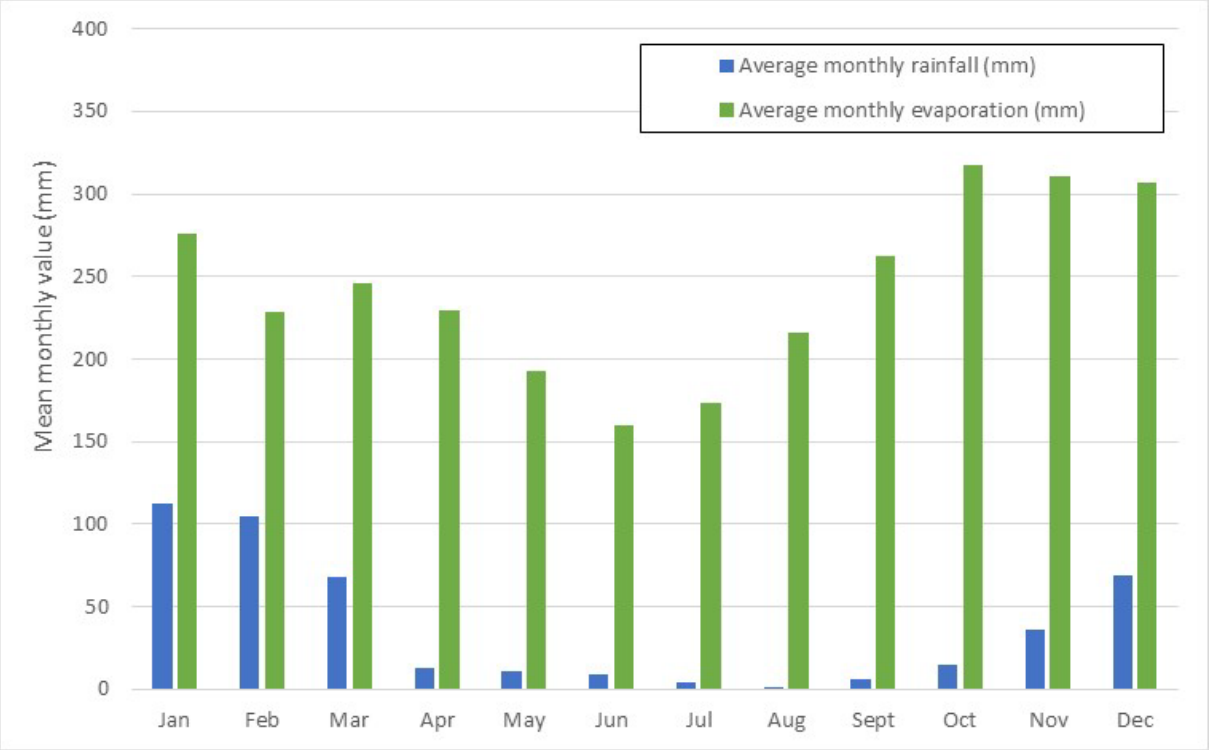


Figure 5: Climatic Conditions

3.1.1.3. Geology and Soils

LLM is situated in the Western Fold Belt of the Mt Isa Inlier. The deposit targeted by the LLM is a Pb-Zn-Ag deposit within the Mount Isa Inlier, with the ML within the Lady Loretta Formation. The deposit is considered a classic sediment-hosted base metal deposit. Sediments hosting the deposit comprise interbedded bedded siltstone, sandstone, interclastic dolomite, carbonaceous and pyritic shale. The ore horizon is a distinctive finely banded massive sulphide lens up to 50 m thick and contains pyrite, sphalerite, galena and in places barite (Noranda Pacific, 2000).

The deposit is hosted within the Palaeoproterozoic Lady Loretta Formation, which is the uppermost outcropping unit of the McNamara Group (Valenta, 2018) within the keel of the Small Syncline, a tight north-east trending fold. The Small Syncline as well as the Big Syncline are heavily faulted with a series of north-east and south trending faults.

Local geology, from Hancock and Purvis (1990), is summarised in Figure 6.

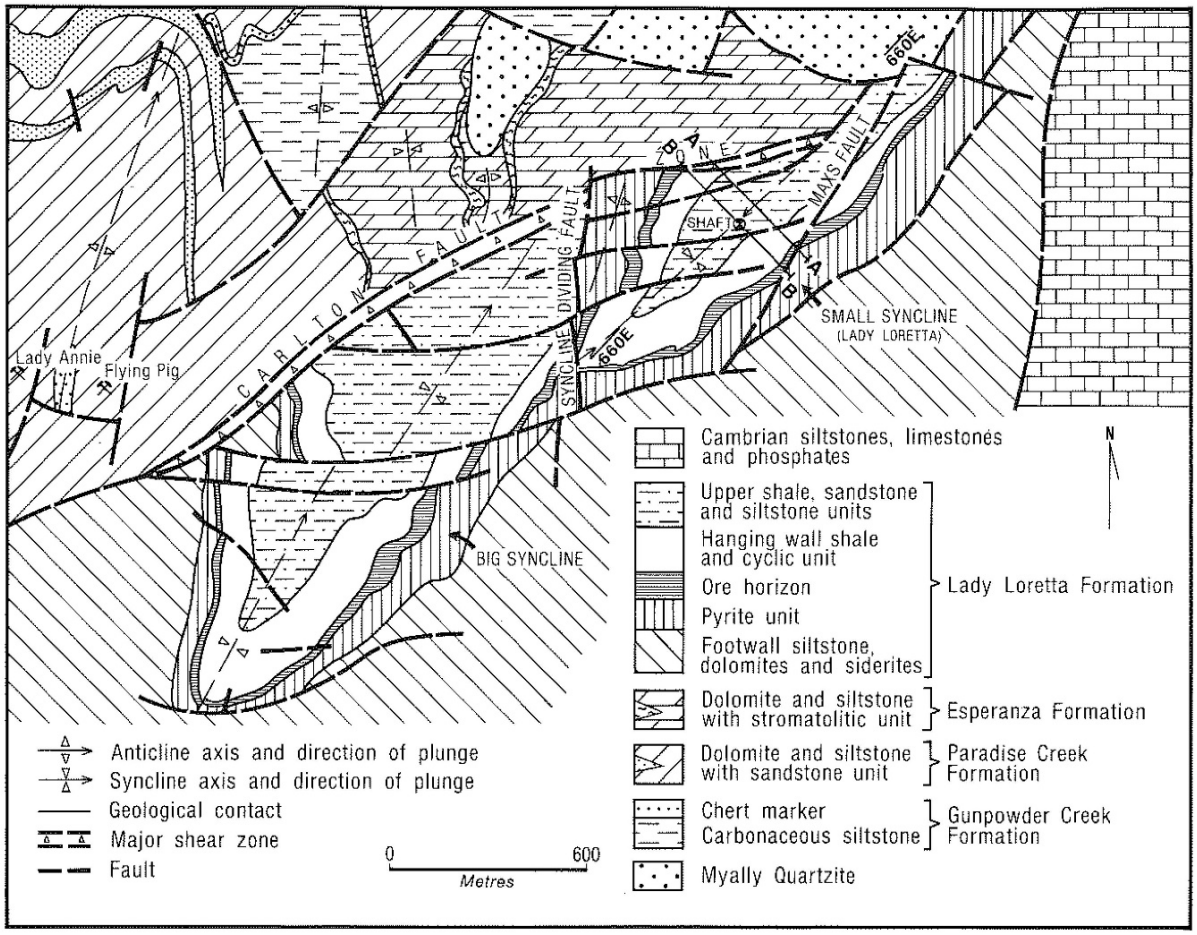


Figure 6: Plan View Geological Map of the Lady Loretta Deposit and Stratigraphic Column for the Region

The Mount Isa Soil Landscape Province is a dissected plateau of Precambrian igneous, metamorphic and sedimentary rocks. Lithosols (stony or gravelly soils lacking horizon development, other than an A1 horizon) are the dominant soils and have formed either in situ on the near vertically bedded shales, or from eroded material deposited on the lower slopes and along waterways. Lithosols typically consist of a shallow gravelly layer, containing minor silt and sand content, up to 1 m thick which grades into a fine to medium grained sandy loam (0.5 to 1 m thick). In some areas the gravelly layer grades into a silty clay loam or a silty clay (0.5 to 2 m depth) (Noranda Pacific, 2000). The soil horizons within the LLM generally contain a large proportion of coarse textured material, as well as iron and manganese nodules. Some sections (particularly the north-eastern part) have a thick 30cm layer of very fine-grained chert (Noranda Pacific, 2000). Soils along the laterite ridge above LLM site have naturally elevated concentrations of lead, zinc and silver associated with surface outcrops of the underlying ore horizon and associated pyrite bed (TropWATER, 2021).

The Mount Isa Land System, where LLM lies, has a relatively low stock carrying capacity, low pastoral potential and minimal agricultural potential. Broadly, the system consists of undulating country with spinifex pastures covering large areas, and smaller regions of woodland. The land use is restricted to exploration/mining and very low intensity stock grazing.

The Environmental Management Overview Strategy (EMOS) (Noranda Pacific, 2000) reports the Lady Loretta area to be predominantly land capability class VI on the flatter plains to the east of the deposit and the valley floors between ridgelines. On the slopes and ridges the land capability class is reported VII due to steepness of the slopes and generally shallow, rocky soils.

Emery (1985) describes capability class VI as:

- Land not suited to any type of cultivation but best used for grazing, and
- Generally comprising land with a range of physical or climatic limitations which may include shallow soils, high rock content, excess salt concentration, steep or awkward slope gradients.

Capability class VII is described as:

- Land best to remain under green timber owing to its high soil erosion hazard and severe site restrictions, and
- Generation areas of steep slopes, shallow soils and/or rock outcrop.

The strategy identifies the objective to return land disturbed by the mining activities to pre-mining land use of low intensity grazing and pre-mining capability class.

3.1.1.3.1. Site Soils

A soil sampling program was undertaken by RGS in 2020 and 2021, which included surface (grab) sampling of soils in addition to test pitting and augering. The purpose of this sampling program was to identify soil and rock units at LLM from borrow areas that will be suitable for rehabilitation of areas disturbed by mining operations.

Based on observed conditions during the investigation, the following soil horizons were identified (RGS, 2023):

Topsoil – top layer of the native soil profile recognised by higher organic carbon content, some development of soil structure, the presence of plant roots, and typically containing the soil seed bank.

Subsoil – soil layer underlying the native topsoil, typically identified by a decrease in organic carbon content and fewer (and finer) roots. The characteristics of subsoil materials vary markedly depending on the soil type. Subsoils that are not acidic, saline or sodic are a valuable resource suitable for use during the rehabilitation program. Together, topsoil and subsoil constitute growth medium as a Major RM_{UNIT}.

Weathered–clay – typically massive heavy clays with low permeability, high plasticity and increased soil strength. The characteristics of these materials vary markedly depending on the clay mineralogy and the presence of salts in the landscape. Weathered clay that is not sodic may be suitable for use as a subsoil during the rehabilitation program due to its capacity to retain water.

Saprolite – typically weathered-rock materials identified by the presence of iron and aluminium oxides. Depending on the chemistry, these materials may be suitable for use as a subsoil or rocky soil mulch layer during the rehabilitation program due to its more favourable physical characteristics when compared to the heavy clay overburden.

Saprock – typically weathered materials and partially weathered rock identified by the presence of fines (< 2 mm particle size distribution (PSD) comprising iron and aluminium oxides and residual rock fragments (from gravel to cobble size rock). Together, saprolite and saprock are generally classified as rocky soil mulch as a Major RM_{UNIT}.

Fresh rock (bedrock) – depending on various physical characteristics and benign chemistry, fresh rock may be suitable for use during the rehabilitation program as rock mulch or surface rock armouring. Fresh rock is usually classified as competent rock as a Major RM_{UNIT}.

A summary of laboratory test results, which are relevant to erosion stability modelling and general soil characteristics as outlined in RGS (2023) is provided below. The location of test samples taken during 2020 and 2021 is shown in **Figure 7**.

The details of the soil sampling program are provided as Appendix A.

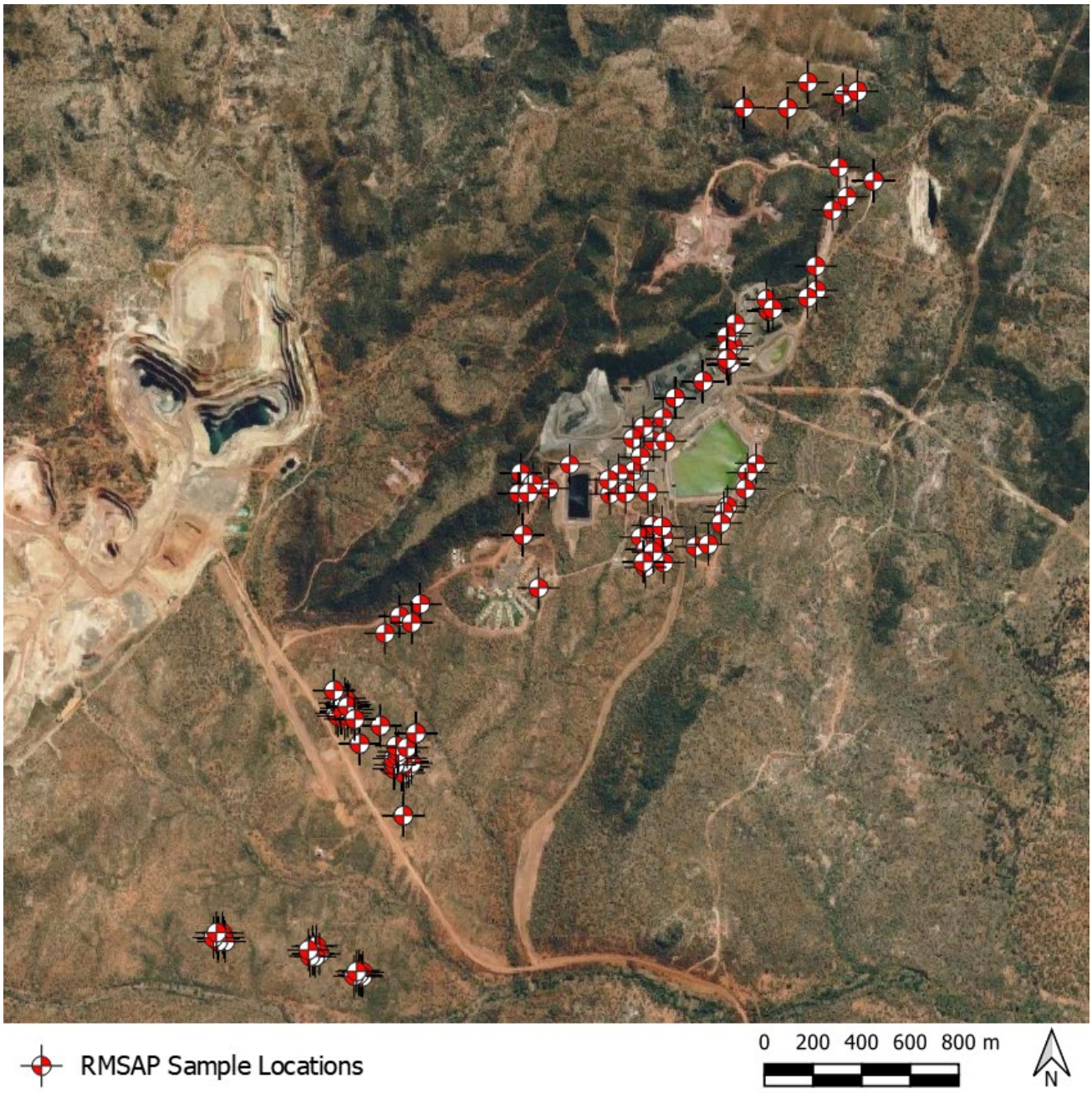


Figure 7: Soil Sample Locations

Dispersion

Emerson class testing was undertaken with results summarised as follows:

- 2% are Emerson Class 1: a single sample of saprolite is both slaking and dispersive
- 19% are Emerson Class 2: these tests are done on soil peds and samples have some dispersion
- 49% are Emerson Class 3: this is a sub class of Class 7 that has no dispersion from a soil ped and after remoulding samples have some dispersion
- 15% were Emerson Class 4: this is a sub class of Class 7 that has no dispersion from a soil ped and after remoulding samples have minor dispersion attributed to gypsum (4g) (n=6) or carbonate (4c) (n=1) minerals
- 15% were Emerson Class 6: this is a sub class of Class 7 that has no dispersion from a soil ped and after remoulding samples remain aggregated (flocculated).

Particle Size distribution

Excluding gravels, soils from borrow areas are generally 40 – 60% sand, 20 – 40% silt and 30 – 50% clay. Soils from infrastructure areas are generally 45 – 60% sand, 30 – 50% silt and 0 – 30% clay.

Organic (%)

Soil nutrients such as organic matter, phosphorous and cation exchange capacity are naturally low in the soils and saprolite but nevertheless support native flora and can be used for rehabilitation of mine areas. Total organic carbon (TOC) was 0.3% to 10.6% with a median of 0.3% and total organic matter (OM) was 0.3% to 6.1% with a median of 0.3%. TOC and OM are highest in topsoil (0.0 – 0.5 m) samples from all borrow and infrastructure areas.

CEC (meq/100g)

The cation exchange capacity (CEC) results from borrow areas were 0.9 to 21.2 meq/100g with a median of 4.9 meq/100g and are sufficient to support native vegetation. Based on the results, the CEC is higher in topsoil and subsoil due to their higher clay content and lower in saprolite samples, verifying that topsoil and subsoil have a better ability to provide nutrients. The exchangeable sodium percentage (ESP) results were 0.1% to 73% with a median value of 6%. The ESP tests verify 49% of the samples are sodic and strongly sodic based on agricultural classification (Hazelton and Murphy, 2016) and were found in topsoil, subsoil and saprolite samples.

3.1.1.4. Hydrology

In the EA, the receiving environment for LLM is defined as the waters of Magazine Creek, Desert Creek and connected waterways within 10 km downstream of the release, or further if an impact is detected beyond 10 km. Stream flow, surface water quality, stream sediment quality, aquatic habitat and macroinvertebrates are all required to be monitored to assess the health of the receiving environment.

3.1.1.4.1. LLM catchments and drainage

ML5568 is in the upper catchments of the Nicholson and Leichhardt Rivers, both of which drain to the Gulf of Carpentaria. The northern section of the lease drains in a northerly direction into the Gregory and Nicholson system. The south-eastern section of the lease drains to the east via a network of minor ephemeral streams. Desert and Magazine Creeks drain into Battle Creek before entering Gunpowder Creek and ultimately the Leichhardt River.

It should be noted that Desert Creek and its tributaries also receive runoff from the Lady Annie Mining Lease (ML90179). Gunpowder Creek has a catchment area of approximately 3,600 km^2 and Battle Creek has a catchment of approximately 475 km^2. ML5568 occupies less than 1% of either of these catchment areas. There are no permanent natural surface water bodies in the LLM operational area.

There is also no permanent surface water flow within ML5568. Flows are typically short, discrete events that coincide with rainfall events (Glencore, 2019). Flow gauging stations installed in Magazine and Desert Creeks demonstrates that they generally experience flows lasting one to three hours. Further downstream, in Desert Creek, flow events last on average 33 hours (Noranda Pacific, 2018).

3.1.1.4.2. Surface water quality

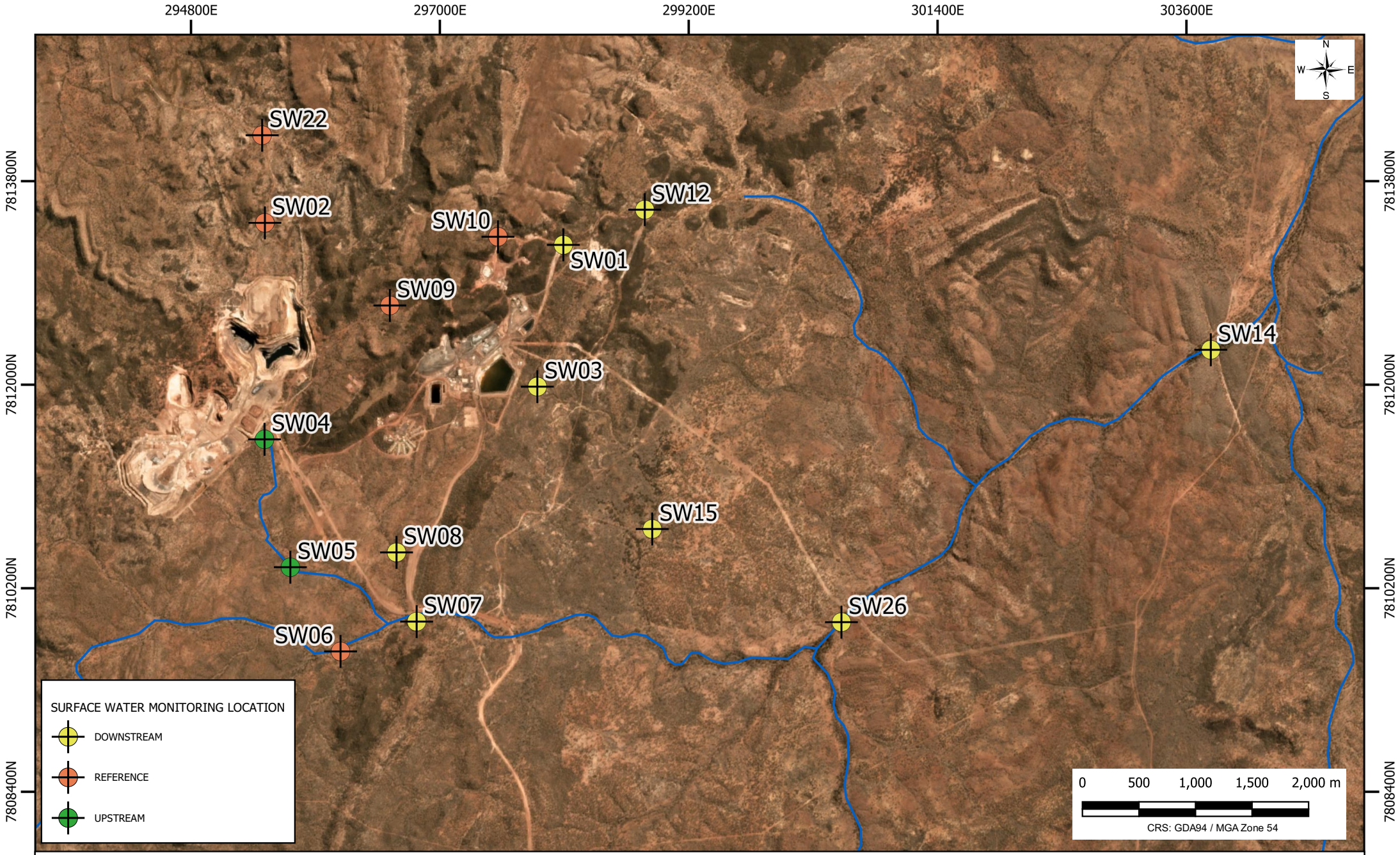
The Receiving Environment Monitoring Program (REMP) Design Report (NRA, 2013) developed for LLM nominated the key Environmental Values (EVs) as:

- Aquatic ecosystems (slightly to moderately disturbed),
- Livestock drinking water (primary industries- cattle),
- Industrial use (mining), and
- Cultural and spiritual values.

These nominated EVs are protected through the active management of Water Quality Objectives (WQOs), which have been derived based on the *Australia and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG) (2018). The adopted trigger level for toxicants is generally the higher of the default ANZG at the 95% level of protection and 80th percentile of reference site data (see Schedule C, Table 5 of the EA). Note that an exceedance of trigger values is an early warning mechanism to alert of a potential problem, not an instrument to assess compliance (ANZG, 2018).

The surface water sampling locations are shown in Figure 8.

Data from five references sites within and downstream of the LLM perhaps unsurprisingly identified water to be naturally highly mineralised. The reference sites are reported (Noranda Pacific, 2018) to exceed guideline values for the protection of slightly-to-moderately disturbed aquatic ecosystems, with median values for aluminium, copper, selenium and zinc exceeding guideline values. The reference sites also have pH values more acidic than the guideline values.



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LADY LORETTA MINE
SURFACE WATER MONITORING

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FIGURE 008

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3.1.1.4.3. Stream sediment quality

The quality of stream sediments is monitored twice a year (once at the end of the wet season and once at the end of the dry season) as per the requirements of the EA. Samples are collected from five reference sites, two interim upstream sites (which provide an indication of the quality of water entering the Desert Creek catchment) and eight downstream receiving environment sites (defined in Schedule C, Table 4 of the EA). The sediment sampling locations are the same as the water quality monitoring locations (refer to Figure 7). Sediment quality guideline values (SQGVs) were derived from the Revision of the ANZECC/ARMCANZ Sediment Quality Guidelines (Simpson *et al*., 2013) and where there are no SQGVs, interim site-specific trigger values were calculated using the SQG guidelines (Simpson *et al*., 2013). Currently stream sediment is monitored by the site under the routine Sediment Quality Monitoring Program.

Glencore has recently engaged TropWATER to undertake an assessment of the current compliance framework of the EA for both water and sediment. The current compliance framework relies on comparison to up-gradient reference conditions which do not accommodate the underlying natural mineral influences (TropWATER, 2021).

3.1.1.5. Hydrogeology

Several groundwater resources occur within and proximal to ML5568. The Lady Loretta Formation is unconformably overlain by the Beetle Creek Formation and the Thorntonia Limestone, which are both significant water-bearing units. The Lady Loretta Formation itself also hosts groundwater resources that are less well characterised. The extensive fracturing in the Middle Proterozoic Carpentarian bedrock is thought to be the sole mechanism for flow, extraction and recharge of groundwater in the area.

The Hydrogeological Conceptual Model (AGE, 2018, 2020; CDM Smith, 2022) identified three distinct hydrogeological provinces or blocks, known as the Cambrian, Lady Loretta and Palaeoproterozoic blocks, which are separated by two major fault networks. The Carlton Fault is located north of LLM Operations and the Western Border Fault is located south-east of the LLM Operations (refer to Figure 6). LLM operations are wholly contained within the Lady Loretta Block.

Detailed hydrogeological modelling indicates that there is negligible hydraulic connectivity (i.e. groundwater flow) across these faults (AGE, 2018, 2020; CDM Smith, 2022). Dewatering is conducted by LLM operations in order to conduct underground mining activities, and evidence suggests it directly controls groundwater flow direction. Groundwater flows north beneath the mine infrastructure, towards the underground workings (CDM Smith, 2022).

The groundwater relevant EVs identified by CDM Smith (2022) include: aquatic ecosystem protection, waters that may be used for agricultural purposes and drinking water, industrial use, and cultural and spiritual values. CDM Smith (2022) indicate that the nearest potential groundwater dependent ecosystems (GDEs) are located more than 4 km southeast of LLM, based on the Bureau of Meteorology GDE Atlas. Groundwater use for agricultural purposes and drinking water are both associated with the Cambrian block, where it has been demonstrated that there is negligible hydraulic connection from the Lady Loretta block (i.e. LLM Operations) to the Cambrian block. As groundwater flow in the Lady Loretta block is northwards towards the underground dewatering operations, and there is minimal hydraulic connection between the Proterozoic block and the Cambrian block, it can be reasonably inferred that there are no EVs associated with groundwater in the LLM (dewatering) footprint.

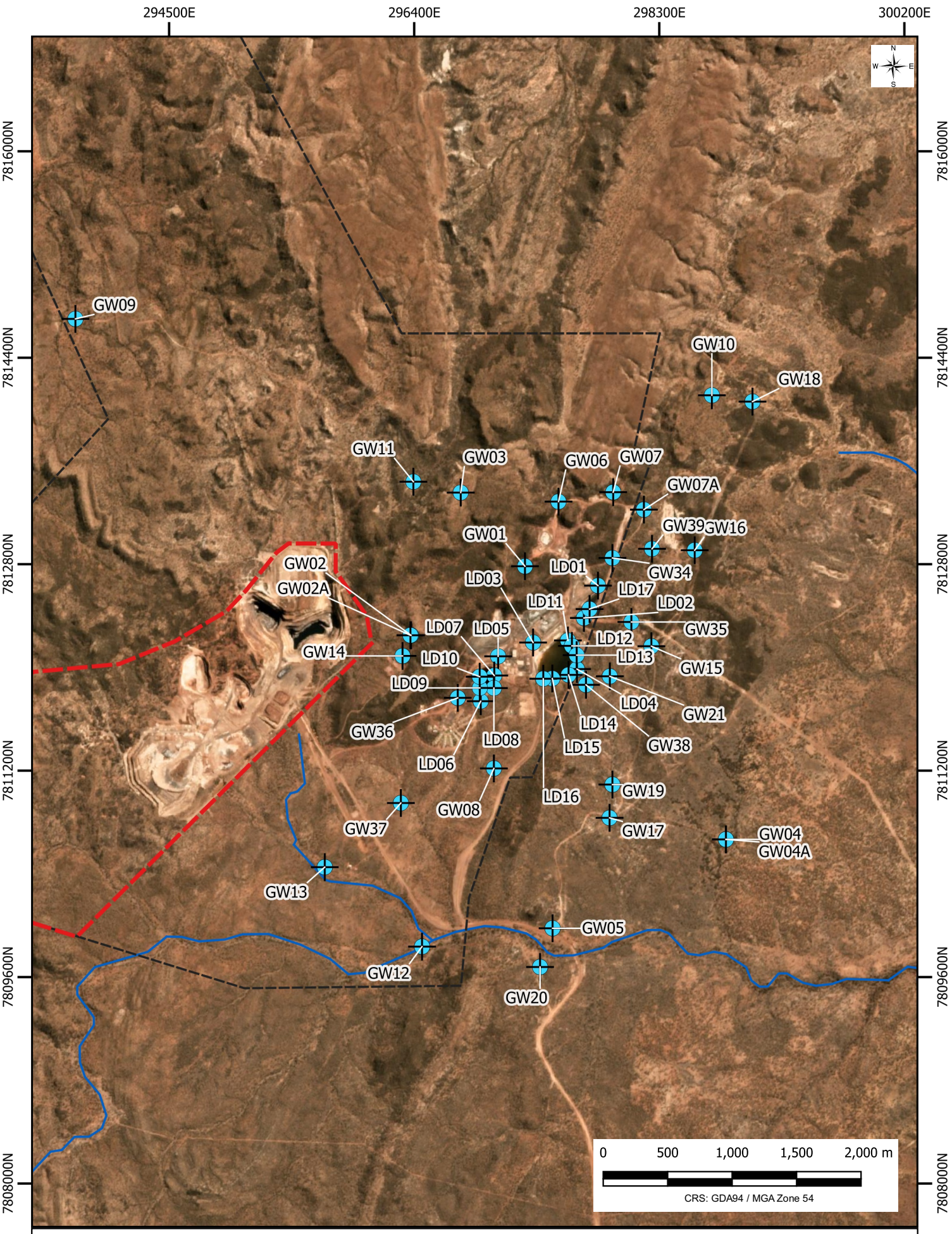
Groundwater is monitored in compliance with the EA. The groundwater monitoring locations, including reference bores, compliance bores and seepage detection bores were updated as part of the *Groundwater Monitoring Network Design Plan* (Glencore, 2019b).

The current monitoring locations are shown in Figure 9.

The construction of older bores is unknown and as such it is unclear which aquifer units they are screened across. However, static water levels (SWL) are generally between 40 and 70 metres below ground surface.

Based on groundwater monitoring undertaken on site, electrical conductivity, sulphate and concentrations of metals and metalloids are elevated at some bores within the immediate vicinity of the mine. This is likely due to the naturally elevated levels resulting from the mineralised lithology.

Further information on groundwater is presented in the Post Mine Land Use Plan (Noranda Pacific, 2018).



LEGEND

- GROUNDWATER MONITORING BORE LOCATION
- LADY LORETTA MINE LEASE
- LADY ANNIE LEASE BOUNDARY

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LADY LORETTA MINE
GROUNDWATER MONITORING NETWORK

FIGURE 009

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3.1.2 Regional Ecosystems

3.1.2.1. Terrestrial Flora

LLM is located within the Mount Isa Inlier province of the Northwest Highlands Bioregion. The bioregion is characterised by stony hills and ranges. The land within and external to the mine is dominated by spinifex pastures, with smaller areas of woodland and Mitchell grass. The pre-mining (contemporary) land use within the lease was low intensity grazing and mining.

James Warren and Associates Pty Ltd surveyed the flora of the project area in July 2000 and NRA Environmental Consultants reported post-wet season monitoring results in April 2012. The objectives of these studies were to describe plant communities (including rare and threatened species) occurring within the ML. James Warren and Associates (2000) reported four broad vegetation communities including:

- Mid-high Closed-Open Forest (lancewood) (analogous with regional ecosystem (RE) 1.7.1)—This community is found on the scree slopes in the northern section of the ML. Lancewood dominates the community and little ground and mid cover is evident.
- Mid-high Woodland (snappy gum) (analogous with RE 1.11.2) —This community dominates the valley floors in the north and undulating plains in the south of the ML. Snappy gum and other Eucalypt and Corymbian species are common. The mid-storey is dominated by climbing shrubs while Spinifex dominates the groundcover.
- Mid-high Woodland (silver-leaved box) (analogous with RE 1.11.4) —Floodways in the south and south-east of the ML are dominated by this community. Silver-leaved box and bean trees (to a lesser extent) are common in this community. River red gums occur along the edge of the main flood channel and become more prominent in the south.
- Mid-high Open Woodland (small-fruited bloodwood) (analogous with RE 1.11.2) —This community is restricted to the mesa plateaus in the northern section of the ML. The community is dominated by small-fruited bloodwood with scattered snappy gum.

Studies reported by NRA (2012) documented an updated list of RE types encountered during surveys. The RE types based on the 2012 NRA study are shown in Table 5.

***Table 5*: Regional Ecosystem Types Encountered within the ML**

Regional Ecosystem[1]	Short Description[1]
1.3.6	Ghost gum (*Corymbia aparrerinja*), bloodwood (*Corymbia terminalis)* open woodland on sandy terraces.
1.3.6a	Floodplain (other than floodplain wetlands). Woodland of *Corymbia aparrerinja* often with *C. terminalis, Eucalyptus leucophylla, E. camaldulensis, Lysiphyllum cunninghamii* and/or *Acacia cambagei* with a sparse ground layer of tussock grasses with *Triodia longiceps* in some places.
1.3.6x1	Riverine wetland or fringing riverine wetland. Woodland of *Eucalyptus leucophylla* and/or *E. pruinosa*, often with *Corymbia terminalis*, *Acacia cambagei, Atalaya hemiglauca* and *C. aparrerinja* with a mixed ground layer of tussock grasses and *Triodia spp*.
1.3.7b	Riverine wetland or fringing riverine wetland. Fringing woodland of *Eucalyptus camaldulensis*, usually with *Lophostemon grandiflorus* and *Melaleauca bracteata* and/or *M.dissitiflora.*
1.5.3	Snappy gum (*Eucalyptus leucophloia*) low open woodland on red earths on plateaus
1.71	Snappy gum (*Eucalyptus leucophloia*) low open woodland on skeletal soils on lateritic scarps and plateaus.
1.7.1x1	Low open-woodland of *Acacia shirleyi.* Occurs on laterite.
1.7.1x3	Low open-woodland of *Corymbia capricornia* +/- *Eucalyptus leucophloia* with mixed shrub layer and ground layer of *Triodia pungens* and *Schizachyrium fragile*. Occurs on silcrete.

Regional Ecosystem[1]	Short Description[1]
1.9.6	Snappy gum (*Eucalyptus leucophloia*) and bloodwood (*Corymbia terminalis*) low open woodland on limestone hills.
1.11.2	Snappy gum (*Eucalyptus leucophloia*) low open woodland on siliceous rocky hills on folded sediments.
1.11.2a	Low open-woodland of *Eucalyptus leucophloia* often with *Corymbia spp., Terminalia aridicola* and *E. leucophylla* with shrub layer of *Acacia spp*. and ground layer of *Triodia spp*.
1.11.2x2a	Low woodland to open-forest of *Acacia shirleyi*. Occurs on metamorphic hills.
1.11.2x3	Low open-woodland of *Corymbia aspera*, often with *Terminalia aridicola subsp. aridicola*, *Eucalyptus leucophloia* and *C. capricornia* with a *Triodia spp*. understorey. Occurs on rocky metamorphic outcrops.
1.11.3	Cloncurry box (*Eucalyptus leucophylla*) low open woodland on basic rocky hills on folded sediments.

NOTE 1: Descriptions reported by NRA 2012. RE types and descriptions have since been updated

Source: NRA, 2012

RE types and descriptions have since been updated and recent mapping can be found on the DES website (i.e. RE 1.7.1x1 has recently been described as 1.7.5a, 1.11.2x2a as 1.7.5b and 1.7.1x3 as 1.7.7a). The river red gum riparian community associated with larger drainage lines in the ML and the silver-leaf box communities associated with the flat areas adjacent to the waterways are identified as conservation significant flora communities.

No flora species listed under *the Environment Protection and Biodiversity Conservation Act 1999* or *Nature Conservation (Wildlife) Regulation 2006* (previously the *Nature Conservation [Wildlife] Regulation 1994*) at the time of survey were recorded at the Project area. When surveyed by NRA, a relatively low proportion of species recorded were non-native. Buffel grass *(Cenchris ciliaris), calotrope (Calotropis procera)* and *sida (Sida acuta)* were the most significant species recorded.

The land has an inherently low pastoral and agricultural potential and a low capacity to carry livestock. Twenty species of weeds are known to occur at LLM on ML5658, none are Prohibited or Restricted Matters in the Queensland Biosecurity Act (DAF, 2014). Three weeds are listed as pest plants under the Mount Isa City Council, *Local Government Area Pest Management Plan* (Mount Isa City Council, 2014):

- Noogoora Burr (*Xanthium occidentale*) – low priority weed,
- Calotrope (*Calotropis procera*) – medium priority weed, and
- Prickly Mimosa Bush (*Vachellia farnesiana*) – environmental weed.

3.1.3 Pre-mining Vegetation and Land Uses

The geology, terrain and vegetation of the Site has been described variously including Section 3 of this PRCP and the EMOS developed by Noranda Pacific in November 2000 to support authorisation of the EA. The EMOS defined four vegetation communities that occur at the Site. The spatial distribution of these communities aligns with the local topography and geology. A plan showing the pre-disturbance vegetation types is presented in Figure 10.

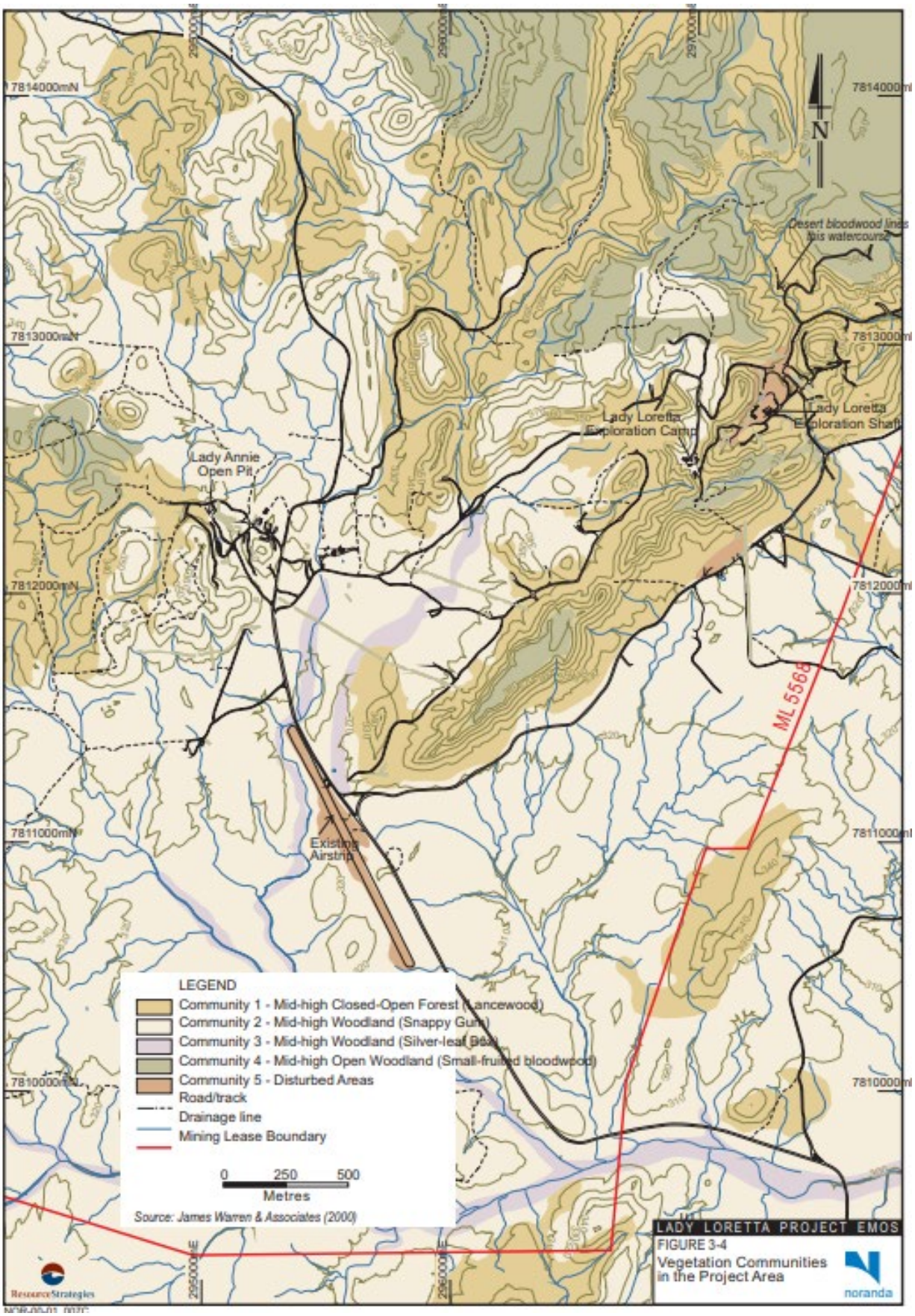


Figure 10: Pre-disturbance Vegetation Map (from EMOS Noranda Pacific 2000)

3.1.3.1. Lowland plain

Much of the fixed plant and surface infrastructure at the Site has been developed on a lowland plain bordered by the eastern boundary of the ML and the ridge that hosts the Lady Loretta orebody. The alluvial plain is relatively flat with slopes typically less than 8%. Although nutrient poor, soils and sub-soils have developed by a combination of in-situ weathering of the underlying strata and/or accumulations of sediments transported from the nearby ridges. Vegetation on this terrain type comprises Regional Ecosystems 1.11.2a and 1.3.6a. The EMOS described them as:

- Community 2 - Mid-High Woodland (Snappy gum).

Prior to mining, the lowland plain was utilised by livestock as a component of a low intensity cattle grazing land use.

3.1.3.2. Steep ridges

The Lady Loretta orebody is hosted in a ridge that runs north-east to south-west. The ridge comprises siliceous sediments that have been folded to form a dipping syncline. The folding has resulted in typical slopes of 15% but scree slopes of 40% are common. The shales and mudstones are relatively tight and resist percolation of meteoric water into the groundwater system except in areas of heavy fracturing. The sloped terrain and low rates of infiltration results in high rates of surface runoff and naturally high rates of erosion. Soils are typically sparse and nutrient poor.

The pre-mining vegetation on this terrain type reflects Regional Ecosystem; 1.11.2 (found on rocky hills), 1.7.5a and 1.7.5b (formally known as 1.7.1x1 and 1.11.2x2a respectively) and was described in the EMOS as:

- Community 1 - Mid-High Closed-Open Forest (Lancewood), and
- Community 4 - Mid-High Open Woodland (Small fruited bloodwood).

Prior to mining, the steep ridges were available for grazing of livestock but is unlikely that cattle utilised the grasses available due to their relative sparseness and lack of available drinking water. The pre-mining land use was Native Ecosystem for native fauna.

3.1.3.3. Terrestrial flora

The four dominant terrestrial fauna habitats on LLM were identified as:

- Snappy gum woodland over spinifex,
- Riparian habitat,
- Stony hills, lateritic scarps and boulder piles, and
- Lancewood woodlands.

Other notable habitat features present include:

- Waterways and springs,
- Disturbed or modified environments (e.g. formed roads, mine camp), and
- Artificial water courses (e.g. mine dams, stock dams, leaking pipelines).

A Rehabilitation Monitoring Program is in place. The Rehabilitation Monitoring Program (Eco Logical, 2019) and commencement of the monitoring program established eleven analogue monitoring sites in 2018, all of which have been comprehensively monitored since that time to allow comparison of rehabilitation to similar vegetation. A map of the analogue monitoring sites is provided in **Figure 11**.

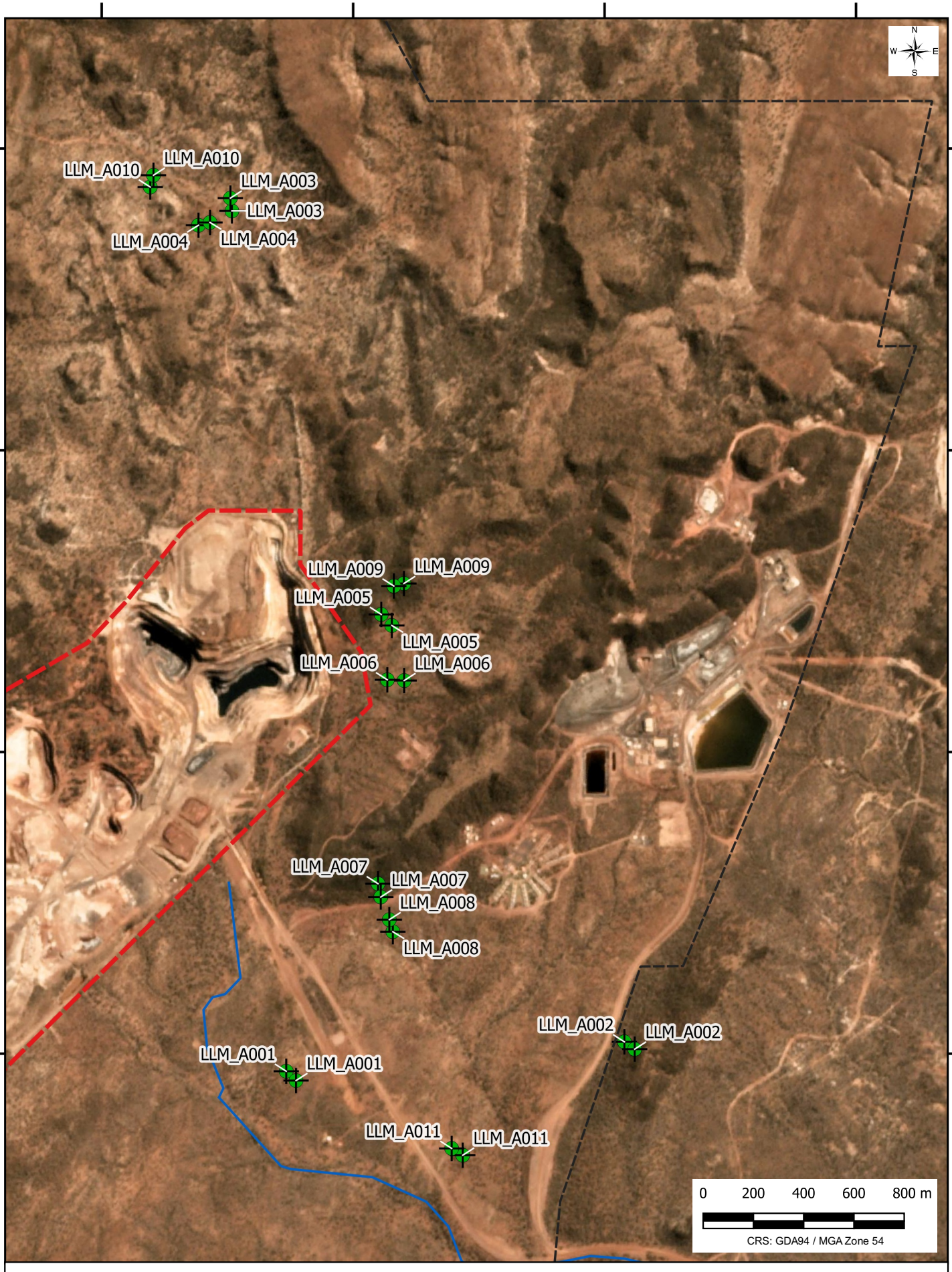
Monitoring included Ecosystem Function Analysis (EFA), which considers Landscape Function Analysis (LFA), vegetation dynamics and habitat complexity.

Recent monitoring for habitat complexity (a key attribute to facilitate fauna inhabitation) was recorded as follows:

- Low canopy cover in tree and shrub layers, minimal woody debris and groundcover available as microhabitat,
- Low canopy cover in tree and shrub layers, presence of termite mounds, minimal woody debris and groundcover available as microhabitat,
- High canopy cover in tree layer, presence of woody debris and loose bark available as microhabitat,
- Moderate canopy cover in the tree and shrub layers, presence of woody debris and ground cover creating fauna habitat, and
- Moderate canopy cover in the tree layer, presence of rocks and woody debris available as microhabitat.

A fauna survey of the lease in 2000 detected a fauna community that included native amphibians, reptiles, birds and mammals. Exotic species were also recorded. Results included species listed as threatened under the *Nature Conservation (Wildlife) Regulation 1994* (now the *Nature Conservation (Animals) Regulation 2020*), as follows:

- Amphibians: most species expected to occur around larger creeks in the south of the mining lease, for example green tree frog, desert tree frog and ornate burrowing frog. The cane toad is known to occur in the area. Most of the mining lease provides low value habitat for amphibians, with most important habitat being larger floodways in the south and southwest.
- Reptiles: several Carlia (four-fingered skinks) and Ctenotus (comb-eared skinks) species expected to occur at the mining lease as well as olive whipsnake (*Demansia olivacea*) and northern spotted rock dtella (*Gehyra nana*). Scree slopes are noted an important refugial habitat in the region.
- Birds: a variety of species are known to occur on the mining lease.
- Mammals: mammal species include small mammals, macropods, microbats and megabats.



LEGEND

- ANALOGUE VEGETATION MONITORING LOCATION
- LADY LORETTA MINE LEASE
- LADY ANNIE LEASE BOUNDARY
- WATERCOURSE

NORANDA PACIFIC PTY LIMITED

LADY LORETTA MINE
ANALOGUE VEGETATION
MONITORING SITES

FIGURE 011

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A fauna survey of the lease in 2000 detected a fauna community that included native amphibians, reptiles, birds and mammals. Exotic species were also recorded. Results included species listed as threatened under the *Nature Conservation (Wildlife) Regulation 1994* (now the *Nature Conservation (Animals) Regulation 2020*), as follows:

- **Amphibians**: most species expected to occur around larger creeks in the south of the mining lease, for example green tree frog, desert tree frog and ornate burrowing frog. The cane toad is known to occur in the area. Most of the mining lease provides low value habitat for amphibians, with most important habitat being larger floodways in the south and southwest.
- **Reptiles**: a number of Carlia (four-fingered skinks) and Ctenotus (comb-eared skinks) species expected to occur at the mining lease as well as olive whipsnake (*Demansia olivacea*) and northern spotted rock dtella (*Gehyra nana*). Scree slopes are noted an important refugial habitat in the region.
- **Birds**: a variety of species are known to occur on the mining lease.
- **Mammals**: mammal species include small mammals, macropods, microbats and megabats.

3.1.3.4. Threatened species

Previous ecological assessments undertaken at LLM have identified eight fauna species of conservation significance which are prescribed matters of state significance under the *Environmental Offsets Act 2014*. A summary of these species and their relevant *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the *Nature Conservation Act 1992* (NC Act) listing status is provided in Table 6. A Biodiversity Offset Strategy has been developed for LLM to manage impacts on relevant significant biodiversity values.

Table 6: LLM Threatened Species

Species	Common Name	Status – NC Act	Status – EPBC Act
Amytornis dorotheae	Carpentarian grass-wren	Endangered	Endangered
Erythrotriorchis radiatus	Red goshawk	Endangered	Vulnerable
Erythrura gouldiae	Gouldian finch	Endangered	Endangered
Falco hypoleucos	Grey falcon	Vulnerable	-
Grantiella picta	Painted honeyeater	Vulnerable	Vulnerable
Hipposideros stenotis	Northern leaf-nosed bat	Vulnerable	-
Petrogale purpureicollis	Purple-necked rock-wallaby	Vulnerable	-
Tachyglossus aculeatus	Short-beaked echidna	Special Least Concern	-

3.1.3.5. Aquatic fauna

The Site is located within the far western portion of the Gunpowder Creek Catchment (which is also part of the greater Leichhardt River Catchment). Both watercourses are non-permanent but retain large permanent holes through the dry season. Pools may remain in some larger creeks during the dry season.

Under natural flow conditions, waterways immediately downstream of the mine generally flow for only short periods of a few hours during and following rainfall. The ephemeral creeks of the receiving environment are unlikely to support biota sensitive to poor water quality.

Results of sampling undertaken in 2018 (FRC Environmental Pty Ltd) reported waterways downstream of LLM to be ephemeral, with sand or cobble substrates and varying cover of riparian vegetation. Channel widths tended to increase with distance downstream from approximately 1 m to 10 m width. Channels are often dry within the ML with isolated pools generally persisting only in the wet season after significant rain. It was reported that during periods of flow there is little potential for aquatic organisms to move upstream (FRC Environmental Pty Ltd, 2018). Short duration of flow events (generally only hours) is considered insufficient time for the movement of organisms from refugial habitat. The upper reaches of ephemeral creeks near the LLM were reported to typically be used by

short-lived aquatic species tolerant of harsh environmental conditions (such as those of ephemeral streams in the region). There is little refuge habitat for aquatic organisms within the receiving environment.

3.1.4 Air Quality

LLM is in a remote area. The nearest potentially sensitive receptors (Noise Mapping Australia, 2013) include:

- Thorntonia Station, 33 km to the north/north-west,
- Carlton Hills Station, 54 km to the south-east,
- Capricorn Copper Mine accommodation camp, 35 km to the east,
- Lady Annie Camp, 17 km to the south-east, and
- Koolamara Station, 19 km to the south-east.

These stations (except for Koolamara) were identified as potentially sensitive receptors by an air quality assessment of the LLM area and surrounds (Noranda Pacific, 2000). While no monitoring was undertaken at that time, key sources of dust/particle emissions in the area were typical of the wider North-west Region, relating to mining/exploration activities, unsealed roads and grazing activities. The typical sources of atmospheric emissions primarily relate to dust or particulates, dominated by coarse particulate fractions (i.e. greater than 10 micrometres [µm]. While presenting management concerns from a nuisance perspective, coarse particles were generally not considered to pose a health threat due to the inability of the larger particles to enter the human respiratory tract.

3.1.5 Integrated Business Processes

3.1.5.1. Rehabilitation and Closure Planning

As a Glencore-owned asset, LLM is required to maintain and implement rehabilitation and closure plans that are consistent with the requirements defined by Glencore's Closure Planning Standard. The objective of this Standard is to set clear requirements for dealing with the risks and costs presented by asset closure. Aspects of the Standard include:

- Appropriate knowledge is recorded and made available,
- Program objectives and success criteria are defined,
- Rehabilitation and closure requirements are integrated into Life of Asset planning,
- Planning specificity is reflective of the Life of Asset, and
- Rehabilitation cost models and financial provisions are complete and transparent.

Business plans established for LLM are prepared pursuant to the requirements defined by Glencore and address all aspects of the LoA including decommissioning and rehabilitation. Closure planning is a process that is adopted for LLM throughout the business life-cycle. The overall target is to deliver a clear, consistently planned and executable process that provides for a sustainable post-mining land use.

3.1.5.2. Operational Business Planning

The management of LLM maintains a suite of business plans that are revised on an annual basis. The Plans set the performance objectives for the Site and allocate suitable resources to meet those objectives. Plans are defined for periods of 12 months and five years.

3.1.5.3. Water Management

Effective water management is a key driver of the overall success of LLM. To that end, the Site has established and maintains a WMS that comprises the following elements:

- Water management plan,
- Water management network, and
- Probabilistic water balance model.

3.1.5.3.1. Water Management Plan

LLM maintains a Water Management Plan (WMP) that describes the context, systems, and equipment used to manage water at the Site**.** The WMP is required under the EA.

3.1.5.3.2. Water Management Infrastructure

The water management infrastructure is the physical or equipment features used to collect, store, distribute and dispose of water at the Site. Key features are described below.

3.1.5.3.2.1. Water supply

Water supply to the site is provided by operating a production wellfield located to the east of ML pursuant to a contractual right. The water supply system includes:

- Four production wells fitted with casing, electric pumps, instrumentation and power supplies,
- Transfer and delivery systems comprising pipes, transfer tanks and transfer pumps,
- Raw water storage tanks,
- Reverse osmosis potable water treatment plant, and
- Reticulation network.

Raw water from the wellfield is transferred to tankage located on elevated land north or the paste plant. Raw (or untreated) water is used variously across the Site including underground for machine cooling and in paste production. Raw water is also treated to produce potable water in a package plant.

3.1.5.3.2.2. Mine affected waters

Surface and groundwaters that interact with mineralised materials such as the orebody, the underground mine workings, ore stockpiles, tailings stockpiles, or waste rock stockpiles can become contaminated with acid and/or dissolved metals and salts. The potentially mine-affected waters are generally unsuitable for direct release to the environment and must be managed on site. Mine-affected waters are generated by dewatering of the underground mine workings as well as by capturing surface runoff from mine-affected catchments. Key features of the mine affected water system include (Glencore, 2017):

- Water storages – including four regulated dams, Containment Dam A (CDA), Containment Dam B (CDB), Paste Plant Dam (PPD) and Leachate Management Dam (LMD). Receiving waterways for each structure is Desert Creek, except for LMD where the receiving waterway is Magazine Creek,
- Transfer systems – includes transfer systems internal to the integrated catchment system, and discharge lines transferring water out of the catchment system,
- Water diversions to maintain a separation of clean water and dirty areas – including WRE Diversion Drain, CDB Diversion Drain, Village Link Drain, ROM Diversion Drain, Batch Plant Diversion Drain, Paste Plant Diversion Drain, Paste Plant Link Drain and LMD Diversion Drain, and
- Process demands – including underground dewatering, bore fields, workshop and vehicle wash dirty water, Clean In Clean Out (CICO) wastewater and water treatment plant rejects.

Management of the mine-affected water inventory is achieved by various means including reuse underground for dust suppression, direct evaporation and treatment. Treatment of mine-affected waters occurs on-site in a

dedicated package plant that utilises filtration and reverse osmosis. The permeate stream is release off-site (under license) for beneficial reuse and the reject is transferred back to the mine-affected water inventory.

3.1.5.3.2.3. Wastewater disposal

Wastewaters generated at the site are collected and treated prior to disposal into the mine-affected water system. The wastewater disposal system includes:

- Sewage collection network,
- Transfer systems comprising pumps and rising mains, and
- Package treatment plant and evaporation beds.

3.1.5.4. Spill Risk and Probabilistic Water Balance

For the reasons outlined above, a key requirement for LLM is to ensure that mine-affected waters are effectively managed at the Site and not released directly to the receiving environment. Inventory management is a key consideration and suitable areas must be maintained to store both the mine-affected water inventory as well as any additional waters generated by rainfall. As a result, the risk of spill is routinely monitored and assessed by site management.

Many of the factors affecting spill risk are relatively well known or controllable. For example, although variable on a day-to-day basis, the rate of direct evaporation over the course of a year is relatively consistent. Similarly, management actions are also relatively predictable. Such actions include controlling the rate of transfer from underground to the surface storages as well as activating water treatment processes.

Inventories of mine-affected waters resultant from the capture of surface runoff however are less predictable. The majority of surface runoff is generated during the short and (generally) intense wet season that occurs between November and March of each year. Median annual rainfall for the site is around 500 mm but accumulations can vary significantly from year to year. The amount of surface water generated and the time at which it is generated is uncertain.

To manage the risk of spill, LLM maintains a probabilistic spill risk model that supports management of the mine-affected water inventory to ensure that the risk of spill is maintained below an acceptable criterion. The current LLM water balance model (WBM) is developed using the GoldSim model software and has recently been updated and calibrated. In early 2022, LLM engaged Engeny Pty Limited (Engeny) to undertake an assessment of the WMS under various post mining operations and closure scenarios. A report documenting this review is provided as Appendix B.

3.1.5.4.1.1. Mining operations

The mine-affected water balance whilst mining operations is expected to be in minor surplus. Raw water used to cool mining equipment underground as well as bleed water from the paste backfill operation is a significant contributor to the overall balance. Passive evaporation from the surface storages (CDA, CDB and PPD) is the most significant water export along with dust suppression underground. Excess water inventories associated with high rainfall years can be effectively managed by enhanced evaporation (e.g. irrigation on the batters of the HPDP lined dams) or by operation of the reverse osmosis plant.

3.1.5.4.1.2. Post mining operations

Engeny concluded that following the cessation of mining operations, the mine-affected water balance will move into long-term deficit and the storage provided by CDA, CDB and the PPD will provide suitable containment for the 1 % AEP rainfall. Long-term water balance modelling also considered how much water will need to be disposed of at the time when the mine affected water dams are converted to ESC facilities. Engeny concluded that 99% of all rainfall scenarios will require that less than 50 ML of mine affected waters will need to be transferred underground. The 50 %ile inventory was estimated to be 2 ML.

3.1.5.5. Demolition Strategy

Decommissioning and rehabilitation of the LLM will require all plant, infrastructure and equipment to be de-energised, demolished and disposed of underground in accordance with the EA. Technical analysis of the activities required to do this is concerned with maximising the commercial value of the installed equipment at the point when it is no longer required. This will be achieved by a combination of salvaging assets for sale or redeployment and by minimising the costs associated with demolition and waste disposal. The analysis requires an appreciation of the specific economic conditions prevailing at the time of assessment.

To assist management of this aspect, LLM routinely engages subject matter specialists to define scope and assess costs associated with the full demolition of all fixed plant and infrastructure located at the Site. This work includes maintenance of a database that details discrete scopes of work and the tonnage of waste streams likely to be generated including scrap steel, concrete and other demolition wastes. The database is routinely reviewed every three years with the most recent review completed in 2020 (CMA, 2020).

3.1.5.6. Non-Mineral Waste Strategy

Decommissioning and rehabilitation of the Site will result in the generation of various non-mineral waste streams. These will include:

- Soils and sediments contaminated with metals and salts,
- High density poly-ethylene (HDPE) sheeting and piping, and
- Demolition waste, including concrete and scrap steel.

Generation of non-mineral waste streams will be avoided as much as reasonably practicable in the lead up and during the post operations phase of the project. This will include run-down of inventories towards the end of operational activities, salvaging plant for beneficial reuse and recovery of saleable scrap.

Non-mineral waste streams such as HDPE and demolition waste generated during the decommissioning and rehabilitation program will be disposed of at the Site pursuant to the requirements of the EA. Permanent disposal strategies for some of the major non-mineral waste streams include:

- Off-site beneficial reuse and recycling: salvage items, scrap steel,
- Encapsulation within upper benches of the WRE: soils and subsoils contaminated with heavy metals and salts;
- Backfill of the upper 460 m of the mine decline: non-regulated wastes,
- Backfill of the upper sections of the mine ventilation shafts: non-regulated wastes, and
- Off-site disposal: others.

Backfill of the upper section of the mine decline and ventilation shafts is a requirement to mitigate the long-term effects of subsidence and may present an opportunity for permanent disposal of demolition wastes.

3.2. POST MINING LAND USE

3.2.1 Rehabilitation Planning Domains and Objectives

Section 176 of the EP Act requires that mined land must be rehabilitated to a stable condition. Section 111A of the Act defines that land is in a stable condition when:

- The land is safe and structurally stable,
- There is no environmental harm being caused by anything on or in the land, and
- The land can sustain the post mining land use.

These three conditions are the general rehabilitation goals for all lands disturbed by mining in Queensland. These high-level goals have informed the location-specific set of Rehabilitation Objectives presented in

Table **7**.

Table 7: Rehabilitation Objectives

Rehabilitation Objective	Element	Design Intention	Measure
Physically Stable	Slope Stability	• ANCOLD Guideline	• Numerical analysis (Stability analysis)
	Consolidation Settlement and Subsidence	• ANCOLD • No ponding of water • Surface subsidence does not exceed 500 mm	• Direct measurement (Survey)
	Erosion	• Long term containment of waste	• Numerical Analysis (Landform evolution modelling) • Direct observation (Photography, survey)
Chemically Stable	Water Flux Through Waste	• Oxidation products (salt, acid) remain contained within the waste mass	• Numerical Analysis (Soil moisture modelling) • Direct measurement (Arrayed soil moisture and matric suction sensors)
	Capillary Rise	• Oxidation products (salt, acid) remain contained • Waste not subject to cyclic wetting and drying	• Numerical Analysis (Soil moisture modelling) • Direct observation (Photography)
	Receiving Environment Surface Waters and Stream Sediment	• Compliance with Conditions of EA (Schedule C)	• Direct measurement (surface water quality and sediment quality) • Receiving Environment Monitoring Program
	Local Groundwater	• No deleterious impacts to groundwater	• Direct measurement (Groundwater quality)
Supports a Viable Vegetation Community	Viable Vegetation	• Suitable diversity • Capable of reproduction • Soil development	• Direct and Indirect measurement (Ecosystem Function Analysis)
	Absence of Declared Weeds	• Legal obligation	• Direct observation (Photography)
	Resilience to Stressors	• Resilience through drought / fire / flood / overgrazing	• Direct and Indirect measurement (Ecosystem Function Analysis)

3.2.2 Assessment of Post Mining Land Use Options

Mining disturbance at the Site has been restricted to a relatively minor 140 Ha located in the south-eastern sector of ML 5568. These disturbances have either occurred on the siliceous rocky hills that comprise the steep ridge hosting the Lady Loretta orebody, or the lowland plain found immediately to the east.

As discussed in Section 3.1.3, the pre-mining land uses at the Site were effectively pre-determined by terrain type and vegetation. The lowland plains which include the open woodland vegetation communities (Community 2) are suitable for grazing livestock at low intensity. The siliceous ridges that support the closed woodland communities (Communities 1 and 4) are not suited to grazing livestock and provide other services related to Native Vegetation and Native Habitat. PMLUs for the Site were first nominated in the EMOS (Noranda Pacific, 2000) and later in the PMLUP (Noranda Pacific, 2018). The PMLUs proposed were Native Habitat, Low Intensity Cattle Grazing, and a combination of the two where domains (rehabilitation areas) intersect both terrain types.

Rehabilitation planning including stakeholder consultation completed after the preparation the PMLUP identified some minor inconsistencies that have been amended. A post mine land use (PMLU) of Native Habitat was previously proposed for the ROM, Paste Plant and Batch Plant area. Rehabilitation of this area however will result in a final landform and terrain type that has been specifically designed to encourage livestock. As a result, the PMLU proposed for the ROM, Paste Plant and Batch Plant has been revised to Low Intensity Cattle Grazing. Rehabilitation of the regulated dams will include reprofiling of the land and establishment of vegetation. Regulated dams CDA, CDB and PPD and associated sediment dams are all located on the lowland plain. As a result, the PMLU proposed for these facilities has been revised to Low Intensity Cattle Grazing.

It should be noted, the proposed PMLUs are consistent with the potential end land uses as described under an approved LOD being the PMLUP, except for the ROM, Paste Plant and Batch Plant and various Regulated Dams.

The Decommissioning and Rehabilitation program has been designed to deliver a final landform that supports PMLUs that are consistent with the pre-mining land uses. Disturbances located on the low slope alluvial plains will be rehabilitated to support a PMLU of Low Intensity Cattle Grazing. Disturbances on the steep ridge terrain will be rehabilitated to support a PMLU of Native Habitat.

The rehabilitation areas (RAs) adopted for the LLM and their proposed PMLU are presented in Table 8 and Figure 12.

For rehabilitation areas RA8 and RA9, minor potential future disturbance may occur from exploration drill holes and tracks. While it is noted that these minor disturbances may potentially be located anywhere within the PMLU areas on the ML, where they occur, they would be isolated to small surface areas only.

Borrow site establishment is also proposed within RA8 and RA9. Where required, any future disturbance from borrow sites will be subject to the maximum disturbance footprints, and associated relevant conditions, as authorised under the EA.

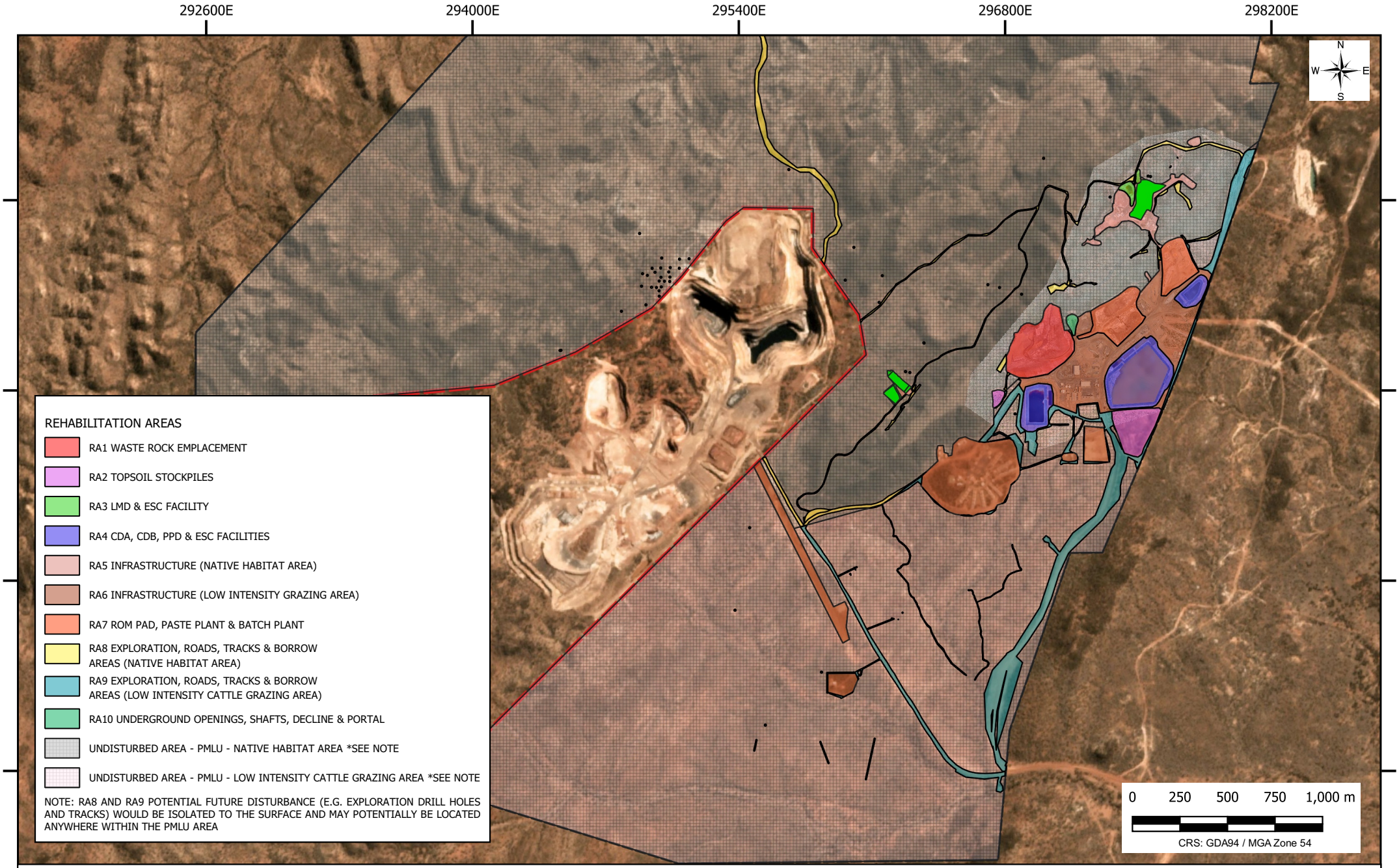
Table 8: Rehabilitation Areas and Proposed PMLU

Rehabilitation Planning Areas	Area (Ha)		Pre-Mining Land Use	Post-Mining Land Use
	Maximum Disturbance *	To be Rehabilitated		
RA1 Waste Rock Emplacement	11	11	Native Habitat	Native Habitat
RA2 Topsoil Stockpiles	6	6	Low Intensity Cattle Grazing	Low Intensity Cattle Grazing
RA3 LMD and ESC Facility	1	1	Native Habitat	Native Habitat
RA4 CDA, CDB, PPD and ESC Facilities	14	14	Low Intensity Cattle Grazing	Low Intensity Cattle Grazing
RA5 Infrastructure (Native Habitat Area)	12	9**	Native Habitat	Native Habitat
RA6 Infrastructure (Low Intensity Grazing Area)	44	44	Low Intensity Cattle Grazing	Low Intensity Cattle Grazing
RA7 ROM Pad, Paste Plant & Batch Plant	11	11	Low Intensity Cattle Grazing	Low Intensity Cattle Grazing
RA8 Exploration, Roads, Tracks and Borrow Sites (Native Habitat Area)	21	20***	Native Habitat	Native Habitat
RA9 Exploration, Roads, Tracks and Borrow Sites (Low Intensity Cattle Grazing Area)	39	39	Low Intensity Cattle Grazing	Low Intensity Cattle Grazing
RA10 Underground Openings, Shafts, Decline and Portal	1	1	Native Habitat	Native Habitat

**Maximum Disturbance – This includes actual disturbance and additional disturbance required to support the rehabilitation activities and final landform design works.*

*** – 3ha has been rehabilitated.*

**** – 1ha has been rehabilitated*



NORANDA PACIFIC PTY LIMITED

LADY LORETTA MINE
REHABILITATION AREAS

ATC WILLIAMS

FIGURE 012
112009-04
DATE: 2023-03-13

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3.2.3 Low Intensity Cattle Grazing

Low intensity cattle grazing is where cattle are grazed in an area with low stocking densities and for short periods of time. Low intensity cattle grazing is a common livestock management technique in areas within extensive rangeland environments, characterised by low rainfall, sparse vegetation, and typically higher temperatures.

The type of ecosystem within and surrounding LLM mining lease has historically supported low intensity cattle grazing (in the context of grazing rates across Queensland) due to the low fertility and low palatable biomass of the ground layer. Based on existing regional conditions, there are natural constraints and annual fluctuations on the long-term carrying capacity of the land.

'Low intensity cattle grazing' is therefore defined as a function of long-term carrying capacities of the land, pasture type, pasture growth, tree cover, weed cover and is variable subject to regional ecosystem type, climate and land/soil fertility. The approach to grazing management is determined by the landholder, with a sustainable balance being achieved in paddock rotation and the numbers of head grazing the area.

Grazing rates and carrying capacity will be assessed prior to the introduction of stock in areas that have been rehabilitated—this will be undertaken by a suitably qualified and experienced person, in close consultant with relevant stakeholders. The assessment will be undertaken at the time of stocking as part of the progressive rehabilitation of the mining lease area, and then also upon surrender to confirm achievement of the post mining land use to a stable condition.

Grazing rates and carrying capacity will consider land use factors such as: land type and condition; climate; area available (paddock size) and evenness of use; available pasture at the commencement and end of grazing (dry mass per hectare); feed accessibility due to water availability and geography; growth rates of pasture (seasonal considerations); goals for animal production and land condition; and expected number of days grazing. This is consistent with contemporary grazing practices.

The approach to grazing rates and carrying capacity will also reference the proposed EFA framework and relevant EFA monitoring results. Where proposed relevant EFA milestones are met, the land will be representative of the pre-mining condition—as measured via analogue sites during the rehabilitation monitoring events—and therefore by definition will be able to support low intensity cattle grazing.

The approach will ensure a sustainable grazing outcome is achieved, with both a stable condition being achieved and allowing the regional landholder(s) to continue to obtain economic benefit from the land. The land assessments and EFA framework will form as milestone criteria for achievement of a stable condition applicable to low intensity cattle grazing areas.

Further information is provided in Appendix C.

3.2.4 Regulatory Constraints

There are relatively few regulatory constraints on the PMLU for the Site. Local planning schemes, Regional plans, State Policies and government priorities were reviewed to determine if the proposed PMLUs stated in Table 8 are consistent with these strategies.

These are discussed below.

3.2.4.1. City of Mount Isa Planning Scheme

The City of Mount Isa Planning Scheme is the primary planning instrument for land within the Mount Isa Local Government Area.

Land within the project area and surrounds is zoned as rural in the *Mount Isa Planning Scheme* (MICC, 2020), which allows for cropping, intensive horticulture, aquaculture, grazing, intensive animal industries, renewable energy facilities and extractive industries. These defined uses and zoning intent for the area are consistent with the PMLUs for the Site.

3.2.4.2. North West Regional Plan 2010-2031

Regional planning seeks to provide long-term strategic direction to support the local growth and development of the States regions.

The *North West Regional Plan 2010-2031* (DIP, 2010) (Regional Plan) provides the framework for growth and sets planning requirements for sustainable development, economic growth, protection of regional values and providing positive land use.

The Queensland Government, through the Regional Plan identifies that LLM is located within the mining activity centre within vicinity of the major regional activity centre of Mount Isa.

The Regional Plan identifies that protecting regional landscape and supporting regional production values is a key desired outcome—with the proposed milestone criteria and proposed PMLUs meeting the intent and requirements of the Regional Plan.

3.2.4.3. State Planning Policy

The State Planning Policy (Department of State Development, Infrastructure, Local Government and Planning, 2017) forms a component of the Queensland land use planning system and outlines the Queensland Governments interests and key themes. The State Planning Policy requires that State interests are integrated into local government planning schemes

Of relevance to LLM is the state interest of economic growth.

The resources on which agriculture depends are required to be supported to ensure the long-term viability of the agricultural sector. PMLUs within the Site will comprise and support agricultural activities.

Closure activities for the Site will also generate employment and economic growth for the construction section. This meets the State Planning Policy state interests of development and construction.

3.2.5 Availability of Areas for Progressive Rehabilitation

Most of the RAs include infrastructure that is critical to the underground mining operation and will be required to remain in an operational condition until End of Commercial Proposition is called. As a result, the land currently available for progressive rehabilitation at the Site is limited noting opportunities to undertake progressive rehabilitation on the site have already been implemented as detailed in Section 2.2.7. Key drivers and constraints for each of the RAs is presented in **Table 9**.

Table 9: Availability for Progressive Rehabilitation

Relevant Activity	LoA Requirements *	Progressive Rehabilitation Availability
RA1 Waste Rock Emplacement		
WRE	Present - 2033	Available for rehabilitation once the borrow material source in the mine infrastructure footprint (Borrow Area I) becomes available. Borrow sources in undisturbed locations are an option however may not be pursued. Capping of the WRE is not available until site demolition works and contaminated land stripping works have ceased in 2033 -2034 in the mine development area. Careful planning will be required to ensure demolition scheduling works takes place to ensure the availability of suitable borrow material by 2033. Ongoing reshaping works for the final WRE closure design will continue during operations.
RA2 Topsoil Stockpiles		
Topsoil Stockpile (near WRD)	Present - 2035	Available for rehabilitation following removal of the topsoil stockpile for rehabilitation. It is estimated to take three years to complete the majority of rehabilitation works on site.
Topsoil Stockpile (near CDA)	Present - 2035	Available for rehabilitation following removal of the topsoil stockpile for rehabilitation. It is estimated to take three years to complete the majority of rehabilitation works on site.
RA3 Leachate Management Dam and Erosion and Sediment Control Facility (Low Intensity Cattle Grazing)		
Leachate Management Dam	Present - 2025	Due to progressive rehabilitation works in the LMD catchment, including removal of the LMD Stockpile and other mineralised material, the LMD can be decommissioned prior to the other regulated dams. A timeframe of three years has been proposed to allow completion of a decommissioning plan, including on-going sampling.
Erosion and Sediment Control Facility	2025 - 2045	The ESC facility will be required for water management purposes to manage sediment runoff. The ESC facility will be available for decommissioning following the completion of rehabilitation works in the upper catchment (proposed for completion in 2035) and when the vegetation established on the disturbance areas in the upper catchment is suitably mature. A conservative timeframe has been adopted to account for uncertainty.
RA4 CDA, CDB, PPD, Sediment Dams and Erosion and Sediment Control Facility		
CDA, CDB and PPD and associated Sediment Dams	Present - 2044	Required for ongoing water management of mine-affected water inventory. Decommissioning of the regulated dams cannot commence until underground dewatering ceases, all inventories of mine-affected waters have been removed and rehabilitation of disturbed areas has been completed.
Erosion and Sediment Control Facility	2044 - 2052	The ESC facilities will be required for water management purposes to manage sediment runoff. The ESC facility will be available for decommissioning following the completion of rehabilitation works in the upper catchment (proposed for completion in 2035) and vegetation establishment is considered suitably mature.
RA5 Infrastructure (Native Habitat)		
Former LMD Stockpile	Present - 2025	The area under the former LMD Stockpile will be available for surface preparation and revegetation works.
Infrastructure and Laydown areas	Present - 2032	Available for rehabilitation once the end of commercial proposition is called in 2032. Infrastructure is essential for the ongoing operation of the mine site.

Relevant Activity	LoA Requirements *	Progressive Rehabilitation Availability
RA6 Infrastructure (Low Intensity Cattle Grazing)		
Infrastructure (Camp, Managers Houses, STP, WTP, Power Station and Transmission Station	Present -2039	Available for rehabilitation following completion of the three-year active rehabilitation phase and additional allowance of services to remain for ongoing monitoring and maintenance activities, including mine dewatering and continued water treatment and services.
All other Infrastructure and Laydown areas	Present - 2032	Available for rehabilitation once the end of commercial proposition is called in 2032. Infrastructure is essential for the ongoing operation of the mine site.
Areas adjacent to the dams	Present - 2044	The area adjacent to the regulated dams is not available for rehabilitation until the dams are decommissioned (in 2044). The RO WTP (adjacent to CDA) will be decommissioned in 2044 for continued water treatment associated with the regulated dams.
RA7 ROM Pad, Paste Plant and Batch Plant		
ROM Pad, Paste Plant and Batch Plant	Present - 2032 2033 - 2052	Available for rehabilitation once the end of commercial proposition is called in 2032. Infrastructure is essential for the ongoing operation of the mine site. Optional borrow site (Borrow Area I) is required for site rehabilitation works. Borrow Area I provides rock mulch material for the WRE and on-site growth media requirements. The selected borrow site will not be available for rehabilitation until site stability is moderately achieved.
RA8 Exploration, Roads, Tracks and Borrow Sites (Native Habitat)		
Exploration, Roads, Tracks and Borrow Sites	Present - 2032 Present - 2060 2033 - 2052	The majority of roads and tracks are required to ensure access for ongoing monitoring and maintenance works and future exploration activities to continue. Opportunities to rehabilitate certain roads and tracks have been identified. Borrow sites are required for site rehabilitation works. Borrow Area C will provide rock armouring material for the WRE, ESC facilities and surplus for on-site erosion protection. Borrow Area C will not be available for rehabilitation until completion of construction of ESC facilities (proposed for 2044) and site stability is moderately achieved.
RA9 Exploration, Roads, Tracks and Borrow Sites (Low Intensity Cattle Grazing)		
Exploration, Roads, Tracks and Borrow Sites	Present - 2032-2044 Present - 2060 2033 - 2052	The majority of roads and tracks are required to ensure access for ongoing monitoring and maintenance works and future exploration activities to continue. Opportunities to rehabilitate certain roads and tracks have been identified. Borrow sites are required for site rehabilitation works. Borrow Area B1, B2 or A provides rock mulch material for the WRE and on-site growth media requirements. The selected borrow site will not be available for rehabilitation until site stability is moderately achieved.
RA10 Underground Openings – Shafts, decline, portal		
Four Shafts, Decline and Portal	Present - 2035	The four shafts and decline will be available for backfilling in 2032 when the end of commercial proposition is called and contaminated soils are removed from the ROM Pad and site demolition works are complete. The sealed concrete bulkhead for the decline and backfill of boxcut will be available for installation once the regulated dams have been decommissioned in 2044 to allow further demolition waste disposal underground.

3.3. NON-USE MANAGEMENT AREAS

For the purposes of this PRCP, there are no Non Use Management Areas (NUMAs) proposed for the Site.

3.4. VOIDS IN FLOODPLAINS

In 2020, LLM commissioned a suitably qualified and experienced water engineer to review the risks presented by a failure of any of the regulated dams at the Site. WRM Water and Environment Pty Limited prepared a failure impact assessment which included consideration of the credible modes of failure under both sunny day and flooded conditions.

The failure impact assessment considered the incremental risk afforded by a dam breech under the flooded condition. This included determination of the most critical flood under the 0.5 % Annual Exceedance Probability (AEP) for the Desert Creek catchment. The results of flood inundation mapping under the 0.5 % AEP flood in addition to a dam breech at CDA are provided in Appendix D.

WRM was also commissioned to remodel the inundation zones for Desert Creek under the probable maximum precipitation scenario or 0.1 % AEP for the proposed final landform closure design. Their report was finalised in 2022 and is presented as Appendix D.

Inundation mapping for the 0.1 % AEP rainfall event is provided in Figure 13**.** Results of the modelling clearly indicate that:

- the Site will be free draining, and
- under the 0.1 % AEP flood, the major facilities that comprise LLM are above the inundation zone.

Consequently, the risk of floodwaters affecting future rehabilitation areas or inundating final voids is not material.

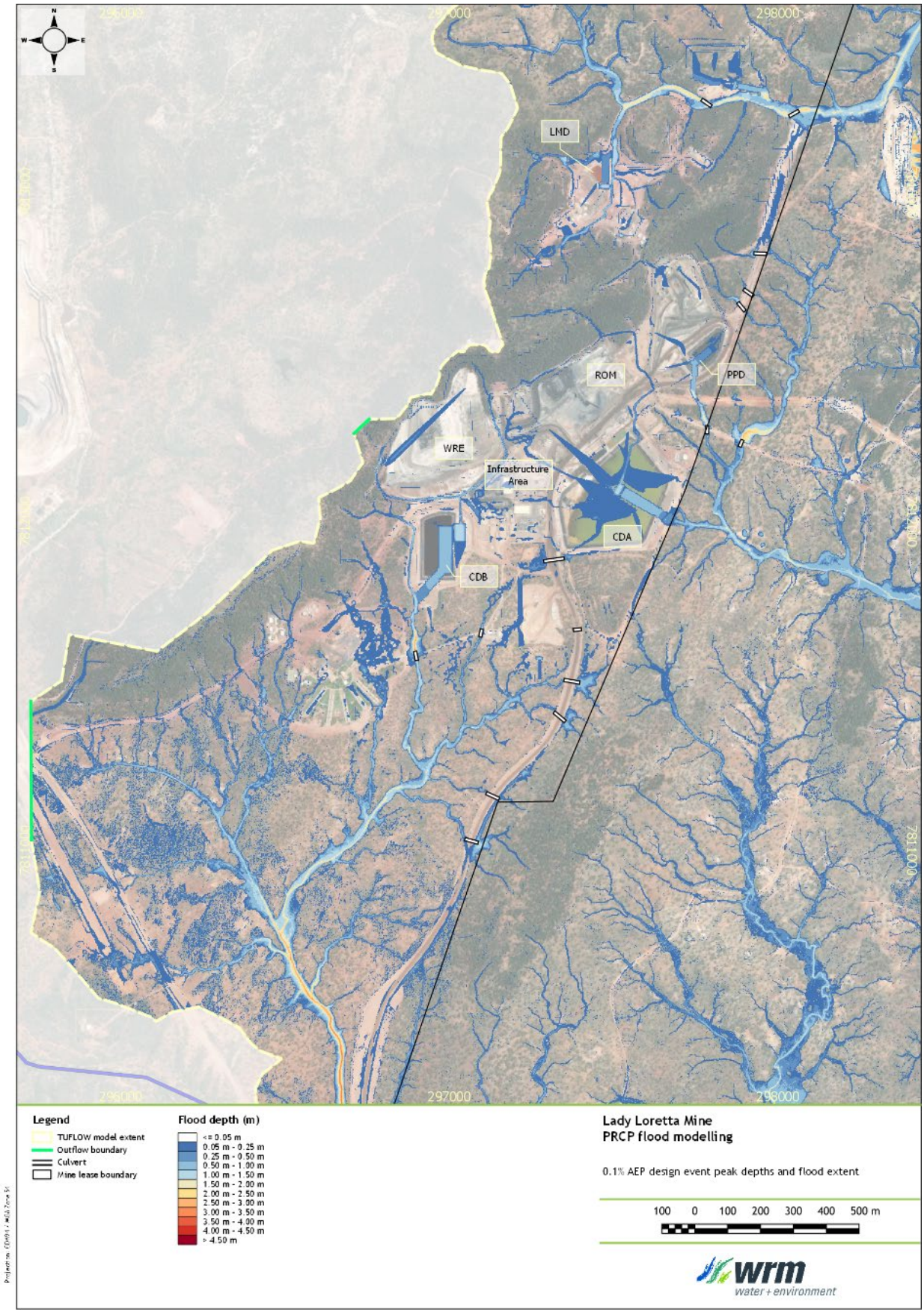


Figure 13: Flood Inundation Map - 0.1 % AEP Rainfall

3.5. STAKEHOLDER CONSULTATION

3.5.1 Overview

These relevant stakeholder groups to the development, operation and rehabilitation of the LLM are presented in Table 10.

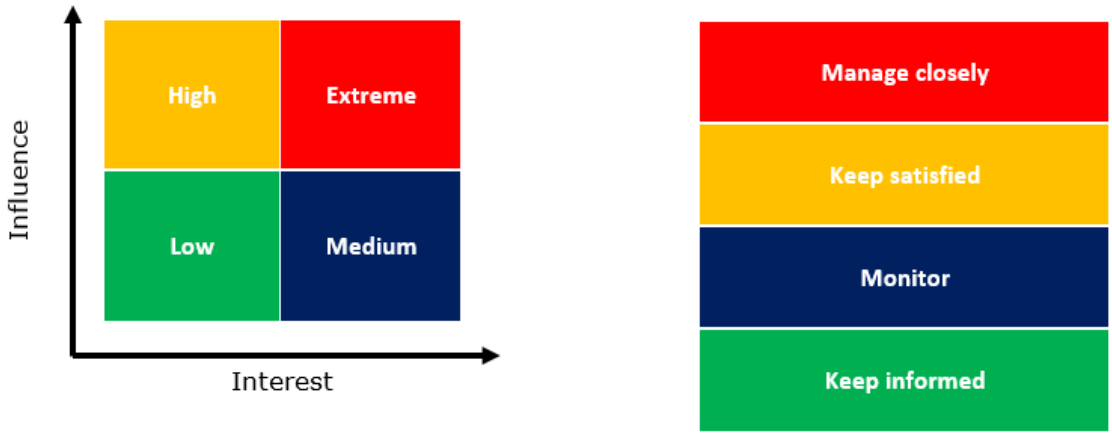
Table 10: LLM Stakeholders

LLM Workforce	Pastoral Landholders	Traditional Owners
• Glencore employees • Redpath employees • Other contractors • Unions	• Koolamara • Skinny Dip Outstation • Thorntonia • Gundaria • Yelvertoft • Calton Hills	• Kalkadoon • Indjilandji • Myuma
Local and State Governments	**Federal Government**	**Non-Government Organisations**
• Mount Isa City Council • Department of Environment and Science • Department of Resources • Department of State Development, Infrastructure, Local Government and Planning • Department of Transport and Main Roads • Department of Agriculture and Fisheries	• Department of Industry, Science, Energy and Resources • Department of Agriculture, Water and the Environment	• Queensland Resources Council • Minerals Council of Australia • Industry Queensland • Commerce North Queensland • North Queensland Conservation Council • Southern Gulf Catchments • Georgina Diamantina Catchment Committee • News media
Neighbouring Mines	**Communities**	**Utilities, Services and Corporations**
• Lady Annie Copper • Paradise South Phosphate • Capricorn Copper	• Mount Isa • Cloncurry • Townsville • Member for Kennedy (Commonwealth) • Member for Traeger (Queensland)	• Ergon Energy • Telstra • Logistics suppliers • Fuel suppliers • Airlines

Glencore recognises and respects the rights, concerns and aspirations of all stakeholders and seeks to engage with them in a fair and transparent manner in planning and executing closure of LLM. Glencore recognises that decommissioning and rehabilitation of LLM will have a different impact on different groups. To that end, Glencore operates pursuant to a LLM Stakeholder Engagement and Communication Strategy that includes a framework to assess the relative importance of each stakeholder group.

The assessment framework is presented in Plate 1.

Plate 1: LLM Stakeholder Assessment Framework



The strategy is aligned with the International Association for Public Participation (IAP2) public participation spectrum which is a recognised framework. The IAP2 Public Participation Spectrum (Inform, Consult, Involve, Collaborate and Empower) was applied to determine the appropriate engagement activity, based on the priority rating of each stakeholder group, as shown in Plate 2.

Plate 2: IAP2 Public Participation Spectrum

IAP2 Public Participation Spectrum

	Inform	Consult	Involve	Collaborate	Empower
Goal	To provide stakeholders with information to assist them in understanding the problems, alternatives, opportunities and solutions	To obtain feedback on analysis, alternative and or decisions	To work directly with stakeholders throughout the process to ensure public concerns are consistently understood and considered	To partner with stakeholder in each aspect of the decision including the development of alternatives and the identification of the preferred solution	To place final decision-making in the hands of stakeholders
Promise	"We will keep you informed."	"We will keep you informed, listen to and acknowledge your concerns aspirations and provide feedback on how your input influenced the decision."	"We will work with you to ensure your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision."	"We will look to you for direct advice and innovation in formulating solutions, and incorporate your advice and recommendations into the decision to the maximum extent possible."	"We will implement what you decide."
Risk Rating	Low	Medium	High	Extreme	Not applicable to our activities at this time

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The stakeholder groups identified as "Collaborate" or those that will be directly engaged in the development and implementation of this PRCP are:

- LLM workforce,
- Traditional owners – Kalkadoon, Indjilandji and Myuma peoples,
- Neighbouring landholders,
- Local government – MICC, and
- State government – Queensland.

Affected stakeholders are engaged in rehabilitation planning and performance, LoA, regulatory compliance and other relevant topics as a matter of course. Consultation and discussion regarding decommissioning and rehabilitation plans and works occur within a broader context.

A key stakeholder engagement event that occurs annually is the Neighbours' Day which is held on-site at LLM. All key stakeholders (including landholders) and other community stakeholders are invited. Topics of discussion include LoA planning, closure planning and the PRCP, the proposed PMLUs, progressive rehabilitation and beneficial reuse opportunities. In addition to the Neighbours Day, broader Community Information Sessions are convened in Mount Isa by Glencore's Queensland Metals on a six-monthly basis. These take a town-hall style but include opportunity for question and answers. LoA, regulatory compliance and mine closure are regular topics. The stakeholders who attend often include: the Mount Isa City Council, Mount Isa Community, local industry leaders, workforce and contractors/suppliers. Ongoing stakeholder engagement will occur, including further collaboration (face-to-face meetings) with neighbouring landowners to discuss potential transfer of facilities.

A key element of the Stakeholder Strategy is that engagements with stakeholders affected by the development, operation and rehabilitation of the LLM are registered. Glencore maintains a Stakeholder Engagement Register which includes past and future consultations. The following data is recorded in the Stakeholder Engagement Register:

- Date of engagement,
- Topic/event – includes type of interaction,
- Stakeholder details,
- Glencore representatives involved,
- Details of the engagement – list of stakeholders, information provided, record of issues / questions raised by stakeholders, discussions and outcomes, and
- Follow up action – to address how issues have been considered, who's responsible and commitment dates, where applicable.

3.5.2 Development of this PRCP

Development of LLM has included extensive engagement and consultation with key stakeholders. This engagement commenced prior to the grant of the EA and will continue until at least when the EA is surrendered. Key episodes in the development of the closure strategy and in the development of this PRCP are described in Table **11**.

Table 11: Stakeholder Consultation Register

Date	Consultation Type	Stakeholders Engaged	Information Provided or Sought	Decisions/Outcomes	Commitments Made
May 2022	Community Information Session	Mount Isa Community Mount Isa City Council Contractors/Suppliers MIM Workforce Media Local industry leaders	Operational update on mine production and Life of Asset. Progressive rehabilitation and closure planning works discussed including progressive rehabilitation of the LLM waste disposal trench. Expected closure and post-closure periods, including discussion on key activities and milestones within each period. ABC Interview with Queensland Metals and Zinc Assets Australia Chief Operating Officer (COO) occurred following the Community Information Session.	No follow up actions	Continuation of community information session on LLM
April 2022	Kalkadoon Native Title Corporation face to face meeting	Board Members of Kalkadoon Native Title Corporation	Indigenous land use agreements (ILUA). Queensland Metals business updates, with LLM business continuing as planned at LLM and Life of Asset on track.	No action	Ongoing engagements on ILUA and other relevant topics
October 2021	Site Visit to LLM	Qld Fire and Emergency Services (QFES) officers President of Commerce North West Treasurer of Commerce North West Regional Development Officer of Mount Isa to Townsville Economic Development Zone (MITEZ) Executive Officer of MITEZ Electorate Officer to Hon Bob Katter MP, Federal Member for Kennedy	Presentation on site history, operations and production, site domains and disturbance footprints, rehabilitation and key closure studies, including completed and proposed progressive rehabilitation works. Post Mine Land Uses, PRCP obligations and legislative process, Life of Asset and community support programs discussed. Key closure planning programs mentioned including: final landform designs, WRE cover system, borrow material investigations, infrastructure demolition plans, rehabilitation methodology, long term water management and closure criteria. Questions were raised regarding changes to the legislative process around rehabilitation. Clarification was provided; LLM rehabilitation and closure commitments will change should legislation change. Questions were raised regarding workforce transition once mine comes to end of its life. Many Departments, in particular environment staff, will be needed until rehabilitation process is complete. Workforce transition opportunities will be available once mine comes to an end, through rotation across other Glencore operations. Surface and underground tour provided.	No follow up actions identified	Compliance with regulatory mechanisms for closure. Progressive rehabilitation efforts continue. PMLUs of grazing and native habitat remain unchanged.

Date	Consultation Type	Stakeholders Engaged	Information Provided or Sought	Decisions/Outcomes	Commitments Made
October 2021	Community Information Session	33 attendees made up of key stakeholders and community members	Overview of current LLM Life of Asset and progressive rehabilitation and closure planning process. Discussion topics included demand for metals, major projects, mining rosters, HSEC programs and school pathway programs. ABC Interview with Queensland Metals and Zinc Assets Australia COO occurred following the Community Information Session.	No follow up actions	Continuation of community information session on LLM
December 2020	Newsletter	All Stakeholders	Fact Sheet supplied detailing PRPC obligations for mining companies and the process for LLM.	Nil	Compliance with PRCP obligations.
October 2020	Site Visit to LLM	20 Stakeholders in attendance: QFES Police-Citizens Youth Club Mount Isa Commerce North West Mount Isa to Townsville Economic Development Zone (MITEZ) Department of State Development Tourism and Innovation Federal Member for Kennedy office Koolamara Station May Downs Station Austral Resources (Lady Annie Mine).	Presentation including site history, Life of Asset, life of asset production, closure planning activities, and key milestone dates, progressive rehabilitation undertaken on site (LMD remediation works, exploration borehole program, trench works and rehabilitation material program update), proposed post mining land uses (of grazing and native habitat), Queensland Government reforms and PRCP requirements discussed including closure goals for LLM. Surface and underground tour provided.	Positive feedback received on the day of the event. No issues or enquiries requiring action/feedback.	Compliance with regulatory mechanisms for closure. Progressive rehabilitation efforts. PMLUs of grazing and native habitat.

3.5.3 Stakeholder Engagement Plan

Implementation of this PRCP and execution of the Decommissioning and Rehabilitation program will occur over several years. Evolution of the plan is inevitable, so it is essential that stakeholders remain engaged and are relevantly included in any future modifications or amendments. Specific changes are difficult to predict but are likely to include LoA extension, technical understanding of the risks and opportunities presented at the Site, as well as technological improvement in their control. Glencore will continue to engage with key stakeholders with a view to maximising opportunities and minimising losses associated with the decommissioning and rehabilitation of LLM. The current plan detailing the specific objectives and approaches of this consultation is provided in Table 12. The planned consultation will allow stakeholders the opportunity to comment and provide feedback, a fundamental part to the success of the stakeholder consultation process. This plan will adapt as new opportunities and/or challenges present themselves, as appropriate.

Table 12: Stakeholder Engagement Plan

IAP2 Public Participation Spectrum Category	Engagement Type	Engagement Frequency	Stakeholders	Information Topic	Objective and Information Released
Inform	Resourceful e-newsletter (Queensland Metals)	Monthly (monthly publication with LLM content included as appropriate)	All	Life of Asset	• Education on lifecycle of a mine, detailing activities required under Life of Asset plan and next steps. • Life of Asset operational stories, where appropriate. • Social media posts and direct linking relevant stories from e-newsletter in Queensland Metals Facebook posts.
				Operational performance / regulatory compliance	• Major operational milestones, including production and safety achievements and any improvement initiatives and include Life of Asset status.
				Rehabilitation and Closure Activities	• Updates on progressive rehabilitation underway across LLM operation.
	Intranet	As required	Workforce	All Topics	• Continue to use intranet to support LLM internal engagement regarding key milestones and activities.
	COO/General Manager/Manager briefings	Quarterly	Workforce	Life of Asset / Rehabilitation and Closure / Operational Performance / Regulatory compliance	• Written reporting and/or face-to-face engagement where practicable to reflect on performance and clarify goals. • Incorporate video upload to intranet for key talks, as appropriate.
	Social Media	Ongoing	All	Life of Asset / Rehabilitation and Closure Activities / Operational Performance / Regulatory Compliance / Others, as required	• Incorporate social media into regular external communication planning where appropriate.
	Glencore website	Ongoing	All	Life of Asset / Rehabilitation and Closure Activities / Operational Performance / Regulatory Compliance / Others, as required	• Provide information on Life of Mine discussions, decisions, milestones and closure timeframes as well as an update on rehabilitation plans and activities including those relevant to the PRCP.
Monitor	Contractors/Suppliers Forum	One-year before closure	Contractors/suppliers	Life of Asset	• Host forum in Mount Isa to outline Lady Loretta Mine Closure timeframes. • Ensure key suppliers informed and engaged through transition.
	Pre-deployment meetings/Toolbox talks	Ongoing	Mount Isa Mines workforce	Life of Asset / Rehabilitation and Closure / Operational Performance / Regulatory Compliance / Others, as required	• Provide information on Life of Mine discussions, decisions, milestones and closure timeframes as well as an update on rehabilitation plans and activities.

IAP2 Public Participation Spectrum Category	Engagement Type	Engagement Frequency	Stakeholders	Information Topic	Objective and Information Released
Involve	Site visit	Annually	Mount Isa Community Leaders Neighbouring Landowners Neighbouring Mines The occasional state or federal representative as requested or required	Life of Asset / Rehabilitation and Closure Activities / Operational Performance / Regulatory Compliance / Others, as required Potential transfer of LLM facilities / infrastructure to Neighbouring Landowners	• Host a Neighbours Day at Lady Loretta Mine to discuss closure timeframes and plans, Post Mine Land Uses, progressive rehabilitation activities, final landform designs and PRCP requirements. • Stakeholder awareness of site activities and how mining impacts are managed during operations and closure. • Provide forum for discussion on topics relevant to stakeholders (risk to livestock, dust impacts, availability of site infrastructure - i.e. roads). • Requests/invitations to State or Federal representatives to visit the operations to achieve a greater understanding of the closure timeframes and plans.
	Water Licence Extraction Permit	One-year before closure	Neighbouring Landowner – Thorntonia Limestone Borefield	Regulatory Compliance	• Adherence to Water Licence permits extraction from Thorntonia Limestone Borefield. Licence specifies that Noranda must enter arrangements with the bore owner one-year prior to closure.
	Community Information Sessions	Bi-Annually	Mount Isa Community Mount Isa Council Contractors/Suppliers MIM Workforce Media Local industry leaders	Life of Asset / Rehabilitation and Closure / Operational Performance / Regulatory Compliance / Others, as required	• Content of the information sessions to be simple and provide an operational update and information relating to operational performance and other topics, as required.
	Stakeholder feedback and complaints	Ongoing	ALL	Life of Asset / Rehabilitation and Closure / Operational Performance / Regulatory Compliance / Others, as required	• Maintain grievance mechanisms in line with Glencore Corporate Practice, including 24-hour Community Feedback Hotlines across all operational communities.
	Media Engagement	As required	Media/All	Life of Asset / Rehabilitation and Closure / Operational Performance / Regulatory Compliance / Others, as required	• Background briefings for key challenges/changes. • Proactive media releases detailing progress of closure and rehabilitation plans.

IAP2 Public Participation Spectrum Category	Engagement Type	Engagement Frequency	Stakeholders	Information Topic	Objective and Information Released
Collaborate	Queensland Department Briefings	Ongoing	Queensland Government departments	Life of Asset / Rehabilitation and Closure Activities / Operational Performance / Regulatory Compliance / Others, as required	• Face-to-face engagement where possible to reflect on performance and clarify goals.
	Face-to-face meetings	Ongoing	Representatives of: Mount Isa Local Council State Government Federal Government Neighbouring Landowners Government Owned Corporations Glencore Corporate Office	Life of Asset / Rehabilitation and Closure Activities / Operational Performance / Regulatory Compliance / Others, as required	• Face-to-face engagement where possible to reflect on performance and clarify goals.
	Face to face meetings with Indigenous groups	Ongoing	Indigenous groups	Life of Asset / Rehabilitation and Closure / Operational Performance / Regulatory Compliance / Others, as required	• Face-to-face engagement with the Kalkadoon People where practicable to reflect on quarterly performance and clarify goals. • Face-to-face engagement to discuss LLM rehabilitation and closure activities and promote opportunities for involvement. • Provide forum for discussion on topics of relevance to indigenous groups.
	Stakeholder closure planning workshops / face-to-face meetings	As required	Neighbouring Landowners Mount Isa City Council Southern Gulf NRM Ltd	Life of Asset / Rehabilitation and Closure Activities / Operational Performance / Regulatory Compliance / Others, as required	• Stakeholder awareness of site activities and how mining impacts are managed during operations and closure. • Opportunities for beneficial reuse identified and assessed with stakeholders. • Face-to-face meetings with landholders to discuss closure timeframes and plans, PMLUs, progressive rehabilitation activities, final landform designs and PRCP requirements. • Provide forum for discussion on topics relevant to stakeholders (risk to livestock, dust impacts, availability of site infrastructure - i.e. roads).

3.6. REHABILITATION AND MANAGEMENT METHODOLOGY

3.6.1 General Practices

Full implementation of the Decommissioning and Rehabilitation program will result in a post mining final landform that broadly reflects the pre-mining condition. Mining development at the Site has not included a Tailings Storage Facility (TSF). The most significant change is the development of the Waste Rock Emplacement (WRE). Minor changes will also include the vicinity of the ROM Pad and the regulated dams (CDA, CDB and PPD). These are discussed in the following sections.

The post mining final landform for most of the disturbance area will see a return to the pre-disturbance condition. Following the removal of the site fixed plant and infrastructure, any voids will be sealed and backfilled before being reprofiled to coincide with the undisturbed areas at slopes approximating the pre-mining condition. These slopes will generally not exceed 4 H:1 V (14°) and are generally flatter than 10 H:1 V (5.5°). Following reprofiling, disturbed areas will be deep-ripped along contour and revegetated with species consistent with the proposed PMLU.

A snapshot of the landform and surface water drainage features of the Site in 2021 is presented in Figure 14. Catchment A drains from the northern portion of the Site to Magazine Creek via the SW01 monitoring station. Catchments B and C drain to Desert Creek via SW03 and SW07 respectively. A snapshot of the landform following conversion of the mine affected water dams to ESC facilities is presented in Figure 15 and the proposed post mining final landform is presented in Figure 16.

A three-dimensional representation of the Site following implementation of the Decommissioning and Rehabilitation program is attached in Appendix E.

295800E 296400E 297000E 297600E 298200E

7813800N 7813200N 7812600N 7812000N 7811400N 7810800N 7810200N

N W E S

CATCHMENT A
112.70Ha

CATCHMENT B
96.67Ha

CATCHMENT C
257.00Ha

SW01

SW03

SW07

LMD DAM

PASTE PLANT

CWD4

CWD3

OD9

OD6

OD8

PPD

OD2

OD2

ROM PAD

WRE

OD5

OD4

OD1

OD10

INFRASTRUCTURE

CDA

TS

CDB

OD7

TS

LAYDOWN

CAMP

0 0.25 0.5 0.75 1 km

CRS: GDA94 / MGA Zone 54

LEGEND

- WM POINTS
- CURRENT MINING CATCHMENT
- PHASE 1 INFRASTRUCTURE
- PHASE 1 DAMS
- PHASE 1 CLEAN WATER DRAINS
- PHASE 1 DIRTY WATER DRAINS
- PHASE 1 CONTOURS (2.5m)

LADY LORETTA MINE PROJECT

CURRENT LANDFORM

FIGURE 014

112009-04

DATE: 2023-03-11

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295800E 296400E 297000E 297600E 298200E

7813800N 7813200N 7812600N 7812000N 7811400N 7810800N 7810200N

N W E S

CATCHMENT A
112.70Ha

SW01

ESC2

CATCHMENT B
96.67Ha

ESC3

ROM PAD

WRE

ESC4

SW03

ESC5

CATCHMENT C
257.00Ha

SW07

0 0.25 0.5 0.75 1 km

CRS: GDA94 / MGA Zone 54

LEGEND

- WM POINTS
- POST MINING CATCHMENT
- ESC Facility
- ROM PAD
- WRE
- PHASE 2 CLEAN WATER DRAINS
- PHASE 2 SEDIMENT LADEN DRAINS
- PHASE 2 CONTOURS (2.5m)

LADY LORETTA MINE PROJECT

TRANSITIONAL LANDFORM
- END OF MINE AFFECTED WATER MANAGEMENT

FIGURE 015

112009-04

DATE: 2023-03-11

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295800E 296400E 297000E 297600E 298200E

7813800N 7813200N 7812600N 7812000N 7811400N 7810800N 7810200N

N W E S

CATCHMENT A
112.70Ha

SW01

CATCHMENT B
96.67Ha

SW03

CATCHMENT C
257.00Ha

SW07

0 0.25 0.5 0.75 1 km

CRS: GDA94 / MGA Zone 54

LEGEND

- WM POINTS
- CURRENT MINING CATCHMENT
- PHASE 3 CONTOUR (2.5m)
- PHASE 3 DRAINS

LADY LORETTA MINE PROJECT

POST MINING
FINAL LANDFORM

FIGURE 016

112009-04

DATE: 2023-03-11

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3.6.1.1. Soil and Capping Material Assessment

Decommissioning and rehabilitation of the Site will require a suitable inventory of borrow materials to be available for various works including capping, revegetation, backfill and water management.

Borrow material requirements will include:

- Topsoil and sub-soil,
- General backfill (ROM Pad),
- Rock mulch, and
- Rock armour.

General Backfill is Non-Acid Forming (NAF) material that is currently stored at and will be sourced from the ROM Pad.

LLM engaged RGS Environmental Consultants Pty Ltd to identify, characterise and quantify suitable inventories of borrow materials to support the Decommissioning and Rehabilitation program. This work produced a material balance confirming sufficient volume of rehabilitation material of a suitable quality exists at the Site and provided multiple options for borrow pit locations and design. Selection of the preferred borrow areas and/or off-site sources will be confirmed through further investigation, in accordance with the conditions of the EA, the EP Act and additional legislation as relevant.

Current borrow material requirements are presented in Table 13 and quality requirements are presented in Appendix A.

Table 13: Borrow Material Requirements

Borrow Type	Volume Required (loose m^3)*	Basis Requirement	Available Volume (lcm)* and Material Source
Topsoil and Sub-soil	28,990	Sufficient to apply: • 150 mm over ROM Pad, Paste Plant and Batch Plant area (RA7) of 10.1 Ha (15,180 lcm) • 150 mm over selected borrow footprint (within RA9) of 7 ha (10,500 lcm) Surplus of growth media for infrastructure areas for conservative estimates only	Topsoil stockpiles: 42,448 Local on-site borrow pits: • Borrow Area B1: 53,031 • Borrow Area B2: 38,473 • Borrow Area A: 122,671 • Borrow Area I: 62,880 • Borrow Area C: 16,900
General Backfill (ROM Pad)**	32,500	Sufficient to backfill RA10: • Decline and box-cut (20,500 m3) • Ventilation shafts (12,000 m3) Surplus to remain in ROM Pad	ROM material: 200,000
Rock Mulch	141,407	Sufficient to apply: • 1.5m to 1.9 Ha crest of WRE (RA1) as infiltration storage layer (ISL) (29,586 lcm) • Conservatively includes 0.3m subgrade and liner protection layers above and below bituminous geomembrane (BGM) liner of WRE (RA1) (11,834 lcm) • 1.2m NAF Rind protection layer to 9 Ha WRE (RA1) batter (99,987 lcm) as batter treatment • 1m over LMD (RA3) for partial backfill reshaping works (2,750 lcm)	Local on-site borrow pits: • Borrow Area B1: 158,683 • Borrow Area B2: 158,754 • Borrow Area A: 174,689 • Borrow Area I: 76,976

Borrow Type	Volume Required (loose m^3)*	Basis Requirement	Available Volume (lcm)* and Material Source
Rock Armour	120,850	Sufficient to apply: • 0.9m protection layer to 9 Ha of WRE (RA1) batter (75,930 lcm) • Clean and dirty water diversions around WRE (13,500 lcm) • Regulated dams (CDA, CDB, PPD) (RA4) conversion to ESC facilities for inlet and outlet spillways (assume 20 lcm per dam) • Surplus for erosion protection across site (i.e. in surface water drains) (28,050 lcm) (conservatively assumes 2.8 Ha)	Local on-site borrow pits: • Borrow Area C: 320,628

* It is assumed that saprolith and pedolith material will settle or consolidate more than competent rock so a swell factor of 1.25 is used for growth medium and rocky soil mulch and 1.30 is used for rock armour

**General Backfill is NAF material that is currently stored at and will be sourced from the ROM Pad

3.6.1.1.1. Optional Borrow Sites

Based on the Rehabilitation Sampling and Analysis Program, a number of optional borrow areas have been considered. These include Borrow Area B1, Borrow Area B2, Borrow Area A and Borrow Area I. The final selection of the best for Project borrow site will be subject to further investigation.

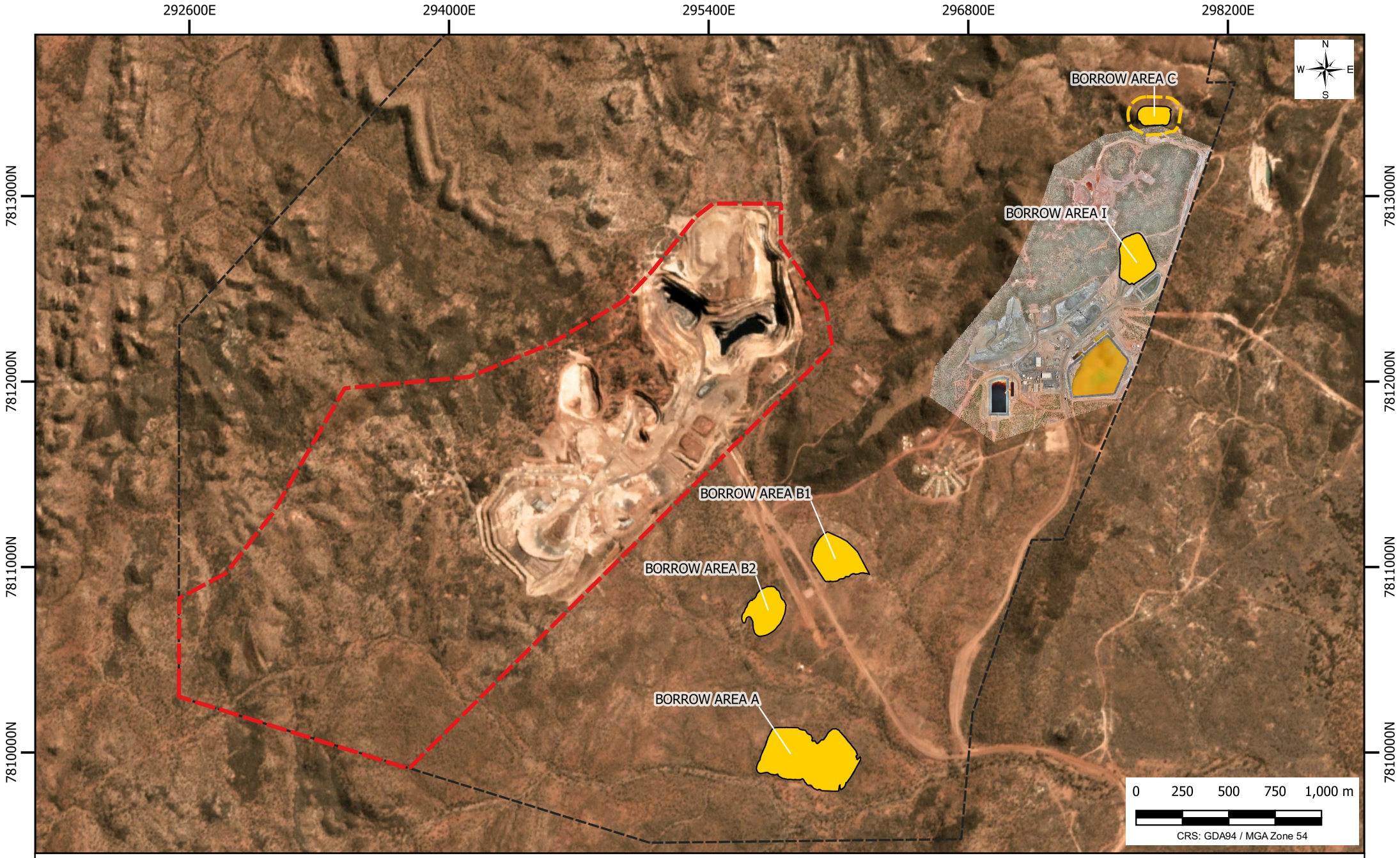
The purpose of providing optional borrow areas is to provide sufficient information within this PRCP to demonstrate that the Project concept planning and design is both reasonable and practicable, and that the Project can subsequently proceed in a technically feasible manner.

Material balance estimates verify that a sufficient volume of rehabilitation materials can be sourced from the topsoil stockpiles, ROM NAF material, Borrow Area C and either B1, B2 or A. Borrow Area B1, B2 and A, offer suitable rocky soil mulch and growth medium without the requirement for fertiliser or ameliorants application. Borrow Area C is the preferred source of competent fresh rock to provide surface armouring of the WRE and offers erosion protection across site. No additional borrow areas are required and a surplus of material is available based on the WRE cover design and site rehabilitation requirements (RGS, 2023).

Borrow Area I is also available within the current disturbed area of the mine located to the northeast of the mine area and has been nominated as the preferred borrow site within the mine disturbance footprint. Borrow Area I poses the constraint of material being unavailable during mining operations and offers approximately half material volumes of rocky soil mulch. The material balance from this borrow area could be increased by mixing growth media found within Borrow Area I and combined with the topsoil stockpiles would yield the required material balance. It is assumed that the top 0.5m of this borrow area would be removed due to risk of contamination (RGS, 2023).

The locations of the optional borrow areas are shown in **Figure 17.**

No borrow site establishment works or ground disturbance will occur without all relevant consent being obtained and all necessary approvals, or amendment to approvals, being secured.



LEGEND

- LADY LORETTA MINE LEASE
- LADY ANNIE LEASE BOUNDARY
- OPTIONAL BORROW AREAS
- BORROW AREA C 50M BUFFER

NORANDA PACIFIC PTY LIMITED

LADY LORETTA MINE
OPTIONAL BORROW AREAS

ATC WILLIAMS

FIGURE 017

112009-04

DATE: 2023-03-13

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3.6.1.1.2. Stockpiled Soils

Development of the infrastructure and fixed plant at the Site required that topsoil and subsoils were stripped to expose suitable foundations. Most of the stripping occurred during major construction and these soil inventories were stockpiled for reuse in rehabilitation works at two locations. Both stockpiles were developed to a maximum height of 2 m and the viable seed bank enabled vegetation to establish quickly.

Topsoil Dump North is located immediately south of the CDA and holds approximately 35,500 m^3 of soil media. The WRE Topsoil Dump is located to the west of the WRE and contains approximately 7,000 m^3 of material. Balancing growth media requirements for disturbed areas is an important component to mine rehabilitation planning, in particular at LLM where topsoil is limited. The topsoil inventory is insufficient to apply a 100 – 200 mm layer over the entirety of the disturbance envelope. The stockpiled topsoil will be used as a soil ameliorant and as growth media on disturbed areas at the Site in areas characterised by low fines or poor moisture holding capacity.

Rehabilitation Area RA7 has been nominated for growth media application. This is based on material properties in this area (lower fines) and poorer moisture-holding capacity. A minimum depth of 150 mm growth media application for Rehabilitation Area RA7 is considered suitable for vegetation establishment and in minimising erosion. The minimum 150 mm depth is also consistent with adopted default criteria stipulated in DES guideline *Estimated Rehabilitation Cost under the EP Act 1994, Version 5* (DES, 2022). The growth media site inventory can readily accommodate a minimum depth of 150 mm across Rehabilitation Area RA7.

Additional surplus material (~13,000 lcm) is available to apply to other areas across site if required (i.e. in higher contamination risk areas that warrant greater depths of soil remediation and subsequent soil application rates) or as a soil ameliorant subject to ongoing monitoring of rehabilitated areas.

Characterisation of the topsoil inventory was documented by RGS in 2023 (RGS, 2023). The characterisation included assessment of soil nutrition and physical properties. The topsoil stockpiles were found to have low salinity, be non-sodic, and non-dispersive, have good aggregate stability and are optimal for mine soils in terms of providing nutrients for plant growth.

Soil characterisation has confirmed the topsoil stockpiles are fit for the intended purpose as a source of growth medium and without the need for fertiliser and/or ameliorants (RGS, 2023).

3.6.1.1.3. Topsoil and Subsoils

In addition, the topsoils and subsoils at the proposed optional borrow sites were characterised and include sandy-clay-loam or clay-loam, with some material that is moderately dispersive.

The characterisation confirmed topsoil and subsoil layers on site supports plant growth and has been verified to be sufficient for native vegetation establishment. The topsoil and subsoils available at the proposed optional borrow sites will be suitable for use during site rehabilitation and can also be incorporated with the rocky soil mulch material for development of the WRE cover.

Any topsoil applied (in particular on slopes) will be undertaken in a manner that minimises the risk of sheet erosion.

3.6.1.1.4. ROM Pad Borrow

The ROM Pad was developed to store extracted ore prior to crushing. The Pad was constructed with approximately 200,000 m^3 of non-mineralised waste extracted during development of the decline. Waste rock used to develop the ROM Pad is characterised as NAF.

This material will be available for reuse as borrow material for various work elements defined in the Decommissioning and Rehabilitation Program.

Decommissioning and rehabilitation of the ROM Pad will include re-mining of a portion of the inventory for the purposes of backfilling the decline and ventilation shafts. The ROM Pad will be managed to ensure that any potential contamination arising from storage and handling of extracted ore is removed. Decommissioning and rehabilitation of any unused material will include recontouring to match the local topography and drainage lines.

3.6.1.1.5. Rock Mulch

The Decommissioning and Rehabilitation Program requires that rock mulch is available for reuse as growth media as well as forming low permeability zones. Rock mulch is typically sourced by borrowing moderately to highly weathered sedimentary rocks that yield a well graded, non-plastic to low plasticity matrix. A combination of both fine and coarse particles provides both acceptable moisture holding capacity whilst retaining some resistance to erosion making them generally suitable for use as growth media. Similarly, these well graded materials can be compacted to form low permeability zones in embankments and cover systems.

The Decommissioning and Rehabilitation Program requires that the rock mulch be comprised of materials that are:

- Chemically stable that do not generate acid or saline drainage on weathering,
- Comprised of well-graded, non-plastic to low plasticity matrix with:
    - Moderate fines (30 % < 2 mm), and
    - Moderate coarse (30 % > 4.75 mm)

3.6.1.1.5.1. Proposed Use of Rock Mulch

Implementation of the Decommissioning and Rehabilitation Program requires that vegetation communities are established on areas disturbed by the mining development. Soils and meta-soils derived or remnant from mining operations in northern Australia are typically characterised by poor soil structure, very low levels of soil organic matter and nutrients, and poor moisture holding capacity. In addition, rainfall at the Site occurs during a short but intense wet season during summer followed by long dry winters. Desiccation during the long dry spells and erosion during periods of intense rainfall are key risk factors for rehabilitation of disturbed land.

For rehabilitation of disturbed land at the Site, the growth media quantity (availability) and quality (nutrition and moisture storage) to support plant establishment and growth has also been considered. The Decommissioning and Rehabilitation program assumes growth media will be available as follows:

- Excavation of subsoils/saprolite/saprock to yield rock mulch,
- Deep-rip into in-situ subsoils/saprolite/saprock and placement of a 150 mm layer or topsoil/subsoil layer within RA7 and borrow sites within RA8, and
- Deep-rip of in-situ subsoils/saprolite/saprock to yield in-situ rocky soil mulch as a substitute for growth media placement.

Investigations undertaken by RGS have identified that suitable inventories of rock mulch are available on the lowland plain located to the south-west of the Lady Loretta ridge. These optional borrow areas are Borrow Area B1, B2 and A, with the final borrow site selected upon further investigation during future Project phases. The shallow soils and subsoils are underlain by weathered mudstones and siltstones that are not affected by mineralisation. Rock mulch material is also available within the current disturbed area of the mine (Borrow Area I) and, post soil stripping to remove potentially unsuitable topsoil, can offer some suitable rock mulch material.

3.6.1.1.5.2. Rock Mulch Characterisation

The lowland plains located to the south of the Lady Loretta ridge are comprised of shallow soils and subsoils underlain by mudstones and shales with diminishing degrees of weathering with depth. RGS investigated and characterised the subsoils and saprolite. The investigation found that borrow pits excavated between 5 to 13 m depth would yield inventories of rock mulch (saprolith horizon) suitable for use as growth media at the Site.

RGS characterised the rock mulch at the site as:

- Well graded with moderate fines (30 % (by mass) < 2 mm) and moderate coarse (30 % > 4.75 mm),
- NAF,
- Neutral to mildly acidic with a median soil pH of 8.1
- Mostly non-saline,
- Mostly non-sodic and non-dispersive, and
- Sufficient for native vegetation establishment with or without the addition of fertiliser and/or ameliorants.

3.6.1.1.5.3. In Practice Use of Rock Mulch

Rock mulch has been used to rehabilitate lands disturbed by mining at several locations in northern Australia with measurable success. A selection of analogous sites where rock mulch has been used as growth media is presented in **Table 14**. These sites are all located in northern Australia and in climatic zones comparable to the LLM, with typical cycles of short and generally intense monsoonal season followed by long dry spells.

Table 14: Sites that have used rock mulch as a growth media

Location	Climatic Conditions (Koppen Geiger Classification)	Rock Mulch Characteristics	Location Lat/Long (AGD84)
Kidston Mine Qld	BSH – Hot Semi-arid 550 mm / annum Intense monsoonal wet season–	Well graded, run-of-mine oxide waste rock	18°51’56.29”S 144° 8’41.61”E””
Century Mine Qld	BSH – Hot Semi-arid 560 mm / annum Intense monsoonal wet season	Well graded, run-of-mine, limestone/dolostone waste rock	18°44’44.19”S 138°36’29.26”E
Lady Loretta Mine Qld	BSH – Hot Semi-arid 450 mm / annum Intense monsoonal wet season	Well graded, run-of-mine, siltstone/mudstone/shale waste rock	19°46’20.57”S 139° 3’28.62”E

A description of the approach to rehabilitation at each location follows.

3.6.1.1.5.3.1. Kidston Mine, Qld

Decommissioning and rehabilitation of the waste rock dumps at the Kidston Mine in northern Queensland utilised rock mulch as the primary growth media. Development of the dumps resulted in large, low slope crests that had been compacted by wheel action of the haul fleet. A layer of rock mulch was placed on top of the compacted crests to act as an Infiltration Storage layer (ISL) as well as growth media. The rock mulch comprised run-of-mine oxide waste excavated using conventional drill and blast, load and haul mining methods. The rock mulch was placed using 180 T rigid haul trucks in a tight paddock dumped arrangement to achieve a nominal layer thickness of 2.2 m.

Vegetation was initiated by the application of tree and shrub species endemic to the local area. No fertiliser or soil ameliorants were used in the establishment or maintenance of the vegetation cover.

The program of works was reported by Williams et al (2006). Williams et al (2022) reported that after 25 years from commencement of rehabilitation works, established vegetation is self-sustaining and community diversity on the revegetated waste material was higher than surrounding land that was subject to burning. The establishment of vegetation of rehabilitated landforms is clearly observable in a review of publicly available aerial photography.

3.6.1.1.5.3.2. Century Mine, Qld

Decommissioning and final closure of the southern waste rock dump at the Century Mine in northern Queensland included reuse of rock mulch as a growth media. The works included installation of an enhanced store and release cover over the crest of the waste rock final landform that had been developed to permanently store PAF waste. The ISL was constructed by placing a nominal 2.2 m layer of rock mulch in a tight paddock dumped pattern during 2010. The rock mulch comprised blocky limestone/dolostone waste rock excavated using conventional drill and blast, load and haul techniques.

Vegetation was initiated by the application of tree and shrub species endemic to the local area. No fertiliser or soil ameliorants were used in the establishment or maintenance of the vegetation cover.

The program to decommission and rehabilitate the southern waste rock dump at Century Mine was reported by Rohde et al (2016). The vegetation was established and has developed in line with expectations**.**

3.6.1.1.6. Rock Armour

High intensity rainfall events occur commonly at the Site and soils and meta-soils disturbed by mining are at high risk of erosion particularly during the period whilst vegetation is establishing. Suitable inventories of rock armour are required to provide a very high level of resistance to erosion along high slope and/or high-rate drainage as well as slopes greater than 4 H:1 V.

Characteristics of suitable Rock Armour include:

- Chemically stable that does not generate acid or saline drainage on weathering, and
- Comprised of predominantly coarse rock (70 % > 4.75 mm) with minor fines.

Site-based investigations have identified that the ridge immediately to the north of the magazine is comprised of quartzite rock that would make a suitable rock armour, subject to further investigation. A small quarry would need to be developed where material would be won using conventional drill and blast techniques. This rock would then be crushed to achieve the required particle size.

3.6.1.2. Borrow Site Design and Development

Simple borrow pits of relatively shallow depth will yield the required inventories of rock mulch and growth medium. Borrow Areas B1 (5.2 ha), B2 (4.1 ha), A (13.4 ha) and I (4 ha) are individually sized to provide the required material volumes. It is noted that not all borrow locations will be required to deliver the material volume required.

At this stage of the Project (concept design), options have been provided to demonstrate surplus of source material and provide optionality for future Project phases.

The method of development in the optional borrow areas (either Borrow Area B1, B2, A or I) would be to cut into the borrow area from the lowest topographic point so the borrow area remains self-draining. Batter angles have been designed at 1V:4H providing sufficient geotechnical stability in Borrow Areas B1, B2, A or I. The pedolith and saprolith from Borrow Area B1, B2, A or I is expected to be excavated using standard free dig truck and shovel methods.

Based on the conceptual design, the maximum batter heights in Borrow Area B1 will be approximately 7 m, Borrow Area B2 will be approximately 1 m (due to being a gently sloped mound), Borrow Area A will be approximately 2 m, and Borrow Area I will be approximately 6 m. Based on these maximum batter heights, no berms are expected to be required.

The pit floor of any proposed borrow area will be excavated no lower than the lowest elevation on the pit perimeter to prevent the capture of surface water flows. Borrow Area B1, B2, A and I are free draining landforms. At this stage a maximum 1% slope on the pit floors will be adopted, which is considered a sufficient gradient for drainage and is readily constructable (RGS, 2023).

A suitable volume of stockpiled growth medium would be hauled and placed over the base of the borrow area when the design reduced level is achieved. A minimum thickness of 150 mm is expected to be applied. The as-placed growth medium will be ripped into the floor of the borrow area. Sufficient nutrient content and seed in the growth medium is expected to be present to enable a strike of vegetation after wet season rain (RGS, 2023).

Borrow Area C (1.7 ha) would be excavated in a small open cut quarry developed into the spur and will likely require some form of blasting. An additional 3.3 ha for a 50 m buffer around the borrow area has been applied, to accommodate any required minor changes to the geometry of the borrow site based on field observations and to enable access and extraction of rock armour material. Batter angles of 60 degrees will provide sufficient geotechnical stability in Borrow Area C, however, further design refinement particularly in relation to safety considerations is anticipated to be necessary. At a concept level, batters with maximum bench heights of 20 m and berm widths of 10 m will provide sufficient geotechnical stability. Growth media application and ripping and seeding works are not proposed at Borrow Area C due to the hard rock surface being non-supportive to such rehabilitation activities. The small excavated landform is proposed to be retained with opportunistic successional development of vegetation proposed (RGS, 2023).

Appropriate buffer zones from existing roads, tributaries and creeks have been adopted for the borrow areas, with a minimum 50 m buffer from adjacent tributaries/creeks. Existing roads can be utilised to access the borrow areas. It is expected that diversion drains would be installed within the excavated borrow pits to reduce ponding (RGS, 2023).

Erosion and sediment control facilities will be installed to manage surface runoff. These facilities will be retained until appropriate water quality objectives are achieved. Any temporary facilities will be appropriate to site conditions, responding to expected risks from erosion, receiving environment, climatic conditions and seasonal factors.

Contour furrows are proposed on the borrow floors as a scour and protection measure. These will appropriately manage and reduce the risk of sheet flow.

3.6.1.3. Waste Rock Characterisation

Extraction of zinc and lead ores requires development of suitable access to the economic orebodies. This development involves excavation of sub-economic material which is referred to as waste rock. Much of the waste rock inventory is used in the mining effort as back-fill but a component is brought to the surface for permanent disposal. Permanent storage of the waste rock inventory at surface presents various risks which are managed pursuant to the Waste Rock and Spoil Management Plan (WRSMP).

All waste rock generated at the Site is characterised in terms of its geochemical risk. The classification criteria are represented in Table 15.

Table 15: Waste Rock Classification

Geochemical Management Unit	Criteria	Rock Units	Management
NAF Non-Acid Forming	Total Sulphur < 0.1 % Maximum Potential Acidity ≥ 3 times Acid Neutralising Capacity NAG pH ≥ 4.5	Upper Siltstone Unit – Interbedded to interlaminated siltstone Cyclic Unit – Interbedded dolomitic sandstone/siltstone Lower Dolomite Unit – Interbedded dolomitic siltstone and sandstone	Reused in development of the ROM Pad
PAF Potentially Acid Forming	Total Sulphur > 0.1 % Maximum Potential Acidity ≤ 3 times Acid Neutralising Capacity NAG pH ≤ 4.5	Cyclic Unit – Interbedded dolomitic sandstone/ siltstone Upper Pyrite Marker – Upper Mineralised Marker – Interbedded siltstones and sulphides Massive Unit – Massive siltstone, locally pyritic Ore Horizon – Banded to massive sulphides Pyrite Unit – Interbedded pyrite	Permanent storage at WRE

Early development of the underground mine was focussed on establishing access to the Lady Loretta orebody and excavation of the access decline. Much of this development occurred in the Upper siltstone and Cyclic units which yielded NAF waste rock. This material was available for reuse in development of the ROM Pad and embankments of the regulated dams.

Following initial development, most of the waste rock generated was from the Massive Unit, Ore horizon and Pyrite unit which are predominantly PAF. Any waste rock brought to surface that was not used in construction was placed into the WRE for permanent storage.

In 2016, Glencore undertook a validation program to confirm the geochemical character of the waste rock stored in the WRE. A total of 32 samples representing the lateral and elevation extent of the facility were collected and tested for acid-base-accounting (ABA) parameters and well as total metals and chromium reducible sulphur. The survey returned an average total sulphur concentration of 7.6% giving an average Maximum Potential Acidity (MPA) of 240 KgH_2SO_4/T. The average Acid Neutralising Capacity (ANC) was determined to be 43 KgH_2SO_4/T. Further detail on waste rock characterisation undertaken at the Site is outlined in the WRSMP.

3.6.2 Landform Design – WRE

This section summarises the proposed landform conceptual design, engineering decision-making process and technical assessment supporting the WRE closure concept design. The WRE closure concept design is provided as Appendix F.

The WRE closure concept design incorporates Glencore's closure objectives, specific requirements outlined in the EA and the Progressive Rehabilitation and Closure Plans Guideline (DES, 2021).

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 (PMLU). These three components of stability are the general rehabilitation goals for all areas disturbed by mining in Queensland.

The WRE closure concept design addresses adopted rehabilitation goals through cover system and batter slope design. The WRE closure concept design considers:

- Local climatic conditions,
- Regional erosion rates,
- Reactivity of the LLM mine waste material,
- Seepage to groundwater and exposure of contaminants to the receiving environment,
- Landform footprint and approved disturbance area,
- Capacity to hold all planned LoM waste volumes, and
- Available construction materials to minimise erosion, environmental harm and sustain the PMLU of native habitat.

Key design elements of the WRE closure concept design landform were defined through a series of options assessments to identify and evaluate multiple options for the cover system, batter slopes and landform geometry as well as trade-offs. Design elements were identified with reference to relevant guidelines (i.e. International Network for Acid Prevention Global Acid Rock Drainage Guide (GARD Guide), ANCOLD guidelines and other literature), technical experience, and Glencore's recent experience on WREs.

A fatal flaw analysis was completed during the development of the criteria. It addressed key constraints that may preclude or eliminate any of the options assessed (e.g. a catastrophic failure of the cover system).

The initial options assessment was completed in 2021 followed by a multiple-accounts analysis (MAA) to select the preferred landform design. The initial options assessment were defined based on the review of similar previous studies, (Section 3.6.1.1.5.3), the working group, regional examples, peer-reviewed literature and best practice guidelines. The MAA criteria included:

- Environmental protection,
- Technical viability/constructability,
- Cover design effectiveness,
- Cost, and
- Other – (stakeholder, regulatory matters)

The original cover system design presented in LLM PMLUP (Noranda Pacific, 2018), which comprised of a hybrid store and release cover design was compared to four alternative cover system design options as part of the MAA Workshop. The original cover system design was ranked third out of the five options, (and ranked fourth for criteria such as environment, cover design effectiveness and stakeholder, regulatory matters), while the adopted option ranked highest. The highest ranking option was adopted as the preferred option for the WRE final landform design.

The WRE closure concept design footprint and height presented in Appendix F, has changed from the original design. To accommodate increased LoM waste volume estimates completed in 2022, the WRE height was increased, resulting in steeper batter slopes to maintain a footprint within the approved disturbance area whilst maintaining acceptable factors of safety for geotechnical stability. Further revisions to the landform geometry were undertaken to achieve operational requirements for waste rock disposal, as follows:

- Additional storage capacity to store current WRE volume (as at October 2022) plus 370,000 m^3 (Loose Cubic Metres).
- Batter slopes of 1V:2.5H
- Bench spacing (vertical increments) of 15 m
- Bench width of 9 m to allow for vehicle access on benches.
- Maintain less than 11 ha disturbance area (per EA).

Assessments demonstrating the cover system and batter slope design effectiveness at achieving the WRE rehabilitation goals, i.e., safe, stable and non-polluting, include:

- **Seepage modelling** – Precipitation infiltration is a key driver of post-closure seepage-related groundwater impacts. This is due to ongoing saturation of PAF waste and continued downward migration of contaminants into groundwater and the receiving environment. The adopted cover system concept design minimises potential environmental harm by preventing ongoing seepage.
    - Seepage modelling results indicate that downward seepage (and upward capillary flow) through the cover system into the underlying waste material is negligible due to the inclusion of the BGM liner.
    - The risk of infiltration on WRE batters when compared to the plateau are reduced due to the slopes adopted and higher rates of surface runoff during a storm event. Notwithstanding, a zone of NAF fill has been included in the concept design to ensure moisture which may infiltrate is appropriately captured. This will ensure percolation into the PAF waste is not an issue.

- **Stability modelling** – The WRE landform concept design is structurally stable. The batter slope angles consider the LoM waste volumes and maintain the footprint within the current approved disturbance area.
    - Stability controlling failure modes and loading conditions have been considered for the WRE. Slope stability modelling results indicate that the proposed final landform is structurally stable for all loading conditions analysed, with factors of safety greater than those recommended by ANCOLD (2019) guidelines.
- **Landform evolution modelling** – Long-term erosion mechanisms (such as sheet wash and rill or gully formation) have potential to expose PAF waste material if the cover system design is not resistant to long-term erosion risks. Long-term landform stability was assessed by estimating the soil loss across the landscape and WRE over a 1000-year period.
    - Erosion rates were estimated using Water Erosion Prediction Project (WEPP) while multiple erosion mechanisms were evaluated using SIBERIA Landform Evolution Model.
    - Erosion modelling results demonstrate that 500 mm erosion depth is similar or less than natural erosion rates in nearby undisturbed areas and predicted erosion will be accommodated by the cover system design such that no unacceptable erosion risks were identified.
    - The concept design thickness of 1.5 m of rocky mulch for the proposed WRE cover system and batter slope geometry will not be adversely impacted by long-term erosion and will not present an unacceptable erosion risk.

  Factors considered within the concept design to ensure the success of the final landform stability include:
    - Avoiding concentrated flow which has generally been achieved by the conceptual final landform design presented in the PRCP.
    - The establishment of vegetation through appropriate surface preparation, seeding, and grazing management.
    - Monitoring and maintenance of drainage controls and assessment of the causes of localised scour until stability is established.

Based on the WRE closure concept design and required functioning of the WRE plateau (which will include vegetation establishment) fertiliser and/or ameliorants maybe applied to the plateau subject to monitoring under the PRCP schedule. The WRE closure concept design and required functioning of the WRE outer batters is to control erosion, with growth media application at risk of 'wash off' or sheet erosion on design slopes making it ineffective. The rock armouring on the outer surface of the WRE will mimic similarities with the natural ridgeline, offering native habitat features that assist in sustaining the PMLU of native habitat.

Further supporting information to justify the chosen WRE final landform and cover system design, inclusive of modelling outcomes is provided in Appendix F.

3.6.2.1. Basis of Design

The WRE will constitute the most significant post-mining landform and will provide for containment of the moderate-high risk waste rock inventory.

Basis of Design criteria for the WRE are provided in **Table 16**.

Table

16: Basis of Design Waste Rock Emplacement

Aspect	Criteria
Design objectives	Long-term containment of high-capacity waste rock Not require ongoing maintenance No direct runoff from crest Maximise (low slope) crest area Minimise batter slope area and length
Bulk stability minimum factor of safety	Static/long term > 1.5 Operating basis earthquake >1.1 Maximum design earthquake > 1.0
Erosion	No active rill/gully erosion > 500m
Water flux	Net infiltration into PAF waste < 10% of rainfall

3.6.2.1.1. Installation of Cover System

Technical evaluation of the works required to decommission and rehabilitate the WRE have been completed by a suitably qualified and experienced consulting engineer. Studies including options assessments and closure design were completed by ATCW.

Works to decommission and rehabilitate the WRE will be focused on the installation of a cover system to provide for permanent containment of the waste rock. The cover system will include:

- Recontouring of the waste rock inventory to achieve batter slopes of 2.5 H:1 V and a crest slope of less than 20 H:1 V (5%),
    - Placement of batter treatments comprising a buttress comprised of 1.2 m compacted PAF waste, 1.2 m compacted NAF protection layer using Rock Mulch, and a 0.9 m Rock Armour protection layer.
- Placement of crest treatments based on the ‘Store and Release’ (SAR) concept comprising:
    - An Infiltration Storage Layer (ISL) comprised of 1.5 m of loosely placed Rock Mulch and vegetation,
    - A Reduced Permeability Layer (RPL) comprised of a Bituminous Geo-Membrane (BGM) and protection material which eliminates water flux and salt flux between the cover and the underlying waste materials,
- Installation of four monitoring stations comprising arrayed volumetric soil moisture and matric suction sensors,
- Modification of existing clean water diversion drains at the perimeter of the WRE including the application of rock armour to resist erosion, and
- Documentation of the construction via an As-constructed Report including certification that the design intention was achieved by a suitably qualified and experienced engineer.

Specific features of the design as well as key risk areas are discussed in the following sections.

BGM will be installed in accordance with manufacturer’s guidelines and verified though appropriate QA/QC measures as part of implementation.

3.6.2.2. WRE Plateau

The low slope (20 H:1 V) plateau area of the WRE will be treated with a Store and Release (SAR) cover. The design includes an ISL that features a highly textured, loosely placed layer of rock mulch that acts as the growth media for a vegetation community dominated by shrubs. The ISL thickness (1500 mm), and method of placement (paddock dumped with no compaction) increases plant available moisture and provides for complete storage of rainfall within the ISL which results in a no runoff surface. Water stored in the ISL is then lost to direct evaporation or evapotranspiration.

The design of the ISL was informed by water balance modelling undertaken in SEEP/W. This analysis considered climatic conditions as well as the soil moisture characteristics of the rock mulch to determine the optimum thickness of the ISL and to ensure full storage of rainfall over the course of a wet season. The additional storage provided by the hummocked landscape was not considered in the analysis making the design conservative. SAR covers have been successfully applied on lands disturbed by mining activities at numerous sites in northern Australia including Kidston (Qld) and Century (Qld).

Placement of the proposed crest treatments can only occur after all the mineralised waste generated by the mining operation and any contaminated soils generated by rehabilitation of other RAs have been placed into final position on the WRE. These streams will include:

- Waste rock generated by the Mining Operations program, and
- Contaminated soils generated by stripping potentially contaminated materials in RA 6 (Infrastructure (Low Intensity Cattle Grazing Area) and RA7 (ROM Pad, Paste Plant and Batch Plant).

As a result, the proposed schedule includes a three-year window to place all mineralised waste into the WRE and a further two years to undertake final reprofiling and installation of the crest treatments.

3.6.2.3. WRE Batter Slopes

The outer batters (2.5 H:1 V) of the WRE will be covered with a buttress comprised of 1.2 m compacted PAF waste rock, 1.2 m compacted rock mulch overlain by a 0.9 m layer of rock armour. Vegetation is not proposed on the batters.

The design of the final landform adopted this approach because it provides for robust containment that is consistent with the PMLU and the alternate approach of a vegetated batter slope is not feasible. A vegetated batter slope would require suitable growth media (containing fine particles) to be applied to the batters. These sloped surfaces would generate high rates of surface runoff which would result in:

- High rates of erosion even on slopes flatter than 5 H:1 V, and
- Low retention of plant available moisture resulting in stunted vegetation growth.

Placement of the proposed crest treatments can only occur after all the mineralised waste generated by the mining operation and any contaminated soils generated in rehabilitation of other areas has been placed into final position on the WRE. These streams will include:

- Waste rock generated by the Mining Operations program, and
- Contaminated soils generated by stripping potentially contaminated materials.

As a result, the proposed schedule includes a three-year window to place all mineralised waste into the WRE and a further two years to undertake final reprofiling and installation of the cover system.

Placement of the proposed treatments on the outer batters of the WRE commenced in 2022 with foundations and drainage works applied at the southern margin. Construction of the batter treatments can and will progress concurrently with the placement of waste rock but they cannot advance in front of mining operations. As a result, installation of the batter treatments will occur on a campaign basis where construction teams are periodically mobilised to raise the batter treatments up to a level that corresponds with placement of the waste rock.

Operational practicalities are such that the campaign to place the uppermost section of the batter treatments will coincide with placement of the crest treatments.

3.6.2.4. Oxidation During Construction

The waste rock generated at the site contains appreciable concentrations of acid forming minerals that are available to oxidise when exposed to atmospheric moisture and air. The inventory also includes alkaline minerals that act to neutralise the acid generated but this does little to reduce the risk of neutral mine drainage.

Controlled placement of waste rock into the WRE has included placement of thin (approximately 1 m) lifts and routine compaction using a vibrating pad-foot roller pursuant to the WRSMP. This approach has resulted in a well-consolidated landform that has resisted the infiltration of water and air. This in turn has limited the rate of oxidation of the accumulated waste rock. Tell-tale signs such as fumaroles and heaving have not been observed.

A significant consequence of this approach is that only minor volumes of seepage are generated. These are acidic and contain dissolved heavy metals and salts, but the volume is minor. Surface runoff however is significant, and it too is of poor quality.

3.6.2.5. Flux of Water through the Contained Waste

Infiltration of rainfall into the stored waste will bring water and oxygen into contact with the acid forming minerals which over the long term will result in oxidation. Most importantly however, infiltration of rainfall may result in a flux of water through the contained waste. This flux would act to flush (existing and new) oxidation products including acid, dissolved heavy metals and salt, from the final landform and potentially into the receiving environment. By limiting infiltration of rainfall, water flux through the waste and therefore contaminant transport, can be suitably reduced to ensure chemical stability in the long-term.

The adopted design for the crest treatment includes a duplex SAR cover comprised of an ISL as well as a BGM. The ISL will provide storage that will act to hold incident rainfall within the cap and the RPL will retard infiltration into the underlying waste. The RPL will include a BGM which will provide for negligible infiltration.

Infiltration into the batter slopes of the WRE will be negligible as the adopted slope will cause rainfall to runoff rather than infiltrate. The WRE has been designed so that the majority of infiltration that does occur will penetrate the NAF buttress before desiccating.

Performance monitoring will be undertaken to validate performance of the batter and crest treatments. Monitoring stations comprised of arrayed volumetric moisture content and matric suction sensors will be used to confirm that net infiltration into the contained waste is less than 10 % of rainfall.

3.6.2.6. Runoff from High Intensity Rainfall

The design of the WRE includes a crest surface that will generate little to no surface runoff. Placement of the ISL will occur so that the layer remains loose and highly textured. The thickness of the ISL has been designed to provide sufficient storage for the short but intense wet seasons experienced at the Site and the hummocked surface will provide short term storage whilst infiltration into the ISL occurs. Meteoric water stored in the ISL will then be available to support plant growth.

The decommissioning and rehabilitation works will also include a layer of rock armour placed on the batters to protect against erosion. The high-intensity rainfall and dispersive nature of the soils encountered at the Site means that a batter treatment based on vegetation is unlikely to provide suitable protection against erosion in the long term. The rock armour layer adopted in the design will be highly resistant to erosion and discourage access by cattle.

3.6.2.7. Sustain the PMLU of Native Habitat

The crest of the rehabilitated WRE will include an open woodland vegetation community comprised of endemic species consistent with the adjacent ridgelines. The ISL will be placed to a thickness of 1.5 m which will provide ample root space for species endemic to the local area and the creation of a native habitat PMLU.

Vegetation is not expected to readily establish on the outer batters within the decades immediately following the rehabilitation works. Trees will establish in the rocky slopes over a prolonged period but they will provide no function to the final landform other than aesthetics.

The proposed rocky scree slopes are commonly found on the local ridges.

3.6.2.8. Demonstration of Chemical Stability

Works to decommission and rehabilitate the WRE are primarily concerned with ensuring physical and chemical stability of the final landform that contains an inventory of moderate-high-risk mineralised waste rock.

The works described in this PRCP have been designed to provide suitable containment in the long term. It is essential however that the performance of the crest and batter treatments are suitably demonstrated prior to decommissioning of the facilities used to manage mine-affected water.

Performance of the cover will be assessed following periodic review of monitoring data. Classes of monitoring data will include:

- Drawdown of the phreatic surface within the waste stockpile,
- Rate of infiltration into the contained waste,
- Volume and chemical constituency of drainage deporting from the stockpile,
- Photography, and
- Visual assessment.

The WRE final landform will be surveyed during execution and following completion – with as-constructed documentation and close-out reporting prepared to ensure compliance with Issued for Construction designs. These surveys constitute a rehabilitation milestone (Section 3.14.3).

3.6.2.9. Cover System Design Trial

Trials for the cover system design are not planned as part of WRE closure as the proposed cover system design adopts a BGM liner. The purpose of proposing a BGM liner is to prevent infiltration. Post-construction monitoring as presented in this PRCP will be sufficient to validate the infiltration modelling and demonstrate cover system performance.

Based on documented performance of a similar SAR cover system at the nearby Century Mine (Rohde et al, 2016), post-closure monitoring data of cover system performance was in accordance with modelled predictions. That is, observed infiltration rates into the cover system were less than or similar to modelled infiltration, which indicates that infiltration modelling is sufficient for construction of an appropriately adopted cover system design, provided that the design is based on a representative dataset and robust conceptual model.

3.6.2.10. Construction Methodology Summary

A summary of construction details for the cover system on the batter and plateau is provided as follows:

Plateau:

The Contractor shall ensure that the surface (subgrade) upon which the BGM is to be deployed is smooth and generally free of protrusions and ruts, which will limit potential damage to the BGM.

The BGM shall be installed in accordance with the manufacturer's guidelines and best practices. A high level of supervision will be implemented during BGM installation, with the following hold points included during execution:

- Review and approval of BGM manufacturer's quality assurance data
- Third-party testing of the BGM product to ensure it meets the specified requirements
- Destructive and non-destructive seam testing to ensure continuity and integrity of the lining system.

Rocky mulch is proposed to be paddock dumped to form a hummocked surface. Placement methods will limit disturbance to the underlying material while providing a stable surface to limits erosion. Placement methods shall ensure that material has sufficient moisture and appropriately conditioned prior to placement such that the final surface is stable.

Batters:

Construction of the batter cover system will comprise of a rocky mulch layer with overlying rock armour.

NAF rocky mulch material shall be placed in approximately uniform layers of not greater than 300 mm loose thickness, then compacted appropriately as confirmed by compaction testing. After placement, this material shall be brought to a specified moisture content by wetting, or aeration and drying, as required.

Following placement, compacted NAF rocky mulch shall be mixed by means of grading or tyning, to produce a relatively uniform moisture content across the lift.

Rock armouring used in batter armouring shall be placed by excavator, with voids being filled by agreed method to ensure suitable interlocking and void-filling on batters. Rock must be tamped down using excavator bucket (or similar) upon completion of void-filling and manual interlocking. Rock must not be placed in a manner that causes segregation of rock sizes. Rock must not be placed to dislodge/damage geotextile underlay.

It is noted that the above construction methodology is conceptual and that a detailed construction methodology would be developed at a later study phase.

3.6.2.11. Final Landform Geometry - ROM Pad

The ROM Pad was constructed with non-mineralised waste rock generated by development of the mine decline. Following decommissioning works, a component of the ROM Pad will be reclaimed for reuse as borrow material but approximately 150,000 m^3 will remain unused. The remaining material will form a side-hill landform at the transition between the steep ridges and lowland plains. The ROM Pad will be reprofiled to coincide with local terrain.

3.6.2.12. Final Landform Erosion Stability

An erosion assessment for areas to be reshaped as part of closure works was completed to assess if erosion rates of the final landform are comparable to pre-mining conditions and to identify any erosion control measures required or changes to the proposed landform to mitigate erosion risks. Landform stability modelling and erosion modelling completed as part of this PRCP concludes that the proposed final landform is expected to be stable under a PMLU of low-intensity cattle grazing and native habitat. This modelling considers the local landscape, vegetation and protective cover on natural and engineered slopes.

The stability assessment incorporates the following:

- Review of regional climatic conditions, vegetation, topography and geology,
- Review of site-specific soil information,
- Assessment of predicted erosion loss rates for rehabilitated areas using WEPP, and
- Identification of erosion controls required or if changes to final landform are required.

WEPP is a 2-dimensional erosion simulation model used to predict and calculate estimates of soil detachment and deposition as well as simulation of the hydrologic and erosion processes on small watersheds. The purpose of the WEPP model is to estimate the soils loss for the final landform, based on site climate, soil characteristics, expected vegetation conditions and catchment geometry.

The performance objective for the final landform is to achieve similar erosion loss rates to analogous locations around the site, undisturbed by mining. Analogous locations are defined as areas with similar surface grades and soil types.

WEPP has been used to estimate soil loss for rehabilitation areas within the following site areas:

- Paste and Batch Plant area (decommissioned ESC facility),
- ROM area,
- CDA area (decommissioned dam and ESC facility),
- CDB area (decommissioned dam and ESC facility),
- LMD area, and
- Borrow Areas A, B1, B2, C and I.

It is noted that the WEPP model adopts a typical section, which may not include features such as drains or access roads. Notwithstanding, as WEPP results are used to estimate soil loss from the entire catchment, adopted geometry is deemed to represent average catchment conditions.

3.6.2.12.1. Stable Non-Polluting Landform Success Criteria and Objectives

Successful rehabilitation and closure of LLM will result in a stable non-polluting landform. A stable non-polluting landform from an erosion perspective is one that mimics the pre-development conditions.

Success criteria for LLM landform erosion modelling are based on both quantitative and qualitative criteria. The quantitative success criteria are based on achieving a soil loss rate similar to that of the surrounding land. The qualitative success criteria are based on how the proposed landform adopts similar topographical features to that of the surrounding land. Additional landform closure objectives with respect to soil loss from the final landforms is to achieve grades similar to natural, undisturbed land, achieve suitable vegetation cover and appropriate land management.

Landform closure criteria are summarised in **Table 17**.

Table 17: Landform Closure Criteria

Criteria	Description
Soil Loss Rate	30 t/ha yr (maximum average threshold)
Cover soil type	Steep Ridges - Rocky Mulch Lowland Plain – Topsoil and / or Subsoil
Vegetative Cover	Refer to example Figure 20 Trees on the steep ridges and spinifex on the lowland plain areas
Drainage Pathways and Features	Limit drainage pathways (all areas). Steep Ridges - batter chutes for the conveyance of upstream catchments as appropriate; bunds at top of batters to reduce surface flows across batters, rock armouring to assist in slowing flows and reducing scour as appropriate. Lowland Plains –flow lengths less than 100m, furrows at set spacings to ensure that the target soil loss is not exceeded. Based on the example landform (defined in s. 3.6.2.12.4 below), gullies will likely vary between 20m and 70m.

Criteria	Description
	It is noted here that future project phases are expected to refine the above conceptual design specifications.

3.6.2.12.2. Regional Erosion Rates

Establishing a baseline for regional erosion rates is important to quantify rehabilitation objectives and success criteria. Soil erosion rates are notoriously difficult to measure, due to the number of variables including, but not limited to surface grade, rainfall, soil type, vegetation cover and land management.

Lu et al (2001) presents a national hillslope erosion loss estimate as depicted in Figure 18 based on empirical soil loss equations. Based on this figure, soil loss rates within the LLM region are in the order of 20 to 50 tonnes per hectare per year (t/ha/yr).

Recognising natural soil loss rates presented by Lu, et. al. (2001), climatic conditions limiting vegetation growth and moderate dispersity of site soils can be found, a maximum annual average erosion loss rate of 30t/ha/yr is deemed appropriate for rehabilitated landforms at LLM and therefore has been adopted as the threshold for drainage controls.

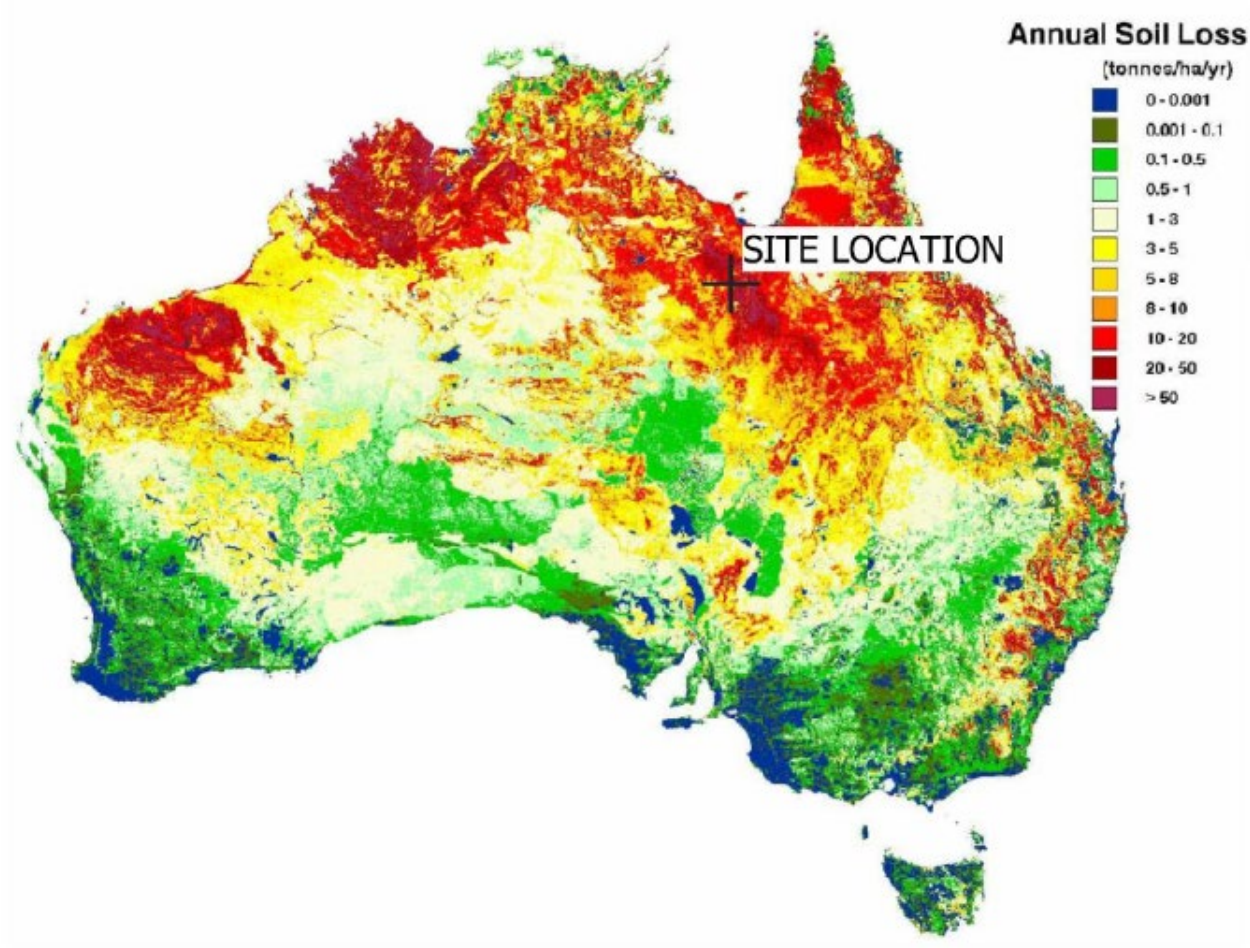


Figure 18: Australian Soil Loss Rates (Lu, et al, 2001)

3.6.2.12.3. Model Inputs and Assumptions

Key model inputs and assumptions such as soil properties, topography and climate are aligned with the baseline information presented in Section 3.1.1 and supplemental investigations referenced in the appropriate sections of this PRCP. Landform geometry adopted for modelling is based on the final landform design outlined in **Figure 16** and the rehabilitation management methodologies described in this PRCP. Key model inputs and assumptions are summarised below.

- ROM Area: External batters graded to 1V:4H, surface graded at 1% to the back of the natural hill and growth media application.
- Paste Plant, CDA, CDB Areas: Areas reshaped to ensure no slopes steeper than 25% and are free draining. No growth media in these areas would be required as the underlying subsoil is suitable for supporting vegetation growth.
- LMD Area: Area to be reshaped to ensure no slopes steeper than 25%. No growth media would be applied due to stated reason above.
- Borrow Areas: Five conceptual borrow areas (A, B1, B2, C and I), as described in Section 3.6.1.1. Batter angles designed at 1V:4H (A, B1, B2 and I) and 1H:2V (Borrow Pit C). Growth media applied to base of pits.

3.6.2.12.3.1. Model Duration and Assumed Ground Conditions

A model duration of 20 years was adopted for all sections. This time period is considered an appropriate model duration noting the following ground conditions:

- Vegetation is assumed to be established at the beginning of the model start time, as erosion control structures would remain in place until sufficient ground cover was established, nominally to be established by a construction and rehabilitation works completion date of 2038.
- The 20-year period adopted includes years of high and low rainfall, allowing assessment of loss rates for varying climatic conditions.
- Although annual or seasonal short term soil loss rates will vary over time, predicted erosion rates are not expected to expose soil multiple horizons (i.e. erosion into the subsoil).
- Results indicated erosion loss rates (across the 40 modelled scenarios to range from <1t/ha/yr in dry years to around 100t/ha/yr in wet years) fluctuated annually depending on rainfall and generally did not trend upwards or downwards (model in state of equilibrium).

3.6.2.12.4. Example Landform

To characterise the local natural topography and drainage conditions, an example landform similar in scale to the LLM rehabilitation areas has been mapped. The chosen landform appears to be generally undisturbed by mining or other human activities. The example landform includes both steep ridges and lowland plains. The landform is located approximately 800 m southeast of the site and includes both steep ridges and lowland plains as shown in **Figure 19**.

Steep ridges have minimal drainage features owing to surfaces generally comprised of weathered rock, with higher resistance to erosion. Lowland plains have a high density of drainage features (incised gullies), with spacing generally ranging from 15 m to 50 m, depending on the surface grade (ranging from 15% to <3%). In reviewing the example landform and other landforms surrounding LLM, the maximum overland flow length is generally 100 m. This means that surface flows are only conveyed up to a maximum of 100 m or so before their flow depth and velocity create a drainage path. Based on observations of site soils, the high density of incised gullies is likely a result of moderately dispersive site soils and typically low vegetation density. This chosen example landform is therefore a great point of reference to determine whether the success criteria for stable and non-polluting is achieved for the LLM assessment areas.

Based on observations of the example landform, considerations for final landforms are as follows:

- Steep, rocky faces are a natural occurrence and are likely to withstand erosion and scouring, provided in-situ materials are comprised of competent rock.
- Lowland plains require drainage features to control conveyance flow volumes and velocities and to confine deposition, erosion and scouring. Without constructed drainage features to reduce the length of overland flow paths, incised gullies will likely form through erosion and scouring, with the severity subject to soil type, vegetation cover, slope and contributing catchment area. During this process the landform is unlikely to be considered stable as there is a risk of undercutting steep batter slopes and scouring which potentially could change the landform and surface hydrology. By defining the locations of drainage features the final landform will be stable at Day One of completion of the rehabilitation.

Figure 19 shows steep batters only form drainage paths to convey flows from upstream contributing catchments. Whilst within the lowland plain areas, drainage paths are formed with a separation distance of 20 m where surface slopes are steep and a separation distance of 50 m or more where surface slopes are flat.

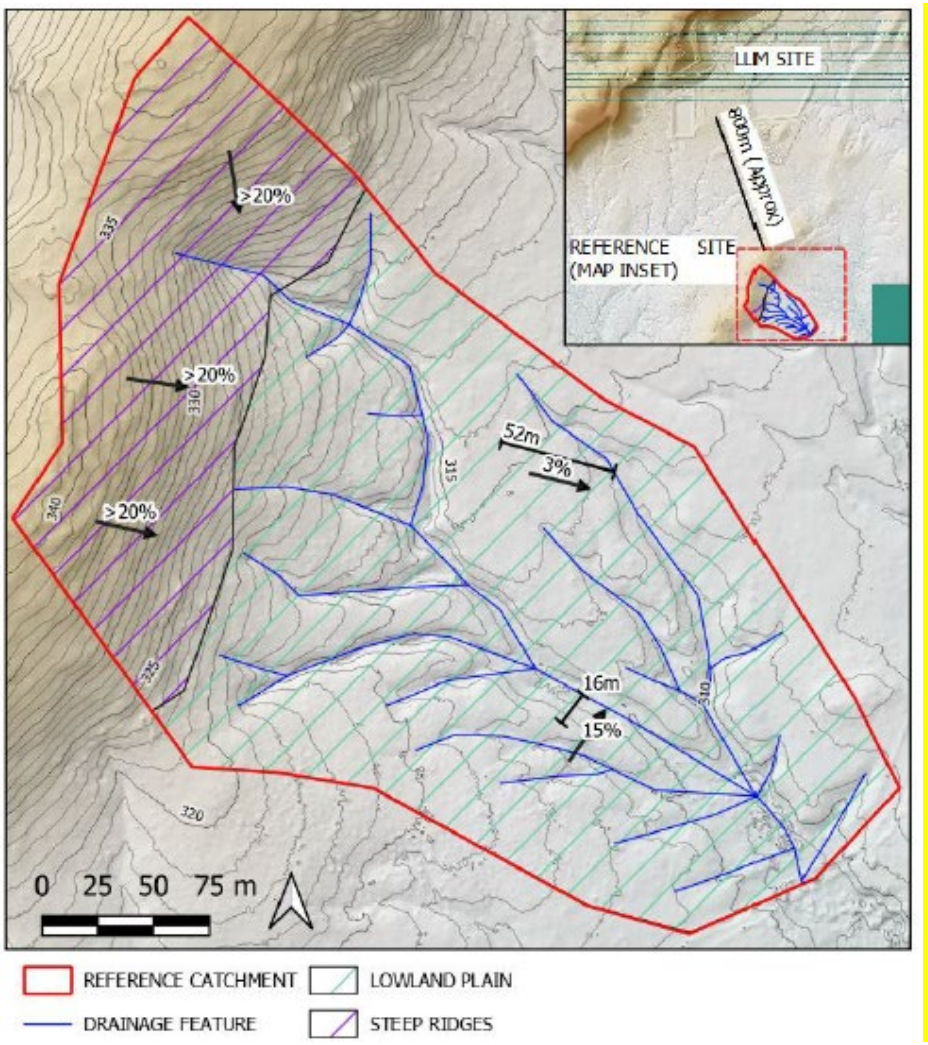


Figure 19: Reference Site

3.6.2.12.5. Vegetative Cover

The target vegetative cover is to mimic two vegetation types defined in **Section 3.1.3**, these being steep batters and lowland plains. An example photo of both the steep batters and lowland plains and are shown in **Figure 20**.

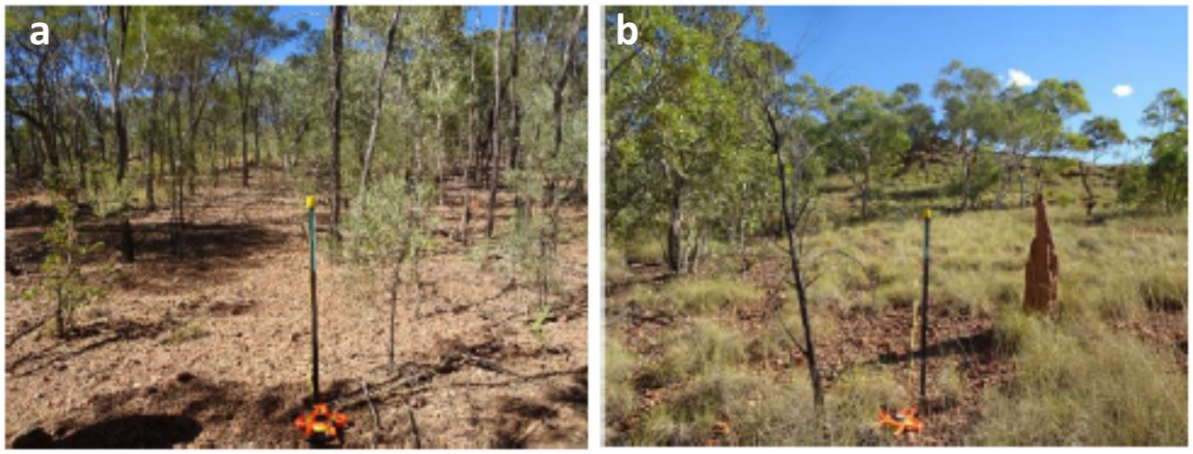


Figure 20: Native Habitat/Steep Batters (a) and Low Intensity Cattle Grazing/Lowland Plains (b)

3.6.2.12.6. Erosion Assessment

The model predicts an average soil loss rate of 30 t/ha/yr for the LLM final landform, which is in line with the regional soil loss rates and other regional factors including:

- Climate - characterised by relatively low rainfall (average 460 mm/year),
- Soils - moderately dispersive, and
- Slopes - generally low (typically 2 to 4%, with short batters at 25%) and comparable to the surrounding landscapes.

A key feature of the natural landscape (particularly low-lying areas) is a high density of incised gullies, reducing the sheet flow lengths for rainfall runoff. The final landform requires drainage controls to reduced sheet flow lengths. Without these drainage controls, high erosion rates would likely occur, with incised gullies forming resulting in sediment laden runoff. Model results indicate once the furrows are implemented, acceptable soil loss rates are achievable, set at an average loss rate of 30 t/ha/yr. A qualitative review of furrow spacing compared to undisturbed areas, indicates similar spacing between drainage features. Expected soil loss rates are comparable to catchments undisturbed from mining activities.

The modelled average annual soil loss rates for each of the rehabilitation areas if no furrows were implemented and with furrows are provided in Table 18.

Table 18: Estimated Annual Average Soil Loss Rates

Rehab Area	Slope gradient range (%)	Max flow length (m)	Soil Loss w/o Furrows (t/ha/yr)	Soil Loss w/ Furrows (t/ha/yr)	Furrow Spacing (m)
CDA Area	2-4	250	160	28	30
CDB Area	2-12	40 (steep slopes) 100 (shallow slopes)	121	25	20
Paste and Batch Plant Area	1-4 (north area) <14 (south area)	400	159	19 (north area) 23 (south area)	50 30
LMD Area	3-4	300	70	22	60
ROM Pad Area	1 (floor) 25 (batters)	80 n/a	140 24	29 n/a	15 n/a
Borrow Areas floor	1	n/a	54	29	100
Borrow Areas Batters	25 (A, B1, I) 50 (C)	15 30	26 26	n/a	n/a

Note: n/a – not applicable

No furrows are proposed on the borrow pit batters noting the following:

- Furrows would be difficult to construct on batters and result in the steepening of batters, thus potentially increasing local erosion along the batter slope.
- If batters were flattened, to achieve the required borrow volume, the batter footprint area would increase, resulting in increases in disturbance areas or reduces the volume of available borrow material if current borrow footprints were to be maintained.
- Soil loss rates are maintained below regional soil loss rates of 50t/ha/yr and as far as reasonably practicable, recognising that undisturbed catchments contain natural steep slopes which have inherently more erosion potential than flatter slopes.
- Batters exceeding 15m in length, comprise less than 10% of the total landform footprint.

Based on the erosion stability assessment, the proposed final landform, with required controls can achieve soil loss performance objectives, and is suitable as a final landscape.

The above notwithstanding, key factors to the success of the final landform are:

- Avoiding concentrated flow (having the potential to cause significant erosion and scouring, i.e. reducing sheet flow to <10 mm in depth and avoiding channelised flow) which has generally been achieve with the conceptual final landform design presented in the PRCP.
- The establishment of vegetation through appropriate surface preparation, seeding, and grazing management for varying post mine land uses adopted for site.
- Monitoring and maintenance of drainage controls until stabilisation is established to verify the landform design is appropriate and functioning according to the design. Monitoring and maintenance activities including inspection of sediment build up post wet season, removing debris and inspection of gully-forming erosion will form part of LLM monitoring and maintenance program.

Details of the WEPP model development are presented in Appendix G.

Monitoring of the final landform will be integral to the early detection of erosion and will allow for early intervention. Section 3.14.13 and Section 3.14.17.1 details how erosion and land stability will be monitored.

3.7. WATER MANAGEMENT SYSTEM

The WMS has two primary functions which are to manage the mine-affected and non-mine affected water streams. Surface run-off from low disturbance and non-mineralised areas are referred to as non-mine affected waters. These are diverted away from the management area and passively released to the receiving environment via ESC facilities.

Decommissioning and rehabilitation of the WMS can only occur after major works are completed in the catchments generating mine affected waters and these works have been shown to be effective in mitigating the risks presented to the receiving environment. In addition, the Site must reasonably demonstrate that surface and drainage waters reporting from these catchments are suitable for direct release to the receiving environment in terms of dissolved heavy metals and salinity.

Works to decommission and rehabilitate the water management system should not commence until:

- Dewatering of the underground workings has been discontinued,
- Batter and crest treatments have been applied to the WRE,
- All significant inventories of mineralised ore and pastefill inputs have been removed from the ROM Pad, Paste and Batch Plant, and
- All significant inventories of Dangerous Goods have been removed as a foreseeable source of contamination within relevant catchments.

Decommissioning and rehabilitation of the water management system have been designed to support a PMLU of Low Intensity Cattle Grazing. To achieve this outcome, the following rehabilitation activities will be undertaken:

- Infrastructure decommissioning and removal,
- Contaminated soils removal,
- Landform development/reshaping,
- Surface preparation, and
- Revegetation of disturbed areas.

For the purposes of this PRCP, these works are scheduled to be completed within 20 years of End of Commercial Proposition. Key aspects of the program, including risk mitigation measures, are discussed in the following sections.

3.7.1 Decommissioning of Regulated Dams

The CDA, CDB and PPD dams are formed by embankments constructed with a combination of non-mineralised waste rock generated by development of the mine access decline, and in-situ material (residual soils, weathered rock) excavated from the impoundment areas. The largest dam is CDA with a crest height approximately 6 m above the surrounding landscape. The CDA, CDB and PPD facilities are ‘Regulated Dams’ pursuant to the EP Act and are therefore subjected to specific requirements related to surveillance and provision of suitable freeboard. In addition, the Site must maintain these facilities until it can reasonably demonstrate that surface and drainage waters reporting from these catchments is suitable for direct release to the receiving environment in terms of dissolved heavy metals and salinity.

Works to decommission and rehabilitate the Dams should not commence until:

- Dewatering of the underground workings has been discontinued,
- Batter and crest treatments have been applied to the WRE,
- All inventories of mineralised ore and tailings have been removed from the ore storage and paste preparation areas, and

- All inventories of Dangerous Goods have been removed as a foreseeable source of contamination within relevant catchments.

Decommissioning and rehabilitation of the dam embankments will include removing sections of the embankments so that they become free draining. Other sections of the embankments will be reprofiled to reduce the slopes to flatter than 4 H:1 V (14°) before deep ripping along contour. Vegetation will then be established on the slopes.

At the point when these facilities do become available for decommissioning, they will first be converted to ESC facilities. Decommissioning and rehabilitation of the mine affected water facilities will be undertaken in stages which are described in the following sections.

3.7.2 Removal of mine affected water inventory

As discussed in Section 3.1.5.4, cessation of dewatering of the underground workings will put the mine affected water inventory stored at surface into substantial deficit. Water will accumulate during the wet season but will be lost to evaporation each year. The 50%^{ile} inventory has been estimated at 2 ML and the 99%^{ile} estimated at 50 ML. At the appropriate time, any waters remaining in the surface storages will be transferred to the underground workings. Survey of the mine workings indicates that in excess of 600 ML of storage is available.

3.7.3 Convert water storages to ESC facilities

Following the removal of the mine affected water inventory from the surface storages and rehabilitation of disturbed upstream areas as necessary, CDA, CDB and the PPD will no longer be required and will be available for repurposing as ESC facilities. At this point in the program schedule, revegetation on the disturbed areas in the upslope catchments will be immature and surface runoff may be affected by erosion. Repurposing the CDA, CDB and PPD to ESC facilities will mitigate these risks and include:

- Recovery of accumulated sediments and HDPE liners and disposal underground pursuant to the requirements of the EA,
- Assessing the contaminated land risk and where necessary implementing remediation measures,
- Removal of leak detection system, piezometers, monitoring equipment (if present),
- Lowering the invert level of the emergency spillways, and
- Reprofiling of the containment embankments to achieve a final landform that is consistent with the PMLU and slopes that do not exceed 4 H:1 V.

Conversion of the CDA, CDB and PPD will extinguish their Regulated Dam status.

3.7.4 Decommissioning of ESC Facilities

The ESC facilities will be available for decommissioning when the vegetation established on the disturbance area is suitably mature to provide soil conservation services. This is expected to be ten years following the conversion of the regulated dams to ESC facilities. At that time, the ESC facilities will be reprofiled so that the final landform is free draining.

At the time of decommissioning, the ESC facilities will be deep ripped, and seed applied pursuant to the methods described in the Revegetation Plan.

A key requirement for decommissioning and rehabilitation of the Site is that the landscape does not pond water. Accumulations of water that persist for more than a few days tend to attract livestock and feral animals such as pigs. This in turn leads to localised overgrazing, tracking and associated erosion as well as weeds infestations.

3.8. TAILINGS STORAGE FACILITY

All lead and zinc bearing ore extracted from the underground mine is crushed at Site before being transported to Mount Isa for further beneficiating and processing. Development of the Site has not included a Tailings Storage Facility. Some process tailings are imported to the Site for production of cemented paste back-fill however, these volumes will be managed by running down stocks and removing from site any residual volumes at closure.

3.9. VOIDS

Mineral development at the Site did not include excavation of conventional open pits. The most significant excavation was the box-cut that provides safe access to the underground mine portal and access decline which will be back-filled.

3.10. UNDERGROUND MINING

Extraction of lead and zinc bearing ores at the Site has occurred via underground mining methods. The major surface expressions of the Underground Mine are presented in **Figure 3** and include:

- Box-cut, decline and underground workings, and
- Ventilation shafts.

The infrastructure provides both primary access and secondary egress to the mine workings as well as ventilation. As a result, these are essential to future operations and decommissioning and rehabilitation of this infrastructure cannot commence until End of Commercial Proposition has been called. Decommissioning and rehabilitation activities will include:

- Surface infrastructure decommissioning and removal,
- Underground infrastructure decommissioning,
- Landform development/reshaping,
- Surface preparation, and
- Revegetation of disturbed areas.

For the purposes of this PRCP, these works are scheduled to be completed within 13 years of End of Commercial Proposition, to allow additional demolition waste disposal underground upon completion of regulated dam decommissioning works. Specific aspects of the Decommissioning and Rehabilitation program that relate to the underground mine including risk mitigation measures are discussed in the following sections.

3.10.1 Box-cut, Access Decline and Underground Workings

Disturbance related to the box-cut and mine decline includes a 6.5 m by 6.0 m tunnel that provides the main access to the underground workings. The system has been designed, constructed and maintained to provide safe access for personnel and mobile equipment and includes various reinforcements to resist collapse of the surrounding ground. As a result, the box-cut and mine decline are robust systems and will be capable of remaining open for several decades without any intervention.

The underground workings present significant risks to humans, livestock and native fauna. Such risks include fall from height, collapse of unstable ground, drowning, asphyxiation, and disorientation. In addition, the underground workings provide a potential habitat for fauna such as bats and invertebrates.

In the long term however, the mine workings will not remain open. Natural movement in the rock mass, weathering and the effects of groundwater movement will cause localised failures and rock will effectively break-off and into

the available void space in a process known as caving. The voids will fill but large void spaces relatively close to surface can result in cave induced subsidence at surface. Subsidence at surface would represent a significant risk to livestock and would potentially influence recharge of the local groundwater system.

The subsidence risk has been assessed by a suitably qualified and experienced mining engineer and their findings are documented in Appendix H.

Decommissioning and rehabilitation works proposed for the box-cut, decline and underground workings include:

- Partial backfill of the decline to chainage 460 m from portal to mitigate the subsidence risk. Backfill materials will include:
    - Construction and demolition waste from decommissioning of the Site,
    - ROM Pad borrow,
- Installation of concrete bulkheads at the top and bottom of the backfill zone to resist the ingress of water, humans, livestock and native fauna,
- Backfill of the box-cut to 3 m above the top of the portal with rock mulch material along with appropriate profiling to resist the infiltration of surface runoff into the groundwater environment, followed by necessary surface preparation and revegetation activities, and
- Documentation of the construction via an As-Constructed Report including certification that the design intention was achieved by a suitably qualified and experienced engineer.

Whilst the geotechnical stability study recommends the upper 460 m section of mine decline be backfilled to manage subsidence, this is based at a concept level with future detailed works expected to verify and validate this requirement. Works to decommission the Access Decline and Box-cut will require ROM Pad borrow to be reclaimed for use as back-fill. Site demolition works also needs to be completed prior to the waste being used as backfill underground. As a result, this work should not commence until relevant infrastructure and sources of contamination have been removed from the ROM Pad. This is not scheduled to occur until three years after End of Commercial Proposition.

3.10.2 Ventilation Shafts

Development at the Site has also included sinking of four large diameter shafts that are used for ventilation and emergency egress from the mine. The shafts range in depth between 120 m and 200 m.

These shafts present a significant risk of fall under the proposed PMLU. The shafts are currently protected with mechanical barriers, but these require routine inspection and maintenance. As such, they are not permanent features.

In addition to the risk of fall, the ventilation shafts also present a subsidence risk. These risks have been assessed and are reported in Appendix H.

To mitigate these risks, the Decommissioning and Rehabilitation Program includes the backfill of the upper sections of the ventilation shafts. Backfill material will comprise rock-fill borrow from the ROM Pad and suitable borrow from alternate sources as authorised by the EA. Material backfilled into the ventilation shafts will exhibit significant consolidation settlement. As a consequence, subsequent backfill episodes will be required to “top-up” the volume lost to consolidation. Surplus backfill material will be stockpiled for this purpose.

For the purposes of this PRCP, initial backfill of the ventilation shafts cannot commence until sufficient works have been completed at the ROM Pad to support reclaim of this borrow source.

3.10.3 Hydrogeological Assessment

The underground also includes the groundwater in the vicinity of the mine workings. These groundwaters are naturally saline and reflect the extent of mineralisation of the area, but disturbance by mining has increased the potential volume of groundwater through available storage within the rock mass and underground voids. Dewatering of the underground workings will continue for six months after the End of Commercial Proposition milestone is called at which time groundwater will flood the underground workings and the phreatic surface will recover to a long-term equilibrium level.

This new equilibrium level and the rate of rebound is an important consideration and is influenced by:

- Availability of preferential pathways to accelerate groundwater recharge such as the ventilation shafts and decline,
- Transfers of mine affected waters from the regulated dams,
- Natural groundwater inflow, and
- Rainfall.

The hydrogeological conceptual model developed for the numerical modelling was used to understand the fate and transport for potential contaminants of concern (COCs). The conceptual model identified contaminant sources, migration pathways and sensitive receptors for potential COCs and determined that contaminated groundwater migration to surface water is not a complete pathway and does not present a significant risk.

Fate and transport modelling was based on conservative assumptions regarding contaminant source areas at each of the water dams remaining in place after closure as a measure to assess a “worst-case” scenario. However, the water dams will be decommissioned during mine closure and therefore will not remain a contaminant source. Removal of the dams as a contaminant source is a mitigation measure that will reduce the potential groundwater contamination and migration predicted in the conservative model.

Assessments of the groundwater conditions following the cessation of dewatering have been undertaken by CDM Smith (2022) and documented in Appendix I.

These assessments have concluded that:

- Potential COCs associated with decommissioned water dams do not migrate more than 200 m from the contaminant source areas and do not preclude the PMLU,
- Recovery of the phreatic surface to its post-mining equilibrium state will reach an approximate elevation of 280 m AHD. Most of the recovery will occur between 2036 and 2040, but will take more than 200 years to fully reach equilibrium, and
- There will be little to no interaction between the groundwater and Desert Creek.

Routine groundwater monitoring is required to understand post-closure groundwater recovery and to validate the predictions of the model. Given the long timeframes for groundwater recovery (on the order of decades), bi-annual monitoring will provide sufficient information to understand long-term groundwater behaviour and capture seasonal influence. Routine groundwater monitoring will continue to be conducted for a period of time to build a dataset that provides statistically valid trends. This will allow measurement of groundwater level recovery and groundwater quality for comparison against the groundwater model predictions.

3.11. BUILT INFRASTRUCTURE

3.11.1 Overview

Development at the Site has resulted in a significant portfolio of built infrastructure including:

- Mineral processing and rotating equipment,
- Buildings,
- Utilities and services, and
- Exploration drill-holes.

The built infrastructure provides essential services to the underground mining operation. As a result, decommissioning and rehabilitation of this infrastructure cannot commence until End of Commercial Proposition has been called. Any plant that is not salvaged for beneficial reuse will be demolished and scrapped. Scrap metal will be segregated and removed from site for recycling. The primary demolition waste generated will be concrete. Some of this stream may be suitable for reuse as rock armour. All other demolition waste will be disposed of pursuant to the EA either on or off-site. Further detail including a full list of infrastructure identified for decommissioning including associated costs are outlined in the demolition studies undertaken by CMA, as stated in Section 3.1.5.5 above.

In accordance with the EA, exploration drillholes will be decommissioned in accordance with the *Eligibility Criteria* and *Standard Conditions for Exploration and Mineral Development Projects – Version 2* (ESR/2016/1985), which came into effect on 31 March 2016.

For the purposes of this PRCP, these works are scheduled to be completed within three years of End of Commercial Proposition. Specific aspects of the Decommissioning and Rehabilitation program including risk mitigation measures are discussed in the following sections.

3.11.2 Beneficial Reuse

For the purposes of this PRCP, the built infrastructure will not present a beneficial reuse opportunity under the proposed PMLU. As a consequence, the current assumption is that all of this fixed plant will be either salvaged for off-site reuse or demolished and scrapped. Demolition waste will be disposed of on-site pursuant to the requirements of the EA.

Transition of the Site from mining operations to the proposed PMLUs however is highly likely to present numerous opportunities for beneficial reuse. Decommissioning and removal of the infrastructure suite is likely to include controlled removal as modular components. To that end, implementation of the Asset Management program is scheduled to continue right up to End of Commercial Proposition. Acting upon these opportunities will be the result of engagement and negotiation with key stakeholders prior to entering into written agreements.

Beneficial reuse opportunities are likely to include:

- Retention of the mine access road and its appurtenant works (drainage, signage),
- Water bore-field including pumps, power supplies, pipelines,
- Workshop buildings,
- Accommodation camp, and
- Mine access road.

3.11.3 Contamination from Mineralised Streams

A key requirement for decommissioning and rehabilitation at RA7 will be the removal of contaminant source terms prior to reprofiling and establishment of a self-sustaining vegetation community.

Storage and handling of mineralised ore and process tailings at the Rom Pad, paste plant and batch plant presents a significant long-term risk. The extracted ore and process tailings imported to the Site for paste production are enriched with metals including zinc and lead but also arsenic, cadmium and copper. Both streams are enriched with pyrite and are potentially acid forming.

All inventories of mineralised ore, process tailings and dangerous goods will be removed by run-out of the active stock levels during the final months of the current mining campaign. In addition, the crushing circuit as well as the paste preparation plant will be washed down.

Run-out and wash-down of the ore handling and paste preparation circuits is unlikely to remove all sources of contamination. Transport by spillage, dust and runoff presents a material contamination risk to the stockpile pads, roadways and drainage lines. These areas will be investigated, and contaminated areas remediated so that they do not present an unacceptable risk to the PMLU. Remediation efforts will be focused on excavating contaminated soils and sediments. These streams will be disposed of by placement on the crest of the WRE or underground.

3.11.4 Contamination from Dangerous Goods

Elements of the Mining Operations and Asset Management Programs are concerned with storage and handling of various Dangerous Goods at the Site. These include liquid hydrocarbons (diesel fuel and lubricants), explosives, binding agents, solvents and gases.

Storage and handling of Dangerous Goods at the Site is unlikely to have resulted in any long-term risks arising from spillage or improper use or storage. These inventories however will have no reuse opportunities pursuant to the PMLU and therefore will be removed as a component of the Decommissioning and Rehabilitation Program. Management of Dangerous Goods at the Site includes management of stock levels to minimise risks. Any surplus Dangerous Goods will be removed from the Site when they are no longer required.

3.12. METHODS TO REHABILITATE LAND TO A STABLE CONDITION

3.12.1 Revegetation Plan

Mining development at the Site has resulted in material areas of disturbance. These areas are at increased risk of erosion and associated impacts related to final landform stability and water quality in the receiving environment. Disturbance areas are also at increased risk of infestation by weeds. Development of robust vegetation communities comprised of trees, shrubs and groundcovers are essential to mitigating these risks.

A key objective of the Decommissioning and Rehabilitation Program is to establish a robust vegetation cover on all areas that have been disturbed by mining development. The disturbed areas at the Site are comprised of soils and meta-soils that have low levels of soil structure and moisture holding capacity. Establishment of an effective vegetation cover comprised of shrubs and/or groundcovers is necessary to support the proposed PMLUs.

A viable vegetation cover is essential in the development of productive soils and play an important role in nutrient capture/cycling and particularly in the accumulation of soil carbon. Plants are also critical in providing food-sources and microhabitats for fauna. Effective vegetation is essential in building biodiversity and overall ecosystem resilience.

The methods used to establish vegetation of the disturbance areas at the Site are described in the following sections. Revegetation works will occur as campaigns following the completion of the decommissioning works described elsewhere in this PRCP.

Establishment of vegetation on mine affected soils is generally a challenging undertaking. Risks and issues faced includes:

- The degree of disturbance and availability of soil services including structure, nutrition and soil moisture capacity,
- The climatic conditions experienced at the site,
- The influence of stressors such as fire, drought and over-grazing, and
- Weed infestation from areas outside of the control of LLM.

LLM has defined the methods and processes used for establishing viable and self-sustaining vegetation communities on mine disturbed soils and meta-soils at the Site.

3.12.2 Application of Soil Ameliorants

Previous studies have determined that the soils and sub-soils at the site are naturally low in nutrients and organic carbon/matter when compared to agricultural soils, however, do support native vegetation and on-site soils can be used for rehabilitation of mine areas. Notwithstanding, these studies found that successful rehabilitation of the Site could be expected if suitable methods and practices were adopted (RGS, 2023).

Following the removal of infrastructure and contaminated soils, reshaping works will be undertaken to achieve the final profile. At that point, a suitably qualified person will assess the growth media and whether amelioration is required to support establishment of vegetation consistent with the PMLU. The assessments will consider key aspects including soil nutrition, moisture holding capacity, and texture and provide advice as to the applicability of soil ameliorants.

Should the application of soil ameliorants be required, the following options are available:

- Application of fertiliser to improve soil nutrition,
- Application of gypsum to act as a soil binder,
- Application of sulphur (to increase soil pH) or agricultural limestone/gypsum (to lower soil pH),
- Application of dry vegetation matter to reduce erosion and increase recruitment of soil carbon,
- Application of growth media to improve nutrition, moisture holding capacity and recruit soil microbes,
- Application of rock mulch as growth media.

Where practicable, application of soil ameliorants will be undertaken during the dry season so that deep ripping and seed application can occur at the onset of the wet season.

The stockpile of topsoil available at the Site is a significant resource but it is not unlimited. Topsoil will be applied on a greatest needs/benefits basis until the entire inventory is exhausted. The topsoil inventory includes limited coarse particles which are not useful for use as an ameliorant on sloped disturbance areas due to being prone to erode.

3.12.3 Deep Ripping

Deep ripping is an important component of revegetation and is undertaken for the following purposes:

- Reduces path length for surface run-off thereby reducing concentrations of flow and the risk of erosion,
- Softens the overall texture of the landscape and improves accumulation of soil nutrients and organic matter,
- Reduces surface runoff and increases storage of plant available moisture to support vegetation growth, and
- Provides microhabitat for seed germination and early establishment.

Deep ripping will be completed to a nominal depth of 500 mm using a track-dozer fitted with rippers. Deep ripping will be completed along contour with an overall density of one line every two metres down slope. On occasion, deep ripping will cause large boulders to be brought to surface. This is tolerable and provides micro habitat for reptiles and avian fauna.

Where practicable, deep ripping will be completed during the late dry season and early wet season and coordinate closely with application of soil ameliorants and seed. “Fresh” rip-lines provide a more favourable substrate for seed germination.

Deep ripping will not be undertaken on surfaces treated with rock armour or other erosion protection measures.

3.12.4 Application of Seed

Vegetation will be established on disturbed areas by broadcasting suitable seed onto suitably prepared surfaces. This method has been successfully demonstrated at metalliferous mine sites in northern Australia including Century (Qld) and Kidston (Qld).

The following seed application measures will be implemented, and will also include specific preparations including seed scarification, coating and inoculation where appropriate:

- Specific species mixes have been designed for each of the PMLUs—these are presented in Table 19,
- Application by hand: suited to small areas such as drill pads,
- Application by vehicle mounted air spreader: suited to moderate to large areas including slopes of 4 H:1 V,
- Application by helicopter: suited to high sloped terrain and highly textured surfaces such as the ISL of the WRE.

Seed for revegetation purposes will generally be applied during the first few weeks of the wet season when:

- Initial storms have provided some plant available moisture, and
- The probability of follow up rain is maximised, thereby providing the greatest possible growing season.

The species mix applied to the Low Intensity Cattle Grazing area reflects the open woodlands dominated by *Eucalyptus leucophloia* and native grasses including spinifex. Some improved pasture species will be used to improve the palatability of the grasses present. The species mix applied to the Native Habitat area (except for the WRE) will reflect the woodlands dominated by Lancewood and the small-fruited bloodwood.

The WRE cover design requires species that offer structural integrity and evapotranspiration for effective functioning of the SAR system on the crest. The proposed mid-storey sowing rate of 7 kg/ha will offer evapotranspiration necessary for the SAR concept and will support a PMLU of native habitat. The benefits of a shrub layer provides a low biomass understorey and lower risk of wildfire and nitrogen fixation. An assessment of the proposed seed mix for the WRE crest was undertaken to ensure species selected do not impact the integrity of

the proposed WRE cover system. Based on literature review of root depths of seeded species listed in Table 19 (for the WRE) and the proposed cover system comprising of a BGM with a root limiting layer to prevent penetration, it is viewed unlikely that the proposed seed mix will impact the long-term integrity of the WRE cover system. In addition, the seed mix excludes the tree layer to limit formation of strong tree roots. Further information can be found in Appendix C.

The species mixes have been designed to give due regard to availability as well as to meet the success criteria defined in this PRCP. Specific mixes may be modified slightly to account for variation in environmental features of the rehabilitation area. For example, sites along watercourses would also include the seed of Eucalyptus camaldulensis (River Red Gum: 200 g ha^{-1}), while sites on rocky scree slopes would include a greater proportion of Acacia shirleyi (300 g ha^{-1}) and no Eucalyptus pruinosa, Corymbia terminalis or Grevillea striata. Further refinement will be subject to ongoing seed availability, implemented application rates and conditions present leading up to and during revegetation activities.

Table 19: Revegetation Seed Mix

Species	Common Name	PMLU 1: Low Intensity Grazing	PMLU 2: Native Habitat		PMLU 2: WRE (Crest)		
		Selection	Sowing Rate (g/ha)	Selection	Sowing Rate (g/ha)	Selection	Sowing Rate (g/ha)
Groundcover (Grasses)							
Aristida holathera	Kerosene grass	✓	180	✓	10	✓	30
Aristida latifolia	Feathertop Wiregrass	✓	180	✓	10	✓	30
Aristida lazaridis	Wiregrass	✓	150	✓	10	✓	20
Bothriochloa ewartiana	Desert Bluegrass	✓	100	✓	10	✓	20
Cymbopogon bombycinus	Silk Grass	✓	100	✓	20	✓	100
Enneapogon polyphyllus	Leafy Nineawn Grass	✓	70				
Eriachne mucronata	Mountain Wanderrie Grass	✓[1]	500	✓[1]	100	✓[1]	200
Eulalia aurea	Silky Browntop	✓	100				
Paspalidium rarum	Bunch Paspalidium	✓[1]	400	✓[1]	100	✓[1]	200
Ptilotus clementii	Pussycats Tails	✓	150	✓	20	✓	100
Ptilotus exaltatus	Mulla Mulla	✓[1]	300	✓[1]	90	✓[1]	100
Ptilotus fusiformis	Skeleton Bush	✓	150	✓	40	✓	50
Ptilotus schwartzii	Horse Mulla Mulla	✓	100	✓	40	✓	50
Schizachyrium fragile	Fire Grass	✓	200	✓	50	✓	60
Senna notabilis	Cockroach Bush	✓	150	✓	50	✓	60
Setaria surgens	Pigeon Grass	✓	100	✓	100	✓	100
Solanum echinatum	Poison Gooseberry	✓	50				
Solanum ellipticum	Potato Bush	✓	50				
Triodia molesta	Buck Spinifex	✓	640	✓	450	✓	620

Species	Common Name	PMLU 1: Low Intensity Grazing	PMLU 2: Native Habitat		PMLU 2: WRE (Crest)		
		Selection	Sowing Rate (g/ha)	Selection	Sowing Rate (g/ha)	Selection	Sowing Rate (g/ha)
Triodia longiceps	Giant Grey Spinifex	✓	630	✓	400	✓	610
Triodia pungens	Soft Spinifex	✓[1]	700	✓[1]	500	✓[1]	650
Groundcover (TOTAL Sowing Rate)			**5kg/ha**		**2kg/ha**		**3kg/ha**
Midstorey Species (Shrubs)							
Acacia cambagei	Gidgee	✓	200	✓[1]	250	✓[1]	300
Acacia chisholmii	Turpentine	✓[1]	500	✓[1]	700	✓[1]	1000
Acacia holosericea	Silver Wattle	✓	100	✓	400	✓	900
Acacia megalantha	None recorded	✓	100	✓	300	✓	700
Acacia monticola	Hill Turpentine	✓[1]	400	✓[1]	400	✓	900
Acacia retivenea	Net-veined Wattle	✓[1]	400	✓[1]	300	✓[1]	900
Acacia tenuissima	Broom Wattle	✓	100	✓	200	✓	500
Atalaya hemiglauca	Whitewood	✓[1]	400	✓[1]	500	✓[1]	900
Flueggea virosa	White Currant	✓	200		250	✓	300
Gossypium australe	Native Cotton	✓	200	✓	250	✓	300
Grevillea wickhamii	Wickham's Grevillea	✓	200	✓	250	✓	300
Midstorey (TOTAL Sowing Rate)			**3kg/ha**		**4kg/ha**		**7kg/ha**
Canopy Species (Trees)							
Acacia shirleyi	Lancewood			✓[1]	800		
Corymbia terminalis	Inland Bloodwood	✓[1]	200	✓[1]	500		
Corymbia aparrerinja	Inland Ghost Gum	✓[1]	100	✓[1]	300		
Corymbia dichromophloia	Small-fruited Bloodwood	✓[1]	400	✓[1]	500		
Eucalyptus leucophloia	Snappy Gum	✓[1]	600	✓[1]	600		
Eucalyptus leucophylla	Cloncurry Box	✓[1]	300	✓[1]	500		
Eucalyptus pruinosa	Silver-leaf Box	✓[1]	300	✓[1]	500		
Canopy (TOTAL Sowing Rate)			**2kg/ha**		**4kg/ha**		**0kg/ha**

[1] Priority Species

3.12.5 Adaptive Management

If the rehabilitation monitoring identifies that revegetation results are sub-optimal and/or improvements can be made, further investigation will be undertaken to establish a cause and appropriate strategy(s) will be implemented. Aspects that may be considered as part of the investigation may include, but are not necessarily limited to:

- Nutrient availability,
- pH, salinity and metal toxicity,
- Shallow root depth,
- Other soil limitations,
- Plant diseases,
- Insect attack,
- Lack of nitrogen fixing legumes,
- Insufficient density and diversity of long-lived plants (e.g. overstorey trees),
- Lack of organisms involved in litter breakdown (e.g. fungal fruiting bodies) and nutrient cycling (e.g. puff balls),
- Predation,
- Evidence of drought effects or rainfall damage,
- Inappropriate plant species density and diversity,
- Poor soil and/or landscape preparation, and
- Weed competition and/or competition with other species in the seed / tube stock mix.

The composition and structure of revegetated areas will also be compared with the target vegetation found at the analogue sites, as per LLM Rehabilitation Monitoring Program. A representative number of analogue sites within both PMLUs have been established with ongoing improvements made, where necessary.

3.12.6 Maturation of Vegetation Communities

Revegetation of landscapes disturbed by mining is characterised by various risks that are very difficult to mitigate. The most significant of these is the variability of rainfall. The success of seed germination and seedling development is largely dependent on the soil moisture conditions experienced in the six months following revegetation works. Rainfall years that are characterised by low total accumulations and/or a low number of rainfall days are likely to result in poor rates of establishment and growth.

Other issues including seed viability, unplanned fire and unplanned grazing can also be significant. An unplanned fire in an immature revegetation area late in the dry season can be catastrophic and may require revegetation of the affected area recommence.

To account for these risks, the PRCP Schedule proposes a nominal 20-year period to allow for the establishment, development and maturation of vegetation to the point that it is on a suitable trajectory to support the PMLUs. To provide greater clarity and certainty to the overall program, this PRCP frames the establishment of vegetation as a series of waypoints.

These include:

- An initial waypoint that demonstrates that works to initiate establishment of vegetation have been completed,
- A trajectory waypoint (nominally 10 years after seeding) at which it can be reasonably expected that revegetation works are broadly on target, and
- A final waypoint (nominally 20 years after seeding) at which the PMLU objectives have been achieved.

3.13. RISK ASSESSMENT

3.13.1 Hazard Identification and Risk Management

LLM takes a risk-based approach to the planning, scheduling and execution of all decommissioning and rehabilitation activities undertaken at the Site.

Glencore has defined the framework requirements for hazard identification and risk assessment via the Glencore Corporate Risk Management Framework (RMF). The RMF applies at all Glencore operations including LLM. The RMF aligns with the requirements of ISO31000 – Risk Management and requires that all credible loss events are defined and assessed. The RMF applies to all classes of risk including long-term exposures including impediments to relinquishment of the Mining Leases. The Framework requires that all identified risks are assessed using a standardised approach that gives due consideration to various impact classes including regulatory, environmental, societal and financial consequences. This qualitative approach considers both consequence and likelihood using a conventional a five-by-five matrix.

Development of the mineral resources at the Site has exposed LLM to a number of risks and hazards that must be mitigated if closure of the Site and lease relinquishment is to be achieved. LLM has defined these risks by way of a Closure Risk Assessment (CRA). The CRA defines all of the aspects and impacts (risks) that are currently at foot and nominates the current control measures. Each aspect is then assessed to determine the residual risk value on a one to twenty-five scale and the CRA ranked in terms of residual risk. An action plan is then implemented including timing and scheduling.

The CRA identified the risks of a stable condition for LLM rehabilitation not being achieved, and how those risks are intended to be managed or minimised in accordance with section 126C of the EP Act.

The risk treatment component of the CRA outlines the additional controls/actions, reasons for selection of the relevant treatment options/actions, resourcing requirements, performance measures and constraints, reporting and monitoring requirements and timing and scheduling.

Current control measures were identified, and the residual risks assessed using the tools defined by the RMF. Any risks with a current risk rating of high based on the current controls were designated key risks. The CRA identified a total of sixteen main risks of a stable condition not being achieved which are presented in Table 20. Upon implementation of additional controls, the residual risk scores of these main risks were reduced to medium or low.

Table 20: Key Risks to LLM Rehabilitation not being achieved, and their Controls

Aspect and Impacts	Current Controls	Current Risk	Additional Controls	Justification of Treatment Option	Resource Requirements	Performance Measures and Constraints	Reporting and Monitoring Requirements	Residual Risk Score	Applicable Rehabilitation Milestone
Inadequate design and construction of the waste rock emplacement (WRE), and WRE cover system relevant to milestone RM2 and RM12	• Options analysis for the WRE final landform and capping system (performed by suitably qualified organisation) - assessing environmental performance and engineering and maintenance optimisation and cost • WRE final landform and cover system design works including performance modelling • Waste characterisation completed • Leachate water quality modelling for WRE • Geotechnical investigation work of WRE • Construction methods for WRE • Borrow source investigations to identify availability of suitable material types for WRE cover	18 H	• Finalise WRE final landform and detailed cover system design • Ensure construction of the WRE according to design (including construction supervision). • Collate construction methods, obtain as-builts for construction verification and quality assurance. • Design and implement a WRE cover system trial, if required • Monitor and undertake a comparison of WRE cover system findings with trial results to support the preferred WRE cover option, if required • Installation of cover system performance monitoring	The proposed actions include adequate research and modelling to predict the long-term stability of WRE design. Cover trials / performance monitoring can assist in determining whether proposed cover design meets stable conditions. Construction records allow PRCP milestones to be achieved.	Suitably qualified personnel to complete WRE design. Site personnel involved during critical stages of construction. Adequate budget, borrow material and personnel required for WRE cover construction. Rehabilitation and Closure Team required for cover trial investigation work. Field trials	Performance measured through inspections and monitoring by suitably qualified person	• WRE Design Report • WRE Construction Reports • Waste Rock and Spoil Management Plan • Internal reporting	14 M	RM2 and RM12

Insufficient availability of material (spoil, subsoil, and topsoil) to achieve the final landform and rehabilitation, relevant to milestone RM2 and RM7	• Current topsoil stockpiles are mapped, surveyed and sampled
	• Disturbance mapping is up to date with process in place to map future disturbance
	• WRE landform and cover system design completed
	• Borrow source investigation works completed
	• Materials balance updated in 2023
	• Borrow/quarry shell designs developed
		18 H	• Finalise WRE landform and detailed cover system design and prepare a final material balance.
			• Finalise borrow/quarry shell designs. Once the proposed borrow areas are established:
			  ○ Determine the final extent of disturbance required for closure
			  ○ Undertake an environmental assessment of the proposed additional disturbance areas
			  ○ Lodge an EA Amendment
			• Ensure ongoing monitoring of rehabilitation material availability for site rehabilitation works. This is to include:
			  ○ Ongoing review and update of material availability and assumptions and develop contingency for maintenance process
			  ○ Construction supervision and controls (to avoid overuse of material)
				The borrow source investigation project will ensure sufficient quantities and qualities of material are available for rehabilitation. The project assesses quality and quantify pf topsoil stockpiles for growth media usage. Contaminated land investigation works will inform required remediation and growth media replacement. Maintaining accurate soil inventories and managing the overuse of material will aid in rehabilitation success.	Suitably qualified personnel to investigate on-site material quality and quantity. Suitably qualified personnel to complete WRE detailed design. Personnel required for regular supervision of construction work and monitoring stockpile inventories.	Performance measured by inspections and monitoring	• WRE Detailed Landform and Cover Design Report
							• Borrow Source Investigation Reports
							• Field surveys, inspections and reports
							• Internal reporting of borrow material inventories
								9 M	RM2, RM7

Plant decommissioning schedule is delayed and does not align with requirements during closure works, relevant to milestone RM1	• Standard procurement process • Internal budget for closure and acknowledges requirements for ongoing services. • PRCP milestone schedule acknowledges requirements for ongoing services.	12 M	• Develop and implement an asset decommissioning strategy that considers strategic asset retention. • Workforce planning for closure works. • Develop a contractor execution strategy for closure works.	Developing an asset decommissioning strategy allows appropriate scheduling of works. The proposed actions ensure that sufficient services and facilities are available throughout the closure and post-closure phases.	Personnel to develop and implement an asset decommissioning strategy	Performance measured through assessment of asset management requirements for closure	• Internal reporting on asset retention and decommissioning	5 L	RM1
Unknown levels of land contamination from mining activities relevant to milestone RM3	• Contaminated land preliminary investigation work • Contaminated Land sampling plan developed • Contaminated land auditor engaged in investigations • Pre-mining in-situ soils database	13 M	• Bunding designed to relevant standards • Spill clean-up and reporting • Formalise rules for use of contaminated water for dust suppression • Contaminated land intrusive investigation work • Update material balance if required and cost estimates • Contaminated Land auditor engaged • Collate and present to DES data on natural mineralisation of the ground and impacts to surface water quality. • Develop remediation action plan to include management measures for unknown contamination finds	Completing contaminated land investigations will ensure the extent of contamination is known and appropriate remediation action plan to be developed. Engagement of a contaminated land auditor will ensure investigations meet legislative requirements. Natural mineralisation studies will ensure appropriate remediation targets are developed	Suitably qualified person to develop contaminated land investigations General record management	Performance measured through regular site audits by site personnel and investigations by suitably qualified person	• Field Inspections • Review of incident register • Contaminated land investigations and reporting	9 M	RM3
Surface subsidence caused by the underground operations, relevant to milestone RM4	• Mining methods and backfilling • Geotechnical study assessment to determine risk	6 L	• As low as reasonably practical	Completion of study will assist in predicting the risk of surface subsidence	Suitably qualified person to develop Geotechnical stability assessment	Performance measured through inspections by suitably qualified person	• Inspection reports	6 L	RM4

Aspect and Impacts	Current Controls	Current Risk	Additional Controls	Justification of Treatment Option	Resource Requirements	Performance Measures and Constraints	Reporting and Monitoring Requirements	Residual Risk Score	Applicable Rehabilitation Milestone
Surface slumping or erosion of the WRE, relevant to milestone RM12 and RM13	• WRE final landform and cover design works assesses landform stability, environmental performance and erosion stability modelling • Geotechnical investigation work of WRE • Material specifications identified for WRE cover construction • Development of Post Closure Monitoring and Maintenance Plan	14 M	• Construction of WRE according to design • Preparation of Construction Documentation for WRE • Suitable material types selected and used for WRE cover • Implement Post Closure Monitoring and Maintenance Plan (routine inspections, rehabilitation inspections, cover system design performance monitoring) • Stability investigations for erosional and geotechnical stability	The proposed actions will address the stated risk. Continual monitoring of the WRE over time will inform appropriate maintenance to ensure PRCP milestones are achieved.	Suitably qualified person to prepare construction documentation and certification for WRE. Personnel to conduct post closure monitoring and maintenance of the WRE. Contractors (incl. consumables, tools, equipment and machinery) required to address surface slumping / erosion.	Performance measured through regular inspections by suitably qualified person and design certifications complete	• Reporting against post-closure monitoring and maintenance program • Field inspections and rehabilitation monitoring reports • Construction certification reports	14 M	RM12, RM13
Water flux entering underlying PAF waste / capillary risk associated with WRE, relevant to milestones RM12 and RM13	• Options analysis for the WRE final landform and capping system (performed by suitably qualified organisation) - assessing environmental performance • WRE final landform and cover design performance modelling includes downward and upward flux) • Material specifications identified for WRE cover construction • Development of Post Closure Monitoring and Maintenance Plan	14M	• Construction of WRE according to design • Preparation of Construction Documentation for WRE • Suitable material types selected and used for WRE cover • Implement Post Closure Monitoring and Maintenance Plan (routine inspections, rehabilitation inspections, cover system design performance monitoring)	Continual monitoring of the WRE cover system over time will identify whether oxidation products remain contained within the waste mass and will inform appropriate maintenance to ensure PRCP milestones are achieved.	Suitably qualified person to prepare construction documentation and certification for WRE. Personnel to conduct post closure monitoring and maintenance of the WRE. Contractors (incl. consumables, tools, equipment and machinery) required to install instrumentation for monitoring of cover system performance.	Performance measured through regular inspections by suitably qualified person and design certifications complete	• Reporting against post-closure monitoring and maintenance program • Field inspections and rehabilitation monitoring reports • Construction certification reports	14 M	RM12, RM13
Inability of the WRE cover system to achieve a stable condition relevant to milestones RM13	• WRE final landform and cover system options analysis, design and modelling • Waste characterisation • Geotechnical investigation work of WRE • Construction methods for WRE • Requirement for all technical design elements to consider historical long term climatic events • WRE detailed design includes long-term stability modelling • Final landform designs and erosion stability modelling assessments • Flood modelling of final landform completed • Development of revegetation strategies to address environmental constraints such as climate variability and natural events	18 H	• Finalise WRE landform and detailed cover system design • Construction of WRE according to design and preparation of construction documentation • Installation of monitoring equipment for cover system design performance • Implement revegetation strategy • Ongoing assessment and monitoring of WRE landform for physical stability (slope stability, erosion), chemical stability (water flux through the waste, capillary rise and receiving environment surface waters and stream sediment and groundwater) and vegetation performance on the crest, in accordance with PRCP milestones • Adaptive management with early intervention of rehabilitation failure	Implementing stated rehabilitation milestones will achieve rehabilitation success. Continual monitoring of the WRE cover system for physical, chemical and vegetation stability will provide early indicators of failure and adaptive management to be implemented	On-going sufficient budget review process and resources allocation to ensure monitoring and management for the WRE landform	Performance assessed through regular inspections and rehabilitation monitoring by suitably qualified person	• Field inspections • Rehabilitation monitoring reports • Reporting against post-closure monitoring and maintenance program	14 M	RM13
Inadequate revegetation strategies (including surface preparation), relevant to milestone RM7, RM8, RM9, RM10, RM11, RM12, RM13 and RM14	• Borrow source investigations to identify suitable quality and quantity of material • Rehabilitation monitoring program and key learnings identified • Development of revegetation strategies to address constraints (i.e. unsuitable seed mix, methods of application, insufficient growth media, naturally low levels of soil fertility, availability of seed mix, environmental constraints such as climate variability and available plant / soil moisture), timing of revegetation and pest / native / cattle control).	13 M	• Undertake rehabilitation monitoring against milestone criteria • Implement revegetation strategy • Regular reviews of revegetation strategies and updates, if required • Rework of rehabilitation areas, if required • Erect fauna exclusion fencing, where required	Development of revegetation strategies will address the causes (as listed) and will be appropriate to the site's geographical location and climatic conditions. Ongoing rehabilitation monitoring will inform the effectiveness of revegetation methods and appropriate adjustments to be made to achieve PRCP milestones. The borrow source investigation project will ensure site constraints are well understood and addressed in rehabilitation methodologies	Material characterisation data. Field data. Suitably qualified person to identify corrective actions necessary to meet PRCP milestone schedule. Personnel and machinery required for rehabilitation rework	Performance assessed through regular inspections and rehabilitation monitoring by suitably qualified person	• Field inspections • Rehabilitation monitoring reports • Borrow Source Investigation Report	9 M	RM7, RM8, RM9, RM10, RM11, RM12, RM13, RM14
Rehabilitated landforms will be subject to variable climatic conditions (including natural events such as bushfire,	• Engineering designs completed by appropriately qualified person	13 M	• Final landform slopes to be reprofiled similar to pre-mining conditions • Implement post closure monitoring and maintenance plan	The modelling predictions determine long-term stability of the final landform. Ongoing rehabilitation monitoring will provide early indicators of failure, allowance for adaptive	Field data. Climate data	Performance assessed through technical design review, regular inspections and	• Field inspections • Design reports	9 M	RM4, RM5, RM6, RM10, RM11, RM12, RM13, RM14

Aspect and Impacts	Current Controls	Current Risk	Additional Controls	Justification of Treatment Option	Resource Requirements	Performance Measures and Constraints	Reporting and Monitoring Requirements	Residual Risk Score	Applicable Rehabilitation Milestone
drought, storms, floods) relevant to milestone RM4, RM5, RM6, RM10, RM11, RM12, RM13, RM14	• Requirement for all technical design elements to consider historical long term climatic events • WRE detailed design includes long-term stability modelling • Final landform designs and erosion stability assessments • Flood modelling of final landform completed • Development of revegetation strategies to address environmental constraints such as climate variability and natural events		• Develop and implement a bushfire management plan • Rehabilitation monitoring (including monitoring changes to climate over time) • Erosion and sediment control practices to be implemented and maintained • Regular reviews of revegetation strategies and updates, if required • Rework of rehabilitation areas, if required	management. Rework of rehabilitated areas will maximise rehabilitation success (this may include supplementary seeding (i.e. during prolonged drought), further erosion control / maintenance of furrows.	Suitably qualified person to identify corrective actions necessary to meet PRCP milestone schedule. Personnel and machinery required for rehabilitation rework	rehabilitation monitoring by suitably qualified person	• Rehabilitation monitoring reports		
Proliferation of weeds and pests during closure activities and post closure monitoring and maintenance phase, relevant to milestone RM10, RM11, RM13 and RM14	• Pest management • Ongoing weed control • Fencing to exclude cattle • Development of revegetation strategies to address weeds and pest	8 M	• Implement revegetation strategy • Ongoing rehabilitation monitoring and maintenance	Weed and pest management will ensure successful rehabilitation.	Contractors (incl. consumables, tools, equipment and machinery) required to complete revegetation works incl. weed/pest maintenance work. Adequate budget to implement site rehabilitation works.	Performance measured through regular inspections and rehabilitation monitoring by suitably qualified person	• Field inspections • Rehabilitation monitoring reports	2 L	RM10, RM11, RM13, RM14
Inadequate contractor engagement and management during closure works relevant to achieve all milestones	• Standard procurement process	17 H	• Develop a scope of works/tender package • Contractual Agreements in place for the execution of closure works • Develop a contractor execution strategy for closure works	Contractor agreements completed ahead of the closure phase will be required to ensure successful delivery of closure works. This in turn will ensure PRCP milestones are achieved according to schedule.	Contract and Procurement Team to undertake contract review process and develop contracts. Personnel to oversee contractor management.	Performance assessed through monitoring of contractor progress and costs Regular contract reviews	• Internal reporting/monitoring of Contract performance	13 M	RM1 – RM14

Progressive rehabilitation progress does not achieve rehabilitation milestones in accordance with the PRCP or PRCP Schedule	• Annual review of rehabilitation provision internal budget
	• Progressive rehabilitation opportunities identified and implemented during operations (trench, exploration pads, Leachate Management Dam area)
	• WRF landform design work underway
	• Operational borrow areas identified
	• On-site rehabilitation works and key learnings identified
		18 H	• Undertake ongoing meetings with DES
			• Complete the LLM PRCP submission to DES
			  ○ Identify opportunities for progressive rehabilitation
			  ○ Prepare the PRCP schedule with realistic and achievable milestone and outcomes (i.e. consideration of climate variability and strategic retention of infrastructure)
			  ○ Establish appropriate/achievable milestone criteria
			• Undertake ongoing rehabilitation monitoring to test the revegetation strategies and optimise rehabilitation methods and monitoring to ensure milestone criteria can be achieved.
				The development of PRCP Milestones and scheduling that account for all possible delays will ensure greater certainty of compliance.
				Progressive rehabilitation will allow early identification of issues and necessary actions. The implementation of current Revegetation strategies will also involve regular review and update, to allow necessary modifications to the revegetation strategy to be made.
					PRCP schedule. Rehabilitation monitoring program and performance measured through inspections by suitably qualified person. Rehabilitation and Closure Team to review rehabilitation provisions annually to ensure adequate budget for rehabilitation. Contractors (incl. seed suppliers, tools, equipment and machinery) required to complete progressive rehabilitation and maintenance works.	Performance measured through site audits against milestone criteria and schedule. Delay in achieving milestones resulting in non-compliances	• Field inspections and rehabilitation monitoring reports.
							• Audits for performance against PRCP milestones and schedule
							• External reporting (annual return submissions to DES)
							• Internal reporting (rehabilitation provision annual reviews)
								9 M	RM1 – RM14

Insufficient defensible data is available to demonstrate that rehabilitation milestone criteria have been achieved to meet final milestones (achievement of PMLUs) RM13 and RM14	• EA monitoring and internal monitoring programs • Contaminated land investigations • Ongoing rehabilitation monitoring • Database to store information and data trend analysis • Development of Post Closure Monitoring and Maintenance Plan • Development of revegetation strategies	13 M	• Implement post closure monitoring and maintenance plan • Ongoing EA monitoring and investigations, including development of revised criteria • Further development of groundwater modelling and expand groundwater network design plan, as required • Contaminated land intrusive investigation work and develop remediation action plan • Implement remediation and program to confirm suitable remediation actions have been implemented and site is suitable for PMLU • Rehabilitation monitoring and rework • Ongoing review of internal budgets to allow closure works to continue (rehabilitation provision schedules and resourcing) • Constructed to design specifications (as-builts for verification) • Implement plans throughout the closure and post closure phases	Developing and implementing the stated plans (including the review and update) will ensure successful rehabilitation. Recording the observations allows adequate data to convey PRCP obligations and milestones are adhered to.	Suitably qualified engineer to design and certify landform construction. Rehabilitation monitoring inspections and reporting with performance measured by suitably qualified person.	Performance assessed through compliance and available data against stated plans	• Internal and External reporting • Reporting against post-closure monitoring and maintenance program • Field inspections and rehabilitation monitoring reports • Contaminated land investigations and reporting • Construction certification reports • EA compliance monitoring and reporting	9 M	RM13, RM14
Changing government expectations over time	• Planning to look at emerging regulatory updates • Involvement in industry forums	17 H	• As low as reasonably practical	Current control measures considered adequate. Continued monitoring for	Adequate staffing to continue monitoring governmental mandates and communicate with DES, as needed.	Performance measured through ongoing	• External reporting (DES)	8 M	RM1 – RM14

Aspect and Impacts	Current Controls	Current Risk	Additional Controls	Justification of Treatment Option	Resource Requirements	Performance Measures and Constraints	Reporting and Monitoring Requirements	Residual Risk Score	Applicable Rehabilitation Milestone
	• Regular engagement with DES • DES approval of PRCP • Final land use consistent with surrounding landscape			governmental mandates will occur and obtaining PRCP approval.		awareness of governmental changes			
Inability to surrender the EA	• Planning to look at emerging regulatory updates • Involvement in industry forums • Regular engagement with DES • DES approval of the PRCP • Final land use consistent with surrounding landscape	18 H	• Implementation of all additional controls identified herein • Implementation of PRCP and PRCP schedule	Refer to all of the above	On-going sufficient budget review process and resources allocation to ensure successful rehabilitation that meets stated milestone criteria (under the PRCP) and EP Act requirements.	Performance assessed through consistent review of PRCP milestones and schedule and EP Act requirements. Adequate available budget for ongoing rehabilitation / rework	• Internal and External reporting • EA compliance monitoring and reporting • PRCP audits (milestone performance) • Final Rehabilitation Report (for Surrender submission) • Site Management Plan (for ongoing contaminated land legacy issues) • Post-mining Management Report (for ongoing management)	13 M	RM13, RM14

L = Low Risk

M = Medium Risk

H= High Risk

3.14. MONITORING AND MAINTENANCE

3.14.1 Overview

This monitoring and maintenance program describes the monitoring and maintenance systems that will be carried out to determine whether milestone criteria have been achieved. The rehabilitation milestones are later described in Section 4 (PRCP Schedule).

Monitoring and maintenance activities are often relevant to more than a single rehabilitation milestone. As such, various performance monitoring and maintenance methodologies that are relevant for more than one milestone are described in Section 3.14.16 to Section 3.14.21.

Monitoring and maintenance of the Site will be undertaken to support implementation of the Decommissioning and Rehabilitation program. Key aspects of the monitoring and maintenance program that demonstrate a specific rehabilitation milestone has been achieved include:

- Inspection and surveillance,
- Performance monitoring,
- Corrective and preventative action, and
- Review and reporting.

These key aspects are captured in the following Section 3.14.2 to Section 3.14.15.

3.14.2 Rehabilitation Milestone 1: Infrastructure Decommissioning and Removal (Fixed Plant)

Following the de-energisation (mechanically and electrically) and disconnection of services, controlled removal of infrastructure will be undertaken.

Once all fixed plant has been removed and waste streams from demolition appropriately disposed of, or recycled, a visual inspection will be completed. The visual inspection will determine any further decommissioning or assurance requirements and recommendations of any necessary corrective actions. An inspection checklist will be developed to record findings.

Drill holes will be decommissioned in accordance with the *Eligibility Criteria and Standard Conditions for Exploration and Mineral Development Projects – Version 2* (ESR/2016/1985).

This rehabilitation milestone is applicable to rehabilitation areas RA5 (Infrastructure – Native Habitat), RA6 (Infrastructure – Low Intensity Cattle Grazing), RA7 (ROM pad, Paste Plant and Batch Plant), RA8 (Exploration, roads, tracks and borrow sites – Native Habitat) and RA9 (Exploration, roads, tracks and borrow sites – Low Intensity Cattle Grazing).

3.14.3 Rehabilitation Milestone 2: Installation of cover system (WRE)

Decommissioning and rehabilitation of the WRE will include the application of low water flux covers to the crest and batters. These will act to minimise the infiltration of water into the contained waste rock and thereby remove the mechanism that may act to transport contaminants into the receiving environment. In addition, the crest and batter treatments have been designed to provide functions such as resistance to erosion and storage of water to support plant growth.

Quality Assurance/Quality Control works will be completed to demonstrate the cover system construction has met the design criteria. Verification works will comprise of the following:

- Depth of rock mulch layer on the crest,
- Depth of compacted PAF and compacted NAF on the batters,
- Maximum hydraulic conductivity of the compacted PAF and compacted NAF layer on the batters is to specified design,
- Review that the manufacturer's quality assurance/quality control testing results meet stated specifications for the BGM liner, including maximum hydraulic conductivity,
- In-field construction verification testing, including seam testing to ensure continuity and integrity of the lining system, and
- No PAF material is present within the cover material.

Monitoring for conditioning under the BGM liner is not recommended due to risk of puncturing the BGM liner and causing preferential flow paths for seepage.

Following construction of the WRE cover system, inspection and reporting will be completed to provide assurance that rehabilitation activities were completed in accordance with approved designs. Upon completion of physical works, the cover system construction works will have as-constructed plans prepared and certified by a suitably qualified person. Deviations between design and construction are to be identified. Records to be kept include:

- Chemical and physical properties of all cover materials (including lab-based material characterisation results),
- Surface and any available sub-surface preparation including information related to the base layer under the BGM liner (e.g. compacting, establishing bunds) and including evidence, photos, and records of any tests conducted,
- Amelioration (for example gypsum/lime, rate, spreading/layer application) (including lab-based material characterisation results),
- Details of installation methodology, and
- Monitoring equipment installation.

3.14.4 Rehabilitation Milestone 3: Remediation of Contaminated Land

Contaminated land works will include:

- Completion of preliminary and intrusive contaminated land investigations,
- Controlled removal or remediation of contaminated water, soils and sediments, as recommended by suitably qualified person,
- Removal of dam liners, and
- Completion of validation testing to confirm contaminated soils have been contained, treated, remediated or removed.

A contaminated land investigation document is to be prepared by a suitably qualified person, which is to contain the following components:

- Sampling Analysis and Quality Plan detailing the proposed investigation works,
- Site investigation report, assessing existing contamination status, in accordance with *National Environment Protection (Assessment of Site Contamination) Measure Guidelines,* and
- Validation report, describing works undertaken to contain, treat, remediate or remove any contamination, to meet the requirements of the EA and obligations under the EP Act.

Rehabilitation areas for which this milestone is relevant include RA3 (LMD and ESC facility), RA4 (CDA, CDB, PPD and ESC facilities), RA5 (Infrastructure – Native Habitat), RA6 (Infrastructure – Low Intensity Cattle Grazing), RA7 (ROM pad, Paste Plant and Batch Plant), RA10 (Underground Openings – Shafts, decline, portal), and roads within RA8 (Exploration, roads, tracks and borrow sites – Native Habitat) and RA9 (Exploration, roads, tracks and borrow sites – Low Intensity Cattle Grazing).

3.14.5 Rehabilitation Milestone 4: Landform development and reshaping/re-profiling (Underground Openings)

Following partial backfilling of underground openings and sealing of the portal, inspection and reporting will be completed, including preparation of an As-Constructed Report and identification of any deviations between design and construction. The rehabilitation area for which this milestone is relevant include RA10 (Underground Openings – Shafts, decline, portal).

3.14.6 Rehabilitation Milestone 5: Landform development and reshaping / re-profiling (ROM Pad, Paste Plant and Batch Plant, Infrastructure Area, Topsoil Stockpiles and Borrow Sites)

Following landform development and reshaping, inspection and reporting will be completed to provide assurance that rehabilitation activities were completed in accordance with approved designs.

As constructed works will be appropriately documented and verified.

Rehabilitation areas requiring reshaping/reprofiling include RA2 (Topsoil Stockpiles), RA5 (Infrastructure – Native Habitat), RA6 (Infrastructure – Low Intensity Cattle Grazing), RA7 (ROM pad, Paste Plant and Batch Plant) and borrow sites within RA8 (Exploration, roads, tracks and borrow sites – Native Habitat) and RA9 (Exploration, roads, tracks and borrow sites – Low Intensity Cattle Grazing).

3.14.7 Rehabilitation Milestone 6: Landform development and reshaping / re-profiling (Regulated Dams and Erosion and Sediment Control Facilities)

Following landform development and reshaping of dam areas, inspection and reporting will be completed to provide assurance that rehabilitation activities were completed in accordance with approved designs. Upon decommissioning of regulated structures, physical works will be surveyed and certified where appropriate. As-built documentation will be prepared for the erosion and sediment control facilities, and deviations between design and construction are to be identified.

Routine inspections of erosion and sediment control facilities will be completed to determine if any future maintenance action is required. The routine visual inspections will be supported by a suitable check-sheet and will include instances of erosion or scour and sediment accumulation in ESC facilities.

Upon decommissioning of the erosion and sediment control facilities physical works will be inspected. Rehabilitation areas under RM6 include RA3 (LMD and ESC facility) and RA4 (CDA, CDB, PPD and ESC facilities).

3.14.8 Rehabilitation Milestone 7: Surface Preparation

Ongoing record of topsoil and subsoil inventories will occur to manage material deficits. Records of milestone completion should be kept including:

- Areas where deep ripping has occurred including rip line spacing and depth,
- Areas and bulk quantities:
    - where growth medium has been applied,
    - ameliorants and/or fertiliser has been applied, and
    - rock mulch was applied.

Rehabilitation areas relevant to this milestone include RA1 (WRE) crest area only, RA3 (LMD and ESC facilities), RA4 (CDA, CDB, PPD and ESC facilities), RA5 (Infrastructure – Native Habitat), RA6 (Infrastructure – Low Intensity Cattle Grazing), RA7 (ROM pad, Paste Plant and Batch Plant), RA8 (Exploration, roads, tracks and borrow sites – Native Habitat), RA9 (Exploration, roads, tracks and borrow sites – Low Intensity Cattle Grazing) and RA10 (Underground Openings – Shafts, decline, portal).

3.14.9 Rehabilitation Milestone 8: Revegetation (all disturbed areas excluding WRE)

All areas in which framework species seeding have been carried out are to be recorded, this is to include the seed mix, sowing rates applied to, and target density for, each area.

Rehabilitation areas relevant to this milestone include RA2 (Topsoil Stockpiles), RA3 (LMD and ESC facilities), RA4 (CDA, CDB, PPD and ESC facilities), RA5 (Infrastructure – Native Habitat), RA6 (Infrastructure – Low Intensity Cattle Grazing), RA7 (ROM pad, Paste Plant and Batch Plant), RA8 (Exploration, roads, tracks and borrow sites – Native Habitat), RA9 (Exploration, roads, tracks and borrow sites – Low Intensity Cattle Grazing) and RA10 (Underground Openings – Shafts, decline, portal).

3.14.10 Rehabilitation Milestone 9: Revegetation (WRE)

The WRE cover system revegetation will be monitored and recorded to include seed mix and sowing rates applied to the WRE crest. No seed mix will be applied to the WRE batters.

RM9 is of relevance to RA1 only.

3.14.11 Rehabilitation Milestone 10: Achievement of surface requirements - Vegetation on Developmental Trajectory (Native Habitat areas)

Following the implementation of the Decommissioning and Rehabilitation program, which includes completion of the above mentioned RMs, monitoring for revegetation establishment in native habitat areas will occur. This will involve a combination of inspections and field survey analysis.

Monitoring will comprise:

- Ecosystem Function Analysis (EFA),
- Soil geochemical analysis,
- Erosion,
- Weeds, and
- Livestock impacts.

EFA will be used to monitor the establishment of the self-sustaining landform at the Site in accordance with the schedule as outlined in the Glencore NQ Rehabilitation Monitoring Program. The EFA methodology includes assessment of three core components:

- Landscape Function Analysis (LFA),
- Vegetation dynamics, and
- Habitat complexity.

Further detail of EFA methodology is described in Section 3.14.16.

Each rehabilitation area is inspected concurrently with the EFA monitoring assessment. The rehabilitation inspection consists of soil geochemical analysis and a "walkover" of the rehabilitation areas. Further detail is described in Section 3.14.16 and 3.14.17. A rehabilitation monitoring report will be prepared for each monitoring event.

In addition to the above scheduled monitoring, routine or event-based inspections will occur to identify non-conformances, or corrective action. Further detail of the routine and event-based inspection program including corrective action is described in Section 0 to 3.14.19.

Rehabilitation areas relevant to this milestone include RA1 (WRE), RA3 (LMD and ESC facilities) and RA5 (Infrastructure – Native Habitat).

3.14.12 Rehabilitation Milestone 11: Achievement of surface requirements - Vegetation on Developmental Trajectory (Low Intensity Cattle Grazing areas)

Monitoring revegetation establishment in low intensity cattle grazing areas will occur. This will involve similar aspects and methodologies outlined in Section 3.14.16, with the addition of monitoring of basal area ground cover necessary for Low Intensity Cattle Grazing areas.

Field assessments to determine the percentage of basal groundcover, using ground methods will be completed concurrently with the EFA monitoring assessment and conducted by suitably qualified personnel. Ground cover composition will be recorded along the transect established for LFA. An assessment of ground cover within five representative 1m x 1m quadrants, will be completed.

3.14.13 Rehabilitation Milestone 12: Achievement of surface requirements – WRE

The WRE will be a permanent feature of the post-mining landscape and it is essential that the performance of the crest and batter treatments are demonstrated before other risk control measures such as the WMS are decommissioned. For the purposes of this PRCP, a minimum performance demonstration period of five years has been adopted to account for the variable climatic conditions experienced at the Site.

RM12 applicable to the WRE (RA1) involves monitoring for erosion, water flux into the contained waste and contaminant mass flux out of the WRE. Achievement of RM12 will involve review of performance monitoring data for the WRE undertaken by a suitably qualified person and reporting on performance.

Performance of the cover will be assessed following periodic review of monitoring data. Classes of monitoring data will include:

- Drawdown of the phreatic surface within the WRE,
- Rate of infiltration into the contained waste as measured through the cover system water balance,
- Volume and chemical constituency of drainage deporting from the WRE,
- Sediment loss from the batters and crest,
- Photography, and
- Visual assessment.

Monitoring of the WRE water balance will demonstrate the performance of the cover system, including the bituminous geo-membrane liner to prevent infiltration into the contained waste. Because the BGM liner is a manufactured material with a very low hydraulic conductivity ($<1x10^{-9}$ m/s), any penetration of the liner will compromise its integrity. As such, the cover system water balance will be used to evaluate the rate of infiltration (or lack of infiltration) into the waste material. Monitoring will be completed using a network of four instrumented monitoring stations located in both the crest and batter treatment areas, two within the crest and two within the batter. Each station will comprise paired sensor arrays monitoring volumetric moisture content and matric suction located at strategic levels in the capping media. A Fredlund thermal conductivity sensor measures matric suction. Measurement of matric suction in the cover system will provide an indication of the fate of moisture within the cover system including at the base of the cover profile and at the surface of the waste material.

Climate monitoring will be conducted with an automated, on-site weather station and will include:

- Rainfall,
- Evaporation,
- Relative humidity,
- Wind strength,
- Wind direction, and
- Air temperature.

This data will be analysed annually to assess the water balance of the landform including:

- Storage,
- Losses to runoff,
- Losses to evapotranspiration, and
- Net losses to infiltration.

Erosion

Ongoing cover system performance assessment will occur to include erosion extent and measurement against RM12. This will primarily be conducted through visual assessments during on-site routine inspections and as a component of the rehabilitation monitoring program. Direct measurements of erosion depths can be collected. Visual assessment of prolonged surface water ponding and surface water runoff on the crest may indicate potential for erosion of embankments and instability issues.

As the WRE batters will be constructed using rock armour erosion of the surface is not anticipated. However, instability risks at the compacted NAF and rock armour interface can be measured. Surface water runoff and sediment loss will be monitored through flumes at the base of the embankments.

The geotechnical stability risk for the cover system will also be measured at primary monitoring locations (established in representative locations). This will comprise of vibrating wire piezometers (VWPs) installed in the embankment below the rock armour following completion of the reshaping of the final landform. This will allow direct measurement of the phreatic surface within the embankment which will be used to evaluate both stability risk and water flux out of the landform as well as an indirect indicator of infiltration through the cover system.

Water Flux into contained waste

Water flux into the contained PAF waste is to be less than 10% of rainfall and appropriate flux monitoring sites to be installed as per RM12. The cover system water balance will be used to evaluate water flux in the contained waste. The in-situ monitoring stations (four in total as mentioned above) will be installed to measure available water holding capacity of the cover soil profile and moisture in the profile, nominally to be installed within the upper 30% and at the base of the cover profiles on the crest and batters. The surface of the PAF waste material will also be measured on the batters to determine water infiltration into the underlying waste. Appropriate locations and depths will be determined during detailed design. These measuring devices will also provide an indication of any potential erosion and instability risks of the embankments.

Monitoring for the condition of the interface at the BGM and NAF layer is not recommended due to risk of puncturing the BGM liner and preferential flow paths for seepage. BGM is a manufactured product and the permeability of the BGM (measured at maximum hydraulic conductivity) will be demonstrated through appropriate QA/QC under RM2.

The VWP data will be used as an indirect indicator of cover system infiltration. As the cover system prevents infiltration into the waste, the phreatic surface is expected to decrease over time.

Contaminant Mass Flux out of WRE

Cover system performance will also be measured through contaminant mass flux monitoring out of the WRE. This can be achieved via installation of a V-notch weir installed at an appropriate location to assess seepage out of the WRE. An appropriate and representative location will be selected.

As above, the VWP data will be used as an indicator of infiltration through the cover system. As the cover system prevents infiltration into the waste, the phreatic surface is expected to decrease over time, which will reduce contaminant mass flux out of the WRE due to the reduced hydraulic head within the WRE

Mass contaminant flux out of the WRE will also be interpreted through ongoing groundwater monitoring, pursuant to the requirements of the EA.

Instrumentation and sensors used in the monitoring program will be calibrated to the material type being monitored using the manufacturers specifications and installed, operated and maintained by an appropriately qualified person.

3.14.14 Rehabilitation Milestone 13: Achievement of post-mining land use to stable condition (Native Habitat areas)

The achievement of a stable landscape that can support native habitat is to be monitored through a combination of inspections and field survey programs. Monitoring will comprise of the following aspects:

- Ecosystem Function Analysis,
- Erosion,
- Weeds,
- Surface water quality,
- Groundwater quality,
- Geotechnical stability (WRE and Underground Openings),
- Safety risks (Underground Openings), and
- Contaminated land investigation.

Routine and event-based inspections will occur until completion of the PRCP Schedule. Additional aspects not previously described are outlined below.

3.14.14.1. Surface Water, Stream Sediment and Macroinvertebrates

Monitoring of surface waters, stream sediment and macroinvertebrate communities at the Site and in the receiving environment will continue to be undertaken as per Schedule C of the EA.

3.14.14.2. Groundwater Quality and Flow

Monitoring of groundwater quality will continue to be undertaken pursuant to the requirements Schedule C of the EA.

While monitoring in accordance with the EA is appropriate for collecting a dataset and identifying rehabilitation performance during the post closure period prior to relinquishment, the architecture of this monitoring regime, specifically the contaminant limits, are inappropriate as success criteria.

The following proposed drafting of groundwater success criteria (also defined in Section 4.4) is consistent with requirements of the EP Act and relevant guideline.

> *Assessment and validation by a suitably qualified person that the groundwater quality is safe, does not cause environmental harm (benchmarked to appropriate reference site(s)) and is able to sustain the nominated PMLU.*

Continued data collation on groundwater quality will occur in accordance with the EA, including any necessary expansion of LLM groundwater monitoring network over time, to support the above assessment and validation.

3.14.14.3. Geotechnical Stability and Safety

A geotechnical stability assessment for the WRE and underground openings will be prepared and will include an appropriate risk assessment and control measures for RA1 (WRE) and RA10 (Underground Openings – Shafts, decline, portal). The risk assessment will address safety risks associated with the backfilled ventilation shafts and decline, to confirm no unacceptable safety risk to humans or wildlife is occurring. The geotechnical assessment will include certification and completion by suitably qualified geotechnical engineer.

3.14.14.4. Contaminated Land Investigation

The final component to a contaminated land investigation program is to determine whether suitable remediation actions have been adequately implemented and the site is suitable for the final land-use. A site suitability statement, prepared by a suitably qualified person stating that land is suitable for the intended PMLU, will be prepared.

Rehabilitation areas relevant to this milestone include RA1 (WRE), RA3 (LMD and ESC facilities), RA5 (Infrastructure – Native Habitat), RA8 (Exploration, roads, tracks and borrow sites – Native Habitat) and RA10 (Underground Openings – Shafts, decline, portal).

3.14.15 Rehabilitation Milestone 14: Achievement of post-mining land use to stable condition (Low Intensity Cattle Grazing areas)

The achievement of a stable landscape that can support low-intensity cattle grazing is to be monitored through a combination of inspections and field survey programs. Monitoring will comprise of those aspects listed and described in Section 3.14.14, with the addition of monitoring of basal area ground cover described in Section 3.14.12.

Rehabilitation areas relevant to this milestone include RA2 (Topsoil Stockpiles), RA4 (CDA, CDB, PPD and ESC facilities), RA6 (Infrastructure – Low Intensity Cattle Grazing), RA7 (ROM pad, Paste Plant and Batch Plant) and RA9 (Exploration, roads, tracks and borrow sites – Low Intensity Cattle Grazing).

3.14.15.1. Grazing Rates and Carrying Capacity

Grazing rates and carrying capacity will be assessed by a suitably qualified and experienced person, in close consultant with relevant stakeholders. The assessment will be undertaken at the time of stocking and then also upon surrender to confirm achievement of the post mining land use to a stable condition.

Grazing rates and carrying capacity will consider land use factors such as: land type and condition; climate; area available (paddock size) and evenness of use; available pasture at the commencement and end of grazing (dry mass per hectare); feed accessibility due to water availability and geography; growth rates of pasture (seasonal considerations); goals for animal production and land condition; and expected number of days grazing. This is consistent with contemporary grazing practices.

3.14.15.2. Reintroduction of Grazing

The reintroduction of grazing may be conducted on proportions of relevant RAs proposed for low intensity cattle grazing. Specific locations will be determined at a later time. Reference pens may also be trialled to provide data to compare with the rehabilitated sites. Reference pens should be in locations that have not been disturbed by mining, and that have been spelled from cattle for at least two years. Reference sites will be selected in areas that display similar vegetation communities and soil characteristics to the rehabilitated sites.

It is recommended that the reintroduction of grazing on rehabilitation sites do not take place until pasture biomass remains stable for at least three years and landscape function analyses indicate that the sites are moving on a trajectory towards a stable, functional ecosystem. Reintroduction of grazing should not commence until at least ten years after rehabilitation sites are first seeded. Reintroduction of grazing may provide the final indicators of rehabilitation performance. The details for the proposed reintroduction of grazing will be finalised at a later date, in consultation with relevant suitably qualified personnel and the local graziers.

3.14.16 Revegetation Success Monitoring

EFA used for revegetation success monitoring was developed by Australian researchers including the CSIRO during the 1990s and early 2000s. The methods have undergone refinements including codification and have become widely accepted as the appropriate framework to assess the value of soils and vegetation on lands disturbed by mining. A detailed methodology is provided in *Landscape Function Analysis: Procedures for Monitoring and Assessing Landscapes* (Tongway and Hindley, 2005). A summary of the methodology is provided below.

The EFA methodology includes assessment of three core components:

- Landscape Function Analysis (LFA),
- Vegetation dynamics, and
- Habitat complexity.

3.14.16.1. Landscape Function Analysis

LFA is a measure of how well the landscape retains and uses key resources such as water and organic matter. The way in which each type of resource is utilised within micro catchments influences the way the landscape develops and ultimately functions. A well-functioning landscape will recruit and retain resources including moisture and nutrients effectively. LFA monitoring assesses 11 attributes of the soil surface and vegetation cover to derive indices of “stability”, “infiltration” and “nutrient cycling”, on which several milestone criteria will be assessed against.

3.14.16.2. Vegetation dynamics

The vegetation dynamics component of EFA focuses on the functional role of vegetation in rehabilitation performance. Data is collected using either the Point Centred Quarter or Wandering Quarter method, both of which measure plant density and canopy volume using the LFA transect as an analogue.

3.14.16.3. Habitat complexity

The habitat complexity component of EFA assesses the extent to which habitat and shelter for vertebrate fauna are developing in the rehabilitated landscape. Habitat complexity involves the assessment of five habitat characteristics within an area surrounding the centre of the LFA transect. The following five attributes are assessed include canopy cover, shrub cover, ground vegetation cover, non-vegetative ground cover (litter, fallen logs and rocks) and free water availability.

The EFA process works by undertaking specific measurements in the field at locations representative of the ecosystems under consideration. Results from the specific measurements are used to determine index scores for the specific monitoring event. Index scores derived from subsequent monitoring events are then assessed to establish the success or otherwise of the vegetation establishment.

3.14.16.4. EFA Thresholds

The approach presented in the LFA Methods (Tongway and Hindley, 2005) requires that the system is dependent on receiving good rainfall during the wet season. At LLM, recovery will be generally slower compared to other bioregions in Queensland due to the arid conditions. Progress towards completion may occur in a step-wise fashion, experience occasional regression, or be slower than anticipated due to climatic conditions.

The mid-term goals for RM10 and RM11 are to demonstrate progress towards the end goal. This will be outlined in rehabilitation monitoring reporting, alongside any adaptive management requirements. The final completion index score values (RM13 and RM14) are to demonstrate stable land conditions are achieved.

A suitably qualified person completed an assessment to validate the EFA thresholds proposed for EFA indices (stability, infiltration, nutrient cycling, species richness, vegetation dynamics and habitat complexity). Assessment of indicators that make up each the stability, infiltration and nutrient cycling scores was undertaken, including reference to existing available data at analogue and rehabilitation sites. The indicators that make up nutrient cycling score take many years to develop, hence the mid-term milestone criteria set at >20% of reference for RM10 and RM11 and >60% of reference for RM13 and RM14 allows time for the site to develop towards final completion and also accounts for the variation in nutrient cycling scores within the reference site data.

The proposed milestone criteria will achieve conditions of analogue sites at completion, with allowance of mid-term metrics for adaptive management measures to be implemented, as required. The proposed milestone criteria are sufficient to achieve the final outcome of land that is in a stable condition.

Further discussion is presented in Appendix C.

3.14.16.5. Species richness and recruitment

In addition to the EFA method, species richness will be assessed. Species richness collects data on the development of the vegetation community as well as to assess germination success of the seed mix. A representative 20m x 20m plot is expected to be established with its centre point coinciding with the centre point of the LFA transect. Species richness will be calculated as the total number of vascular plant species within the plot. All living, above-ground plant parts, including overhanging vegetation, that occur within each plot are included in the count.

Recruitment is also assessed for tree species within the plot. Assessment of species recruitment gives an indication of the sustainability of the vegetation community. Any seedlings or suckers that have established at least two years after initial seeding took place will be recorded as evidence of recruitment. The species recruiting and the number of juveniles will be recorded.

3.14.16.6. Rehabilitation Monitoring Sites

Establishment of viable vegetation communities on soils disturbed by, and derived from, mining wastes are influenced by factors such as nutrition, terrain type and sun aspect. Variable factors include climatic conditions, effects of bushfire, and grazing. Of these, rainfall is considered the most significant factor—particularly in the highly seasonal and highly variable rainfall.

To account for this variability, the monitoring program will consider both reference (or analogue) sites and monitoring sites. Reference sites will be established on land not affected by mining and will be subjected to the same tests and measurements as the monitoring sites.

LLM has established 11 reference monitoring sites to support revegetation. Monitoring campaigns undertaken since 2018 have been used to refine methodologies and develop a baseline dataset.

In accordance with condition E9 of the EA, vegetation monitoring will continue to be undertaken. The frequency may be adjusted based on the results of early monitoring and changing risk profile over time. Vegetation monitoring will target the March thru June period to provide the most accurate species diversity results.

Condition E10 of the EA specifies that "…verification of rehabilitation success is to be carried [out] for each domain. Monitoring must be carried out for each domain at a minimum sampling intensity of 1:15,000 and must include sufficient replication to enable statistical analysis of …." A sampling intensity of 1:15,000 equates to an approximate density of one site per nine hectares.

The Glencore NQ Rehabilitation Monitoring Program will be periodically updated to ensure an appropriate schedule is adopted and the number of monitoring locations per domain will support assessment against the milestone criteria stipulated in this PRCP.

3.14.16.7. Soil Geochemical Analysis

Soil geochemical analysis is undertaken to identify any potential constraints to rehabilitation success associated with the growth media at each rehabilitation area. For example, if growth media salinity is high vegetation germination and establishment success is likely to be reduced and overall rehabilitation outcomes may be negatively impacted.

Where areas of persistent bare ground exist at a rehabilitation area (and this is not consistent with analogue sites), targeted soil geochemical analysis may be required to identify the cause and any required remediation.

3.14.16.8. Rehabilitation Inspection

The rehabilitation inspection, performed concurrently with the EFA monitoring assessment, consists of a "walkover" of the rehabilitation area, with a focus on identifying:

- Any areas that appear to have generally poor vegetation condition,
- Areas that lack vegetation or have large areas that are bare,
- The presence and abundance of key weeds,
- Livestock management issues,
- Rubbish, vandalism or damage caused by vehicles,
- Integrity of water management structures,
- Stability and function of erosion and sediment structures,
- Soil issues (e.g. contamination or staining) at a scale that is likely to affect milestone criteria and/or relinquishment, and
- Areas of erosion, instability, slumping or other surface instability.

The "Walkover" will record details of any remedial actions required for each rehabilitation area. This is consistent with the Glencore NQ Rehabilitation Monitoring Program.

3.14.16.9. Assessment and Reporting

A suitably qualified person will periodically prepare rehabilitation monitoring reports to record data and any necessary corrective actions. The assessment and reporting will capture climate risks associated with natural events such as prolonged periods of drought, storm, floods or fire that may impact rehabilitation success. LLM will review the rehabilitation monitoring data on an ongoing basis. Relevant monitoring information from the preceding year will be reviewed, assessed and integrated with historic datasets.

3.14.17 Routine Inspections

The Site will be subjected to routine inspection to ensure that any potential compliance issues or non-conformances are identified early and appropriate responses taken. Routine inspections of the Site will be completed:

- Four times per year, or at less regular intervals subject to site conditions over time, and
- By a person or persons with suitable understanding of the Site and knowledge in land management practices.

The routine inspections will be recorded on a Site-specific check-sheet. Aspects recorded will include:

- Water management—mine affected water inventory, spill risk, drainage lines,
- Erosion and sediment control—instances of erosion or scour, sediment accumulation in ESC facilities,
- Consolidation settlement—evidence or instances of ground subsidence,
- Fauna activity—evidence or sightings of native fauna in underground workings, and
- Land management—status of stockproof fencing, fire risk, presence of weeds.

3.14.17.1. Erosion

Three separate processes will be used to monitor erosion at the Site. These are:

- Survey,
- Visual observation, and
- Comparison of photographs/aerial imagery.

3.14.17.2. Weeds

Monitoring for the presence of declared and potentially problematic weeds at the Site will be undertaken as a component of the routine inspections. Any weed incursions identified, based on composition and abundance, will be mapped and typically controlled with residual herbicide.

3.14.17.3. Subsidence and Consolidation Settlement

Subsidence and consolidation assessment will be monitored by comparison of regular topographic surveyor LiDAR. Assessment results would typically be reported by way of “heat maps” that identify areas of potential concern.

Consolidation settlement of the backfill material placed into the ventilation shafts will be assessed visually as a component of the routine inspection program. This would include evidence or instances of ground subsidence as well as fauna activity.

Subsidence and Consolidated settlement are relevant to RA10 (Underground Openings – Shafts, decline, portal).

3.14.18 Event-Based Inspections

Event-based inspections may be undertaken in response to natural hazards and specific events such as: earthquake, fire, heavy rainfall, or any other suitable trigger. Event-based inspections would typically be completed pursuant to the check sheets used to support the routine inspections. Event-based inspections would occur throughout the entire site across all RAs, and at any stage during the rehabilitation monitoring schedule. Appropriate interventions will be initiated from these inspections and may include additional ripping and seeding works, fence repair to maintain livestock exclusion.

3.14.19 Non-Conformance, Corrective and Preventative Action

Non-conformances with the requirements of this Plan may come about from a variety of sources including:

- Routine or event-based inspection,
- Review of rehabilitation performance data,
- Stakeholder inspection or concern, or
- Regulator inspection.

Minor non-conformances are expected and once identified, appropriate steps should be taken to correct the issue and if appropriate, prevent recurrence. In most cases this will entail scheduling non-routine maintenance via the Glencore enterprise reporting platform. Maintenance activities may include:

- Repairs to fencing and exclusion of livestock,
- Repairs to drainage paths,
- Application of soil ameliorants/fertilisers, or
- Additional deep ripping and broadcast of seed.

Significant non-conformances may delay the rehabilitation schedule. Such instances will be formally investigated, and a suitable corrective actions plan initiated.

3.14.20 Bushfire Monitoring

The approach to revegetation, including planting and establishment recognises that bushfires have the potential to destabilise rehabilitation efforts.

Monitoring of rehabilitated areas via the methods described above will give best indication of possible fire management practices.

The Mine Rehabilitation: Leading Practice Sustainable Development Program for the Mining Industry (Grant et al. 2016) guidance is that a Project specific fire protection plan may be needed to protect rehabilitation for several years until vegetation is able to survive fire or have set seed so that it can re-established.

Bushfire monitoring will occur throughout the entire site across all RAs, and during the rehabilitation monitoring schedule period.

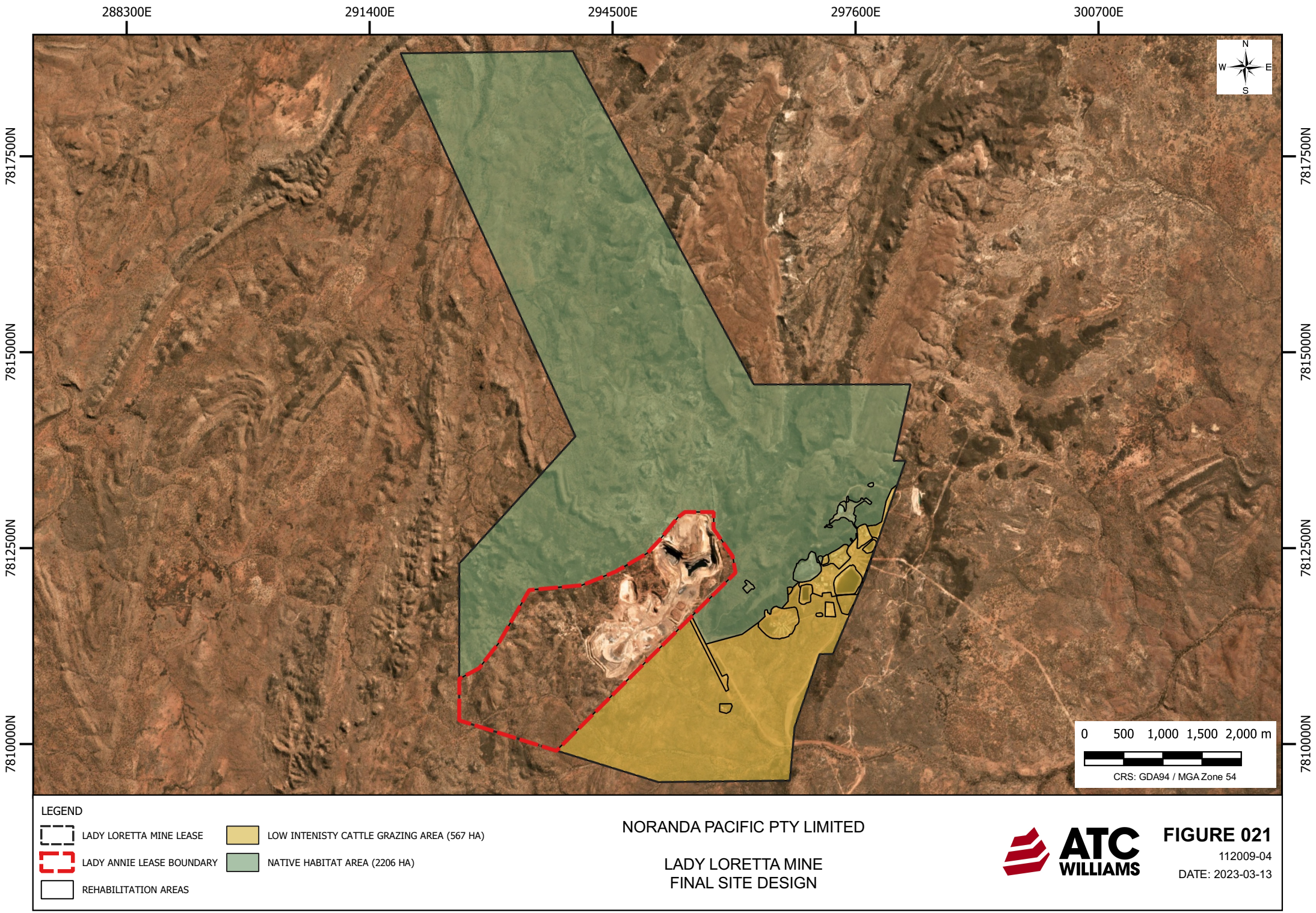
3.14.21 Meteorological Monitoring

LLM operates an automatic weather station located adjacent to the mining block carpark. The station is fitted with sensors suitable to record key climatic data including temperature, rainfall and evaporation. This data will be utilised and referenced as part of ongoing inspection and reporting programs throughout the PRCP schedule.

4. PRC SCHEDULE

4.1. FINAL SITE DESIGN

The final site design proposes a PMLU for the entire area of the ML. No NUMAs are proposed for ML5568. The final site design is presented as Figure 21.



NORANDA PACIFIC PTY LIMITED

LADY LORETTA MINE
FINAL SITE DESIGN

ATC WILLIAMS

FIGURE 021
112009-04
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4.2. REHABILITATION AREAS

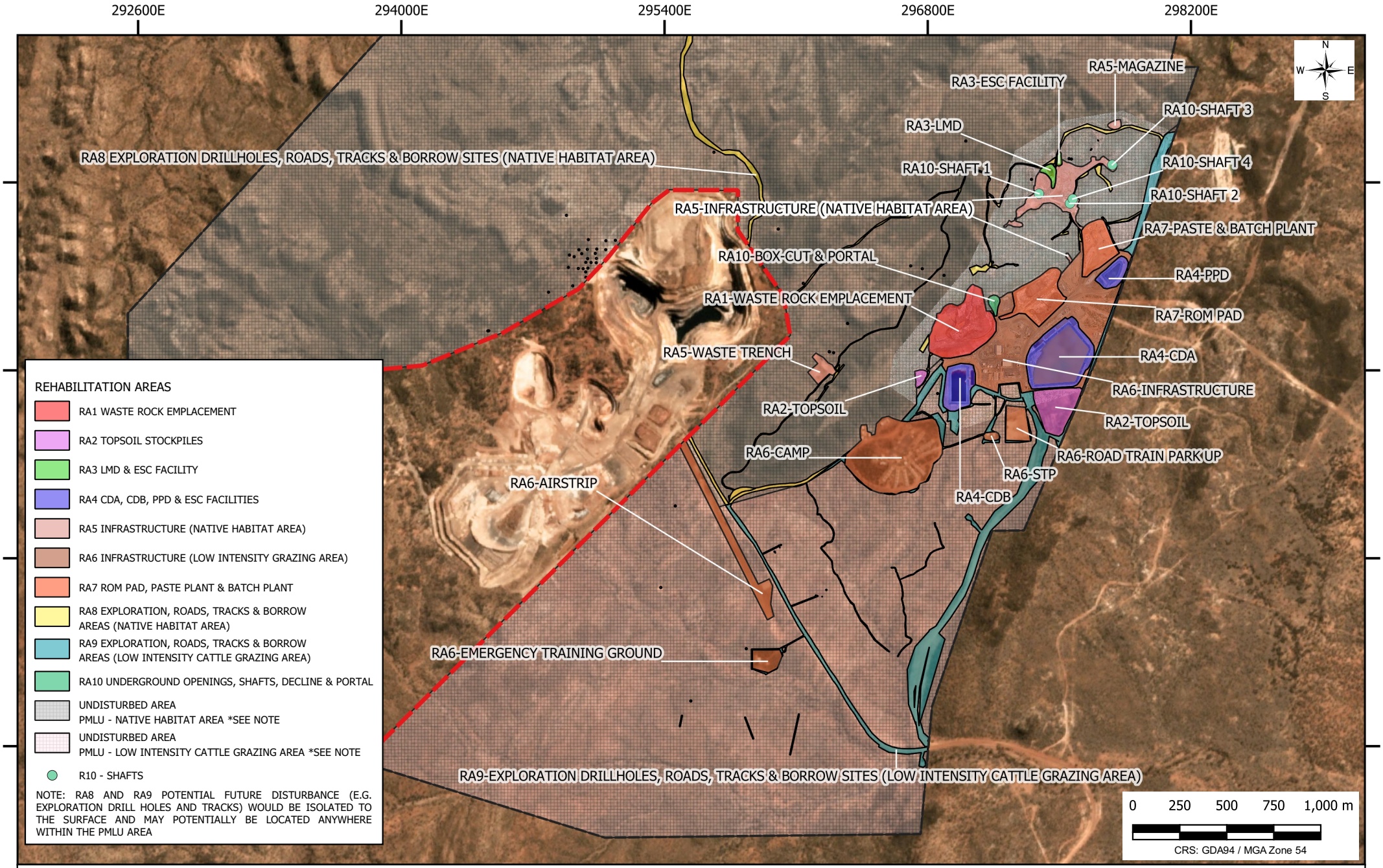
Rehabilitation and closure planning for sites affected by mining operations is a complex undertaking. Different types of disturbance result in various risk exposures which in turn require the application of diverse mitigation measures. To deal with this complexity, a precinct planning approach has been adopted in this PRCP.

The final site design includes ten Rehabilitation Areas (RAs). The RAs have been categorised according to the mitigation measures required to achieve the objectives of the Decommissioning and Rehabilitation program and a common PMLU.

The RAs adopted for the Site are:

- RA1 Waste Rock Emplacement,
- RA2 Topsoil Stockpiles,
- RA3 LMD and ESC Facility,
- RA4 CDA, CDB, PPD, Sediment Dams and ESC Facilities,
- RA5 Infrastructure (Native Habitat Area),
- RA6 Infrastructure (Low Intensity Grazing Area),
- RA7 ROM Pad, Paste Plant and Batch Plant,
- RA8 Exploration, Roads, Tracks and Borrow Sites (Native Habitat Area),
- RA9 Exploration, Roads, Tracks and Borrow Sites (Low Intensity Cattle Grazing Area), and
- RA10 Underground Openings, Shafts, Decline and Portal.

A map showing the location and extent of the RAs is presented in Figure 22.



NORANDA PACIFIC PTY LIMITED

LADY LORETTA MINE
REFERENCE MAP

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FIGURE 022

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4.3. PRC SCHEDULE

The proposed PRC Schedule for LLM is presented as the standard template which was downloaded from:

https://www.business.qld.gov.au/running-business/environment/licences-permits/rehabilitation/progressive-rehabilitation-closure-plans.

The proposed PRC Schedule is provided in Appendix J.

4.4. REHABILITATION MILESTONES AND SUCCESS CRITERIA

Effective demonstration that the rehabilitation objectives have been achieved and that the PMLUs can be implemented requires definition of objective criteria.

Rehabilitation milestones and success criteria for the Native Habitat and Low Intensity Cattle Grazing PMLUs areas are presented in Table 21. These criteria were adopted from knowledge and experience in rehabilitating lands disturbed by mining activities in Queensland, Australia and internationally.

Table 21: Rehabilitation Milestones and Success Criteria

Milestone Reference	Rehabilitation Milestone	Milestone Criteria	Applicable Rehabilitation Areas
RM1	Infrastructure Decommissioning and Removal (Fixed Plant)	a) Services disconnected (excluding services agreed with stakeholders for retention) b) Surface fixed plant and infrastructure including foundations (excluding that required for drainage or otherwise agreed with stakeholders for retention) has been removed ## c) Drillholes are capped/plugged and decommissioned in accordance with ESR/2016/1985 ## NOTE: Criteria transitioned from Land Outcome Document (Post Mine Land Use Plan, dated August 2018).	RA5, RA6, RA7, RA8, RA9
RM2	Installation of cover system (WRE)	a) Crest treatments have been applied, and monitoring stations installed consistent with the WRE engineering design with Quality Assurance/Quality Control measures specified by an RPEQ to achieve the following performance objectives: (i) Maximum hydraulic conductivity of the cover system is < 1.0 x 10^{-9}m/s for bituminous geomembrane cover (ii) Oxygen ingress to the underlying material is restricted (iii) Effective overlap/joining of materials b) Batter treatments have been applied consistent with the WRE engineering design with Quality Assurance/Quality Control measures specified by an RPEQ c) A suitably qualified and experienced person has prepared an As-Constructed Report that details the works undertaken, and certified by an RPEQ that construction and encapsulation works were completed in accordance with design specifications, including: (i) Sub grade preparation (ii) Chemical and physical properties (iii) Geometry and spatial characteristics (iv) Drainage and flow conveyance	RA1
RM3	Remediation of contaminated land	a) Contaminated land investigation completed by suitably qualified person b) Soils and sediments contaminated by site activities have been assessed and managed (e.g. removed/remediated), as recommended by suitably qualified person c) A contaminated land survey carried out by a suitably qualified person including whether contamination unsuitable for the post-mining land use is occurring	RA3, RA4, RA5, RA6, RA7, RA8, RA9, RA10
RM4	Landform development and reshaping/re-profiling (Underground Openings)	a) Upper sections of ventilation shafts have been backfilled with ROM borrow material to preclude access to underground workings b) Surface subsidence generated depression as determined by subsidence monitoring is no greater than > 500 mm c) Upper section of mine decline has been backfilled with ROM borrow material to preclude access to underground workings d) Portal sealed and box-cut backfilled with inert material to form a free draining final surface e) A suitably qualified and experienced person has prepared an As-Constructed Report that details the works undertaken, and certified that construction and backfilling of underground openings met the design intent	RA10
RM5	Landform development and reshaping / re-profiling (ROM Pad, Paste Plant and Batch Plant, Infrastructure Area, Topsoil Stockpiles and Borrow Sites)	a) Terrain has been reprofiled with disturbed slopes not steeper than 4 H:1 V and appropriately verified, with the exception of Borrow Area C b) A suitably qualified and experienced person has prepared a geotechnical stability report and safety assessment for slopes > 30 degrees and > 5m in height[##] c) Erosion and sediment control systems have been installed	RA2, RA5, RA6, RA7, RA8, RA9
RM6	Landform development and reshaping / re-profiling (Regulated Dams and Erosion and Sediment Control Facilities)	a) Recommendation by suitably qualified and experienced engineer that Regulated Dam status can be rescinded. b) Erosion and sediment control systems have been installed c) Terrain has been reprofiled with disturbed slopes not steeper than 4 H:1 V and verified by an appropriately qualified person d) Erosion and sediment control facilities (excluding facilities agreed with stakeholders for retention) decommissioned and left free draining e) Mine affected water will be either remediated, removed or disposed in accordance with relevant regulations. f) Contaminated sediment, along with synthetic liners, is remediated, removed or disposed in accordance with relevant regulations.	RA3, RA4
RM7	Surface Preparation	a) A suitably qualified person has assessed the characteristics of the soil and growth media and defined requirements for ameliorants and other treatments necessary to achieve the PMLU b) Ameliorants and other treatments (including application of stockpiled growth media) have been applied, as recommended by suitably qualified person. c) Final surface has been deep ripped on surfaces, with the exception of WRE (RA1) and Borrow Area C (RA8) d) Placement of minimum thickness of 150 mm of growth media at ROM, Paste Plant and Batch Plant Area (RA7) and borrow site within (RA9), subject to recommendations by suitably qualified person.	RA1, RA3, RA4, RA5, RA6, RA7, RA8, RA9, RA10

Milestone Reference	Rehabilitation Milestone	Milestone Criteria	Applicable Rehabilitation Areas
RM8	Revegetation (all disturbed areas excluding WRE and Borrow Area C)	a) Complete seeding using seed mix and sowing rates described in Table 19 of this PRCP, or based on more recent seed mix and sowing rates as recommendations by suitably qualified person	RA2, RA3, RA4, RA5, RA6, RA7, RA8, RA9, RA10
RM9	Revegetation (WRE)	a) Complete seeding to the WRE crest area using seed mix and sowing rates described Table 19 of the PRCP, or based on more recent seed mix and sowing rates as recommendations by suitably qualified person	RA1
RM10	Achievement of surface requirements - Vegetation on Developmental Trajectory (Native Habitat areas)	a) Corrective actions that are recommended by a suitably qualified person identified through the rehabilitation monitoring methodology has been implemented. b) Corrective action arising from the routine inspections program have been undertaken to include weed control, erosion repair, livestock management. c) Ecosystem Function Analysis index scores compared to equivalent reference sites are: - Stability > 50% of reference - Infiltration > 40% of reference - Nutrient Cycling > 20% of reference - Species Richness > 40% of reference - Vegetation Dynamics >20 % of reference - Habitat Complexity > 40% of reference	RA1, RA3, RA5
RM11	Achievement of surface requirements - Vegetation on Developmental Trajectory (Low Intensity Cattle Grazing areas)	a) Corrective actions that are recommended by a suitably qualitied persons identified through the rehabilitation monitoring methodology has been implemented. b) Corrective action arising from the routine inspections program have been undertaken to include weed control, erosion repair, livestock management. c) Ecosystem Function Analysis index scores compared to equivalent reference sites are: - Stability > 50% of reference - Infiltration > 40% of reference - Nutrient Cycling > 20% of reference - Vegetation Dynamics > 20% of reference d) The basal area of grasses is > 30% of reference	RA2, RA6, RA7
RM12	Achievement of surface requirements - WRE	a) A suitably qualified person has assessed the performance monitoring data for the WRE and verified that: - No active rill/gully erosion > 500 mm - Water flux into contained PAF waste is < 10 % of rainfall at the installed flux monitoring sites within the cover - Contaminant mass flux out of the WRE exhibits stable or decreasing trends when measured at an appropriate and representative location; if no trend can be determined then no persistent adverse environmental impacts when measured over a minimum 2-year monitoring period	RA1

Milestone Reference	Rehabilitation Milestone	Milestone Criteria	Applicable Rehabilitation Areas
RM13	Achievement of post-mining land use to stable condition (Native Habitat areas)	a) Ecosystem Function Analysis index scores compared to Native Habitat reference sites are: - Stability Index > 80% of reference - Infiltration > 60% of reference - Nutrient Cycling > 60% of reference - Species Richness > 60% of reference - Vegetation Dynamics > 40% of reference - Habitat Complexity > 60% of reference b) Proportion of Category 3 restricted invasive plant species is not >10% of total vegetation groundcover** c) Weed densities will be similar to surrounding reference sites[##] d) No unrepaired active gullies (i.e. showing active sediment deposition and sides/floor devoid of cover) > 1 m deep[##] e) Surface water quality at downstream compliance points to meet contaminant limits defined in the current EA[##] f) Assessment and validation by suitably qualified person that the groundwater quality is safe, does not cause environmental harm (benchmarked to appropriate reference site(s)) and is able to sustain the nominated PMLU g) Evidence in rehabilitation report that appropriate risk assessment for geotechnical stability at the WRE and Underground Openings and Borrow Area C has been undertaken and control measures are in place[##] h) Contaminated Land Site Investigation verifies residual contamination presents no unacceptable risk to achieving the PMLU i) Backfill of ventilation shaft complete to pose no unacceptable safety risks to humans or wildlife j) Underground opening certified as safe by a suitably qualified geotechnical engineer (this only applies to RA10) **Defined by Biosecurity Act 2014	RA1, RA3, RA5, RA8, RA10
RM14	Achievement of post-mining land use to stable condition (Low Intensity Cattle Grazing areas)	a) Assessment of carrying capacity by an appropriately qualified person demonstrates a sustainable grazing outcome has been achieved b) Ecosystem Function Analysis index scores compared to equivalent reference sites are: a. Stability > 80% of reference b. Infiltration > 60% of reference c. Nutrient Cycling > 60% of reference d. Vegetation Dynamics > 40% of reference c) The basal area grasses is > 60% of reference d) Proportion of Category 3 restricted invasive plant species is not >10% of total vegetation groundcover** e) Weed densities will be similar to surrounding reference sites[##] f) No unrepaired active gullies (i.e. showing active sediment deposition and sides/floor devoid of cover) > 1 m deep[##] g) Evidence in rehabilitation report that appropriate risk assessment for geotechnical stability at the ROM, Paste Plant and Batch Plant, Infrastructure and Water Dam areas has been undertaken and control measures are in place[##] h) Surface water quality at downstream compliance points to meet contaminant limits defined in the current EA[##] i) Assessment and validation by suitably qualified person that the groundwater quality is safe, does not cause environmental harm (benchmarked to appropriate reference site(s)) and is able to sustain the nominated PMLU j) Contaminated Land Site Investigation verifies residual contamination presents no unacceptable risk to achieving the PMLU **Defined by Biosecurity Act 2014	RA2, RA4, RA6, RA7, RA9

NOTE. Success Criteria previously approved under a Land Outcome Document (LOD) are indicated as notes to the Tables.

[##] Milestone Criteria adopted from LLM Post Mining Land Use Plan (Noranda Pacific, 2018)

[**] *Biosecurity Act 2014*

5. SURRENDER OF ENVIRONMENTAL AUTHORITY

5.1. OVERVIEW

The ultimate objective of this PRCP is to transition the Site to the proposed PMLUs and support surrender of the EA. Implementation of the Decommissioning and Rehabilitation program defined in this PRCP will result in a landscape capable of supporting the proposed PMLUs. Surrender of the EA will require:

- Demonstrated compliance will all requirements of the EA,
- Compilation of a Contaminated Lands Assessment for the Site, and
- Preparation of a Post Mining Management Report.

These specific requirements are described in the following sections.

5.2. COMPLIANCE WITH ENVIRONMENTAL AUTHORITY

Any application to surrender the EA must demonstrate full compliance with the requirements of the EA and demonstrate that ongoing compliance can be expected under the proposed PMLU. For EA EPML00982013, this would require compliance with:

- Schedule C - Water Management
- Schedule E - Land and Rehabilitation

5.3. CONTAMINATED LANDS ASSESSMENT

Prior to surrender of the EA, soil and groundwater contamination must be remediated in compliance with the requirements of the EA and applicable Queensland regulations, including removal from the Environmental Management Register.

Removal from the Register requires a Site Suitability Statement that the land is not contaminated land and is suitable for any reasonably foreseeable use. A Contaminated Land Investigation Document (CLID) is also required that establishes the land (where land also includes associated airspace or water):

- is not being used for a notifiable activity,
- is not affected by a hazardous contaminant, and
- has been subject to an appropriate assessment of site contamination in accordance with the risk-based process under *National Environment Protection (Assessment of Site Contamination) Measure Guidelines*.

The CLID must be completed by a Suitably Qualified Person and certified by an approved Auditor. The CLID is required to have regard to the requirements of the EP Act and the *Environmental Protection (Water) Policy* 2009 (as well as other relevant regulations and guidelines). The CLID presents site investigation outcomes, remedial objectives and actions, validation of clean-up efforts and a site management plan, if necessary, for any further work required to address residual or prevailing site conditions.

The Site Suitability Statement will be completed to certify that the land is suitable for the designated PMLU.

5.4. POST MINING MANAGEMENT REPORT

Any application to surrender the EA must include submission of a Post Mining Management Report. The Post Mining Management Report must be prepared by a suitably qualified and experienced person and certify that satisfies the requirements of section 111A of the EP Act, and specifically that:

- The land is safe and structurally stable,
- There is no environmental harm being caused by anything on or in the land, and
- The land can sustain the post mining land use.

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7. APPENDICES AND ATTACHMENTS

APPENDIX A: REHABILITATION MATERIAL SAMPLING PROGRAM
APPENDIX B: MINE CLOSURE WATER BALANCE ASSESSMENT
APPENDIX C: REHABILTATION AND REVEGETATION MILESTONE TECHNICAL MEMORANDUM
APPENDIX D: FLOOD ASSESSMENT
APPENDIX E: FINAL LANDFORM 3D MODEL
APPENDIX F: WRE CLOSURE CONCEPT DESIGN REOPRT
APPENDIX G: FINAL LANDFORM EROSION ASSESSMENT
APPENDIX H: CLOSURE GEOTECHNICAL STUDY
APPENDIX I: CLOSURE GROUNDWATER MODELLING REPORT
APPENDIX J: PRCP SCHEDULE

APPENDIX A REHABILITATION MATERIAL SAMPLING PROGRAM

Factual report

Phase 1 and Phase 2 – Rehabilitation material sampling and analysis program (RMSaAP) and material management

Lady Loretta Mine

Prepared for: **Glencore PLC**

MINE WASTE AND WATER MANAGEMENT

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Factual report

Phase 1 and Phase 2 – Rehabilitation material sampling and analysis program (RMSaAP) and material management

Lady Loretta Mine

Prepared for: **Glencore PLC**

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Executive Summary

RGS Environmental Consultants Pty Ltd (RGS) was commissioned by Glencore PLC on behalf of Noranda Pacific Pty Ltd to develop a Rehabilitation Material Sampling and Analysis Program (RMSaAP) to obtain measured data for potential rehabilitation materials for the Lady Loretta Mine (LLM) including the waste rock emplacement (WRE).

This RMSaAP report addresses requirements under the Progressive Rehabilitation and Closure Plan (PRCP) and Schedule E of the Environmental Authority (EA) EPML00982013.

The objectives of the RMSaAP completed for LLM include:

- collecting samples from test pits and drill holes in potential borrow areas at LLM
- obtaining measured soil quality, geochemical and physical properties for pedolith and saprolith and rock samples
- verifying if the pedolith and saprolith and rock samples are suitable for rehabilitation of areas disturbed by mining activities
- quantifying available material balances from potential borrow areas
- developing borrow area designs to support the PRCP.

The Phase 1 RMSaAP field work was completed in 2020 and included sampling and analysis of 31 samples obtained from Borrow Area A, B and C. Selected data from the Phase 1 Factual report (RGS, 2020) are included in this Phase 2 report.

The Phase 2 RMSaAP commenced in November 2021 and included:

- supplementary sampling and analysis to fill analytical data gaps from the Phase 1 RMSaAP,
- investigation of other potential borrow areas and additional reporting for the purposes of the PRCP.

The Phase 2 program consisted of 19 bulk samples from 5 test pits in Borrow Area B, 13 bulk samples from 3 test pits in Borrow Area V and 15 bulk samples from Borrow Areas I, T, and W. Two existing topsoil stockpiles also formed part of the Phase 2 RMSaAP with 7 samples collected and analysed.

The Phase 2 RMSaAP included soil quality, geochemical and physical analyses of topsoil (A horizon), subsoil (B horizon), saprolite and saprock (C horizon), and fresh rock units at LLM. Excavation of test pits were completed using a 35-tonne excavator to collect samples including intact but weathered saprock from the regolith. Analytical results for the Phase 1 and Phase 2 RMSaAP are compiled in a rehabilitation material database.

There are no constraints to using the material from the borrow areas for rehabilitation at LLM. Specifically all samples analysed are non-acid forming and present a low hazard of producing metalliferous drainage that would lead to non-compliance of water quality objectives in the receiving environment. The salinity and sodic potential of all material was quantified using multiple analytical methods. The data have verified that there are some units in some borrow areas with elevated salinity in the order of 5,000 µS/cm and exchangeable sodium percentages > 30%. However, samples classified with moderate or high exchangeable sodium percentage were also verified as having low dispersive potential or would flocculate and would therefore have a low potential for erosion. Mining, scheduling, and placement of all materials would be done to optimise the rehabilitation outcomes. This could include mixing saline, sodic and non-sodic materials together from different areas to achieve desired cover design criteria.

A conceptual stratigraphic model was constructed in Deswik.CAD from available test pit logs to quantify the area, potential volume, and mass of materials available from selected borrow sites. Borrow Area B1, B2, A, and C, are nominated as optional and preferred borrow sites based on their measured soil quality, geochemical and physical properties. Borrow Area I could provide half the required material balance for rocky soil mulch. The material balance from this borrow area could be increased by mixing growth media with it. Borrow Area I is adjacent to the run of mine pad and loading area and would not be available until the cessation of mining and processing. It is assumed that the top 0.5 m of this borrow area would be removed as used as fill.

The available material balance from the topsoil stockpiles and the borrow areas was then compared with the material requirements for rehabilitation to document if the total material balance for rehabilitation of the LLM was in deficit or surplus. Borrow Areas B1, B2 and A are individually sized to provide the required volumes for rehabilitation including additional surplus of growth media for rehabilitation of the borrow areas themselves (**Table A**). Borrow Area C is sized to provide the required blocky rock fill that would be used for rock armouring or lining drains.

Borrow Area B1 (5.2 ha), Borrow Area B2 (4.1 ha) and Borrow Area A (13.4 ha) are shallow open cut areas of disturbance that will provide the pedolith (topsoil: A horizon and subsoil: B horizon) and saprolith (saprolite and saprock: C horizon) units using free dig truck and shovel methods. Borrow Area I (4 ha) would be similarly excavated with the exception of topsoil (A horizon), which has already been stripped and a surface layer of 0.5 m which has been impacted by mining operations and will be removed (if required). These open cuts will have a maximum final internal bench height of < 10 m. After the required materials are recovered from these borrow areas, the internal batters will be graded to a 1:4 slope, ripped and seeded to support the required beneficial use. The floor of each borrow area will be covered with growth media, ripped, and seeded to support the required beneficial use.

Borrow Area C has 1.7 ha of disturbance and an additional 3.3 ha for a 50 m buffer around the borrow area to accommodate any required minor changes to the geometry of the borrow site based on field observations and to enable access and extraction of rock armour material. This borrow area is an open cut hard rock quarry that will require blasting, will have a final wall of 44 m and will be mined by truck and shovel methods to obtain fresh rock with lesser amounts of weathered saprolith. The hard rock from this quarry is proposed to be crushed, screened, and sized to achieve the required design criteria for rehabilitation. This borrow area will be designed so it can be left in a geotechnically stable condition. The physical composition of the exposed rock will make it non-erodible. Based on the available analyses this site will not contribute to adverse water quality. Vegetation is likely to colonise this quarry in the same way that vegetation has established on the slopes adjacent to the quarry site. The access road into the base of the quarry would be closed off to stop vehicular access.

Terminology used in this report, the required and available material balance from the defined Borrow Areas are in **Table A**.

Table A: Rehabilitation material balance volumes

LLM material terms	Geological strata	Soil horizon	Required volume (lcm) *	Available volume (lcm) **
Growth Medium	Pedolith	A and B horizons	28,990	42,000 – 123,000
Rocky Soil Mulch	Saprolith	C horizon	141,407	77,000 – 175,000
Blocky Rock Fill	Quartzite	Fresh rock – D horizon	120,850	321,000

Note:

- All quantities in LCM and have been rounded to the nearest 1,000m^3.
- *Required volumes include 10% contingency.
- **Available volumes are subject to selected borrow site (Borrow Area B1, B2, A or I).

Technical summary of the borrow areas

Evaluation of rehabilitation materials

Australian soil classification. The soils are mapped regionally as Sodosol and Rudosol soil orders. The regional classification is appropriate, and these soil orders are also appropriate at a local scale within the borrow areas. Our work has, however verified that saline and sodic classification requires the use of multiple chemical and physical analytical methods to verify how saline and sodic materials will perform.

Material suitability for rehabilitation. There are no constraints to using the material from the borrow areas for rehabilitation at LLM. Specifically all samples analysed are non-acid forming and present a low hazard of producing metalliferous drainage that would lead to non-compliance of water quality objectives in the receiving environment.

The salinity and sodic potential of all material was quantified using soil quality, geochemical and physical analytical methods. The data verify that there are some units in some borrow areas that are saline with electrical conductivity ($EC_{1:5}$) of > 5,000 µS/cm) and that also have exchangeable sodium percentages (ESP) of > 30%. This work has verified that ESP results cannot, in their own right, be used to determine if the soils are dispersive or could have erosive potential. For example, some samples have ESP values of 21 to 71% but are classified as Emerson Class as 3, 4C and 6, so are not dispersive. The need for gypsum to reduce the ESP is considered unlikely if the materials are selectively mined, mixed and placed for rehabilitation.

Mining, scheduling, and placement of all materials would be done during construction to optimise the rehabilitation outcomes. This could include mixing saline, sodic and non-sodic materials together from different areas to achieve desired engineering cover design criteria. Quartzite from Borrow Area C will provide competent and durable rock for armouring slopes or lining drains. Fertiliser is unlikely to be required if native species are selected for the revegetation. However, if the revegetation process includes using pasture species as an initial cover, that have a higher nutrient demand, then fertiliser would be required.

Preferred borrow areas

Borrow Area A (13.4 ha) is gently sloping with upper and lower elevations of 314.5 m and 307.5 m (RL) bounded by ephemeral drainage lines, covered with sparse native vegetation, located to the southwest of the mine. Test pits from Phase 1 works verify that soil depth was 0.6 to 1.3 m, with neutral to mildly alkaline $pH_{1:5}$ (6.13 to 8.72) very low electrical conductivity ($EC_{1:5}$) of 30 to 106 µS/cm and low exchangeable sodium percentages (ESP) of 0.1 to 1.4%. These samples had Emerson Class values of 2-3, classifying them with minor potential for dispersion. Soil, regolith and saprock units are extremely to partially weathered and NAF_{BARREN} (non-acid forming with < 0.2% total sulfur). Borrow Area A contains growth medium and rocky soil mulch (material comprising sand, silt, clay, and residual rock fragments from gravel to cobble size fractions). Borrow Area A has been nominated as an optional borrow site. A growth medium cover of 0.15 m comprising topsoil and subsoil will be ripped into the base of Borrow Area A before seeding to rehabilitate this site.

Borrow Area B1 (5.2 ha) is a smaller borrow area within Borrow Area B that was evaluated in Phase 1 with test pits and shallow drill holes developed to 9.2 m bgl. Partially weathered claystone and siltstone saprock identified in Phase 1 drill holes would be suitable as rocky soil mulch or even competent rock.

Borrow Area B1 is gently sloping with upper and lower elevations of 319.5 m and 309 m (RL). When Borrow Area B1 is developed it would have a maximum 1:4 batter with a height of approximately 7 m. It is located to the southwest of the camp is undisturbed and sparsely covered in native vegetation.

Test pits within or immediately south of Borrow Area B1 (from both Phase 1 and Phase 2) verify that soil thickness is 0.4 to 2.8 m. Borrow area B1 has some test pits that are saline/sodic in both topsoil and subsoil and some that are non-sodic/non-saline in both the topsoil and subsoil. Topsoil and subsoil have $pH_{1:5}$ 5.9 to 9.1 and the $EC_{1:5}$ is highly variable.

Phase 2 test pits 5 and 6 are at a lower elevation (310 m RL) in the borrow area adjacent to the ephemeral drainage lines and have higher $EC_{1:5}$ of 850 to 5,410 µS/cm with an average of 2,638 µS/cm and exchangeable sodium percentage (ESP) values of 54 to 73%. Test pits 1 to 4 and 7 are at higher elevations in the borrow area and have lower $EC_{1:5}$ of 22 to 4,000 µS/cm with an average of 1,320 µS/cm and lower exchangeable sodium percentage (ESP) values of 0.1 to 45% with an average of 15.4%. As discussed above there are no

clear relationships between ESP and Emerson Classes and ESP values are contradictory and cannot be used to infer that materials will be sodic and have poor engineering properties.

Moderately weathered saprolite encountered in Phase 2 test pits could be used as rocky soil mulch for the WRE cover. Borrow Area B1 growth medium does not require fertiliser or ameliorants and could be supplemented by the topsoil stockpiles and other competent rock to provide an adequate volume of suitable materials for site rehabilitation. Borrow Area B1 has been nominated as an optional borrow site. A growth medium cover of 0.15 m comprising topsoil and subsoil will be ripped into the base of Borrow Area B1 to rehabilitate this site.

Borrow Area B2 (4.1 ha) is located to the southwest of the LLM airstrip. This site is gently sloping mound with an upper and lower elevation of 331 m and 317.6 m (RL), is undisturbed and sparsely covered in native vegetation. Because this borrow area is removing a small mound the internal batters (if present) would be less than 1 m in height. No test pits have been developed within Borrow Area B2, however based on proximity to existing test pits from the Phase 1 and Phase 2 RMSaAP, similar results are expected, and this assumption will be confirmed as part of the forward works program. Borrow Area B2 has been nominated as an optional borrow site. A growth medium cover of 0.15 m comprising topsoil and subsoil will be ripped into the base of Borrow Area B2 to rehabilitate this site.

Borrow Area C (1.7 ha of proposed activity) is on a quartzite spur with an upper and lower elevation of 370.8 m and 332.0 m (RL), and is the preferred source of competent fresh rock that can be blasted and sized to provide rock for surface armouring of the waste rock emplacement (WRE) and the construction of surface water drains. There is an allowance for a 50 m buffer around Borrow Area C that is being included to accommodate any required minor changes to the geometry adding 3.3 ha to this site.

A thin (~1 m) layer of gravelly soil overlies the quartzite and is suitable to supplement other growth medium sources with the following characteristics: $pH_{1:5}$ (4.5 to 6.2), $EC_{1:5}$ (12 to 94 µS/cm), NAPP -1.8 to 0.4 H_2SO_4/t classifying them as non-acid forming (NAF), bulk density (1.6 to 1.8 t/m^3). The quartzite has a point load strength (Is(50)) (7.27 Mpa). Borrow Area C would be excavated in a small open cut quarry developed into the spur and will require blasting. The landform will be retained as a safe, stable, and non-polluting quarry with opportunistic, successional development of vegetation proposed for the final land use.

Optional borrow areas

Borrow Area I (4 ha) is an electrical laydown area located to the northeast of the mine area. This site is gently sloping with an upper and lower elevation of 338.8 m and 329.5 m (RL). The area is disturbed by mining, and the original topsoil has been stripped and transported to a stockpile. The underlying soil profile is still relatively thick and contains both topsoil and subsoil units, as well as saprolite. Borrow Area I has a mildly acidic to mildly neutral $pH_{1:5}$ (4.7 to 8.0), with variable $EC_{1:5}$ 423 to 2,790 µS/cm. Saprolite units are NAF_{BARREN} with low to moderate buffering capacity. Topsoil units contain sufficient sulfide sulfur (0.2%) to produce acid, but also enough ANC ((8.7 kg H_2SO_4/t) to be classified as NAF. The Phase 2 test pit has verified that the soil thickness is 2 m, and deeper material is highly weathered saprolite with a high proportion of fine particles (55-84%). Borrow Area I provides half the required material volume of rocky soil mulch, however substituted with growth media found within Borrow Area I it would yield 139,856 loose cubic metres (lcm) of rehabilitation material. When Borrow Area I is combined with the topsoil stockpiles it would meet the required material balance. Borrow Area I is adjacent to the run of mine pad and loading area and would not be available until the cessation of mining and processing. It is assumed that the top 0.5 m of this borrow area would be removed as used as fill. Borrow Area I whilst selected as an optional borrow site, is not preferred due to unavailability of material during mining operations.

Excluded borrow areas

Borrow Area W is located on the side of a hill west of the WRE and is undisturbed and covered in sparse native vegetation. The soil profile is thin on the slopes (0.3 m) but thickens to 1.3 m approaching the base of the hill. Subsoil is limited or absent, and gravelly topsoil (colluvium) often overlies weathered saprolite in rapid transition. Borrow Area W is mildly acidic to neutral $pH_{1:5}$ (4.7 to 8.3), with low $EC_{1:5}$ 48 to 506 µS/cm. Soil and saprolite units are NAF_{BARREN} with low buffering capacity. Topsoils contain a high proportion of gravel (51-62%) and the saprolite has high point load strength and is moderately strong compared to other borrow areas. Borrow Area W could provide a source of growth medium or rocky soil mulch, however, has not been nominated as a borrow area as it provides a smaller quantity of suitable rehabilitation materials.

Borrow Area T is a truck turnaround located to the south of the mine area. The area is disturbed, and the topsoil (thickness unknown) has been stripped and placed in bunds surrounding the area. New topsoil has begun to form through pedogenesis and is approximately 0.1 m. Borrow Area T has a neutral $pH_{1:5}$ (6.1 to 8.1), with variable $EC_{1:5}$ 74 to 2040 µS/cm. Saprolite units are NAF_{BARREN} with moderate buffering capacity. Topsoil units contain sufficient sulfide sulfur (0.12%) to produce acid, but also enough acid neutralising capacity (ANC) (16.1 kg H_2SO_4/t) to produce pH neutral runoff and are classified as NAF. Topsoil from the bunds has 32% gravel and subsoil is limited or absent. Saprolite is moderately weathered and moderately weak. Borrow Area T could provide a source of growth medium or rocky soil mulch, however it has not been nominated as a borrow area due to the thin soil profile. Topsoil from the bunds will be used as a growth medium to rehabilitate the disturbance after closure.

Borrow Area V is located to the west of the accommodation camp, is gently sloping with an upper and lower elevation of 313 m and 309 m (RL), is undisturbed, and covered with sparse native vegetation. Test pits verify that combined topsoil and subsoil depth is 0.4 to 1.1 m, with $pH_{1:5}$ 5.3 to 9.0 and $EC_{1:5}$ of 18 to 5,510 µS/cm. Borrow area V has some test pits that are saline/sodic in both topsoil and subsoil and some that are non-sodic/non-saline in both the topsoil and subsoil. The topsoil EC is 45 to 5,510 µS/cm and the subsoil is 2,540 to 3,190 µS/cm. These samples had Emerson Class values of 1-4, classifying some with minor potential for dispersion, but most samples have a low potential for dispersion. Soil and saprolite units are extremely to partially weathered and NAF_{BARREN} (non-acid forming with < 0.2% total sulfur). Borrow Area V contains low permeability clay, growth medium and rocky soil mulch (material comprising sand, silt clay and residual rock fragments from gravel to cobble size fractions). Borrow Area V has not been nominated as an optional borrow site.

Topsoil stockpile characterisation

There are two existing topsoil stockpiles, located south of Containment Dam A (CDA) (6 ha) and SW of the WRE (0.6 ha) assessed in Phase 2. The soils have low salinity (36 to 451 µS/cm), are non-sodic (ESP 0.1 to 5%) and non-dispersive (Class 2A and 3C), have good aggregate stability and are high in organic matter compared to other borrow material soils. They are optimal for mine soils in terms of providing nutrients for vegetation plant growth and have a low risk of leaching soluble metal(loids). The topsoil stockpile soils contain more gravel and less clay than Borrow Area B1 and immediate surrounds. Based on the samples obtained, the topsoil supports native vegetation and ameliorants and fertilisers are not required. The topsoil stockpiles are fit for the intended purpose as a source of growth medium and provide 42,448m^3 loose cubic metres (lcm) of soil for the material balance. The soil and rock materials from the optional borrow areas support native vegetation and are suitable as rehabilitation materials. The nutrient, geochemical and physical properties of the borrow areas characterised in Phase 2 provide concentrations that can be used as reference points for derivation of rehabilitation criteria.

Material balance

Borrow Areas C, B1, B2 and A are preferred over Borrow Areas V, W, T and I as they provide a larger quantity and wider range of rehabilitation materials. Borrow Area B1, B2 and A are in the upper area of the catchment, are bounded by roads enabling good access, and have deep soil profiles that support native vegetation.

The method of development in the optional borrow areas (Borrow Areas B1, B2, A, and I) would be to cut into the borrow area from the lowest topographic point at 1 % so the borrow area remains self-draining to existing ephemeral drainage lines. Borrow Area C will provide the remaining source of fresh, competent rock for surface armouring and will be developed as a small quarry with a final wall of 44 m. Sedimentary saprock screened from Borrow Area B1, (and assumed present in B2, A, and I) can also be used as a source of competent rock, if required, but the measured data verify its long-term durability will be less than the quartzite in Borrow Area C.

Material balance calculations verify that a sufficient volume of rehabilitation materials can be sourced from the topsoil stockpiles, combined with Borrow Areas B1, B2, A, I, and C. No additional borrow areas are required and a surplus of material is available based on site rehabilitation requirements. None of the Borrow Areas B1, B2, A, I, or C would suffice on their own, based on the current footprint geometry documented in this report. Existing roads can be utilised to access the borrow areas, but diversion drains will need to be installed within the excavated borrow pits to reduce ponding. Haulage distances between the borrow areas and the WRE have been considered in this assessment, but optimisation of the land haulage schedule could occur once a detailed cover design has been developed.

Forward works

The RMSaAP Phase 1 and Phase 2 work program has confirmed that there are sufficient materials within Borrow Areas B1, B2, A, and C suitable to rehabilitate the WRE and other areas of LLM. Borrow Area I has been nominated as the preferred borrow site within existing disturbances.

No further works are required to address PRCP requirements.

Prior to construction and development of the borrow areas infill sampling and analysis would be beneficial. The main purpose of the infill sampling and analysis would be to identify saline and sodic zones so these units can be mixed with low saline and sodic units to optimise material properties for construction and rehabilitation.

Where deemed necessary, a detailed landform haulage schedule model could be developed to optimise the borrow material dig plan to minimise stockpile volumes and rehandle. Should such a model be developed, this should be integrated with the construction plan for the WRE.

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Glossary of Terms and Acronyms

ALS	Australian Laboratory Services Pty Ltd
AMD	Acid, saline, and metalliferous drainage
ANC	Acid neutralising capacity
BCM	Bank cubic metres
DTPA	Diethylenetriamine Penta acetic acid
EA	Environmental Authority
EC	Electrical Conductivity, expressed as µS/cm, is a measure of electrical conductance.
ESP	Exchangeable sodium percentage
GIS	Geographic Information Systems
LCM	Loose cubic metres
LLM	Lady Loretta Mine
LMD	Leachate Management Dam
LoR	Limit of reporting – equivalent to a detection limit
ML	Mining Lease
MPA	Maximum potential acid
NAF	Non-acid forming
NAPP	Net acid production potential
NPR	Neutralisation potential ratio
PAF	Potentially acid forming
pH	Measure of the hydrogen ion (H+) activity in a sample solution, expressed in pH units.
PMLUP	Post Mine Land Use Plan
PRCP	Progressive Rehabilitation and Closure Plan
PSD	Particle size distribution of a sample material measured by hydrometer.
RMSaAP	Rehabilitation materials sampling and analysis plan
Sodic	Sodic soil and rock materials are characterised by a disproportionately high concentration of sodium (Na) in their cation exchange complex and are innately unstable, exhibiting poor physical and chemical properties, which impede water infiltration, water availability, and plant growth.
SWCC	Soil water characteristic curves
TOC	Total organic carbon
TOM	Total organic mater
WRE	Waste rock emplacement
XRF	X-Ray Fluorescence – a type of spectrometry using the XMET 7500 Mining Analyser

1 Requirement for the work program

RGS Environmental Consultants Pty Ltd (RGS) was contracted by Glencore PLC on behalf of Noranda Pacific Pty Ltd to develop a Rehabilitation Materials Sampling and Analysis Program (RMSaAP) for the Lady Loretta Mine (LLM) to address Schedule E of the Environmental Authority (EA) EPML00982013 and the requirements for a Progressive Rehabilitation and Closure Plan (PRC Plan). The Phase 1 RMSaAP commenced in 2020 and included 31 samples from Borrow Area A, B and C. A desktop review of existing geochemical (XRF) and geological background information, as well as a risk and opportunity register were completed in the Phase 1 RMSaAP. Outcomes from the Phase 1 RMSaAP were used to inform the Phase 2 work program. The Phase 2 RMSaAP commenced in November 2021 and included supplementary test pits to investigate other potential borrow areas and provide confirmation and certainty to existing data obtained in Phase 1. Phase 2 included 19 bulk samples from 5 test pits to provide additional information in Borrow Area B, and 13 bulk samples from 3 test pits in Borrow Area V. Samples (n=15) were also collected and analysed from Borrow Area I, T, and W to determine suitability as borrow material.

1.1 Background information

LLM is an operational underground zinc, lead, and silver mine on Mining Lease (ML) 5568 and is 140km North-north-west of Mount Isa in North-West Queensland. The LLM lease covers an area of 2,780 ha and is adjacent to the Lady Annie open cut Copper Mine (ML90179). The mine and associated infrastructure are contract operated by Redpath Mining Australia. Potentially acid forming (PAF) material is placed in the waste rock emplacement (WRE). A second, smaller PAF waste rock stockpile adjacent to the leachate management dam (LMD) was created during exploration phases in 1986 – 1987 and has recently been relocated to the main WRE. There are two topsoil stockpiles (denoted WRE and CDA) located adjacent to containment dams which are intended for rehabilitation purposes. Mine infrastructure areas include paste plant and batch plant, crusher pad, workshop, exploration chemical storage area, several laydown areas, and various other utilities.

1.2 Quality, standards, regulation, legislation, and guidelines

LLM require the deliverables for this project to comply with applicable legislation, regulation, guidelines, standards, and best industry practice and be of high quality. RGS has undertaken this work in accordance with applicable legislation, regulation, guidelines, and standards. In Queensland this includes the following.

- Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).The Mineral Resources and Energy (Financial Provisioning) Act 2018 amended the Environmental Protection Act 1994 and the Environmental Protection (Rehabilitation Reform) Amendment Regulation 2019 implements key elements of the Mined Land Rehabilitation Policy. This includes introducing the new requirements for a Progressive Rehabilitation and Closure Plan (PRC plan) and progressive rehabilitation and closure plan guideline ESR/2019/4964 • Version 2.00 • Last reviewed: 17 MAR 2021.
- DES (2020) Department of Environment and Science. Residual Risk Assessment Guideline - Interim ESR/2020/5433 • Version 1.00 • Effective: 2 OCTOBER 2020.

Other Commonwealth and International requirements may include the following.

- Global Acid Rock Drainage (GARD) Guide (INAP, 2020);
- Commonwealth of Australia Leading Practice Sustainable Development Program (LPSDP) for the Mining Industry: Preventing Acid and Metalliferous Drainage (COA, 2016)
- Australian and New Zealand Water Quality Guidelines 2018 that supersede the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) (ANZECC).
- Commonwealth of Australia Leading Practice Sustainable Development Program (LPSDP) for the Mining Industry: Rehabilitation (2016).
- This RMSaAP conforms with Australian guidelines that are used in the mining and agricultural sectors (Hazelton and Murphy, 2016, Isbell, 2016, MacDonald et. al., 1998).

1.3 Purpose

The RMSaAP outputs will be used to support the LLM PRCP to assist in the development of a financially viable and environmentally sustainable rehabilitation outcome for LLM.

The PRCP schedule must demonstrate that the land can be rehabilitated to a stable condition that does not cause environmental harm and can sustain a post mine land use. The PRCP requirements for a soil assessment must identify and characterise the following.

- Quality and quantity of available resources (such as topsoil, clay material and competent rock) required to complete the target rehabilitation methodology
- Location (i.e. with respect to haul distance) and accessibility of cover material
- Assessment to determine the need for ameliorants and fertilisers
- Relationship between soils and vegetation ecosystems for the rehabilitation methodology.

The Phase 2 RMSaAP supports the PRCP requirements and work in Phase 1 and verifies (i) the materials are suitable for rehabilitation of the LLM domains, (ii) have appropriate soil fertility, geochemical and physical properties and (iii) the material balance will provide enough material for complete rehabilitation.

1.4 Objectives

The Phase 2 RMSaAP objectives include the following tasks.

- Identify test pit locations at Borrow Areas V, B, W, T, and I and the topsoil stockpiles
- Develop and then implement a soil fertility, and geochemical and physical sampling and analytical program (GaPSaAP)
- Compile data into the existing Phase 1 rehabilitation materials database ($RM_{DATABASE}$)
- Produce geological cross sections to supplement the Phase 1 $RM_{GEOMODEL}$
- Update the LLM rehabilitation material balance to document if there is a material deficit or surplus
- Produce forwards work plans
- Produce this factual report.

This RMSaAP has utilised available data and measured results for sampled geological units to document material specifications. The report identifies potential uses for each material type e.g., Saprolite may be classified as NAF material that could be suitable for rocky soil mulch. Rehabilitation material types are defined in **Attachment B (Table 7-1).**

1.5 Rehabilitation goals and objectives

In accordance with PRCP requirements land must be rehabilitated to a stable condition. Stable condition is defined under Section 111A of the EP Act as follows.

- The land is safe and structurally stable.
- There is no environmental harm being caused by anything on or in the land.
- The land can sustain the post mining land use.

LLM closure objectives have been developed by Glencore in the PRCP (**Table 1-1)**.

Table 1-1: Rehabilitation goals and objectives at LLM based on the PRCP

Rehabilitation Objective	Element	Design Intention	Measure
Physically Stable	Slope Stability	• ANCOLD Guideline	• Numerical analysis (Stability analysis)
	Consolidation Settlement and Subsidence	• ANCOLD • No ponding of water • Surface subsidence does not exceed 500 mm	• Direct measurement (Survey)
	Erosion	• Long term containment of waste	• Numerical Analysis (Landform evolution modelling) • Direct observation (Photography, survey)
Chemically Stable	Water Flux Through Waste	• Oxidation products (salt, acid) remain contained within the waste mass	• Numerical Analysis (Soil moisture modelling) • Direct measurement (Arrayed soil moisture and matric suction sensors)
	Capillary Rise	• Oxidation products (salt, acid) remain contained • Waste not subject to cyclic wetting and drying	• Numerical Analysis (Soil moisture modelling) • Direct observation (Photography)
	Receiving Environment Surface Waters and Stream Sediment	• Compliance with Conditions of EA (Schedule C)	• Direct measurement (surface water quality and sediment quality) • Receiving Environment Monitoring Program
	Local Groundwater	• No deleterious impacts to groundwater	• Direct measurement (Groundwater quality)
Supports a Viable Vegetation Community	Viable Vegetation	• Suitable diversity • Capable of reproduction • Soil development	• Direct and Indirect measurement (Ecosystem Function Analysis)
	Absence of Declared Weeds	• Legal obligation	• Direct observation (Photography)
	Resilience to Stressors	• Resilience through drought / fire /flood / overgrazing	• Direct and Indirect measurement (Ecosystem Function Analysis)

1.6 Geology

The surface geology within ML5568 contains Cambrian and Proterozoic geological units including dolomite, sandstone, siltstone, and quartzite. The Lady Loretta Formation is the predominant outcrop and is overlain by Mesozoic and Quaternary sedimentary sequences. The targeted ore mineralisation is hosted within the Lady Loretta Formation at the crux of a major syncline that is complicated by major and minor faults. The Lady Loretta deposit is considered a classic sedimentary exhalative sediment hosted Pb-Zn deposit. The primary sulfides consist essentially of massive, banded pyrite, sphalerite, and galena. A pyritic unit underlies the ore bearing layer, and the oxidation of reduced ore minerals has potential to generate acid if not managed correctly.

The stratigraphic sequence of LLM geology is shown in **Figure 1-1** (based on AGE, 2020; Large and McGoldrick, 1998). Mesozoic and Quaternary sedimentary sequences are most likely to be encountered in the borrow pit and rehabilitation materials investigation. These relatively young rocks are thin and somewhat

variable in lithology but widespread. The weathered sandstone and siltstone encountered in Borrow Area A and B is slightly to moderately weathered and will be suitable as a rocky soil mulch. Quartzite in Borrow Area C and dolomitic siltstone and sandstone in the Upper RoM are less weathered and are potentially suitable as competent rock for surface armouring.

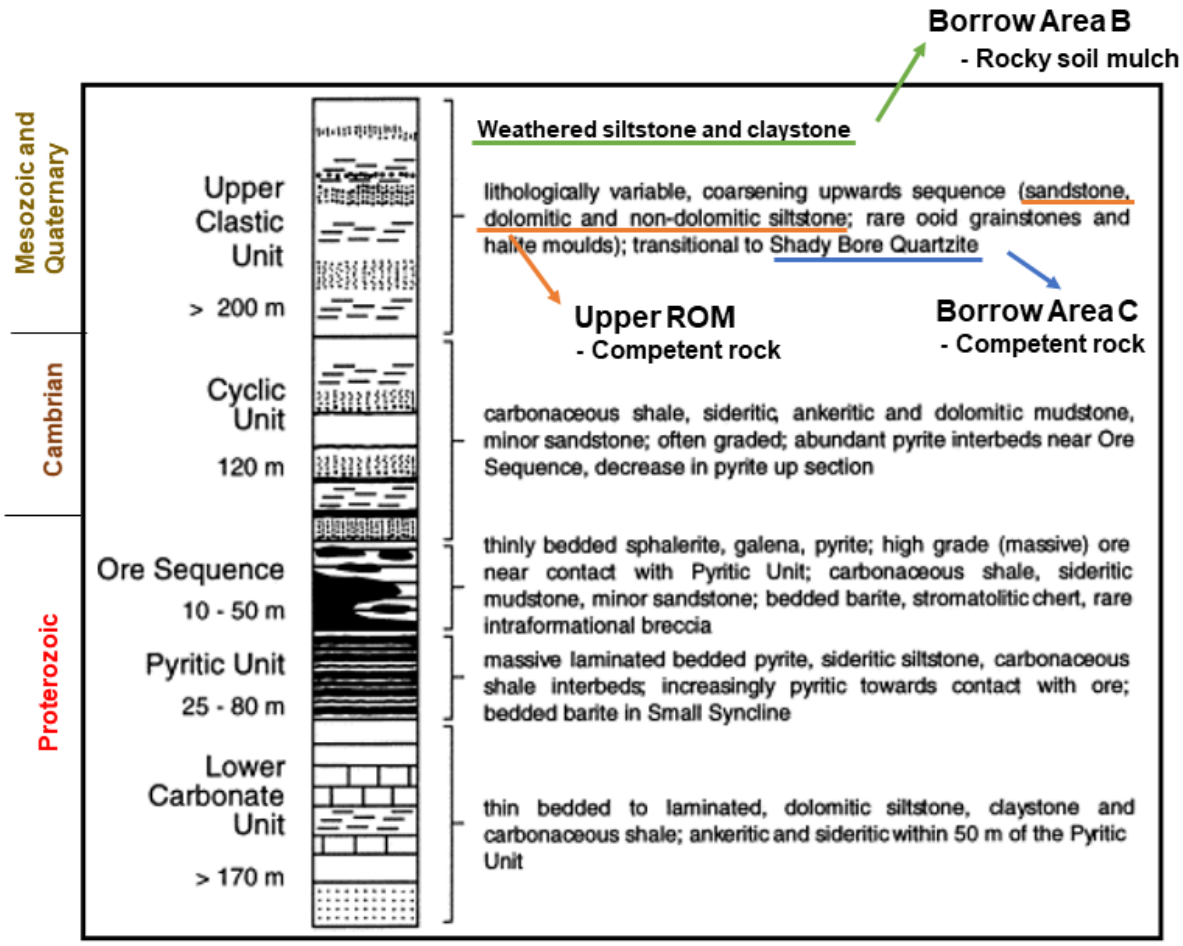


Figure 1-1: Stratigraphic sequence of the Lady Loretta Formation

1.7 Soil orders

Using the regional Australian Soil Classification, RGS identified two soil types present within ML 5568 (**Table 1-2** and **Figure 1-2)**. Rudosols are present in the area shaded in lime green, while the remaining surrounding areas shaded red are sodosols. Both of these soil types are capable of supporting local vegetation communities. Sodosols are present in Borrow Area A and Borrow Area B, while rudosols are present in Borrow Area C. Soil types of D, E, and F are provided for reference (**Table 1-2** and **Figure 1-2)**.

Table 1-2: Detailed descriptions of soil units at LLM

Borrow Areas	Landscape and topography	Detailed soil deCRSiption
C and E	Rudosol – has rudimentary soil development	High sandstone plateaux with prominent cliffs and steep rocky slopes, much dissected at the margins. Rock outcrop is very common, and all soils have much gravel throughout the profile: dominant soils are very shallow gravelly sands (Uc1.23).
A, B, D, and F	Sodosol – soil influenced by sodium	Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)

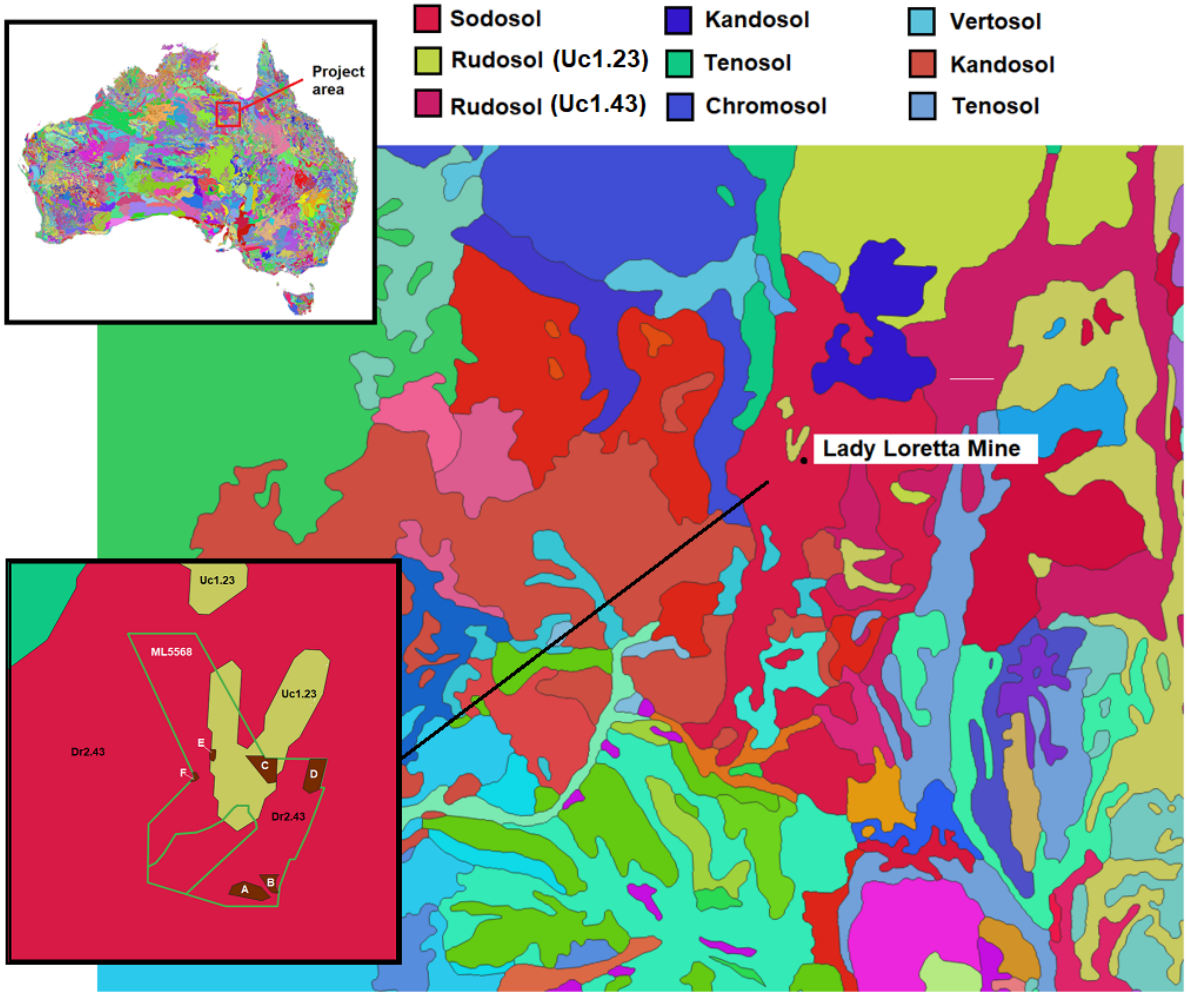


Figure 1-2: Regional soil classifications at LLM

2 Sampling and analytical program

2.1 Borrow areas

The nominal extent of all borrow areas sampled and analysed in Phase 1 and Phase 2 are in **Figure 2-1**.The revised Borrow Area B1 footprint includes a minimum 70 m buffer from the un-named drainage line running along the western side of the borrow area that runs into Desert Creek (EA, monitoring point SW08) and a 25 m buffer that aligns with the road to the east. All other borrow area maintain a minimum of a 50 m buffer from adjacent drainage lines, tributaries and creeks: A – 50 buffer, B2 – 100 m buffer and C – 70 m buffer. The final design for the optional borrow areas has included offsets from haul roads and necessary offsets from any adjacent drainage lines based on technical guidance. The borrow areas have sufficient material balances to accommodate changes in the WRE design.

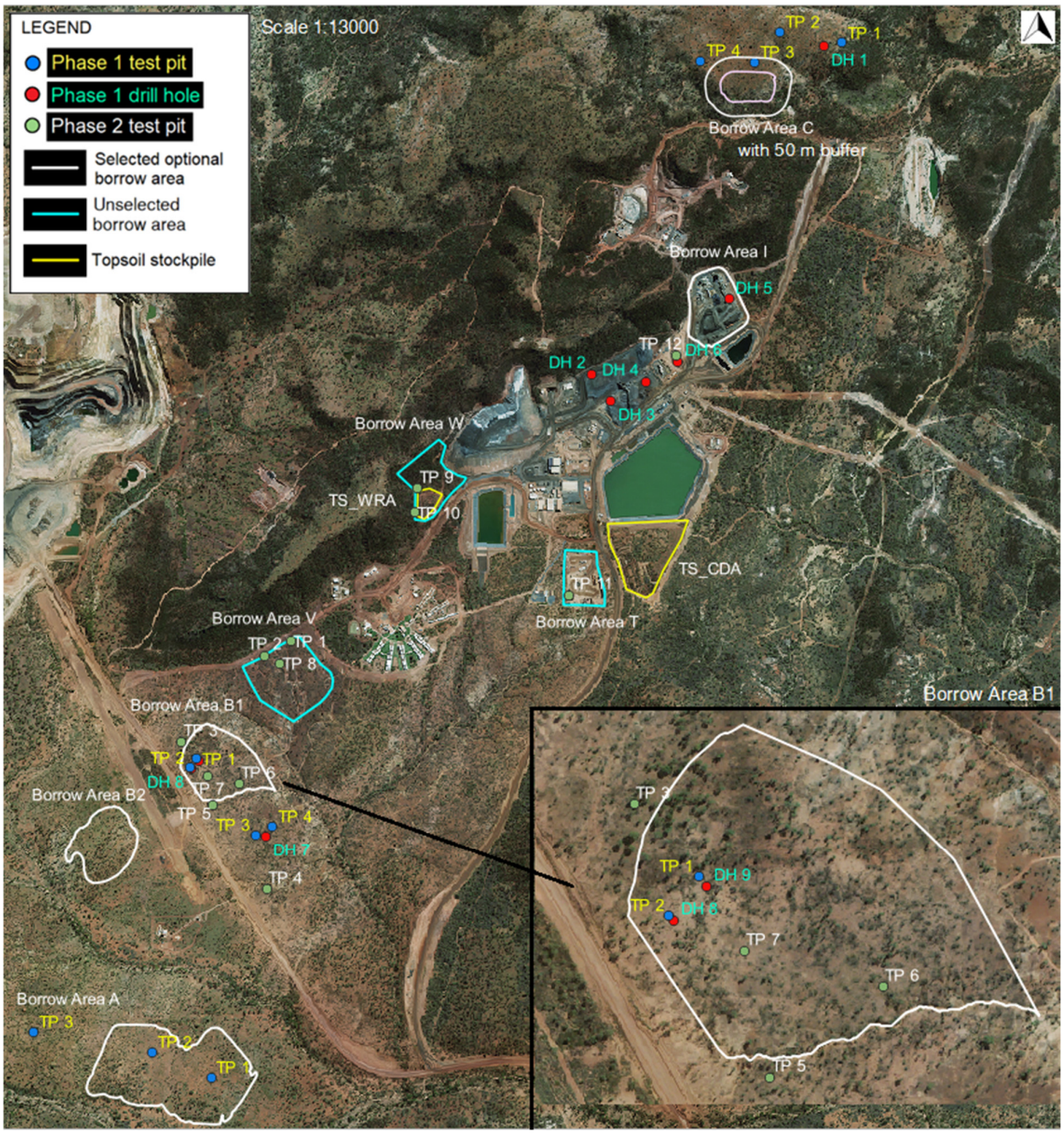


Figure 2-1: Test pit and topsoil stockpile sampling locations

2.2 Sampling program

At each test pit location and in each pedolith or saprolith zone approximately 15 kg of material was collected for each sample. The method of test pitting is outlined in **Attachment A: Test pit method**.

At each test pit site, soil or saprolite type, appearance, particle size, strength, density (from in-situ cores), and horizon thickness were entered into test pit logs **(Attachment C: Test pit logs)**.

Seven topsoil stockpile samples were collected from topsoil stockpile "WRE" located to the southwest of the waste rock emplacement and topsoil stockpile "CDA" located to the south of containment dam A. Approximately 15 kg of material was collected from each topsoil stockpile sampling location from a depth of 0.2 m. The test pit codes, location, depth and the number of samples obtained in each test pit are in **Table 2-1** and topsoil stockpile data are in **Table 2-2**.

Table 2-1: Phase 1 and Phase 2 test pit locations and samples (Projection: MGA Zone 54; GDA 94)

Borrow Area	Test pit number	Easting	Northing	Total depth	Number of samples
V	1	296313.7	7811480	4.6 m	6
V	2	296228.6	7811429	1.6 m	3
B	3	295958.6	7811125	3.3 m	3
B	4	296244.5	7810611	3.1 m	4
B	5	296064.8	7810906	2.7 m	5
B	6	296150.3	7810980	3.2 m	4
B	7	296043.9	7811007	1.5 m	3
V	8	296279.3	7811403	3.3 m	4
W	9	296727.6	7812018	2.5 m	3
W	10	296718.7	7811934	2.2 m	3
T	11	297232.8	7811653	1.3 m	3
I	12	297576.7	7812491	4.1 m	6
				TOTAL	**47**

Table 2-2: Topsoil stockpile locations and samples (Projection: MGA Zone 54; GDA 94)

Topsoil Stockpile	Sample number	Easting	Northing	Total depth	Number of samples
WRE	TS1	296778	7811974	0.2 m	1
WRE	TS2	296758	7811936	0.2 m	1
CDA	TS1	297578	7811881	0.2 m	1
CDA	TS2	297564	7811858	0.2 m	1
CDA	TS3	297552	7811812	0.2 m	1
CDA	TS4	297447	7811716	0.2 m	1
CDA	TS5	297500	7811725	0.2 m	1
				TOTAL	**7**

Table 2-3 provides a summary of all sample numbers and their lithologies collected by RGS in Nov 2021. Material types and their correlating soil horizons are in

Table 2-4. Detailed descriptions of rehabilitation units and terms are in **Attachment B** (**Table 7-1)**.

Table 2-3: Sampling program summary for Phase 2 RMSaAP

Sample description	Lithology	Number of samples
Test pit samples	Topsoil, subsoil, and saprolite	47
Topsoil stockpile samples	Topsoil	7
	TOTAL	**54**

Table 2-4: Summary of material types

LLM material terms	Geological strata	Lithology	Soil horizon
Growth Medium	Pedolith	Topsoil and subsoil	A and B horizons
Rocky Soil Mulch	Saprolith	Saprolite	C horizon
Rock Armouring	Saprolith and parent rock	Saprock and bedrock	D and R horizons

2.3 Analytical program

Soil fertility and geochemical analyses were conducted by ALS Environmental and ALS Minerals, Brisbane. Physical analyses were conducted by Trilab, Brisbane. ALS and Trilab are NATA accredited laboratories. Soil water characteristic curves (SWCC) were completed by the Soil Water Group, in Perth as a sub-contractor to Trilab. The suite of static geochemical and physical analysis and sample numbers are in **Table 2-5.**

Static geochemical tests are done to quantify the bulk chemical attributes of materials for parameters such as the hydrogen ion concentration (pH), total sulfur (TS), sulfide sulfur measured using the chromium reducible sulfur (CRS) method, acid neutralising capacity (ANC) and total or water-soluble elemental content. This helps to evaluate the potential for acid, neutral, alkaline, metalliferous, and saline drainage (collectively referred to as AMD) to determine the risks and opportunities for their use in rehabilitation.

Physical analyses determine geotechnical properties of the materials and can be used to interpret changes in geochemical behaviour over time, e.g., changes in permeability due to weathering. The susceptibility of rocks to degradation impacts their suitability as rehabilitation materials.

Table 2-5: Analysis program for Phase 2 test pit and topsoil stockpile samples. Similar methods were used in Phase 1 (RGS, 2020)

Soil fertility analyses	ALS Code	Method Code	Number of analyses
Drying at low temperature 40ºC	EN020-D40		54
Moisture content	EA055		54
Crushing to -2 mm	EN84		18
pH and EC (1:5)	AG-1	APHA 4500 H+ - B and APHA 2510 B	0
Exchangeable Cations (Ca, Mg, Na, K) plus ECEC & ESP on Alkaline Soils (pH > 7.3)		Soil Survey Test Method C5	0
Exchangeable Cations (Ca, Mg, Na, K) plus ECEC & ESP on Soils (pH < 7.3 and EC <300µm) NOTE: If pH < 6.0 ECEC includes ED005 - Exchange Acidity (includes Exchangeable Aluminium)		Rayment & Lyons 2011 15A1ED005: Rayment & Lyons 2011 15G10.1	0
Exchangeable Cations (Ca, Mg, Na, K) plus ECEC & ESP with pre-treatment on Soils (pH <7.3 and EC >300µm) NOTE: If pH < 6.0 ECEC includes ED005 - Exchange Acidity (includes Exchangeable		Rayment & Lyons 2011 15A1 ED005 - Rayment & Lyons 2011 15G1	0
AG-1 + NT8S Nutrients (TN, TP, TKN, NO_2, NO_3, NH_3 and NO_x)	AG-2	APHA 4500-NH_3 B, APHA 4500 NO_3- B, APHA 4500 NO_3- – I/NO_2- -B, Thermo Scientific Method D08727 and NEMI: 9171, APHA 4500 Norg – D	0
AG-2 + Chloride (1:5), pH ($CaCl_2$) Colwell P and K, DTPA extractable Fe, Cu, Zn and Mn, Organic Matter and Organic Carbon by Walkley Black	AG-3	APHA 4500-NH_3 B, APHA 4500 NO_3- B, APHA 4500 NO_3- – I/NO_2- -B, Thermo Scientific Method D08727 and NEMI: 9171, APHA 4500 Norg – D	54
Static geochemical analyses	**ALS Code**	**Method Code**	**Number of analyses**
NAPP (includes ANC, Total S)	ASS1	III. Coastech Research (Canada)	19
Major, minor and trace elemental analysis (Total) (48 elements)	ME-MS41 - 2 acid aqua regia digest		24
Fluoride (Total)	EK040T	EK040T In-house Fusion	23
Shale Flask Extraction 1:3 and 16 hr leach for water soluble elements	**ALS Code**	**Method Code**	**Number of analyses**
Leach method	EN35		22
pH and EC (1:3)	IN-4S	APHA 4500 H+ - B and APHA 2510 B	22
Acidity as CaCO3 only	ED038P $CaCO_3$	APHA 2310 B	22
Cations - Dissolved: Calcium, Magnesium, Sodium, Potassium	NT-01	APHA 3120B, APHA 3125B	22
Anions: Major (Cl, SO_4, Alkalinity), Fluoride	NT-02A	APHA 3120B, APHA 3125B	22
Trace metals by ICP/MS (including digestion)	EG020F (ME-02)	USEPA 6020 ICP/MS	22
Reactive Phosphorus as P by discrete analyser	EK071G	APHA 4500 P – F	0
Dissolved Mercury	EG035F	APHA 3112 Hg-B CV/FIMS	0
Physical Parameter (Trilab Brisbane)	**Code**	**Method Code**	**Number of analyses**
Sample Preparation (drying)	Based on method		1
Grading - Coarse (75mm to 0.075mm)	Based on method	AS 1289.3.6.1	9
Grading with Hydrometer (includes Particle Density)	Based on method	AS 1289.3.6.1 , AS 1289.3.6.3	15
Sample compositing, crushing and sieving -2 mm (Trilab/RGS)	Based on method		24
Atterberg Limits - Standard Oven Preparation	Based on method		11
Soaked California Bearing Ratio (CBR) - includes Standard MDD	Based on method		8
Permeability (falling head) - includes MDD Standard 90%	Based on method		15
Permeability additional remoulding ratio 95% (Compaction Curve)	Based on method		15
Emerson Class No.	Based on method	AS1289.3.8.1	54
Point Load - Either axial, diametral or irregular lump	Based on method		23
Los Angeles value (strength and durability of rock)	Based on method		1
SWCC Testing (Soil Water Group)	**Code**	**Method Code**	**Number of analyses**
Soil Water Characteristic Curve (10 Point)	Based on method		24

3 Results and interpretation

This section of the report includes the interpretative results for Phase 1 and Phase 2. The complete details for Phase 1 are in RGS (2020).

The Phase 1 and Phase 2 material specifications for the topsoil and subsoil comprising the growth medium and the rocky soil mulch within the saprolith are in **Section 3.3**. The material specifications provide laboratory measured data for samples that have been prepared in accordance with required laboratory standards. For example permeability measured with falling head tests use samples that have been crushed to pass a 19 mm sieve, whereas the particle size distribution of the in-situ samples may have included a large amount of cohesive soil peds, cemented partially weathered regolith or fresh rock with particles much larger than 19 mm diameter.

The material specifications can be used to infer how the material are likely to perform under field conditions within an engineered cover system.

The design criteria for an engineered cover system and the performance criteria of the materials and the cover system are dependent on the way the materials are used for construction and rehabilitation: this work is detailed in other studies. Field assessment is typically undertaken during the detailed design phase of work to verify how the rehabilitation material will perform under field conditions.

Additional details related to the results are in the following Attachments.

Attachment A: Test pit method

Attachment B: Additional figures and results

Attachment C: Test pit logs

Attachment D: Material balance tables

Attachment E: Borrow area pit shells

Attachment G: Trilab Laboratory Certificate of Analyses

Attachment G: Trilab Laboratory Certificate of Analyses

Attachment H: Soil Water Group Laboratory Certificates

3.1 Phase 1 results for Borrow Areas A, B and C

3.1.1 Borrow Area C

Borrow Area C was investigated in the Phase 1 – RMSaAP report (RGS, 2021). Borrow Area C contains a thin layer of rudimentary soil, or "rudosol" over a highly resistant to weathering rock, referred to as Shady Bore Quartzite. Rudosols are coarse soils with a high proportion of gravel, and low sand, silt, and clay content. While rudosols can support some vegetation types, test pits and drill holes show that in general they do not provide more than 1 m thickness of soil fines containing organic matter.

The soil fertility, geochemical and physical characteristics of Borrow Area C soil are as follows.

- Mildly acidic to circumneutral ($pH_{1:5}$ 4.5 to 6.2)
- Non-saline (median $EC_{1:5}$ 63 µS/cm)
- Low total sulfur content, low acid neutralising capacity, and NAF-barren classification
- Non-sodic, non-dispersive (Class 2A)
- Low organic matter (median 1.7%) and cation exchange capacity (median 3.6 meq/100g)
- Very low moisture content (median 0.5%) and water retention ability
- Clay content 8-14%, gravel content 0 – 48%.

The topsoil in Borrow Area C is stable and non-dispersive, however it is gravelly and coarse. The topsoil thickness ranges from 10 to 20 cm. The soil can support sparse native vegetation.

Borrow Area C is of interest as the quartzite underneath provides an excellent source of blocky rock. The area forms an outcropping hill which can be quarried.

The geochemical and physical properties of the Borrow Area C competent rock are as follows.

- Circumneutral ($pH_{1:5}$ 6.6)
- Non-saline ($EC_{1:5}$ 65 µS/cm)
- Weathering ranges from fresh rock to highly weathered, unconsolidated rock fragments
- Bulk density of the fresh rock is 2.6 t/m^3
- Point load strength (Is(50)) of the fresh rock is 7.3 MPa.

The proposed Borrow Area C quarry shell is in **Figure 7-43**. The area of disturbance is 1.7 ha. The total volume of material sourced from Borrow Area C is 16,900 lcm of growth medium and 320,628 lcm of fresh, competent rock. The buffer area around Borrow Area C is unlikely to be disturbed but is included as a contingency.



Figure 3-1: Weathering profile of quartzite to soil

3.1.2 Soil fertility

3.1.2.1 Soil pH $CaCl_2$

Soil pH ($CaCl_2$) for borrow area samples and drillhole composites from infrastructure areas (n=43) was 4.1 to 8.2 with a median pH of 5.7. The 9 soil samples from Borrow Area C had the lowest soil pH values of 4.1 to 5.2, median 4.7 (**Figure 3-2**). The 0.01 M $CaCl_2$ pH method provides pH results about 1 pH unit lower than a

water-soluble $pH_{1:5}$ test and the results for the borrow areas are typical for soil unimpacted by mining in the ML and can be used as baseline values. The $pH_{1:5}$ values for pasture/woodland land use range from pH 5 – 8.5.

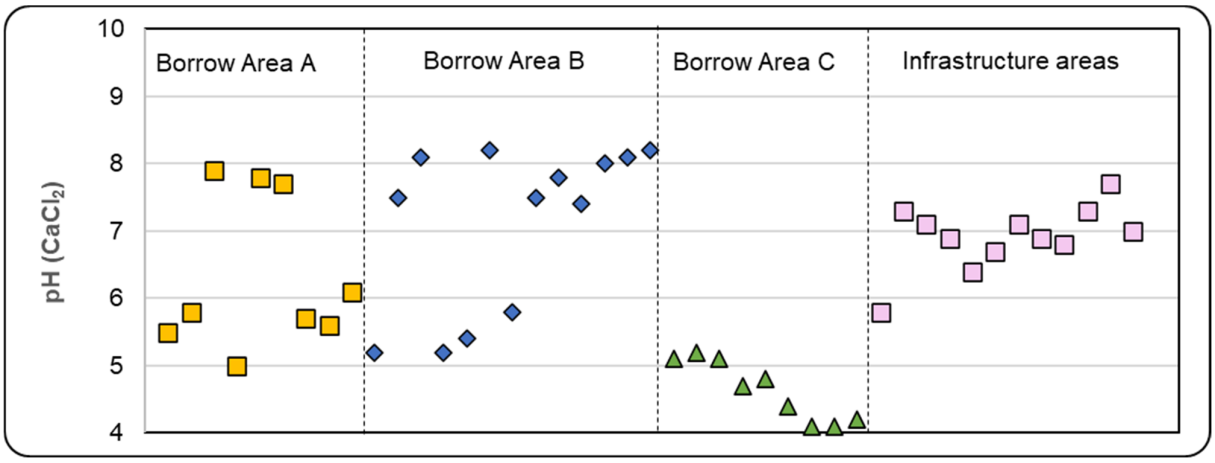


Figure 3-2: Soil pH ($CaCl_2$) for soil samples from borrow areas and infrastructure areas

3.1.2.2 Total organic carbon and total organic matter

Total organic carbon (TOC) was 0.25% to 4.3% with a median of 0.5% and total organic matter (OM) was 0.25% to 2.5% with a median of 0.3%. TOC and OM are highest in topsoil (0.0 – 0.5 m) samples from all borrow and infrastructure areas. The TOC and OM results provide baseline data to derive rehabilitation criteria within soil cover systems.

3.1.2.3 DTPA extractable metals

DTPA extractable metal results are in **Table 3-1**. The soil results contain sufficient trace metals for plant growth. The soil surface grab samples (0.1 – 1 m) from the Lower RoM pad had high concentrations of Zn (107 – 1300 mg/kg). Zn concentrations from infrastructure areas varies between 1 – 15 mg/kg through the subsoil and regolith and should be considered naturally elevated as a baseline.

3.1.2.4 Nitrogen

Nitrate (NO_3) results for the test pit samples is 0.1 mg/kg to 66.4 mg/kg with a median of 2.2 mg/kg. Total nitrogen (TN) results for the samples were 60 mg/kg to 1180 mg/kg with a median of 250 mg/kg. Infrastructure area soils are relatively low in TN and relatively high in bicarbonate extractable Potassium (K) compared to borrow areas.

3.1.2.5 Phosphorous

The total phosphorous (TP) results for the soil samples from borrow areas was 56 to 309 mg/kg with a median of 155 mg/kg. The bicarbonate extractable (Colwell) P results for the samples was 2.5 mg/kg to 12 mg/kg with a median of 2.5 mg/kg.

3.1.2.6 Potassium

The bicarbonate extractable (Colwell) method measures the amount of K available for plant uptake. The results for the samples were 50 mg/kg (below the LoR) to 525 mg/kg with a median of 291 mg/kg. Critical values for extractable K that begin to limit plant growth are 80 to 200 mg/kg (Hazelton and Murphy, 2007; Gourley 1999). As the median extractable K value is above this upper critical limit, it is unlikely that K fertiliser will be required for these soils.

TN, TP, bicarbonate extractable Phosphorus (P) and Potassium (K) for soil samples from borrow and infrastructure areas at LLM are in **Section 3.3**.

Table 3-1: DTPA extractable metals for soils from borrow and infrastructure areas

		Borrow Area A			Borrow Area B			Borrow Area C			Infra-structure areas
		Topsoil	Subsoil	Regolith	Topsoil	Subsoil	Regolith	Topsoil	Subsoil	Regolith	
Cu	Min	1.8	0.5	0.5	1.8	1.0	0.5	0.5	0.5	0.5	0.5
	Max	2.4	1.1	0.5	9.5	28.1	9.7	1.3	0.5	0.5	2.9
	Med	**2.1**	**0.5**	**0.5**	**8.2**	**1.4**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
Fe	Min	8.5	1.7	2.1	3.1	2.0	1.5	10.5	3.5	5.3	1.9
	Max	12.8	7.7	4.5	12.0	8.4	3.3	30.1	10.6	5.3	12.1
	Med	**9.4**	**3.6**	**2.5**	**9.4**	**2.1**	**2.4**	**20.7**	**7.0**	**5.3**	**5.1**
Mn	Min	37.8	2.0	1.9	2.6	2.7	1.1	13.1	1.1	2.8	0.5
	Max	73.3	10.2	5.6	84.1	7.3	3.0	40.4	10.4	2.8	23.5
	Med	**56.3**	**9.0**	**3.2**	**16.6**	**3.4**	**2.3**	**17.9**	**6.0**	**2.8**	**0.5**
Zn	Min	1.6	0.5	0.5	1.4	0.5	0.5	0.5	0.5	0.5	0.5
	Max	2.1	0.5	0.5	5.2	5.1	3.4	11.1	2.7	0.5	1300
	Med	**1.9**	**0.5**	**0.5**	**3.1**	**0.5**	**0.5**	**2.3**	**0.5**	**0.5**	**5.7**

3.1.3 Acid base account

3.1.3.1 $pH_{1:5}$

The $pH_{1:5}$ of all samples (n=31) were 4.4 to 10.1 with a median of 7.7: only five samples were < $pH_{1:5}$ 5.5 (**Figure 3-3** to **Figure 3-5**). The 5 samples with minor acid were from Borrow Area C. 64% of the samples were mildly alkaline (over pH 7). Lower pH concentrations in surface soil is not due to sulfide oxidation or AMD but occurs naturally as major cations are leached from the soil over time. The $pH_{1:5}$ generally increased with depth in undisturbed areas (**Figure 3-3**). $pH_{1:5}$ for samples from Borrow Area C is lower than Borrow Area A and B (**Figure 3-3**)

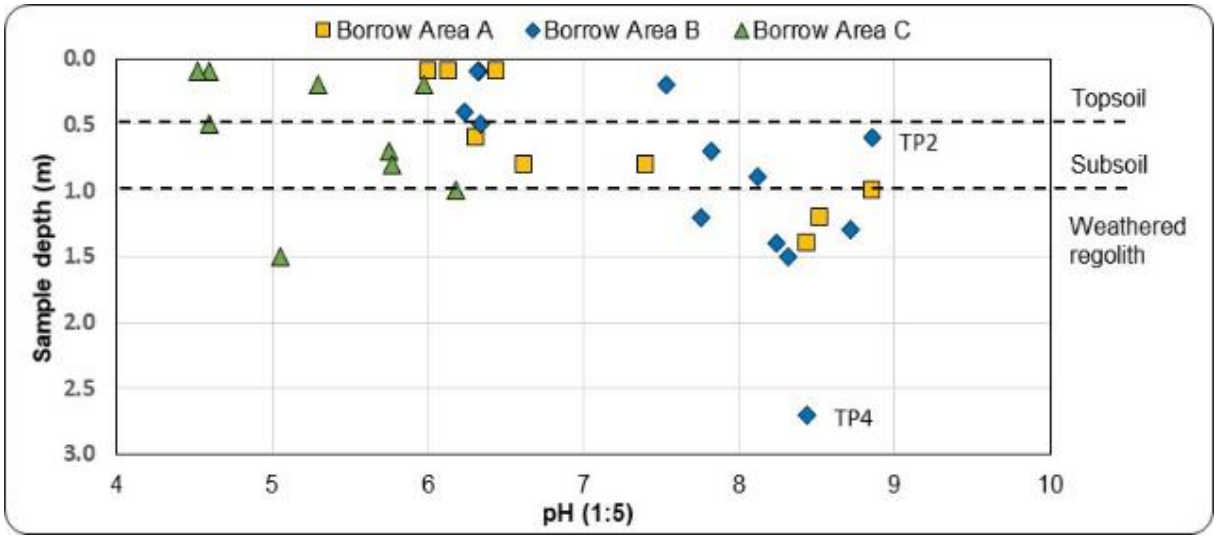


Figure 3-3: $pH_{1:5}$ test pit soil samples from borrow areas

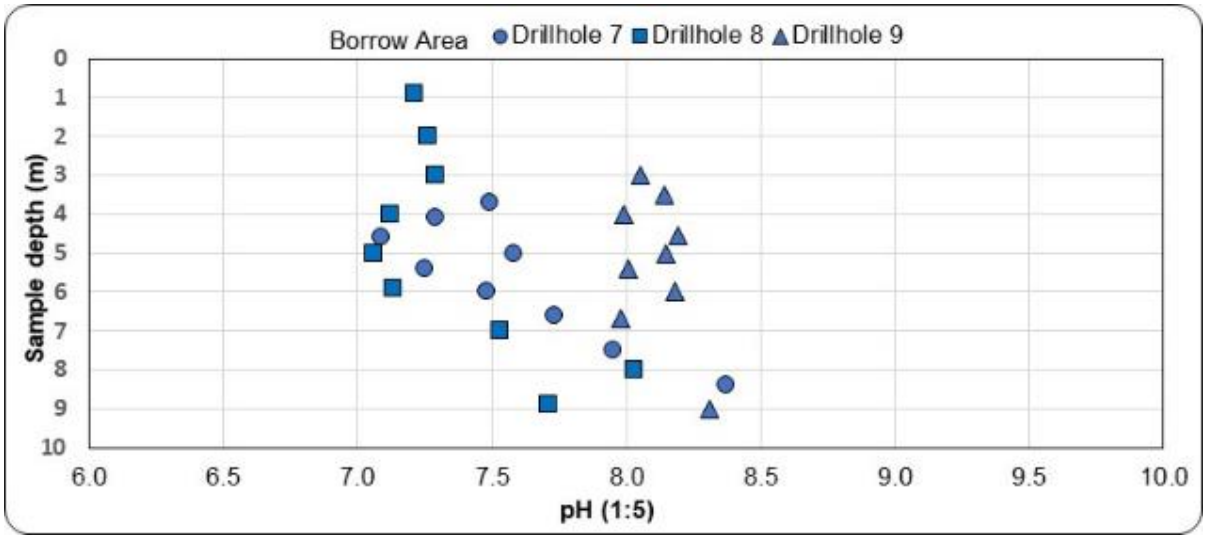


Figure 3-4: $pH_{1:5}$ drillhole fresh rock samples from Borrow Area B

3.1.3.2 Borrow Area A and Borrow Area C

Test pit samples from Borrow Area A (n=9) and Borrow Area C (n=9) have < 0.005 to 0.03%TS and 0.007 to 0.002%CRS. These samples will not produce acid from sulfide oxidation due to the low CRS and have a low potential to leach sulfate because of the low TS.

The NAPP concentration derived using CRS for the samples from Borrow Area A was -2.4 to -94.8 kg H_2SO_4/t and Borrow Area C was -1.8 to 0.4 kg H_2SO_4/t. The samples from Borrow Area A and C are classified as NAF_{BARREN}.

3.1.3.3 Borrow Area B

Test pit samples from Borrow Area B have two groupings: TP1 and TP2 (at the higher elevation) have < 0.01 to 0.02%TS and 0.005 to 0.018% CRS. These samples will not produce acid from sulfide oxidation due to the low CRS and have a low potential to leach sulfate because of the low TS.

The other two test pits (TP3 and TP4 that are at lower elevation) have < 0.02 to 0.69%TS but low sulfide at 0.008 to 0.016% CRS. These samples will not produce acid from sulfide oxidation due to the low CRS but do have the potential to leach sulfate (and therefore have a higher EC) because of the moderate TS.

The NAPP concentration derived using CRS for the samples from Borrow Area B was -1.3 to -52.3 kg H_2SO_4/t and the samples are classified as NAF_{BARREN} (TP1 and TP2) or NAF (TP3 and TP4).

In Borrow Area B, 27 samples were collected from three holes (DH7, DH8 and DH9). The drill hole samples have: 0.005 to 0.05% in DH7 (n=9), 0.01 to 0.13% in DH8 (n=9), and 0.02 to 0.06% in DH9 (n=9). Of the 27 samples 25 are NAF_{BARREN}.

Total sulfur results for test pit samples and drill hole samples in Borrow Area B are in **Figure 3-5** and **Figure 3-6. Table 3-9** provides a summary of the geochemical classification criteria used by RGS to classify the acid forming nature of the rehabilitation material samples from LLM.

- 89% of samples contain negligible TS to produce any AMD risk and are NAF_{BARREN}
- 10% of samples contain sufficient sulfide sulfur (CRS) to produce acid, but also enough neutralising capacity (ANC) to produce a pH neutral leachate (NAF)
- 1% of samples have similar amounts of sulfide sulfur and ANC which may or may not be sufficient to buffer any acid produced (Non-Acid Forming – Low Capacity). These samples are considered low but

possible risk. Only the 0.0 – 0.5 m drillhole soil composite sample from infrastructure areas was classified as Non-Acid Forming – Low Capacity.

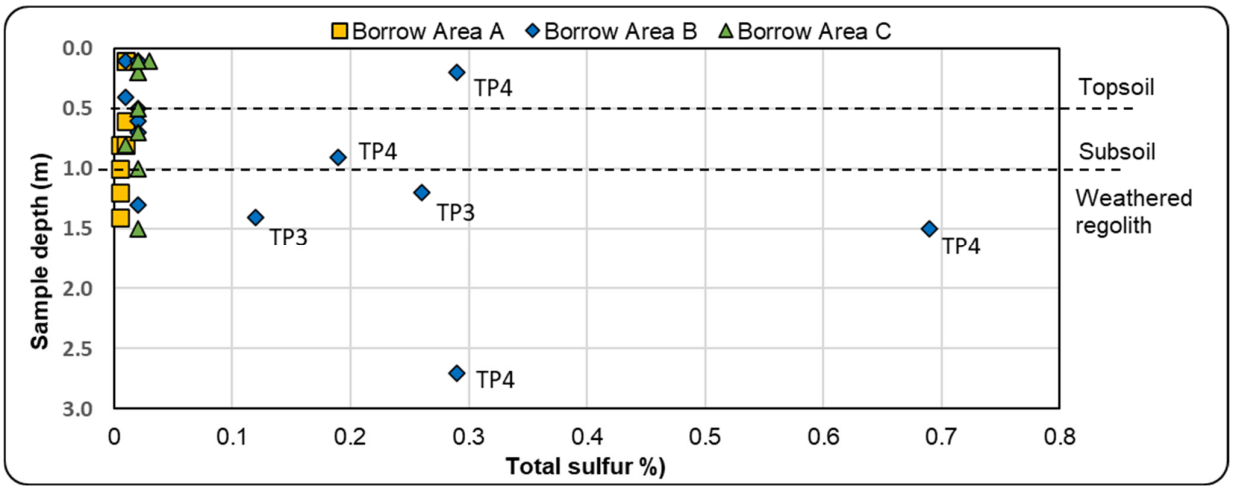


Figure 3-5: Total sulfur for test pit soils from borrow areas

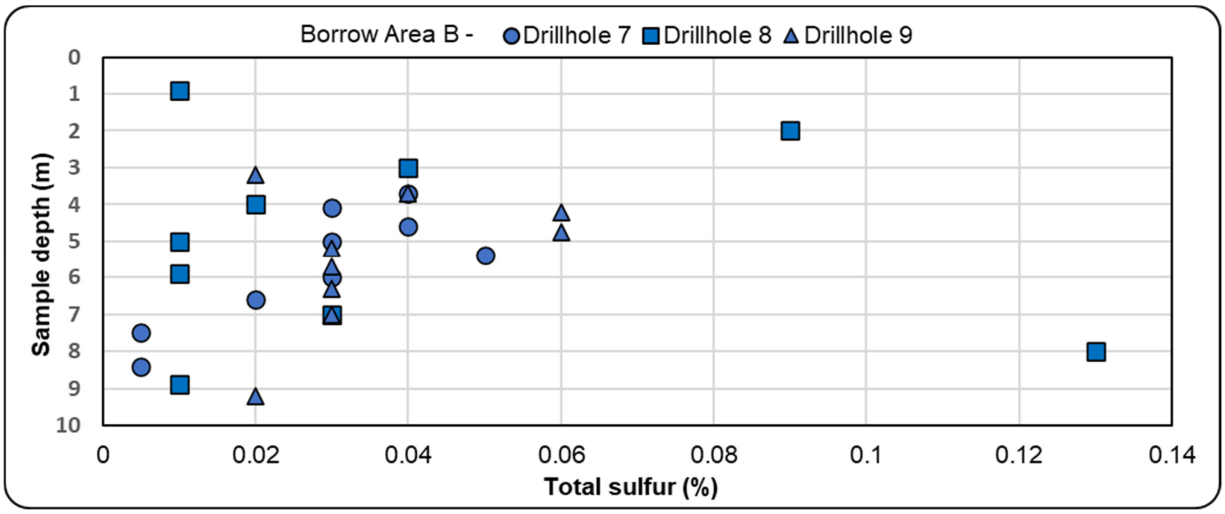


Figure 3-6: Total sulfur for drillhole fresh rock from Borrow Area B

Table 3-2: Geochemical classification criteria for rehabilitation materials

Geochemical Classification	Total Sulfur [1] (%)	ANC: MPA Ratio	NAPP (kg H_2SO_4/t)	Rehabilitation Samples (n=123)
Non-Acid Forming (Barren)	≤ 0.1	≥ 3	-	110
Non-Acid Forming	> 0.1	≥ 3	≤ -5	12
Non-Acid Forming (Low Capacity)	> 0.1	> 2 < 3	> -5 and ≤ +5	1
Potentially Acid Forming (Low Capacity)	> 0.1	< 2 > 1	> 5 to ≤ 10	0
Potentially Acid Forming	> 0.1	< 1	> 10	0

Notes: 1. Sulfide sulfur (using the CRS test) has been measured for selected rehabilitation samples and where available, sulfide sulfur has been used in place of total sulfur for sample classification and to calculate MPA.

3.1.4 Salinity classification

$EC_{1:5}$ was high in TP 3 and TP 4 from Borrow Area B (**Figure 3-7**). These samples also have high TS and the salinity in these samples are dominated by sulfate, as well as sodium chloride; the source of this could be celestite ($SrSO_4$) as strontium is elevated in the water soluble results (RGS, 2020).

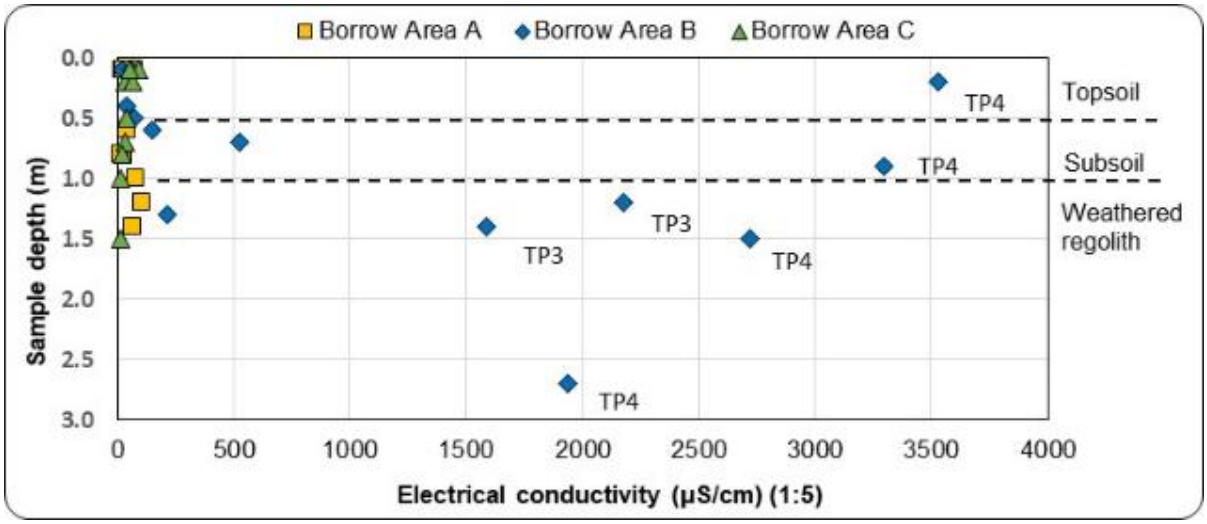


Figure 3-7: $EC_{1:5}$ test pit soil samples from borrow areas

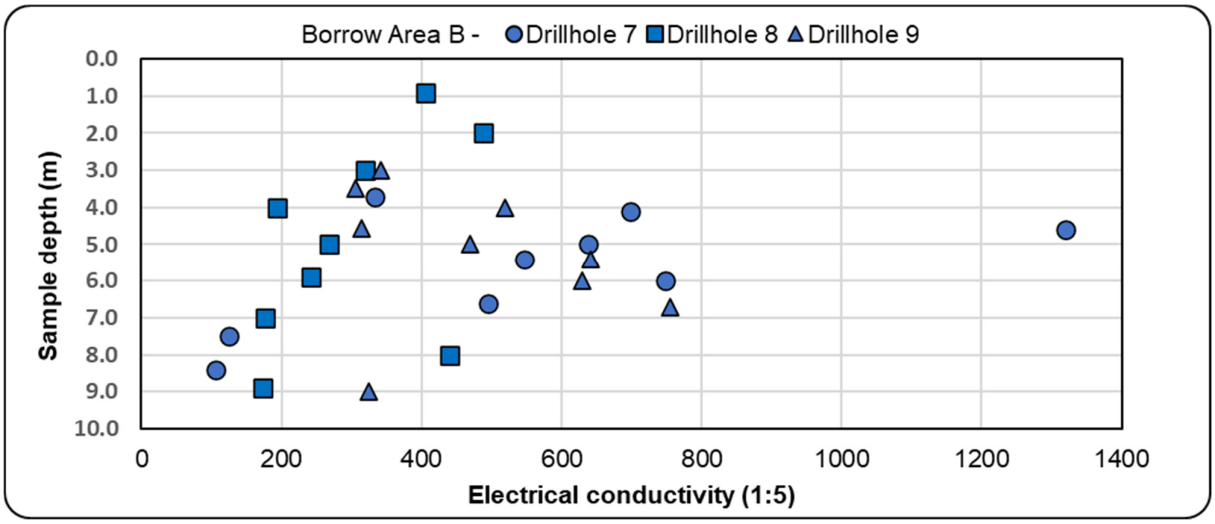


Figure 3-8: $EC_{1:5}$ drillhole fresh rock samples from Borrow Area B

The ESP analyses from Phase 1 indicated that 68% of the analysed samples were non-sodic. The sodic materials are in the subsoil and regolith of Test Pits 3 and 4 in Borrow Area B. The Ca:Mg ratio shows that most soils will be Ca deficient (96%) and only a few will be low in Mg (2%). The remainder of soil samples (2%) have a good balance.

Table 3-3: Emerson Class test results for soils from borrow and infrastructure areas

Area	Borrow A	Borrow A	Borrow A	Borrow A	Borrow A	Borrow A	Borrow B
Type/number	Test pit 1	Test pit 1	Test pit 2	Test pit 2	Test pit 3	Test pit 3	Test pit 1
Composite	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil

Depth (m)	0 - 0.1	0.1 - 0.8	0 - 0.1	0.1 - 1	0 - 0.1	0.1 - 0.6	0 - 0.4
Description	Silty CLAY - dark brown	Clayey SILT - brown	Silty Clayey GRAVEL - brown	Clayey GRAVEL - brown	Silty Clayey GRAVEL - brown	Silty Clayey GRAVEL - brown	Clayey Sandy GRAVEL - brown
Emerson Class Number	**2**	**3**	**2**	**3**	**2**	**2**	**2**

Area	Borrow B	Borrow B	Borrow B	Borrow B	Borrow B	Borrow B	Borrow B
Type/number	Test pit 1	Test pit 2	Test pit 2	Test pit 3	Test pit 3	Test pit 4	Test pit 4
Composite	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Subsoil 1	Subsoil 2
Depth (m)	0.4 - 0.7	0 - 0.1	0.1 - 0.5	0 - 0.1	0.1 - 1.2	0 - 0.2	0.2 - 0.9
Description	Sandy GRAVEL - brown	Clayey Sandy GRAVEL - brown	Clayey Sandy GRAVEL - brown	Silty Sandy GRAVEL - brown	Silty CLAY - brown	Silty CLAY - brown	Silty CLAY - brown
Emerson Class Number	**3**	**2**	**2**	**3**	**2**	**2**	**2**

Area	Infrastructure	Infrastructure	Infrastructure	Infrastructure	Infrastructure	Infrastructure
Type/number	Drillhole 3-6	Drillhole 3-6	Drillhole 3-6	Drillhole 3-6	Drillhole 3-6	Drillhole 3-6
Composite	Topsoil	Topsoil	Subsoil	Subsoil	Regolith	Regolith
Depth (m)	0.1 - 0.5	0.5 - 1.5	1.5 - 2.5	2.5 - 4	4 - 8	8 - 13
Description	Sandy Silty CLAY - orange brown	Sandy Silty CLAY - red brown	Sandy Silty CLAY - red brown	Sandy Silty CLAY - brown	Sandy Silty CLAY - brown	Sandy Silty CLAY - orange brown
Emerson Class Number	**5**	**2**	**5**	**2**	**5**	**5**

3.1.5 Metalliferous drainage potential

The elemental content and water-soluble properties of the samples from Borrow Areas A, B and C are described in RGS (2021). There were no adverse effects from these materials that would preclude their use for rehabilitation.

3.1.6 Physical properties

3.1.6.1 Particle size distribution

For the borrow areas, **Table 3-4** show that the topsoil, subsoil and regolith of Borrow Area A and B contain a larger proportion of fine (clay, silt and sand) material compared to Borrow Area C, which has a higher proportion of gravel. Borrow Area B has a relatively coarse topsoil compared to Borrow Area A, but has more clay in the subsoil and regolith (i.e. in the more sodic units).

In the drillhole soil samples from infrastructure areas, the PSD curves of the fine fraction between 0.075 – 2.36 mm are generally similar. These highly weathered soils contain a higher proportion of silt compared to borrow area materials and contain only a small proportion of gravel.

Table 3-4: Summary of PSD results for rehabilitation materials

	Clay (<0.04 mm)	Silt (0.004 – 0.062 mm)	Sand (0.062 – 2.0 mm)	Gravel (> 2.0 mm)
Borrow A	33 – 65%	3 – 8%	17 – 64%	0 - 28%
Borrow B	24 – 75%	4 – 7%	22 – 60%	0 – 37%
Borrow C	8 – 30%	3 – 6%	28 – 81%	19 – 54%
Infrastructure	0 – 30%	30 – 50%	25 – 45%	4 - 21%

3.1.6.2 Soil texture classification

Using the PSD results and proportions (0 – 100%) of clay (< 0.002 mm PSD), silt (> 0.002 to < 0.05 mm PSD), and sand (> 0.05 to < 2 mm PSD), the soils from the borrow and infrastructure areas have been plotted on soil texture classification triangles (**Figure 3-9** and **Figure 3-10**). The results range from clay to sand and confirm that in test pit samples from borrow areas, fine clay and silt particles are more common in topsoil, while regolith tends to have a higher proportion of sand. Classifications range from loamy sand and sandy loam to loam. By comparison, infrastructure areas have more clay and silt throughout the entire soil profile, inferring a higher degree of weathering. Classifications range from silt loam to clay loam to loam. Excluding gravels, soils from borrow areas are generally 60 – 85% sand, 10 – 20% silt and 5 – 20% clay; whereas soils from infrastructure areas are generally 45 – 60% sand, 30 – 50% silt and 0 – 30% clay.

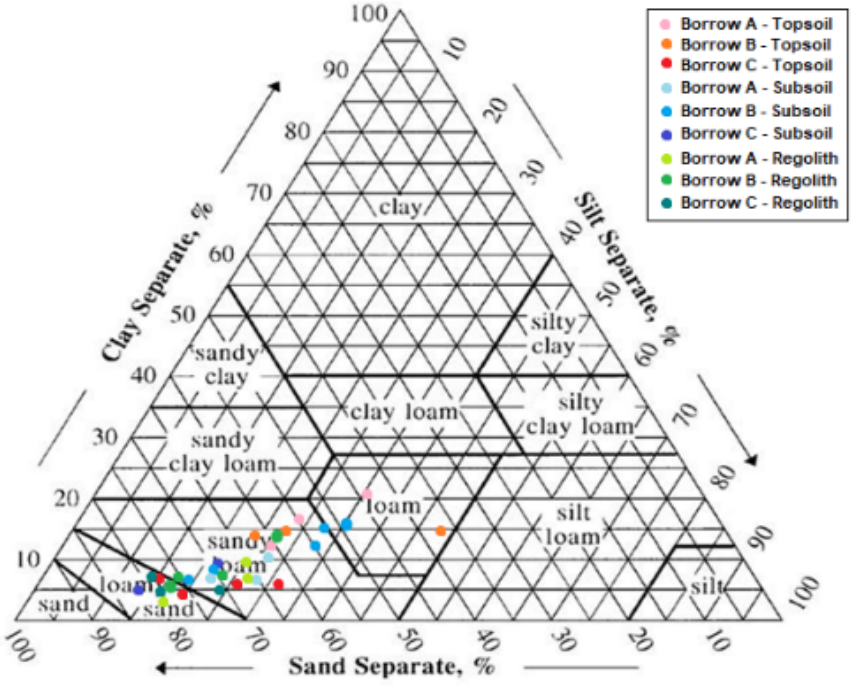


Figure 3-9: Soil texture classification triangle for test pit soils from borrow areas

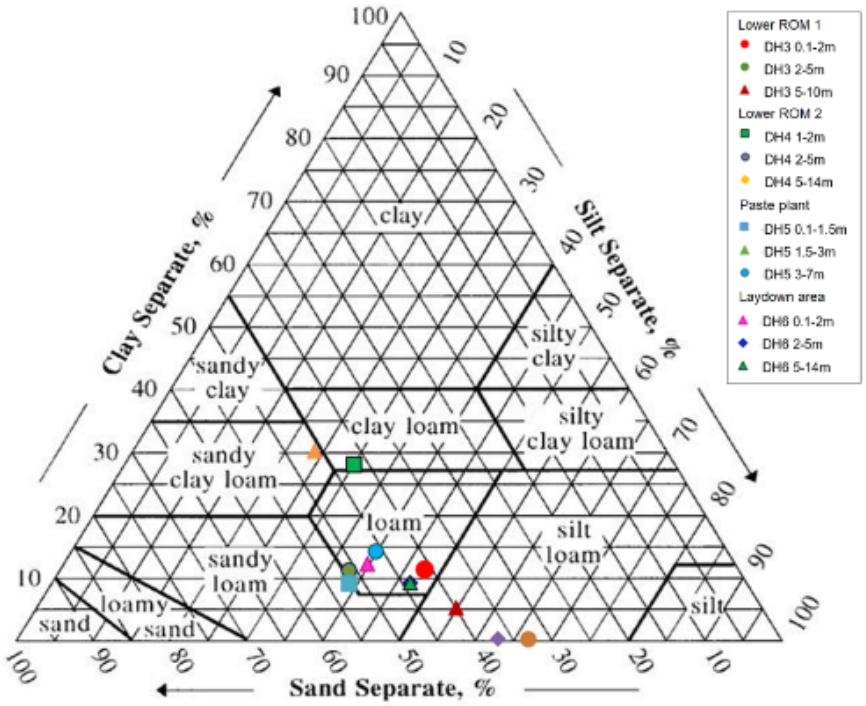


Figure 3-10: Soil texture classification triangle for drillhole soils from infrastructure areas

3.1.6.3 Atterberg Limits

Borrow Area A and Borrow Area B soils were tested for Atterberg Limits. Borrow Area C was not tested as the thin soils in the area are gravelly and do not contain much clay, making them unsuitable as a sealing layer. The Atterberg results verify the topsoil, subsoil, and regolith all have low liquid limits and linear shrinkage values. This infers that the soils are low in clay or do not contain shrinking and swelling clay mineral types (**Table 3-15**). Plasticity index (PI) % is the water content at which the soil begins to display plastic properties. It can be non-plastic (0%), slightly plastic (1-6%), medium plastic (7-17%), or highly plastic (18-100%) (Sowers, 1979). Silt, sand, and gravel have very low or no plasticity. The AASHTO soil classifications based on WAQTC (2020) are presented in **Figure 3-11.**

- Borrow Area A and Borrow Area B contain similar topsoil that is slightly plastic by its Plasticity Index % (6-7%), and is a low plasticity silt according to AASHTO soil classifications;
- Borrow Area A and Borrow Area B contain subsoil and regolith that are medium plastic (11-15%) and are classified as low plasticity clays according to AASHTO soil classifications.

Table 3-5: Atterberg limits for borrow area soil composites

	Borrow Area A			Borrow Area B		
	Topsoil	Subsoil	Regolith	Topsoil	Subsoil	Regolith
Liquid Limit (%)	22	30	30	22	29	31
Plastic Limit (%)	16	15	19	15	15	20
Plasticity Index (%)	6	15	11	7	14	11
Linear Shrinkage (%)	2	6	4	2	6	4
Moisture Content (%)	0.8	4.5	2.3	0.9	4.2	3.8

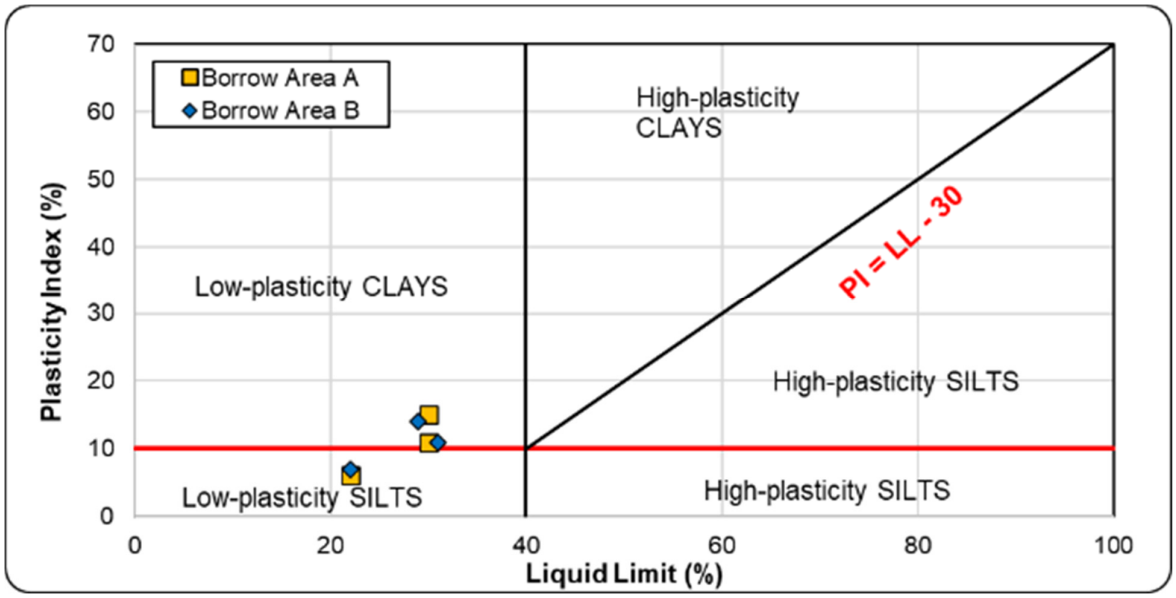


Figure 3-11: AASHTO soil classifications for borrow area soils

3.1.6.4 Maximum dry density and bulk density

Maximum dry density is a measure of the dry soil weight per unit volume and is measured as part of permeability testing (**Section 3.2.5.6**). Bulk density is the soil weight per unit volume measured in-situ. The bulk densities of soil and rock materials collected from test pit excavations and drillholes in Borrow Area A, B, C and from infrastructure areas are in **Table 3-6**. Results range from 1.25 to 1.75 m^3/t for soil and regolith, and from 1.8 to 2.9 m^3/t for fresh rock.

3.1.6.5 Permeability

The soil composites have $k_{(20)}$ values that range from 1.1×10^{-9} m/s to 7.3×10^{-8} m/s (median 7.1×10^{-9} m/s) (**Table 3-7**). In general, soils from Borrow Area A had higher permeability than Borrow Area B, for both the constant head and falling head test methods. Drillhole soil composites from the infrastructure areas were comparable in permeability to Borrow Area B, with permeability increasing slightly with depth from topsoil into subsoil and regolith. Borrow Area B soil has low permeability and may be suitable as a sealing layer. Topsoil from soil in infrastructure areas also has low permeability.

Table 3-6: Bulk density and dry density measurements of rehabilitation materials

Area	Test pit	Bulk density (m^3/t)
Borrow A	TP 1	1.5
Borrow A	TP 1	1.3
Borrow A	TP 1	1.25
Borrow A	TP 2	1.5
Borrow A	TP 2	1.4
Borrow A	TP 2	1.25
Borrow A	TP 3	1.56
Borrow A	TP 3	1.3
Borrow A	TP 3	1.25
	Median	**1.30**
Borrow B	TP 1	1.69
Borrow B	TP 1	1.25
Borrow B	TP 1	1.25
Borrow B	TP 2	1.56
Borrow B	TP 2	1.44
Borrow B	TP 2	1.25
Borrow B	TP 3	1.63
Borrow B	TP 3	1.25
Borrow B	TP 3	1.13
Borrow B	TP 4	1.25
Borrow B	TP 4	1.25
Borrow B	TP 4	1.50
Borrow B	TP 4	1.31
	Median	**1.25**
Borrow C	TP 1	1.56
Borrow C	TP 1	1.75
Borrow C	TP 1	1.88
Borrow C	TP 2	1.56
Borrow C	TP 2	1.63
Borrow C	TP 3	1.75
Borrow C	TP 3	1.75
Borrow C	TP 4	1.81
Borrow C	TP 4	1.81
	Median	**1.75**

Area	Drillhole	Depth (m)	Bulk density (m^3/t)
Borrow B	DH 7	3.85	2.24
Borrow B	DH 7	6.6	2.24
Borrow B	DH 7	7.7	2.24
Borrow B	DH 7	8.4	2.24
Borrow B	DH 8	1.2	2.11
Borrow B	DH 8	5.2	2.11
Borrow B	DH 8	7.8	2.11
Borrow B	DH 8	8	2.11
Borrow B	DH 9	3.96	1.80
Borrow B	DH 9	4.55	1.86
Borrow B	DH 9	4.75	2.16
Borrow B	DH 9	9.2	1.97
Borrow C	DH 1	0.4	1.60
Borrow C	DH 1	0.6	1.80
Borrow C	DH 1	0.7	2.63
Upper ROM	DH 2	1.2	2.50
Upper ROM	DH 2	1.6	2.70
Upper ROM	DH 2	2.2	2.90
		Median	**2.14**

Area	Composite	Perm. test	Dry density (m^3/t)
Borrow A	TS/SS/REG	Constant head	1.84
Borrow A	TS/SS/REG	Falling head	1.71
Borrow B	TS/SS/REG	Constant head	2.00
Borrow B	TS/SS/REG	Falling head	1.79
Infrastructure	TS	Falling head	1.81
Infrastructure	SS/REG	Falling head	1.72
		Median	**1.80**

Table 3-7: Permeability of Borrow Areas and infrastructure soils

		Constant head method		Falling head method	
Area	Composite	kSat 95% (m/s)	kSat 90% (m/s)	kSat 95% (m/s)	kSat 90% (m/s)
Borrow A	TS/SS/REG	3.7×10^{-9}	2.9×10^{-5}	2.7×10^{-8}	7.3×10^{-8}
Borrow B	TS/SS/REG	1.1×10^{-9}	1.2×10^{-5}	1.6×10^{-9}	8.5×10^{-9}
Infrastructure	TS			1.9×10^{-9}	
Infrastructure	SS/REG			5.6×10^{-9}	

3.1.6.6 Soil-water characteristic curves

Soil water characteristic curves measure the limits of water storage capacity. The upper limit is called field capacity, and the lower limit is called the permanent wilting point. Between these two limits is the plant available water. After a rainfall event saturates the soil, there will be infiltration due to gravity which is referred to as drainage. During this process, the soil moisture decreases, and the rate at which it decreases is dependent on the soil texture class. In general, soils with higher clay content will retain water for longer. The results in **Figure 3-12** demonstrate that the soils from infrastructure areas have higher water retention properties than soils from Borrow Areas A, B, and C.

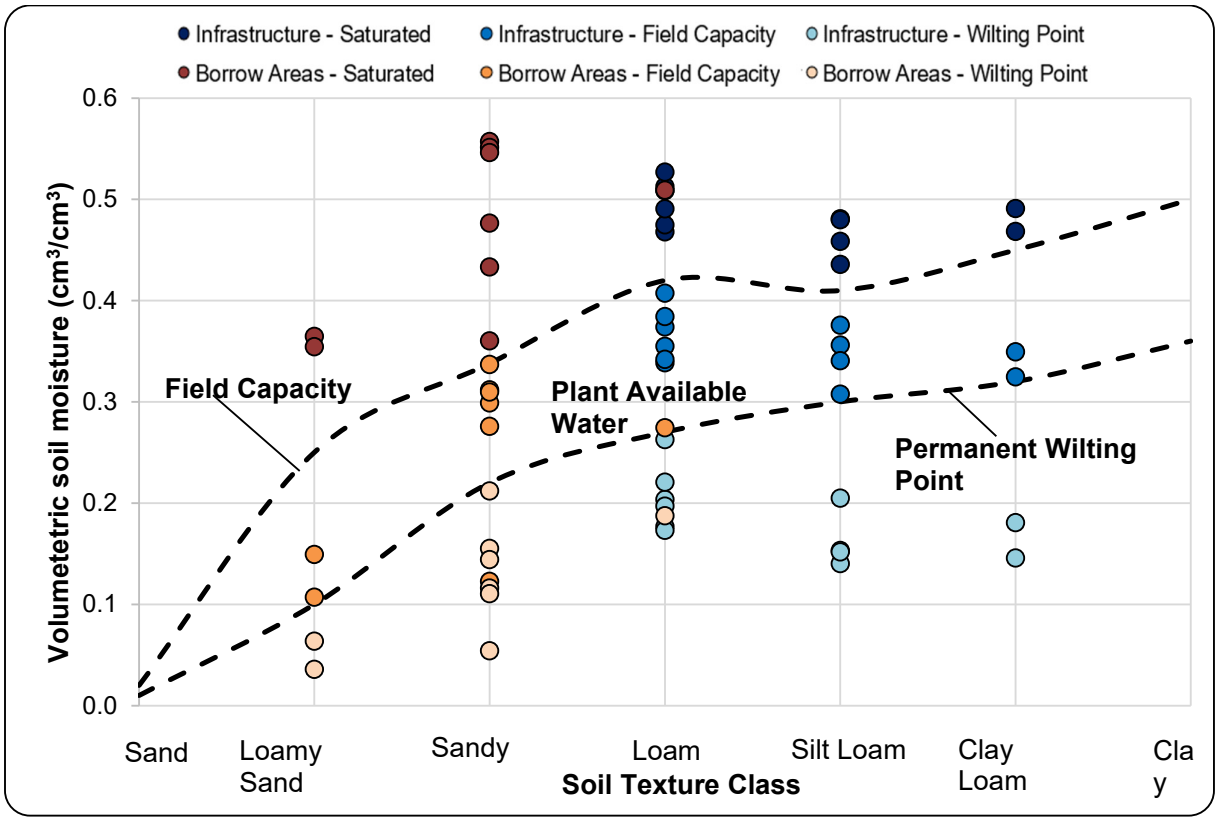


Figure 3-12: Relationship between soil texture class and plant available water

3.1.7 Oxidised and fresh rock

3.1.7.1 Point load strength

The point load strength of fresh rock samples that were diamond drill cored from borrow areas have been analysed (**Table** 3-20). The load strengths (Is) of the materials range from 0.06 to 6.77 MN/m^2 (or MPa), and are classified as irregular lumps. When a correction factor is applied to standardise the samples to have a 50 mm diameter, the corrected load strengths (Is(50)) range from 0.06 to 7.27 MN/m^2 (median 0.66 MN/m^2). These values have been plotted in **Figure 3-13**, and range from weak to very strong.

- The majority of rock types from Borrow Area B fall within the expected point load strength range for mudstone and sandstone (DH7 #2, DH8, DH9) and have medium Is(50) ranging from 0.63 to 0.82 MN/m^2 (Mpa);
- The exception is extremely weathered claystone rock found at Borrow Area B (DH7 #1), which has Is(50) 0.06 MN/m^2 (Mpa), and is weak and equivalent to stiff clay;
- The quartzite from Borrow Area C is very strong, has Is(50) of 7.27 MN/m^2 (Mpa) and equivalent to granite (DH1).

Table 3-8: Point load strength of fresh rock from borrow areas

Drillhole	Depth from	Depth to	Lithology	Weathering	Is (Mpa)	Class	Is(50) (Mpa)	Class
DH7 #1	3.75	3.85	Claystone	Extremely weathered	0.06	Weak	0.06	Very low
DH7 #2	7.5	7.7	Siltstone	Moderately weathered	0.58	Mod. Strong	0.63	Medium
DH8 #1	1	1.2	Siltstone	Lightly weathered	0.66	Mod. Strong	0.72	Medium
DH8 #2	5	5.2	Siltstone	Lightly weathered	0.62	Mod. Strong	0.66	Medium
DH9 #1	3.73	3.96	Siltstone	Moderately weathered	0.75	Mod. Strong	0.82	Medium
DH9 #2	4.35	4.55	Siltstone	Moderately weathered	0.56	Mod. Strong	0.63	Medium
DH1 #1	0.6	0.7	Quartzite	Unweathered	6.77	Extra Strong	7.27	Very high

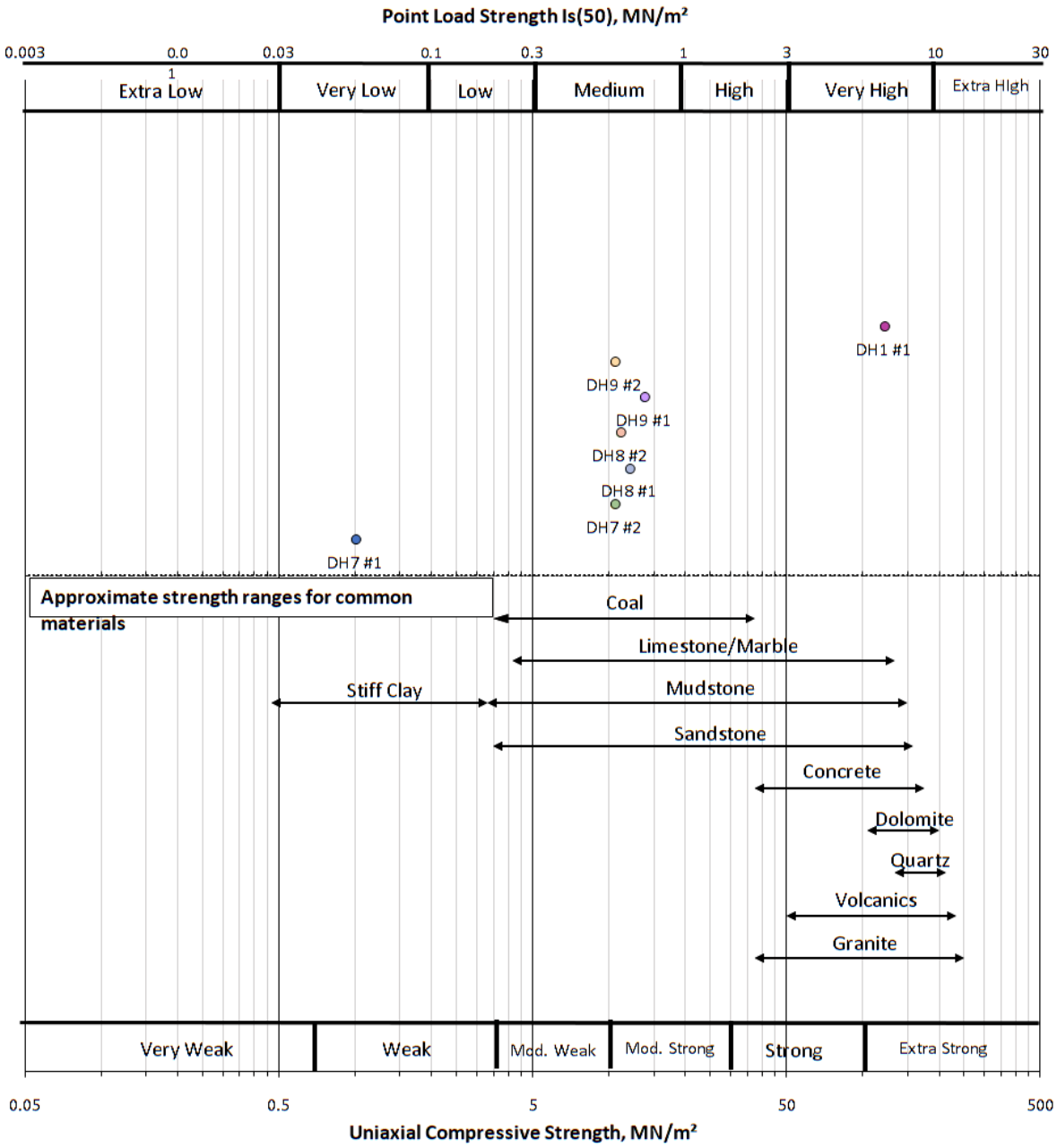


Figure 3-13: Point load strength of borrow materials compared to standard materials

3.1.7.2 Sodium Soundness

Fresh rock from Borrow Area B was subjected to sodium soundness testing at the RGS in-house laboratory (to **Figure 3-19**). The rock samples have been subjected to two complete cycles over a period of 3 months.

- No significant degradation was observed for any of the fresh rock samples over the test period (<5% change).

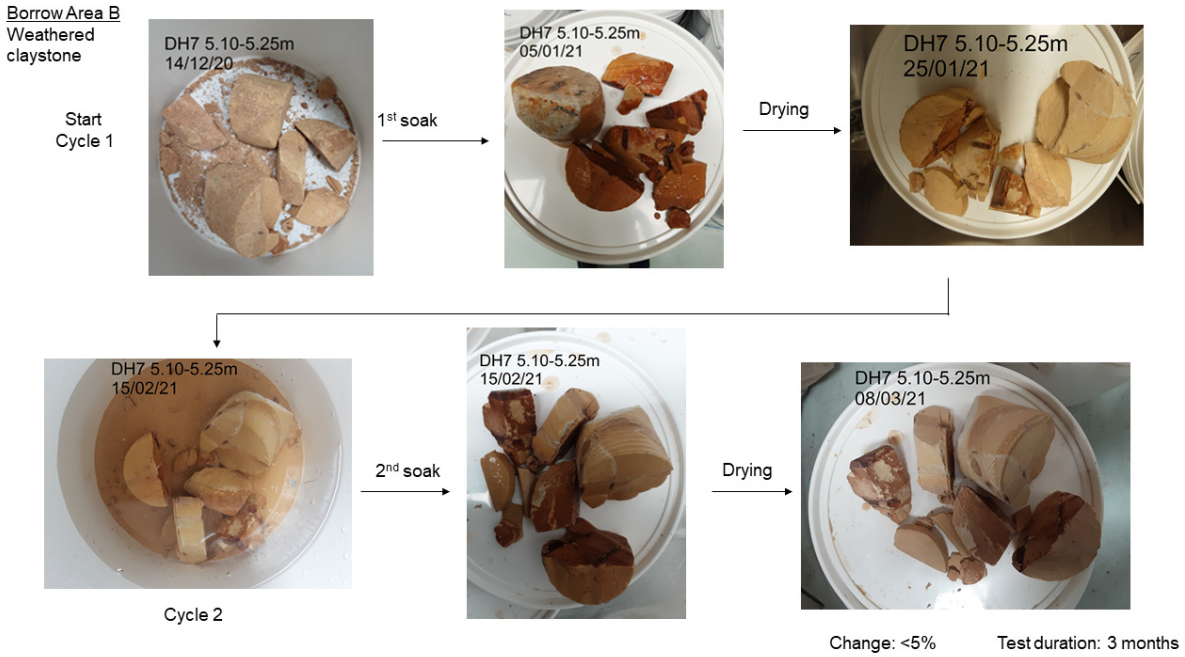


Figure 3-14: Sodium soundness test at Borrow Area B: DH7 5.10-5.25 m

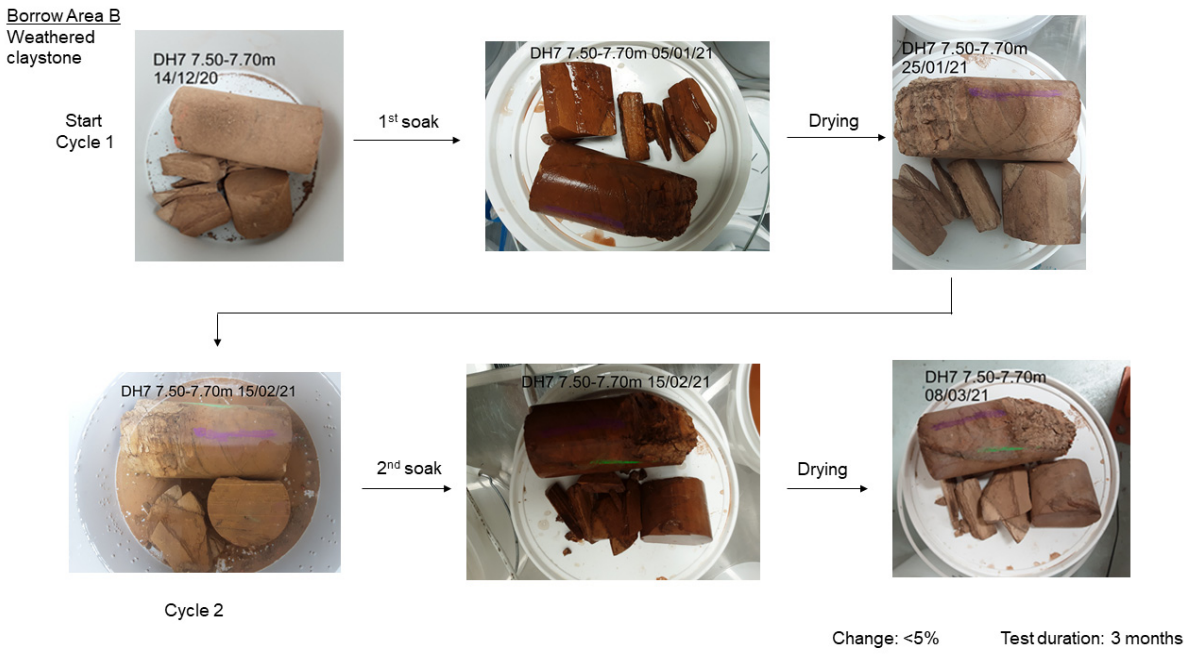


Figure 3-15: Sodium soundness test at Borrow Area B: DH7 7.50-7.90 m

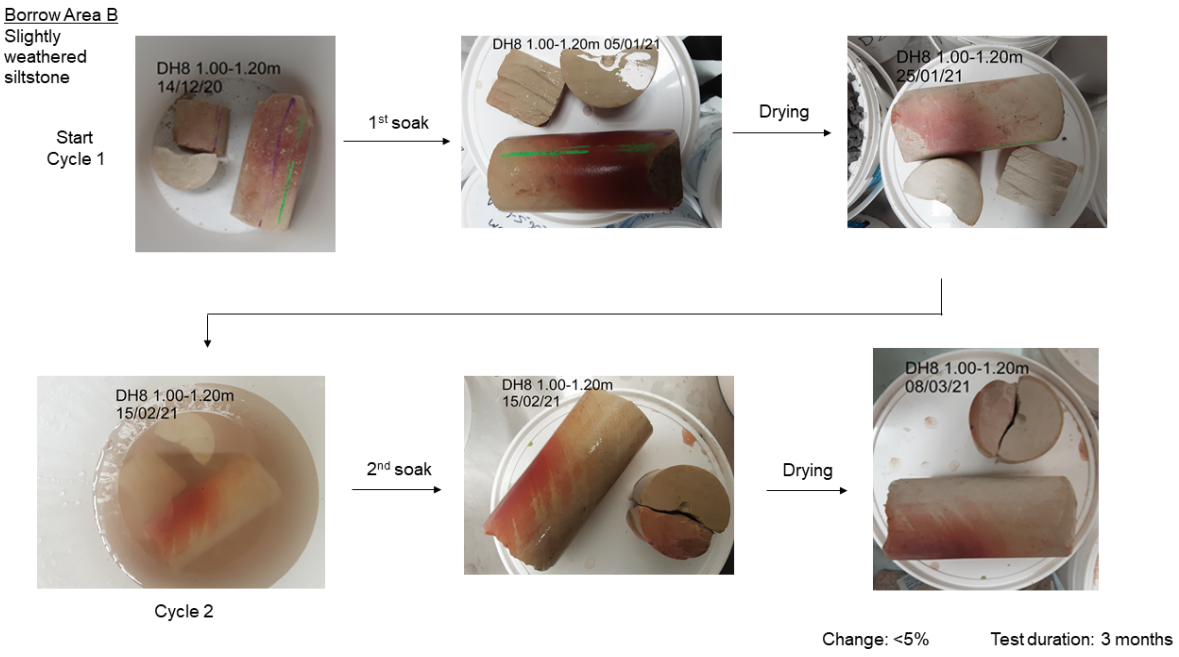


Figure 3-16: Sodium soundness test at Borrow Area B: DH8 1.00-1.20 m

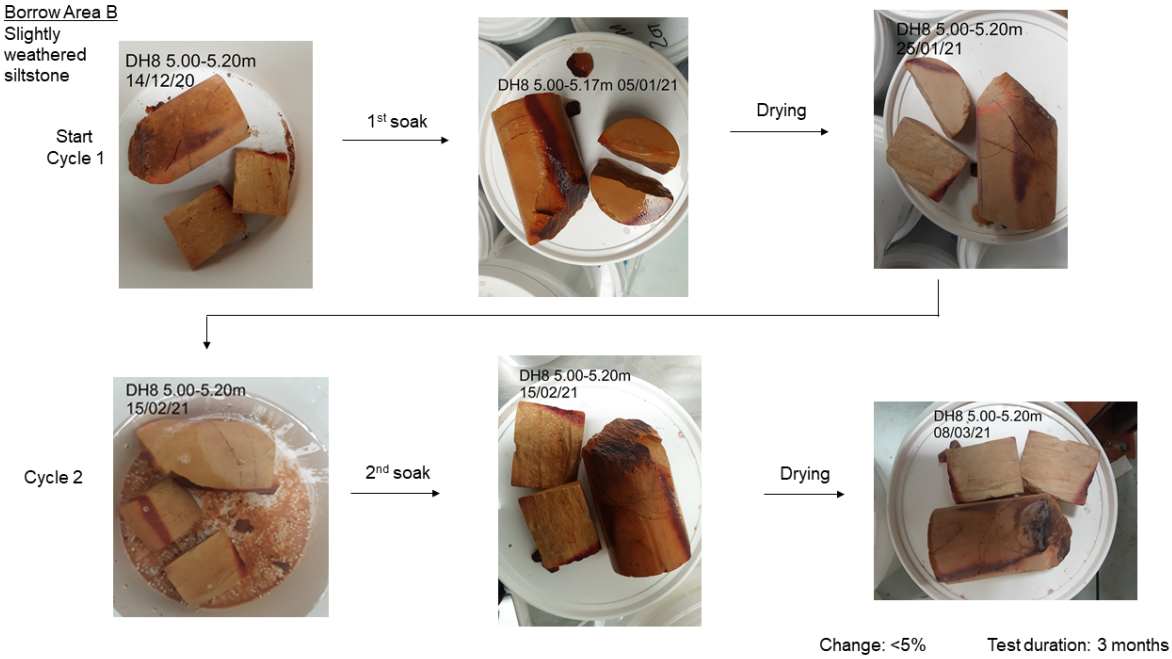


Figure 3-17: Sodium soundness test at Borrow Area B: DH8 5.00-5.20 m

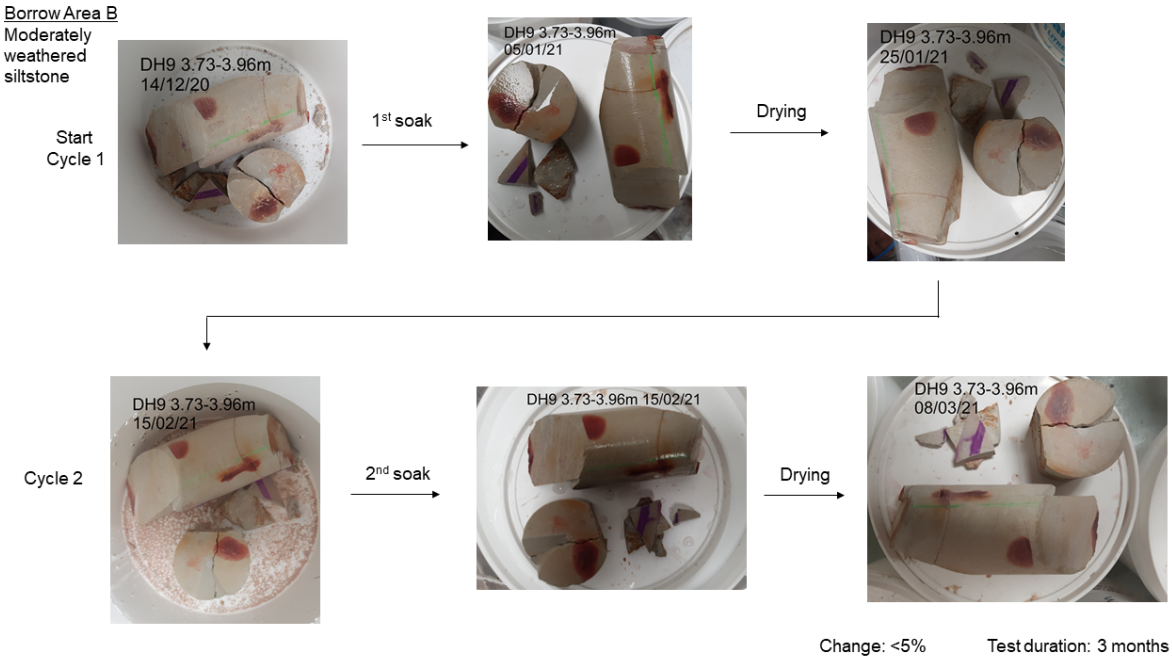


Figure 3-18: Sodium soundness test at Borrow Area B: DH9 3.73-3.98 m

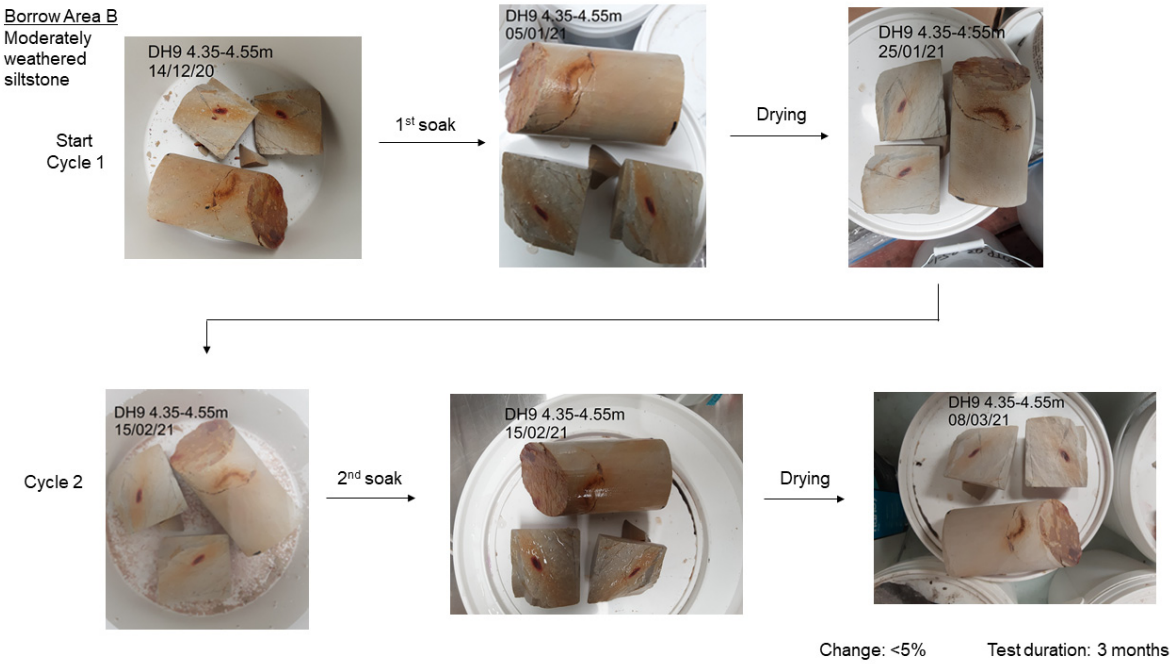


Figure 3-19: Sodium soundness test at Borrow Area B: DH9 4.35-4.55 m

3.2 Phase 2 results for Borrow Areas V, B, W, T, and I

3.2.1 Soil fertility

Soil fertility results provide baseline data to derive rehabilitation criteria within soil cover systems.

3.2.1.1 Soil pH $CaCl_2$

The 0.01 M $CaCl_2$ pH method provides pH results about 1 pH unit lower than a water-soluble $pH_{1:5}$ analytical method and the results for the borrow areas are typical for soil unimpacted by mining on the ML and can be used as baseline values. Soil pH ($CaCl_2$) for soil samples from Borrow Area V, B, W, T, and I (n=47) is 4.7 to 9.1 with a median pH of 8.0 **(Figure3-2)**. Topsoil has a median pH ($CaCl_2$) of 5.7, which is lower than subsoil (7.5), and saprolite (8.0).

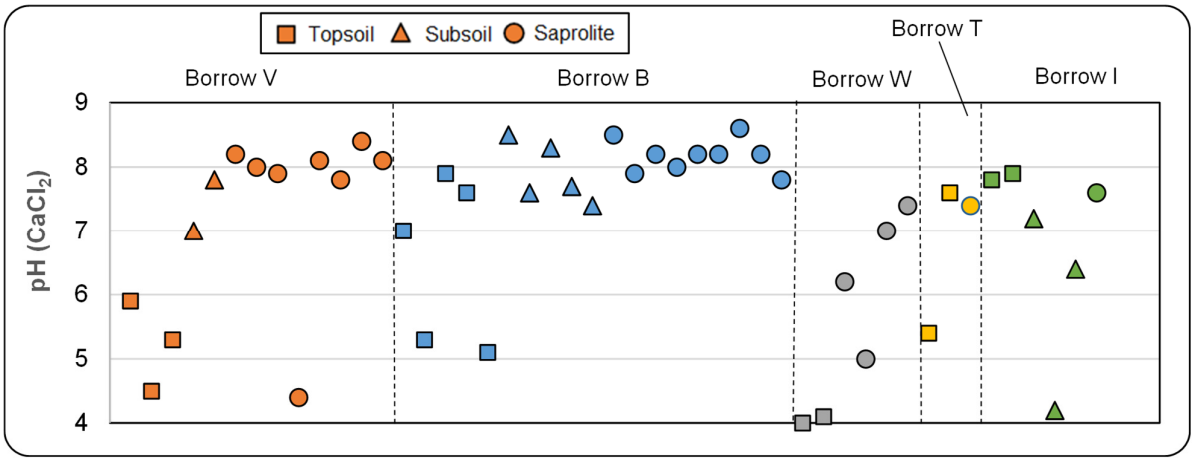


Figure 3-20: Soil pH ($CaCl_2$) for soil samples from borrow areas

3.2.1.2 Total organic carbon and total organic matter

Total organic carbon (TOC) is 0.3% to 10.6% with a median of 0.3% and total organic matter (OM) was 0.3% to 6.1% with a median of 0.3%. TOC and OM are highest in topsoil (0.0 – 0.5 m) samples from all borrow areas. Additional figures for TOC and OM are in **Section 7.2.8.1 (Attachment B)**.

3.2.1.3 Nitrogen

Nitrogen is continually stored, recycled, and lost from soil over time from a range of bio-geo-chemical processes. Nitrates (NO_3) are highest in topsoils and lowest in saprolite for all borrow areas. Nitrate results for the test pit soil samples are 0.2 mg/kg to 51.0 mg/kg with a median of 5.0 mg/kg. The optimum criteria based on Grazing Bushland guidelines is >12.5 kg. Topsoils and subsoils have sufficient nitrates to support native vegetation but saprolite materials may benefit from nitrate amelioration. Total nitrogen (TN) results for the samples are 50 mg/kg to 2130 mg/kg with a median of 220 mg/kg. Based on TOC and TN median values, the carbon to nitrogen ratio (C:N) is 14:1. At this ratio, rapid mineralisation and release of N occurs (Brust, 2019). Additional figures for total and bicarbonate extractable N, P, and K are in **Section 7.2.8.2 (Attachment B).**

3.2.1.4 Phosphorous

The total phosphorous (TP) results for soil samples from borrow areas is 48 to 380 mg/kg with a median of 170 mg/kg. The bicarbonate extractable (Colwell) P results for the samples is 2.5 mg/kg to 14 mg/kg with a median of 2.5 mg/kg.

3.2.1.5 Potassium

The bicarbonate extractable (Colwell) method measures the amount of K available for plant uptake. The results for the samples are 50 mg/kg (below the LoR) to 462 mg/kg with a median of 232 mg/kg. All extractable K

results that are below the LoR (n=10) occur in Borrow Areas W, T, and I. Critical values for extractable K that begin to limit plant growth are 80 to 200 mg/kg under agricultural guidelines (Hazelton and Murphy, 2016; Gourley 1999). As the median extractable K value is above this upper critical limit, it is unlikely that K fertiliser will be required for Borrow Areas B and V, which contain relatively high results for extractable K.

3.2.2 Acid base account

3.2.2.1 $pH_{1:5}$

The $pH_{1:5}$ of all borrow area samples (n=47) are 4.7 to 9.1 with a median of 8.0: only six samples were ≤ $pH_{1:5}$ 5.5 (**Figure 3-21**). The 6 samples with minor acid were from Borrow Areas V, W, and I. Lower $pH_{1:5}$ concentrations in surface soil are not due to sulfide oxidation or AMD but occurs naturally due to the leaching of base cations and the presence of Al and Mn. 74% of the samples were mildly alkaline (over pH 7) and the $pH_{1:5}$ increased with depth in undisturbed areas.

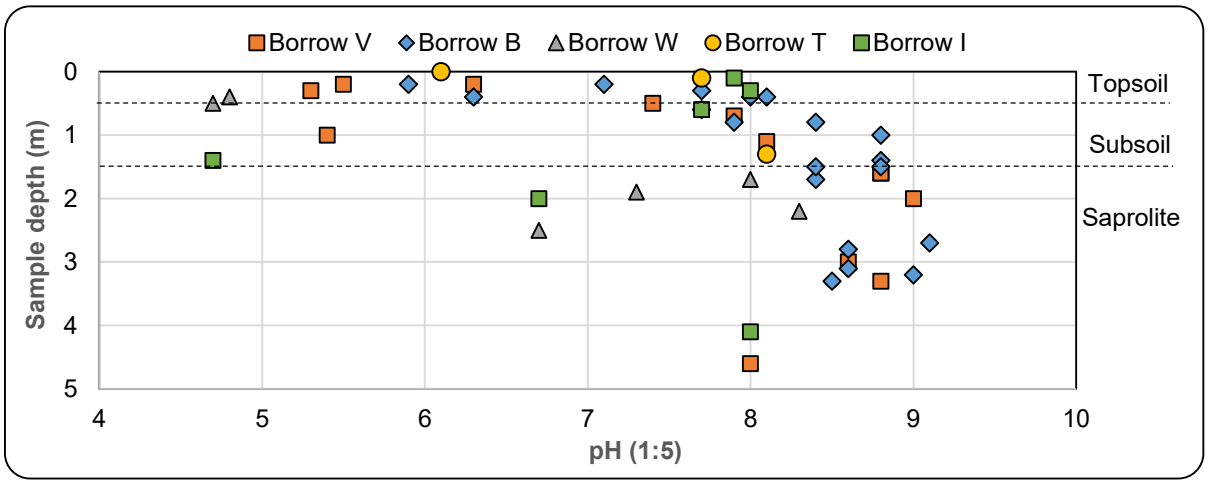


Figure 3-21: $pH_{1:5}$ for borrow area soils and saprolite

3.2.2.2 Net acid producing potential

Total sulfur (TS) results are in **Figure 3-22**. TS and chromium reducible sulfur (CRS) correlations are in **Figure 3-23,** and suggest that in all samples the sulfur content is dominated by sulfate bearing minerals (e.g., barite ($BaSO_4$), celestine ($SrSO_4$), gypsum ($CaSO_4 \cdot 2H_2O$), or alunite ($KAl_3(SO_4)_2(OH)_6$) rather than sulfide mineralogy. Neutralisation potential ratios (NPR) are in **Figure 3-24** and net acid production potential (NAPP) data is in **Figure 3-25**.

Borrow Areas V and B

Test pit composite samples from Borrow Area V (n=4) and Borrow Area B (n=7) have two TS groupings. Samples in the higher group (n=6) have 0.17 to 0.83% TS and 0.013 to 0.02% CRS. These samples have low MPA due to the low CRS but have a high potential to leach sulfate that may precipitate as secondary sulfate minerals. This interpretation is based on the water-soluble sulfate concentration after leaching for 16 hours (**Figure 3-28**). Samples in the lower group (n=5) have 0.04 to 0.1% TS. These samples have low TS and are unlikely to produce acid from sulfide oxidation as they are geochemically barren of sulfur and have a median NAPP of -30 kg H_2SO_4/t.

The NAPP concentration derived using TS and CRS where available for the samples from Borrow Areas V and B is -62.4 to -1.3 kg H_2SO_4/t. The composite samples from Borrow Areas V and B are classified as NAF_{BARREN}.

Borrow Areas W, T, and I

Composite samples from Borrow Areas W, T, and I (n=8) fall into two categories. Those in the higher group (n=4) have 0.11 to 0.55% TS and <0.005 to 0.2% CRS. Of these four samples, two are unlikely to produce acid from sulfide oxidation due to the low CRS and negative NAPP (median -2.4 kg H_2SO_4/t) and have a low potential to leach sulfate. The remaining two samples are not barren of sulfide sulfur but still have negative NAPP (median -7.6 kg H_2SO_4/t). Topsoil from Borrow Area T has 0.012% CRS but sufficient ANC to neutralise any acid produced. Topsoil from Borrow Area I has 0.2 % CRS and has a low capacity to produce acid and the amount of ANC produced may or may not be sufficient for neutralisation.

Samples in the lower group (n=4) have 0.01 to 0.1% TS. These samples have low TS and will not produce acid from sulfide oxidation as they are geochemically barren of sulfur (≤0.1%). The NAPP concentration derived using TS and CRS where available for the samples from Borrow Areas W, T, and I is -12.6 to -1.2 kg H_2SO_4/t. The ANC/MPA ratio is 1 to 38 using MPA values derived using TS and CRS. Six samples from Borrow Areas W, T, and I are classified as NAF_{BARREN}. One sample is NAF, and one is $NAF_{LOW\ CAPACITY}$.

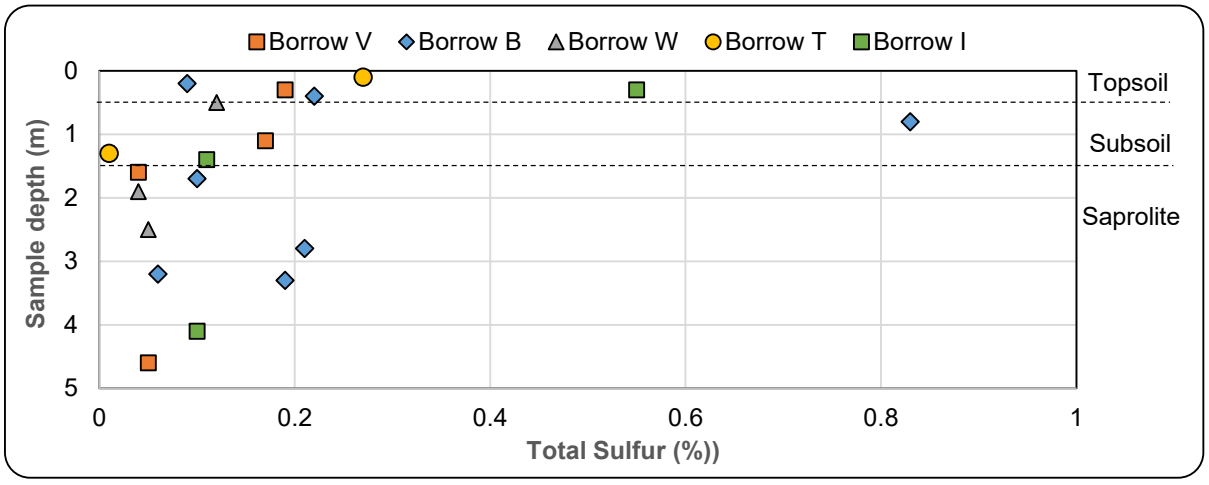


Figure 3-22: Total sulfur for borrow area soils

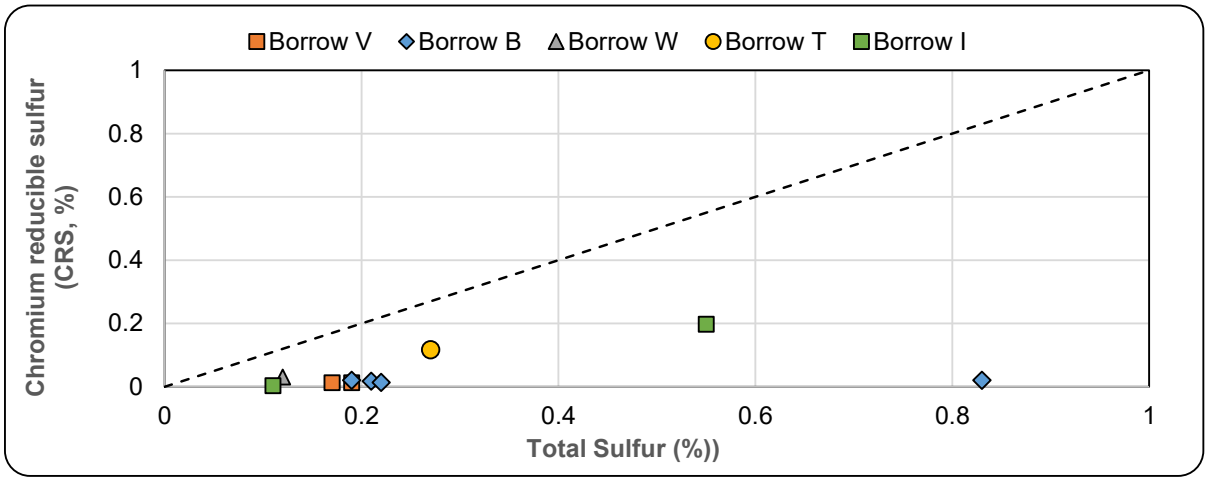


Figure 3-23: Relationship between TS and CRS for borrow area soils

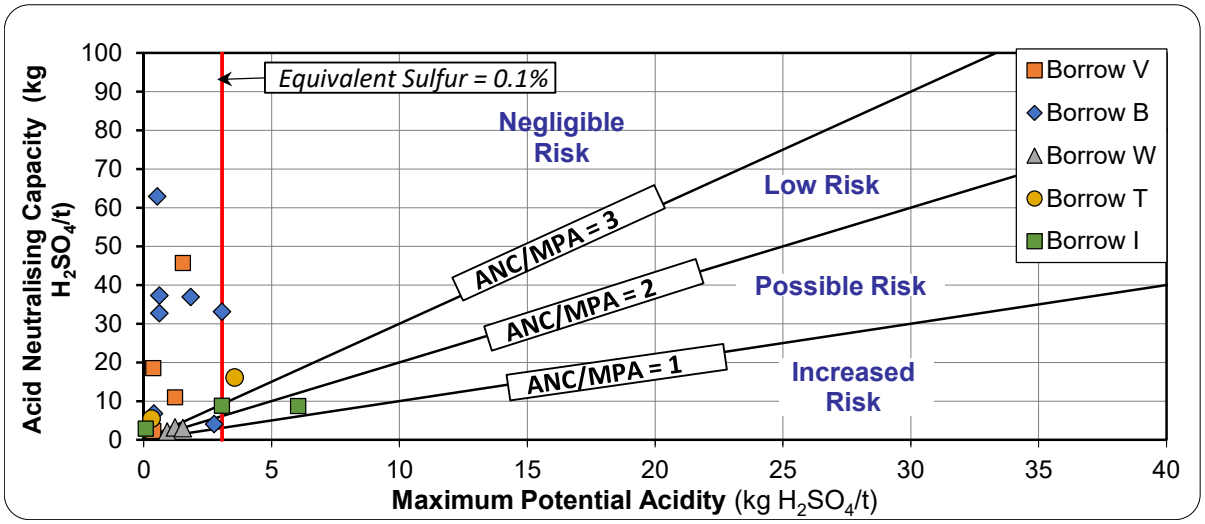


Figure 3-24: Correlation between ANC and MPA

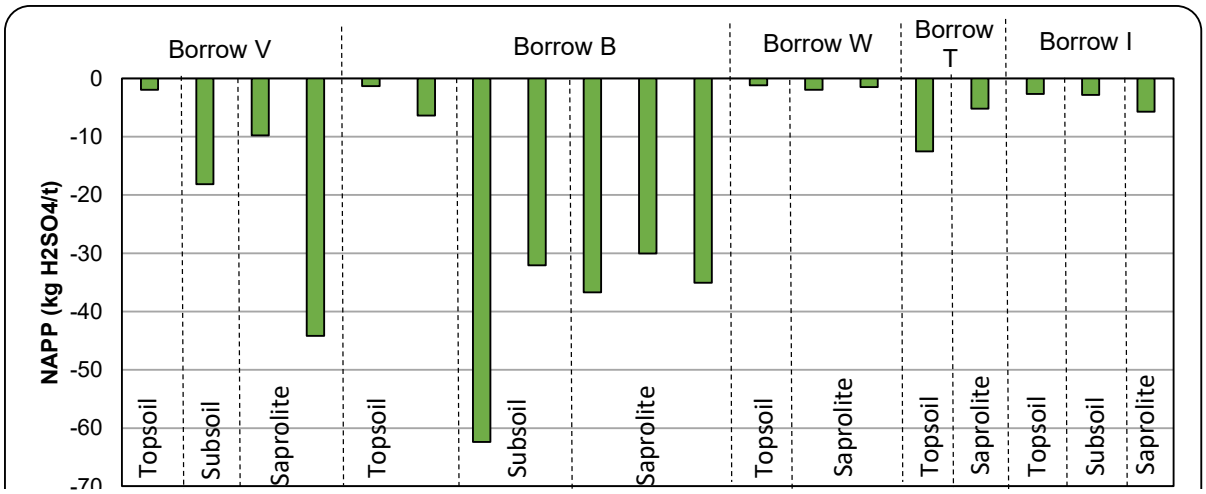


Figure 3-25: NAPP values for borrow area soils

3.2.2.3 NAPP classification

Table 3-9 provides a summary of the geochemical classification criteria used by RGS to classify the acid forming nature of the rehabilitation material samples from LLM.

- 90% of samples contain negligible TS to produce any AMD risk and are NAF_{BARREN}
- 5% of samples contain sufficient sulfide sulfur (CRS) to produce acid, but also enough neutralising capacity (ANC) to produce a negative NAPP value (≤-5 kg H_2SO_4/t). The topsoil sample from Borrow Area T was classified as Non-Acid Forming (NAF).
- 5% of samples have similar amounts of sulfide sulfur and ANC which may or may not be sufficient to buffer any acid produced (Non-Acid Forming – Low Capacity). This sample is considered low but possible risk. Only the topsoil sample from Borrow Area I was classified as Non-Acid Forming – Low Capacity (NAF-LC).

Table 3-9: Geochemical classification criteria for rehabilitation materials

Geochemical Classification	Total Sulfur [1] (%)	NAPP (kg H_2SO_4/t)	ANC: MPA Ratio	Rehabilitation Samples (n=19)
Non-Acid Forming (Barren)	≤ 0.1	-	≥ 3	17
Non-Acid Forming	> 0.1	≤ -5	≥ 3	1
Non-Acid Forming (Low Capacity)	> 0.1	> -5 and ≤ +5	> 2 < 3	1
Potentially Acid Forming (Low Capacity)	> 0.1	> 5 to ≤ 10	< 2 > 1	0
Potentially Acid Forming	> 0.1	> 10	< 1	0

Notes: 1. Sulfide sulfur (using the CRS test) has been measured for selected rehabilitation samples and where available, sulfide sulfur has been used in place of total sulfur for sample classification and to calculate MPA.

3.2.3 Salinity

3.2.3.1 Electrical conductivity

The $EC_{1:5}$, of the 47 samples is 18 to 5,510 µS/cm with a median of 776 µS/cm: 8 samples have > 3,000 µS/cm, 14 samples have 1,000 to 3,000 µS/cm and 25 samples have < 1,000 µS/cm (**Figure 3-26**).

The 8 samples with high $EC_{1:5}$ are all from topsoil and subsoil in Borrow Area V and B. $EC_{1:5}$ is 2,000 to 3,000 µS/cm in topsoil from Borrow Area T and I. All of the high $EC_{1:5}$ samples also have high TS and the salinity in these samples are dominated by sulfate, with a contribution from sodium chloride. The source of this could be celestine ($SrSO_4$) as strontium is elevated in the water soluble results (**Figure 3-28**). Other sulfate bearing minerals in the weathered zone could include gypsum, alunite, or barite.

3.2.3.2 Cation exchange capacity and exchangeable sodium percentage

Soil fertility results for the samples from borrow areas are in **Table 7-6 (Attachment B)**. Cation exchange capacity (CEC) results are 0.9 to 21.2 meq/100g with a median of 4.9 meq/100g and are sufficient to support native vegetation. From the results at LLM, CEC is higher in topsoil and subsoil due to their higher clay content and lower in saprolite samples, verifying that topsoil and subsoil have a better ability to provide nutrients. CEC is highest in Borrow Area V and B. The exchangeable sodium percentage (ESP) results are 0.1% to 73% with a median value of 6%. The ESP tests verify 49% of the samples are sodic or strongly sodic based on agricultural classification (Hazelton and Murphy, 2016). Sodic materials are in Borrow Area V and B (83%), and in Borrow Area I (17%) and were found in topsoil, subsoil, or saprolite samples.

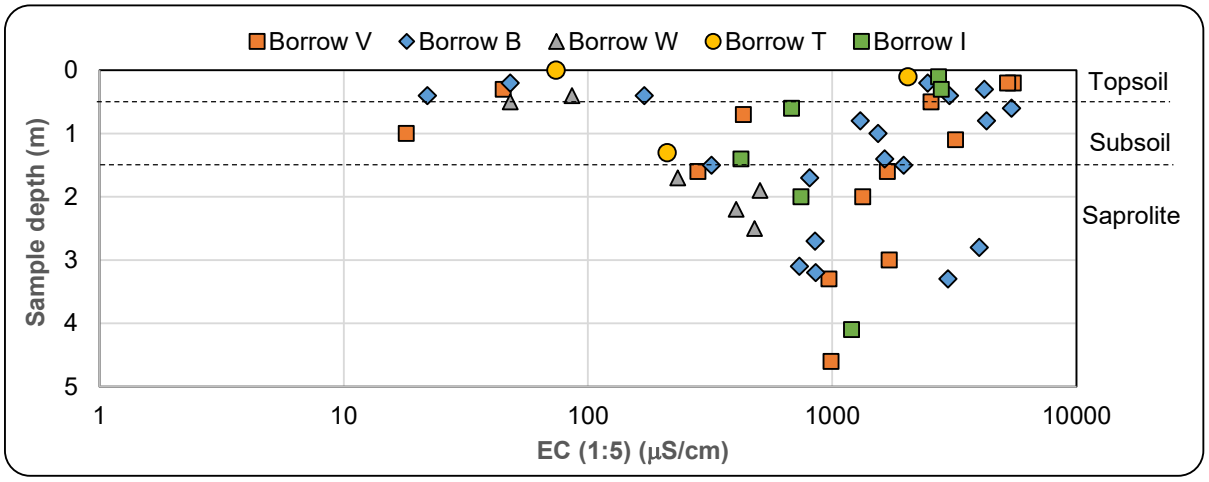


Figure 3-26: $EC_{1:5}$ for borrow area soils

3.2.3.3 Emerson Class

All individual test pit samples from Borrow Areas V, B, W, T, and I (n=47) underwent aggregate stability (Emerson Class) analysis. A lithological sample description is outlined for each test result in **Table 7-7 (Attachment B)**. Colours range from white to red-brown to brown, and from clays to sands. The range of classifications for each material verify Borrow Areas V, B, and W contain some dispersive materials (Class 1 or 2) but Borrow Areas T and I contain stable soil (Class 3 or 4) **(Table 3-10)**.

Emerson Class results are qualitative, not quantitative and exclude the effect of chemical parameters such as EC, and individual ion chemistry.

- 2% are Emerson Class 1: a single sample of saprolite from Borrow Area V is both slaking and dispersive
- 19% are Emerson Class 2: these tests are done on soil peds and samples have some dispersion
- 49% are Emerson Class 3: this is a sub class of Class 7 that has no dispersion from a soil ped and after remoulding samples have some dispersion
- 15% were Emerson Class 4: this is a sub class of Class 7 that has no dispersion from a soil ped and after remoulding samples have minor dispersion attributed to gypsum (4g) (n=6) or carbonate (4c) (n=1) minerals
- 15% were Emerson Class 6: this is a sub class of Class 7 that has no dispersion from a soil ped and after remoulding samples remain aggregated (flocculated).

Emerson Class 3 samples had the highest percentage (49%). Emerson Class 3 soils are defined as stable and suitable for most earthworks (Hazelton and Murphy, 2016). Only a small proportion (2%) of samples are Emerson Class 1 and dispersive, which suggests that not all sodic samples (based on ESP values) will be dispersive.

Table 3-10: Emerson Class results for rehabilitation materials

	Emerson Class Number		
	Topsoil	Subsoil	Saprolite
Borrow V	3 - 4	2	1 - 4
Borrow B	2 -6	2 - 6	2 - 6
Borrow W	2 - 3	---	3 - 4
Borrow T	3 - 4	---	3
Borrow I	4	3 - 6	3

3.2.3.4 Salinity classification

A quantitative method of soil classification for determination of soil slaking/dispersion/flocculation is the method developed by Rengasamy et al. (1984). The $EC_{1:5}$ and ESP results for 46 samples (including both topsoil and subsoil) were plotted to qualify the soil dispersion and assign a soil classification (**Figure 3-27**). Soils from Borrow Areas W and T (n=9) are Class 2A (n=5 or 56%), Class 3B (n=1 or 11%), or Class 3C (n=3 or 33%) which have few structural problems provided they are managed using minimum tillage.

Soils from Borrow Areas V, B, and I (n=37) classify as Class 2A (n=6 or 16%), Class 3C (n=6 or 16%), Class 3B (n=4 or 11%), Class 2B (potentially dispersive) (n=14 or 38%) or Class 3A (flocculated) (n=7 or 19%). Potentially dispersive soils with greater than 4,000 µS/cm have improved stability (Hazelton and Murphy, 2016). Dispersive materials with less than 4,000 µS/cm may be suitable as a low permeability layer to replace clay layer materials, which are unavailable at LLM.

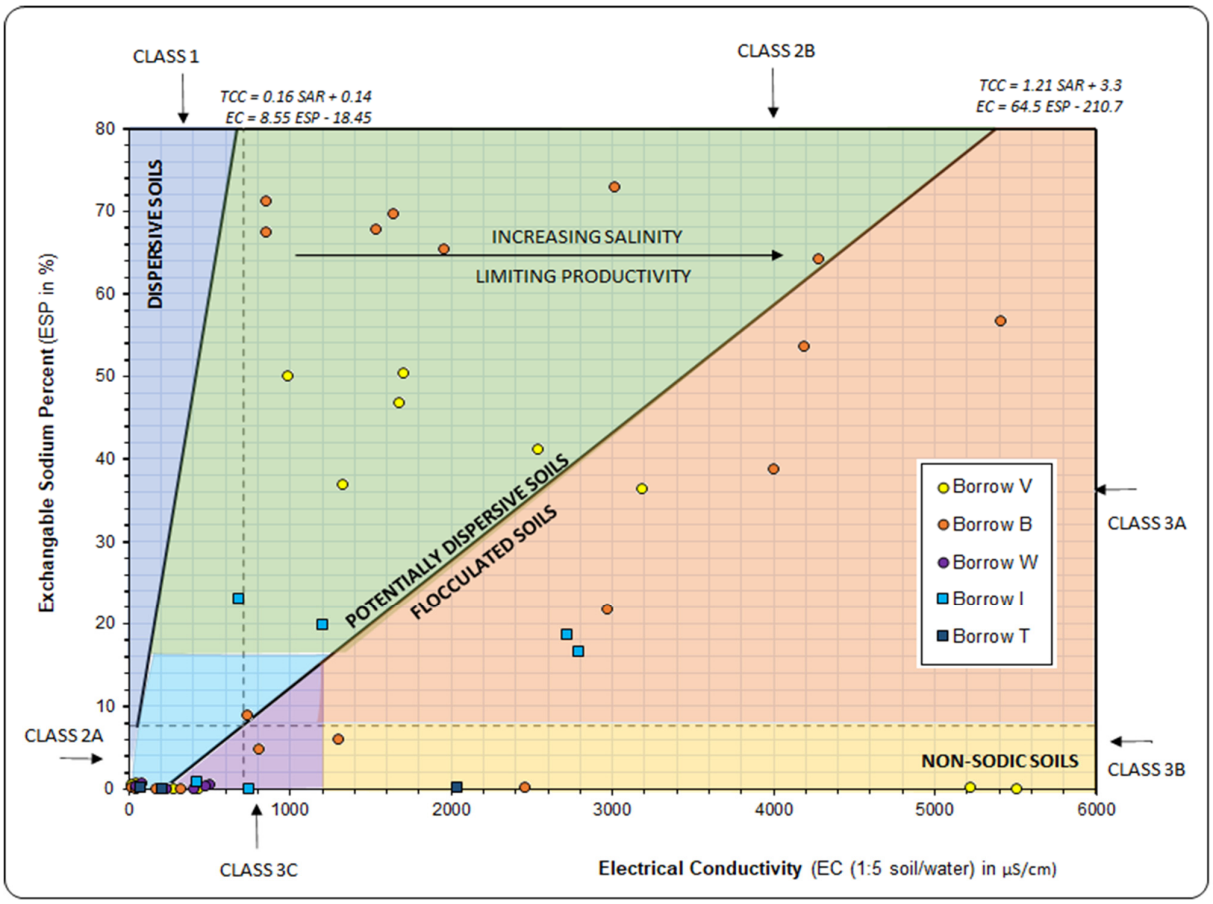


Figure 3-27: Salinity classification classes for soils from borrow areas

3.2.4 Metalliferous drainage potential

The 2-acid aqua regia digestible major cations, major anions, and multi-elements content (total metals) does not infer that the elements will be susceptible to environmental mobility but provides an indication of elemental enrichment. The 2-acid aqua regia digest elemental content of rehabilitation materials can be compared to baseline soil concentrations in order to determine any possible enrichment at least three orders of magnitude above global mean soil concentrations (**Table 3-11** and **Table 3-12**). Arsenic (As), Lead (Pb), and Zinc (Zn) is enriched in some soils and saprolite in Borrow Areas W, T and I, when compared to Borrow Areas V and B

(refer to shaded blue cells). Complete ALS analytical results are in **Section 7 (Attachment F: Attachment F: ALS** Certificate of Analyses**)**.

3.2.4.1 Water soluble elements

Water soluble multi-element results enable the solubility of major ions and metal(loids) in different material types to be compared and are not directly comparable to water quality guidelines.

The 1:3 – 16-hour water-soluble statistics and selected plots are in **Figure 3-28**. Analysis was undertaken on composite samples from Borrow Areas V, B, W, T, and I. Observations from these measurements are summarised below.

- No acid ($pH_{1:3}$) results below pH 5 were observed in any samples (n=19).
- $EC_{1:5}$, sodium (Na^+), sulfate (SO_4^{2-}), and chloride (Cl^-) concentrations (i.e., mobile salts) are highest in topsoil and subsoil samples from Borrow Area V, B, T, and I. Materials from Borrow Area W are comparatively low in mobile salts.
- Soluble Fluoride (F) is higher in subsoil and saprolite compared to topsoil samples in Borrow Areas V, B, W, and T which may infer the presence of muscovite and biotite (Chowdhury and Mohamed, 2018). These common silicate minerals have a high affinity to donate F during water and rock interactions. Water quality is monitored for soluble F as per the EA.
- High concentrations of soluble Aluminium (Al) in Borrow Area B observed in the Phase 1 investigation (3 – 4 mg/L) appear to be significantly lower (<0.01 – 0.03 mg/L) in Phase 2 results. Further investigation regarding Al colloidal particles will not be necessary.
- Soluble Manganese (Mn) appears in topsoil in both the Phase 1 (median 1.9 mg/L) and Phase 2 (median 2.1 mg/L) investigations. Mn(II) is present at acidic pH <5.5 and low redox potential, with increasing colloidal Mn at higher pH (Howe et. al. 2004).
- Concentrations of soluble Strontium (Sr) and Barium (Ba) as well as SO_4 in the leachate suggest the presence of barite and celestine. These minerals are usually sparingly soluble in water (pKsp values are 9.97 for barite and 6.63 for celestine) (Aqion, 2021).
- Despite the natural mineralisation of As, Pb, and Zn in soil and saprolite, these elements do not appear to be mobile. Soluble concentrations are very low, and only slightly above the LoR.

Table 3-11: Total metal (2-acid digest) results for borrow area soils and saprolite (Al-Mg)

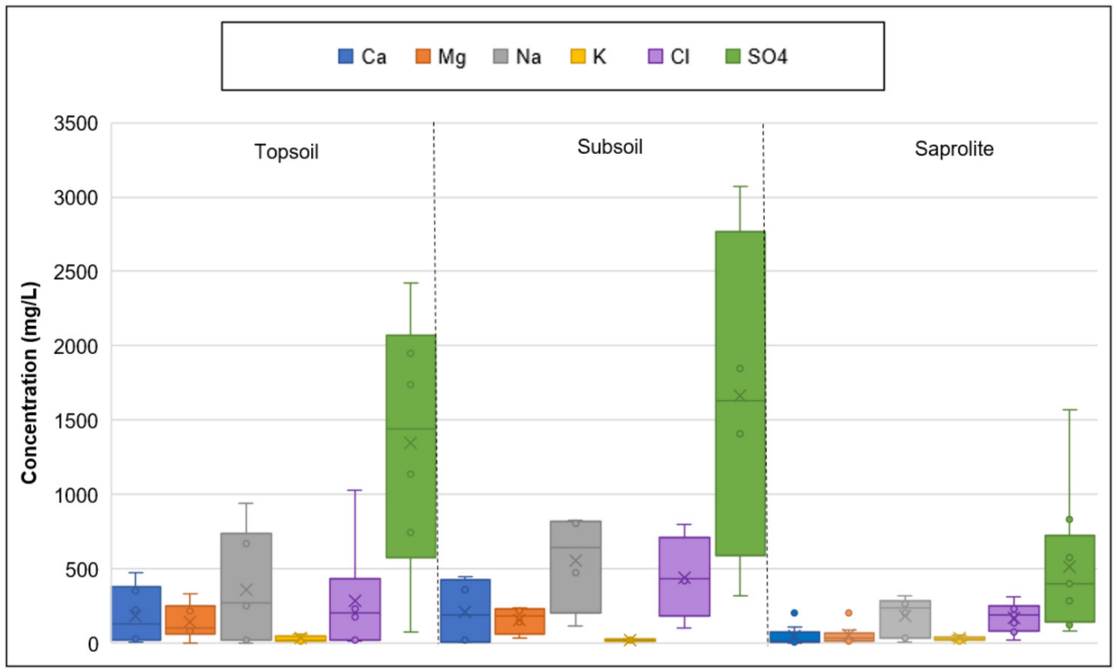
Borrow Area	Sample number	Aluminium	Antimony	Arsenic	Barium	Beryllium	Bismuth	Boron	Cadmium	Calcium	Caesium	Cerium	Chromium	Cobalt	Copper	Fluoride	Gallium	Germanium	Indium	Iron	Potassium	Lanthanum	Lead	Lithium	Magnesium
		Concentrations in mg/kg																							
V	C001	7400	1.3	15	130	0.7	0.3	5	0.1	300	0.3	35	12	6	13	770	3	0.05	0.03	36200	1500	17	14	4	2300
V	C002	13100	1.9	20	230	0.6	0.4	10	0.1	1400	0.4	42	14	6	16	750	4	0.05	0.04	48800	2300	20	21	5	5900
V	C003	5900	1.2	9	80	0.4	0.2	5	0.0	1800	0.2	45	8	4	9	770	2	0.05	0.02	24300	1400	22	10	3	2400
V	C004	6100	1.2	8	110	0.4	0.2	10	0.0	9300	0.3	48	7	3	6	870	2	0.05	0.02	19300	1600	24	7	4	6600
B	C005	9400	0.9	13	150	1.4	0.4	5	0.3	600	0.4	61	16	16	52	700	4	0.06	0.03	40500	1700	28	15	5	1700
B	C006	9800	0.9	12	210	1.6	0.4	5	0.2	15500	0.5	54	14	14	42	920	4	0.07	0.03	31700	1700	27	9	9	8200
B	C007	5800	0.5	6	60	0.9	0.4	5	0.2	7900	0.4	58	10	6	19	1090	2	0.06	0.02	14200	2000	30	7	5	5200
B	C008	11700	0.8	16	170	3.1	0.4	5	0.1	2000	0.5	60	24	26	44	700	5	0.07	0.03	47600	1500	24	15	14	2700
B	C009	14400	0.6	14	360	3.1	0.4	10	0.1	15000	0.6	49	21	19	36	680	6	0.07	0.03	38700	1700	22	10	16	6800
B	C010	8900	0.8	12	100	3.8	0.3	5	0.1	7800	0.4	56	14	11	18	1080	4	0.08	0.02	44400	1900	28	7	19	9400
B	C011	8000	0.6	13	160	3.2	0.3	5	0.1	7500	0.4	77	13	18	21	1100	4	0.07	0.02	29900	2000	30	11	24	8800
W	C012	7800	1.5	25	120	0.8	0.4	10	0.3	1300	0.5	26	11	4	18	770	3	0.05	0.03	46500	1900	12	202	2	500
W	C013	3700	1.7	9	120	0.5	0.5	10	0.0	100	0.2	7	4	2	5	1040	1	0.03	0.01	28300	2100	4	97	2	400
W	C014	3700	1.7	10	140	0.5	0.4	10	0.0	100	0.2	7	6	1	6	1180	1	0.03	0.01	34900	2100	4	112	2	400
T	C015	7300	1.8	18	200	1.2	0.3	5	1.4	5800	0.3	48	13	10	33	900	3	0.05	0.05	20700	1900	21	225	7	2100
T	C016	6700	0.7	10	60	1.1	0.3	5	0.1	400	0.3	55	11	7	20	1300	3	0.03	0.03	16500	2200	28	18	5	1800
I	C017	6300	2.3	53	330	3.3	0.5	5	1.6	4700	0.2	42	6	18	61	1030	2	0.05	0.09	37300	1800	19	250	4	2400
I	C018	9400	2.1	56	180	1.4	0.4	5	0.1	300	0.3	41	15	10	24	820	4	0.06	0.05	64100	1900	17	101	4	1100
I	C019	9200	1.9	40	250	2.4	0.4	10	0.2	800	0.3	16	9	23	40	930	3	0.03	0.05	72800	1700	7	74	3	2400

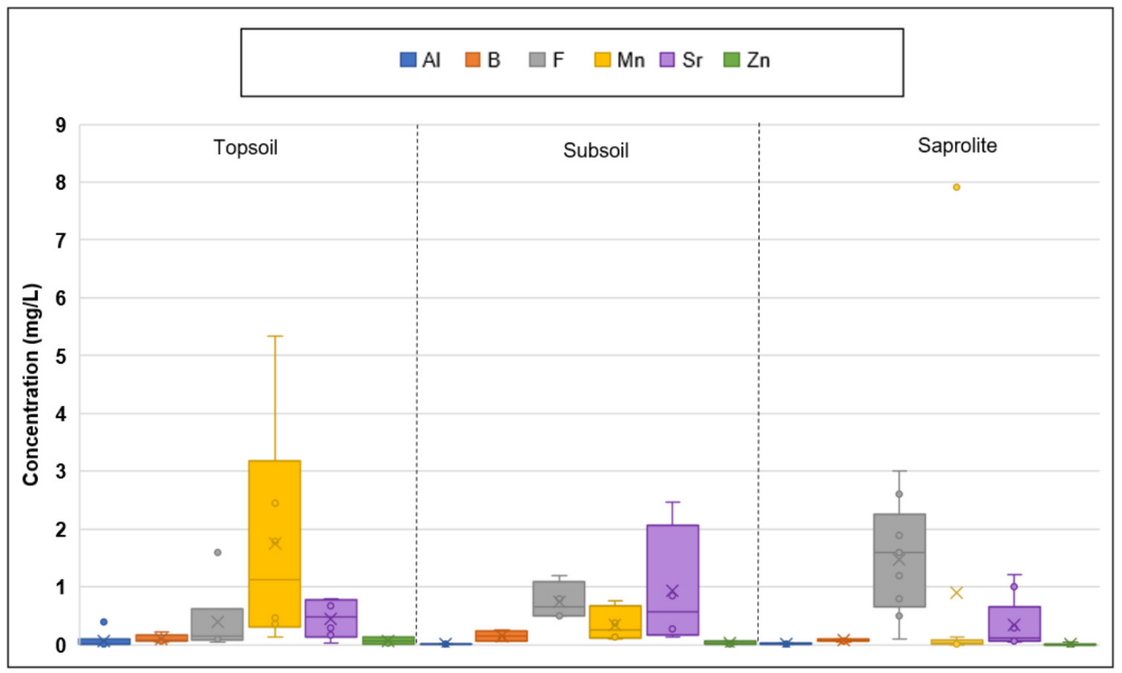
*Results below Limit of Reporting (LoR) not shown.

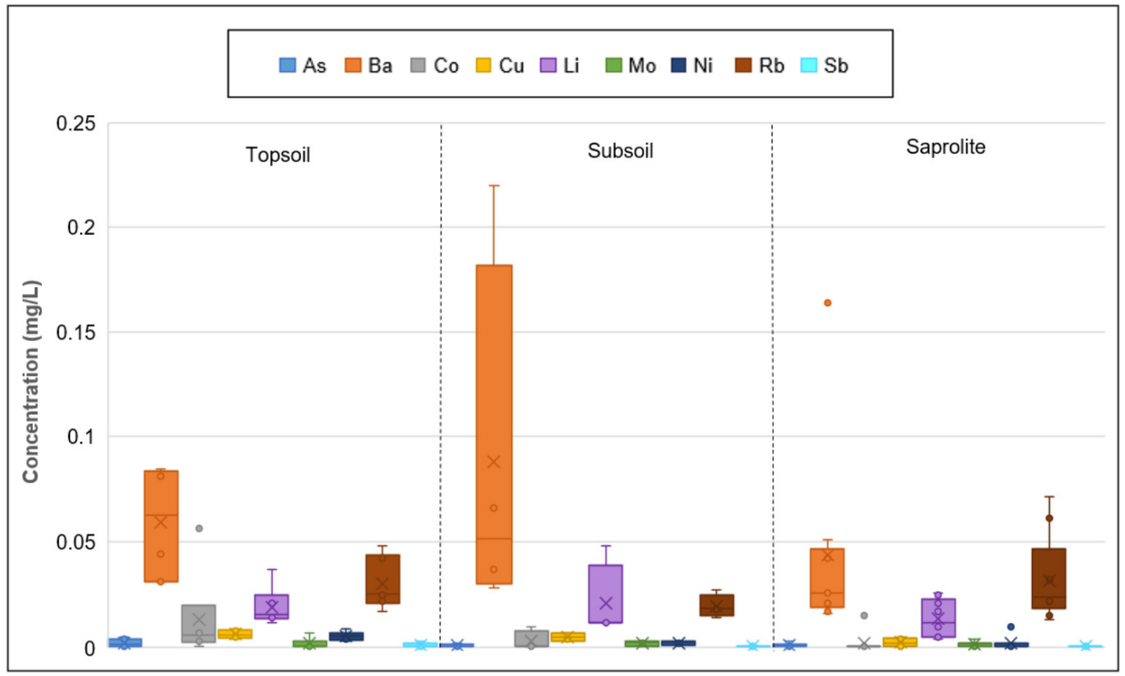
Table 3-12: Total metal (2-acid digest) results for borrow area soils and saprolite (Mn-Zr)

Borrow Area	Sample number	Manganese	Mercury	Molybdenum	Nickel	Niobium	Phosphorous	Rubidium	Scandium	Selenium	Silver	Sodium	Strontium	Sulfur	Tellurium	Thallium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Yttrium	Zinc	Zirconium
		Concentrations in mg/kg																							
V	C001	138	0.01	0.8	6	0.4	90	10	2	0.3	0.1	3200	11	2100	0.04	0.2	5.0	0.6	190	0.11	1.9	23	6	36	10
V	C002	144	0.01	0.9	7	0.3	90	14	2	0.3	0.2	3000	21	1700	0.06	0.3	7.0	0.8	250	0.11	2.6	30	7	61	18
V	C003	89	0.01	0.5	4	0.2	60	9	2	0.2	0.1	900	10	300	0.05	0.1	5.3	0.4	180	0.08	1.0	16	5	21	10
V	C004	55	0.01	0.4	4	0.2	70	9	2	0.1	0.1	1200	29	400	0.06	0.2	6.1	0.4	150	0.07	1.2	14	5	16	11
B	C005	713	0.02	1.0	19	0.2	270	13	4	0.4	0.1	1300	12	900	0.04	0.3	6.6	0.5	110	0.03	1.9	30	12	147	7
B	C006	401	0.02	0.9	19	0.1	230	14	4	0.3	0.1	1700	40	2000	0.05	0.3	6.7	0.4	100	0.05	2.0	25	11	102	9
B	C007	87	0.01	0.4	11	0.0	190	11	3	0.1	0.1	700	48	2100	0.03	0.1	7.1	0.2	25	0.03	1.6	9	6	118	11
B	C008	1035	0.01	1.4	38	0.1	260	14	5	0.7	0.1	2500	19	2200	0.07	0.3	6.1	0.5	120	0.05	1.5	41	17	136	9
B	C009	641	0.01	1.0	41	0.1	190	16	4	0.5	0.1	3100	62	8500	0.10	0.3	5.8	0.6	110	0.05	1.6	38	17	124	11
B	C010	435	0.03	0.7	38	0.0	240	12	4	0.1	0.1	1300	27	1000	0.07	0.1	5.6	0.2	50	0.03	1.3	14	11	226	12
B	C011	797	0.03	1.4	32	0.0	320	12	3	0.2	0.1	1200	29	600	0.07	0.4	5.9	0.2	25	0.03	1.9	14	13	211	12
W	C012	81	0.05	1.7	8	1.0	220	16	2	0.5	0.6	200	14	500	0.03	0.5	3.5	0.6	190	0.19	2.8	18	12	150	2
W	C013	25	0.01	0.9	3	0.3	130	10	1	0.1	0.2	300	8	200	0.03	0.2	3.6	0.3	120	0.16	1.0	4	2	33	11
W	C014	26	0.01	0.8	3	0.6	120	10	1	0.2	0.2	300	11	200	0.04	0.2	3.8	0.4	190	0.22	0.9	6	2	35	13
T	C015	259	0.10	1.0	12	0.2	240	12	3	0.4	0.6	300	15	2900	0.07	0.7	3.9	0.4	80	0.05	1.6	19	12	674	5
T	C016	52	0.01	0.5	19	0.0	290	11	2	0.2	0.0	200	11	100	0.09	0.1	4.5	0.2	50	0.03	2.7	9	20	108	10
I	C017	287	0.10	2.2	22	0.1	290	8	5	0.4	0.6	1100	17	5700	0.10	2.0	5.3	0.3	60	0.06	3.4	14	10	810	9
I	C018	359	0.02	3.0	13	0.4	220	13	3	0.9	0.4	600	23	600	0.09	3.2	5.1	0.8	180	0.09	1.9	32	11	118	6
I	C019	378	0.02	2.3	32	0.1	320	11	5	0.5	0.3	1100	51	900	0.07	1.0	4.7	0.6	120	0.07	1.6	19	8	698	11

*Results below Limit of Reporting (LoR) not shown.







*Results below Limit of Reporting (LoR) not shown.

Figure 3-28: 1:3 (16hr) water-soluble multi-element results for rehabilitation materials

3.2.5 Physical properties

3.2.5.1 Soil moisture

The soil moisture contents for borrow area materials are shown in **Table 7-8 (Attachment B)**. Soil moisture shows little variation throughout the profile. Subsoil has the highest moisture content (median 8.9%) and topsoil is the driest (median 7.9%) due to evaporation. The amount of water held will also depend on the soil texture (clay, silt, sand, or gravel) as well as the structure of the soil e.g., compaction.

3.2.5.2 Particle size distribution

For the borrow areas, **Figure 3-29** and **Table 3-13** show that the topsoil, subsoil and saprolite of Borrow Areas V and B contain a larger proportion of fine (clay, silt and sand) material compared to Borrow Areas W, T, and I, which have a higher proportion of gravel. In Borrow Areas V and B, subsoil has a higher proportion of clay compared to topsoil. However, Borrow Area V topsoil contains more gravel (33%) than Borrow Area B topsoil (18-23%). Soil and saprolite from Borrow W has 51-62% gravel, and only 0-9% clay, verifying that the geology of the parent materials is different.

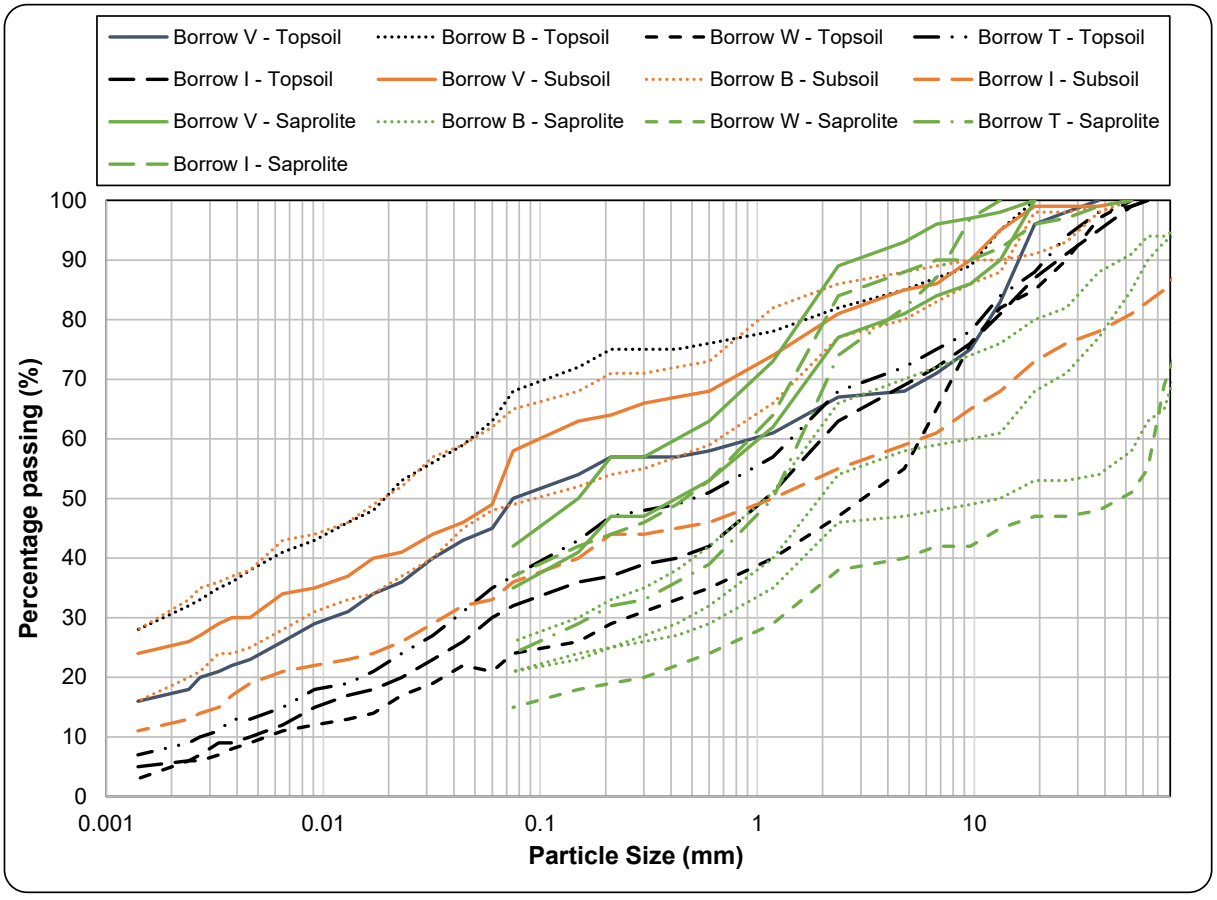


Figure 3-29: PSD results for rehabilitation materials

Table 3-13: Summary of PSD results for soil and saprolite

	Clay (<0.04 mm)	Silt (0.004 – 0.062 mm)	Sand (0.062 – 2.0 mm)	Gravel (> 2.0 mm)
Borrow V	0 – 30%	0 – 22%	22 – 89%	11 - 33%
Borrow B	0 – 38%	0 – 25%	19 – 66%	14 – 54%
Borrow W	0 – 9%	0 – 12%	26 – 49%	51 – 62%
Borrow I/T	0 – 19%	0 – 22%	22 – 84%	16 – 45%

3.2.5.3 Soil texture classification

Using the PSD results and only the fine (excluding gravels) proportions (0 – 100%) of clay (< 0.002 mm PSD), silt (> 0.002 to < 0.05 mm PSD), and sand (> 0.05 to < 2 mm PSD), topsoils and subsoils from the borrow areas have been plotted on a soil texture classification triangle (**Figure 3-30**).

Saprolite has been excluded as only coarse PSD down to 0.075 mm was performed on these samples. The results confirm that in Borrow Area V and B, the < 2 mm PSD fraction is classifying as clay to clay loam, while the 2mm PSD fraction from Borrow Area W, T, and I, tend to have a higher proportion of sand classifying them as clay loam to sandy loam (**Table 3-14**).

Excluding gravels, topsoil and subsoil from Borrow Areas V and B are 40 – 60% sand, 20 – 40% silt and 30 – 50% clay; whereas topsoil and subsoil from Borrow Areas W, T, and I are 60 – 80% sand, 20 – 40% silt and 10 – 20% clay.

Table 3-14: Soil texture triangle classifications for borrow area soils

	Soil Texture	
Borrow Area	Topsoil	Subsoil
Borrow V	Clay loam	Clay loam
Borrow B	Clay - Clay Loam	Clay - Clay Loam
Borrow W	Sandy Loam	---
Borrow T	Loam	---
Borrow I	Loam	Clay Loam

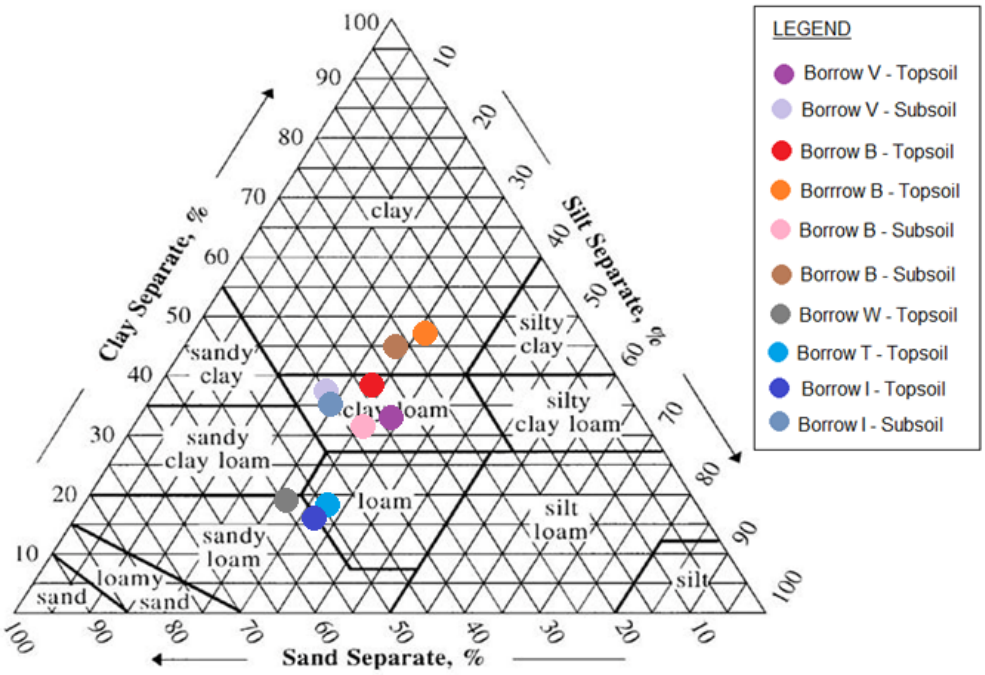


Figure 3-30: Soil texture triangle for borrow area soils

3.2.5.4 Atterberg Limits

Topsoils and subsoils (<0.004 mm) from Borrow Areas V, B, W, T, and I underwent analysis for Atterberg Limits, which is a measure of clay plasticity. Saprolite was not tested as the materials are rocky, making them unsuitable for the analysis.

The Atterberg results verify the topsoils and subsoils have low liquid limits and linear shrinkage values. This verifies that the soils are low in shrinking and swelling clay mineral types (

Table 3-15). Plasticity index (PI) % is the water content at which the soil begins to display plastic properties. It can be non-plastic (0%), slightly plastic (1-6%), medium plastic (7-17%), or highly plastic (18-100%) (Sowers, 1979). Silt and sand have very low or no plasticity. Complete physical results from Trilab are included in **Section 7 (Attachment G: Trilab Laboratory Certificate of Analyses)**.

The AASHTO soil classifications based on WAQTC (2020) are presented in **Figure 7-19 (Attachment B).**

- Topsoil and subsoil from Borrow Areas V and B, as well as subsoil from Borrow Area I is medium to highly plastic by its Plasticity Index % (11-28%), and is a low plasticity clay according to AASHTO soil classifications;
- Borrow Areas W, T, and I contain topsoil that is slightly to medium plastic by its Plasticity Index % (8-11%), with T classified as low plasticity silt and W as low plasticity clay according to AASHTO soil classifications. Borrow Area I can be either low plasticity silt or clay.

Table 3-15: Atterberg limits for borrow area soil composites

	Borrow V		Borrow B				Borrow W	Borrow T	Borrow I	
	Topsoil	Subsoil	Topsoil	Topsoil	Subsoil	Subsoil	Topsoil	Topsoil	Topsoil	Subsoil
Liquid Limit (%)	24	29	25	28	31	39	30	27	26	29
Plastic Limit (%)	13	11	11	10	13	11	19	18	18	13
Plasticity Index (%)	11	18	14	18	18	28	11	9	8	16
Linear Shrinkage (%)	2	8	7	8	7	11	2	2	2	8

3.2.5.5 Maximum dry density and bulk density

The median results for bulk density and maximum dry density are shown in **Table 3-16**. Bulk density is the soil weight per unit volume measured in-situ. Topsoil from Borrow Areas V and B have a higher bulk density than subsoil due to the higher proportion of gravel (**Section 3.2.5.2**). Saprolite usually has a high bulk density compared to topsoil and subsoil but varies depending on the proportion of fine particles and how weathered the material is. The median bulk density results range from 1.44 to 2.12 t/m^3 for soil and saprolite.

Maximum dry density is a measure of the dry soil weight per unit volume and is measured as part of permeability testing. The median results range from 1.72 to 1.92 t/m^3.

Table 3-16: Bulk density and dry density measurements of rehabilitation materials

	Median bulk density (t/m^3)			Median maximum dry density (t/m^3)		
	Topsoil	Subsoil	Saprolite	Topsoil	Subsoil	Saprolite
Borrow V	1.59	1.44	1.55	1.86	1.83	1.72
Borrow B	1.58	1.53	1.51	1.92	1.83	1.72
Borrow W	1.60	---	2.12	1.77	---	---
Borrow T	1.48	---	1.53	1.72	---	---
Borrow I	1.69	2.00	1.61	1.79	1.89	---

3.2.5.6 Permeability

The soil composites have permeability (K_{sat} 90% standard compaction) values that are lowest (3.8 x 10^{-8} m/s) in Borrow Area B topsoil and highest (2.9 x 10^{-5} m/s) in Borrow Area I topsoil, with a median result of 7.8 x 10^{-6} m/s. When remoulded to a higher Proctor Compaction Test ratio (K_{sat} 95% standard compaction), permeability decreases and is lowest (1.8 x 10^{-9} m/s) in Borrow Area B subsoil and highest (4.0 x 10^{-7} m/s) in Borrow Area I topsoil, with a median 5.6 x 10^{-8} m/s (**Table 3-17**). Permeability graphs are in **Section 7.2.10.4 (Attachment B)**.

Soils from Borrow Area B have lower permeability than Borrow Area V, for both compaction ratios. Borrow Areas W, T, and I have higher permeability than the other borrow areas. Permeability decreases with depth from topsoil to subsoil but increases from subsoil to saprolite. These results verify that subsoil from Borrow Area B has the lowest permeability of all the rehabilitation materials.

Table 3-17: Permeability of rehabilitation materials

		Falling head permeability k Sat 95% (m/sec)	Falling head permeability kSat 90% (m/sec)
Borrow Area V	Topsoil	9.4×10^{-8}	1.5×10^{-5}
Borrow Area V	Subsoil	1.2×10^{-8}	1.5×10^{-5}
Borrow Area B	Topsoil	1.7×10^{-8}	1.1×10^{-5}
Borrow Area B	Topsoil	5.4×10^{-9}	3.8×10^{-8}
Borrow Area B	Subsoil	1.1×10^{-7}	1.6×10^{-6}
Borrow Area B	Subsoil	1.8×10^{-9}	1.4×10^{-7}
Borrow Area W	Topsoil	2.2×10^{-7}	4.6×10^{-6}
Borrow Area T	Topsoil	2.8×10^{-7}	1.3×10^{-5}
Borrow Area I	Topsoil	4.0×10^{-7}	2.9×10^{-5}
Borrow Area I	Subsoil	1.4×10^{-8}	7.7×10^{-7}

3.2.5.7 Compaction

California Bearing Ratio (CBR) results verify that topsoils and subsoils (CBR 1.5 – 2.5%) in Borrow Areas V and B have lower CBR values compared to saprolite (CBR 6-7%). Saprolite in Borrow Area B compacts to form a slightly harder surface than saprolite from Borrow Area V (**Table 3-18**). Additional graphs are shown in **Figure 7-24 (Attachment B)**.

Table 3-18: California Bearing Ratio (CBR) compaction results for Borrow Areas V and B

		Max Force	Max Penetration	CBR Penetration	CBR Value	Equivalent to	Comments
Sample	Material	(kN)	(mm)	(mm)	(%)		
C001	Topsoil - Borrow V	0.60	12.5	2.5	1.5	Clay	Low
C002	Subsoil - Borrow V	0.68	12.5	2.5	2.5	Clay-silt	Low-moderate
C003	Saprolite - Borrow V	1.79	12.5	2.5	6.0	Sand	Moderate
C004	Saprolite - Borrow V	2.40	12.5	2.5	6.0	Sand	Moderate
C005	Topsoil - Borrow B	0.52	12.5	5.0	1.5	Clay	Low
C006	Subsoil - Borrow B	0.78	12.5	2.5	2.5	Clay-silt	Low-moderate
C010	Saprolite - Borrow B	2.10	12.5	5.0	7.0	Sand	Moderate-high
C011	Saprolite - Borrow B	2.80	12.5	5.0	7.0	Sand	Moderate-high

3.2.5.8 Soil-water characteristic curves

Table 3-19 document that the clay loam soils from Borrow Areas V and B have a field capacity of 0.2 cm^3/cm^3 and a permanent wilting point of 0.4 cm^3/cm^3. By comparison, loamy soils from Borrow Areas W, T, and I have a field capacity of 0.15 cm^3/cm^3 and a permanent wilting point of 0.35 cm^3/cm^3. Borrow Area V and B soils have a higher water retention capacity than other borrow areas, although the volume of plant available water (i.e., the difference between the permanent wilting point and field capacity) is similar for all borrow areas. In **Table 3-19**, saturated moisture content refers to a matric suction of 0 kPa; field capacity is 33 kPa, and wilting point is 1,500 kPa. Complete results from Soil Water Group are included in **Section 8 (Attachment H: Soil Water Group Laboratory Certificates**

Table 3-19: Soil water characteristic curve results with derived van Genuchten parameters

Borrow area	Material type	Soil texture classification	Volumetric Moisture Content (cm^3/cm^3)					Derived van Genuchten Parameters			
			0 kPa	10 kPa	33 kPa	100 kPa	1,500 kPa	a (1 /cm)	N (-)	qs (cm^3/cm^3)	qr (cm^3/cm^3)
Borrow V	Topsoil	Clay Loam	0.40	0.24	0.22	0.20	0.16	1.000	1.158	0.41	0.09
Borrow V	Subsoil	Clay Loam	0.44	0.25	0.22	0.20	0.15	1.000	1.157	0.44	0.07
Borrow V	Saprolite	Silt Loam	0.46	0.29	0.25	0.22	0.13	0.182	1.153	0.46	0.00
Borrow V	Saprolite	Silt Loam	0.46	0.31	0.26	0.22	0.13	0.080	1.174	0.46	0.00
Borrow B	Topsoil	Clay Loam	0.44	0.21	1.18	0.16	0.13	0.999	1.246	0.44	0.10
Borrow B	Subsoil	Clay Loam	0.46	0.21	0.19	0.18	0.14	1.000	1.263	0.47	0.11
Borrow B	Saprolite	Silt Loam	0.48	0.35	0.31	0.25	0.14	0.043	1.178	0.48	0.00
Borrow B	Topsoil	Clay	0.48	0.23	0.20	0.19	0.17	1.000	1.334	0.48	0.16
Borrow B	Subsoil	Clay	0.52	0.25	0.24	0.22	0.17	0.084	1.694	0.52	0.17
Borrow B	Saprolite	Silt Loam	0.48	0.36	0.30	0.24	0.14	0.038	1.192	0.48	0.00
Borrow B	Saprolite	Silt Loam	0.50	0.34	0.29	0.23	0.13	0.054	1.196	0.50	0.00
Borrow W	Topsoil	Sandy Loam	0.49	0.32	0.28	0.23	0.15	0.149	1.154	0.49	0.00
Borrow W	Saprolite	Silt Loam	0.43	0.28	0.23	0.16	0.12	0.040	1.377	0.43	0.09
Borrow W	Saprolite	Silt Loam	0.38	0.20	0.18	0.15	0.09	0.487	1.157	0.38	0.00
Borrow T	Topsoil	Loam	0.45	0.26	0.24	0.20	0.13	0.347	1.144	0.45	0.00
Borrow T	Saprolite	Silt Loam	0.52	0.34	0.27	0.20	0.10	0.046	1.248	0.52	0.00
Borrow I	Topsoil	Loam	0.42	0.31	0.26	0.20	0.09	0.023	1.250	0.42	0.00
Borrow I	Subsoil	Clay Loam	0.46	0.26	0.23	0.20	0.15	1.000	1.146	0.46	0.05
Borrow I	Saprolite	Loam	0.49	0.40	0.33	0.25	0.13	0.015	1.243	0.49	0.00

3.2.5.9 Point load index

The point load index value of saprolite samples from Borrow Areas V, B, W, T, and I have been analysed (**Table 3-20).** The load strengths (Is) of the materials range from 0.06 to 1.60 MPa (or MN/m^2) and are classified as irregular lumps. When a correction factor is applied to standardise the samples to have a 50 mm diameter, the corrected load strengths (Is(50)) range from 0.06 to 1.90 MPa (median 0.40 MPa). These values are shown in **Table 3-20,** and range from weak to strong. A comparison of the saprolite samples to standard rock materials is shown in **Figure 3-31**.

- The majority of rock types from all borrow areas fall within the expected point load strength range for mudstone and sandstone and have low to medium Is(50) ranging from 0.1 to 1.0 MPa.
- Borrow Area W provides the most competent saprolite of all the borrow areas and has a median Is(50) of 0.98 MPa.
- The weakest saprolite is highly weathered material from Borrow Areas V and B and two samples (0015 and 0004) have ≤0.1 MPa which is equivalent to stiff clay.
- By comparison, quartzite from Borrow Area C is very strong, has Is(50) of 7.27 MPa (**Table 3-20**).

Table 3-20: Point load strength of saprolite from borrow areas

Borrow area	#	Depth from	Depth to	Weathering	Is (Mpa)	Class	Is(50) (Mpa)	Class
Borrow V	0004	1.1	1.6	Highly weathered	0.10	Weak	0.10	Very low
Borrow V	0005	1.6	3.0	Highly weathered	0.42	Mod. weak	0.40	Medium
Borrow V	0006	3.0	4.6	Moderately weathered	0.14	Weak	0.14	Low
Borrow V	0008	0.3	1.0	Moderately weathered	0.69	Mod. strong	0.70	Medium
Borrow V	0009	1.0	1.6	Highly weathered	0.64	Mod. strong	0.69	Medium
Borrow V	0030	0.2	0.7	Moderately weathered	0.35	Mod. weak	0.39	Medium
Borrow V	0031	0.7	2.0	Highly weathered	0.57	Mod. strong	0.66	Medium
Borrow V	0032	2.0	3.3	Highly weathered	0.36	Mod. weak	0.39	Medium
				Median	**0.39**		**0.40**	
Borrow B	0012	2.8	3.3	Highly weathered	0.13	Weak	0.14	Low

Borrow B	0015	0.8	1.7	Moderately weathered	0.06	Weak	0.06	Very low
Borrow B	0016	1.7	3.1	Moderately weathered	0.78	Mod. strong	0.87	Medium
Borrow B	0019	0.8	1.0	Moderately weathered	0.35	Mod. weak	0.38	Medium
Borrow B	0020	1.0	1.4	Highly weathered	0.43	Mod. weak	0.42	Medium
Borrow B	0021	1.4	2.7	Highly weathered	0.16	Weak	0.18	Low
Borrow B	0024	0.6	1.5	Highly weathered	0.21	Weak	0.22	Low
Borrow B	0025	1.5	3.2	Highly weathered	0.18	Weak	0.20	Low
Borrow B	0028	0.4	1.5	Slightly weathered	1.52	Strong	1.48	High
				Median	**0.21**		**0.22**	
Borrow W	0034	0.5	1.9	Moderately weathered	0.90	Mod. Strong	0.93	Medium
Borrow W	0035	1.9	2.5	Moderately weathered	1.05	Mod. Strong	1.11	High
Borrow W	0037	0.4	1.7	Moderately weathered	0.83	Mod. Strong	0.91	Medium
Borrow W	0038	1.7	2.2	Moderately weathered	1.60	Strong	1.90	High
				Median	**0.98**		**1.02**	
Borrow T	0041	0.1	1.3	Moderately weathered	0.45	Mod. weak	0.46	Medium
Borrow I	0047	2.0	4.1	Highly weathered	0.13	Weak	0.14	Low

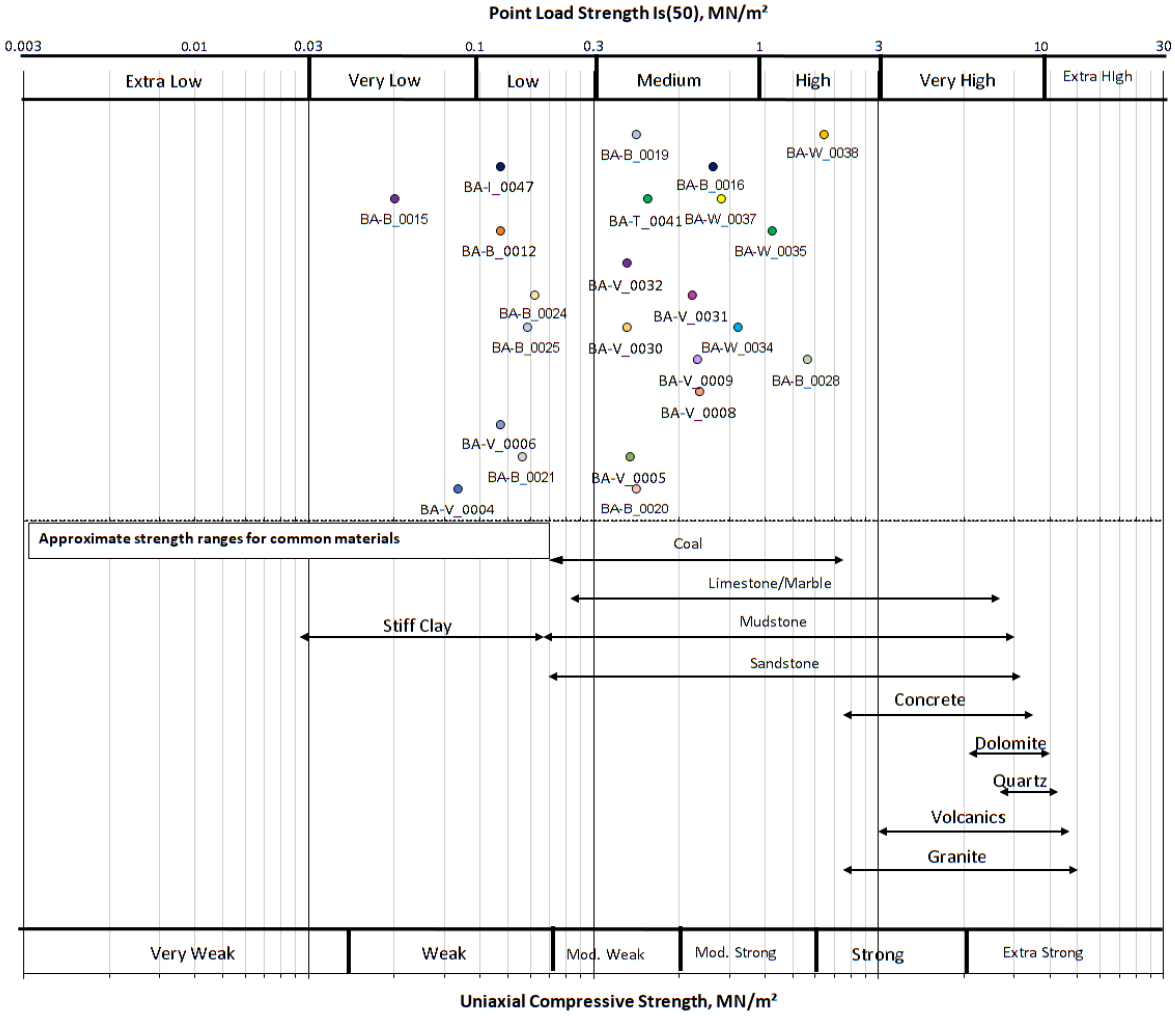


Figure 3-31: Point load strength of borrow materials compared to standard materials

3.2.6 Topsoil stockpiles

The topsoil stockpiles were stripped during site construction and then stockpiled in paddock dumped piles or windrows. The analyses for these samples verify they will provide suitable growth medium. Parameters to verify the characteristics of the topsoil stockpile samples (n=7) and composites (n=5) are in **Table 3-21** and summarised in **Section 3.2.6.1** and **3.2.6.2.** Additional data tables and figures are in **Section 7.2.3 (Attachment B)**.

3.2.6.1 Soil fertility and geochemistry

The soils are mildly acidic to circumneutral ($pH_{1:5}$ 4.5 to 6.7) and are non-saline to slightly saline ($EC_{1:5}$ 36 to 451 µS/cm, median 241 µS/cm). They have good soil fertility, including organic matter (OM) at 2.8 to 14% with a median of 4.4%). Cation exchange capacity (CEC) is sufficient for plant growth (0.8 to 5.6 meq/100g) and the soils are non-sodic (ESP <0.1 to 5%). Fertiliser addition should not be required as the nutritional content of the topsoil is sufficient to support native vegetation as evidenced in non-disturbed areas.

3.2.6.2 Physical properties

The topsoils are classed as a clayey gravel (GC) by the Unified Soil Classification System (USCS). The topsoils contain gravel (35 to 51%) as well as clay, silt, and sand (65 to 49%). The fines fraction (< 2 mm PSD) is classified as a sandy clay loam in terms of soil texture. They are low plasticity clays and silts and have a bulk density of 1.3 to 1.9 t/m^3. All the samples are classified as Emerson Class 3, which are stable with good structure and suitable for most earthworks. Permeability is 2.9×10^{-5} to 1.3×10^{-6} at 90% compaction ratio but could be reduced with further compaction. The extracted volumetric soil moisture is 0.20 cm^3/cm^3 at field capacity to 0.36 cm^3/cm^3 at permanent wilting capacity, demonstrating that the soils have sufficient water retention capability for their intended purpose.

3.3 Phase 1 and Phase 2 material specification

Borrow Areas B1, B2, A and I have been nominated as optional borrow sites to provide (i) growth medium for local vegetation and (ii) rocky soil mulch. Borrow Area C will provide blocky rock for rock armouring. Definitions of material types is included in **Table 7-1 (Attachment B)**.

Borrow pit shells for Borrow Areas B1, B2, A, I and C have been modelled and images can be found in **Attachment E: Borrow area pit shells.**

The key findings from Phase 1 and 2 are as follows.

- All soil samples (n=32) are circumneutral at $pH_{1:5}$ 5.3 to alkaline at $pH_{1:5}$ 9.1 with a median of $pH_{1:5}$ 8.3.
- The $EC_{1:5}$, of the 47 samples is 18 to 5,510 µS/cm with a median of 776 µS/cm: 8 samples have > 3,000 µS/cm, 14 samples have 1,000 to 3,000 µS/cm and 25 samples have < 1,000 µS/cm (**Figure 3-26**).
- Soil and saprolite samples in Borrow Areas V and B have the highest $EC_{1:5}$ (dominated by sulfate, with a contribution from sodium chloride) and are suitable for rehabilitation.
- The $EC_{1:5}$, ESP and Emerson Classification of the samples (**Section 3.2.3.4** and **Figure 3-27, Attachment B**) verify the soils are Class 2A (n=7), Class 3A (n=5), or Class 3C (n=4) that are flocculated soils and the remaining soils are Class 3B (n = 4) that are non-sodic, or Class 2B (n=12) that are potentially dispersive.
- Some of the Borrow Area B soils are Class 2B (potentially dispersive), but most are Class 2A, 3A, or 3C that are flocculating.
- Soil and saprolite from Borrow Area V and B also have 0.04 to 0.83 % TS, but very low sulfide at 0.012 to 0.02 % CRS. The 1:3 – 16 hr water soluble leach tests infer that the sulfate may be associated with celeste ($SrSO_4$) (**Table 3-12**) which is a non-acid forming mineral.
- Soils have a low potential for metalliferous drainage (**Table 3-11**).

- Borrow Area V and B soils contain a higher proportion of fine material (<2 mm) compared to Borrow Areas W, T, and I.
- Borrow Area B is the preferred growth medium sources over Borrow Areas W, T, and I due to their higher moisture retention capability.
- Soils in Borrow Areas V and B are low plasticity clays based on Atterberg limits results.
- Topsoil and subsoil samples from Borrow Areas B and V have lower permeability than soils from Borrow Area W, T, and I, which could be attributed to sodic and dispersive behaviour in some samples and the physical nature of the materials.
- Saprolite samples from Borrow Area A and B verify that the saprolite and saprock within this profile should be amenable for use as a reduced permeability layer in a soil cover system, as the material has appropriate proportions of competent NAF rock in the gravel to cobble size fraction and a relatively high proportion of fines (< 2mm PSD material).
- Soil nutrients such as organic matter, phosphorous and cation exchange capacity support native flora and can be used to rehabilitate mine areas to natural woodland.

The key findings from Borrow Area C include the following:

- Blocky rock can be easily accessed at the side of a hill that is suitable for quarrying and is covered by a thin layer of soil.
- The quartzite rock is fresh and unweathered, neutral pH and very low $EC_{1:5}$ and although not tested geochemically typically has a NAF classification
- The bulk density of the rock is very high (2.6 t/m^3).
- The point load strength (Is(50)) of the fresh rock is 7.3 MPa.
- The rock is highly durable and suitable for slope rock armouring to reduce erosion.

The key findings from Borrow Area A include the following:

- Soils have neutral $pH_{1:5}$ (6.1 to 8.7), low $EC_{1:5}$ (30 to 106 µS/cm), Emerson Class values of 2-3; minor potential for dispersion.
- Soil, saprolite and saprock units are extremely to partially weathered and NAF_{BARREN} (non-acid forming with < 0.2% total sulfur).
- Contains soil, low permeability clay, growth medium and rocky soil mulch (material comprising sand, silt clay and residual rock fragments from gravel to cobble size fractions).
- Rehabilitation materials are geochemically and physically similar to Borrow Area B /B1, however topsoil and subsoil (A and B horizons) are thinner, verifying a less weathered soil profile.

Table 3-21 to **Table 3-23** provide a summary of topsoil, subsoil, and saprolite results for all of the nominated borrow areas (V, B, and C) as well as topsoil stockpiles.

Table 3-21: Material specification for topsoil unit

	Topsoil stockpiles			Borrow Area B			Borrow Area C			Borrow Area A		
Selected parameter	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**
$pH_{1:5}$	4.5	5.1	5.9	5.9	7.1	8.1	4.5	5.1	6.0	6.0	6.1	6.4
$EC_{1:5}$ (µS/cm)	36	241	451	22	2460	4190	34	63	319	24	30	72
Cation exchange capacity (CEC) (meq/100g)	0.2	3.7	19	4.4	4.9	17.3	1.6	3.6	5.2	3.6	5.0	7.3
Exchangeable Sodium Percent (ESP, %)	0.1	1.4	5.0	<0.1	73	0.3	<0.1	0.2	0.4	<0.1	0.2	0.3
Organic matter (%)	2.8	4.4	14.0	<0.5	0.5	1.1	1.1	1.7	4.3	1.2	2.0	3.6
Total N (%)	680	890	1920	250	290	820	100	475	1180	300	540	680
Total P (%)	232	278	330	163	191	218	116	129	155	116	168	234
Plant-available P (%)	2.5	2.5	7.0	<5	<5	8	<5	<5	5	9	10	11
Plant-available K (%)	50	50	1220	266	294	408	<100	137	308	335	362	476
Soil moisture (%)	2.7	7.6	12.5	6.3	9.2	11.3	0.2	0.3	0.4	0.8	0.8	0.8
Salinity classification	2A	2A	2A	2A	2A	3A	2A	2A	2A	2A	2A	2A
Chloride (mg/kg)	30	50	330	10	190	1960	<10	<10	20	5	5	20
Emerson Class	3	3	3	2	3	6	---	---	---	2	2	2
Soil texture (< 2 mm PSD)	Sandy clay loam	Sandy clay loam	Sandy clay loam	Clay	Clay loam	Clay loam	Loamy sand	Loamy sand	Sandy loam	Silty clay	Loamy sand	Loamy sand
Particle size distribution (< 75 mm) (%)												
- Gravel	35	47	51	18	21	24	0	35	48	35	35	35
- Sand	24	26	29	19	23	26	46	65	80	26	26	26
- Silt	13	14	19	20	23	25	3	3	6	30	30	30
- Clay	11	13	17	30	34	38	8	10	14	9	9	9
Atterberg limits - Plasticity Index (%	8	11	16	14	16	18	---	---	---	6	6	6
Bulk density (t/m^3)	1.3	1.6	1.9	1.4	1.6	1.7	1.6	1.7	1.8	1.5	1.5	1.6
Maximum dry density (t/m^3)	1.7	1.9	1.9	1.9	1.9	1.9	---	---	---	1.9	1.9	1.9
California Bearing Ratio (CBR)	-	-	-	1.5	1.5	1.5	---	---	---	---	---	---
Permeability (<20 mm)												
- ksat 95%	2.0×10^{-8}	2.3×10^{-7}	4.4×10^{-7}	1.7×10^{-8}	2.2×10^{-8}	5.4×10^{-9}	---	---	---	2.7×10^{-8}	2.7×10^{-8}	2.7×10^{-8}
- ksat 90%	2.7×10^{-6}	1.2×10^{-5}	2.9×10^{-5}	1.1×10^{-5}	1.6×10^{-6}	3.8×10^{-8}	---	---	---	7.3×10^{-8}	7.3×10^{-8}	7.3×10^{-8}
Volumetric moisture content (cm^3/cm^3)												
- 0 kPa	0.41	0.43	0.50	0.44	0.46	0.48	0.37	0.37	0.37	0.48	0.48	0.48
- 10 kPa	0.22	0.28	0.36	0.21	0.22	0.23	0.20	0.20	0.20	0.38	0.38	0.38
- 33 kPa	0.20	0.24	0.31	1.18	0.69	0.20	0.15	0.15	0.15	0.31	0.31	0.31
- 100 kPa	0.19	0.20	0.26	0.16	0.18	0.19	0.11	0.11	0.11	0.24	0.24	0.24
- 1,500 kPa	0.12	0.13	0.17	0.13	0.15	0.17	0.06	0.06	0.06	0.12	0.12	0.12
Derived van Genuchten parameters												
- a (1/cm)	0.06	0.12	1.00	0.99	1.00	1.00	0.12	0.12	0.12	0.02	0.02	0.02
- N (-)	1.15	1.15	1.19	1.25	1.29	1.33	1.26	1.26	1.26	1.25	1.25	1.25
- qs (cm^3/cm^3)	0.41	0.43	0.50	0.44	0.46	0.48	0.37	0.37	0.37	0.41	0.41	0.41
- qr (cm^3/cm^3)	0.00	0.00	0.08	0.10	0.13	0.16	0.02	0.02	0.02	0.09	0.09	0.09

Table 3-22: Material specification for subsoil unit

	Borrow Area B			Borrow Area C			Borrow Area A		
Selected parameter	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**
$pH_{1:5}$	7.7	8.0	8.6	4.6	5.4	5.8	6.3	6.6	8.9
$EC_{1:5}$ (µS/cm)	170	4000	5410	12	26	43	30	39	80
Cation exchange capacity (CEC) (meq/100g)	5.7	16.5	21.2	2.1	2.3	2.6	5.1	6.4	9.3
Exchangeable Sodium Percent (ESP, %)	0.1	38.8	64.3	<0.1	<0.1	<0.1	0.1	0.4	1.4
Organic matter (%)	<0.5	<0.5	1	0.6	1.1	0.8	0.3	0.7	1.2
Total N (%)	240	270	510	80	165	390	240	280	1000
Total P (%)	152	161	170	76	100	118	110	153	186
Plant-available P (%)	<5	<5	<5	<5	<5	<5	<5	<5	<5
Plant-available K (%)	176	238	267	<100	<100	130	105	207	252
Soil moisture (%)	3.4	7.6	9.8	0.6	1.2	8.5	3.1	4.5	6.0
Salinity classification	2B	2B	3A	2A	2A	2A	2A	2A	2A
Chloride (mg/kg)	30	1510	2330	<10	<10	<10	5	10	30
Emerson Class	2	3	6	---	---	---	2	3	3
Soil texture (< 2 mm PSD)	Clay	Clay loam	Clay loam	Loamy sand	Loamy sand	Sandy loam	Clay silt	Loamy sand	Loamy sand
Particle size distribution (< 75 mm) (%)									
- Gravel	14	19	23	---	---	---	21	21	21
- Sand	24	27	29	64	74	84	23	23	23
- Silt	23	24	24	4	5	6	31	31	31
- Clay	25	32	38	12	21	30	25	25	25
Atterberg limits - Plasticity Index (%	18	23	28	---	---	---	15	15	15
Bulk density (t/m^3)	0.9	1.5	1.7	1.6	1.8	1.8	1.3	1.3	1.4
Maximum dry density (t/m^3)	1.8	1.8	1.8	---	---	---	1.7	1.7	1.7
California Bearing Ratio (CBR)	2.5	2.5	2.5	---	---	---	---	---	---
Permeability (<20 mm)									
- ksat 95%	1.8×10^{-9}	1.8×10^{-9}	1.8×10^{-9}	---	---	---	2.7×10^{-8}	2.7×10^{-8}	2.7×10^{-8}
- ksat 90%	1.4×10^{-7}	1.4×10^{-7}	1.4×10^{-7}	---	---	---	7.3×10^{-8}	7.3×10^{-8}	7.3×10^{-8}
Volumetric moisture content (cm^3/cm^3)									
- 0 kPa	0.46	0.49	0.52	0.36	0.36	0.36	0.56	0.56	0.56
- 10 kPa	0.21	0.23	0.25	0.16	0.16	0.16	0.35	0.35	0.35
- 33 kPa	0.19	0.22	0.24	0.12	0.12	0.12	0.30	0.30	0.30
- 100 kPa	0.18	0.20	0.22	0.09	0.09	0.09	0.24	0.24	0.24
- 1,500 kPa	0.14	0.15	0.17	0.05	0.05	0.05	0.16	0.16	0.16
Derived van Genuchten parameters									
- a (1/cm)	0.08	0.54	1.00	0.37	0.37	0.37	0.15	0.15	0.15
- N (-)	1.26	1.48	1.69	1.24	1.24	1.24	1.17	1.17	1.17
- qs (cm^3/cm^3)	0.47	0.49	0.52	0.36	0.36	0.36	0.56	0.56	0.56
- qr (cm^3/cm^3)	0.11	0.14	0.17	0.01	0.01	0.01	0.00	0.00	0.00

Table 3-23: Material specification for saprolite unit

	Borrow Area B			Borrow Area C			Borrow Area A		
Selected parameter	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**
$pH_{1:5}$	8.4	8.8	9.1	6.2	6.5	7.0	7.4	8.4	8.5
$EC_{1:5}$ (µS/cm)	320	855	2970	15	65	424	15	65	106
Cation exchange capacity (CEC) (meq/100g)	1.3	4.7	7.7	1.5	1.5	1.5	3.8	6.4	10.9
Exchangeable Sodium Percent (ESP, %)	0.1	71.3	65.4	<0.1	<0.1	<0.1	0.1	0.1	1.2
Organic matter (%)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	0.9
Total N (%)	150	170	220	150	150	150	120	380	580
Total P (%)	115	172	337	56	56	56	134	152	194
Plant-available P (%)	<5	<5	<5	<5	<5	<5	<5	<5	<5
Plant-available K (%)	126	245	307	<100	<100	<100	116	158	305
Soil moisture (%)	4.3	6.8	8.1	0.5	0.5	0.5	2.3	2.3	2.3
Salinity classification	2B	2B	3A	2A	2A	2A	2A	2A	2A
Chloride (mg/kg)	130	630	1140	<10	<10	<10	<10	<10	<10
Emerson Class	2	3	6	---	---	---	---	---	---
Soil texture (< 2 mm PSD)	---	---	---	Loamy sand	Loamy sand	Sandy loam	---	---	---
Particle size distribution (< 75 mm) (%)									
- Gravel	34	46	54	2	12	37	30	30	30
- Sand	46	54	66	84	88	98	29	29	29
- Silt	---	---	---	3	4	6	30	30	30
- Clay	---	---	---	8	11	12	11	11	11
Atterberg limits - Plasticity Index (%	---	---	---	---	---	---	---	---	---
Bulk density (t/m^3)	1.4	1.5	2.3	1.6	1.8	1.8	1.3	1.3	1.3
Maximum dry density (t/m^3)	1.7	1.7	1.7	---	---	---	1.7	1.7	1.7
California Bearing Ratio (CBR)	7	7	7	---	---	---	---	---	---
Point load strength (Is(50) (Mpa)	0.06	0.2	1.5	7.3	7.3	7.3	---	---	---
Permeability (<20 mm)									
- ksat 95%	1.1×10^{-7}	1.1×10^{-7}	1.1×10^{-7}	---	---	---	2.7×10^{-8}	2.7×10^{-8}	2.7×10^{-8}
- ksat 90%	1.6×10^{-6}	1.6×10^{-6}	1.6×10^{-6}	---	---	---	7.3×10^{-8}	7.3×10^{-8}	7.3×10^{-8}
Volumetric moisture content (cm^3/cm^3)									
- 0 kPa	0.48	0.48	0.50	0.36	0.36	0.36	0.55	0.55	0.55
- 10 kPa	0.34	0.35	0.36	0.14	0.14	0.14	0.36	0.36	0.36
- 33 kPa	0.29	0.30	0.31	0.11	0.11	0.11	0.31	0.31	0.31
- 100 kPa	0.23	0.24	0.25	0.07	0.07	0.07	0.25	0.25	0.25
- 1,500 kPa	0.13	0.14	0.14	0.04	0.04	0.04	0.14	0.14	0.14
Derived van Genuchten parameters									
- a (1/cm)	0.04	0.04	0.05	0.27	0.27	0.27	0.09	0.09	0.09
- N (-)	1.18	1.19	1.20	1.28	1.28	1.28	1.18	1.18	1.18
- qs (cm^3/cm^3)	0.48	0.48	0.50	0.36	0.36	0.36	0.55	0.55	0.55
- qr (cm^3/cm^3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

4 Rehabilitation material management

The Phase 1 RMSaAP analysed samples from Borrow Areas A, B and C, which were nominated as some of the preferred borrow sites (RGS, 2021).

The Phase 2 RMSaAP analysed additional samples from Borrow Areas B and samples from Borrow Areas I, T, V and W. Borrow Area W and T have not been nominated as suitable sources of rehabilitation material for closure works as they provide smaller volumes of rehabilitation material and have thinner soil profiles. The poorer quality of material from Borrow Area W and T and unavailability of borrow material from these areas during mining operations have also contributed to their exclusion from the material balance. Borrow Area I, whilst not available until closure, has been nominated as the preferred borrow site within the current operational footprint, due to offering greater volumes and types of rehabilitation material. Borrow Area V has not been nominated as an optional borrow site due to a reduction in material requirements discovered during Phase 2 completion and availability of suitable material found in close proximity.

The final borrow areas proposed to source material for rehabilitation of the WRE and other mine domains has not been determined, except for Borrow Area C. Instead, optional borrow areas of B1, B2, A and I have been determined subject to future ecological assessments. Borrow Areas B1, A, I and C evaluated in this RMSaAP can be used to source rehabilitation material to comply with the PRCP requirements for final landform design and rehabilitation. Borrow Area B2 whilst no evaluation has yet been undertaken, is expected to provide suitable material volumes and types due to its size and proximity to existing borrow areas completed under the RMSaAP.

The investigations of Borrow Areas B1, B2, A, and C verify that enough suitable material is available and accessible within a reasonable haul distance of the mine.

Borrow Area I offers approximately half material volumes of rocky soil mulch, however substituted with growth media found within Borrow Area I can offer volumes of 139,856 loose cubic metres (lcm) of rehabilitation material. When Borrow Area I is combined with the topsoil stockpiles it would meet the required material balance.

A summary of the required material types, definitions and use is outlined in **Table 7-1** and material specifications are in **Section 3.3**. A detailed description of the material balance required for site rehabilitation is in **Attachment D: Material balance tables.** The borrow area footprints and depth of material to be recovered are in **Attachment E: Borrow area pit shells.**

4.1 Required material balance

LLM developed a PRCP that defines the rehabilitation completion plan and the soil and capping material requirements for site rehabilitation. While there are existing topsoil stockpiles at LLM, they will not provide sufficient material to complete rehabilitation at the site. Therefore, the development of additional borrow areas will be required to meet the material deficit. Areas that require borrow material across site are:

- WRE cover system – requirement for growth medium, rocky soil mulch, and rock armouring
- RoM, Paste Plant and Batch Plant – requirement for growth medium application
- Surface water drainage and erosion risk areas – rock armouring and or rocky soil mulch applied
- Borrow areas – growth medium applied for rehabilitation

Whilst additional material requirements are not proposed, a conservative approach has been applied to the material balance calculations, to include growth medium application for various infrastructure areas which will be subject to future contaminated land assessment works. The underground openings will be backfilled using ROM material.

Major rehabilitation material units (RM_{UNITS}) available from borrow materials required to address the material balance needs at LLM are summarised below:

- Competent “blocky” rock for armouring slopes – this may include extremely hard (quartzite) to very hard (sedimentary) rock
- Growth medium – this may include topsoil O and A horizons and / or subsoil in the B horizon

- Rocky soil mulch – this includes a combination of fines from subsoil B and saprolite C horizons and residual rock fragments from C and D horizons.

4.2 Material suitability

There are no constraints to using the material from the borrow areas for rehabilitation at LLM. Specifically all samples analysed are non-acid forming and present a low hazard of producing metalliferous drainage that would lead to non-compliance of water quality objectives in the receiving environment.

The salinity and sodic potential of all material was quantified using soil quality, geochemical and physical analytical methods. The data verify that there are some units in some borrow areas that are saline with electrical conductivity ($EC_{1:5}$) of > 5,000 µS/cm) and that also have exchangeable sodium percentages (ESP) of > 30%. This work has verified that ESP results cannot, in their own right, be used to determine if the soils are dispersive or could have erosive potential. For example, some samples have ESP values of 21 to 71% but are classified as Emerson Class as 3, 4C and 6, so are not dispersive. The need for gypsum to reduce the ESP is considered unlikely if the materials are selectively mined, mixed and placed for rehabilitation.

Mining, scheduling, and placement of all materials would be done during construction to optimise the rehabilitation outcomes. This could include mixing saline, sodic and non-sodic materials together from different areas to achieve desired engineering cover design criteria. Quartzite from Borrow Area C will provide competent and durable rock for armouring slopes or lining drains. Fertiliser is unlikely to be required if native species are selected for the revegetation. However, if the revegetation process includes using pasture species as an initial cover, that have a higher nutrient demand, then fertiliser would be required.

The material specifications include a complete suite of measurable parameters that can be used as inputs for numerical modelling to quantify how proposed cover systems are likely to perform.

No additional mine material sampling or analysis is required to support LLM rehabilitation plans for a PRCP submission.

The Phase 1 and Phase 2 RMSaAP has verified that the rehabilitation materials are suitable for their intended use in mine site rehabilitation.

The Phase 1 and Phase 2 work:

- Verified the mine materials are NAF or NAF_{BARREN}
- Identified that there is naturally occurring, moderately saline conditions in localised zones of Borrow Area B and V
- Determined that the salinity is dominated by sulfate minerals, although in some areas the salinity is associated with sodium chloride
- Defines baseline conditions in undisturbed areas of the mining lease
- Verified the borrow materials will support native vegetation and the proposed post mine land use for LLM.

4.2.1 Topsoil stockpiles

Existing topsoil stockpiles south of CDA (6 ha) and SW of WRE (0.6 ha) assessed in this report are fit for purpose. The soils have low salinity, are non-sodic and non-dispersive (Class 2A and 3C). They are high in organic matter compared to other borrow material soils and have good aggregate stability. They are optimal for mine soils in terms of providing nutrients for vegetation plant growth and have a low risk of leaching soluble metal(loids) at concentrations that may have adverse effects on terrestrial or freshwater ecosystem biota. The estimated quantity of material from the existing topsoil stockpiles is 42,448vm^3 loose cubic metres (lcm) and is included in the material balance calculations. Total growth media requirements across site are 28,990 m^3, verifying there is a surplus of growth media.

4.2.2 Borrow Areas B1, B2 and A

Borrow Area B1 (5.2 ha), and A (13.4 ha) are described as shallow open cut areas of disturbance that are topographically low with as little as 10 m difference in elevation between the highest and lowest points. Borrow

Area B2 (4.1 ha) is a hilltop with approximately 11 m difference in elevation between the highest and lowest points. These borrow areas are bounded by small ephemeral drainage lines that only flow during high intensity rainfall events, or prolonged rainfall events; these drainage lines are not designated creeks. Test pits in Borrow Areas B encountered two classes of sodosol. Approximately half of the topsoil, subsoil, and saprolite samples are slightly alkaline, have low salinity, are non-sodic, non-dispersive, and have low total sulfur (Class 2A, 3B and 3C). The remaining samples are alkaline, have strong sodicity, are potentially dispersive or flocculated, and have higher total sulfur concentrations (Class 2B and 3A). All soils in Borrow Areas B1 classify as NAF_{BARREN}.

The geochemical and physical properties of saprock in Borrow Area A and B are in the Phase 1 report (RGS, 2021). The top of the saprock is defined as the base of the saprolite i.e., when the rock becomes too firm (less weathered) to excavate without using a rock hammer. Overall, Borrow Area B1 and A provide sufficient materials to meet rehabilitation requirements for growth medium, rocky soil mulch and may contain some blocky rock suitable for rock armouring. It is assumed that soil and rock units in Borrow Area B2 has similar properties to Borrow Area B/B1 based on geological occurrence and proximity.

4.2.3 Borrow Area C

Borrow Area C (1.7 ha) is on a quartzite ridgeline. The soil quality is good, but the soil profile is very shallow and the fines content (< 2 mm PSD fraction) is much lower than in Borrow Area B (RGS, 2021). Fresh rock is the primary target material in this borrow area. It will be excavated in an open cut quarry that will require blasting and have a final wall of 44 m. Borrow Area C will be mined by truck and shovel methods to obtain the fresh rock (with lesser amounts of soil and saprolite). Borrow Area C provides sufficient competent rock for armouring but has a deficit for growth medium, low permeability layer, and rocky soil mulch.

4.2.4 Borrow Area I

Borrow Area I (4 ha) is disturbed, and the original topsoil has been stripped. Soils from Borrow Area I are intermediate in terms of salinity and can be either sodic or non-sodic. Reformed topsoil in the surface 0.5 m of Borrow Area I has a higher concentration of sulfide sulfur due to mining impacts, when compared to other soil in undisturbed borrow areas. This 0.5 m depth of impacted soil will be removed prior to borrow pit development and has been excluded from material balance calculations. The underlying soil profile is still relatively thick and contains subsoil units, as well as saprolite. Saprolite units are NAF_{BARREN} with low to moderate buffering capacity. Borrow Area I offers growth media and rocky soil mulch. Borrow Area I provides half the required material volume of rocky soil mulch, however substituted with growth media found within Borrow Area I it would yield 139,856 loose cubic metres (lcm) of rehabilitation material. When Borrow Area I is combined with the topsoil stockpiles it would meet the required material balance.

The location and extent of Borrow Area B1, B2, A, I and C is illustrated in **Figure 2-1** and **Figure 4-1** and a summary of material types and their suitability for rehabilitation is outlined in **Table 7-1** in **Section 7 Attachment B: Additional figures and results**.

4.2.5 Supplementary Borrow Areas T and W

Soil from test pits in Borrow Areas W and T are neutral to slightly alkaline, non-sodic and stable (Class 2A, 3B, and 3C). They tend to contain a higher proportion of gravel than other borrow areas but like the topsoil stockpiles, provide a good growth medium. Borrow Area W contains the most competent saprolite that has a high point load strength. Like other disturbed areas, reformed topsoils in Borrow Area T have a higher concentration of sulfide sulfur due to mining impacts. Borrow Areas T and W have been excluded from the Phase 2 material balance.



Figure 4-1: Borrow areas and creek and road buffer zones.

4.3 Borrow pit design assumptions and modelling method

This section describes how the evaluation of different borrow area disturbance footprints for Borrow Areas B1, B2, A and I was undertaken to optimise the volume of material available for excavation, while minimising the footprint and disturbance of natural drainage lines. Other considerations included the slope of the pit floor to direct surface flow, the number of drainage points, and the slope of the internal batters.

The following assumptions developed with Glencore apply to the borrow pit designs.

- Growth media and rocky soil mulch material volumes will swell 25% and competent rock will swell 30% when excavated (i.e., bench cubic metres (bcm) x 130% = loose cubic metres (lcm)).
- Elevation data provided for the borrow areas will still be accurate at the time of closure.
- Batter angles of 1V:4H, or shallower, will provide sufficient geotechnical stability in Borrow Areas B1, B2, and I.
- Batter angles of 60° to provide sufficient geotechnical stability in Borrow Area C.
- Maximum batter heights in Borrow Area A will be approximately 2 m, Borrow Area B1 will be approximately 7 m, Borrow Area B2 will be approximately 1 m, and Borrow Area I will be approximately 6 m so no berms are needed.
- The average depth of material to be excavated ranges from 1.8 m in Borrow Pit A to 3.8 m in Borrow Pit B2.
- That 0.5 m depth of contaminated growth medium will be removed from Borrow Area I.
- Batters with maximum bench heights of 20 m and berm widths of 10 m in the Borrow Area C quarry will provide sufficient geotechnical stability.
- A 1% slope on the pit/quarry floors is both a sufficient gradient to facilitate drainage and is achievable with the planned excavation equipment.
- The floor of the pits/quarry will be excavated no lower than the lowest elevation on the pit perimeter to prevent the capture of surface water flows.
- A buffer zone is required from existing roadways and from the identified Magazine Creek and tributaries to Desert Creek (**Figure 4-1**).
- The magazine has been moved prior to quarrying at Borrow Area C.
- Inverse distance interpolation using a power of 2 over a grid of 1 x 1 m provides a reasonable estimate of the surface elevation and thicknesses of topsoil, subsoil, and saprolite (that contains intact rock fragments ranging from gravel to large cobbles) in the proposed borrow areas.
- That Borrow Pit B2 is sufficiently close to the Borrow Area B test pits that soil profile depth, geochemical, and physical data from these pits are applicable to Borrow Pit B2.
- All material below the modelled base of saprolite in Borrow Areas A, B1, B2, and I will be saprock and material below the modelled base of saprolite in Borrow Area C will be fresh rock.
- Averaging the thickness of a borrow material horizon across a borrow area provides a reasonable representation of the distribution of material for mining purposes.

The following method was used to create the Borrow Area designs.

- Initial boundary polylines were digitised in Deswik.CAD, offset from creeks and roads.
- Batter toes and floors sloping at 1% toward the lowest point of the boundaries were created for the Borrow Areas.
- Initial borrow pit surfaces were created from the initial design lines.
- Volume solids were created for available rocky soil mulch or competent rock from the initial borrow pit surfaces and modelled soil horizons.
- The rocky soil mulch or competent rock volume solids iteratively trimmed to the required volumes.
- Updated borrow pit design lines and surfaces were created based on the trimmed rocky soil mulch or competent rock volume solids.
- Volume solids were created between the modelled pit surfaces and the digital elevation model surface created from the 0.5 m Lidar contours supplied by Glencore.
- The area of each volume solid was determined by plotting polygons from the intersection of the digital elevation model surface and the modelled pit floor surfaces.
- The volume solids were split into growth medium and rocky soil mulch or competent rock solids.

The method to calculate material volumes included the following.

- Test pit coordinates and logged soil horizon thicknesses from the 2020 and 2021 sampling programs were collated in a table and imported into Golden Software's Surfer.
- Surfer was used to interpolate the thicknesses of the topsoil, subsoil, and saprolite horizons.
- A 1 x 1 m surface elevation grid was created in Surfer using the Grids | New Grid | Grid from Contours function from the 0.5 m Lidar contours provided by LLM.
- The Grids | Calculate | Math function was then used to subtract the topsoil thickness grid from the surface elevation grid, producing a base of topsoil grid.
- The subsoil thickness grid was then subtracted from the base of topsoil grid to create a base of subsoil grid. A similar process was used to model the base of the saprolite.
- Next the Grids | Calculate | Volume function was used to calculate the volume of material between the surface elevation grid and the base of topsoil grid for the borrow areas. The same function and similar method were used to calculate the volumes of subsoil and saprolite.
- An average thickness of each material type was calculated for each borrow area by dividing the modelled volume of each material by the area of each borrow area.
- The average material thicknesses were then used to translate copies of the modelled topography surface down in Deswik.CAD to represent the bases of topsoil, subsoil, and saprolite.
- The base of material surfaces were then used to cut the borrow area volume solids into growth medium and rocky soil mulch or competent rock solids.

Conceptual geological models were developed using the detailed soil logs in **Attachment C: Test pit logs**. The conceptual geological models were used to develop an inferred 3D stratigraphic model in Deswik.CAD and these solids were then used to derive the materials balances (**Table 7-12**).

Simplistic 3D stratigraphic models have been developed in Deswik.CAD for each optional borrow site. Each borrow area was then cut into simple quarries to derive material balances for each stratigraphic unit. The nominated borrow pit shells have been developed based on current material balance requirements. The borrow areas and the depth of material that will be recovered in each borrow area are in **Attachment E: Borrow area pit shells.**

4.4 Available material balance

The Phase 2 material balance is based on the understanding of how rehabilitation will be implemented. These numbers may change based on the outcome of design work that will be documented in the PRCP. The volume of borrow materials (in loose cubic meters, lcm) required for rehabilitation and available from the Phase 2 borrow areas is summarised in **Table 4-1.** A detailed material balance providing required and available volumes for LLM is in **Attachment D: Material balance tables**.

Table 4-1: Rehabilitation material balance volumes

LLM material terms	Geological strata	Soil horizon	Required volume (lcm) *	Available volume (lcm) **
Growth Medium	Pedolith	A and B horizons	28,990	42,000 – 123,000
Rocky Soil Mulch	Saprolith	C horizon	141,407	77,000 – 175,000
Blocky Rock Fill	Quartzite	Fresh rock – D horizon	120,850	321,000

Note:

- All quantities in LCM and have been rounded to the nearest 1,000m^3.
- *Required volumes include 10% contingency.
- **Available volumes are subject to selected borrow site (Borrow Area B1, B2, A or I).

4.5 Borrow pit - development and management

The pedolith and saprolith from Borrow Area B1, B2, A and I can be excavated using free dig truck and shovel methods, with a maximum final internal bench height of < 10 m. Borrow Area B1, B2, A and I are free draining landforms and surface runoff will drain from the borrow pits at 1% slopes to the lowest points in each area. Sediment and erosion control structures are to be constructed on the boundary of selected borrow sites. Contour furrows are proposed on the borrow floors as part of landform erosion modelling assessment undertaken for the PRCP.

4.6 Landform haulage schedule (LHS)

The sequence of development of the Borrow Areas must be integrated with the construction sequence for the WRE cover and the proposed rehabilitation program for the LLM. The WRE design would specify how the WRE cover system will be built and what plant and equipment would be used.

RGS envisage that the development mining and rehabilitation of the preferred borrow areas would occur during the dry season. This assumption will be dependent on the WRE design constraints and construction sequence. A landform haulage schedule (LHS) will verify if this is feasible using the proposed plant and equipment specified by the rehabilitation contractor.

Prior to development, LLM should develop a detailed (truck by truck) landform haulage schedule that would verify how each borrow area is developed, where the excavated material is stockpiled or utilised, where the material from the borrow area is placed and how and when each borrow area is rehabilitated and decommissioned.

The construction sequence for the cover system is an inverse sequence to development of the borrow areas and is likely to require stockpiling and rehandling.

In broad terms the sequence of development would include the following:

- Surface drains / structures will be developed upgradient of each borrow area to minimise surface flow into Borrow Area B1, B2, A, I and C, as required. Contour furrows are proposed on the borrow floors as part of landform erosion modelling undertaken for the PRCP. The need for additional sediment and erosion control along these flow paths would be evaluated. As each borrow area is located on the upper most part of the catchments in which they sit, the changes in surface runoff and potential impact are likely to be minimal and additional sediment and erosion control requirements are unlikely. Erosion and sediment control measures will be developed in accordance with standard practice.
- In each borrow area, larger trees would be chipped and pushed with growth medium (nominally 0.5 to 1.5 m bgl) using a dozer from the highest point to lowest point in each borrow area into large windrows. The stockpiled growth medium would only be retained here for a short period of time.
- The growth medium and rock mulch may be obtained from defined dig areas in each borrow area as it is required for use in the WRE cover. Preference would be to extract material starting from the lowest elevation and finishing at the highest elevation, to enable surface water drainage away from the work zone.
- A suitable volume of stockpiled growth medium would be progressively hauled from the windrows and placed over the base of the borrow area when the desired elevation is achieved.
- The as-placed growth medium would be ripped into the floor of the borrow area. There should be sufficient nutrient content and seed in the growth medium to enable a strike of vegetation after wet season rain.
- Erosion and sediment control facilities would be retained until the water quality objectives for the surface runoff from the borrow areas are achieved.

5 Forward works

The RMSaAP Phase 1 and Phase 2 work program has confirmed that there are sufficient materials within Borrow Areas B1, B2, A, and C suitable to rehabilitate the WRE and other areas of LLM. Borrow Area I has been nominated as the preferred borrow site within existing disturbances.

No further works are required to address PRCP requirements.

Prior to construction and development of the borrow areas infill sampling and analysis would be beneficial. The main purpose of the infill sampling and analysis would be to identify saline and sodic zones so these units can be mixed with low saline and sodic units to optimise material properties for construction and rehabilitation.

Where deemed necessary, a detailed landform haulage schedule model could be developed to optimise the borrow material dig plan to minimise stockpile volumes and rehandle. Should such a model be developed, this should be integrated with the construction plan for the WRE.

6 References

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7 Attachments

7.1 Attachment A: Test pit method

The test pits will be excavated by an excavator or backhoe provided by the mine site, under the supervision of an RGS staff member. The procedure for excavating a test pit is as follows:

1. Ensure access is available (e.g. via track or road) to the proposed test pit location. Generally, it is better to move the test pit location to be convenient, rather than to clear excess vegetation to access the exact spot that has been pinpointed.
2. Preferably, the test pit should be dug on a flat surface, facing away from the sun. This is to ensure that photographs of the test pit walls are not obscured by shadows.
3. Carefully remove any obstructing vegetation. Test pit dimensions will be about 1 m wide x 2 m long x 1-4 m deep. The excavator will also need room to swing the arm and to turn around (**Figure 7-1**)



Figure 7-1: Illustration of a test pit excavation

4. Excavate the test pit, placing the regolith materials into a bulk pile on the right side (**Figure 7-2**). Stop excavating at a depth of approximately 1.2 m (or until a hard base is reached). Place the arm on the ground to signal the sampler that it is safe to approach.
5. At depths of up to 1.2 m, the sampler will climb into the pit and remove soil samples from the fresh wall face (the sides) of the test pit using a chisel or scoop. The sample will be collected in a bucket.
6. Up to 5 samples may be collected, which will take approximately 15-30 minutes. The sampler will then climb out of the test pit.
7. The excavator operator and the sampler must then communicate to decide whether to continue digging the test pit deeper (i.e. there is more soil in the profile), or to stop (a hard base has been reached).
8. If the test pitting is to continue to a deeper depth, the sampler will retreat to a safe distance for excavation to recommence. Continue to excavate to 2-4 m (depending on the size and reach of the excavator), or until a hard base is reached.
9. The material from the deeper excavation should be placed in bulk piles on the left side of the pit (**Figure 7-2**). Where possible, try to separate the piles into different soil materials (e.g. on the basis of colour or texture).
10. For the deeper depths, the sampler will not climb into the pit, but will sample from the bulk piles.

11. After all of the samples have been collected, the sampler should move away and signal the operator to infill the test pit. Care should be taken to ensure that the soil placed back in the test pit is:
    - As flat as possible (i.e. not a concave depression or mound); and,
    - Moderately compacted by stamping the bucket over the disturbed area.

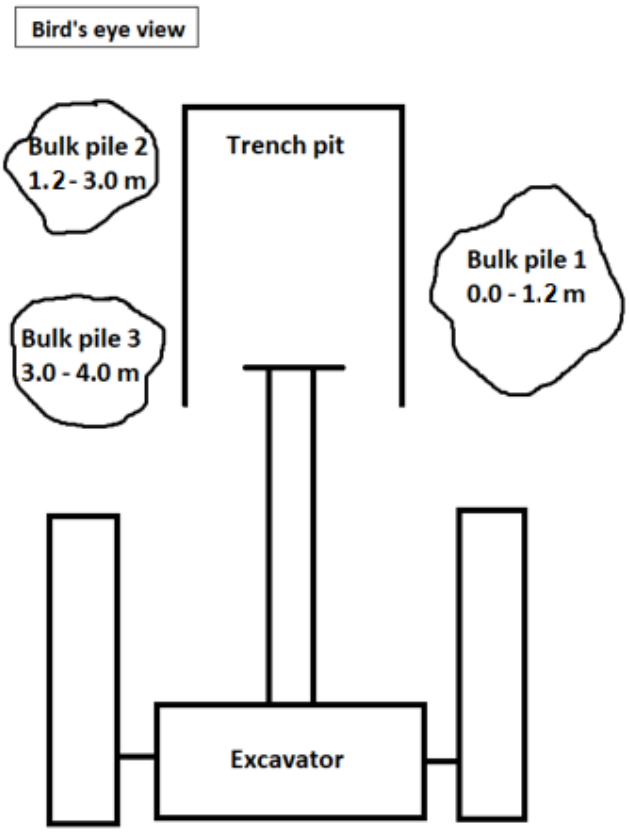


Figure 7-2: Diagram showing placement of excavated material from a test pit

7.2 Attachment B: Additional figures and results

7.2.1 Rehabilitation material table

Table 7-1: Rehabilitation material types, definitions, and use

		Soil/rock type	Horizon	Organic matter	Weathering	Definition/description	Fabric	Physical characteristics/texture available at LLM	Geochemical parameters available at LLM	Desired rehabilitation use	Preferred Qualities	Recommended use at LLM
Regolith	Pedolith	Leaf litter	O Horizon	Leaves, decaying fauna and flora, microbes	Partially decomposed organic matter	Horizon is dominated by organic material and may be saturated with water for long periods. It may consist of undecomposed or partially decomposed litter (such as leaves, needles, twigs, moss, and lichens) that have been deposited on the surface. The mineral fraction constitutes only a small percentage of its volume and weight.	Predominantly organic, negligible mineral matter	Not sampled/negligible		Growth medium	NAF, support vegetation growth, suitable moisture holding capacity, suitable nutrition characteristics, non-dispersive	O Horizon will be recovered with soils to be used as growth medium.
		Topsoil	A Horizon	Roots, burrowing animals, microbes	Extremely weathered	Topsoil is the upper, outermost layer of soil. It has the highest concentration of organic matter and microorganisms and is where most of the biological soil activity occurs. Topsoil is composed of mineral particles, organic matter, water, and air. Organic matter varies in quantity on different soils. The strength of soil structure decreases with the presence of organic matter, creating weak bearing capacities.	Parent materials are no longer distinguishable (Taylor and Eggleton 2001). Primary fabric is destroyed (Aust Geosciences). The major minerals are quartz, clays (e.g. smectite, vermiculite, kaolinite), and iron oxyhydroxides (e.g. goethite) (Taylor and Eggleton 2001).	- Topsoil is present from 0 m bgl to between 0.1 to 0.5 m bgl. - The <2 mm fraction is sandy loam, moisture content: 0.3 - 0.8%. - Overall matrix PSD: 10-30% clay, 10% silt, 30-50% sand, 30-40% gravel. - Permeability: 2.7 x 10^{-6} to 1.2 x 10^{-5} m/s. - Bulk density: 1.4 to 1.8 m^3/t	- $pH_{1:5}$: 4.5 to 9.1 - $EC_{1:5}$: 7 to 6140 µS/cm - Organic matter: <0.5 to 14% - CEC: 0.2 to 19 meq/100g - ESP: <0.1 to 73%			Topsoil at LLM meets pasture/bushland criteria and is typical of North Queensland soil. Some material is potentially dispersive. Surplus of subsoil indicates that some subsoil could be mixed with topsoil to be used as growth medium.
		Subsoil	B Horizon	Few roots	Highly weathered	Subsoil is the layer of soil under the topsoil that is composed of a variable mixture of small particles such as sand, silt and/or clay, but it generally lacks the organic matter and humus content of topsoil. As it is lacking in dark humus, subsoil is usually paler in colour than the overlying topsoil. It may contain the deeper roots of some plants, such as trees, but a majority of plant roots lie within the surface topsoil.		- Subsoil is present from depths beginning 0.1 m bgl and up to 2.8 m bgl. - The <2 mm fraction is sandy loam to loamy sand, moisture content: 3.3 - 5.1 %. - Overall matrix PSD: 10-60% clay, 10% silt, 20-60% sand, 10% gravel. - Permeability: 1.4 x 10-7 to 1.6 x 10-6 m/s. - Bulk density: 1.3 to 2.1 m3/t	- $pH_{1:5}$: 4.6 to 9.5 - $EC_{1:5}$: 12 to 5990 µS/cm - Organic matter: <0.5 to 2.8% - CEC: 1.6 to 21.2 meq/100g - ESP <0.1 to 64%			Due to lack of available pure clay lenses, recommend using sodic (high ESP)/saline (high EC) subsoil from Borrow B as replacement. This material has 10 to 60% clay fractions and <10% gravel. Permeability results verify Borrow B subsoil has lowest permeability from all borrow areas at 1.4 x 10^{-7} to 1.6 x 10^{-6} m/s.
		Clay pans	B Horizon		Highly weathered	As clay shrinks and swells, the fissures where clay has been deposited can be enlarged. This becomes a preferential path for water movement and hence further clay accumulation (i.e. clay lens). The accumulated clay acts as a throttle to water movement and the soil close to the clay remains wet for longer than the rest of the soil mass (Vict Govt 2022). May also be		No pure clay pans / lenses / horizons evident		Not required.		None available

		Soil/rock type	Horizon	Organic matter	Weathering	Definition/description	Fabric	Physical characteristics/texture available at LLM	Geochemical parameters available at LLM	Desired rehabilitation use	Preferred Qualities	Recommended use at LLM
						referred to as Plasmic zone (including residual clays) (Australian Geosciences).						
	Saprolith	Saprolite	C Horizon	Deep tree roots only	Moderately weathered	Saprolite is more altered than saprock but still retains the fabric and most of the structural characteristics of the parent rock (Taylor and Eggleton 2001). Saprolite contains >20% weatherable minerals altered. Saprolite is variably weathered bedrock (Aust Geosciences).	Primary fabric is preserved (Aust Geosciences). Parent and weatherable minerals are wholly or partially pseudomorphed to clays, oxides, and oxyhydrides so that the rock fabric is maintained (Taylor and Eggleton 2001).	- Moisture content: 0.6 - 4.8%. - PSD: 10-30% clay, 10% silt, 50-60% sand, 10-20% gravel. - Point load strength (Is(50): 0.1 to 1.48 Mpa. - Bulk density: 1.4 to 2.3 m3/t. - Permeability topsoil/ subsoil/ saprolite composite 1.2 x 10^{-5} to 1.1 x 10^{-9}. - Resistant to degradation based on sodium soundness	- $pH_{1:5}$: 5.4 to 10.1 - $EC_{1:5}$: 15 to 3180 µS/cm - Organic matter: <0.5 to 1.7% - CEC: 0.9 to 15.9 meq/100g - ESP: <0.1 to 71%	Rocky soil mulch – (NAF rock only)	NAF, not prone to generating neutral/saline drainage, suitable moisture holding capacity, suitable nutrition characteristics	Saprolite at all borrow areas is NAF-Barren and is suitable for use as a rocky soil mulch. Some materials are dispersive, saline, and/or sodic, but this is not expected to make them unsuitable for use in rehabilitation.
		Saprock	C Horizon		Partially /slightly weathered	Saprock is the first stage of weathering and consists of partially weathered and unweathered minerals (Taylor and Eggleton 2001). Saprock contains <20% weatherable minerals altered (Aust Geosciences). Saprock is slightly weathered bedrock (Aust Geosciences).	Primary fabric is preserved (Aust Geosciences).	- (Saprock is present but not sampled in test pits- rock hammer required for excavator. Data sourced from Borrow B drill holes in Phase 1 work program). - Point load strength: 0.63 to 0.66 Mpa - Bulk density: 2.0 to 2.2 m3/t - Resistant to degradation based on sodium soundness	- $pH_{1:5}$: 6.5 to 9.8, - $EC_{1:5}$: 13 to 1060 µS/cm - Organic matter: <0.5% - CEC: 1.3 to 1.4 meq/100g - ESP: 2 to 19%			Saprock is present underneath saprolite. However, removal of saprock from Borrow B/V may cause potential ponding issues after heavy storm events if the borrow area is too deep. Excavation of saprock is constrained by topography. Rock is NAF and suitable for use. Saprock could be substituted for fresh rock and used as blocky rock based on results of sodium soundness tests.
		Fresh rock	D Horizon		Unweathered	Fresh rock is unaltered by the processes of weathering. Absence of red or yellow staining from iron oxidation (Taylor and Eggleton 2001).		- (Data from Drill Hole 1 Borrow C in Phase 1 work program. Quartzite is too strong to be removed with excavator in test pits). - Point load strength(Is(50): 7.27 Mpa, - Bulk density: 2.6 m3/t	- $pH_{1:5}$: 6.5 - $EC_{1:5}$: 13 µS/cm	"Blocky rock" - Rock armouring (NAF rock only) and capillary break	NAF rock: NAF, high strength and durable, mix of boulders and smaller particles; capillary break: well-graded drainage aggregate material, free draining, NAF	A quarry to excavate quartzite at Borrow C will provide plenty of fresh/competent rock for rock armouring and as a capillary break. Additional material could be excavated to supplement rocky soil mulch quantities, although it would make a poor transitional soil due to the lack of fine particles and nutrients.

7.2.2 Additional topographic contour data



Figure 7-3: Topographic contours (1 m) in the LLM mine survey area

7.2.3 Topsoil stockpiles

7.2.4 Soil fertility

7.2.4.1 Total organic carbon and organic matter

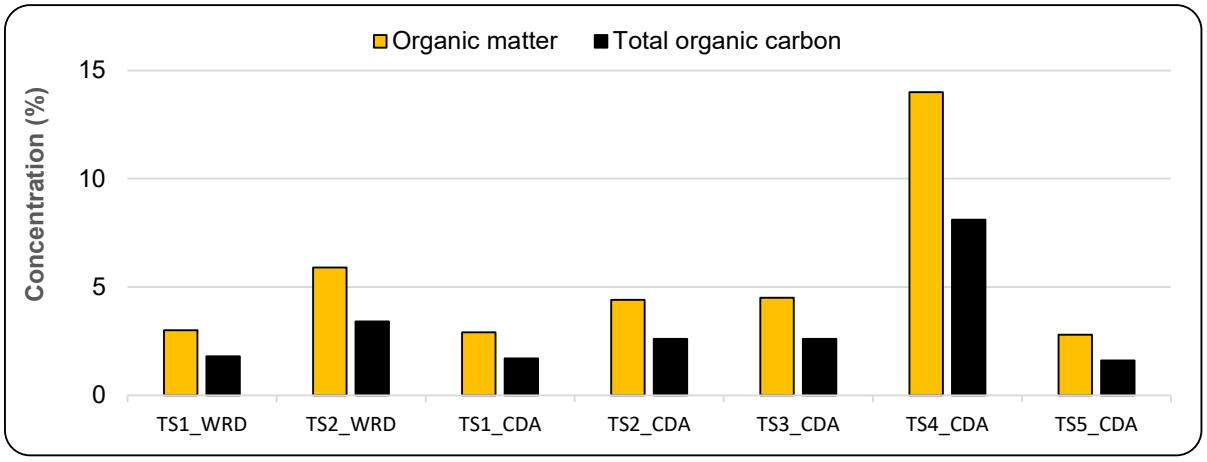


Figure 7-4: Organic matter and total organic carbon for topsoil stockpiles

7.2.4.2 Total and extractable nitrogen, phosphorous and potassium

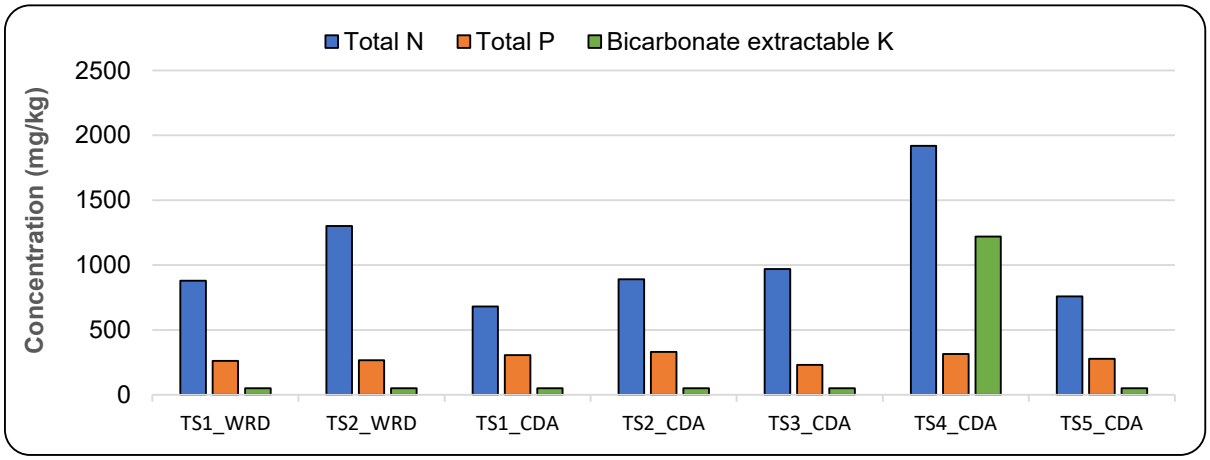


Figure 7-5: Total N, Total P, and extractable K for topsoil stockpiles

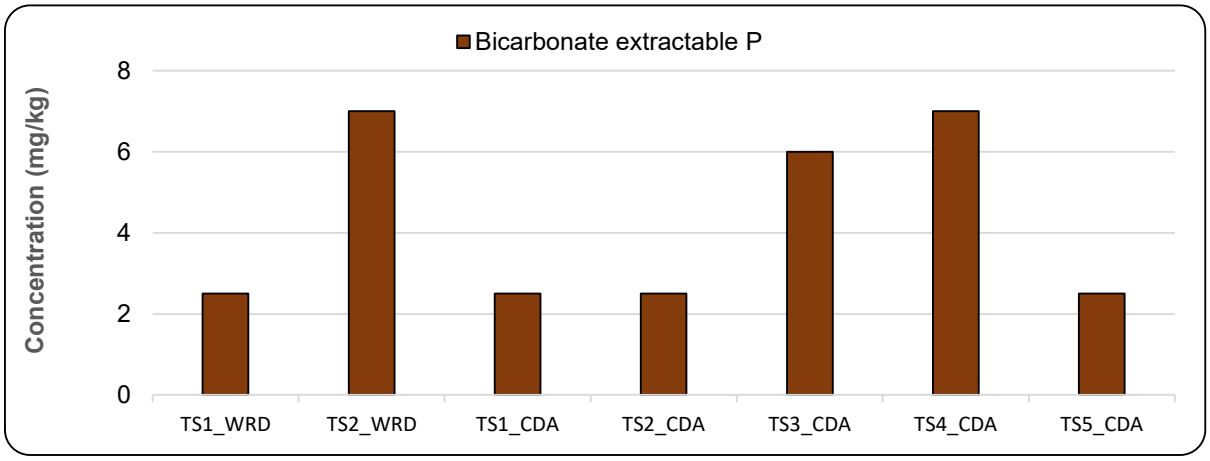


Figure 7-6: Bicarbonate extractable P for topsoil stockpiles

7.2.5 Salinity

7.2.5.1 Cation exchange capacity and exchangeable sodium percentage

Table 7-2: Summary of characterisation results for topsoil stockpiles

Parameter	Analysis	Min	Max	Median	Classification[1]
pH	Acidity/alkalinity	4.5	5.9	5.1	Neutral
Electrical Conductivity (EC) (µS/cm) (1:5)	Salinity	36	451	241	Low salinity
Exchangeable Ca (meq/100g)	Exchangeable Cations	1.5	9.5	3.0	Low
Exchangeable Mg (meq/100g)	Exchangeable Cations	0.6	7.9	1.1	Moderate
Exchangeable K (meq/100g)	Exchangeable Cations	0.3	1.1	0.3	Low - Moderate
Exchangeable Na (meq/100g)	Exchangeable Cations	0.1	0.3	0.1	Very Low - Low
Cation exchange capacity (CEC) (meq/100g)	Soil fertility	0.2	19.0	3.7	Low - Moderate
Exchangeable Sodium Percentage (ESP) (%)	Sodicity	0.1	5.0	1.4	Non-Sodic
Calcium/Magnesium Ratio	Soil stability	1.2	8.2	4.7	Balanced

[1]Classification based on Hazelton and Murphy (2016).

7.2.5.2 Emerson Class classifications and reference tables

Table 7-3: Emerson Class test results for topsoil stockpiles

Area	WRE Stockpile	CDA Stockpile	WRE Stockpile	CDA Stockpile	CDA Stockpile	CDA Stockpile	CDA Stockpile
Test pit no.	TS1	TS1	TS2	TS2	TS3	TS4	TS5
Material type	Topsoil	Topsoil	Topsoil	Topsoil	Topsoil	Topsoil	Topsoil
Description	SILT - brown	SILT - brown	SILT - brown	SILT - pale brown	SILT - brown	SILT - brown	SILT - red
Emerson Class Number	**3**	**3**	**3**	**3**	**3**	**3**	**3**

7.2.5.3 Salinity classification

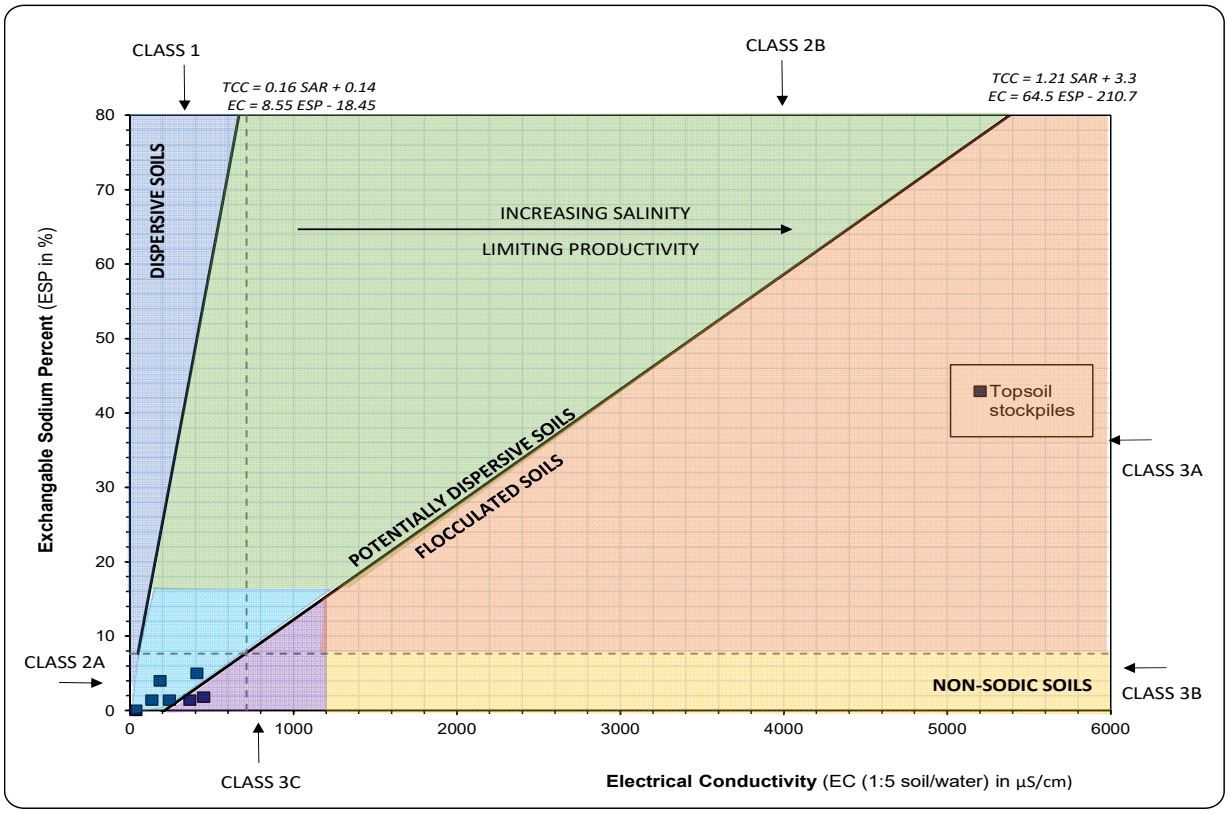


Figure 7-7: Salinity classification classes for topsoil stockpiles

7.2.6 Physical properties

7.2.6.1 Particle size distribution

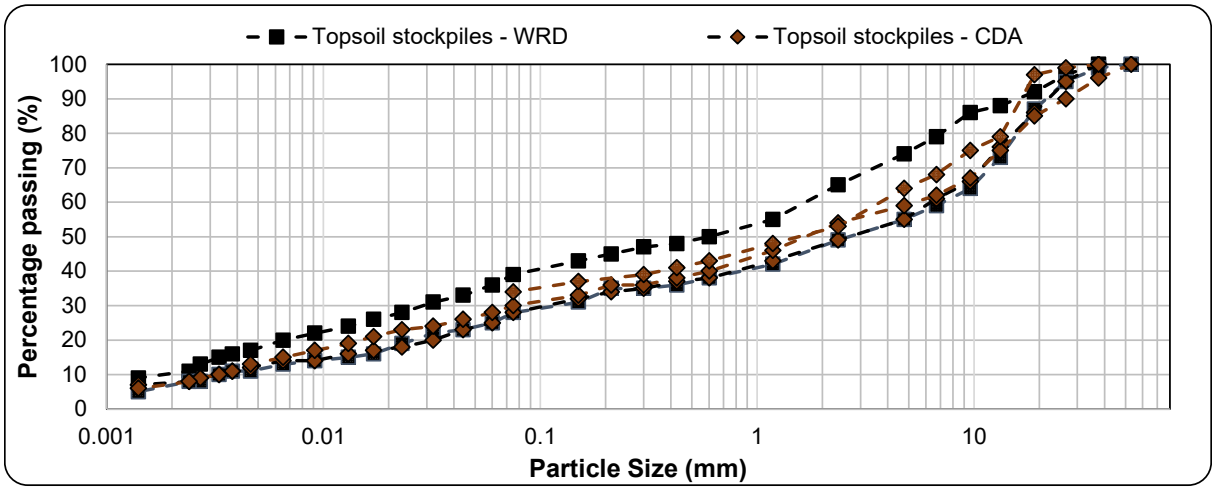


Figure 7-8: PSD results for topsoil stockpiles

7.2.6.2 Soil texture classification

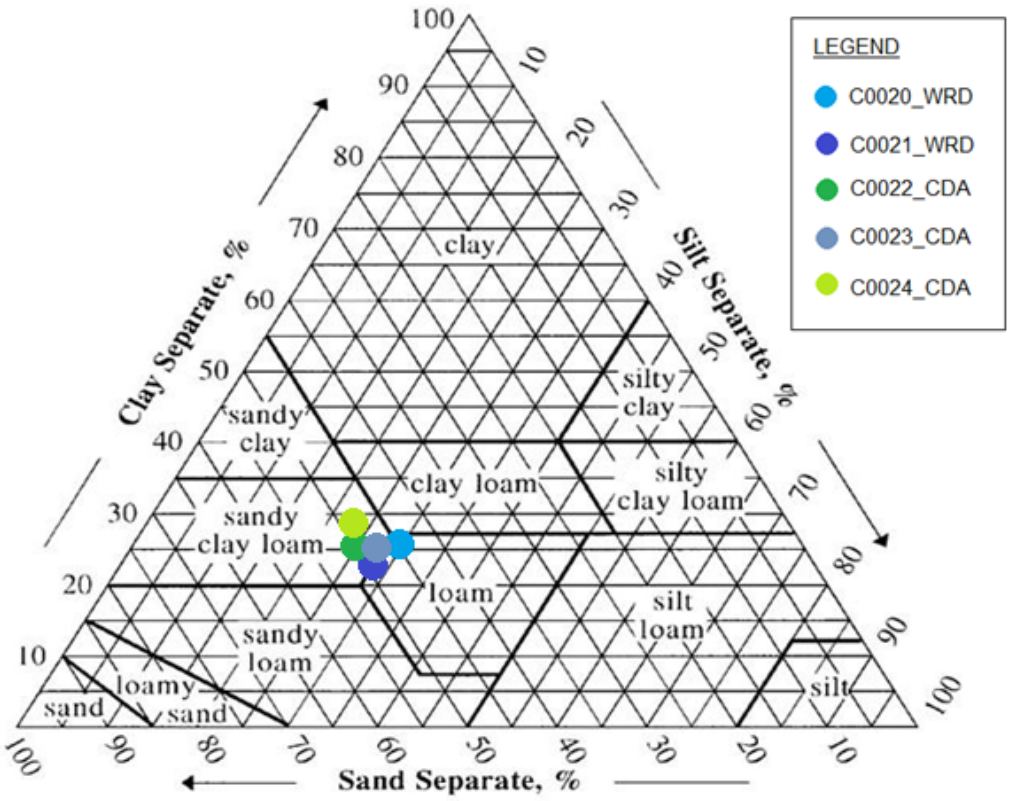


Figure 7-9: Soil texture triangle for topsoil stockpiles

7.2.6.3 Atterberg limits

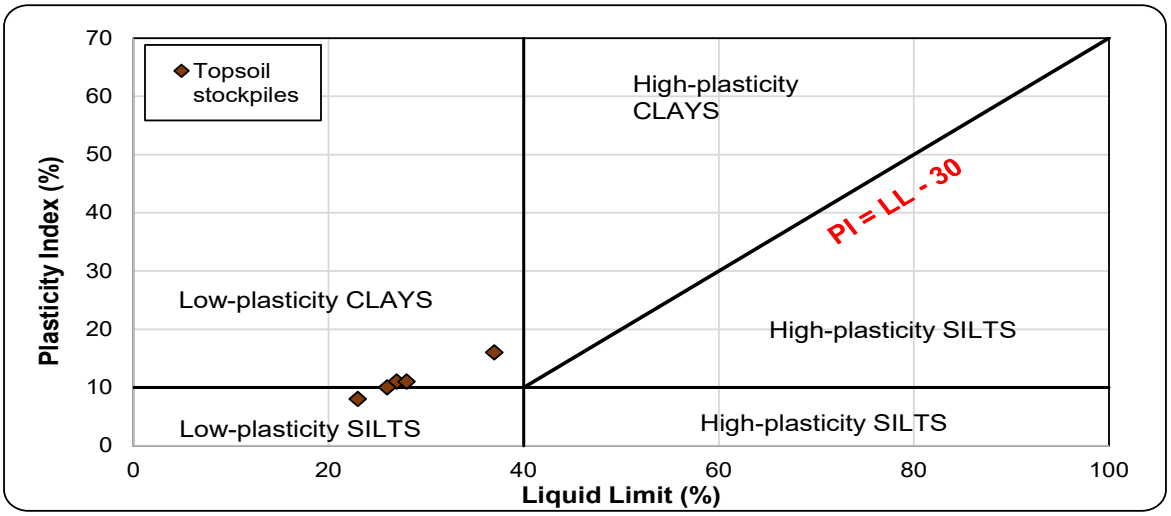


Figure 7-10: AASHTO soil classifications for topsoil stockpiles

7.2.6.4 Bulk density

Table 7-4: Bulk density measurements for topsoil stockpiles

Test pit	Material Type	Bulk density (m^3/t)
TS1 WRA	Topsoil	1.74
TS1 CDA	Topsoil	1.38
TS2 WRA	Topsoil	1.71
TS2 CDA	Topsoil	1.85
TS3 CDA	Topsoil	1.61
TS4 CDA	Topsoil	1.30
TS5 CDA	Topsoil	1.55

7.2.6.5 Permeability

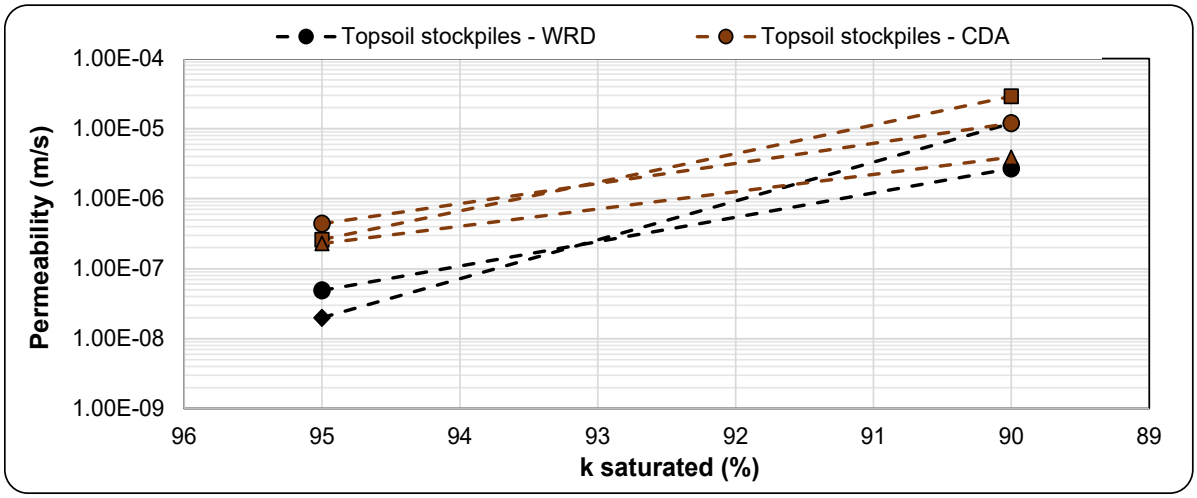


Figure 7-11: Permeability results for topsoil stockpiles

7.2.6.6 Soil water characteristic curves

Table 7-5: Soil water characteristic curves with derived van Genuchten parameters

Borrow area	Material type	Soil texture classification	Volumetric Moisture Content (cm^3/cm^3)					Derived van Genuchten Parameters			
			0 kPa	10 kPa	33 kPa	100 kPa	1,500 kPa	a (1/cm)	N (-)	qs (cm^3/cm^3)	qr (cm^3/cm^3)
TS_WRE	Topsoil	Clay Loam	0.41	0.28	0.24	0.20	0.13	0.123	1.148	0.41	0.00
TS_WRE	Topsoil	Clay Loam	0.43	0.31	0.27	0.22	0.14	0.062	1.164	0.43	0.00
TS_CDA	Topsoil	Clay Loam	0.42	0.25	0.23	0.19	0.12	0.258	1.147	0.42	0.00
TS_CDA	Topsoil	Clay Loam	0.50	0.36	0.31	0.26	0.17	0.086	1.149	0.50	0.00
TS_CDA	Topsoil	Clay Loam	0.45	0.22	0.20	0.19	0.13	1.000	1.193	0.45	0.08

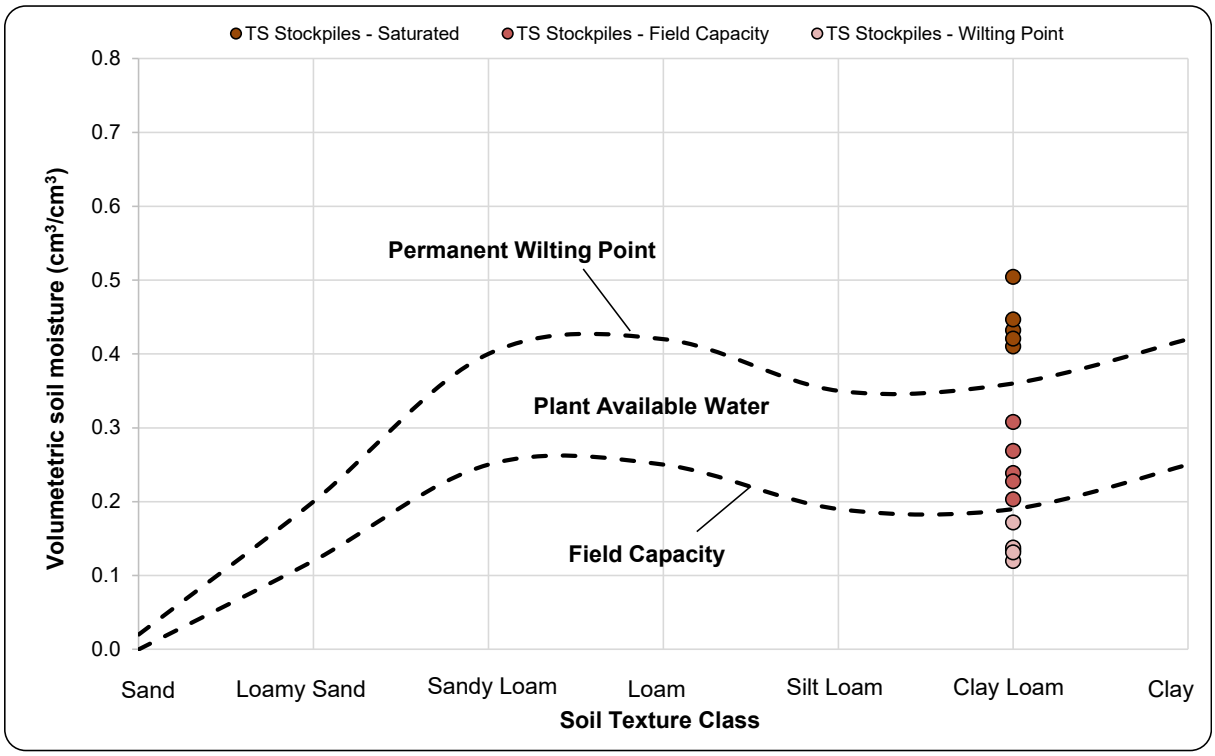


Figure 7-12: Relationship between soil texture class and plant available water for topsoil stockpiles

7.2.7 Borrow areas

7.2.8 Soil fertility

7.2.8.1 Total organic carbon and organic matter

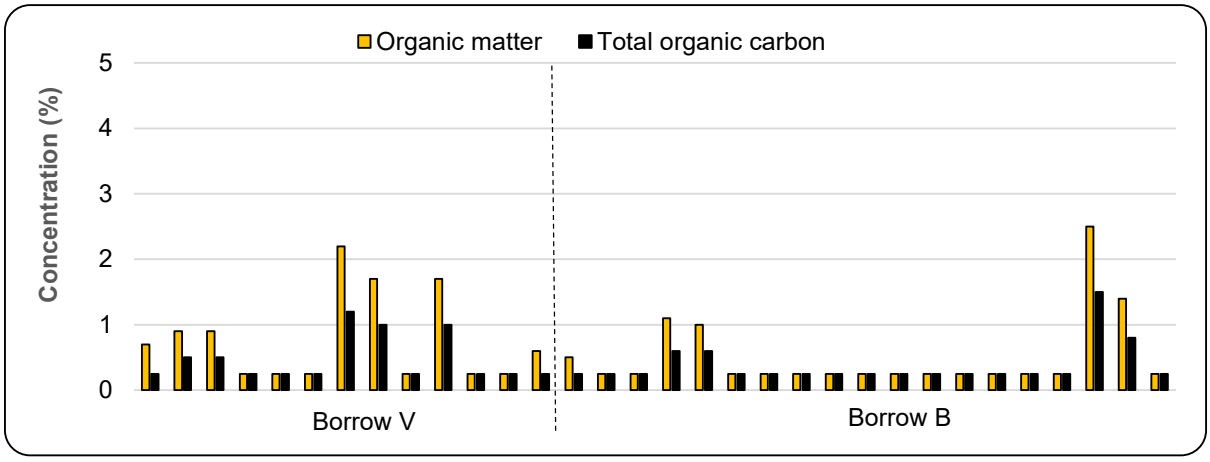


Figure 7-13: Organic matter and total organic carbon for Borrow V and Borrow B

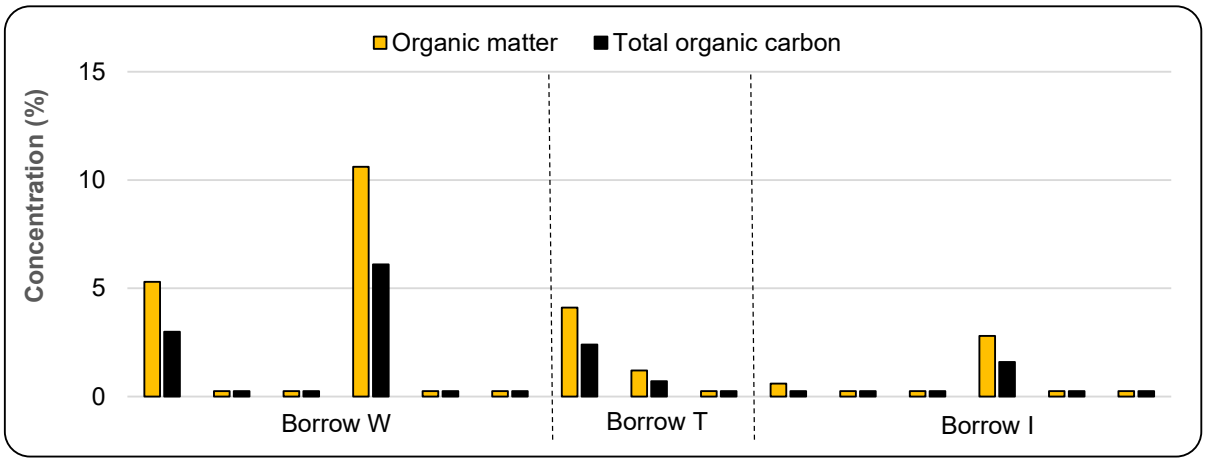


Figure 7-14: Organic matter and total organic carbon for Borrow W, T, and I

7.2.8.2 Total and extractable nitrogen, phosphorous and potassium

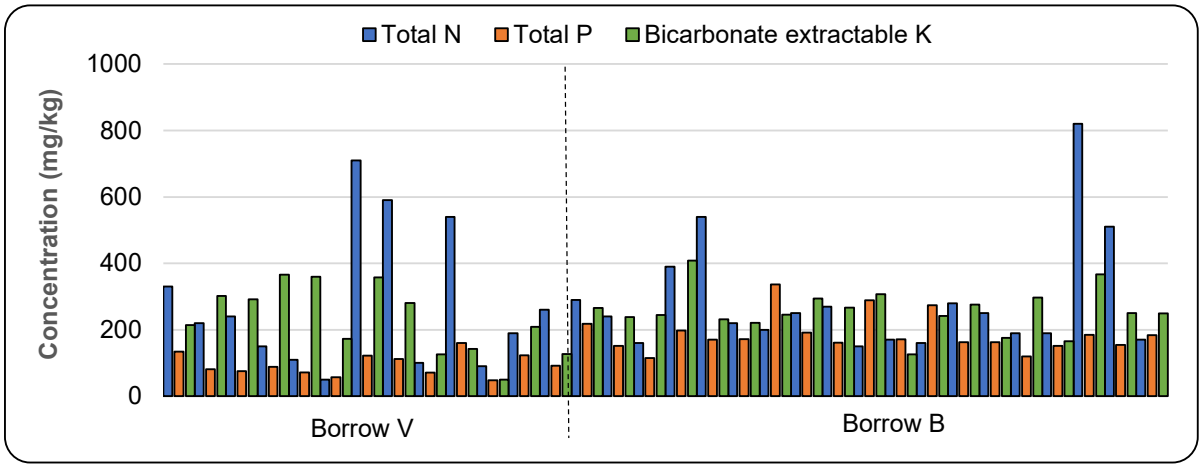


Figure 7-15: Total N, P, and extractable K for soils and saprolite from Borrow V and B

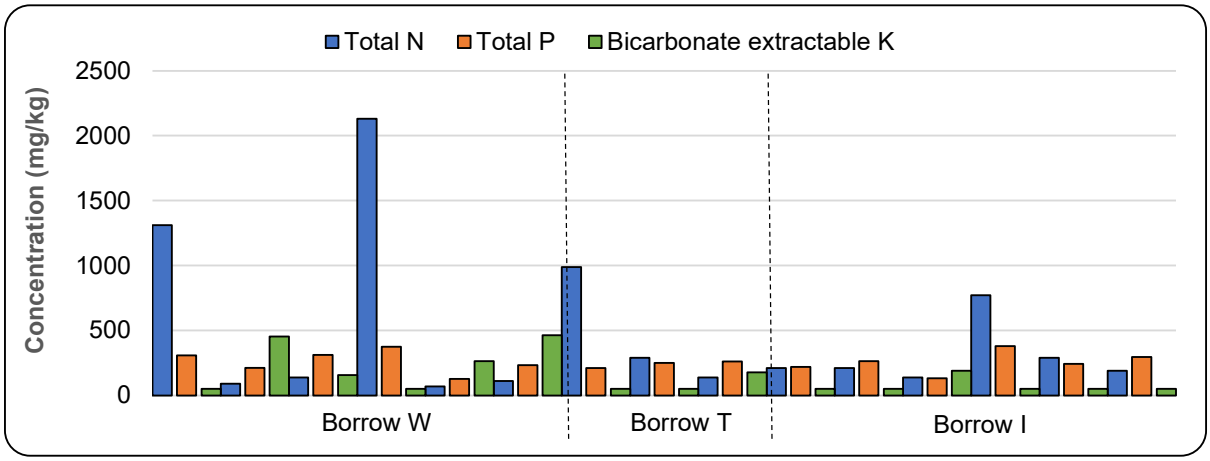


Figure 7-16: Total N, Total P, and extractable K for soils and saprolite from Borrow W, T, and I

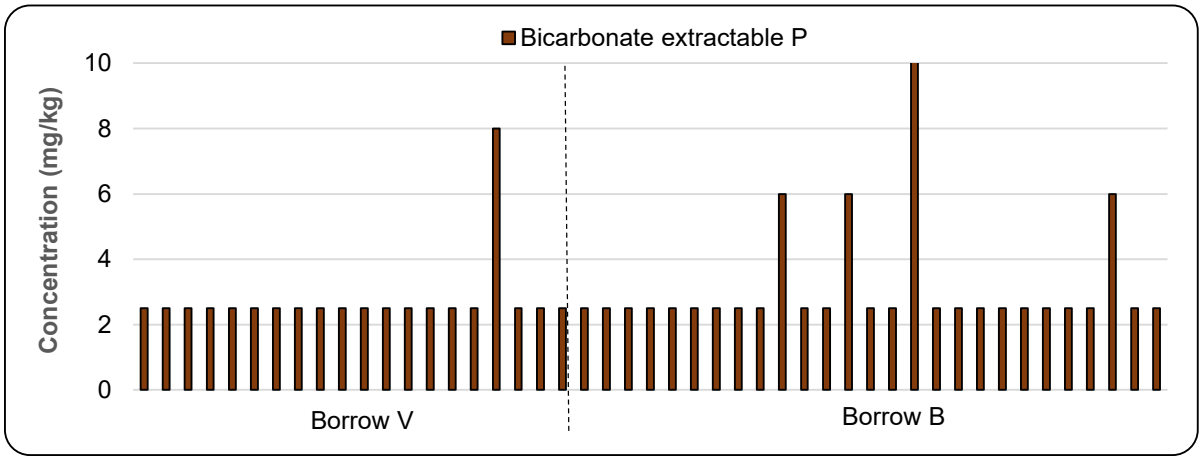


Figure 7-17: Extractable Phosphorus (P) for soils and saprolite from Borrow V and B

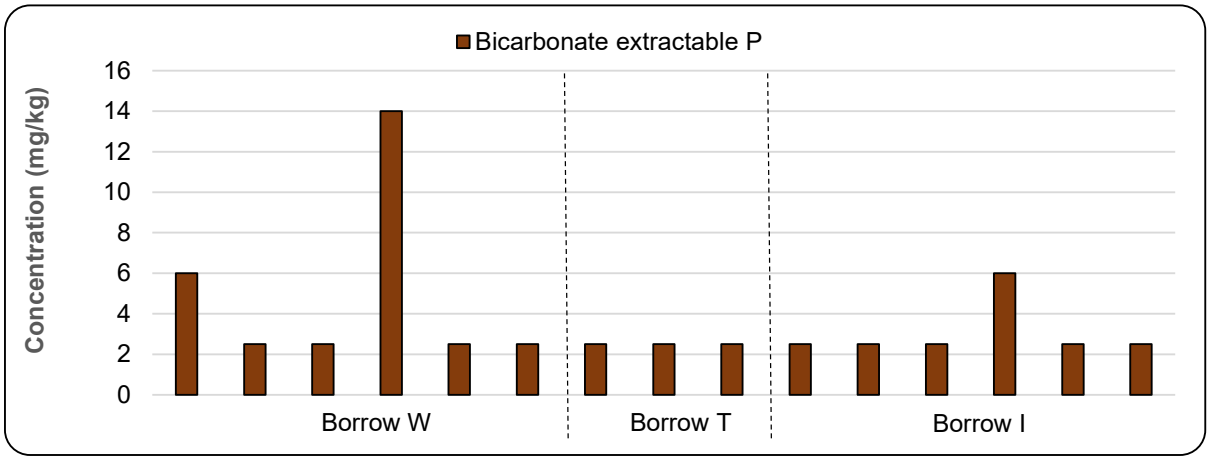


Figure 7-18: Extractable P for soils and saprolite from Borrow W, T, and I

7.2.9 Salinity

7.2.9.1 Cation exchange capacity and exchangeable sodium percentage

Table 7-6: Summary of characterisation results for borrow areas

Parameter	Analysis	Min	Max	Median	Classification[1]
pH	Acidity/alkalinity	4.7	9.1	8.0	Slightly alkaline
Electrical Conductivity (EC) (µS/cm) (1:5)	Salinity	18	5510	968	Moderate salinity
Exchangeable Ca (meq/100g)	Exchangeable Cations	0.1	5.6	0.6	Very low
Exchangeable Mg (meq/100g)	Exchangeable Cations	0.4	10.4	1.9	Moderate
Exchangeable K (meq/100g)	Exchangeable Cations	0.1	0.7	0.2	Low
Exchangeable Na (meq/100g)	Exchangeable Cations	0.1	12.3	0.4	Low
Cation exchange capacity (CEC) (meq/100g)	Soil fertility	0.9	21.2	4.9	Moderate
Exchangeable Sodium Percentage (ESP) (%)	Sodicity	0.1	73.0	6.0	Sodic (based on median value)
Calcium/Magnesium Ratio	Soil stability	0.1	28	0.3	Ca (low)

[1]Classification based on Hazelton and Murphy (2016).

7.2.9.2 Emerson class classifications

Table 7-7: Emerson Class test results for soils and saprolite from borrow areas

Area	Borrow V	Borrow V	Borrow V	Borrow V	Borrow V	Borrow V	Borrow V
Test pit no.	Test pit 1	Test pit 1	Test pit 1	Test pit 1	Test pit 1	Test pit 1	Test pit 2
Material type	Topsoil	Subsoil	Subsoil	Saprolite	Saprolite	Saprolite	Topsoil
Description	Silty CLAY - red	Silty CLAY - red	Silty CLAY - red	Silty CLAY - red	Silty CLAY - red	Silty CLAY - red	Silty SAND - brown
Emerson Class Number	**4g**	**2**	**2**	**1**	**3**	**3**	**3**

Area	Borrow V	Borrow V	Borrow B	Borrow B	Borrow B	Borrow B	Borrow B
Test pit no.	Test pit 2	Test pit 2	Test pit 3	Test pit 3	Test pit 3	Test pit 4	Test pit 4
Material type	Saprolite	Saprolite	Topsoil	Subsoil	Saprolite	Topsoil	Subsoil
Description	Silty SAND - brown	Clayey SILT- white	Silty CLAY - brown	Silty CLAY - brown	SILT - pale brown	SILT - brown	Silty CLAY - brown
Emerson Class Number	**3**	**4g**	**6**	**4c**	**6**	**3**	**6**

Area	Borrow B	Borrow B	Borrow B	Borrow B	Borrow B	Borrow B	Borrow B
Test pit no.	Test pit 4	Test pit 4	Test pit 5	Test pit 5	Test pit 5	Test pit 5	Test pit 5
Material type	Saprolite	Saprolite	Topsoil	Subsoil	Saprolite	Saprolite	Saprolite
Description	Clayey SILT - brown	Clayey SILT - brown	Silty CLAY - brown	Silty CLAY - pale brown	SILT - brown	Clayey SILT - pale brown	SILT - brown
Emerson Class Number	**6**	**6**	**2**	**2**	**3**	**3**	**3**

Area	Borrow B	Borrow B	Borrow B	Borrow B	Borrow B	Borrow B	Borrow B
Test pit no.	Test pit 6	Test pit 6	Test pit 6	Test pit 6	Test pit 7	Test pit 7	Test pit 7
Material type	Topsoil	Subsoil	Saprolite	Saprolite	Topsoil	Subsoil	Saprolite
Description	Silty CLAY - red/brown	Silty CLAY - red	Clayey SILT- brown	Clayey SILT- brown	SILT - brown	SILT - brown	SILT - brown
Emerson Class Number	**2**	**3**	**2**	**3**	**3**	**3**	**3**

Area	Borrow V	Borrow V	Borrow V	Borrow V	Borrow W	Borrow W	Borrow W
Test pit no.	Test pit 8	Test pit 8	Test pit 8	Test pit 8	Test pit 9	Test pit 9	Test pit 9
Material type	Topsoil	Saprolite	Saprolite	Saprolite	Topsoil	Saprolite	Saprolite
Description	SILT - red/brown	Clayey SILT - red	SILT - red/brown	SILT - red/brown	SILT - brown	SILT - red/white	SILT - red/brown
Emerson Class Number	**4g**	**3**	**2**	**2**	**2**	**4g**	**3**

Area	Borrow W	Borrow W	Borrow W	Borrow T	Borrow T	Borrow T	Borrow I
Test pit no.	Test pit 10	Test pit 10	Test pit 10	Test pit 11	Test pit 11	Test pit 11	Test pit 12
Material type	Topsoil	Saprolite	Saprolite	Topsoil	Topsoil	Saprolite	Topsoil
Description	SILT - brown	SILT - brown/red	SILT - brown/red	SILT - brown	SILT - pale brown	SILT - brown	SILT - pale brown
Emerson Class Number	**3**	**3**	**3**	**3**	**3**	**3**	**4g**

Area	Borrow I	Borrow I	Borrow I	Borrow I	Borrow I
Test pit no.	Test pit 12	Test pit 12	Test pit 12	Test pit 12	Test pit 12
Material type	Topsoil	Subsoil	Subsoil	Subsoil	Saprolite
Description	SILT - pale brown	SILT - pale brown	SILT - brown	Silty CLAY - brown	Sandy SILT - brown
Emerson Class Number	**4g**	**3**	**6**	**6**	**3**

7.2.10 Physical properties

7.2.10.1 Soil moisture

Table 7-8: Soil moisture content of rehabilitation materials

		Moisture Content		
Area	Lithological unit	Min (%)	Max (%)	Median (%)
Borrow Area V	Topsoil	6.7	12.3	9.5
Borrow Area B	Topsoil	6.3	10.4	6.6
Borrow Area W	Topsoil	8.6	9.6	9.1
Borrow Area I/T	Topsoil	4.4	8.8	6.0
			Median all topsoil	**7.9**
Borrow Area V	Subsoil	8.1	9.6	8.9
Borrow Area B	Subsoil	3.4	9.8	7.0
Borrow Area I/T	Subsoil	7.9	10.5	9.2
			Median all subsoil	**8.9**
Borrow Area V	Saprolite	6.8	8.8	7.1
Borrow Area B	Saprolite	8.1	8.1	8.1
Borrow Area I/T	Saprolite	9.5	9.5	9.5
			Median all saprolite	**8.1**

7.2.10.2 Atterberg limits

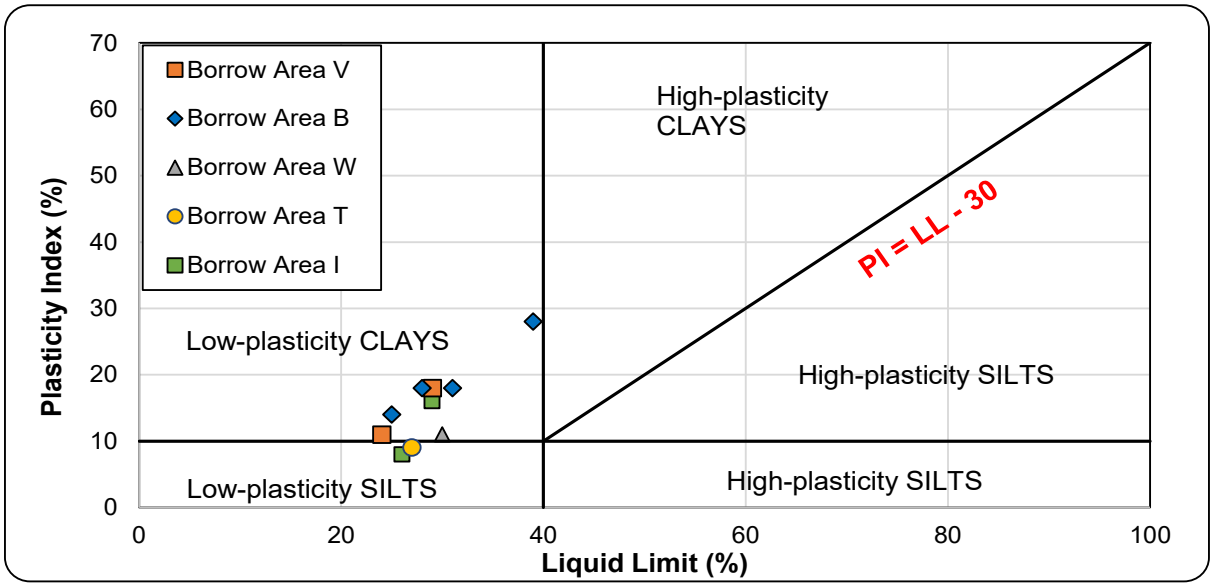


Figure 7-19: AASHTO soil classifications for borrow area soils

7.2.10.3 Bulk density

Table 7-9: Bulk density measurements for borrow areas

Borrow Area	Test pit	Material Type	Bulk density (t/m^3)
Borrow Area V	Test Pit 1	Topsoil	1.69
Borrow Area V	Test Pit 2	Topsoil	1.35
Borrow Area V	Test Pit 8	Topsoil	1.59
Borrow Area V	Test Pit 1	Subsoil	1.58
Borrow Area V	Test Pit 1	Subsoil	1.29
Borrow Area V	Test Pit 1	Saprolite	1.10
Borrow Area V	Test Pit 2	Saprolite	1.36
Borrow Area V	Test Pit 8	Saprolite	1.75
Borrow Area V	Test Pit 1	Saprolite	1.37
Borrow Area V	Test Pit 1	Saprolite	2.31
Borrow Area V	Test Pit 2	Saprolite	1.53
Borrow Area V	Test Pit 8	Saprolite	1.71
Borrow Area V	Test Pit 8	Saprolite	1.57
Borrow Area B	Test Pit 3	Topsoil	1.36
Borrow Area B	Test Pit 7	Topsoil	1.51
Borrow Area B	Test Pit 3	Subsoil	0.89
Borrow Area B	Test Pit 7	Subsoil	1.60
Borrow Area B	Test Pit 3	Saprolite	1.48
Borrow Area B	Test Pit 7	Saprolite	2.32
Borrow Area B	Test Pit 4	Topsoil	1.58
Borrow Area B	Test Pit 5	Topsoil	1.66
Borrow Area B	Test Pit 6	Topsoil	1.64
Borrow Area B	Test Pit 4	Subsoil	1.29
Borrow Area B	Test Pit 5	Subsoil	1.66
Borrow Area B	Test Pit 6	Subsoil	1.53
Borrow Area B	Test Pit 4	Saprolite	1.51
Borrow Area B	Test Pit 5	Saprolite	2.16
Borrow Area B	Test Pit 6	Saprolite	1.47
Borrow Area B	Test Pit 4	Saprolite	1.33
Borrow Area B	Test Pit 5	Saprolite	1.37
Borrow Area B	Test Pit 5	Saprolite	1.79
Borrow Area B	Test Pit 6	Saprolite	2.22
Borrow Area W	Test Pit 9	Topsoil	1.73
Borrow Area W	Test Pit 10	Topsoil	1.46
Borrow Area W	Test Pit 9	Saprolite	2.24
Borrow Area W	Test Pit 10	Saprolite	2.09
Borrow Area W	Test Pit 9	Saprolite	2.08
Borrow Area W	Test Pit 10	Saprolite	2.14
Borrow Area T	Test Pit 11	Topsoil	1.43

Borrow Area T	Test Pit 11	Topsoil	1.52
Borrow Area T	Test Pit 11	Saprolite	1.53
Borrow Area I	Test Pit 12	Topsoil	1.60
Borrow Area I	Test Pit 12	Topsoil	1.78
Borrow Area I	Test Pit 12	Subsoil	2.06
Borrow Area I	Test Pit 12	Subsoil	2.00
Borrow Area I	Test Pit 12	Subsoil	1.61
Borrow Area I	Test Pit 12	Saprolite	1.61

7.2.10.4 Permeability

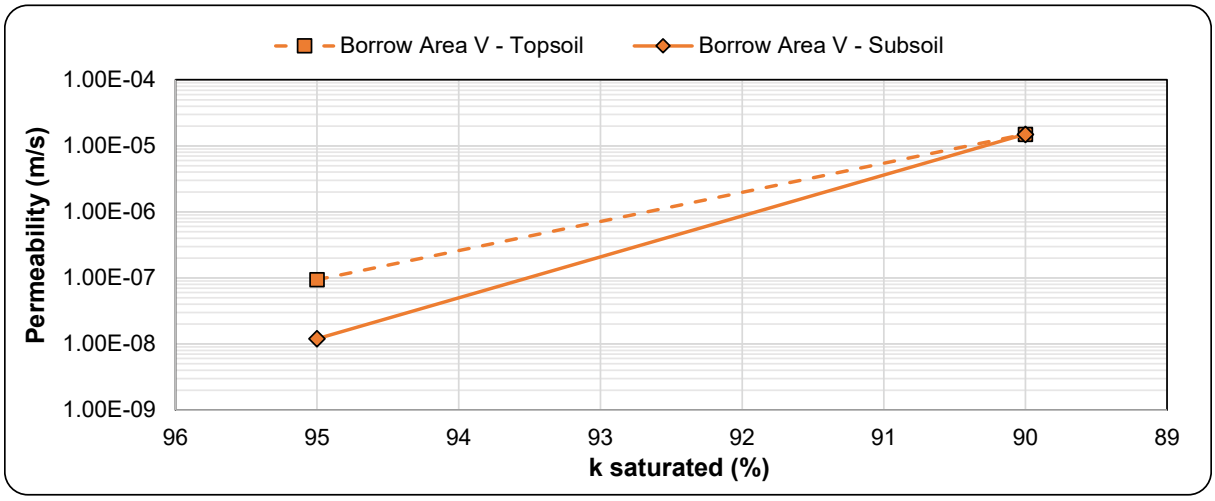


Figure 7-20: Permeability results for Borrow Area V

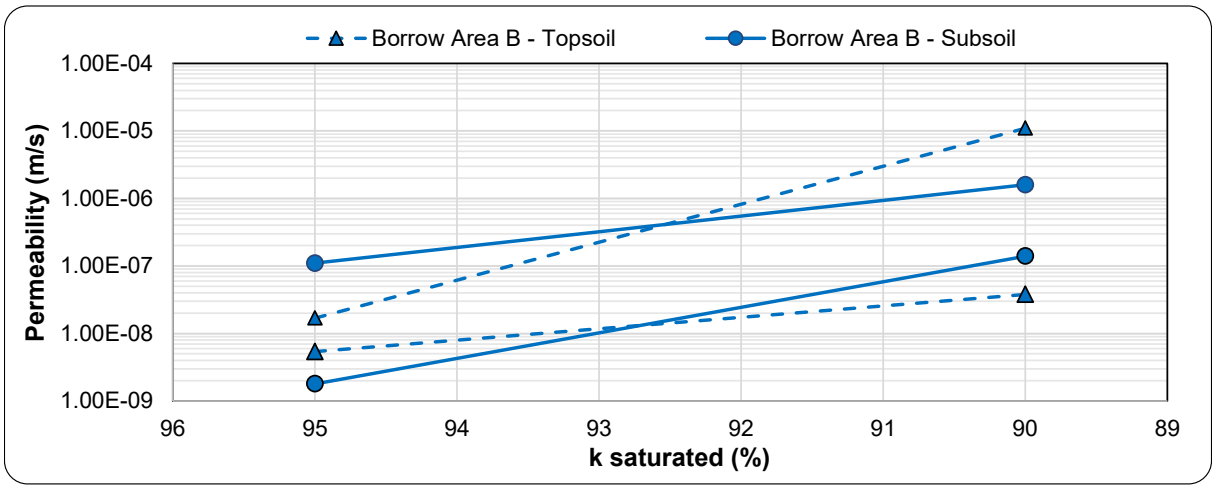


Figure 7-21: Permeability results for Borrow Area B

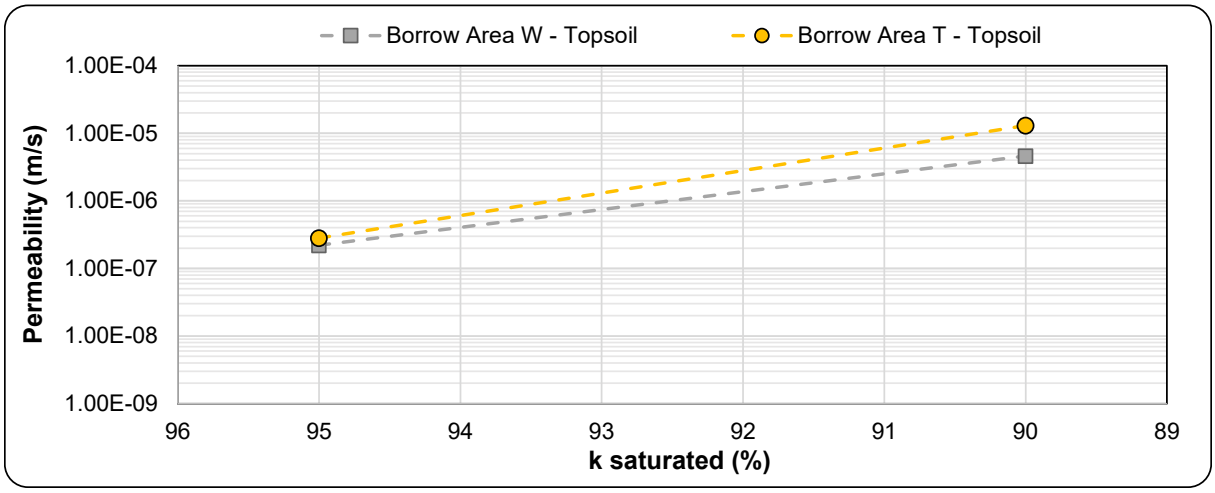


Figure 7-22: Permeability results for Borrow Area W and T

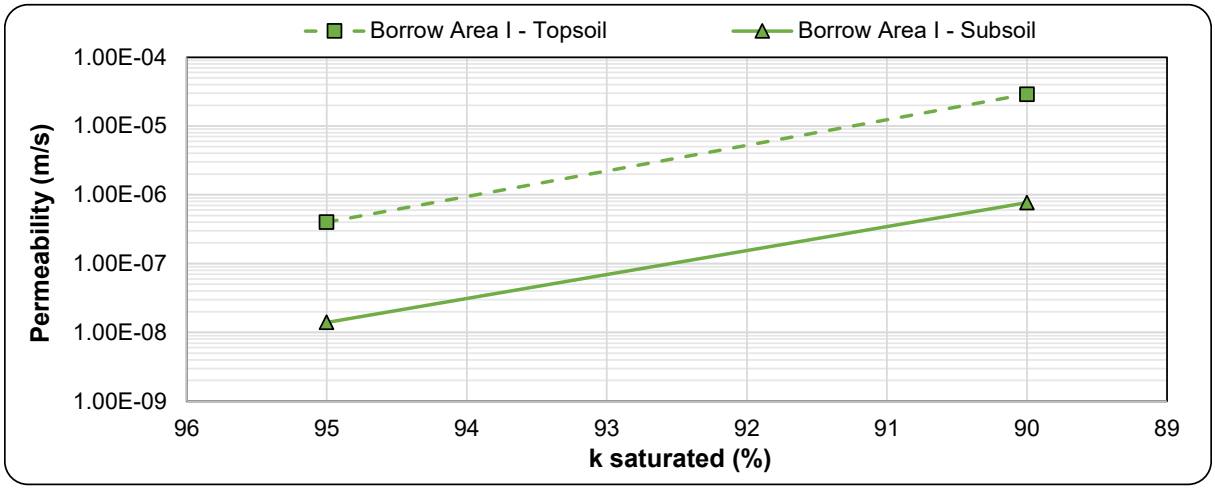
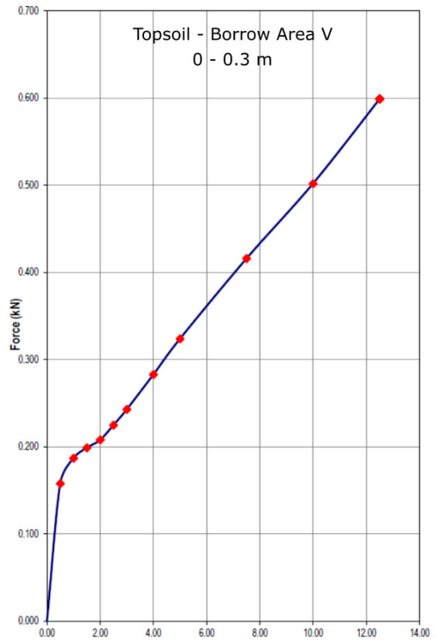
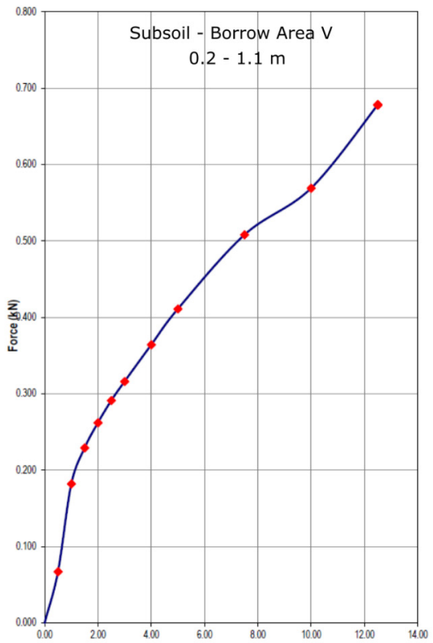
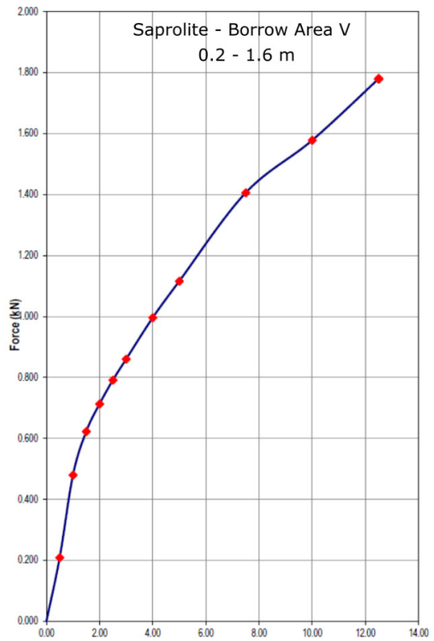


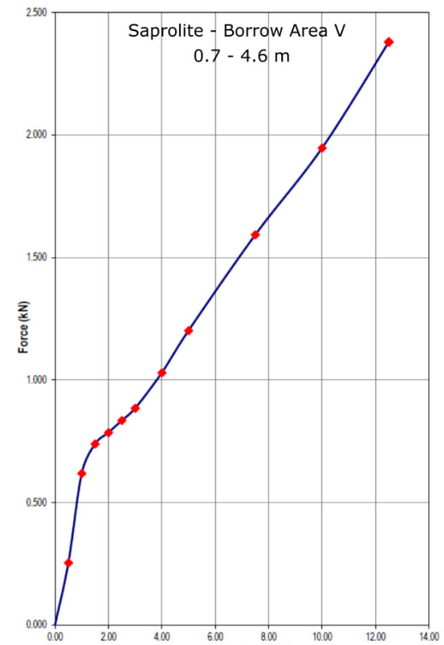
Figure 7-23: Permeability results for Borrow Area I

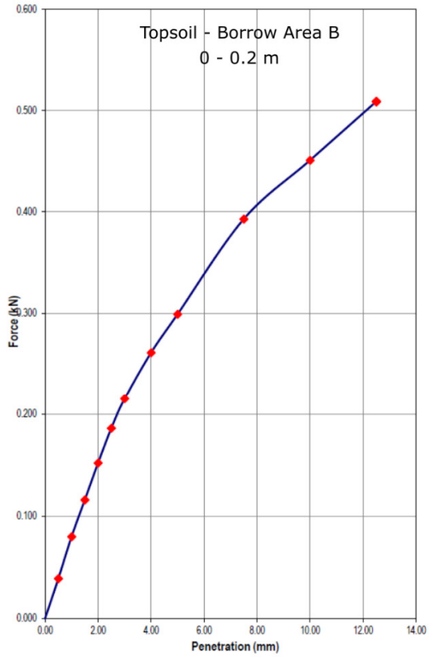
7.2.10.5 Compaction

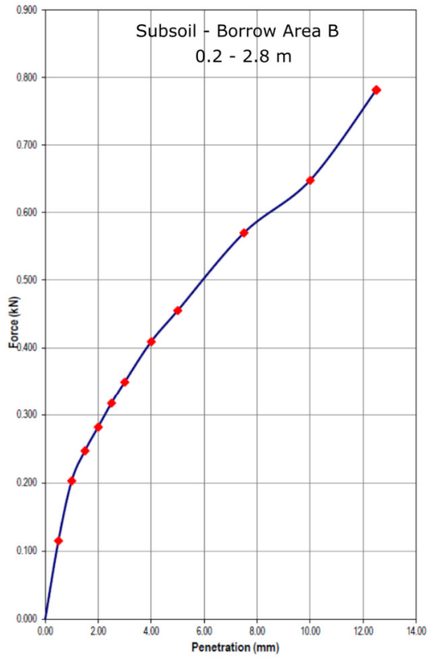


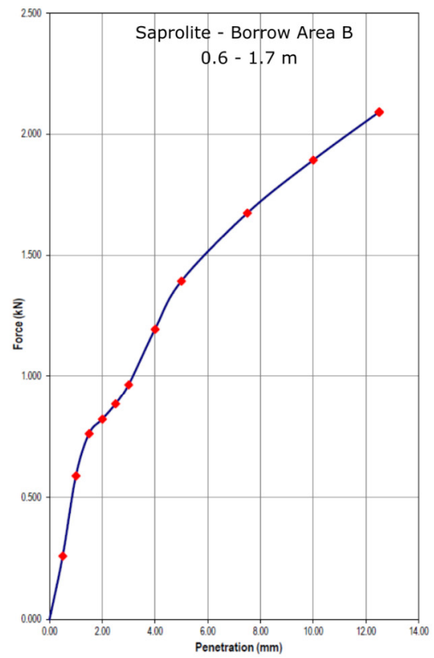












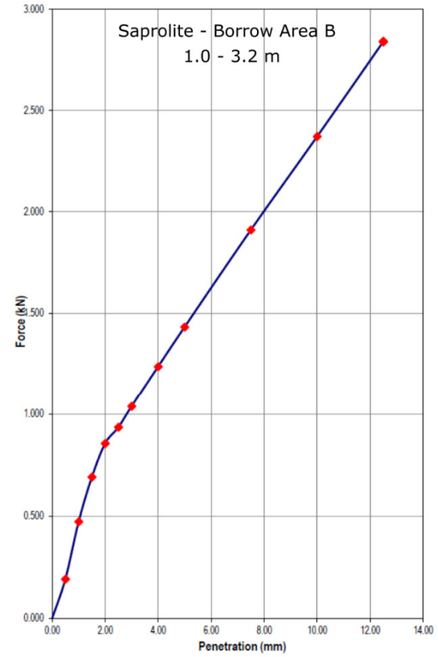


Figure 7-24: California Bearing Ratio (CBR) graphs for Borrow Areas V and B

7.2.10.6 Soil water characteristic curves

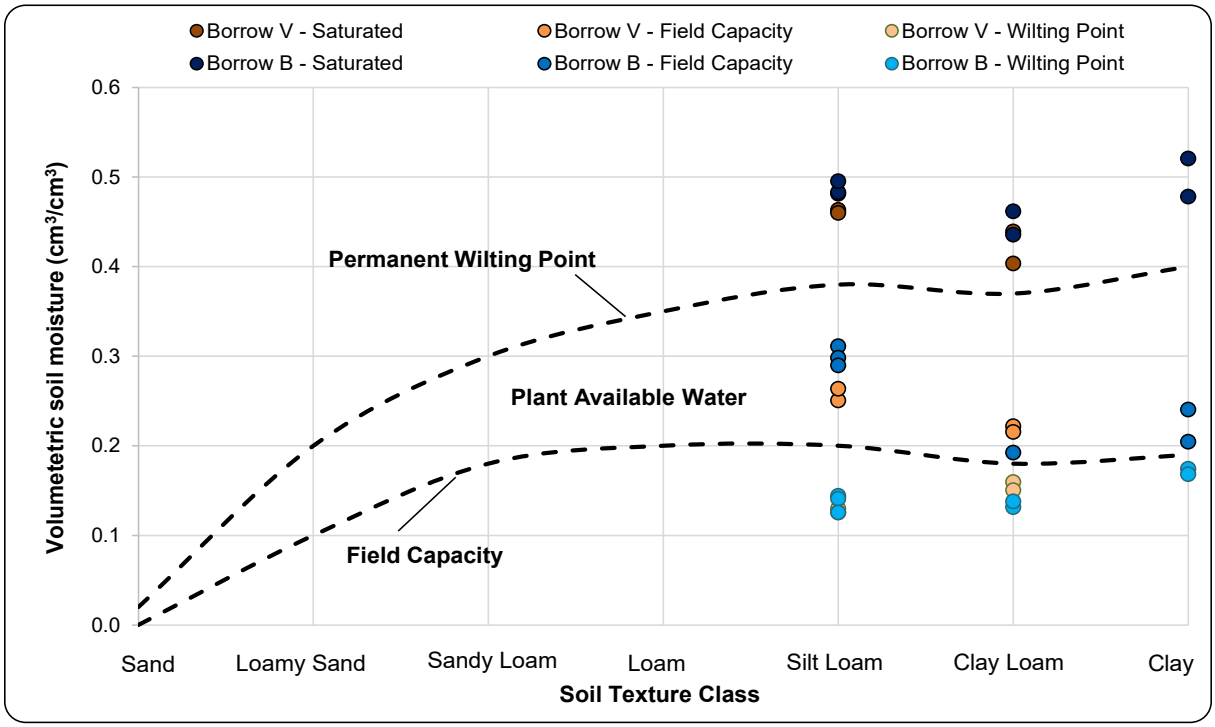


Figure 7-25: Relationship between soil texture class and plant available water for Borrow V and B

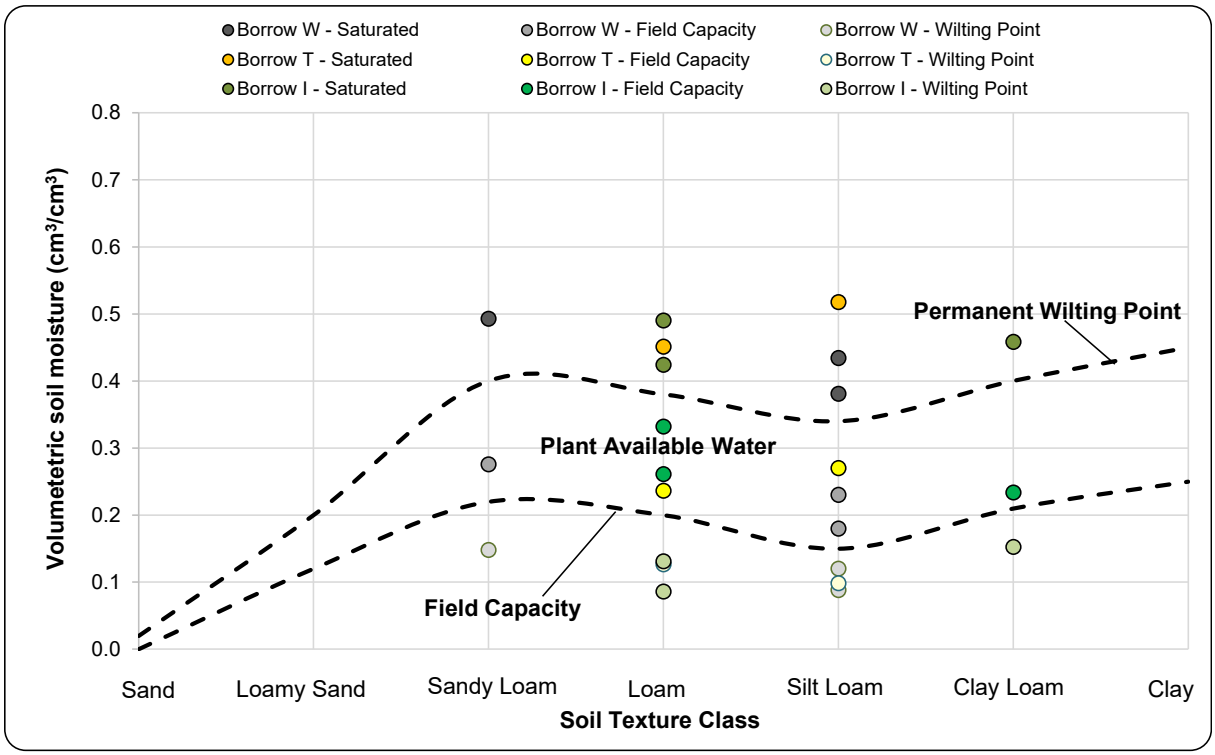


Figure 7-26: Relationship between soil texture class and plant available water for Borrow W, T, and I

7.3 Attachment C: Test pit logs

TEST PIT LOG

TEST PIT:	Phase 2 - Test Pit 1 Borrow Area V

Client:	Glencore	Easting:	296313.7
Project:	Lady Loretta RMSaAP Phase 2	Northing:	7811480
Site:	Lady Loretta Mine	GCS:	
Method:	35T Excavator	Logged	
Contractor:	Redpath	Datum:	GDA 94; Zone 54
Log Date:	3 November 2021	Page:	1/1

Atlas of Australian Soils Description:

Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)

Atlas of Australian Soils Major Unit:	Sodosol
ASC DSM Unit:	
Logged Unit:	
Regional Geology:	Lady Loretta Formation

Hole ID:	TP01
Top of Hole:	0.0 m
End of Hole:	4.6 m
Logged by:	Melinda Hilton
Checked by:	Greg Maddocks
Compiled by:	
Reviewed by:	
Approved by:	

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes	From (m)	To (m)	Interval (m)	Samples	Bulk density (t/m^3)	Emerson Test and ESP	$pH_{1:5}$ & $EC_{1:5}$	% Clay, Silt, Sand & Gravel
	TS		Dark red-brown, moderately sorted, sub-rounded loam Extremely weathered	M	S	VL	A1 Horizon - Topsoil Fine roots Clear boundary Crumb peds	0.0	0.2	0.2	2021044_0001	1.69	4 (gypsum) <0.1%	pH 5.9 4620 µS/cm	33% Gravel 22% Sand 22% Silt 23% Clay
0.5	SS1		Dark red-brown, poorly sorted, sub-rounded loam Extremely weathered	M	S	VL	B2 Horizon - Subsoil A few fine roots Abrupt boundary Sub-angular peds Ironstone fragments	0.2	0.5	0.3	2021044_0002	1.58	2 41.2%	pH 6.3 1278 µS/cm	19% Gravel 32% Sand 19% Silt 30% Clay
1.0	SS2		Red-brown, very poorly sorted, loam and angular siltstone Highly weathered	D	S	L	B3 Horizon - Subsoil No roots Transitional - soil and saprolite Abrupt boundary Massive	0.5	1.1	0.6	2021044_0003	1.29	2 36.4%	pH 6.8 1762 µS/cm	19% Gravel 32% Sand 19% Silt 30% Clay
1.5	SL1		Red-brown, very poorly sorted, angular siltstone Highly weathered	D	F	L	C1 Horizon - Saprolite No roots Gradual boundary Massive Contains some fine material	1.1	1.6	0.5	2021044_0004	1.10	1 46.8%	pH 6.9 972 µS/cm	11% Gravel 89% Sand 0% Silt 0% Clay
2.0 2.5 3.0	SL2		Light red-brown, very poorly sorted, angular siltstone Highly weathered	D	F	L	C2 Horizon - Saprolite No roots Gradual boundary Massive Contains some fine material	1.6	3.0	1.4	2021044_0005	1.37	3 50.5%	pH 7.5 1468 µS/cm	23% Gravel 77% Sand 0% Silt 0% Clay

Photos













2.5																		
3.0	SL3		Red-white, very poorly sorted, angular saprolite Moderately weathered	D	St	MD	C3 Horizon - Saprolite No roots Massive	3.0	4.6	1.6	2021044_ 0006		2.31	3 50.1%	pH 6.9 843 µS/cm	23% Gravel 77% Sand 0% Silt 0% Clay
3.5																		
4.0																		
4.5																		
			0															
5.0			TOTAL SOIL = 1.1 m TOTAL DEPTH = 4.6 m															





TS - Topsoil;SS - Subsoil; SL - Saprolite; SR - Saprock; Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 7-27: Test pit soil log: Test Pit 1 - Borrow Area V

TEST PIT LOG		TEST PIT:	Phase 2 - Test Pit 2 Borrow Area V	Atlas of Australian Soils Description:		Hole ID:	TP02
				Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)		Top of Hole:	0.0 m
						End of Hole:	1.6 m
						Logged by:	Melinda Hilton
Client:	Glencore	Easting:	296228.6	Atlas of Australian Soils Major Unit:	Sodosol	Checked by:	Greg Maddocks
Project:	Lady Loretta RMSaAP Phase 2	Northing:	7811429	ASC DSM Unit:		Compiled by:	
Site:	Lady Loretta Mine	GCS:		Logged Unit:		Reviewed by:	
Method:	35T Excavator	Logged				Approved by:	
Contractor:	Redpath	Datum:	GDA 94; Zone 54	Regional Geology:	Lady Loretta Formation		
Log Date:	3 November 2021	Page:	1/1				

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes	From (m)	To (m)	Interval (m)	Samples	Bulk density (t/m³)	Emerson Test and ESP	$pH_{1:5}$ & $EC_{1:5}$	% Clay, Silt, Sand & Gravel
	TS		Brown, very poorly sorted, sub-rounded sand Extremely weathered	M	S	VL	A1 Horizon - Topsoil Fine roots Transitional - soil and saprolite Crumb peds Clear boundary Small saprolite blocks	0.0	0.3	0.3	2021044_0007	1.35	3 0.7%	pH 6.0 21 µS/cm	33% Gravel 22% Sand 22% Silt 23% Clay
0.5 1.0	SL1		Red-brown, very poorly sorted, angular siltstone Highly weathered	D	F	L	C1 Horizon - Saprolite A few roots Abrupt boundary Massive	0.3	1	0.7	2021044_0008	1.36	3 0.5%	pH 5.5 12 µS/cm	11% Gravel 89% Sand
1.5	SL2		Red-white, very poorly sorted, angular siltstone Highly weathered	D	F	L	C2 Horizon - Saprolite No roots Massive Contains some fine material	1.0	1.6	0.6	2021044_0009	1.53	4 (gypsum) 0.1%	pH 7.4 216 µS/cm	23% Gravel 77% Sand
2.0 2.5 3.0			**TOTAL SOIL = 0.3 m** **TOTAL DEPTH = 1.6 m**												

Photos











TS - Topsoil;SS - Subsoil; SL - Saprolite; SR - Saprock; Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 7-28: Test pit soil log: Test Pit 2 - Borrow Area V

RGS	TEST PIT LOG	TEST PIT:	Phase 2 - Test Pit 3 Borrow Area B	Atlas of Australian Soils Description: Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)	Hole ID: TP03 Top of Hole: 0.0 m End of Hole: 3.3 m Logged by: Melinda Hilton
Client: Project: Site: Method: Contractor: Log Date:	Glencore Lady Loretta RMSaAP Phase 2 Lady Loretta Mine 35T Excavator Redpath 4 November 2021	Easting: Northing: GCS: Logged Datum: Page:	295958.6 7811125 GDA 94; Zone 54 1/1	Atlas of Australian Soils Major Unit: Sodosol ASC DSM Unit: Logged Unit: Regional Geology: Lady Loretta Formation	Checked by: Greg Maddocks Compiled by: Reviewed by: Approved by:

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes	From (m)	To (m)	Interval (m)	Samples	Bulk density (t/m^3)	Emerson Test and ESP	$pH_{1:5}$ & $EC_{1:5}$	% Clay, Silt, Sand & Gravel
	TS		Dark red-brown, moderately sorted, sub-rounded loam Extremely weathered	D	S	VL	A1 Horizon - Topsoil Some roots Crumb peds Abrupt boundary	0.0	0.2	0.2	2021044_0010	1.36	6 0.2%	pH 6.9 1385 µS/cm	24% Gravel 26% Sand 20% Silt 30% Clay
	SS1		Light red-brown, poorly sorted, sub-rounded loamy gravel Extremely weathered	D	S	VL	B2 Horizon - Subsoil No roots Crumb peds Clear boundary	0.2	2.8	2.6	2021044_0011	0.89	4 (calcite) 38.8%	pH 7.0 2209 µS/cm	23% Gravel 29% Sand 23% Silt 25% Clay

Depth scale: 0.5, 1.0, 1.5, 2.0, 2.5

Photos









2.5																	
3.0	SL1		Red-white, very poorly sorted, angular siltstone Highly weathered	D	S	VL	C1 Horizon - Saprolite No roots Massive Contains some fine material	2.8	3.3	0.5	2021044_ 0012	 Heavily weathered profile in dip of valley	1.48	6 21.8%	pH 6.9 935 µS/cm	54% Gravel 46% Sand
3.5			**TOTAL SOIL = 2.8 m** **TOTAL DEPTH = 3.3 m**														

TS - Topsoil;SS - Subsoil; SL - Saprolite; SR - Saprock; Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 7-29: Test pit soil log: Test Pit 3 - Borrow Area B

TEST PIT LOG

TEST PIT: Phase 2 - Test Pit 4 — Borrow Area B

Client:	Glencore	Easting:	296244.5
Project:	Lady Loretta RMSaAP Phase 2	Northing:	7810611
Site:	Lady Loretta Mine	GCS:	
Method:	35T Excavator	Logged Datum:	GDA 94; Zone 54
Contractor:	Redpath	Page:	1/1
Log Date:	4 November 2021		

Atlas of Australian Soils Description:

Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)

Atlas of Australian Soils Major Unit:	Sodosol
ASC DSM Unit:	
Logged Unit:	
Regional Geology:	Lady Loretta Formation

Hole ID:	TP04
Top of Hole:	0.0 m
End of Hole:	3.1 m
Logged by:	Melinda Hilton
Checked by:	Greg Maddocks
Compiled by:	
Reviewed by:	
Approved by:	

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes	From (m)	To (m)	Interval (m)	Samples	Bulk density (t/m^3)	Emerson Test and ESP	$pH_{1:5}$ & $EC_{1:5}$	% Clay, Silt, Sand & Gravel
	TS		Dark red-brown, moderately sorted, sub-rounded loam Extremely weathered	M	S	VL	A1 Horizon - Topsoil Lots of roots Crumb peds Clear boundary Soft and fertile	0.0	0.4	0.4	2021044_0013	1.58	3 0.3%	pH 6.8 17 µS/cm	18% Gravel 19% Sand 25% Silt 38% Clay
0.5	SS1		Red-brown, very poorly sorted, sub-angular gravelly loam Extremely weathered	D	S	VL	B2 Horizon - Subsoil Transitional - soil with blocky saprolite No roots Angular peds Clear boundary	0.4	0.8	0.4	2021044_0014	1.29	6 6.0%	pH 7.2 670 µS/cm	14% Gravel 24% Sand 24% Silt 38% Clay
1.0	SL1		Red-yellow, very poorly sorted, angular siltstone Highly weathered	D	F	L	C1 Horizon - Saprolite No roots Massive Gradual boundary	0.8	1.7	0.9	2021044_0015	1.51	6 4.8%	pH 7.0 322 µS/cm	46% Gravel 54% Sand
1.5															
	SL2		Yellow-brown, very poorly sorted, angular siltstone Moderately weathered	D	F	L	C2 Horizon - Saprolite No roots Massive Tabulated fracturing	1.7	3.1	1.4	2021044_0016	1.33	6 8.9%	pH 6.8 171 µS/cm	34% Gravel 66% Sand
2.0															
2.5															
3.0															

Photos











2.0	SL2		Yellow-brown, very poorly sorted, angular siltstone Moderately weathered	D	F	L	C2 Horizon - Saprolite No roots Massive Tabulated fracturing	1.7	3.1	1.4	2021044_ 0016		1.33	6 8.9%	pH 6.8 171 µS/cm	34% Gravel 66% Sand
2.5																
3.0																
3.5			**TOTAL SOIL = 0.8 m** **TOTAL DEPTH = 3.1 m**													

TS - Topsoil;SS - Subsoil; SL - Saprolite; SR - Saprock; Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 7-30: Test pit soil log: Test Pit 4 - Borrow Area B

TEST PIT LOG		TEST PIT:	Phase 2 - Test Pit 5 Borrow Area B	Atlas of Australian Soils Description: Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)	Hole ID: TP05 Top of Hole: 0.0 m End of Hole: 2.7 m Logged by: Melinda Hilton
Client:	Glencore	Easting:	296064.8	Atlas of Australian Soils Major Unit: Sodosol	Checked by: Greg Maddocks
Project:	Lady Loretta RMSaAP Phase 2	Northing:	7810906	ASC DSM Unit:	Compiled by:
Site:	Lady Loretta Mine	GCS:		Logged Unit:	Reviewed by:
Method:	35T Excavator	Logged			Approved by:
Contractor:	Redpath	Datum:	GDA 94; Zone 54	Regional Geology: Lady Loretta Formation	
Log Date:	4 November 2021	Page:	1/1		

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes	From (m)	To (m)	Interval (m)	Samples	Bulk density (t/m^3)	Emerson Test and ESP	$pH_{1:5}$ & $EC_{1:5}$	% Clay, Silt, Sand & Gravel
	TS		Red-brown,well sorted, rounded loam Extremely weathered	M	S	VL	A1 Horizon - Topsoil A few roots Crumb peds Abrupt boundary	0.0	0.4	0.4	2021044_0017	1.66	2 73.0%	pH 6.9 1089 µS/cm	18% Gravel 19% Sand 25% Silt 38% Clay
0.5	SS1		Light red-white, very poorly sorted gravelly loam Highly weathered	D	S	VL	B2 Horizon - Subsoil Transitional - soil and saprolite No roots Sub-angular peds Abrupt boundary	0.4	0.8	0.4	2021044_0018	1.66	2 64.3%	pH 7.3 1466 µS/cm	14% Gravel 24% Sand 24% Silt 38% Clay
1.0	SL1		Grey, very poorly sorted, angular claystone Moderately weathered Possible clay lens, not continuous	D	F	L	C1 Horizon - Saprolite No roots Massive Abrupt boundary	0.8	1	0.2	2021044_0019	2.16	3 67.9%	pH 7.5 564 µS/cm	46% Gravel 54% Sand
	SL2		Yellow, very poorly sorted, angular siltstone Highly weathered	D	F	L	C2 Horizon - Saprolite No roots Massive Clear boundary	1	1.4	0.4	2021044_0020	1.37	3 69.7%	pH 7.8 801 µS/cm	34% Gravel 66% Sand
1.5 2.0 2.5	SL3		Light yellow, very poorly sorted, angular siltstone Highly weathered	D	F	L	C3 Horizon - Saprolite No roots Massive	1.4	2.7	1.3	2021044_0021	1.79	3 67.5%	pH 7.8 506 µS/cm	34% Gravel 66% Sand
3.0			**TOTAL SOIL = 0.8 m** **TOTAL DEPTH = 2.7 m**												

Photos















TS - Topsoil;SS - Subsoil; SL - Saprolite; SR - Saprock; Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 7-31: Test pit soil log: Test Pit 5 - Borrow Area B

RGS	TEST PIT LOG			TEST PIT:	Phase 2 - Test Pit 6 Borrow Area B					Atlas of Australian Soils Description: Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)				Hole ID: Top of Hole: End of Hole: Logged by: Checked by: Compiled by: Reviewed by: Approved by:	TP06 0.0 m 3.2 m Melinda Hilton Greg Maddocks			
Client: Project: Site: Method: Contractor: Log Date:	Glencore Lady Loretta RMSaAP Phase 2 Lady Loretta Mine 35T Excavator Redpath 4 November 2021			Easting: Northing: GCS: Logged Datum: Page:	296150.3 7810980 GDA 94; Zone 54 1/1					Atlas of Australian Soils Major Unit: ASC DSM Unit: Logged Unit: Regional Geology:	Sodosol Lady Loretta Formation								
Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes	From (m)	To (m)	Interval (m)	Samples	Photos				Bulk density (t/m^3)	Emerson Test and ESP	pH$_{1:5}$ & EC$_{1:5}$	% Clay, Silt, Sand & Gravel
	TS		Red-brown, moderately sorted, sub-rounded loam Extremely weathered	M	S	VL	A1 Horizon - Topsoil A few roots Crumb peds Clear boundary	0.0	0.3	0.3	2021044_0022					1.64	2 53.6%	pH 6.9 1876 µS/cm	18% Gravel 19% Sand 25% Silt 38% Clay
0.5	SS1		Red-brown, moderately sorted, sub-rounded loam Extremely weathered	D	S	VL	B2 Horizon - Subsoil No roots Crumb peds Clear boundary Drier than topsoil	0.3	0.6	0.3	2021044_0023					1.53	3 56.8%	pH 6.6 2335 µS/cm	14% Gravel 24% Sand 24% Silt 38% Clay
1.0	SL1		Yellow, very poorly sorted, angular siltstone Highly weathered	D	F	L	C2 Horizon - Saprolite No roots Massive Gradual boundary Contains some fine material	0.6	1.5	0.9	2021044_0024					1.47	2 65.4%	pH 7.6 1538 µS/cm	46% Gravel 54% Sand
1.5																			
2.0	SL2		Yellow, very poorly sorted, angular siltstone Highly weathered	D	F	L	C2 Horizon - Saprolite No roots Massive Contains some fine material	1.5	3.2	1.7	2021044_0025					2.22	3 71.3%	pH 7.8 766 µS/cm	34% Gravel 66% Sand
2.5																			
3.0																			

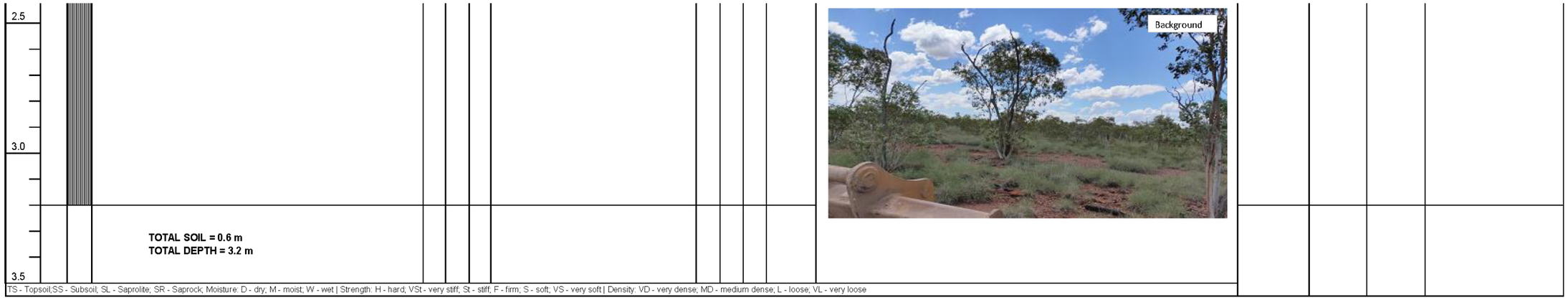


Figure 7-32: Test pit soil log: Test Pit 6 - Borrow Area B

TEST PIT LOG		TEST PIT:	Phase 2 - Test Pit 7 Borrow Area B	Atlas of Australian Soils Description:		Hole ID:	TP07
				Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)		Top of Hole: End of Hole: Logged by:	0.0 m 1.5 m Melinda Hilton
Client:	Glencore	Easting:	296043.9	Atlas of Australian Soils Major Unit:	Sodosol	Checked by:	Greg Maddocks
Project:	Lady Loretta RMSaAP Phase 2	Northing:	7811007	ASC DSM Unit:		Compiled by:	
Site:	Lady Loretta Mine	GCS:		Logged Unit:		Reviewed by:	
Method:	35T Excavator	Logged		Regional Geology:	Lady Loretta Formation	Approved by:	
Contractor:	Redpath	Datum:	GDA 94; Zone 54				
Log Date:	5 November 2021	Page:	1/1				

Unit	Material	Moisture	Strength	Density	Notes	From (m)	To (m)	Interval (m)	Samples	Bulk density (t/m³)	Emerson Test and ESP	pH 1:5 & EC 1:5	% Clay, Silt, Sand & Gravel
TS	Dark red-brown, moderately sorted, sub-rounded loam Extremely weathered	M	S	VL	A1 Horizon - Topsoil Lots of roots Crumb peds Clear boundary	0.0	0.2	0.2	2021044_0026	1.51	3 <0.1%	pH 7.5 19 µS/cm	24% Gravel 26% Sand 20% Silt 30% Clay
SS1	Red-brown, very poorly sorted, sub-rounded loam with siltstone Extremely to highly weathered	M	S	VL	B2 Horizon - Subsoil Transitional - soil and saprolite Some roots Clear boundary	0.2	0.4	0.2	2021044_0027	1.60	3 0.1%	pH 7.4 57 µS/cm	23% Gravel 29% Sand 23% Silt 25% Clay
SL1	Red-yellow, very poorly sorted, angular siltstone Slightly to moderately weathered	D	St	MD	C1 Horizon - Saprolite No roots Massive Fairly competent rock	0.4	1.5	1.1	2021044_0028	2.32	3 0.1%	pH 8.6 193 µS/cm	54% Gravel 46% Sand

Depth scale: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0

TOTAL SOIL = 0.4 m
TOTAL DEPTH = 1.5 m

Photos











TS - Topsoil;SS - Subsoil; SL - Saprolite; SR - Saprock; Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 7-33: Test pit soil log: Test Pit 7 - Borrow Area B

TEST PIT LOG

TEST PIT:	Phase 2 - Test Pit 8 Borrow Area V	Hole ID:	TP08
Client:	Glencore	Top of Hole:	0.0 m
Project:	Lady Loretta RMSaAP Phase 2	End of Hole:	3.3 m
Site:	Lady Loretta Mine	Logged by:	Melinda Hilton
Method:	35T Excavator	Checked by:	Greg Maddocks
Contractor:	Redpath	Compiled by:	
Log Date:	5 November 2021	Reviewed by:	
Easting:	296279.3	Approved by:	
Northing:	7811403		
GCS: Logged			
Datum:	GDA 94; Zone 54		
Page:	1/1		

Atlas of Australian Soils Description:	Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)
Atlas of Australian Soils Major Unit:	Sodosol
ASC DSM Unit:	
Logged Unit:	
Regional Geology:	Lady Loretta Formation

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes	From (m)	To (m)	Interval (m)	Samples	Photos	Bulk density (t/m^3)	Emerson Test and ESP	$pH_{1:5}$ & $EC_{1:5}$	% Clay, Silt, Sand & Gravel
	TS		Red-brown, very poorly sorted, sub-rounded sand Extremely weathered	D	S	VL	A1 Horizon - Topsoil Transitional - soil and saprolite Abrupt boundary A few roots	0.0	0.2	0.2	2021044_0029		1.59	4(gypsum) 0.3%	pH 6.7 3840 µS/cm	33% Gravel 22% Sand 22% Silt 23% Clay
0.5	SL1		Red-brown, very poorly sorted, angular siltstone Moderately weathered	D	St	MD	C1 Horizon - Saprolite No roots Massive Clear boundary Less weathered than units underneath	0.2	0.7	0.5	2021044_0030		1.75	3 0.1%	pH 6.2 978 µS/cm	11% Gravel 89% Sand
1.0 1.5 2.0	SL2		Red-brown, very poorly sorted, angular siltstone Highly weathered	D	F	L	C2 Horizon - Saprolite No roots Massive Gradual boundary Contains some fine material	0.7	2	1.3	2021044_0031		1.71	2 37.0%	pH 7.4 820 µS/cm	23% Gravel 77% Sand
2.5 3.0	SL3		Dark red-brown, very poorly sorted, angular saprolite Highly weathered	D	F	L	C3 Horizon - Saprolite No roots Massive Saprolite becoming more blocky Contains some fine material	2	3.3	1.3	2021044_0032		1.57	2 37.5%	pH 8.5 589 µS/cm	23% Gravel 77% Sand













Figure 7-34: Test pit soil log: Test Pit 8 - Borrow Area V

TEST PIT LOG		TEST PIT:	Phase 2 - Test Pit 9 Borrow Area W	Atlas of Australian Soils Description:		Hole ID:	TP09
				Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)		Top of Hole:	0.0 m
						End of Hole:	2.5 m
						Logged by:	Melinda Hilton
Client:	Glencore	Easting:	296727.6	Atlas of Australian Soils Major Unit:	Sodosol	Checked by:	Greg Maddocks
Project:	Lady Loretta RMSaAP Phase 2	Northing:	7812018	ASC DSM Unit:		Compiled by:	
Site:	Lady Loretta Mine	GCS:		Logged Unit:		Reviewed by:	
Method:	35T Excavator	Logged		Regional Geology:	Lady Loretta Formation	Approved by:	
Contractor:	Redpath	Datum:	GDA 94; Zone 54				
Log Date:	5 November 2021	Page:	1/1				

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes	From (m)	To (m)	Interval (m)	Samples	Bulk density (t/m^3)	Emerson Test and ESP	$pH_{1:5}$ & $EC_{1:5}$	% Clay, Silt, Sand & Gravel
0.5	TS		Brown, very poorly sorted, sub-angular loam Extremely weathered	D	S	VL	A1 Horizon - Topsoil Transitional - soil and saprolite Clear boundary Lots of roots Thickening from 0.3 to 1.3 m approaching valley/drainage line	0.0	0.5	0.5	2021044_0033	1.73	2 0.4%	pH 6.0 29 µS/cm	53% Gravel 26% Sand 12% Silt 9% Clay
1.0 1.5	SL1		Red-white, very poorly sorted, angular siltstone Highly to moderately weathered	D	F	MD	C1 Horizon - Saprolite No roots Massive Gradual boundary	0.5	1.9	1.4	2021044_0034	2.24	4(gypsum) 0.5%	pH 6.2 311 µS/cm	51% Gravel 49% Sand
2.0 2.5	SL2		Red-brown, very poorly sorted, angular siltstone Moderately weathered	D	H	MD	C2 Horizon - Saprolite No roots Massive Less weathered, more blocky	1.9	2.5	0.6	2021044_0035	2.08	3 0.4%	pH 5.9 366 µS/cm	62% Gravel 38% Sand
3.0			**TOTAL SOIL = 0.5 m** **TOTAL DEPTH = 2.5 m** Test pit is at the bottom of a hill.												

Photos











TS - Topsoil;SS - Subsoil; SL - Saprolite; SR - Saprock; Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 7-35: Test pit soil log: Test Pit 9 - Borrow Area W

RGS	TEST PIT LOG	TEST PIT:	Phase 2 - Test Pit 10 Borrow Area W	Atlas of Australian Soils Description: Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)	Hole ID: TP10 Top of Hole: 0.0 m End of Hole: 2.2 m Logged by: Melinda Hilton
Client: Project: Site: Method: Contractor: Log Date:	Glencore Lady Loretta RMSaAP Phase 2 Lady Loretta Mine 35T Excavator Redpath 5 November 2021	Easting: Northing: GCS: Logged Datum: Page:	296718.7 7811934 GDA 94; Zone 54 1/1	Atlas of Australian Soils Major Unit: Sodosol ASC DSM Unit: Logged Unit: Regional Geology: Lady Loretta Formation	Checked by: Greg Maddocks Compiled by: Reviewed by: Approved by:

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes	From (m)	To (m)	Interval (m)	Samples	Bulk density (t/m³)	Emerson Test and ESP	$pH_{1:5}$ & $EC_{1:5}$	% Clay, Silt, Sand & Gravel
	TS		Brown, very poorly sorted, sub-angular loam Extremely weathered	D	S	VL	A1 Horizon - Topsoil Transitional - soil and saprolite Clear boundary Lots of roots	0.0	0.4	0.4	2021044_0036	1.46	3 0.8%	pH 5.3 51 µS/cm	53% Gravel 26% Sand 12% Silt 9% Clay
0.5 1.0 1.5			Red-brown, very poorly sorted, angular siltstone Highly to moderately weathered	D	St	MD	C1 Horizon - Saprolite No roots Massive Gradual boundary Contains some smaller gravel particles	0.4	1.7	1.3	2021044_0037	2.09	3 0.1%	pH 6.1 213 µS/cm	51% Gravel 49% Sand
2.0			Red-brown, very poorly sorted, angular siltstone Moderately weathered	D	St	MD	C2 Horizon - Saprolite No roots Massive Dipping on an angle consistent with the topography of the hill	1.7	2.2	0.5	2021044_0038	2.14	3 0.1%	pH 6.6 306 µS/cm	62% Gravel 38% Sand
2.5 3.0			**TOTAL SOIL = 0.4 m** **TOTAL DEPTH = 2.2 m** Test pit is located on the side of a hill.												

Photos











TS - Topsoil;SS - Subsoil; SL - Saprolite; SR - Saprock; Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

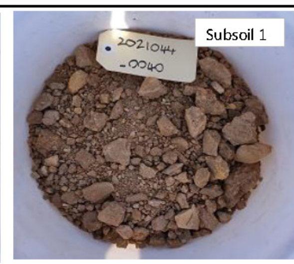
Figure 7-36: Test pit soil log: Test Pit 10 - Borrow Area W

TEST PIT LOG		TEST PIT:	Phase 2 - Test Pit 11 Borrow Area T - Truck Turnaround	Atlas of Australian Soils Description:	Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)	Hole ID:	TP11
Client:	Glencore	Easting:	297232.8	Atlas of Australian Soils Major Unit:	Sodosol	Top of Hole:	0.0 m
Project:	Lady Loretta RMSaAP Phase 2	Northing:	7811653	ASC DSM Unit:		End of Hole:	1.3 m
Site:	Lady Loretta Mine	GCS:		Logged Unit:		Logged by:	Melinda Hilton
Method:	35T Excavator	Logged		Regional Geology:	Lady Loretta Formation	Checked by:	Greg Maddocks
Contractor:	Redpath	Datum:	GDA 94; Zone 54			Compiled by:	
Log Date:	6 November 2021	Page:	1/1			Reviewed by:	
						Approved by:	

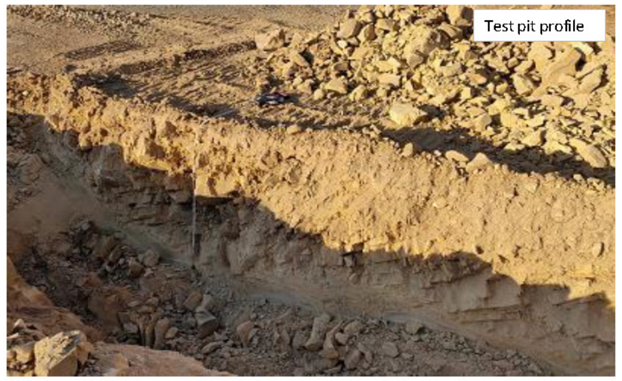
Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes	From (m)	To (m)	Interval (m)	Samples	Bulk density (t/m^3)	Emerson Test and ESP	pH$_{1:5}$ & EC$_{1:5}$	% Clay, Silt, Sand & Gravel
UNKNOWN	TS		Brown, poorly sorted, sub-rounded loam Extremely weathered	D	S	VL	Sample was taken from stockpile Sample is not in-situ DEPTH UNKNOWN Topsoil Transitional - soil and saprolite Lots of roots				2021044_0039	1.43	3 0.2%	pH 6.6 39 µS/cm	32% Gravel 33% Sand 22% Silt 13% Clay
			Light brown, very poorly sorted, gravelly loam Highly to extremely weathered	D	S	L	A1 Horizon - Topsoil No roots, clear boundary	0	0.1	0.1	2021044_0040	1.52	3 0.2%	pH 6.4 1395 µS/cm	32% Gravel 33% Sand 22% Silt 13% Clay
0.5 1.0			Yellow, very poorly sorted, angular siltstone Moderately weathered	D	F	MD	Topsoil/subsoil was stripped in 2011 Thin layer of soil has developed through pedogenesis and crushing from vehicle traffic. C1 Horizon - Saprolite No roots Massive	0.1	1.3	1.2	2021044_0041	1.53	3 0.1%	pH 7.1 86 µS/cm	26% Gravel 74% Sand
1.5 2.0 2.5			**TOTAL SOIL = 0.1 m+** **TOTAL DEPTH = 1.3 m**												

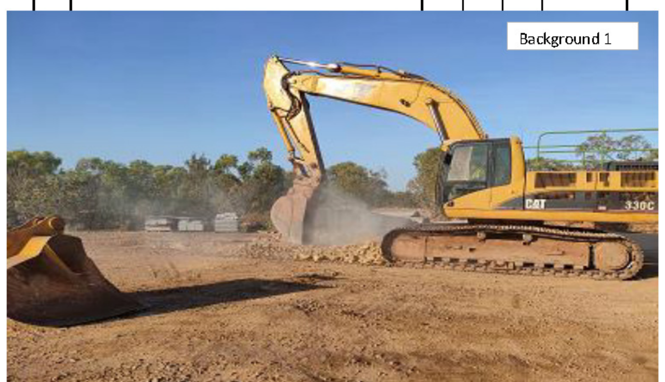
Photos













TS - Topsoil;SS - Subsoil; SL - Saprolite; SR - Saprock; Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 7-37: Test pit soil log: Test Pit 11 - Borrow Area T

TEST PIT LOG

TEST PIT: Phase 2 - Test Pit 12

Borrow Area I - Laydown Area

Atlas of Australian Soils Description:

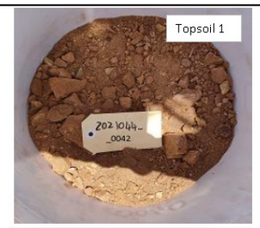
Soil Undulating to moderately undulating lands with some rock outcrop: dominant soils are shallow very gravelly- surfaced bleached loamy red duplex soils (Dr2.43), with associated (Dr2.13). On the crests and upper slopes shallow gravelly loams (Um1.43)

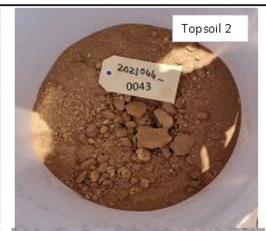
Client:	Glencore	Easting:	297576.7	Hole ID:	TP012
Project:	Lady Loretta RMSaAP Phase 2	Northing:	7812491	Top of Hole:	0.0 m
Site:	Lady Loretta Mine	GCS:		End of Hole:	4.1 m
Method:	35T Excavator	Logged			
Contractor:	Redpath	Datum:	GDA 94; Zone 54	Logged by:	Melinda Hilton
Log Date:	6 November 2021	Page:	1/1	Checked by:	Greg Maddocks
				Compiled by:	
				Reviewed by:	
				Approved by:	

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes	From (m)	To (m)	Interval (m)	Samples	Bulk density (t/m^3)	Emerson Test and ESP	$pH_{1:5}$ & $EC_{1:5}$	% Clay, Silt, Sand & Gravel
	TS1		Yellow-brown, poorly sorted, sub-angular loam Extremely weathered	D	S	VL	A1 Horizon - Topsoil No roots - cleared ground	0.0	0.1	0.1	2021044_0042	1.60	4(gypsum) 18.6%	pH 6.6 1456 µS/cm	37% Gravel | 20% Silt 33% Sand | 10% Clay
	TS2		Yellow-brown, poorly sorted, sub-angular loam Extremely weathered	D	S	VL	A2 Horizon - Topsoil No roots - cleared ground Abrupt boundary Crumb peds	0.1	0.3	0.2	2021044_0043	1.78	4(gypsum) 16.7%	pH 6.7 1404 µS/cm	37% Gravel 33% Sand 20% Silt 10% Clay
0.5	SS1		Purple, very poorly sorted, angular claystone Moderately weathered	D	F	MD	B2 Horizon - Likely precipitation Possible iron-rich liesegang banding Distinctive purple colour Very fine particle size Consolidated but weathered	0.3	0.6	0.3	2021044_0044	2.06	3 23.1%	pH 6.8 363 µS/cm	45% Gravel 22% Sand 14% Silt 19% Clay
1.0	SS2		Brown, poorly sorted, sub-rounded loam Extremely weathered	D	S	VL	B3 Horizon - Subsoil No roots Clear boundary Contains some saprolite fragments	0.6	1.4	0.8	2021044_0045	2.00	6 0.9%	pH 5.3 277 µS/cm	45% Gravel 22% Sand 14% Silt 19% Clay
1.5	SS3		Red-brown, poorly sorted, subrounded gravelly sand Extremely weathered	D	S	VL	B4 Horizon - Subsoil No roots Clear boundary Contains some saprolite fragments	1.4	2	0.6	2021044_0046	1.61	6 0.1%	pH 5.8 466 µS/cm	45% Gravel 22% Sand 14% Silt 19% Clay
2.0	SL1		Yellow-brown, very poorly sorted, angular siltstone Highly weathered	D	F	L	C1 Horizon - Saprolite No roots Massive Contains some fine material.	2	4.1	2.1	2021044_0047	1.61	3 19.9%	pH 6.3 685 µS/cm	16% Gravel 84% Sand
2.5															
3.0															

Atlas of Australian Soils Major Unit:	Sodosol
ASC DSM Unit:	
Logged Unit:	
Regional Geology:	Lady Loretta Formation

Photos

















3.0

3.5

4.0

4.5

TOTAL SOIL = 2.0 m
TOTAL DEPTH = 4.1 m

Excavation forced to stop due to an incoming storm.

TS - Topsoil;SS - Subsoil; SL - Saprolite; SR - Saprock; Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 7-38: Test pit soil log: Test Pit 12 - Borrow Area I

7.4 Attachment D: Material balance tables

Table 7-10: Material balance required for rehabilitation

Description	Current Assumptions for Borrow	Potential Contaminants of concern	Area		Surface Armouring (Competent Rock)			Growth Medium (Topsoil + Subsoil)			Rocky Soil Mulch (NAF Waste Rock)		
			Area size (ha)	Area size (m^2)	Depth required (m)	Volume required BCM(m^3)*	Volume required LCM(m^3)*	Depth required (m)	Volume required BCM(m^3)*	Volume required LCM(m^3)*	Depth required (m)	Volume required BCM(m^3)*	Volume required LCM(m^3)*
DOMAIN: Waste Rock Emplacement													
	Crest Cover comprising: • Reduced Permeability Layer using Bituminous Geo-Membrane (BGM) • Infiltration Storage Layer comprising 1.5m Rocky soil mulch layer	Metals / metalloids, pH, sulfate, salinity (PAF material).	1.97	19.724							2.1	33,136	41,420
WRE	Batter Treatments comprising: • 1.2m Compacted PAF • 1.2m Compacted Rocky Mulch • 0.9m Rock Armour	Metals / metalloids, pH, sulfate, salinity (PAF material).	9.01	90,123	0.9	58,408	75,930**				1.2	79,990	99,987**
WRE Drainage Infrastructure	Clean water diversion (assumes 1,500m length). Dirty water perimeter drain (assumes 1,000 length) . Placement of 100% cover of competent rock placed over surface to protect surface from high energy rainfall events.	Metals / metalloids, pH, sulfate, salinity.	1.35	13,500	1	10,385	13,500						
DOMAIN: Water Management Infrastructure													
LMD (dam)	Regulated dam to be decommissioned. Partial Backfill and Reshaping works	Metals / metalloids, pH, sulphate, salts (associated with PAF material)	0.27	2,750				1	2200	2750			
CDA (incl. sediment dams)	Regulated Dams decommissioned and repurposed as Erosion and Sediment Control Facilities	Metals / metalloids, low pH, high sulphate, herbicides and TRH, PAH, BTEX (associated with Access herbicide mixed with diesel).	9.54	95,400									
CDB (incl. sediment dams)	Regulated Dams decommissioned and repurposed as Erosion and Sediment Control Facilities	Metals / metalloids, very low pH, high sulphate, herbicides and TRH, PAH, BTEX (associated with Access herbicide mixed with diesel).	2.49	24,900									
PPD (incl. sediment dams)	Regulated Dams decommissioned and repurposed as Erosion and Sediment Control Facilities	TRH, PAH, BTEX (associated with fuels and oils), metals, pH, sulfate Review other constituents involved in paste generation process to expand analytical suite.	1.01	10,100									
Erosion and Sediment Control Facilities (CDA, CDB & PPD)	Inlet and outlet spillways upon conversion of regulated dams to Erosion and Sediment Control Facilities (assume 20m3 per dam) Partial backfill and reshaping works.	(Mostly NAF but could contain material with high metals content) Metals and metalloids, pH, sulfate.	13.04	130,400		75	60						
Identified erosion risk areas	Rock armouring required in high erosion risk surface water drains across site. Includes rock armouring of inlet/outlets (rock aprons)	Metals and metalloids, pH, sulfate. (Mostly NAF but could contain material with high metals content)	2.8	28,050	1	21,577	28,050						
DOMAIN: INFRASTRUCTURE+													
Workshop (including oily water separators)	Remove infrastructure. Contaminated surface material removal/ remediated	TRH, PAH, BTEX (hydrocarbons associated with diesel, grease, oils and hydraulic fluid), VOCs (associated with solvents, degreasers and engine coolant).	1.44	14,400				0.10	1,152	1,440			
Fuel Farm	Remove infrastructure. Contaminated surface material removed/remediated	Hydrocarbons (TRH, PAH, BTEX)	0.17	1,700				0.10	136	170			
Explosive Chemical Storage Area	Remove infrastructure. Contaminated surface material removed/remediated	TRH, PAH, BTEX (associated with fuels and oils), explosives	0.6	6,000				0.10	480	600			
Fuel Farm (adj to Power Station)	Remove infrastructure. Contaminated surface material removed/remediated	TRH, PAH, BTEX (associated with fuels and oils)	0.03	300				0.10	24	30			
Wheel Wash	Remove infrastructure. Contaminated surface material removed/remediated	TRH, PAH, BTEX (associated with fuels and oils)	0.05	500				0.10	40	50			
Trench	Trench has been backfilled, reshaped and rehabilitated. Assumed no further placement of borrow material.	TRH, PAH, BTEX (associated with fuel or oil leaks), metals, explosives (residues)	0.6	6,000									
Waste Transfer Station	Remove infrastructure. Contaminated surface material removed/remediated	TRH, PAH, BTEX (associated with waste oils), VOCs (associated with paints and solvents), lead (associated with lead acid batteries) and other metals (associated with scrap metal items).	0.3	3,000				0.10	240	300			

LMD Stockpile	Basement AMD affected material removed to WRE	Metals / metalloids, pH, sulfate, salinity (PAF material).	0.72	7,200				0.10	576	720			
LMD Area	Area has been remediated, reprofiled and seeded. Assumed no further borrow material required.	Metals / metalloids, pH, sulphate, salts (associated with PAF material)	2.11	21,100									
DOMAIN: ROM Pad, Paste Plant and Batch Plant													
ROM and Crushing Plant	ROM partial reuse for backfilling underground openings. Remove infrastructure. Remove contaminated surface material (assumed depth of 0.5m bgl). Reshape and placement of 0.15 m growth medium	Metals and metalloids, pH, sulfate. (Mostly NAF but could contain material with high metals content)	5.33	53,300				0.15	6,396	7,995			
Paste Plant & Batch Plant	Remove infrastructure. Remove contaminated surface material (assumed depth of 0.5 m bgl).	Metals / metalloids, pH, sulphate, salts (associated with tailings)	4.79	47,900				0.15	5,748	7,185			
	Place 0.15 m growth medium.												
DOMAIN: Exploration, Roads and Tracks													
Main Access Road	Main mine access road to Paste Plant, ROM and LMD area, and road to the WRE.	Metals and metalloids, pH, sulfate. (Mostly NAF but could contain material with high metals content)	9.91	99,100									
DOMAIN: Underground Openings													
Shafts - 1, 2, 3, 4	Shafts backfilled. Assumed ROM material for backfill.	Metals and metalloids, pH, sulfate. (Mostly NAF but could contain material with high metals content)	12,000m^3 ##										
Decline Portal	Partial backfill portal.	Metals / metalloids (associated with waste rock material), low pH, sulphates	20,500 m^3 ##										
	Assumed ROM material for backfill.	TRH, PAH, BTEX (associated with storage / parking in laydown area).											
DOMAIN: Borrow Areas													
Borrow Areas	Borrow Area - Place 0.15 m growth medium for selected borrow (maximum footprint 7ha). Borrow Area C - No placement of growth medium (rock quarry)	(Mostly NAF but could contain material with high metals content)	7	70,000				0.15	8,400	10,500			

*It is assumed that saprolith and pedolith will settle or consolidate more than competent rock so a swell factor of 1.25 is used for Growth Medium and Rocky Soil Mulch and 1.30 is used for Competent Rock.
** WRE cover volumes are based on landform model
ROM material used to partially backfill underground openings and no requirement for borrow material. Volumes based on MEC Mine Closure Geotechnical Study, 2022.
+Growth medium for Infrastructure areas are not proposed however have been included in the material balance for conservative estimates only

Table 7-11: Summary table of required material balance

Surface Armouring (Competent Rock)		Growth Medium (Topsoil + Subsoil)		Rocky Soil Mulch	
Volume required BCM	Volume required LCM	Volume required BCM	Volume required LCM	Volume required BCM	Volume required LCM
90,370	120,850	23,192	28,990	113,126	141,407

Table 7-12: Material balance available for rehabilitation

Borrow areas to be used to source material for rehabilitation																	
	Area		Surface Armouring (Competent Rock)					Growth Medium (Topsoil + Subsoil)					Rocky Soil Mulch (NAF Waste Rock)				
Location	Area size (ha)	Area size (m2)	Depth (m)	Volume BCM(m^3)	Volume LCM(m^3)	In-situ Bulk Density (t/m^3)	Mass (t)	Depth (m)	Volume BCM(m^3)	Volume LCM(m^3)	In-situ Bulk Density (t/m^3)	Mass (t)	Depth (m)	Volume BCM(m^3)	Volume LCM(m^3)	In-situ Bulk Density (t/m^3)	Mass (t)
Topsoil stockpile (south CDA)	5.8	58,000						0.61	26,535	35,380	1.4	49,532					
Cover material stockpile (south WRE)	0.57	5,700						1.24	5,301	7,068	1.4	9,895					
Stockpile - Total	6.37	63700						1.9	31,836	42,448		59,427					
Borrow Area A - Topsoil	13.4	69,000						0.1	13,230	16,537	1.5	19,844					
Borrow Area A - Subsoil	13.4	69,000						0.7	84,907	106,134	1.3	110,379					
Borrow Area A - Saprolite	13.4	69,000											0.3	34,441	43,051	1.3	44,773
Borrow Area A - Saprock	13.4	69,000											5.4	105,311	131,638	2.1	221,152
Borrow Area A - TOTAL	13.4	69,000						0.8	98,137	122,671		130,224	5.7	139,751	174,689		265,925
Borrow Area B1 – Topsoil	5.2	52,000						0.2	11,382	14,227	1.5	17,072					
Borrow Area B1 – Subsoil	5.2	52,000						0.6	31,043	38,804	1.4	43,461					
Borrow Area B1 – Saprolite	5.2	52,000											1.1	72,719	90,899	1.2	87,263
Borrow Area B1 – Saprock	5.2	52,000											0.5	54,227	67,784	2.1	113,877
Borrow Area B1 – TOTAL	5.2	52,000						0.8	42,425	53,031		60,533	1.6	126,946	158,683		201,140
Borrow Area B2 – Topsoil	4.1	41,000						0.2	8,798	10,998	1.5	13,197					
Borrow Area B2 – Subsoil	4.1	41,000						0.6	21,980	27,475	1.4	30,772					
Borrow Area B2 – Saprolite	4.1	41,000											1.6	43,538	54,423	1.2	52,246
Borrow Area B2 – Saprock	4.1	41,000											10.3	83,465	104,331	2.1	175,276
Borrow Area B2 – TOTAL	4.1	41,000						0.8	30,778	38,472		43,969	11.9	127,003	158,754		227,522
Borrow Area I – Topsoil	4	52,000						0.3	0	0	1.8	0					

Borrow areas to be used to source material for rehabilitation																
	Area		Surface Armouring (Competent Rock)					Growth Medium (Topsoil + Subsoil)					Rocky Soil Mulch (NAF Waste Rock)				
Location	Area size (ha)	Area size (m2)	Depth (m)	Volume BCM(m^3)	Volume LCM(m^3)	In-situ Bulk Density (t/m^3)	Mass (t)	Depth (m)	Volume BCM(m^3)	Volume LCM(m^3)	In-situ Bulk Density (t/m^3)	Mass (t)	Depth (m)	Volume BCM(m^3)	Volume LCM(m^3)	In-situ Bulk Density (t/m^3)	Mass (t)
Borrow Area I – Subsoil	4	52,000						1.7	50,304	62,880	1.9	95,578					
Borrow Area I – Saprolite	4	52,000												43,776	54,720	1.6	70,042
Borrow Area I – Saprock	4	52,000												17,805	22,256	1.6	28,488
Borrow Area I – TOTAL	4	52,000						2	50,304	62,880		95,578	0	61,581	76,976		98,530
Borrow Area C - Topsoil	1.7	13,000						0.1	2,043	2,553	1.6	3,268					
Borrow Area C - Subsoil	1.7	13,000						0.7	11,478	14,347	1.7	19,512					
Borrow Area C - Saprolite	1.7	13,000	0.1	1,340	1,741	2.6	3,483										
Borrow Area C - Fresh Rock	1.7	13,000	31.6	245,298	318,887	2.6	637,775										
Borrow Area C - TOTAL	1.7	13,000	31.7	246,637	320,628		641,257	0.8	13,521	16,900		22,780					

Table 7-13: Material balance: surplus or deficit by borrow area and material type

TOTAL MASS BALANCE	Area		Surface Armouring (Competent Rock)		Growth Medium (Topsoil + Subsoil)		Rocky Soil Mulch (NAF Waste Rock)	
	Area size (ha)	Area size (m^2)	Volume - BCM (m^3)	Volume - LCM (m^3)	Volume - BCM (m^3)	Volume - LCM (m^3)	Volume - BCM (m^3)	Volume - LCM (m^3)
Total requirements across LLM mine lease area	60.9074	655,326	90,444	117,540	23,192	28,990	115,326	144,157
Total sources at Borrow A	13.4	134,000	0	0	98,137	122,671	139,752	174,689
Total source of Soil stockpiles					31,836	42,448		
Surplus or deficit			-90,444	-117,540	106,781	136,129	24,426	30,532

TOTAL MASS BALANCE	Area		Surface Armouring (Competent Rock)		Growth Medium (Topsoil + Subsoil)		Rocky Soil Mulch (NAF Waste Rock)	
	Area size (ha)	Area size (m^2)	Volume - BCM (m^3)	Volume - LCM (m^3)	Volume - BCM (m^3)	Volume - LCM (m^3)	Volume - BCM (m^3)	Volume - LCM (m^3)
Total requirements across LLM mine lease area	60.9	655,326	90,444	117,540	23,192	28,990	115,326	144,157
Total sources at Borrow B1	5.2	52,000	0	0	42,425	53,031	126,946	158,683
Total source of Soil stockpiles					31,836	42,448		
Surplus or deficit			-90,444	-117,540	51,069	66,489	11,620	14,526

TOTAL MASS BALANCE	Area		Surface Armouring (Competent Rock)		Growth Medium (Topsoil + Subsoil)		Rocky Soil Mulch (NAF Waste Rock)	
	Area size (ha)	Area size (m^2)	Volume - BCM (m^3)	Volume - LCM (m^3)	Volume - BCM (m^3)	Volume - LCM (m^3)	Volume - BCM (m^3)	Volume - LCM (m^3)
Total requirements across LLM mine lease area	60.9	655,326	90,444	117,540	23,192	28,990	115,326	144,157
Total sources at Borrow B2	4.1	41,000	0	0	30,778	38,473	127,003	158,754
Total source of Soil stockpiles					31,836	42,448		
Surplus or deficit			-90,444	-117,540	39,422	51,931	11,677	14,597

TOTAL MASS BALANCE	Area		Surface Armouring (Competent Rock)		Growth Medium (Topsoil + Subsoil)		Rocky Soil Mulch (NAF Waste Rock)	
	Area size (ha)	Area size (m^2)	Volume - BCM (m^3)	Volume - LCM (m^3)	Volume - BCM (m^3)	Volume - LCM (m^3)	Volume - BCM (m^3)	Volume - LCM (m^3)
Total requirements across LLM mine lease area	60.9	655,326	90,444	117,540	23,192	28,990	115,326	144,157
Total sources at Borrow I	4.0	40,000	0	0	50,304	62,880	61,581	76,976
Total source of Soil stockpiles					31,836	42,448		
Surplus or deficit			-90,444	-117,540	58,948	76,338	-53,745	-67,181

TOTAL MASS BALANCE	Area		Surface Armouring (Competent Rock)		Growth Medium (Topsoil + Subsoil)		Rocky Soil Mulch (NAF Waste Rock)	
	Area size (ha)	Area size (m^2)	Volume - BCM (m^3)	Volume - LCM (m^3)	Volume - BCM (m^3)	Volume - LCM (m^3)	Volume - BCM (m^3)	Volume - LCM (m^3)
Total requirements across LLM mine lease area	60.9	655,326	90,444	117,540	23,192	28,990	115,326	144,157
Total sources at Borrow C only	1.7	17,000	246,638	320,628	13,521	16,900	0	0
Total source of Soil stockpiles					31,836	42,448		
Surplus or deficit			156,211	203,112	22,164	31,034	-115,326	-144,157

7.5 Attachment E: Borrow area pit shells



Figure 7-39: Borrow Pit A material solids



Figure 7-40: Borrow Pit B1 material solids



Figure 7-41: Borrow Pit B2 material solids



Figure 7-42: Borrow Pit I material solids



Figure 7-43: Borrow Area C material solids

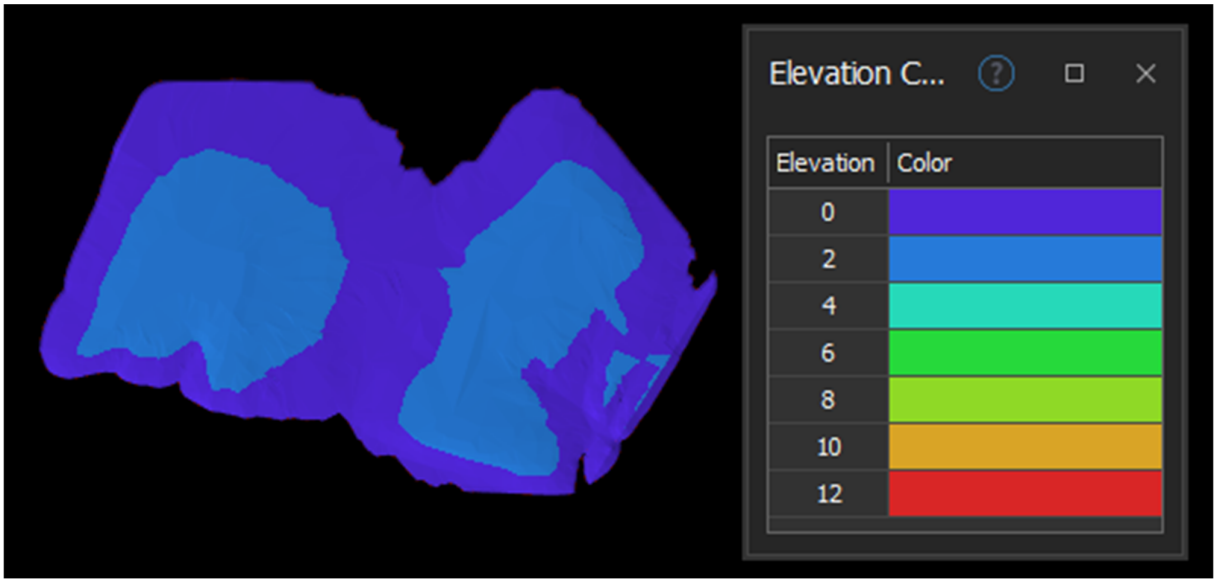


Figure 7-44: Borrow Area A depth of borrow area

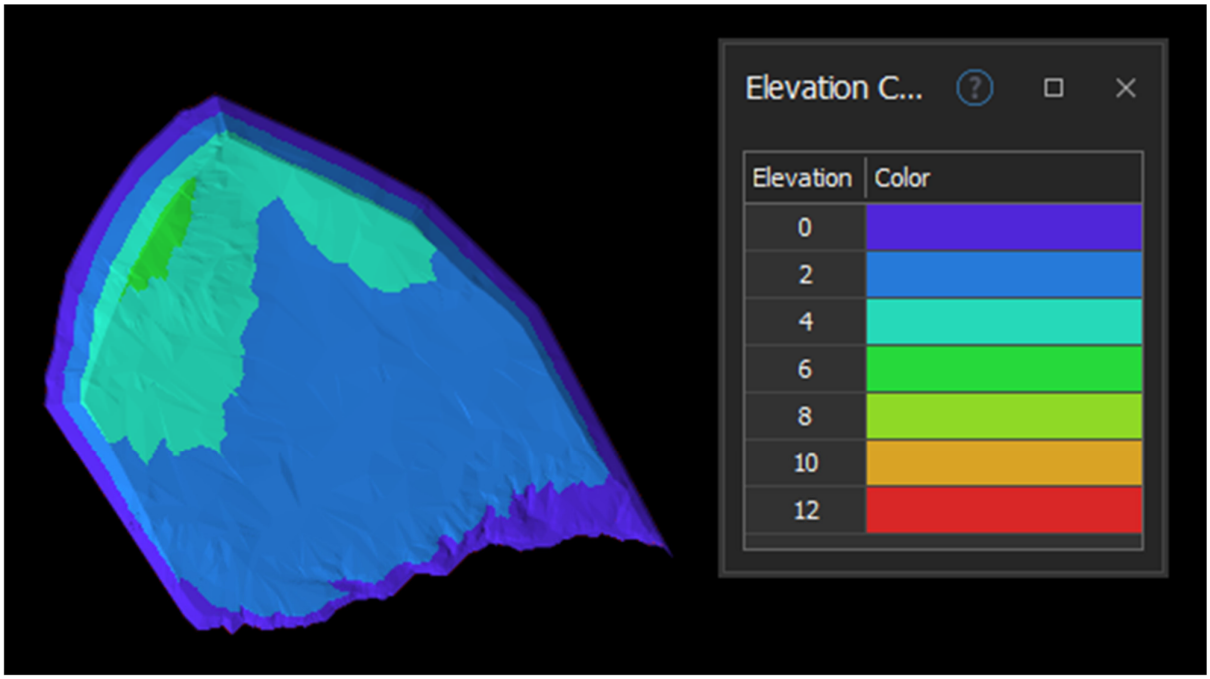


Figure 7-45: Borrow Area B1 depth of borrow area

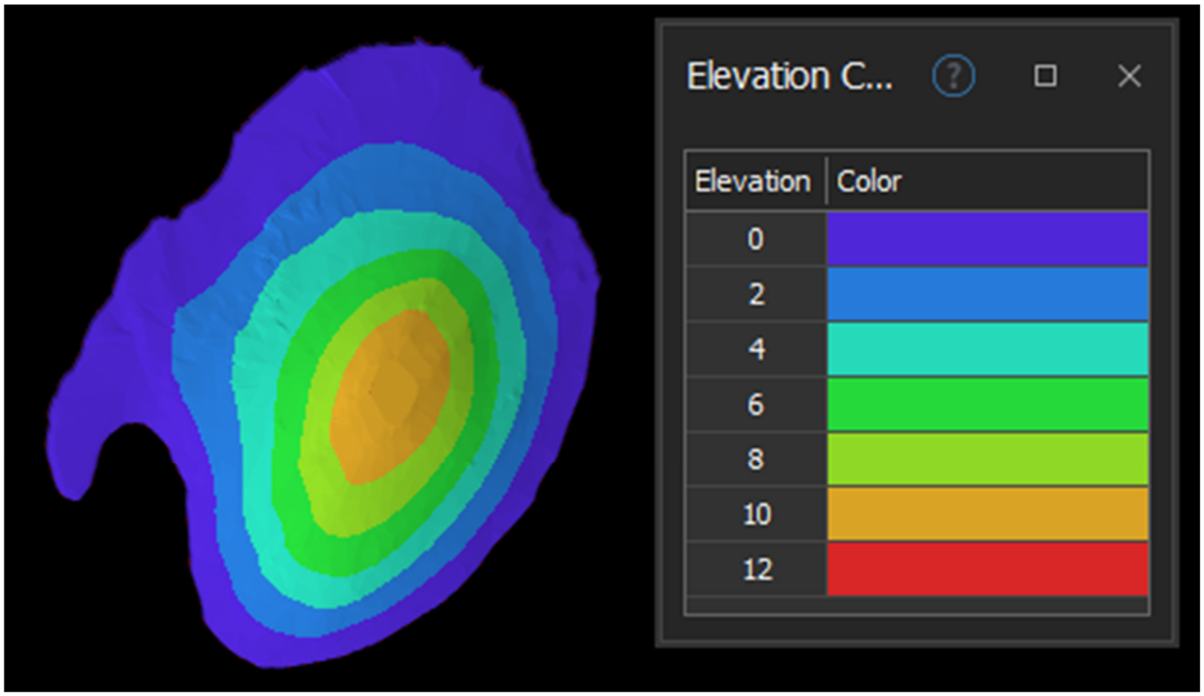


Figure 7-46: Borrow Area B1 depth of borrow area

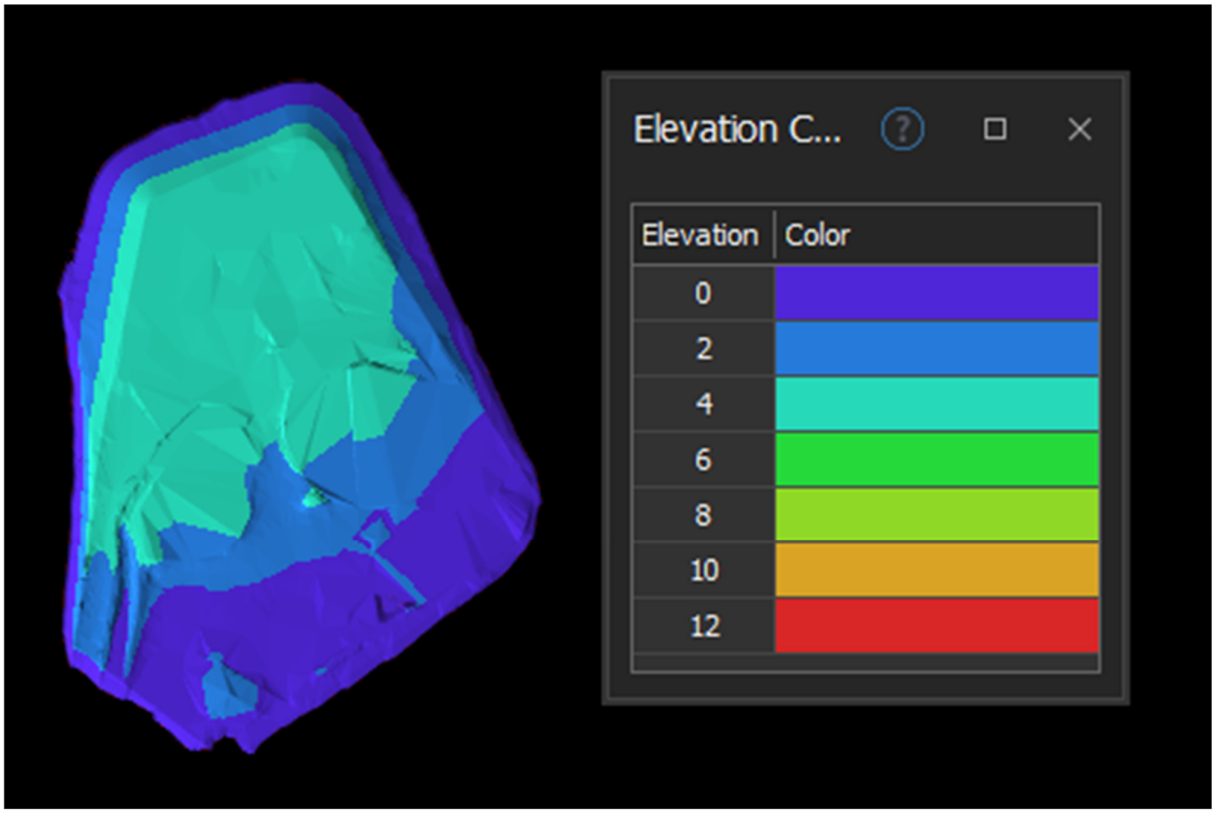


Figure 7-47: Borrow Area I depth of borrow area

7.6 Attachment F: ALS Certificate of Analyses

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB2133723**	Page	: 1 of 37
Client	: **NORANDA PACIFIC PTY LTD T/A LADY LORETTA MINE**	Laboratory	: Environmental Division Brisbane
Contact	: ALICE BEER	Contact	: Joy Morgan
Address	: PO BOX 1867 MOUNT ISA 4825	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: ----	Telephone	: +61 7 4773 0030
Project	: 2021044 Lady Loretta	Date Samples Received	: 22-Nov-2021 15:00
Order number	: AQMLLXXDA	Date Analysis Commenced	: 29-Nov-2021
C-O-C number	: ----	Issue Date	: 13-Jan-2022 18:40
Sampler	: MELINDA MILTON		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 96		
No. of samples analysed	: 96		

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, unless the sampling was conducted by ALS. 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
Mark Hallas	Senior Inorganic Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Mark Hallas	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Satishkumar Trivedi	Senior Acid Sulfate Soil Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Zoran Grozdanovski	Laboratory Operator	Newcastle - Inorganics, Mayfield West, NSW

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.

- ED045G (Chloride) / EK057G (Nitrite as N): Some samples were diluted due to matrix interference. LOR adjusted accordingly.
- 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.
- ED008 (Exchangeable Cations by ICP-AES): Unable to calculate Magnesium/Potassium Ratio result for some samples as required Exchangeable Magnesium and/or Potassium results are less than the limit of reporting.
- ED006 (Exchangeable Cations on Alkaline Soils): Unable to calculate Magnesium/Potassium Ratio result for some samples as required Exchangeable Magnesium and/or Potassium results are less than the limit of reporting.
- ASS: EA013 (ANC) Fizz Rating: 0- None; 1- Slight; 2- Moderate; 3- Strong; 4- Very Strong; 5- Lime.
- 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: SOIL (Matrix: SOIL)			Sample ID	2021044_0001	2021044_0002	2021044_0003	2021044_0004	2021044_0005
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-001	EB2133723-002	EB2133723-003	EB2133723-004	EB2133723-005
				Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	----	7.0	7.8	8.2	8.0
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	----	7.4	8.1	8.8	8.6
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	----	2540	3190	1680	1710
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	5.7	----	----	----	----
Moisture Content	----	1.0	%	----	9.6	8.1	7.1	6.8
ED006: Exchangeable Cations on Alkaline Soils								
ø Exchangeable Calcium	----	0.2	meq/100g	----	<0.2	<0.2	<0.2	<0.2
ø Exchangeable Magnesium	----	0.2	meq/100g	----	7.9	9.4	4.6	3.9
ø Exchangeable Potassium	----	0.2	meq/100g	----	0.2	<0.2	0.2	0.3
ø Exchangeable Sodium	----	0.2	meq/100g	----	5.7	5.5	4.3	4.2
ø Cation Exchange Capacity	----	0.2	meq/100g	----	13.8	15.1	9.1	8.4
ø Exchangeable Sodium Percent	----	0.2	%	----	41.2	36.4	46.8	50.5
ø Calcium/Magnesium Ratio	----	0.2	-	----	<0.2	<0.2	<0.2	<0.2
ø Magnesium/Potassium Ratio	----	0.2	-	----	30.5	----	20.5	14.9
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	----	302	292	366	360
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	----	2010	2890	1420	1540
ED092: DTPA Extractable Metals								
ø Copper	7440-50-8	1.00	mg/kg	----	1.41	<1.00	1.69	<1.00
ø Iron	7439-89-6	1.00	mg/kg	----	4.62	3.04	1.32	1.17
ø Manganese	7439-96-5	1.00	mg/kg	----	2.65	3.23	<1.00	<1.00
ø Zinc	7440-66-6	1.00	mg/kg	----	10.2	1.69	<1.00	<1.00
EK055: Ammonia as N								
Ammonia as N	7664-41-7	20	mg/kg	----	<20	<20	<20	<20
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	----	<0.1	<0.1	<0.1	<0.1
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	----	9.4	9.6	1.6	1.5
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Sample ID	2021044_0001	2021044_0002	2021044_0003	2021044_0004	2021044_0005
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit		EB2133723-001	EB2133723-002	EB2133723-003	EB2133723-004	EB2133723-005
					Result	Result	Result	Result	Result
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser - Continued									
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg		----	9.4	9.6	1.6	1.5
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	20	mg/kg		----	210	230	150	110
EK062: Total Nitrogen as N (TKN + NOx)									
^ Total Nitrogen as N	----	20	mg/kg		----	220	240	150	110
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	2	mg/kg		----	81	76	88	72
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		----	<5	<5	<5	<5
EP004: Organic Matter									
Organic Matter	----	0.5	%		----	0.9	0.9	<0.5	<0.5
Total Organic Carbon	----	0.5	%		----	0.5	0.5	<0.5	<0.5

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0006	2021044_0007	2021044_0008	2021044_0009	2021044_0010
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-006	EB2133723-007	EB2133723-008	EB2133723-009	EB2133723-010
				Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	----	4.5	4.4	----	7.0
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	----	5.3	5.4	----	7.1
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	----	45	18	----	2460
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	3.6	----	----	1.8	----
Moisture Content	----	1.0	%	----	12.3	8.8	----	6.6
ED005: Exchange Acidity								
ø Exchange Acidity	----	0.1	meq/100g	----	0.3	0.5	----	----
ø Exchangeable Aluminium	----	0.1	meq/100g	----	<0.1	0.2	----	----
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	----	1.8	1.2	----	----
Exchangeable Magnesium	----	0.1	meq/100g	----	1.1	1.1	----	----
Exchangeable Potassium	----	0.1	meq/100g	----	0.2	0.1	----	----
Exchangeable Sodium	----	0.1	meq/100g	----	<0.1	<0.1	----	----
Cation Exchange Capacity	----	0.1	meq/100g	----	3.5	3.0	----	----
Exchangeable Sodium Percent	----	0.1	%	----	0.7	0.5	----	----
Calcium/Magnesium Ratio	----	0.1	-	----	1.6	1.1	----	----
Magnesium/Potassium Ratio	----	0.1	-	----	6.5	7.2	----	----
ED008: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	----	----	----	----	1.1
Exchangeable Magnesium	----	0.1	meq/100g	----	----	----	----	6.4
Exchangeable Potassium	----	0.1	meq/100g	----	----	----	----	0.2
Exchangeable Sodium	----	0.1	meq/100g	----	----	----	----	0.4
Cation Exchange Capacity	----	0.1	meq/100g	----	----	----	----	8.3
Exchangeable Sodium Percent	----	0.1	%	----	----	----	----	4.4
Calcium/Magnesium Ratio	----	0.1	-	----	----	----	----	0.2
Magnesium/Potassium Ratio	----	0.1	-	----	----	----	----	28.0
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	----	358	281	----	266
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	----	10	<20	----	1500
ED092: DTPA Extractable Metals								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0006	2021044_0007	2021044_0008	2021044_0009	2021044_0010
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-006	EB2133723-007	EB2133723-008	EB2133723-009	EB2133723-010
				Result	Result	Result	Result	Result
ED092: DTPA Extractable Metals - Continued								
ø Copper	7440-50-8	1.00	mg/kg	----	2.26	1.57	----	2.55
ø Iron	7439-89-6	1.00	mg/kg	----	20.8	15.6	----	2.29
ø Manganese	7439-96-5	1.00	mg/kg	----	12.4	9.58	----	1.12
ø Zinc	7440-66-6	1.00	mg/kg	----	2.75	1.35	----	<1.00
EK055: Ammonia as N								
Ammonia as N	7664-41-7	20	mg/kg	----	<20	<20	----	<20
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	----	<0.1	<0.2	----	<0.1
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	----	9.7	1.9	----	26.6
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	----	9.7	1.9	----	26.6
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	----	700	590	----	260
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	----	710	590	----	290
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	----	122	112	----	218
EK080: Bicarbonate Extractable Phosphorus (Colwell)								
Bicarbonate Ext. P (Colwell)	----	5	mg/kg	----	<5	<5	----	<5
EP004: Organic Matter								
Organic Matter	----	0.5	%	----	2.2	1.7	----	0.5
Total Organic Carbon	----	0.5	%	----	1.2	1.0	----	<0.5

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0011	2021044_0012	2021044_0013	2021044_0014	2021044_0015
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-011	EB2133723-012	EB2133723-013	EB2133723-014	EB2133723-015
				Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	8.5	8.5	5.3	7.6	----
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	8.6	8.5	6.3	7.9	----
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	4000	2970	22	1300	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	----	----	----	----	4.0
Moisture Content	----	1.0	%	3.4	8.1	10.4	8.1	----
ED006: Exchangeable Cations on Alkaline Soils								
ø Exchangeable Calcium	----	0.2	meq/100g	2.6	3.6	----	2.1	----
ø Exchangeable Magnesium	----	0.2	meq/100g	7.3	2.3	----	10.4	----
ø Exchangeable Potassium	----	0.2	meq/100g	<0.2	<0.2	----	0.2	----
ø Exchangeable Sodium	----	0.2	meq/100g	6.4	1.7	----	0.8	----
ø Cation Exchange Capacity	----	0.2	meq/100g	16.5	7.7	----	13.5	----
ø Exchangeable Sodium Percent	----	0.2	%	38.8	21.8	----	6.0	----
ø Calcium/Magnesium Ratio	----	0.2	-	0.4	1.6	----	0.2	----
ø Magnesium/Potassium Ratio	----	0.2	-	----	----	----	49.3	----
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	----	----	2.0	----	----
Exchangeable Magnesium	----	0.1	meq/100g	----	----	2.4	----	----
Exchangeable Potassium	----	0.1	meq/100g	----	----	0.4	----	----
Exchangeable Sodium	----	0.1	meq/100g	----	----	<0.1	----	----
Cation Exchange Capacity	----	0.1	meq/100g	----	----	4.7	----	----
Exchangeable Sodium Percent	----	0.1	%	----	----	0.3	----	----
Calcium/Magnesium Ratio	----	0.1	-	----	----	0.8	----	----
Magnesium/Potassium Ratio	----	0.1	-	----	----	6.8	----	----
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	238	245	408	232	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	2330	930	<20	1510	----
ED092: DTPA Extractable Metals								
ø Copper	7440-50-8	1.00	mg/kg	1.21	<1.00	4.22	1.71	----
ø Iron	7439-89-6	1.00	mg/kg	1.45	<1.00	7.09	3.48	----
ø Manganese	7439-96-5	1.00	mg/kg	<1.00	<1.00	14.9	7.75	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0011	2021044_0012	2021044_0013	2021044_0014	2021044_0015
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-011	EB2133723-012	EB2133723-013	EB2133723-014	EB2133723-015
				Result	Result	Result	Result	Result
ED092: DTPA Extractable Metals - Continued								
ø Zinc	7440-66-6	1.00	mg/kg	<1.00	<1.00	**5.45**	**1.04**	----
EK055: Ammonia as N								
Ammonia as N	7664-41-7	20	mg/kg	<20	<20	<20	<20	----
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	<0.1	<0.1	<0.2	<0.1	----
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	**35.5**	**0.2**	**2.2**	**10.8**	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	**35.5**	**0.2**	**2.2**	**10.8**	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	**200**	**160**	**390**	**530**	----
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	**240**	**160**	**390**	**540**	----
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	**152**	**115**	**198**	**170**	----
EK080: Bicarbonate Extractable Phosphorus (Colwell)								
Bicarbonate Ext. P (Colwell)	----	5	mg/kg	<5	<5	**8**	<5	----
EP004: Organic Matter								
Organic Matter	----	0.5	%	<0.5	<0.5	**1.1**	**1.0**	----
Total Organic Carbon	----	0.5	%	<0.5	<0.5	**0.6**	**0.6**	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0016	2021044_0017	2021044_0018	2021044_0019	2021044_0020
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-016	EB2133723-017	EB2133723-018	EB2133723-019	EB2133723-020
				Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	----	7.9	8.3	----	----
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	----	8.1	8.4	----	----
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	----	3020	4280	----	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	3.1	----	----	2.4	3.2
Moisture Content	----	1.0	%	----	9.2	5.6	----	----
ED006: Exchangeable Cations on Alkaline Soils								
ø Exchangeable Calcium	----	0.2	meq/100g	----	0.8	2.4	----	----
ø Exchangeable Magnesium	----	0.2	meq/100g	----	3.4	3.9	----	----
ø Exchangeable Potassium	----	0.2	meq/100g	----	0.3	0.3	----	----
ø Exchangeable Sodium	----	0.2	meq/100g	----	12.3	11.8	----	----
ø Cation Exchange Capacity	----	0.2	meq/100g	----	16.9	18.4	----	----
ø Exchangeable Sodium Percent	----	0.2	%	----	73.0	64.3	----	----
ø Calcium/Magnesium Ratio	----	0.2	-	----	0.2	0.6	----	----
ø Magnesium/Potassium Ratio	----	0.2	-	----	11.9	13.5	----	----
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	----	294	267	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	----	190	440	----	----
ED092: DTPA Extractable Metals								
ø Copper	7440-50-8	1.00	mg/kg	----	1.16	<1.00	----	----
ø Iron	7439-89-6	1.00	mg/kg	----	1.77	1.56	----	----
ø Manganese	7439-96-5	1.00	mg/kg	----	2.54	1.78	----	----
ø Zinc	7440-66-6	1.00	mg/kg	----	<1.00	<1.00	----	----
EK055: Ammonia as N								
Ammonia as N	7664-41-7	20	mg/kg	----	<20	<20	----	----
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	----	<0.1	<0.1	----	----
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	----	2.0	8.2	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Sample ID	2021044_0016	2021044_0017	2021044_0018	2021044_0019	2021044_0020
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit		EB2133723-016	EB2133723-017	EB2133723-018	EB2133723-019	EB2133723-020
					Result	Result	Result	Result	Result
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser - Continued									
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg		----	2.0	8.2	----	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	20	mg/kg		----	250	260	----	----
EK062: Total Nitrogen as N (TKN + NOx)									
^ Total Nitrogen as N	----	20	mg/kg		----	250	270	----	----
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	2	mg/kg		----	191	161	----	----
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		----	<5	<5	----	----
EP004: Organic Matter									
Organic Matter	----	0.5	%		----	<0.5	<0.5	----	----
Total Organic Carbon	----	0.5	%		----	<0.5	<0.5	----	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0021	2021044_0022	2021044_0023	2021044_0024	2021044_0025
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-021	EB2133723-022	EB2133723-023	EB2133723-024	EB2133723-025
				Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	----	7.6	7.7	----	----
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	----	7.7	7.7	----	----
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	----	4190	5410	----	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	4.8	----	----	4.7	4.0
Moisture Content	----	1.0	%	----	6.3	7.0	----	----
ED006: Exchangeable Cations on Alkaline Soils								
ø Exchangeable Calcium	----	0.2	meq/100g	----	1.9	2.0	----	----
ø Exchangeable Magnesium	----	0.2	meq/100g	----	5.8	6.9	----	----
ø Exchangeable Potassium	----	0.2	meq/100g	----	0.3	0.3	----	----
ø Exchangeable Sodium	----	0.2	meq/100g	----	9.3	12.0	----	----
ø Cation Exchange Capacity	----	0.2	meq/100g	----	17.3	21.2	----	----
ø Exchangeable Sodium Percent	----	0.2	%	----	53.6	56.8	----	----
ø Calcium/Magnesium Ratio	----	0.2	-	----	0.3	0.3	----	----
ø Magnesium/Potassium Ratio	----	0.2	-	----	18.7	22.7	----	----
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	----	276	176	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	----	1960	2210	----	----
ED092: DTPA Extractable Metals								
ø Copper	7440-50-8	1.00	mg/kg	----	2.31	1.94	----	----
ø Iron	7439-89-6	1.00	mg/kg	----	1.66	1.63	----	----
ø Manganese	7439-96-5	1.00	mg/kg	----	2.38	1.35	----	----
ø Zinc	7440-66-6	1.00	mg/kg	----	<1.00	<1.00	----	----
EK055: Ammonia as N								
Ammonia as N	7664-41-7	20	mg/kg	----	<20	<20	----	----
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	----	<0.1	<0.1	----	----
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	----	23.7	28.2	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Sample ID	2021044_0021	2021044_0022	2021044_0023	2021044_0024	2021044_0025
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit		EB2133723-021	EB2133723-022	EB2133723-023	EB2133723-024	EB2133723-025
					Result	Result	Result	Result	Result
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser - Continued									
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg		----	23.7	28.2	----	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	20	mg/kg		----	260	220	----	----
EK062: Total Nitrogen as N (TKN + NOx)									
^ Total Nitrogen as N	----	20	mg/kg		----	280	250	----	----
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	2	mg/kg		----	163	163	----	----
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		----	<5	<5	----	----
EP004: Organic Matter									
Organic Matter	----	0.5	%		----	<0.5	<0.5	----	----
Total Organic Carbon	----	0.5	%		----	<0.5	<0.5	----	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0026	2021044_0027	2021044_0028	2021044_0029	2021044_0030
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-026	EB2133723-027	EB2133723-028	EB2133723-029	EB2133723-030
				Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	5.1	7.4	----	5.3	----
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	5.9	8.0	----	5.5	----
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	48	170	----	5220	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	----	----	3.9	----	3.3
Moisture Content	----	1.0	%	6.3	9.8	----	6.7	----
ED005: Exchange Acidity								
ø Exchange Acidity	----	0.1	meq/100g	<0.1	----	----	<0.1	----
ø Exchangeable Aluminium	----	0.1	meq/100g	<0.1	----	----	<0.1	----
ED006: Exchangeable Cations on Alkaline Soils								
ø Exchangeable Calcium	----	0.2	meq/100g	----	3.8	----	----	----
ø Exchangeable Magnesium	----	0.2	meq/100g	----	1.5	----	----	----
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	----	5.7	----	----	----
ø Exchangeable Sodium Percent	----	0.2	%	----	<0.2	----	----	----
ø Calcium/Magnesium Ratio	----	0.2	-	----	2.6	----	----	----
ø Magnesium/Potassium Ratio	----	0.2	-	----	4.4	----	----	----
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	3.0	----	----	----	----
Exchangeable Magnesium	----	0.1	meq/100g	1.4	----	----	----	----
Exchangeable Potassium	----	0.1	meq/100g	0.5	----	----	----	----
Exchangeable Sodium	----	0.1	meq/100g	<0.1	----	----	----	----
Cation Exchange Capacity	----	0.1	meq/100g	4.9	----	----	----	----
Exchangeable Sodium Percent	----	0.1	%	<0.1	----	----	----	----
Calcium/Magnesium Ratio	----	0.1	-	2.1	----	----	----	----
Magnesium/Potassium Ratio	----	0.1	-	2.8	----	----	----	----
ED008: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	----	----	----	0.8	----
Exchangeable Magnesium	----	0.1	meq/100g	----	----	----	3.0	----
Exchangeable Potassium	----	0.1	meq/100g	----	----	----	<0.1	----
Exchangeable Sodium	----	0.1	meq/100g	----	----	----	0.2	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0026	2021044_0027	2021044_0028	2021044_0029	2021044_0030
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-026	EB2133723-027	EB2133723-028	EB2133723-029	EB2133723-030
				Result	Result	Result	Result	Result
ED008: Exchangeable Cations - Continued								
Cation Exchange Capacity	----	0.1	meq/100g	----	----	----	4.1	----
Exchangeable Sodium Percent	----	0.1	%	----	----	----	4.2	----
Calcium/Magnesium Ratio	----	0.1	-	----	----	----	0.3	----
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	367	250	----	143	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	<20	30	----	5600	----
ED092: DTPA Extractable Metals								
ø Copper	7440-50-8	1.00	mg/kg	6.80	4.46	----	<1.00	----
ø Iron	7439-89-6	1.00	mg/kg	17.5	10.2	----	15.0	----
ø Manganese	7439-96-5	1.00	mg/kg	25.9	6.78	----	4.58	----
ø Zinc	7440-66-6	1.00	mg/kg	7.54	<1.00	----	1.29	----
EK055: Ammonia as N								
Ammonia as N	7664-41-7	20	mg/kg	<20	<20	----	<20	----
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	<0.2	<0.1	----	<0.1	----
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	15.6	4.8	----	14.0	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	15.6	4.8	----	14.0	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	810	510	----	530	----
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	820	510	----	540	----
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	185	155	----	160	----
EK080: Bicarbonate Extractable Phosphorus (Colwell)								
Bicarbonate Ext. P (Colwell)	----	5	mg/kg	6	<5	----	<5	----
EP004: Organic Matter								
Organic Matter	----	0.5	%	2.5	1.4	----	1.7	----
Total Organic Carbon	----	0.5	%	1.5	0.8	----	1.0	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0031	2021044_0032	2021044_0033	2021044_0034	2021044_0035
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-031	EB2133723-032	EB2133723-033	EB2133723-034	EB2133723-035
				Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	8.4	8.1	4.0	----	----
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	9.0	8.8	4.7	----	----
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	1330	968	48	----	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	----	----	----	3.3	3.9
Moisture Content	----	1.0	%	7.2	7.3	9.6	----	----
ED005: Exchange Acidity								
ø Exchange Acidity	----	0.1	meq/100g	----	----	1.7	----	----
ø Exchangeable Aluminium	----	0.1	meq/100g	----	----	1.0	----	----
ED006: Exchangeable Cations on Alkaline Soils								
ø Exchangeable Calcium	----	0.2	meq/100g	<0.2	<0.2	----	----	----
ø Exchangeable Magnesium	----	0.2	meq/100g	3.7	2.8	----	----	----
ø Exchangeable Potassium	----	0.2	meq/100g	0.2	<0.2	----	----	----
ø Exchangeable Sodium	----	0.2	meq/100g	2.3	1.7	----	----	----
ø Cation Exchange Capacity	----	0.2	meq/100g	6.2	4.6	----	----	----
ø Exchangeable Sodium Percent	----	0.2	%	37.0	37.5	----	----	----
ø Calcium/Magnesium Ratio	----	0.2	-	<0.2	<0.2	----	----	----
ø Magnesium/Potassium Ratio	----	0.2	-	15.8	----	----	----	----
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	----	----	2.3	----	----
Exchangeable Magnesium	----	0.1	meq/100g	----	----	0.4	----	----
Exchangeable Potassium	----	0.1	meq/100g	----	----	0.3	----	----
Exchangeable Sodium	----	0.1	meq/100g	----	----	<0.1	----	----
Cation Exchange Capacity	----	0.1	meq/100g	----	----	4.7	----	----
Exchangeable Sodium Percent	----	0.1	%	----	----	0.4	----	----
Calcium/Magnesium Ratio	----	0.1	-	----	----	5.8	----	----
Magnesium/Potassium Ratio	----	0.1	-	----	----	1.3	----	----
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	209	127	<100	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	1340	920	<10	----	----
ED092: DTPA Extractable Metals								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0031	2021044_0032	2021044_0033	2021044_0034	2021044_0035
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-031	EB2133723-032	EB2133723-033	EB2133723-034	EB2133723-035
				Result	Result	Result	Result	Result
ED092: DTPA Extractable Metals - Continued								
ø **Copper**	7440-50-8	1.00	mg/kg	<1.00	<1.00	**1.06**	----	----
ø **Iron**	7439-89-6	1.00	mg/kg	**1.53**	**3.29**	**119**	----	----
ø **Manganese**	7439-96-5	1.00	mg/kg	**1.05**	**1.37**	**4.05**	----	----
ø **Zinc**	7440-66-6	1.00	mg/kg	<1.00	<1.00	**5.36**	----	----
EK055: Ammonia as N								
Ammonia as N	7664-41-7	20	mg/kg	<20	<20	<20	----	----
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	<0.1	<0.1	<0.1	----	----
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	**1.0**	**1.5**	**7.8**	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	**1.0**	**1.5**	**7.8**	----	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	**190**	**260**	**1300**	----	----
EK062: Total Nitrogen as N (TKN + NOx)								
^ **Total Nitrogen as N**	----	20	mg/kg	**190**	**260**	**1310**	----	----
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	**123**	**92**	**309**	----	----
EK080: Bicarbonate Extractable Phosphorus (Colwell)								
Bicarbonate Ext. P (Colwell)	----	5	mg/kg	<5	<5	**6**	----	----
EP004: Organic Matter								
Organic Matter	----	0.5	%	<0.5	**0.6**	**5.3**	----	----
Total Organic Carbon	----	0.5	%	<0.5	<0.5	**3.0**	----	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0036	2021044_0037	2021044_0038	2021044_0039	2021044_0040
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-036	EB2133723-037	EB2133723-038	EB2133723-039	EB2133723-040
				Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	4.1	----	----	5.4	7.6
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	4.8	----	----	6.1	7.7
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	86	----	----	74	2040
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	----	2.1	1.7	----	----
Moisture Content	----	1.0	%	8.6	----	----	8.8	4.4
ED005: Exchange Acidity								
ø Exchange Acidity	----	0.1	meq/100g	1.8	----	----	----	----
ø Exchangeable Aluminium	----	0.1	meq/100g	0.9	----	----	----	----
ED006: Exchangeable Cations on Alkaline Soils								
ø Exchangeable Calcium	----	0.2	meq/100g	----	----	----	----	4.5
ø Exchangeable Magnesium	----	0.2	meq/100g	----	----	----	----	2.7
ø Exchangeable Potassium	----	0.2	meq/100g	----	----	----	----	0.4
ø Exchangeable Sodium	----	0.2	meq/100g	----	----	----	----	0.3
ø Cation Exchange Capacity	----	0.2	meq/100g	----	----	----	----	7.8
ø Exchangeable Sodium Percent	----	0.2	%	----	----	----	----	3.5
ø Calcium/Magnesium Ratio	----	0.2	-	----	----	----	----	1.7
ø Magnesium/Potassium Ratio	----	0.2	-	----	----	----	----	6.7
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	4.4	----	----	5.6	----
Exchangeable Magnesium	----	0.1	meq/100g	1.0	----	----	1.9	----
Exchangeable Potassium	----	0.1	meq/100g	0.4	----	----	0.4	----
Exchangeable Sodium	----	0.1	meq/100g	<0.1	----	----	<0.1	----
Cation Exchange Capacity	----	0.1	meq/100g	7.6	----	----	----	----
Cation Exchange Capacity	----	0.1	meq/100g	----	----	----	7.9	----
Exchangeable Sodium Percent	----	0.1	%	0.8	----	----	0.2	----
Calcium/Magnesium Ratio	----	0.1	-	4.4	----	----	2.9	----
Magnesium/Potassium Ratio	----	0.1	-	2.5	----	----	4.9	----
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	<100	----	----	<100	<100
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	<10	----	----	<10	110

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0036	2021044_0037	2021044_0038	2021044_0039	2021044_0040
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-036	EB2133723-037	EB2133723-038	EB2133723-039	EB2133723-040
				Result	Result	Result	Result	Result
ED092: DTPA Extractable Metals								
ø Copper	7440-50-8	1.00	mg/kg	1.05	----	----	1.22	2.22
ø Iron	7439-89-6	1.00	mg/kg	146	----	----	25.9	9.90
ø Manganese	7439-96-5	1.00	mg/kg	13.4	----	----	10.2	5.39
ø Zinc	7440-66-6	1.00	mg/kg	30.8	----	----	18.8	55.1
EK055: Ammonia as N								
Ammonia as N	7664-41-7	20	mg/kg	<20	----	----	<20	<20
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	<0.1	----	----	<0.1	<0.1
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	13.5	----	----	10.5	20.7
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	13.5	----	----	10.5	20.7
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	2120	----	----	980	270
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	2130	----	----	990	290
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	376	----	----	211	249
EK080: Bicarbonate Extractable Phosphorus (Colwell)								
Bicarbonate Ext. P (Colwell)	----	5	mg/kg	14	----	----	<5	<5
EP004: Organic Matter								
Organic Matter	----	0.5	%	10.6	----	----	4.1	1.2
Total Organic Carbon	----	0.5	%	6.1	----	----	2.4	0.7

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0041	2021044_0042	2021044_0043	2021044_0044	2021044_0045
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-041	EB2133723-042	EB2133723-043	EB2133723-044	EB2133723-045
				Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	----	7.8	7.9	----	4.2
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	----	7.9	8.0	----	4.7
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	----	2720	2790	----	423
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	2.8	----	----	3.4	----
Moisture Content	----	1.0	%	----	6.5	5.5	----	7.9
ED005: Exchange Acidity								
ø Exchange Acidity	----	0.1	meq/100g	----	----	----	----	1.2
ø Exchangeable Aluminium	----	0.1	meq/100g	----	----	----	----	0.8
ED006: Exchangeable Cations on Alkaline Soils								
ø Exchangeable Calcium	----	0.2	meq/100g	----	3.1	3.8	----	----
ø Exchangeable Magnesium	----	0.2	meq/100g	----	4.6	3.7	----	----
ø Exchangeable Potassium	----	0.2	meq/100g	----	0.4	0.5	----	----
ø Exchangeable Sodium	----	0.2	meq/100g	----	1.9	1.6	----	----
ø Cation Exchange Capacity	----	0.2	meq/100g	----	10.1	9.5	----	----
ø Exchangeable Sodium Percent	----	0.2	%	----	18.6	16.7	----	----
ø Calcium/Magnesium Ratio	----	0.2	-	----	0.7	1.0	----	----
ø Magnesium/Potassium Ratio	----	0.2	-	----	11.0	8.0	----	----
ED008: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	----	----	----	----	1.0
Exchangeable Magnesium	----	0.1	meq/100g	----	----	----	----	1.1
Exchangeable Potassium	----	0.1	meq/100g	----	----	----	----	0.2
Exchangeable Sodium	----	0.1	meq/100g	----	----	----	----	0.1
Cation Exchange Capacity	----	0.1	meq/100g	----	----	----	----	3.7
Exchangeable Sodium Percent	----	0.1	%	----	----	----	----	4.6
Calcium/Magnesium Ratio	----	0.1	-	----	----	----	----	0.9
Magnesium/Potassium Ratio	----	0.1	-	----	----	----	----	5.5
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	----	<100	<100	----	<100
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	----	580	490	----	170
ED092: DTPA Extractable Metals								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0041	2021044_0042	2021044_0043	2021044_0044	2021044_0045
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-041	EB2133723-042	EB2133723-043	EB2133723-044	EB2133723-045
				Result	Result	Result	Result	Result
ED092: DTPA Extractable Metals - Continued								
ø **Copper**	7440-50-8	1.00	mg/kg	----	**2.95**	**2.15**	----	<1.00
ø **Iron**	7439-89-6	1.00	mg/kg	----	**9.24**	**7.88**	----	**87.7**
ø **Manganese**	7439-96-5	1.00	mg/kg	----	**2.57**	**2.47**	----	**2.23**
ø **Zinc**	7440-66-6	1.00	mg/kg	----	**34.2**	**34.8**	----	**1.46**
EK055: Ammonia as N								
Ammonia as N	7664-41-7	20	mg/kg	----	<20	<20	----	<20
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	----	<0.1	<0.1	----	**0.1**
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	----	**51.0**	**39.6**	----	**30.1**
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	----	**51.0**	**39.6**	----	**30.2**
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	----	**160**	**170**	----	**740**
EK062: Total Nitrogen as N (TKN + NOx)								
^ **Total Nitrogen as N**	----	20	mg/kg	----	**210**	**210**	----	**770**
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	----	**221**	**265**	----	**380**
EK080: Bicarbonate Extractable Phosphorus (Colwell)								
Bicarbonate Ext. P (Colwell)	----	5	mg/kg	----	<5	<5	----	**6**
EP004: Organic Matter								
Organic Matter	----	0.5	%	----	**0.6**	<0.5	----	**2.8**
Total Organic Carbon	----	0.5	%	----	<0.5	<0.5	----	**1.6**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0046	2021044_0047	2021044_0048	2021044_0049	2021044_0050
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-046	EB2133723-047	EB2133723-048	EB2133723-049	EB2133723-050
				Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	6.4	7.6	4.5	5.5	4.2
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	6.7	8.0	5.0	5.9	4.5
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	744	1200	366	183	409
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	1.0	%	10.5	9.5	4.0	8.3	7.3
ED005: Exchange Acidity								
ø Exchange Acidity	----	0.1	meq/100g	----	----	0.3	<0.1	0.8
ø Exchangeable Aluminium	----	0.1	meq/100g	----	----	0.1	<0.1	0.4
ED006: Exchangeable Cations on Alkaline Soils								
ø Exchangeable Calcium	----	0.2	meq/100g	----	0.6	----	----	----
ø Exchangeable Magnesium	----	0.2	meq/100g	----	4.2	----	----	----
ø Exchangeable Potassium	----	0.2	meq/100g	----	0.6	----	----	----
ø Exchangeable Sodium	----	0.2	meq/100g	----	1.4	----	----	----
ø Cation Exchange Capacity	----	0.2	meq/100g	----	6.8	----	----	----
ø Exchangeable Sodium Percent	----	0.2	%	----	19.9	----	----	----
ø Calcium/Magnesium Ratio	----	0.2	-	----	<0.2	----	----	----
ø Magnesium/Potassium Ratio	----	0.2	-	----	6.6	----	----	----
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	----	----	----	3.6	----
Exchangeable Magnesium	----	0.1	meq/100g	----	----	----	2.7	----
Exchangeable Potassium	----	0.1	meq/100g	----	----	----	0.3	----
Exchangeable Sodium	----	0.1	meq/100g	----	----	----	0.3	----
Cation Exchange Capacity	----	0.1	meq/100g	----	----	----	7.0	----
Exchangeable Sodium Percent	----	0.1	%	----	----	----	4.0	----
Calcium/Magnesium Ratio	----	0.1	-	----	----	----	1.3	----
Magnesium/Potassium Ratio	----	0.1	-	----	----	----	8.2	----
ED008: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	0.7	----	1.6	----	3.0
Exchangeable Magnesium	----	0.1	meq/100g	5.6	----	1.1	----	0.6
Exchangeable Potassium	----	0.1	meq/100g	0.7	----	0.3	----	0.3
Exchangeable Sodium	----	0.1	meq/100g	0.2	----	<0.1	----	<0.1
Cation Exchange Capacity	----	0.1	meq/100g	----	----	3.5	----	4.7

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0046	2021044_0047	2021044_0048	2021044_0049	2021044_0050
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-046	EB2133723-047	EB2133723-048	EB2133723-049	EB2133723-050
				Result	Result	Result	Result	Result
ED008: Exchangeable Cations - Continued								
Cation Exchange Capacity	----	0.1	meq/100g	7.4	----	----	----	----
Exchangeable Sodium Percent	----	0.1	%	2.7	----	0.8	----	0.2
Calcium/Magnesium Ratio	----	0.1	-	0.1	----	1.4	----	5.0
Magnesium/Potassium Ratio	----	0.1	-	8.0	----	3.4	----	2.2
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	<100	<100	<100	<100	<100
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	550	890	100	40	80
ED092: DTPA Extractable Metals								
ø Copper	7440-50-8	1.00	mg/kg	<1.00	<1.00	<1.00	1.34	<1.00
ø Iron	7439-89-6	1.00	mg/kg	2.45	3.22	49.4	21.8	72.9
ø Manganese	7439-96-5	1.00	mg/kg	<1.00	<1.00	16.9	8.72	13.4
ø Zinc	7440-66-6	1.00	mg/kg	<1.00	1.77	5.15	5.65	8.50
EK055: Ammonia as N								
Ammonia as N	7664-41-7	20	mg/kg	<20	<20	40	<20	30
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	<0.1	<0.1	0.1	0.3	0.4
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	10.3	7.6	85.6	34.1	178
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	10.3	7.6	85.7	34.4	178
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	280	180	800	650	1120
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	290	190	880	680	1300
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	243	296	261	306	266
EK080: Bicarbonate Extractable Phosphorus (Colwell)								
Bicarbonate Ext. P (Colwell)	----	5	mg/kg	<5	<5	<5	<5	7
EP004: Organic Matter								
Organic Matter	----	0.5	%	<0.5	<0.5	3.0	2.9	5.9
Total Organic Carbon	----	0.5	%	<0.5	<0.5	1.8	1.7	3.4

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

			Sample ID	2021044_0051	2021044_0052	2021044_0053	2021044_0054	2021044_0001 <2000µm Sieve Fraction
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-051	EB2133723-052	EB2133723-053	EB2133723-054	EB2133723-055
				Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	4.8	4.5	5.0	4.2	5.9
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	5.3	5.1	5.6	5.0	6.3
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	451	133	241	36	5510
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	1.0	%	2.7	7.6	12.5	9.4	----
ED005: Exchange Acidity								
ø Exchange Acidity	----	0.1	meq/100g	<0.1	0.4	0.2	0.9	----
ø Exchangeable Aluminium	----	0.1	meq/100g	<0.1	0.1	<0.1	0.4	----
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	----	3.7	9.5	1.5	----
Exchangeable Magnesium	----	0.1	meq/100g	----	1.0	7.9	1.0	----
Exchangeable Potassium	----	0.1	meq/100g	----	0.4	1.1	0.3	----
Exchangeable Sodium	----	0.1	meq/100g	----	<0.1	0.3	<0.1	----
Cation Exchange Capacity	----	0.1	meq/100g	----	5.6	19.0	3.7	----
Exchangeable Sodium Percent	----	0.1	%	----	1.4	1.4	<0.1	----
Calcium/Magnesium Ratio	----	0.1	-	----	3.7	1.2	1.5	----
Magnesium/Potassium Ratio	----	0.1	-	----	2.2	7.0	3.0	----
ED008: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	2.8	----	----	----	0.2
Exchangeable Magnesium	----	0.1	meq/100g	1.6	----	----	----	6.1
Exchangeable Potassium	----	0.1	meq/100g	0.3	----	----	----	0.3
Exchangeable Sodium	----	0.1	meq/100g	<0.1	----	----	----	1.0
Cation Exchange Capacity	----	0.1	meq/100g	4.8	----	----	----	----
Cation Exchange Capacity	----	0.1	meq/100g	----	----	----	----	7.7
Exchangeable Sodium Percent	----	0.1	%	1.0	----	----	----	12.9
Calcium/Magnesium Ratio	----	0.1	-	1.8	----	----	----	<0.1
Magnesium/Potassium Ratio	----	0.1	-	5.4	----	----	----	22.0
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	<100	<100	1220	<100	214
ED045G: Chloride by Discrete Analyser								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0051	2021044_0052	2021044_0053	2021044_0054	2021044_0001 <2000µm Sieve Fraction
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-051	EB2133723-052	EB2133723-053	EB2133723-054	EB2133723-055
				Result	Result	Result	Result	Result
ED045G: Chloride by Discrete Analyser - Continued								
Chloride	16887-00-6	10	mg/kg	330	30	<100	<100	5220
ED092: DTPA Extractable Metals								
ø Copper	7440-50-8	1.00	mg/kg	1.51	<1.00	1.77	1.11	<1.00
ø Iron	7439-89-6	1.00	mg/kg	32.8	65.5	167	33.3	3.66
ø Manganese	7439-96-5	1.00	mg/kg	40.0	8.99	24.8	7.40	11.9
ø Zinc	7440-66-6	1.00	mg/kg	5.76	7.70	12.0	8.42	<1.00
EK055: Ammonia as N								
Ammonia as N	7664-41-7	20	mg/kg	30	<20	<20	<20	<20
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	0.4	0.1	<1.0	<1.0	<0.1
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	23.2	39.8	20.1	6.8	13.3
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	23.6	39.9	20.1	6.8	13.3
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	870	930	1900	750	320
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	890	970	1920	760	330
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	330	232	314	278	134
EK080: Bicarbonate Extractable Phosphorus (Colwell)								
Bicarbonate Ext. P (Colwell)	----	5	mg/kg	<5	6	7	<5	<5
EP004: Organic Matter								
Organic Matter	----	0.5	%	4.4	4.5	14.0	2.8	0.7
Total Organic Carbon	----	0.5	%	2.6	2.6	8.1	1.6	<0.5

Analytical Results

Sub-Matrix: SOIL
(Matrix: SOIL)

Compound	CAS Number	LOR	Unit	Sample ID	2021044_0006 <2000µm Sieve Fraction	2021044_0009 <2000µm Sieve Fraction	2021044_0015 <2000µm Sieve Fraction	2021044_0016 <2000µm Sieve Fraction	2021044_0019 <2000µm Sieve Fraction
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
					EB2133723-056	EB2133723-057	EB2133723-058	EB2133723-059	EB2133723-060
					Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract									
pH (CaCl2)	----	0.1	pH Unit		7.9	8.1	7.9	8.2	8.0
EA002: pH 1:5 (Soils)									
pH Value	----	0.1	pH Unit		8.0	8.8	8.4	8.6	8.8
EA010: Conductivity (1:5)									
Electrical Conductivity @ 25°C	----	1	µS/cm		989	282	807	734	1540
ED006: Exchangeable Cations on Alkaline Soils									
ø Exchangeable Calcium	----	0.2	meq/100g		<0.2	<0.2	<0.2	<0.2	0.7
ø Exchangeable Magnesium	----	0.2	meq/100g		1.3	1.1	4.4	3.6	1.0
ø Exchangeable Potassium	----	0.2	meq/100g		<0.2	<0.2	<0.2	<0.2	<0.2
ø Exchangeable Sodium	----	0.2	meq/100g		1.4	<0.2	0.2	0.4	3.6
ø Cation Exchange Capacity	----	0.2	meq/100g		2.9	1.1	4.7	4.1	5.3
ø Exchangeable Sodium Percent	----	0.2	%		50.1	<0.2	4.8	8.9	67.9
ø Calcium/Magnesium Ratio	----	0.2	-		<0.2	<0.2	<0.2	<0.2	0.8
ED021: Bicarbonate Extractable Potassium (Colwell)									
Bicarbonate Extractable K (Colwell)	----	100	mg/kg		173	126	221	246	307
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	10	mg/kg		740	110	790	630	160
ED092: DTPA Extractable Metals									
ø Copper	7440-50-8	1.00	mg/kg		<1.00	<1.00	<1.00	<1.00	<1.00
ø Iron	7439-89-6	1.00	mg/kg		1.60	1.75	4.21	4.41	3.03
ø Manganese	7439-96-5	1.00	mg/kg		<1.00	<1.00	1.50	1.08	<1.00
ø Zinc	7440-66-6	1.00	mg/kg		<1.00	<1.00	<1.00	<1.00	<1.00
EK055: Ammonia as N									
Ammonia as N	7664-41-7	20	mg/kg		<20	<20	<20	<20	<20
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg		<0.1	<0.1	<0.1	<0.1	<0.1
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg		0.6	0.6	1.4	0.5	1.5
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg		0.6	0.6	1.4	0.5	1.5
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	20	mg/kg		50	100	220	200	150

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	Sample ID	2021044_0006 <2000µm Sieve Fraction	2021044_0009 <2000µm Sieve Fraction	2021044_0015 <2000µm Sieve Fraction	2021044_0016 <2000µm Sieve Fraction	2021044_0019 <2000µm Sieve Fraction
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
					EB2133723-056	EB2133723-057	EB2133723-058	EB2133723-059	EB2133723-060
					Result	Result	Result	Result	Result
EK062: Total Nitrogen as N (TKN + NOx)									
^ **Total Nitrogen as N**	----	20	mg/kg		**50**	**100**	**220**	**200**	**150**
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	2	mg/kg		**57**	**71**	**172**	**337**	**289**
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		<5	<5	<5	<5	<5
EP004: Organic Matter									
Organic Matter	----	0.5	%		<0.5	<0.5	<0.5	<0.5	<0.5
Total Organic Carbon	----	0.5	%		<0.5	<0.5	<0.5	<0.5	<0.5

Analytical Results

Sub-Matrix: SOIL
(Matrix: SOIL)

Compound	CAS Number	LOR	Unit	Sample ID	2021044_0020 <2000µm Sieve Fraction	2021044_0021 <2000µm Sieve Fraction	2021044_0024 <2000µm Sieve Fraction	2021044_0025 <2000µm Sieve Fraction	2021044_0028 <2000µm Sieve Fraction
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
					EB2133723-061	EB2133723-062	EB2133723-063	EB2133723-064	EB2133723-065
					Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract									
pH (CaCl2)	----	0.1	pH Unit		8.2	8.2	8.6	8.2	7.8
EA002: pH 1:5 (Soils)									
pH Value	----	0.1	pH Unit		8.8	9.1	8.8	9.0	8.4
EA010: Conductivity (1:5)									
Electrical Conductivity @ 25°C	----	1	µS/cm		1640	850	1960	855	320
ED006: Exchangeable Cations on Alkaline Soils									
ø Exchangeable Calcium	----	0.2	meq/100g		0.4	<0.2	0.4	<0.2	<0.2
ø Exchangeable Magnesium	----	0.2	meq/100g		1.4	1.2	1.6	0.9	1.3
ø Exchangeable Potassium	----	0.2	meq/100g		<0.2	<0.2	<0.2	<0.2	<0.2
ø Exchangeable Sodium	----	0.2	meq/100g		4.0	2.5	3.8	2.3	<0.2
ø Cation Exchange Capacity	----	0.2	meq/100g		5.7	3.7	5.8	3.2	1.3
ø Exchangeable Sodium Percent	----	0.2	%		69.7	67.5	65.4	71.3	<0.2
ø Calcium/Magnesium Ratio	----	0.2	-		0.3	<0.2	0.3	<0.2	<0.2
ED021: Bicarbonate Extractable Potassium (Colwell)									
Bicarbonate Extractable K (Colwell)	----	100	mg/kg		126	242	297	166	249
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	10	mg/kg		180	130	1140	670	180
ED092: DTPA Extractable Metals									
ø Copper	7440-50-8	1.00	mg/kg		<1.00	<1.00	<1.00	<1.00	<1.00
ø Iron	7439-89-6	1.00	mg/kg		3.08	3.30	2.56	2.39	4.30
ø Manganese	7439-96-5	1.00	mg/kg		<1.00	<1.00	<1.00	<1.00	1.12
ø Zinc	7440-66-6	1.00	mg/kg		<1.00	<1.00	<1.00	<1.00	<1.00
EK055: Ammonia as N									
Ammonia as N	7664-41-7	20	mg/kg		<20	<20	<20	<20	<20
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg		<0.1	<0.1	<0.1	<0.1	<0.1
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg		2.2	1.1	9.1	2.6	0.4
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg		2.2	1.1	9.1	2.6	0.4
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	20	mg/kg		170	160	180	190	170

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	Sample ID	2021044_0020 <2000µm Sieve Fraction	2021044_0021 <2000µm Sieve Fraction	2021044_0024 <2000µm Sieve Fraction	2021044_0025 <2000µm Sieve Fraction	2021044_0028 <2000µm Sieve Fraction
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
					EB2133723-061	EB2133723-062	EB2133723-063	EB2133723-064	EB2133723-065
					Result	Result	Result	Result	Result
EK062: Total Nitrogen as N (TKN + NOx)									
^ **Total Nitrogen as N**	----	20	mg/kg		**170**	**160**	**190**	**190**	**170**
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	2	mg/kg		**171**	**274**	**120**	**152**	**184**
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		<5	<5	<5	<5	<5
EP004: Organic Matter									
Organic Matter	----	0.5	%		<0.5	<0.5	<0.5	<0.5	<0.5
Total Organic Carbon	----	0.5	%		<0.5	<0.5	<0.5	<0.5	<0.5

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	Sample ID	2021044_0030 <2000µm Sieve Fraction	2021044_0034 <2000µm Sieve Fraction	2021044_0035 <2000µm Sieve Fraction	2021044_0037 <2000µm Sieve Fraction	2021044_0038 <2000µm Sieve Fraction
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
					EB2133723-066	EB2133723-067	EB2133723-068	EB2133723-069	EB2133723-070
					Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract									
pH (CaCl2)	----	0.1	pH Unit		**7.8**	**6.2**	**5.0**	**7.0**	**7.4**
EA002: pH 1:5 (Soils)									
pH Value	----	0.1	pH Unit		**7.9**	**7.3**	**6.7**	**8.0**	**8.3**
EA010: Conductivity (1:5)									
Electrical Conductivity @ 25°C	----	1	µS/cm		**433**	**506**	**480**	**233**	**404**
ED006: Exchangeable Cations on Alkaline Soils									
ø **Exchangeable Calcium**	----	0.2	meq/100g		<0.2	----	----	**0.4**	<0.2
ø **Exchangeable Magnesium**	----	0.2	meq/100g		**1.2**	----	----	**0.5**	**0.7**
ø **Exchangeable Potassium**	----	0.2	meq/100g		<0.2	----	----	**0.5**	**0.4**
ø **Exchangeable Sodium**	----	0.2	meq/100g		<0.2	----	----	<0.2	<0.2
ø **Cation Exchange Capacity**	----	0.2	meq/100g		**1.2**	----	----	**1.4**	**1.1**
ø **Exchangeable Sodium Percent**	----	0.2	%		<0.2	----	----	<0.2	<0.2
ø **Calcium/Magnesium Ratio**	----	0.2	-		<0.2	----	----	**0.8**	<0.2
ø **Magnesium/Potassium Ratio**	----	0.2	-		----	----	----	**0.9**	**2.0**
ED008: Exchangeable Cations									
Exchangeable Calcium	----	0.1	meq/100g		----	**0.2**	**0.2**	----	----
Exchangeable Magnesium	----	0.1	meq/100g		----	**0.4**	**0.5**	----	----
Exchangeable Potassium	----	0.1	meq/100g		----	**0.2**	<0.1	----	----
Exchangeable Sodium	----	0.1	meq/100g		----	<0.1	<0.1	----	----
Cation Exchange Capacity	----	0.1	meq/100g		----	**1.0**	**0.9**	----	----
Exchangeable Sodium Percent	----	0.1	%		----	**3.9**	**2.7**	----	----
Calcium/Magnesium Ratio	----	0.1	-		----	**0.5**	**0.4**	----	----
Magnesium/Potassium Ratio	----	0.1	-		----	**2.1**	----	----	----
ED021: Bicarbonate Extractable Potassium (Colwell)									
Bicarbonate Extractable K (Colwell)	----	100	mg/kg		<100	**454**	**157**	**265**	**462**
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	10	mg/kg		**380**	**360**	**320**	**80**	**220**
ED092: DTPA Extractable Metals									
ø **Copper**	7440-50-8	1.00	mg/kg		<1.00	<1.00	<1.00	<1.00	<1.00
ø **Iron**	7439-89-6	1.00	mg/kg		**1.53**	**2.36**	**6.80**	**3.49**	**4.92**
ø **Manganese**	7439-96-5	1.00	mg/kg		<1.00	<1.00	**1.96**	<1.00	<1.00
ø **Zinc**	7440-66-6	1.00	mg/kg		<1.00	**6.13**	**4.18**	<1.00	<1.00

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_0030 <2000µm Sieve Fraction	2021044_0034 <2000µm Sieve Fraction	2021044_0035 <2000µm Sieve Fraction	2021044_0037 <2000µm Sieve Fraction	2021044_0038 <2000µm Sieve Fraction
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-066	EB2133723-067	EB2133723-068	EB2133723-069	EB2133723-070
				Result	Result	Result	Result	Result
EK055: Ammonia as N								
Ammonia as N	7664-41-7	20	mg/kg	<20	<20	<20	<20	<20
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	**0.6**	**0.4**	**0.4**	**0.5**	**1.2**
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	**0.6**	**0.4**	**0.4**	**0.5**	**1.2**
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	20	mg/kg	**90**	**90**	**140**	**70**	**110**
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	20	mg/kg	**90**	**90**	**140**	**70**	**110**
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	2	mg/kg	**48**	**214**	**313**	**128**	**234**
EK080: Bicarbonate Extractable Phosphorus (Colwell)								
Bicarbonate Ext. P (Colwell)	----	5	mg/kg	<5	<5	<5	<5	<5
EP004: Organic Matter								
Organic Matter	----	0.5	%	<0.5	<0.5	<0.5	<0.5	<0.5
Total Organic Carbon	----	0.5	%	<0.5	<0.5	<0.5	<0.5	<0.5

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	Sample ID	2021044_0041 <2000µm Sieve Fraction	2021044_0044 <2000µm Sieve Fraction	2021044_C001	2021044_C002	2021044_C003
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
					EB2133723-071	EB2133723-072	EB2133723-073	EB2133723-074	EB2133723-075
					Result	Result	Result	Result	Result
EA001: pH in soil using 0.01M CaCl extract									
pH (CaCl2)	----	0.1	pH Unit		**7.4**	**7.2**	**----**	**----**	**----**
EA002: pH 1:5 (Soils)									
pH Value	----	0.1	pH Unit		**8.1**	**7.7**	**----**	**----**	**----**
EA009: Net Acid Production Potential									
Net Acid Production Potential	----	0.5	kg H2SO4/t		**----**	**----**	**3.5**	**-13.3**	**-9.8**
EA010: Conductivity (1:5)									
Electrical Conductivity @ 25°C	----	1	µS/cm		**211**	**682**	**----**	**----**	**----**
EA013: Acid Neutralising Capacity									
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t		**----**	**----**	**2.3**	**18.5**	**11.0**
ANC as CaCO3	----	0.1	% CaCO3		**----**	**----**	**0.2**	**1.9**	**1.1**
Fizz Rating	----	0	Fizz Unit		**----**	**----**	**0**	**1**	**1**
ED006: Exchangeable Cations on Alkaline Soils									
ø **Exchangeable Calcium**	----	0.2	meq/100g		<0.2	<0.2	**----**	**----**	**----**
ø **Exchangeable Magnesium**	----	0.2	meq/100g		**0.9**	**1.1**	**----**	**----**	**----**
ø **Exchangeable Potassium**	----	0.2	meq/100g		<0.2	<0.2	**----**	**----**	**----**
ø **Exchangeable Sodium**	----	0.2	meq/100g		<0.2	**0.4**	**----**	**----**	**----**
ø **Cation Exchange Capacity**	----	0.2	meq/100g		**0.9**	**1.6**	**----**	**----**	**----**
ø **Exchangeable Sodium Percent**	----	0.2	%		<0.2	**23.1**	**----**	**----**	**----**
ø **Calcium/Magnesium Ratio**	----	0.2	-		<0.2	<0.2	**----**	**----**	**----**
ED021: Bicarbonate Extractable Potassium (Colwell)									
Bicarbonate Extractable K (Colwell)	----	100	mg/kg		**178**	**190**	**----**	**----**	**----**
ED042T: Total Sulfur by LECO									
Sulfur - Total as S (LECO)	----	0.01	%		**----**	**----**	**0.19**	**0.17**	**0.04**
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	10	mg/kg		**50**	**220**	**----**	**----**	**----**
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		**3.66**	**4.93**	**----**	**----**	**----**
ø **Manganese**	7439-96-5	1.00	mg/kg		**1.19**	**1.85**	**----**	**----**	**----**
ø **Zinc**	7440-66-6	1.00	mg/kg		<1.00	<1.00	**----**	**----**	**----**
EK040T: Fluoride Total									

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	Sample ID	2021044_0041 <2000µm Sieve Fraction	2021044_0044 <2000µm Sieve Fraction	2021044_C001	2021044_C002	2021044_C003
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
					EB2133723-071	EB2133723-072	EB2133723-073	EB2133723-074	EB2133723-075
					Result	Result	Result	Result	Result
EK040T: Fluoride Total - Continued									
Fluoride	16984-48-8	40	mg/kg		**----**	**----**	**770**	**750**	**770**
EK055: Ammonia as N									
Ammonia as N	7664-41-7	20	mg/kg		<20	<20	**----**	**----**	**----**
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg		<0.1	<0.1	**----**	**----**	**----**
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg		**5.0**	**19.8**	**----**	**----**	**----**
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg		**5.0**	**19.8**	**----**	**----**	**----**
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	20	mg/kg		**140**	**120**	**----**	**----**	**----**
EK062: Total Nitrogen as N (TKN + NOx)									
^ **Total Nitrogen as N**	----	20	mg/kg		**140**	**140**	**----**	**----**	**----**
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	2	mg/kg		**262**	**132**	**----**	**----**	**----**
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		<5	<5	**----**	**----**	**----**
EP004: Organic Matter									
Organic Matter	----	0.5	%		<0.5	<0.5	**----**	**----**	**----**
Total Organic Carbon	----	0.5	%		<0.5	<0.5	**----**	**----**	**----**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_C004	2021044_C005	2021044_C006	2021044_C007	2021044_C008
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-076	EB2133723-077	EB2133723-078	EB2133723-079	EB2133723-080
				Result	Result	Result	Result	Result
EA009: Net Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-44.2	-1.3	-56.5	-31.5	-0.07
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	45.7	4.1	62.9	37.3	6.8
ANC as CaCO3	----	0.1	% CaCO3	4.6	0.4	6.4	3.8	0.7
Fizz Rating	----	0	Fizz Unit	2	0	2	1	0
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	0.05	0.09	0.21	0.19	0.22
EK040T: Fluoride Total								
Fluoride	16984-48-8	40	mg/kg	870	700	920	1090	700

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_C009	2021044_C010	2021044_C011	2021044_C012	2021044_C013
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-081	EB2133723-082	EB2133723-083	EB2133723-084	EB2133723-085
				Result	Result	Result	Result	Result
EA009: Net Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-7.3	-30.0	-35.1	1.6	-2.0
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	32.7	33.1	36.9	2.1	3.2
ANC as CaCO3	----	0.1	% CaCO3	3.3	3.4	3.8	0.2	0.3
Fizz Rating	----	0	Fizz Unit	1	1	1	0	0
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	0.83	0.10	0.06	0.12	0.04
EK040T: Fluoride Total								
Fluoride	16984-48-8	40	mg/kg	680	1080	1100	770	1040

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_C014	2021044_C015	2021044_C016	2021044_C017	2021044_C018
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-086	EB2133723-087	EB2133723-088	EB2133723-089	EB2133723-090
				Result	Result	Result	Result	Result
EA009: Net Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-1.5**	**-7.8**	**-5.2**	**8.1**	<0.5
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**3.0**	**16.1**	**5.5**	**8.7**	**2.9**
ANC as CaCO3	----	0.1	% CaCO3	**0.3**	**1.6**	**0.6**	**0.9**	**0.3**
Fizz Rating	----	0	Fizz Unit	**0**	**1**	**0**	**1**	**0**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.05**	**0.27**	**0.01**	**0.55**	**0.11**
EK040T: Fluoride Total								
Fluoride	16984-48-8	40	mg/kg	**1180**	**900**	**1300**	**1030**	**820**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_C019	2021044_C020	2021044_C021	2021044_C022	2021044_C023
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2133723-091	EB2133723-092	EB2133723-093	EB2133723-094	EB2133723-095
				Result	Result	Result	Result	Result
EA009: Net Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-5.7**	----	----	----	----
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**8.8**	----	----	----	----
ANC as CaCO3	----	0.1	% CaCO3	**0.9**	----	----	----	----
Fizz Rating	----	0	Fizz Unit	**0**	----	----	----	----
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.10**	----	----	----	----
EK040T: Fluoride Total								
Fluoride	16984-48-8	40	mg/kg	**930**	**960**	**780**	**730**	**850**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Sample ID	2021044_C024	----	----	----	----
				Sampling date / time	22-Nov-2021 00:00	----	----	----	----
Compound	CAS Number	LOR	Unit		EB2133723-096	--------	--------	--------	--------
					Result	----	----	----	----
EK040T: Fluoride Total									
Fluoride	16984-48-8	40	mg/kg		**690**	----	----	----	----

Inter-Laboratory Testing

Analysis conducted by ALS Newcastle, NATA accreditation no. 825, site no. 1656 (Chemistry) 9854 (Biology).

(SOIL) EK040T: Fluoride Total

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ALS Brisbane is a NATA Accredited Testing Laboratory. Corporate Accreditation No: 825, Corporate Site No: 818.

To: **ALS ENVIRONMENTAL**
32 SHAND STREET
STAFFORD QLD 4053

Finalized Date: 10-JAN-2022
Account: ALSENV

QC CERTIFICATE BR21349348

Project: EB2133723

P.O. No.: ME-MS41

This report is for 24 samples of Pulp submitted to our lab in Brisbane, QLD, Australia on 22-DEC-2021.

The following have access to data associated with this certificate:

SUB RESULTS -BRIS		

SAMPLE PREPARATION

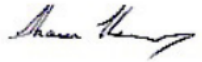
ALS CODE	DESCRIPTION
LOG-22	Sample login - Rcd w/o BarCode
LEV-01	Waste Disposal Levy

ANALYTICAL PROCEDURES

ALS CODE	DESCRIPTION	INSTRUMENT
ME-MS41	Ultra Trace Aqua Regia ICP-MS	

This is the Final Report and supersedes any preliminary report with this certificate number.Results apply to samples as submitted.All pages of this report have been checked and approved for release.
***** See Appendix Page for comments regarding this certificate *****

Signature:



Shaun Kenny, Brisbane Laboratory Manager

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To: **ALS ENVIRONMENTAL**
32 SHAND STREET
STAFFORD QLD 4053

Finalized Date: 10-JAN-2022
Account: ALSENV

Project: EB2133723

QC CERTIFICATE OF ANALYSIS BR21349348

Sample Description	Method	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41
	Analyte	Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu
	Units	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm
	LOD	0.01	0.01	0.1	0.02	10	10	0.05	0.01	0.01	0.01	0.02	0.1	1	0.05	0.2
STANDARDS																
EMOG-17		60.9	1.52	568	0.86	<10	80	0.39	5.48	0.94	19.95	41.0	745	46	6.05	8140
Target Range - Lower Bound		60.3	1.45	522	0.77	<10	30	0.32	5.32	0.87	18.35	37.6	680	42	5.57	7780
Upper Bound		73.7	1.79	638	0.99	20	80	0.56	6.52	1.09	22.5	46.0	832	54	6.91	8960
GBM908-10		2.89	0.92	54.6	0.81	<10	100	0.26	1.06	0.67	1.66	84.9	14.4	22	0.74	3560
Target Range - Lower Bound		2.60	0.85	50.3	0.38	<10	70	0.17	1.09	0.62	1.52	79.3	12.8	20	0.66	3350
Upper Bound		3.20	1.06	61.7	0.51	30	140	0.40	1.35	0.79	1.88	97.0	15.9	27	0.94	3850
MRGeo08		4.46	2.57	34.1	<0.02	<10	440	0.97	0.65	1.09	2.16	70.6	19.2	93	10.15	631
Target Range - Lower Bound		4.00	2.44	29.6	<0.02	<10	370	0.67	0.58	1.00	2.01	66.2	17.0	81	9.40	587
Upper Bound		4.92	3.00	36.4	0.04	20	530	0.95	0.73	1.24	2.47	81.0	21.0	102	11.60	675
OREAS-45e		0.25	3.23	13.3	0.05	10	150	0.40	0.23	0.03	0.02	18.25	53.5	856	0.73	732
Target Range - Lower Bound		0.21	2.98	10.2	<0.02	<10	110	0.29	0.19	<0.01	<0.01	15.90	46.7	763	0.63	659
Upper Bound		0.28	3.66	12.6	0.09	20	170	0.53	0.25	0.05	0.04	19.50	57.3	935	0.91	759
BLANKS																
BLANK		<0.01	<0.01	<0.1	<0.02	<10	<10	<0.05	<0.01	0.01	<0.01	<0.02	<0.1	<1	<0.05	<0.2
BLANK		<0.01	<0.01	<0.1	<0.02	<10	<10	<0.05	<0.01	<0.01	<0.01	<0.02	<0.1	<1	<0.05	0.2
Target Range - Lower Bound		<0.01	<0.01	<0.1	<0.02	<10	<10	<0.05	<0.01	<0.01	<0.01	<0.02	<0.1	<1	<0.05	<0.2
Upper Bound		0.02	0.02	0.2	0.04	20	20	0.10	0.02	0.02	0.02	0.04	0.2	2	0.10	0.4
DUPLICATES																
2021044_C003		0.12	0.59	8.9	<0.02	<10	80	0.43	0.22	0.18	0.04	45.0	3.6	8	0.23	8.7
DUP		0.12	0.56	8.5	<0.02	<10	70	0.47	0.22	0.17	0.04	42.6	3.5	8	0.22	8.3
Target Range - Lower Bound		0.10	0.54	8.2	<0.02	<10	60	0.38	0.20	0.16	0.03	41.6	3.3	7	0.16	8.0
Upper Bound		0.14	0.61	9.2	0.04	20	90	0.52	0.24	0.19	0.05	46.0	3.8	9	0.29	9.0
2021044_C023		0.16	0.64	64.3	<0.02	<10	150	1.30	0.31	0.31	0.15	27.3	8.6	8	0.17	24.6
DUP		0.15	0.68	64.3	<0.02	<10	150	1.05	0.31	0.31	0.15	28.7	8.5	8	0.18	25.0
Target Range - Lower Bound		0.14	0.62	61.0	<0.02	<10	130	1.07	0.28	0.28	0.13	26.6	8.0	7	0.12	23.7
Upper Bound		0.17	0.70	67.6	0.04	20	170	1.28	0.34	0.34	0.17	29.4	9.1	9	0.23	25.9

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32 SHAND STREET
STAFFORD QLD 4053

Finalized Date: 10-JAN-2022
Account: ALSENV

Project: EB2133723

QC CERTIFICATE OF ANALYSIS BR21349348

Sample Description	Method / Analyte / Units / LOD	ME-MS41 Fe % 0.01	ME-MS41 Ga ppm 0.05	ME-MS41 Ge ppm 0.05	ME-MS41 Hf ppm 0.02	ME-MS41 Hg ppm 0.01	ME-MS41 In ppm 0.005	ME-MS41 K % 0.01	ME-MS41 La ppm 0.2	ME-MS41 Li ppm 0.1	ME-MS41 Mg % 0.01	ME-MS41 Mn ppm 5	ME-MS41 Mo ppm 0.05	ME-MS41 Na % 0.01	ME-MS41 Nb ppm 0.05	ME-MS41 Ni ppm 0.2
STANDARDS																
EMOG-17		4.50	5.46	0.18	0.40	0.53	0.895	0.65	20.5	15.3	0.76	631	1035	0.17	0.92	7540
Target Range - Lower Bound		4.18	5.56	0.08	0.39	0.46	0.814	0.60	18.3	17.2	0.69	595	971	0.15	1.24	6930
Upper Bound		5.14	6.90	0.30	0.53	0.64	1.005	0.76	22.9	21.2	0.87	739	1185	0.20	1.80	8470
GBM908-10		2.61	4.04	0.10	0.68	0.01	0.021	0.42	46.0	4.7	0.52	295	58.7	0.11	0.41	2280
Target Range - Lower Bound		2.35	4.18	<0.05	0.62	<0.01	0.012	0.37	42.6	5.5	0.47	259	57.9	0.09	0.35	2020
Upper Bound		2.89	5.22	0.25	0.80	0.04	0.034	0.48	52.5	6.9	0.59	327	70.9	0.15	0.65	2470
MRGeo08		3.61	9.53	0.16	0.67	0.05	0.151	1.28	35.6	36.3	1.16	418	14.05	0.35	0.81	706
Target Range - Lower Bound		3.22	8.73	0.07	0.64	0.04	0.137	1.12	33.2	29.6	1.03	378	13.10	0.30	0.75	622
Upper Bound		3.96	10.80	0.29	0.83	0.10	0.179	1.40	41.0	36.4	1.29	473	16.10	0.39	1.13	760
OREAS-45e		23.3	13.95	0.30	0.74	0.01	0.089	0.05	7.3	2.3	0.09	384	1.80	0.04	0.19	385
Target Range - Lower Bound		20.4	10.50	0.24	0.74	<0.01	0.077	0.03	6.6	2.2	0.07	324	1.55	<0.01	0.14	321
Upper Bound		24.9	12.90	0.48	0.95	0.04	0.106	0.08	8.5	2.9	0.12	408	2.01	0.05	0.39	393
BLANKS																
BLANK		<0.01	<0.05	<0.05	<0.02	<0.01	<0.005	<0.01	<0.2	<0.1	<0.01	<5	<0.05	<0.01	<0.05	<0.2
BLANK		<0.01	<0.05	<0.05	<0.02	<0.01	<0.005	<0.01	<0.2	<0.1	<0.01	<5	<0.05	<0.01	<0.05	<0.2
Target Range - Lower Bound		<0.01	<0.05	<0.05	<0.02	<0.01	<0.005	<0.01	<0.2	<0.1	<0.01	<5	<0.05	<0.01	<0.05	<0.2
Upper Bound		0.02	0.10	0.10	0.04	0.02	0.010	0.02	0.4	0.2	0.02	10	0.10	0.02	0.10	0.4
DUPLICATES																
2021044_C003		2.43	1.95	0.05	0.21	0.01	0.018	0.14	22.4	3.4	0.24	89	0.46	0.09	0.24	3.6
DUP		2.36	1.90	0.06	0.20	0.01	0.018	0.13	21.0	3.5	0.23	89	0.47	0.08	0.24	3.4
Target Range - Lower Bound		2.27	1.78	<0.05	0.17	<0.01	0.012	0.12	20.4	3.2	0.21	80	0.39	0.07	0.17	3.1
Upper Bound		2.52	2.07	0.10	0.24	0.02	0.024	0.15	23.0	3.7	0.26	98	0.54	0.10	0.31	3.9
2021044_C023		4.26	1.95	<0.05	0.16	0.02	0.036	0.15	12.5	2.5	0.14	145	1.14	0.02	0.40	13.5
DUP		4.22	1.94	<0.05	0.16	0.03	0.036	0.15	13.3	2.1	0.14	145	1.14	0.02	0.40	13.4
Target Range - Lower Bound		4.02	1.80	<0.05	0.13	<0.01	0.029	0.13	12.1	2.1	0.12	133	1.03	<0.01	0.32	12.6
Upper Bound		4.46	2.09	0.10	0.19	0.04	0.043	0.17	13.7	2.5	0.16	157	1.25	0.03	0.48	14.3

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Finalized Date: 10-JAN-2022
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Project: EB2133723

QC CERTIFICATE OF ANALYSIS BR21349348

Sample Description	Method	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41
	Analyte	P	Pb	Rb	Re	S	Sb	Sc	Se	Sn	Sr	Ta	Te	Th	Ti	Tl
	Units	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm
	LOD	10	0.2	0.1	0.001	0.01	0.05	0.1	0.2	0.2	0.2	0.01	0.01	0.2	0.005	0.02
STANDARDS																
EMOG-17		720	6980	54.6	0.303	3.03	672	4.3	6.6	1.9	50.7	<0.01	1.32	10.0	0.203	1.87
Target Range - Lower Bound		680	6510	66.5	0.287	2.90	574	4.3	5.5	1.5	47.5	<0.01	1.16	9.3	0.188	1.71
Upper Bound		850	7950	81.5	0.353	3.56	776	5.5	7.2	2.6	58.5	0.03	1.44	11.8	0.240	2.37
GBM908-10		820	1995	28.9	0.001	0.34	1.34	1.7	0.2	1.6	32.5	<0.01	0.05	15.4	0.300	0.20
Target Range - Lower Bound		760	1845	26.4	<0.001	0.33	1.06	1.8	<0.2	1.2	30.8	<0.01	0.03	15.2	0.276	0.15
Upper Bound		960	2250	32.4	0.002	0.43	1.55	2.4	0.9	2.2	38.0	0.02	0.07	19.0	0.348	0.27
MRGeo08		980	1060	148.0	0.008	0.30	3.36	8.2	1.0	3.3	77.0	0.02	0.03	20.4	0.375	0.75
Target Range - Lower Bound		900	959	132.0	0.006	0.27	2.80	6.7	0.6	2.8	72.1	<0.01	<0.01	19.1	0.338	0.64
Upper Bound		1130	1175	162.0	0.010	0.35	3.90	8.4	1.5	4.0	88.5	0.03	0.04	23.7	0.424	0.92
OREAS-45e		280	13.2	7.7	<0.001	0.04	0.54	79.4	1.9	0.9	4.0	<0.01	0.10	10.5	0.102	0.07
Target Range - Lower Bound		250	12.7	7.0	<0.001	0.02	0.45	70.1	1.3	0.5	3.4	<0.01	0.08	9.4	0.090	<0.02
Upper Bound		330	15.9	8.8	0.002	0.07	0.77	85.9	2.3	1.4	4.7	0.03	0.13	12.0	0.122	0.10
BLANKS																
BLANK		<10	<0.2	<0.1	<0.001	<0.01	<0.05	<0.1	<0.2	<0.2	<0.2	<0.01	<0.01	<0.2	<0.005	<0.02
BLANK		<10	<0.2	<0.1	<0.001	<0.01	<0.05	<0.1	<0.2	<0.2	<0.2	<0.01	0.01	<0.2	<0.005	<0.02
Target Range - Lower Bound		<10	<0.2	<0.1	<0.001	<0.01	<0.05	<0.1	<0.2	<0.2	<0.2	<0.01	<0.01	<0.2	<0.005	<0.02
Upper Bound		20	0.4	0.2	0.002	0.02	0.10	0.2	0.4	0.4	0.4	0.02	0.02	0.4	0.010	0.04
DUPLICATES																
2021044_C003		60	9.5	8.8	<0.001	0.03	1.16	1.6	0.2	0.4	9.9	<0.01	0.05	5.3	0.018	0.13
DUP		60	9.2	8.3	<0.001	0.03	1.16	1.7	0.2	0.4	9.6	<0.01	0.05	5.0	0.018	0.13
Target Range - Lower Bound		50	8.7	8.0	<0.001	0.02	1.02	1.5	<0.2	<0.2	9.1	<0.01	0.04	4.7	0.012	0.10
Upper Bound		70	10.0	9.1	0.002	0.04	1.30	1.8	0.4	0.6	10.4	0.02	0.06	5.6	0.024	0.16
2021044_C023		340	24.4	7.6	<0.001	0.05	2.17	3.2	0.6	0.4	22.7	0.01	0.05	3.9	0.009	0.13
DUP		340	24.5	8.0	<0.001	0.06	2.19	2.8	0.5	0.4	23.0	<0.01	0.05	4.0	0.009	0.13
Target Range - Lower Bound		310	23.0	7.3	<0.001	0.04	1.97	2.8	0.3	<0.2	21.5	<0.01	0.04	3.6	<0.005	0.10
Upper Bound		370	25.9	8.3	0.002	0.07	2.39	3.3	0.8	0.6	24.2	0.02	0.06	4.3	0.010	0.16

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Project: EB2133723

QC CERTIFICATE OF ANALYSIS BR21349348

Sample Description	Method / Analyte / Units / LOD	ME-MS41 U ppm 0.05	ME-MS41 V ppm 1	ME-MS41 W ppm 0.05	ME-MS41 Y ppm 0.05	ME-MS41 Zn ppm 2	ME-MS41 Zr ppm 0.5
STANDARDS							
EMOG-17		2.53	61	1.87	7.59	7130	8.9
Target Range - Lower Bound		2.57	58	1.65	10.20	6780	10.6
Upper Bound		3.25	74	2.35	12.60	8290	15.5
GBM908-10		1.14	46	1.79	18.45	1005	29.1
Target Range - Lower Bound		1.15	41	1.62	17.55	921	23.5
Upper Bound		1.51	53	2.32	21.6	1130	32.9
MRGeo08		5.08	101	2.78	19.80	780	21.5
Target Range - Lower Bound		4.93	90	2.44	17.50	708	18.1
Upper Bound		6.13	112	3.42	21.5	870	25.7
OREAS-45e		1.70	291	0.09	5.78	29	28.7
Target Range - Lower Bound		1.51	265	<0.05	5.12	25	23.3
Upper Bound		1.95	326	0.24	6.36	36	32.7
BLANKS							
BLANK		<0.05	<1	<0.05	<0.05	<2	<0.5
BLANK		<0.05	<1	<0.05	<0.05	<2	<0.5
Target Range - Lower Bound		<0.05	<1	<0.05	<0.05	<2	<0.5
Upper Bound		0.10	2	0.10	0.10	4	1.0
DUPLICATES							
2021044_C003		0.95	16	0.08	5.12	21	9.7
DUP		0.92	16	0.08	4.94	22	9.5
Target Range - Lower Bound		0.84	14	<0.05	4.73	18	8.4
Upper Bound		1.03	18	0.10	5.33	25	10.8
2021044_C023		1.52	20	0.11	6.45	155	5.7
DUP		1.55	19	0.11	6.42	143	5.9
Target Range - Lower Bound		1.41	18	<0.05	6.06	140	4.9
Upper Bound		1.66	21	0.17	6.81	158	6.7

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Sample Description	Method	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41
	Analyte	Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu
	Units	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm
	LOD	0.01	0.01	0.1	0.02	10	10	0.05	0.01	0.01	0.01	0.02	0.1	1	0.05	0.2
DUPLICATES																
ORIGINAL		1.20	1.23	268	0.40	<10	60	0.44	5.66	3.18	0.04	106.0	467	27	0.38	8180
DUP		1.18	1.21	265	0.40	<10	60	0.38	5.61	3.10	0.01	112.0	456	26	0.40	7900
Target Range – Lower Bound		1.12	1.15	253	0.36	<10	50	0.34	5.34	2.97	<0.01	103.5	438	24	0.32	7760
Upper Bound		1.26	1.29	280	0.44	20	70	0.48	5.93	3.31	0.04	114.5	485	29	0.46	8320
ORIGINAL		0.15	1.79	105.5	0.15	<10	120	0.61	0.14	7.40	0.15	31.6	15.8	28	7.61	34.3
DUP		0.14	1.83	111.5	0.14	<10	120	0.60	0.14	7.20	0.15	31.3	16.0	29	7.78	35.6
Target Range – Lower Bound		0.13	1.71	103.0	0.12	<10	100	0.52	0.12	6.93	0.13	29.9	15.0	26	7.26	33.5
Upper Bound		0.16	1.91	114.0	0.17	20	140	0.69	0.16	7.68	0.17	33.0	16.8	31	8.13	36.4

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Sample Description	Method	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41
	Analyte	P	Pb	Rb	Re	S	Sb	Sc	Se	Sn	Sr	Ta	Te	Th	Ti	Tl
	Units	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm
	LOD	10	0.2	0.1	0.001	0.01	0.05	0.1	0.2	0.2	0.2	0.01	0.01	0.2	0.005	0.02
DUPLICATES																
ORIGINAL		1750	9.5	31.7	0.071	3.19	2.19	9.3	2.8	5.1	36.2	0.01	0.99	9.3	0.157	0.09
DUP		1710	9.4	29.6	0.069	3.12	2.33	7.8	2.4	5.2	34.2	<0.01	0.97	10.1	0.153	0.09
Target Range – Lower Bound		1630	8.8	29.0	0.066	2.99	2.04	8.0	2.3	4.7	33.2	<0.01	0.92	9.0	0.142	0.06
Upper Bound		1830	10.1	32.3	0.075	3.32	2.48	9.1	2.9	5.6	37.2	0.02	1.04	10.4	0.168	0.12
ORIGINAL		550	12.0	18.4	<0.001	0.06	14.20	6.1	0.5	0.5	173.0	<0.01	0.05	4.7	0.031	1.36
DUP		550	12.6	18.9	<0.001	0.07	13.55	6.0	0.5	0.5	177.0	<0.01	0.06	4.7	0.032	1.34
Target Range – Lower Bound		510	11.5	17.6	<0.001	0.05	12.80	5.6	0.3	0.3	166.0	<0.01	0.04	4.3	0.025	1.23
Upper Bound		590	13.1	19.7	0.002	0.08	14.95	6.5	0.7	0.7	184.0	0.02	0.07	5.1	0.038	1.47

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QC CERTIFICATE OF ANALYSIS BR21349348

Sample Description	Method	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41
	Analyte	P	Pb	Rb	Re	S	Sb	Sc	Se	Sn	Sr	Ta	Te	Th	Ti	Tl
	Units	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm
	LOD	10	0.2	0.1	0.001	0.01	0.05	0.1	0.2	0.2	0.2	0.01	0.01	0.2	0.005	0.02
DUPLICATES																
ORIGINAL		1750	9.5	31.7	0.071	3.19	2.19	9.3	2.8	5.1	36.2	0.01	0.99	9.3	0.157	0.09
DUP		1710	9.4	29.6	0.069	3.12	2.33	7.8	2.4	5.2	34.2	<0.01	0.97	10.1	0.153	0.09
Target Range – Lower Bound		1630	8.8	29.0	0.066	2.99	2.04	8.0	2.3	4.7	33.2	<0.01	0.92	9.0	0.142	0.06
Upper Bound		1830	10.1	32.3	0.075	3.32	2.48	9.1	2.9	5.6	37.2	0.02	1.04	10.4	0.168	0.12
ORIGINAL		550	12.0	18.4	<0.001	0.06	14.20	6.1	0.5	0.5	173.0	<0.01	0.05	4.7	0.031	1.36
DUP		550	12.6	18.9	<0.001	0.07	13.55	6.0	0.5	0.5	177.0	<0.01	0.06	4.7	0.032	1.34
Target Range – Lower Bound		510	11.5	17.6	<0.001	0.05	12.80	5.6	0.3	0.3	166.0	<0.01	0.04	4.3	0.025	1.23
Upper Bound		590	13.1	19.7	0.002	0.08	14.95	6.5	0.7	0.7	184.0	0.02	0.07	5.1	0.038	1.47

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QC CERTIFICATE OF ANALYSIS BR21349348

Sample Description	Method	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41	ME-MS41
	Analyte	U	V	W	Y	Zn	Zr
	Units	ppm	ppm	ppm	ppm	ppm	ppm
	LOD	0.05	1	0.05	0.05	2	0.5
DUPLICATES							
ORIGINAL		26.5	192	38.6	17.50	30	42.4
DUP		27.3	188	39.2	16.60	29	40.5
Target Range - Lower Bound		25.5	180	35.9	16.15	26	37.8
Upper Bound		28.3	201	41.9	17.95	33	45.1
ORIGINAL		1.02	76	0.26	13.70	74	13.6
DUP		1.01	77	0.23	13.65	75	13.8
Target Range - Lower Bound		0.91	72	0.18	12.95	69	12.2
Upper Bound		1.12	81	0.31	14.40	80	15.2

Australian Laboratory Services Pty. Ltd.

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www.alsglobal.com/geochemistry

ALS Brisbane is a NATA Accredited Testing Laboratory. Corporate Accreditation No: 825, Corporate Site No: 818.

To: **ALS ENVIRONMENTAL**
32 SHAND STREET
STAFFORD QLD 4053

Page: Appendix 1
Total # Appendix Pages: 1
Finalized Date: 10-JAN-2022
Account: ALSENV

Project: EB2133723

QC CERTIFICATE OF ANALYSIS BR21349348

CERTIFICATE COMMENTS

ANALYTICAL COMMENTS

Applies to Method: Gold determinations by this method are semi-quantitative due to the small sample weight used (0.5g).
ME-MS41

ACCREDITATION COMMENTS

Applies to Method: NATA Accreditation covers the performance of this service but does not cover the performance of ALS Brisbane Sample Preparation. Corporate Accreditation No: 825, Corporate Site No: 818. The Technical Signatory is David Jones,ICPMS Supervising Chemist
ME-MS41

LABORATORY ADDRESSES

Applies to Method: Processed at ALS Brisbane located at 32 Shand Street, Stafford, Brisbane, QLD, Australia. Processed at ALS Brisbane Sample Preparation at 23 Pineapple Street, Zillmere, QLD, 4034, Australia
LEV-01 LOG-22 ME-MS41

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB2201374**	Page	: 1 of 19
Client	: **NORANDA PACIFIC PTY LTD T/A LADY LORETTA MINE**	Laboratory	: Environmental Division Brisbane
Contact	: GREG (RGS)	Contact	: Joy Morgan
Address	: PO BOX 1867 MOUNT ISA 4825	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: ----	Telephone	: +61 7 4773 0030
Project	: 2021044 Lady Loretta	Date Samples Received	: 19-Jan-2022 13:19
Order number	: AQMLLXXDA	Date Analysis Commenced	: 25-Jan-2022
C-O-C number	: ----	Issue Date	: 09-Feb-2022 18:28
Sampler	: MELINDA MILTON		
Site	: ----		
Quote number	: TV/115/19 v3 from 1/7/21		
No. of samples received	: 24		
No. of samples analysed	: 24		

ilac-MRA NATA
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, unless the sampling was conducted by ALS. 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 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.

- ED041G (Sulfate (Turbidimetric) as SO4 2-): Sample EB2201374_023 (2021044_C023) was diluted due to matrix interference. LOR adjusted accordingly.
- ALS is not NATA accredited for the performance of EN35: Miscellaneous Leaching procedure.
- 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: DI WATER LEACHATE (Matrix: WATER)			Sample ID	2021044_C001	2021044_C002	2021044_C003	2021044_C004	2021044_C005
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2201374-001	EB2201374-002	EB2201374-003	EB2201374-004	EB2201374-005
				Result	Result	Result	Result	Result
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	6.50	7.80	8.05	8.07	7.04
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	6140	4860	1310	1790	2140
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	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	5	80	101	66	22
Total Alkalinity as CaCO3	----	1	mg/L	5	80	101	66	22
ED038: Acidity								
Acidity as CaCO3	----	1	mg/L	5	7	3	4	7
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	1740	1410	284	402	746
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	1030	797	193	311	238
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	36	23	12	16	30
Magnesium	7439-95-4	1	mg/L	334	241	40	38	95
Sodium	7440-23-5	1	mg/L	944	827	203	308	287
Potassium	7440-09-7	1	mg/L	26	24	17	18	25
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	0.01	0.01	0.01	0.03	<0.01
Antimony	7440-36-0	0.001	mg/L	0.001	0.001	<0.001	<0.001	<0.001
Arsenic	7440-38-2	0.001	mg/L	0.001	0.002	0.002	0.003	<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	0.083	0.220	0.051	0.042	0.081
Bismuth	7440-69-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	7440-43-9	0.0001	mg/L	0.0006	0.0001	<0.0001	<0.0001	0.0003
Cerium	7440-45-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Caesium	7440-46-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium	7440-47-3	0.001	mg/L	0.002	0.001	<0.001	<0.001	<0.001
Cobalt	7440-48-4	0.001	mg/L	0.056	0.001	<0.001	<0.001	0.005
Copper	7440-50-8	0.001	mg/L	0.009	0.006	0.005	0.002	0.008
Dysprosium	7429-91-6	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Erbium	7440-52-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)			Sample ID	2021044_C001	2021044_C002	2021044_C003	2021044_C004	2021044_C005
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2201374-001	EB2201374-002	EB2201374-003	EB2201374-004	EB2201374-005
				Result	Result	Result	Result	Result
EG020F: Dissolved Metals by ICP-MS - Continued								
Europium	7440-53-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Gadolinium	7440-54-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Gallium	7440-55-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Hafnium	7440-58-6	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Holmium	7440-60-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lanthanum	7439-91-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lithium	7439-93-2	0.001	mg/L	**0.014**	**0.012**	**0.004**	**0.005**	**0.016**
Lutetium	7439-94-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	7439-96-5	0.001	mg/L	**5.34**	**0.383**	**0.130**	**0.008**	**2.45**
Molybdenum	7439-98-7	0.001	mg/L	<0.001	**0.002**	**0.001**	**0.002**	<0.001
Neodymium	7440-00-8	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	7440-02-0	0.001	mg/L	**0.009**	**0.002**	<0.001	<0.001	**0.004**
Praseodymium	7440-10-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Rubidium	7440-17-7	0.001	mg/L	**0.025**	**0.019**	**0.015**	**0.013**	**0.022**
Samarium	7440-19-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
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	**0.285**	**0.273**	**0.069**	**0.116**	**0.164**
Tellurium	22541-49-7	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Terbium	7440-27-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Thallium	7440-28-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Thorium	7440-29-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Thulium	7440-30-4	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Tin	7440-31-5	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Titanium	7440-32-6	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Uranium	7440-61-1	0.001	mg/L	<0.001	**0.003**	**0.001**	**0.004**	<0.001
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Ytterbium	7440-64-4	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Yttrium	7440-65-5	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc	7440-66-6	0.005	mg/L	**0.126**	**0.070**	**0.032**	<0.005	**0.022**
Zirconium	7440-67-7	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Boron	7440-42-8	0.05	mg/L	**0.22**	**0.26**	**0.08**	**0.08**	**0.07**
Iron	7439-89-6	0.05	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05
EK040P: Fluoride by PC Titrator								

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)				Sample ID	2021044_C001	2021044_C002	2021044_C003	2021044_C004	2021044_C005
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit		EB2201374-001	EB2201374-002	EB2201374-003	EB2201374-004	EB2201374-005
					Result	Result	Result	Result	Result
EK040P: Fluoride by PC Titrator - Continued									
Fluoride	16984-48-8	0.1	mg/L		**0.1**	**1.2**	**0.8**	**2.6**	**0.1**

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)			Sample ID	2021044_C006	2021044_C007	2021044_C008	2021044_C009	2021044_C010
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2201374-006	EB2201374-007	EB2201374-008	EB2201374-009	EB2201374-010
				Result	Result	Result	Result	Result
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	7.69	6.95	7.44	7.67	7.64
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	4270	3180	4170	5990	2310
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	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	54	15	32	47	35
Total Alkalinity as CaCO3	----	1	mg/L	54	15	32	47	35
ED038: Acidity								
Acidity as CaCO3	----	1	mg/L	8	8	7	8	6
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	1850	1570	1950	3070	832
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	419	196	235	447	235
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	359	208	227	452	113
Magnesium	7439-95-4	1	mg/L	146	206	108	218	49
Sodium	7440-23-5	1	mg/L	478	238	671	809	323
Potassium	7440-09-7	1	mg/L	20	38	19	17	28
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	0.01
Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	7440-38-2	0.001	mg/L	0.001	<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	0.066	0.164	0.044	0.028	0.021
Bismuth	7440-69-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	0.0009	<0.0001	<0.0001	<0.0001
Cerium	7440-45-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Caesium	7440-46-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
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	<0.001	0.015	<0.001	<0.001	<0.001
Copper	7440-50-8	0.001	mg/L	0.007	0.005	0.004	0.003	<0.001
Dysprosium	7429-91-6	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Erbium	7440-52-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)			Sample ID	2021044_C006	2021044_C007	2021044_C008	2021044_C009	2021044_C010
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2201374-006	EB2201374-007	EB2201374-008	EB2201374-009	EB2201374-010
				Result	Result	Result	Result	Result
EG020F: Dissolved Metals by ICP-MS - Continued								
Europium	7440-53-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Gadolinium	7440-54-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Gallium	7440-55-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Hafnium	7440-58-6	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Holmium	7440-60-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lanthanum	7439-91-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lithium	7439-93-2	0.001	mg/L	**0.012**	**0.021**	**0.037**	**0.048**	**0.025**
Lutetium	7439-94-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	7439-96-5	0.001	mg/L	**0.108**	**7.91**	**0.136**	**0.131**	**0.005**
Molybdenum	7439-98-7	0.001	mg/L	**0.003**	<0.001	**0.001**	**0.003**	**0.002**
Neodymium	7440-00-8	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	7440-02-0	0.001	mg/L	**0.001**	**0.010**	**0.003**	**0.003**	<0.001
Praseodymium	7440-10-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Rubidium	7440-17-7	0.001	mg/L	**0.018**	**0.032**	**0.017**	**0.014**	**0.022**
Samarium	7440-19-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
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	**0.855**	**1.01**	**0.792**	**2.46**	**0.295**
Tellurium	22541-49-7	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Terbium	7440-27-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Thallium	7440-28-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Thorium	7440-29-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Thulium	7440-30-4	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Tin	7440-31-5	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Titanium	7440-32-6	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Uranium	7440-61-1	0.001	mg/L	**0.007**	<0.001	<0.001	**0.003**	<0.001
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Ytterbium	7440-64-4	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Yttrium	7440-65-5	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc	7440-66-6	0.005	mg/L	**0.011**	**0.044**	**0.014**	**0.005**	<0.005
Zirconium	7440-67-7	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Boron	7440-42-8	0.05	mg/L	**0.06**	**0.06**	**0.15**	**0.20**	**0.06**
Iron	7439-89-6	0.05	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05
EK040P: Fluoride by PC Titrator								

Analytical Results

Sub-Matrix: **DI WATER LEACHATE** (Matrix: **WATER**)				Sample ID	2021044_C006	2021044_C007	2021044_C008	2021044_C009	2021044_C010
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	*CAS Number*	*LOR*	*Unit*		**EB2201374-006**	**EB2201374-007**	**EB2201374-008**	**EB2201374-009**	**EB2201374-010**
					Result	Result	Result	Result	Result
EK040P: Fluoride by PC Titrator - Continued									
Fluoride	16984-48-8	0.1	mg/L		**0.5**	**0.1**	**0.3**	**0.8**	**1.6**

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)			Sample ID	2021044_C011	2021044_C012	2021044_C013	2021044_C014	2021044_C015
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2201374-011	EB2201374-012	EB2201374-013	EB2201374-014	EB2201374-015
				Result	Result	Result	Result	Result
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	7.85	6.10	7.02	7.11	7.66
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	1630	228	591	708	2230
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	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	36	8	5	7	132
Total Alkalinity as CaCO3	----	1	mg/L	36	8	5	7	132
ED038: Acidity								
Acidity as CaCO3	----	1	mg/L	4	9	5	5	10
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	578	75	124	164	1140
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	137	15	76	95	25
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	38	10	6	8	355
Magnesium	7439-95-4	1	mg/L	25	6	13	22	85
Sodium	7440-23-5	1	mg/L	268	4	41	39	26
Potassium	7440-09-7	1	mg/L	26	18	60	54	50
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	0.02	0.39	<0.01	<0.01	<0.01
Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	0.003
Arsenic	7440-38-2	0.001	mg/L	0.001	0.005	<0.001	<0.001	0.004
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	0.016	0.031	0.026	0.028	0.084
Bismuth	7440-69-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	0.0010
Cerium	7440-45-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Caesium	7440-46-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
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	<0.001	0.008	<0.001	<0.001	0.007
Copper	7440-50-8	0.001	mg/L	<0.001	0.006	0.002	0.004	0.006
Dysprosium	7429-91-6	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Erbium	7440-52-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)			Sample ID	2021044_C011	2021044_C012	2021044_C013	2021044_C014	2021044_C015
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2201374-011	EB2201374-012	EB2201374-013	EB2201374-014	EB2201374-015
				Result	Result	Result	Result	Result
EG020F: Dissolved Metals by ICP-MS - Continued								
Europium	7440-53-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Gadolinium	7440-54-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Gallium	7440-55-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Hafnium	7440-58-6	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Holmium	7440-60-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lanthanum	7439-91-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lead	7439-92-1	0.001	mg/L	<0.001	**0.004**	<0.001	<0.001	**0.003**
Lithium	7439-93-2	0.001	mg/L	**0.026**	**0.012**	**0.012**	**0.010**	**0.015**
Lutetium	7439-94-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	7439-96-5	0.001	mg/L	**0.002**	**0.358**	**0.023**	**0.036**	**1.78**
Molybdenum	7439-98-7	0.001	mg/L	**0.004**	<0.001	<0.001	<0.001	**0.002**
Neodymium	7440-00-8	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	7440-02-0	0.001	mg/L	<0.001	**0.006**	**0.002**	**0.002**	**0.006**
Praseodymium	7440-10-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Rubidium	7440-17-7	0.001	mg/L	**0.022**	**0.026**	**0.071**	**0.061**	**0.048**
Samarium	7440-19-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
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	**0.295**	**0.033**	**0.042**	**0.064**	**0.670**
Tellurium	22541-49-7	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Terbium	7440-27-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Thallium	7440-28-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Thorium	7440-29-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Thulium	7440-30-4	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Tin	7440-31-5	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Titanium	7440-32-6	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Uranium	7440-61-1	0.001	mg/L	**0.002**	<0.001	<0.001	<0.001	**0.008**
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Ytterbium	7440-64-4	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Yttrium	7440-65-5	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc	7440-66-6	0.005	mg/L	<0.005	**0.127**	<0.005	**0.006**	**0.095**
Zirconium	7440-67-7	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Boron	7440-42-8	0.05	mg/L	**0.05**	**0.10**	**0.09**	**0.10**	**0.05**
Iron	7439-89-6	0.05	mg/L	<0.05	**0.12**	<0.05	<0.05	<0.05
EK040P: Fluoride by PC Titrator								

Analytical Results

Sub-Matrix: **DI WATER LEACHATE** (Matrix: **WATER**)				Sample ID	2021044_C011	2021044_C012	2021044_C013	2021044_C014	2021044_C015
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	*CAS Number*	*LOR*	*Unit*		**EB2201374-011**	**EB2201374-012**	**EB2201374-013**	**EB2201374-014**	**EB2201374-015**
					Result	Result	Result	Result	Result
EK040P: Fluoride by PC Titrator - Continued									
Fluoride	16984-48-8	0.1	mg/L		**1.9**	<0.1	**1.6**	**0.5**	**0.2**

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)			Sample ID	2021044_C016	2021044_C017	2021044_C018	2021044_C019	2021044_C020
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2201374-016	EB2201374-017	EB2201374-018	EB2201374-019	EB2201374-020
				Result	Result	Result	Result	Result
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	7.76	7.30	6.23	7.70	6.72
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	365	4220	1030	1980	520
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	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	39	26	4	50	11
Total Alkalinity as CaCO3	----	1	mg/L	39	26	4	50	11
ED038: Acidity								
Acidity as CaCO3	----	1	mg/L	1	8	6	6	7
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	87	2420	320	618	105
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	21	180	106	273	30
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	11	473	9	36	16
Magnesium	7439-95-4	1	mg/L	15	222	39	89	19
Sodium	7440-23-5	1	mg/L	11	253	115	238	16
Potassium	7440-09-7	1	mg/L	26	63	31	37	37
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	0.03	<0.01	0.02	<0.01	0.16
Antimony	7440-36-0	0.001	mg/L	0.002	0.002	<0.001	<0.001	<0.001
Arsenic	7440-38-2	0.001	mg/L	0.001	0.002	<0.001	0.001	0.004
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	0.017	0.031	0.037	0.026	0.047
Bismuth	7440-69-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	0.0021	<0.0001	<0.0001	<0.0001
Cerium	7440-45-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Caesium	7440-46-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium	7440-47-3	0.001	mg/L	0.002	<0.001	<0.001	<0.001	<0.001
Cobalt	7440-48-4	0.001	mg/L	<0.001	0.003	0.010	<0.001	0.008
Copper	7440-50-8	0.001	mg/L	0.001	0.005	0.004	0.003	0.008
Dysprosium	7429-91-6	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Erbium	7440-52-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)			Sample ID	2021044_C016	2021044_C017	2021044_C018	2021044_C019	2021044_C020
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2201374-016	EB2201374-017	EB2201374-018	EB2201374-019	EB2201374-020
				Result	Result	Result	Result	Result
EG020F: Dissolved Metals by ICP-MS - Continued								
Europium	7440-53-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Gadolinium	7440-54-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Gallium	7440-55-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Hafnium	7440-58-6	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Holmium	7440-60-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lanthanum	7439-91-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	**0.002**
Lithium	7439-93-2	0.001	mg/L	**0.017**	**0.021**	**0.012**	**0.005**	**0.008**
Lutetium	7439-94-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	7439-96-5	0.001	mg/L	**0.011**	**0.464**	**0.767**	**0.024**	**0.830**
Molybdenum	7439-98-7	0.001	mg/L	**0.002**	**0.007**	<0.001	**0.002**	<0.001
Neodymium	7440-00-8	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	7440-02-0	0.001	mg/L	<0.001	**0.005**	**0.003**	**0.001**	**0.005**
Praseodymium	7440-10-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Rubidium	7440-17-7	0.001	mg/L	**0.024**	**0.042**	**0.027**	**0.024**	**0.043**
Samarium	7440-19-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
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	**0.062**	**0.766**	**0.136**	**1.21**	**0.079**
Tellurium	22541-49-7	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Terbium	7440-27-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Thallium	7440-28-0	0.001	mg/L	<0.001	**0.002**	**0.002**	<0.001	<0.001
Thorium	7440-29-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Thulium	7440-30-4	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Tin	7440-31-5	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Titanium	7440-32-6	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Uranium	7440-61-1	0.001	mg/L	<0.001	**0.004**	<0.001	<0.001	<0.001
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Ytterbium	7440-64-4	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Yttrium	7440-65-5	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc	7440-66-6	0.005	mg/L	<0.005	**0.032**	**0.017**	<0.005	**0.032**
Zirconium	7440-67-7	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Boron	7440-42-8	0.05	mg/L	**0.06**	**0.06**	**0.11**	**0.16**	**0.12**
Iron	7439-89-6	0.05	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05
EK040P: Fluoride by PC Titrator								

Analytical Results

Sub-Matrix: **DI WATER LEACHATE** (Matrix: **WATER**)				Sample ID	2021044_C016	2021044_C017	2021044_C018	2021044_C019	2021044_C020
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	*CAS Number*	*LOR*	*Unit*		**EB2201374-016**	**EB2201374-017**	**EB2201374-018**	**EB2201374-019**	**EB2201374-020**
					Result	Result	Result	Result	Result
EK040P: Fluoride by PC Titrator - Continued									
Fluoride	16984-48-8	0.1	mg/L		**3.0**	**1.6**	<0.1	**1.2**	**0.1**

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)			Sample ID	2021044_C021	2021044_C022	2021044_C023	2021044_C024	----
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	----
Compound	CAS Number	LOR	Unit	EB2201374-021	EB2201374-022	EB2201374-023	EB2201374-024	--------
				Result	Result	Result	Result	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**5.93**	**6.01**	**6.56**	**6.20**	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**795**	**295**	**486**	**83**	----
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**	**6**	**71**	**3**	----
Total Alkalinity as CaCO3	----	1	mg/L	**5**	**6**	**71**	**3**	----
ED038: Acidity								
Acidity as CaCO3	----	1	mg/L	**16**	**8**	**21**	**7**	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**125**	**52**	<5	**18**	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**88**	**11**	**31**	**2**	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**35**	**14**	**26**	**2**	----
Magnesium	7439-95-4	1	mg/L	**26**	**6**	**26**	**2**	----
Sodium	7440-23-5	1	mg/L	**21**	<1	**8**	<1	----
Potassium	7440-09-7	1	mg/L	**49**	**31**	**52**	**13**	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	**0.36**	**0.22**	**1.42**	**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	**0.004**	**0.004**	**0.014**	**0.003**	----
Beryllium	7440-41-7	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Barium	7440-39-3	0.001	mg/L	**0.057**	**0.046**	**0.092**	**0.024**	----
Bismuth	7440-69-9	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	----
Cerium	7440-45-1	0.001	mg/L	**0.001**	<0.001	**0.009**	**0.002**	----
Caesium	7440-46-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Chromium	7440-47-3	0.001	mg/L	**0.001**	<0.001	**0.003**	**0.001**	----
Cobalt	7440-48-4	0.001	mg/L	**0.013**	**0.004**	**0.010**	**0.002**	----
Copper	7440-50-8	0.001	mg/L	**0.008**	**0.008**	**0.026**	**0.006**	----
Dysprosium	7429-91-6	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Erbium	7440-52-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)			Sample ID	2021044_C021	2021044_C022	2021044_C023	2021044_C024	----
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	----
Compound	CAS Number	LOR	Unit	EB2201374-021	EB2201374-022	EB2201374-023	EB2201374-024	--------
				Result	Result	Result	Result	----
EG020F: Dissolved Metals by ICP-MS - Continued								
Europium	7440-53-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Gadolinium	7440-54-2	0.001	mg/L	<0.001	<0.001	**0.001**	<0.001	----
Gallium	7440-55-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Hafnium	7440-58-6	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----
Holmium	7440-60-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Lanthanum	7439-91-0	0.001	mg/L	<0.001	<0.001	**0.003**	<0.001	----
Lead	7439-92-1	0.001	mg/L	**0.002**	**0.002**	**0.004**	**0.001**	----
Lithium	7439-93-2	0.001	mg/L	**0.015**	**0.012**	**0.027**	**0.010**	----
Lutetium	7439-94-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Manganese	7439-96-5	0.001	mg/L	**2.16**	**0.428**	**0.665**	**0.125**	----
Molybdenum	7439-98-7	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Neodymium	7440-00-8	0.001	mg/L	<0.001	<0.001	**0.005**	**0.002**	----
Nickel	7440-02-0	0.001	mg/L	**0.007**	**0.028**	**0.010**	**0.003**	----
Praseodymium	7440-10-0	0.001	mg/L	<0.001	<0.001	**0.001**	<0.001	----
Rubidium	7440-17-7	0.001	mg/L	**0.068**	**0.031**	**0.032**	**0.010**	----
Samarium	7440-19-9	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	----
Silver	7440-22-4	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Strontium	7440-24-6	0.001	mg/L	**0.131**	**0.054**	**0.118**	**0.010**	----
Tellurium	22541-49-7	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	----
Terbium	7440-27-9	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Thallium	7440-28-0	0.001	mg/L	**0.002**	<0.001	<0.001	<0.001	----
Thorium	7440-29-1	0.001	mg/L	<0.001	<0.001	**0.003**	<0.001	----
Thulium	7440-30-4	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Tin	7440-31-5	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Titanium	7440-32-6	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----
Uranium	7440-61-1	0.001	mg/L	<0.001	<0.001	**0.001**	<0.001	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----
Ytterbium	7440-64-4	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Yttrium	7440-65-5	0.001	mg/L	<0.001	<0.001	**0.004**	**0.002**	----
Zinc	7440-66-6	0.005	mg/L	**0.087**	**0.038**	**0.056**	**0.028**	----
Zirconium	7440-67-7	0.005	mg/L	<0.005	<0.005	**0.017**	<0.005	----
Boron	7440-42-8	0.05	mg/L	**0.11**	**0.12**	**0.14**	**0.08**	----
Iron	7439-89-6	0.05	mg/L	**0.13**	**0.06**	**0.92**	<0.05	----
EK040P: Fluoride by PC Titrator								

Analytical Results

Sub-Matrix: **DI WATER LEACHATE** (Matrix: **WATER**)				Sample ID	**2021044_C021**	**2021044_C022**	**2021044_C023**	**2021044_C024**	**----**
				Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	----
Compound	*CAS Number*	*LOR*	*Unit*		**EB2201374-021**	**EB2201374-022**	**EB2201374-023**	**EB2201374-024**	**--------**
					Result	Result	Result	Result	----
EK040P: Fluoride by PC Titrator - Continued									
Fluoride	16984-48-8	0.1	mg/L		**0.1**	<0.1	**0.1**	<0.1	**----**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Sample ID	2021044_C001	2021044_C002	2021044_C006	2021044_C007	2021044_C008
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2201374-001	EB2201374-002	EB2201374-006	EB2201374-007	EB2201374-008
				Result	Result	Result	Result	Result
EA026 : Chromium Reducible Sulfur								
Chromium Reducible Sulphur	----	0.005	%	**0.012**	**0.012**	**0.017**	**0.020**	**0.013**

Analytical Results

Sub-Matrix: **SOIL** (Matrix: **SOIL**)			Sample ID	2021044_C009	2021044_C012	2021044_C015	2021044_C017	2021044_C018
			Sampling date / time	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00	22-Nov-2021 00:00
Compound	CAS Number	LOR	Unit	EB2201374-009	EB2201374-012	EB2201374-015	EB2201374-017	EB2201374-018
				Result	Result	Result	Result	Result
EA026 : Chromium Reducible Sulfur								
Chromium Reducible Sulphur	----	0.005	%	**0.020**	**0.030**	**0.116**	**0.197**	<0.005

7.7 Attachment G: Trilab Laboratory Certificate of Analyses

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EMERSON CLASS NUMBER TEST REPORT

Test Method: AS 1289 3.8.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120203-EM
		Workorder No.	9366
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	06/01/2022
		Report Date	18/01/2022
Project	2021044 - LLM RMSAP2		

Sample No.	21120203	21120204	21120205	21120206	21120207	21120208	21120209
Client ID	26 - 2021044_0022	27 - 2021044_0023	28 - 2021044_0024	29 - 2021044_0025	30 - 2021044_0026	31 - 2021044_0027	32 - 2021044_0028
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
Description	Silty CLAY - red/brown	Silty CLAY - red	Clayey SILT - brown	Clayey SILT - brown	SILT - brown	SILT - brown	SILT - brown
Emerson Class Number	**2**	**3***	**2**	**3**	**3**	**3**	**3**

Sample No.	21120210	21120211	21120212	21120214	21120216	21120217	21120218
Client ID	33 - 2021044_0029	34 - 2021044_0030	35 - 2021044_0031	37 - 2021044_0032	39 - 2021044_0033	40 - 2021044_0034	41 - 2021044_0035
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
Description	SILT - red/brown	Clayey SILT - red	SILT - red/brown	SILT - red/brown	SILT - brown	SILT - red/white	SILT - red/brown
Emerson Class Number	**4 (Gypsum)**	**3**	**2**	**2**	**2**	**4 (Gypsum)**	**3**

Sample No.	21120219	21120220	21120221	21120222	21120223	21120224	21120225
Client ID	42 - 2021044_0036	43 - 2021044_0037	44 - 2021044_0038	45 - 2021044_0039	46 - 2021044_0040	47 - 2021044_0041	48 - 2021044_0042
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
Description	SILT - brown	SILT - brown/red	SILT - brown/red	SILT - brown	SILT - pale brown	SILT - brown	SILT - pale brown
Emerson Class Number	**3***	**3**	**3**	**3***	**3**	**3**	**4 (Gypsum)**

NOTES/REMARKS: * Specimen did not contain any +2.36mm particles to form air dried crumbs to conduct 1st stage of Test.

Sample/s supplied by the client Tested with Distilled water at 21.9°C

Accredited for compliance with ISO/IEC 17025 - Testing.
The results of the tests, calibrations, and/or measurements included in this document are traceable to Australian/National Standards.

Tested at Trilab Brisbane Laboratory

Authorised Signatory



Joshua Hawley

NATA ACCREDITED FOR TECHNICAL COMPETENCE

Laboratory No. 9926

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Trilab Pty Ltd ABN 25 065 630 506

ACCURATE QUALITY RESULTS FOR TOMORROW'S ENGINEERING

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EMERSON CLASS NUMBER TEST REPORT

Test Method: AS 1289 3.8.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120226-EM
		Workorder No.	9366
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	06/01/2022
		Report Date	18/01/2022
Project	2021044 - LLM RMSAP2		

Sample No.	21120226	21120227	21120228	21120229	21120230	21120231	21120232
Client ID	49 - 2021044_0043	50 - 2021044_0044	51 - 2021044_0045	52 - 2021044_0046	53 - 2021044_0047	54 - 2021044_0047	55 - 2021044_0048
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
Description	SILT - pale brown	SILT - pale brown	SILT - brown	Silty CLAY - brown	SILT - brown	Sandy SILT - brown	SILT - brown
Emerson Class Number	**4 (Gypsum)**	**3**	**6**	**6**	**3**	**3**	**3***

Sample No.	21120233	21120234	21120235	21120236	21120237	21120238	-
Client ID	56 - 2021044_0049	57 - 2021044_0050	58 - 2021044_0051	59 - 2021044_0052	60 - 2021044_0053	61 - 2021044_0054	-
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	-
Description	SILT - brown	SILT - brown	SILT - pale brown	SILT - brown	SILT - brown	SILT - red	-
Emerson Class Number	**3***	**3***	**3***	**3***	**3***	**3**	**-**

Sample No.	-	-	-	-	-	-	-
Client ID	-	-	-	-	-	-	-
Depth (m)	-	-	-	-	-	-	-
Description	-	-	-	-	-	-	-
Emerson Class Number	**-**	**-**	**-**	**-**	**-**	**-**	**-**

NOTES/REMARKS: * Specimen did not contain any +2.36mm particles to form air dried crumbs to conduct 1st stage of Test.

Sample/s supplied by the client Tested with Distilled water at 21.9°C

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Tested at Trilab Brisbane Laboratory

Authorised Signatory



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EMERSON CLASS NUMBER TEST REPORT

Test Method: AS 1289 3.8.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120178-EM
		Workorder No.	9366
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	06/01/2022
		Report Date	18/01/2022
Project	2021044 - LLM RMSAP2		

Sample No.	21120178	21120179	21120180	21120181	21120183	21120185	21120186
Client ID	1 - 2021044_0001	2 - 2021044_0002	3 - 2021044_0003	4 - 2021044_0004	6 - 2021044_0005	8 - 2021044_0006	9 - 2021044_0007
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
Description	Silty CLAY - red	Silty CLAY - red	Silty CLAY - red	Silty CLAY - red	Silty CLAY - red	Silty CLAY - red	Silty SAND - brown
Emerson Class Number	**4 (Gypsum)**	**2**	**2**	**1**	**3***	**3**	**3**

Sample No.	21120187	21120189	21120190	21120191	21120192	21120194	21120195
Client ID	10 - 2021044_0008	12 - 2021044_0009	13 - 2021044_0010	14 - 2021044_0011	15 - 2021044_0012	17 - 2021044_0013	18 - 2021044_0014
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
Description	Silty SAND - brown	Clayey SILT - white	Silty CLAY - brown	Sandy CLAY - brown	SILT - pale brown	SILT - brown	Silty CLAY - brown
Emerson Class Number	**3**	**4 (Gypsum)**	**6***	**4* (Calcite)**	**6***	**3**	**6**

Sample No.	21120196	21120197	21120198	21120199	21120200	21120201	21120202
Client ID	19 - 2021044_0015	20 - 2021044_0016	21 - 2021044_0017	22 - 2021044_0018	23 - 2021044_0019	24 - 2021044_0020	25 - 2021044_0021
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
Description	Clayey SILT - brown	Clayey SILT - brown	Silty CLAY - brown	Silty CLAY - pale brown	SILT - brown	Clayey SILT - pale brown	SILT - brown
Emerson Class Number	**6**	**6**	**2**	**2**	**3**	**3**	**3**

NOTES/REMARKS: * Specimen did not contain any +2.36mm particles to form air dried crumbs to conduct 1st stage of Test.

Sample/s supplied by the client Tested with Distilled water at 21.9°C

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Authorised Signatory



Joshua Hawley

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POINT LOAD TEST REPORT

Test Method: AS 4133.4.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120211-PL
		Workorder No.	0009366
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	20/12/2021
		Report Date	21/12/2021
Project	2021044 - LLM RMSAP2		

Sample No.	21120211	21120213	21120215	21120217	21120218	21120220	21120221
Client ID	34 - 2021044_0030	36 - 2021044_0031	38 - 2021044_0032	40 - 2021044_0034	41 - 2021044_0035	43 - 2021044_0037	44 - 2021044_0038
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
I_s (MPa)	0.35	0.57	0.36	0.90	1.05	0.83	1.80
$I_{s(50)}$ (MPa)	0.39	0.66	0.39	0.93	1.11	0.91	1.90
Load Direction	Irregular Lump	Irregular Lump	Irregular Lump	Irregular Lump	Irregular Lump	Irregular Lump	Irregular Lump

Sample No.	21120224	21120231					
Client ID	47 - 2021044_0041	54 - 2021044_0047					
Depth (m)	Not Supplied	Not Supplied					
I_s (MPa)	0.45	0.13					
$I_{s(50)}$ (MPa)	0.46	0.14					
Load Direction	Irregular Lump	Irregular Lump					

NOTES/REMARKS: Tested as received + Irregular Lump

Sample/s supplied by the client

Accredited for compliance with ISO/IEC 17025 - Testing.
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Tested at Trilab Brisbane Laboratory

Authorised Signatory

J. Rasmussen

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Laboratory No. 9926

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POINT LOAD TEST REPORT

Test Method: AS 4133.4.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120182-PL
		Workorder No.	0009366
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	20/12/2021
		Report Date	21/12/2021
Project	2021044 - LLM RMSAP2		

Sample No.	21120182	21120184	21120185	21120188	21120189	21120193	21120196
Client ID	5 - 2021044_0004	7 - 2021044_0005	8 - 2021044_0006	11 - 2021044_0008	12 - 2021044_0009	16 - 2021044_0012	19 - 2021044_0015
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
I_S (MPa)	0.10	0.42	0.14	0.69	0.64	0.13	0.06
$I_{S(50)}$ (MPa)	0.10	0.40	0.14	0.70	0.69	0.14	0.06
Load Direction	Irregular Lump	Irregular Lump	Irregular Lump	Irregular Lump	Irregular Lump	Irregular Lump	Irregular Lump

Sample No.	21120197	21120200	21120201	21120202	21120205	21120206	21120209
Client ID	20 - 2021044_0016	23 - 2021044_0019	24 - 2021044_0020	25 - 2021044_0021	28 - 2021044_0024	29 - 2021044_0025	32 - 2021044_0028
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
I_S (MPa)	0.78	0.35	0.43	0.16	0.21	0.18	1.52
$I_{S(50)}$ (MPa)	0.87	0.38	0.42	0.18	0.22	0.20	1.48
Load Direction	Irregular Lump	Irregular Lump	Irregular Lump	Irregular Lump	Irregular Lump	Irregular Lump	Irregular Lump

NOTES/REMARKS: Tested as received + Irregular Lump

Sample/s supplied by the client

Accredited for compliance with ISO/IEC 17025 - Testing.
The results of the tests, calibrations, and/or measurements included in this document are traceable to Australian/National Standards.

Tested at Trilab Brisbane Laboratory

Authorised Signatory

J. Rasmussen

NATA ACCREDITED FOR TECHNICAL COMPETENCE

Laboratory No. 9926

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ATTERBERG LIMITS TEST REPORT

Test Methods: AS 1289 2.1.1, 3.2.1, 3.3.1, 3.4.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120151-AL
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Report Date**	12/01/2022
Project	2021044 - LLM RMSAP2		

Sample No.	21120151	21120152	21120155	21120156	21120158	21120159
Liquid Limit Determination	AS 1289.3.1.2	AS 1289.3.1.2	AS 1289.3.1.2	AS 1289.3.1.2	AS 1289.3.1.2	AS 1289.3.1.2
Test Date	18/12/2021	18/12/2021	18/12/2021	18/12/2021	18/12/2021	18/12/2021
Client ID	1 - 2021044_C001	2 - 2021044_C002	5 - 2021044_C005	6 - 2021044_C006	8 - 2021044_C008	9 - 2021044_C009
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
Liquid Limit (%)	24	29	25	31	28	39
Plastic Limit (%)	13	11	11	13	10	11
Plasticity Index (%)	11	18	14	18	18	28
Linear Shrinkage (%)	2.0	8.0	6.5	7.0	7.5	11.0
Moisture Content (%)	9.4	9.4	11.3	8.1	10.7	8.3

Sample No.	21120162	21120165	21120167	21120168	21120170	21120171
Liquid Limit Determination	AS 1289.3.1.2	AS 1289.3.1.2	AS 1289.3.1.2	AS 1289.3.1.2	AS 1289.3.1.2	AS 1289.3.1.2
Test Date	18/12/2021	18/12/2021	18/12/2021	18/12/2021	18/12/2021	18/12/2021
Client ID	12 - 2021044_C012	15 - 2021044_C015	17 - 2021044_C017	18 - 2021044_C018	20 - 2021044_C020	21 - 2021044_C021
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
Liquid Limit (%)	30	27	26	29	27	28
Plastic Limit (%)	19	18	18	13	16	17
Plasticity Index (%)	11	9	8	16	11	11
Linear Shrinkage (%)	2.0	2.0	1.5	7.5	2.5	3.0
Moisture Content (%)	7.4	5.8	5.1	8.3	6.9	5.1

NOTES/REMARKS: The samples were tested oven dried, dry sieved and in a 125-250mm mould.

Sample/s supplied by the client * Cracking occurred + Curling occurred

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Tested at Trilab Brisbane Laboratory

Authorised Signatory

Joshua Hawley

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Laboratory No. 9926

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ATTERBERG LIMITS TEST REPORT

Test Methods: AS 1289 2.1.1, 3.2.1, 3.3.1, 3.4.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120172-AL
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Report Date**	12/01/2022
Project	2021044 - LLM RMSAP2		

Sample No.	21120172	21120173	21120174			
Liquid Limit Determination	AS 1289.3.1.2	AS 1289.3.1.2	AS 1289.3.1.2			
Test Date	18/12/2021	18/12/2021	18/12/2021			
Client ID	22 - 2021044_C022	23 - 2021044_C023	24 - 2021044_C024			
Depth (m)	Not Supplied	Not Supplied	Not Supplied			
Liquid Limit (%)	26	37	23			
Plastic Limit (%)	16	21	15			
Plasticity Index (%)	10	16	8			
Linear Shrinkage (%)	2.0	4.5	2.5			
Moisture Content (%)	6.2	9.0	9.3			

Sample No.						
Liquid Limit Determination						
Test Date						
Client ID						
Depth (m)						
Liquid Limit (%)						
Plastic Limit (%)						
Plasticity Index (%)						
Linear Shrinkage (%)						
Moisture Content (%)						

NOTES/REMARKS: The samples were tested oven dried, dry sieved and in a 125-250mm mould.

Sample/s supplied by the client * Cracking occurred + Curling occurred

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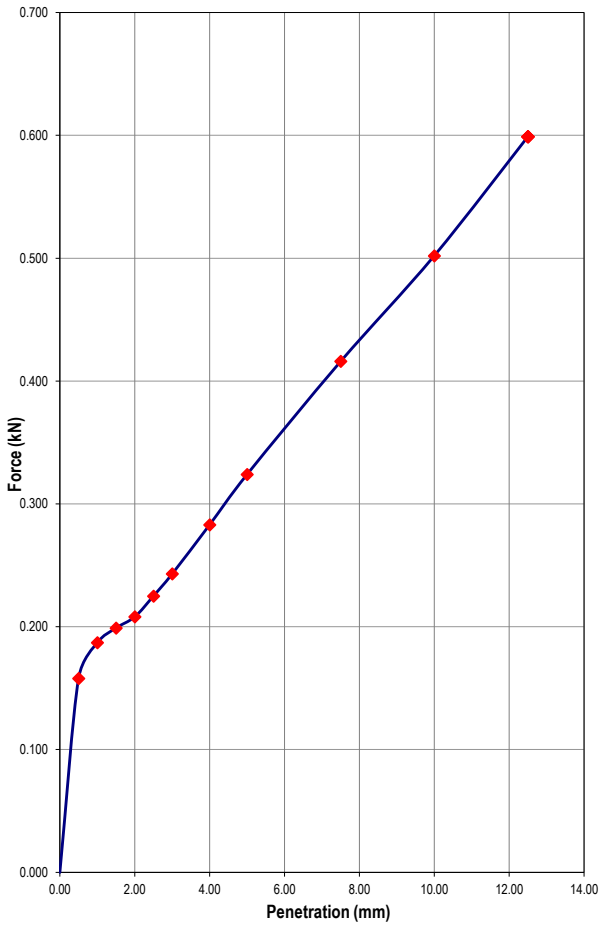
Test Method: AS 1289.6.1.1 & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120151-CBR
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/12/2021
		Report Date	22/12/2021
Project	2021044 - LLM RMSAP2		

Test Results

Sample No.	21120151
Client ID	1 - 2021044_C001
Depth (m)	Not Supplied
Description	Gravelly Clayey SILT - brown
Compaction Criteria	Standard
Curing Time of Specimen	24 hrs - based on visual/tactile assessment of material.
Condition of Specimen	Soaked
Surcharge (kg)	4.5
Period of Soak (Days)	4
Percentage Retained 19 mm (%) (Not Included in Sample)	3.8
Field Moisture Content (%)	9.4
Moisture Content of Top 30 mm (%)	17.5
Swell (%)	0.1
Laboratory Moisture Ratio (%)	100.4
Laboratory Density Ratio (%)	90.0
Optimum Moisture Content (%)	12.5
Maximum Dry Density (t/m^3)	1.86

Force v's Penetration



	CBR Penetration (mm)	**2.5**	
	CBR VALUE	**1.5**	

Notes/Remarks :

Sample/s supplied by the client

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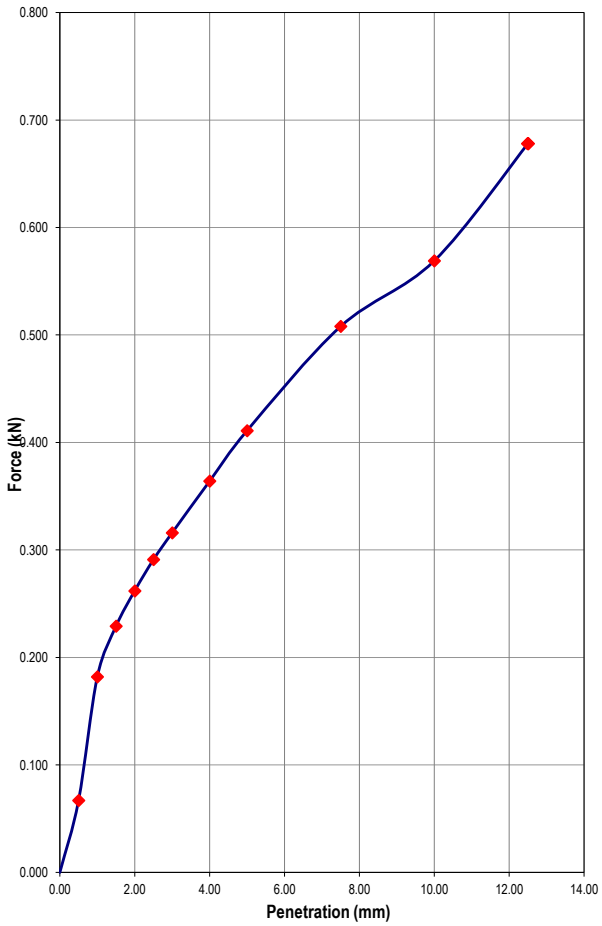
Test Method: AS 1289.6.1.1 & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120152-CBR
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/12/2021
		Report Date	22/12/2021
Project	2021044 - LLM RMSAP2		

Test Results

Sample No.	21120152
Client ID	2 - 2021044_C002
Depth (m)	Not Supplied
Description	Sandy SILT with gravel - brown
Compaction Criteria	Standard
Curing Time of Specimen	24 hrs - based on visual/tactile assessment of material.
Condition of Specimen	Soaked
Surcharge (kg)	4.5
Period of Soak (Days)	4
Percentage Retained 19 mm (%) (Not Included in Sample)	1
Field Moisture Content (%)	9.4
Moisture Content of Top 30 mm (%)	19.4
Swell (%)	0.3
Laboratory Moisture Ratio (%)	100.7
Laboratory Density Ratio (%)	90.0
Optimum Moisture Content (%)	12.9
Maximum Dry Density (t/m^3)	1.83

Force v's Penetration



	CBR Penetration (mm)	**2.5**	
	CBR VALUE	**2.5**	

Notes/Remarks :

Sample/s supplied by the client

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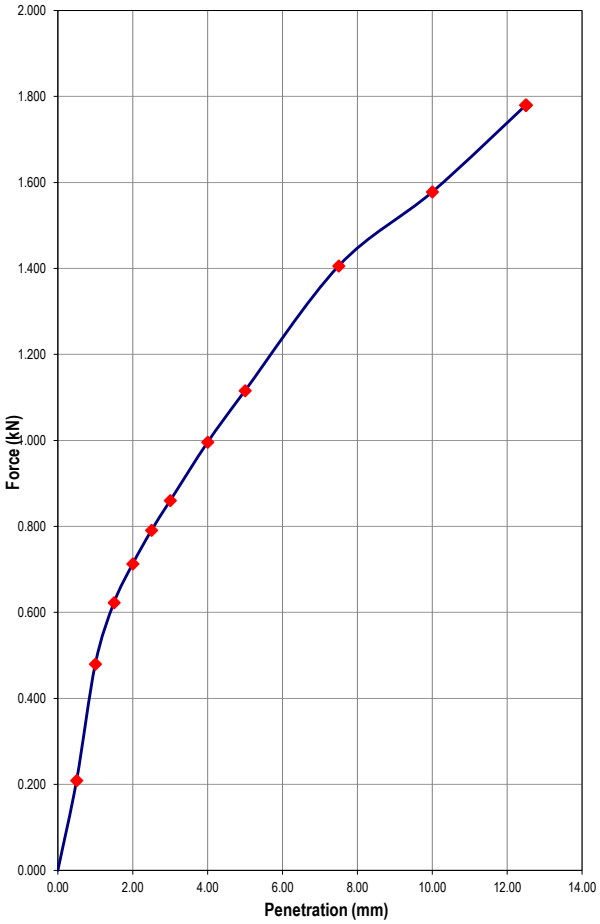
Test Method: AS 1289.6.1.1 & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120153-CBR
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/12/2021
		Report Date	22/12/2021
Project	2021044 - LLM RMSAP2		

Test Results

Sample No.	21120153
Client ID	3 - 2021044_C003
Depth (m)	Not Supplied
Description	Sandy SILT - brown/white
Compaction Criteria	Standard
Curing Time of Specimen	48 hrs - based on visual/tactile assessment of material.
Condition of Specimen	Soaked
Surcharge (kg)	4.5
Period of Soak (Days)	4
Percentage Retained 19 mm (%) (Not Included in Sample)	0
Field Moisture Content (%)	6.8
Moisture Content of Top 30 mm (%)	21.5
Swell (%)	-0.1
Laboratory Moisture Ratio (%)	100.1
Laboratory Density Ratio (%)	89.9
Optimum Moisture Content (%)	15.1
Maximum Dry Density (t/m^3)	1.71

Force v's Penetration



	CBR Penetration (mm)	**2.5**	
	CBR VALUE	**6**	

Notes/Remarks :

Sample/s supplied by the client

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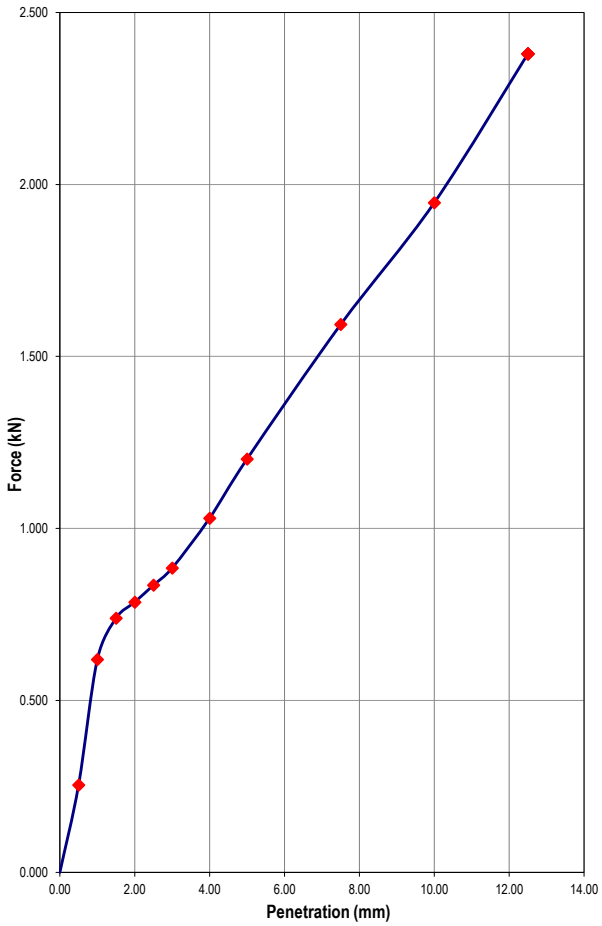
Test Method: AS 1289.6.1.1 & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120154-CBR
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/12/2021
		Report Date	22/12/2021
Project	2021044 - LLM RMSAP2		

Test Results

Sample No.	21120154
Client ID	4 - 2021044_C004
Depth (m)	Not Supplied
Description	Sandy SILT - brown/white
Compaction Criteria	Standard
Curing Time of Specimen	24 hrs - based on visual/tactile assessment of material.
Condition of Specimen	Soaked
Surcharge (kg)	4.5
Period of Soak (Days)	4
Percentage Retained 19 mm (%) (Not Included in Sample)	0
Field Moisture Content (%)	6.1
Moisture Content of Top 30 mm (%)	21.8
Swell (%)	0.0
Laboratory Moisture Ratio (%)	100.6
Laboratory Density Ratio (%)	89.9
Optimum Moisture Content (%)	15.1
Maximum Dry Density (t/m^3)	1.72

Force v's Penetration



	CBR Penetration (mm)	**2.5**	
	CBR VALUE	**6**	

Notes/Remarks :

Sample/s supplied by the client

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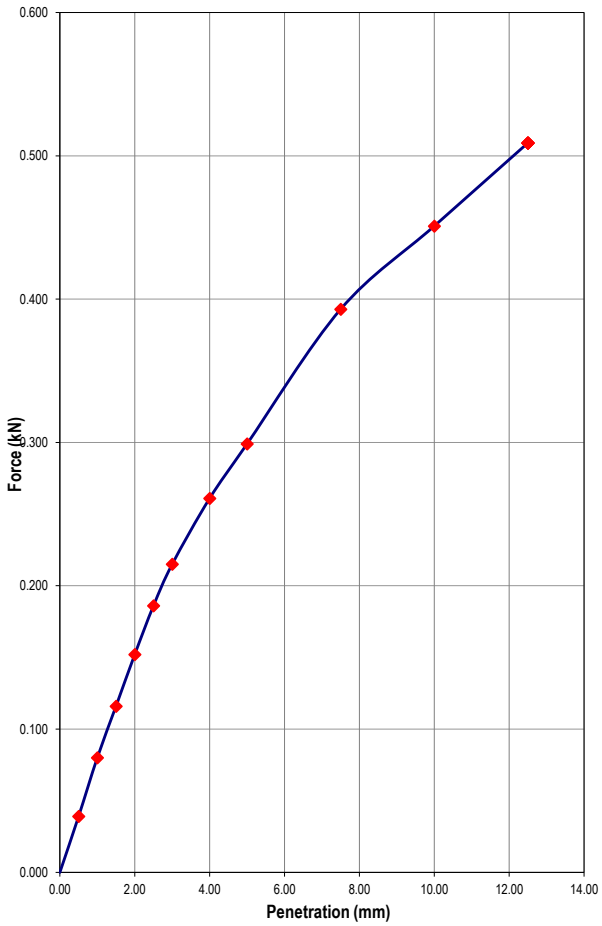
Test Method: AS 1289.6.1.1 & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120155-CBR
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/12/2021
		Report Date	22/12/2021
Project	2021044 - LLM RMSAP2		

Test Results

Sample No.	21120155
Client ID	5 - 2021044_C005
Depth (m)	Not Supplied
Description	Gravelly Sandy CLAY - brown
Compaction Criteria	Standard
Curing Time of Specimen	48 hrs - based on visual/tactile assessment of material.
Condition of Specimen	Soaked
Surcharge (kg)	4.5
Period of Soak (Days)	4
Percentage Retained 19 mm (%) (Not Included in Sample)	1.8
Field Moisture Content (%)	11.3
Moisture Content of Top 30 mm (%)	20.2
Swell (%)	0.3
Laboratory Moisture Ratio (%)	99.2
Laboratory Density Ratio (%)	90.1
Optimum Moisture Content (%)	12.5
Maximum Dry Density (t/m^3)	1.93

Force v's Penetration



	CBR Penetration (mm)	**5.0**	
	CBR VALUE	**1.5**	

Notes/Remarks :

Sample/s supplied by the client

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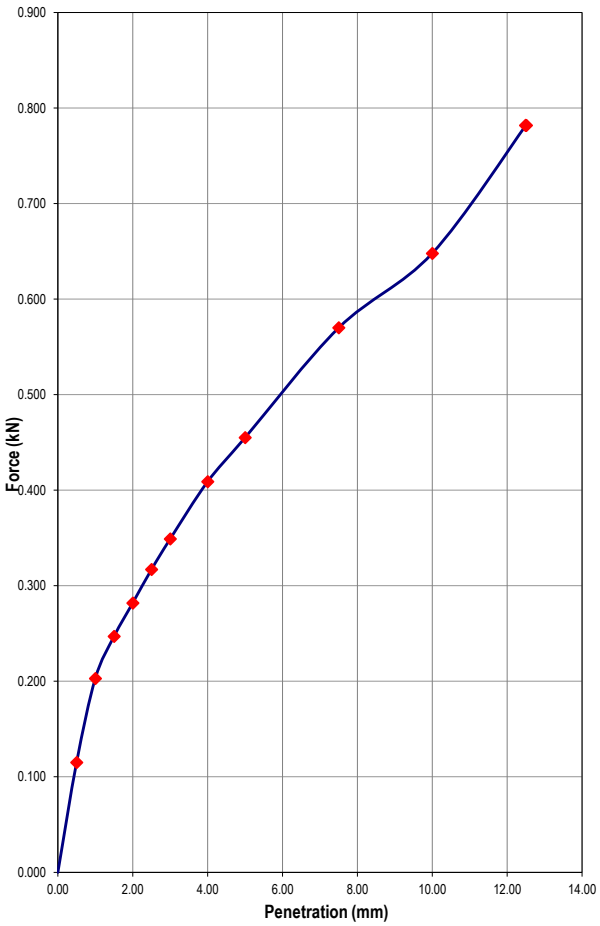
Test Method: AS 1289.6.1.1 & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120156-CBR
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/12/2021
		Report Date	22/12/2021
Project	2021044 - LLM RMSAP2		

Test Results

Sample No.	21120156
Client ID	6 - 2021044_C006
Depth (m)	Not Supplied
Description	Silty CLAY with gravel - brown
Compaction Criteria	Standard
Curing Time of Specimen	48 hrs - based on visual/tactile assessment of material.
Condition of Specimen	Soaked
Surcharge (kg)	4.5
Period of Soak (Days)	4
Percentage Retained 19 mm (%) (Not Included in Sample)	2.1
Field Moisture Content (%)	8.1
Moisture Content of Top 30 mm (%)	21.2
Swell (%)	0.5
Laboratory Moisture Ratio (%)	99.9
Laboratory Density Ratio (%)	90.0
Optimum Moisture Content (%)	13.8
Maximum Dry Density (t/m^3)	1.84

Force v's Penetration



	CBR Penetration (mm)	**2.5**	
	CBR VALUE	**2.5**	

Notes/Remarks :

Sample/s supplied by the client

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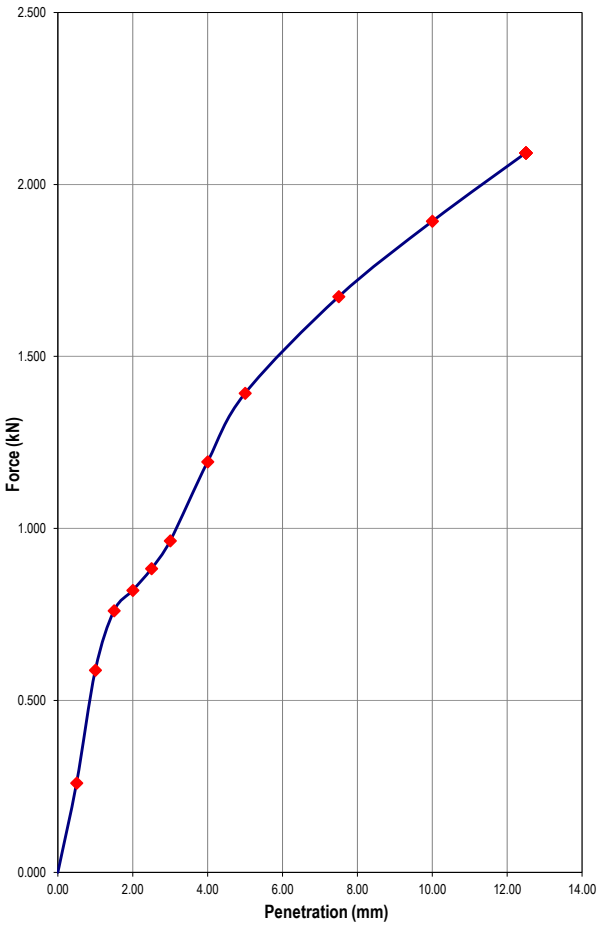
Test Method: AS 1289.6.1.1 & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120160-CBR
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/12/2021
		Report Date	22/12/2021
Project	2021044 - LLM RMSAP2		

Test Results

Sample No.	21120160
Client ID	10 - 2021044_C010
Depth (m)	Not Supplied
Description	SILT trace gravel - pale brown
Compaction Criteria	Standard
Curing Time of Specimen	48 hrs - based on visual/tactile assessment of material.
Condition of Specimen	Soaked
Surcharge (kg)	4.5
Period of Soak (Days)	4
Percentage Retained 19 mm (%) (Not Included in Sample)	31
Field Moisture Content (%)	4.3
Moisture Content of Top 30 mm (%)	21.9
Swell (%)	0.1
Laboratory Moisture Ratio (%)	100.2
Laboratory Density Ratio (%)	90.0
Optimum Moisture Content (%)	16.7
Maximum Dry Density (t/m^3)	1.73

Force v's Penetration



	CBR Penetration (mm)	**5.0**	
	CBR VALUE	**7**	

Notes/Remarks :

Sample/s supplied by the client

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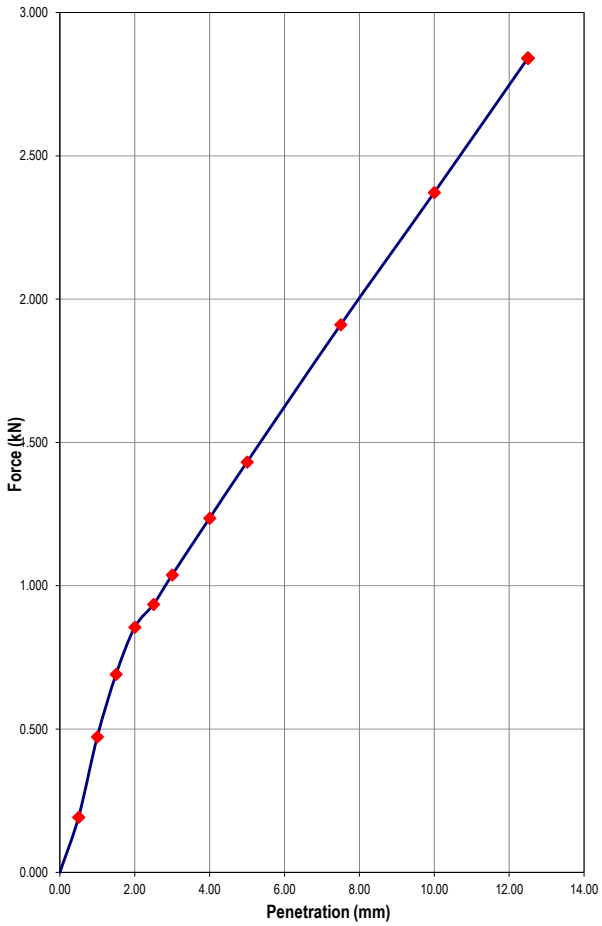
Test Method: AS 1289.6.1.1 & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120161-CBR
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/12/2021
		Report Date	22/12/2021
Project	2021044 - LLM RMSAP2		

Test Results

Sample No.	21120161
Client ID	11 - 2021044_C011
Depth (m)	Not Supplied
Description	SILT trace gravel - brown
Compaction Criteria	Standard
Curing Time of Specimen	48 hrs - based on visual/tactile assessment of material.
Condition of Specimen	Soaked
Surcharge (kg)	4.5
Period of Soak (Days)	4
Percentage Retained 19 mm (%) (Not Included in Sample)	19.8
Field Moisture Content (%)	5.4
Moisture Content of Top 30 mm (%)	22.7
Swell (%)	0.1
Laboratory Moisture Ratio (%)	99.2
Laboratory Density Ratio (%)	90.1
Optimum Moisture Content (%)	17.4
Maximum Dry Density (t/m^3)	1.70

Force v's Penetration



	CBR Penetration (mm)	**5.0**	
	CBR VALUE	**7**	

Notes/Remarks :

Sample/s supplied by the client

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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.1, 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120166-G
		Workorder No.	9363
Address	PO Box 3091, Sunnybank South QLD 4109	**Report Date**	11/01/2022
Project	2021044 - LLM RMSAP2		

Sample No.	21120166	21120169					
Test Date	21/12/2021	15/12/2022					
Client ID	16 - 2021044_C016	19 - 2021044_C019					
Depth (m)	Not Supplied	Not Supplied					
Moisture (%)	3.8	9.7					
AS SIEVE SIZE (mm)	**PERCENT PASSING**						
150							
75							
63							
53		100					
37.5		99					
26.5		97					
19		96					
13.2	100	92					
9.5	97	90					
6.7	87	90					
4.75	82	88					
2.36	74	84					
1.18	50	64					
0.600	39	53					
0.425	36	49					
0.300	33	46					
0.212	32	44					
0.150	29	42					
0.075	24	37					

NOTES/REMARKS:

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ACCURATE QUALITY RESULTS FOR TOMORROW'S ENGINEERING

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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.1, 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120153-G
		Workorder No.	9363
Address	PO Box 3091, Sunnybank South QLD 4109	**Report Date**	11/01/2022
Project	2021044 - LLM RMSAP2		

Sample No.	21120153	21120154	21120157	21120160	21120161	21120163	21120164
Test Date	21/12/2021	21/12/2021	21/12/2021	13/12/2022	14/12/2022	14/12/2022	14/12/2022
Client ID	3 - 2021044_C003	4 - 2021044_C004	7 - 2021044_C007	10 - 2021044_C010	11 - 2021044_C011	13 - 2021044_C013	14 - 2021044_C014
Depth (m)	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied	Not Supplied
Moisture (%)	6.8	6.1	9.0	4.3	5.4	5.0	4.1
AS SIEVE SIZE (mm)	**PERCENT PASSING**						
150			100	100	100	100	100
75			65	93	94	96	69
63			63	90	94	85	55
53			58	85	91	76	51
37.5			54	77	88	72	48
26.5			53	71	82	68	47
19	100	100	53	68	80	67	47
13.2	98	90	50	61	76	62	45
9.5	97	86	49	60	74	58	42
6.7	96	84	48	59	72	54	42
4.75	93	81	47	58	70	52	40
2.36	89	77	46	54	66	49	38
1.18	73	62	35	40	51	36	29
0.600	63	53	29	32	42	30	24
0.425	60	50	27	29	38	28	22
0.300	57	47	26	27	35	26	20
0.212	57	47	25	25	33	26	19
0.150	50	41	23	24	30	24	18
0.075	42	35	21	21	26	21	15

NOTES/REMARKS:

Sample/s supplied by the client

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Tested at Trilab Brisbane Laboratory

Authorised Signatory

Joshua Hawley

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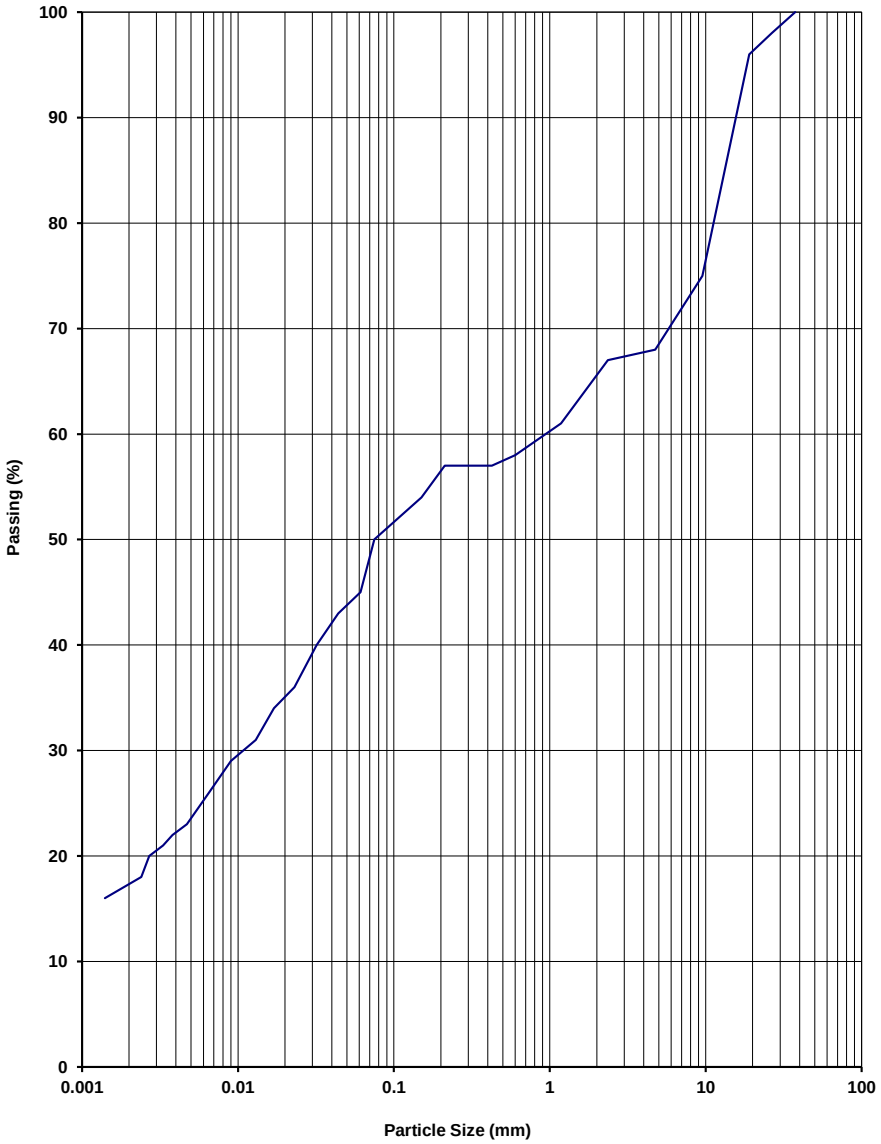
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120151-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	10/12/2021
		Report Date	11/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	1 - 2021044_C001	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	
37.5	100
26.5	98
19.0	96
13.2	83
9.5	75
6.7	71
4.75	68
2.36	67
1.18	61
0.600	58
0.425	57
0.300	57
0.212	57
0.150	54
0.075	50
0.061	45
0.044	43
0.032	40
0.023	36
0.017	34
0.013	31
0.009	29
0.0065	26
0.0047	23
0.0038	22
0.0033	21
0.0027	20
0.0024	18
0.0014	16



NOTES/REMARKS: -

Moisture Content 9.4% -2.36mm Soil Particle Density(t/m^3) 2.59

Sample/s supplied by the client

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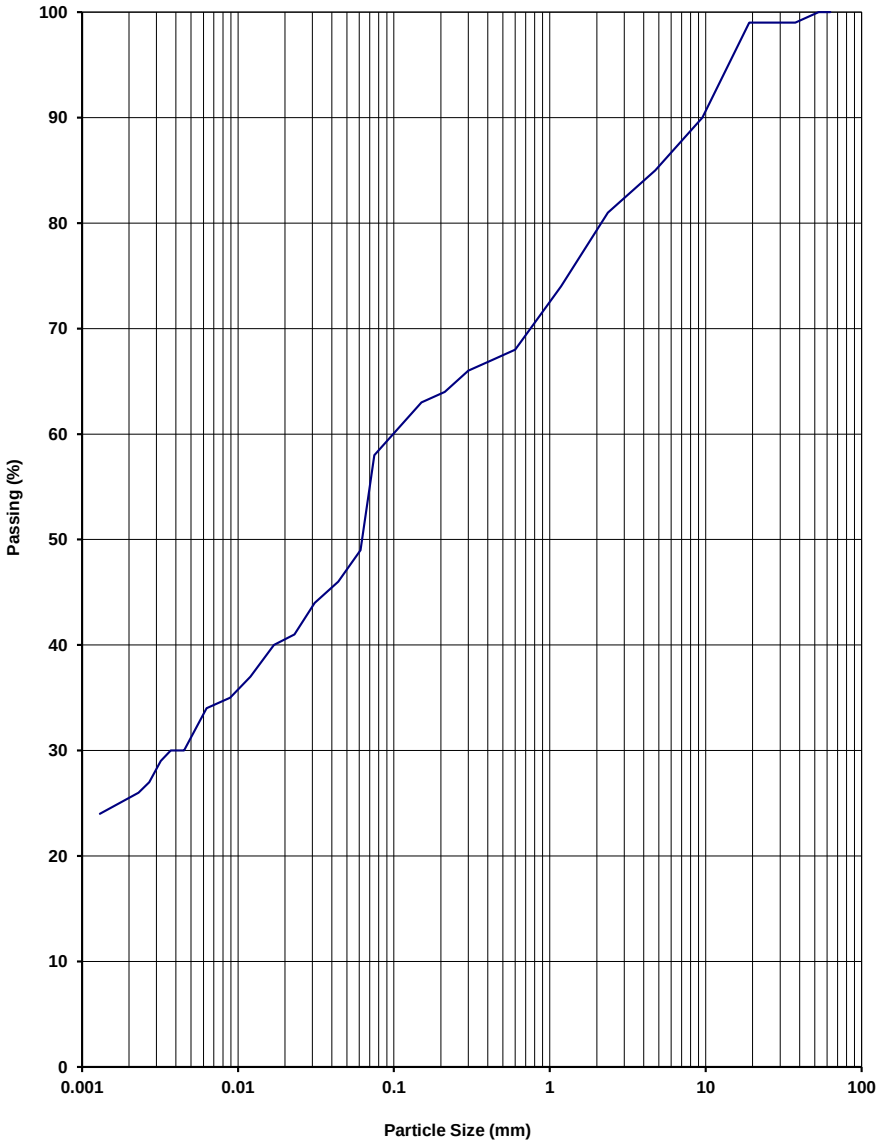
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120152-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	10/12/2021
		Report Date	11/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	2 - 2021044_C002	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	100
37.5	99
26.5	99
19.0	99
13.2	95
9.5	90
6.7	86
4.75	85
2.36	81
1.18	74
0.600	68
0.425	67
0.300	66
0.212	64
0.150	63
0.075	58
0.061	49
0.044	46
0.031	44
0.023	41
0.017	40
0.012	37
0.0089	35
0.0063	34
0.0045	30
0.0037	30
0.0032	29
0.0027	27
0.0023	26
0.0013	24



NOTES/REMARKS: -

Moisture Content 9.4% -2.36mm Soil Particle Density(t/m^3) 2.64

Sample/s supplied by the client

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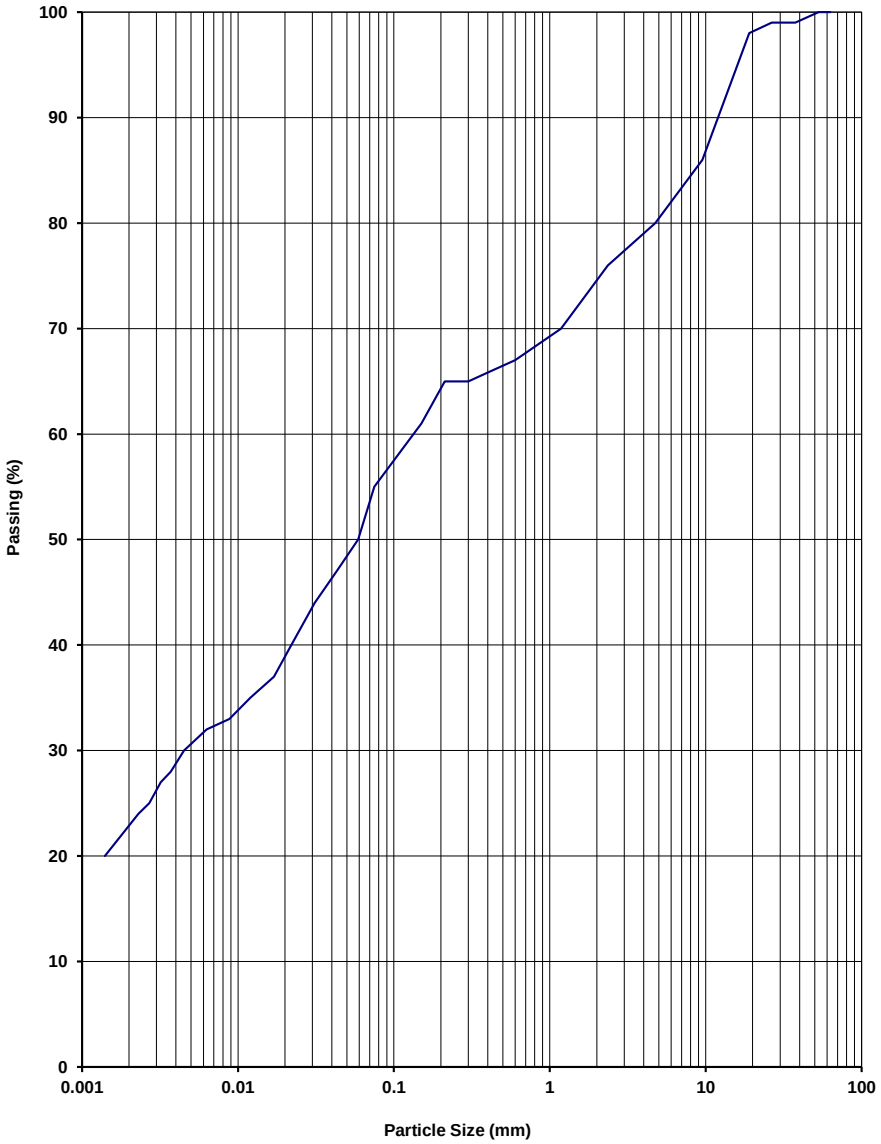
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120155-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	10/12/2021
		Report Date	11/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	5 - 2021044_C005	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	100
37.5	99
26.5	99
19.0	98
13.2	92
9.5	86
6.7	82
4.75	80
2.36	76
1.18	70
0.600	67
0.425	66
0.300	65
0.212	65
0.150	61
0.075	55
0.059	50
0.043	47
0.031	44
0.022	40
0.017	37
0.012	35
0.0088	33
0.0063	32
0.0045	30
0.0037	28
0.0032	27
0.0027	25
0.0023	24
0.0014	20



NOTES/REMARKS: -

Moisture Content 11.3% -2.36mm Soil Particle Density(t/m^3) 2.64

Sample/s supplied by the client

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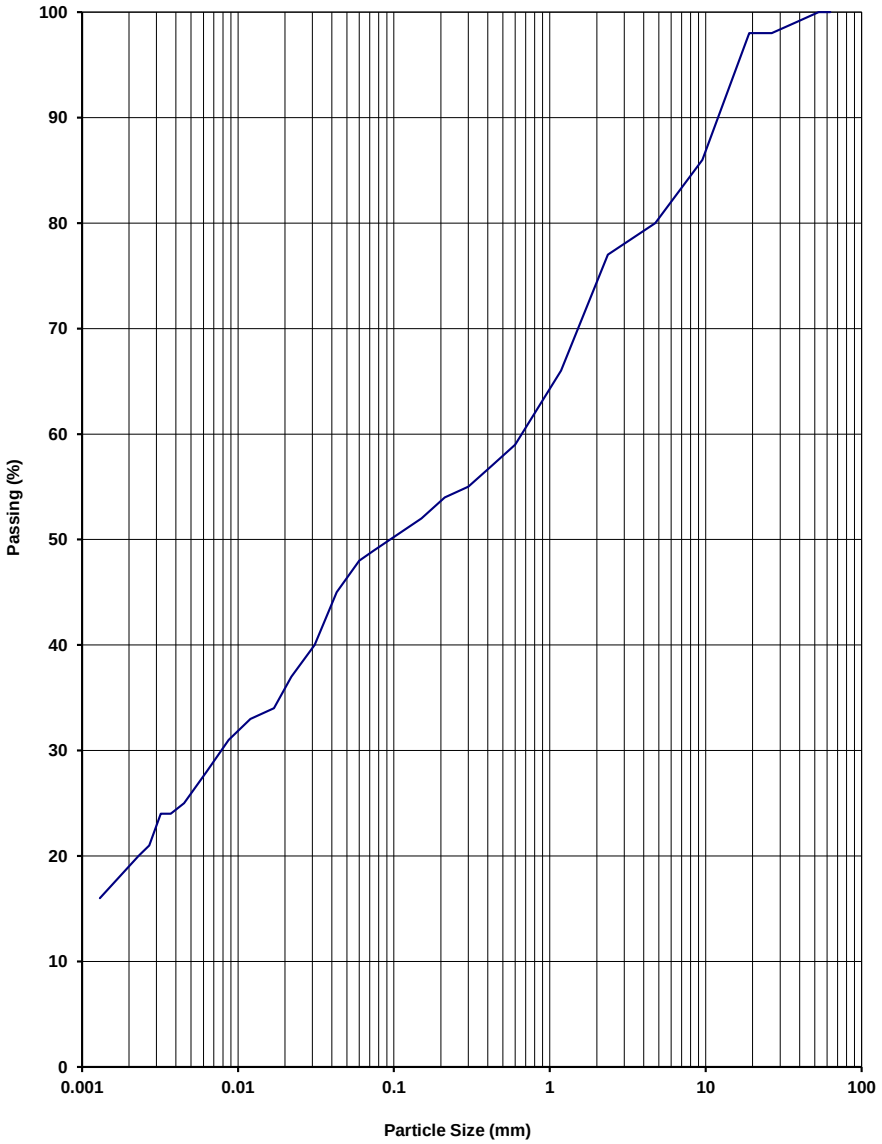
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120156-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	10/12/2021
		Report Date	11/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	6 - 2021044_C006	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	100
37.5	99
26.5	98
19.0	98
13.2	88
9.5	86
6.7	83
4.75	80
2.36	77
1.18	66
0.600	59
0.425	57
0.300	55
0.212	54
0.150	52
0.075	49
0.06	48
0.043	45
0.031	40
0.022	37
0.017	34
0.012	33
0.0087	31
0.0063	28
0.0045	25
0.0037	24
0.0032	24
0.0027	21
0.0023	20
0.0013	16



NOTES/REMARKS: -

Moisture Content 8.1% -2.36mm Soil Particle Density(t/m^3) 2.67

Sample/s supplied by the client

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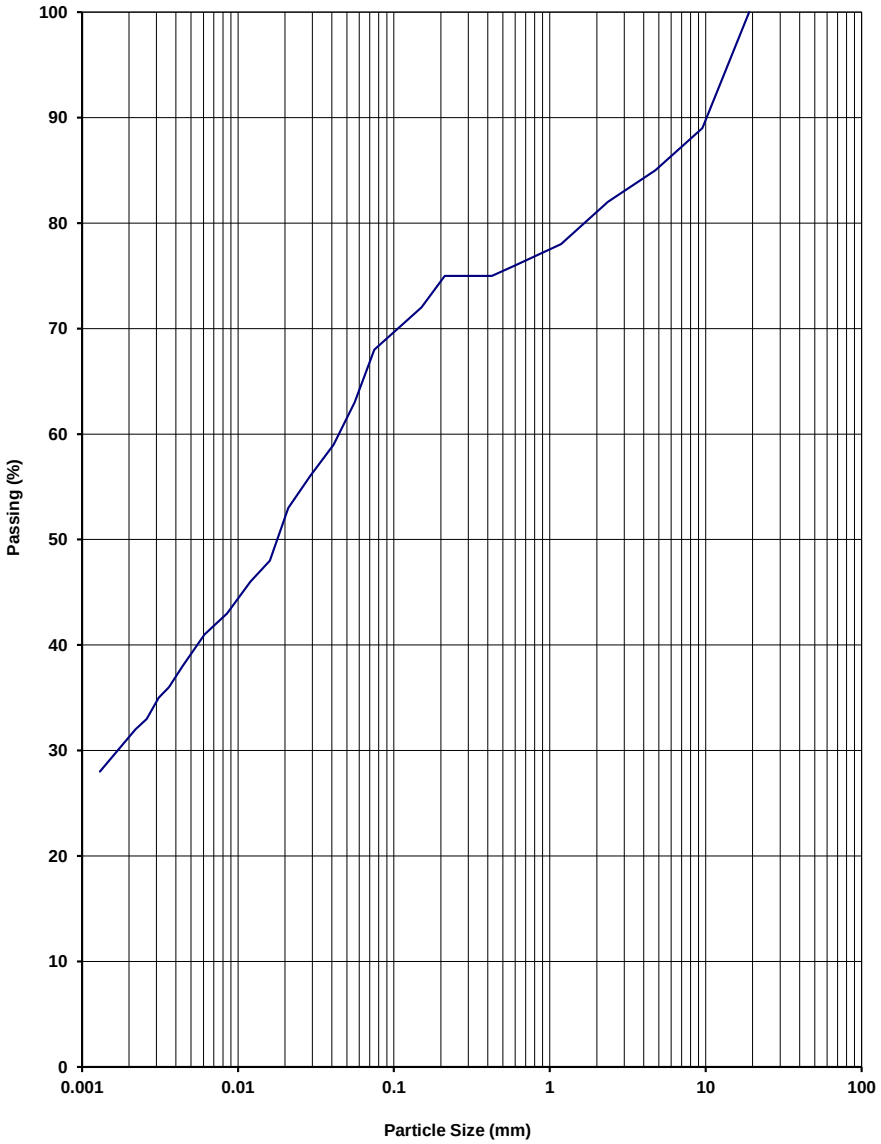
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120158-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	20/12/2021
		Report Date	14/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	8 - 2021044_C008	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	
37.5	
26.5	
19.0	100
13.2	95
9.5	89
6.7	87
4.75	85
2.36	82
1.18	78
0.600	76
0.425	75
0.300	75
0.212	75
0.150	72
0.075	68
0.056	63
0.041	59
0.029	56
0.021	53
0.016	48
0.012	46
0.0085	43
0.0061	41
0.0044	38
0.0036	36
0.0031	35
0.0026	33
0.0022	32
0.0013	28



NOTES/REMARKS: -

Moisture Content 10.7% -2.36mm Soil Particle Density(t/m^3) 2.57

Sample/s supplied by the client

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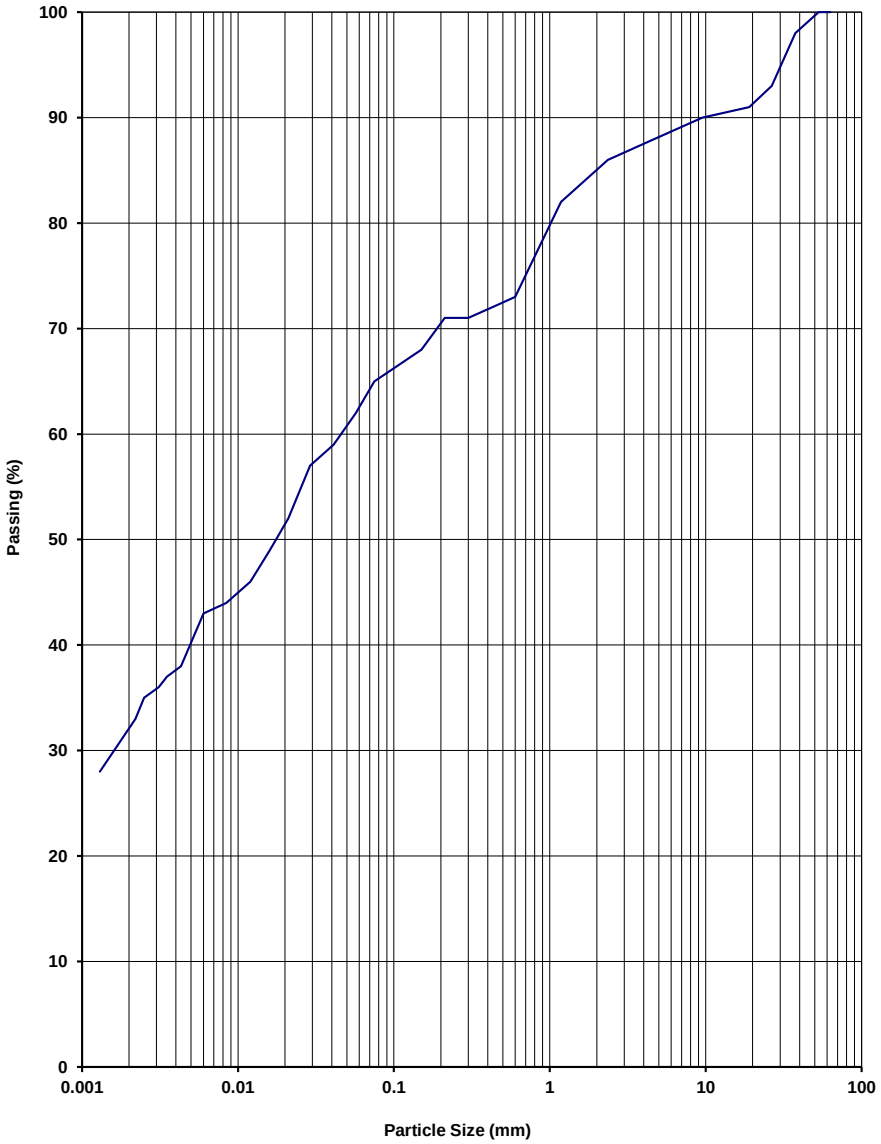
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120159-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	13/12/2021
		Report Date	14/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	9 - 2021044_C009	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	100
37.5	98
26.5	93
19.0	91
13.2	90
9.5	90
6.7	89
4.75	88
2.36	86
1.18	82
0.600	73
0.425	72
0.300	71
0.212	71
0.150	68
0.075	65
0.057	62
0.041	59
0.029	57
0.021	52
0.016	49
0.012	46
0.0084	44
0.006	43
0.0043	38
0.0035	37
0.0031	36
0.0025	35
0.0022	33
0.0013	28



NOTES/REMARKS: -

Moisture Content 8.3% -2.36mm Soil Particle Density(t/m^3) 2.67

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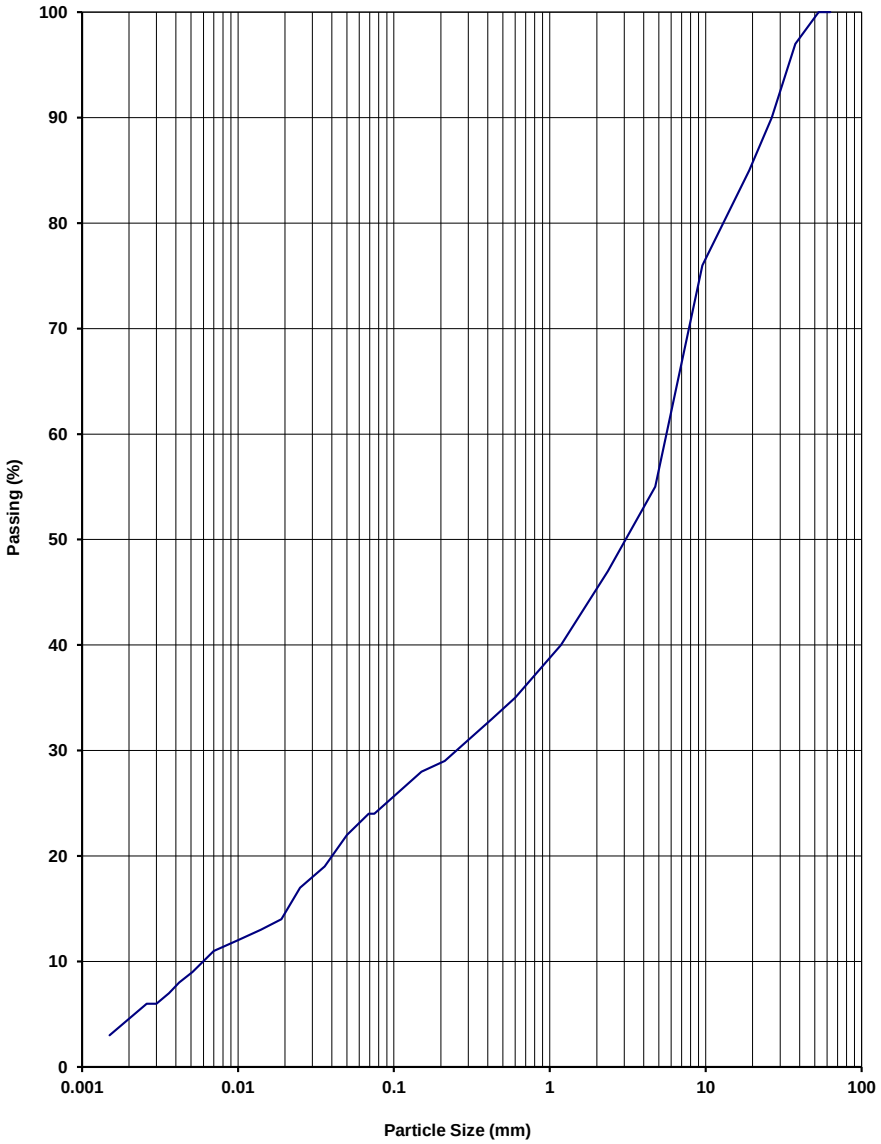
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120162-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	17/12/2021
		Report Date	12/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	12 - 2021044_C012	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	100
37.5	97
26.5	90
19.0	85
13.2	82
9.5	76
6.7	65
4.75	55
2.36	47
1.18	40
0.600	35
0.425	33
0.300	31
0.212	29
0.150	28
0.075	24
0.069	24
0.05	22
0.036	19
0.025	17
0.019	14
0.014	13
0.0099	12
0.007	11
0.0051	9
0.0042	8
0.0036	7
0.003	6
0.0026	6
0.0015	3



NOTES/REMARKS: -

Moisture Content 7.4% -2.36mm Soil Particle Density(t/m^3) 2.50

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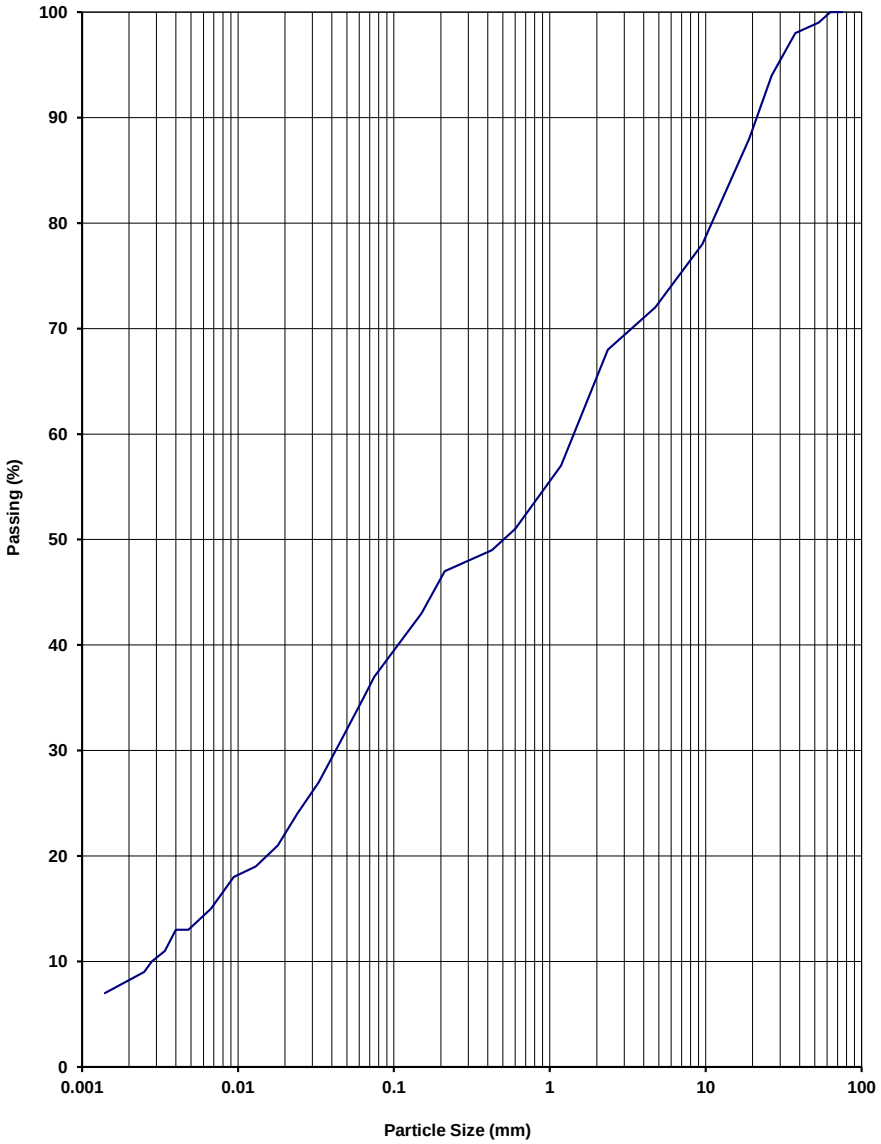
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120165-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	14/12/2021
		Report Date	12/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	15 - 2021044_C015	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	100
53.0	99
37.5	98
26.5	94
19.0	88
13.2	84
9.5	78
6.7	75
4.75	72
2.36	68
1.18	57
0.600	51
0.425	49
0.300	48
0.212	47
0.150	43
0.075	37
0.064	35
0.046	31
0.033	27
0.024	24
0.018	21
0.013	19
0.0094	18
0.0067	15
0.0048	13
0.004	13
0.0034	11
0.0028	10
0.0025	9
0.0014	7



NOTES/REMARKS: -

Moisture Content 5.8% -2.36mm Soil Particle Density(t/m^3) 2.60

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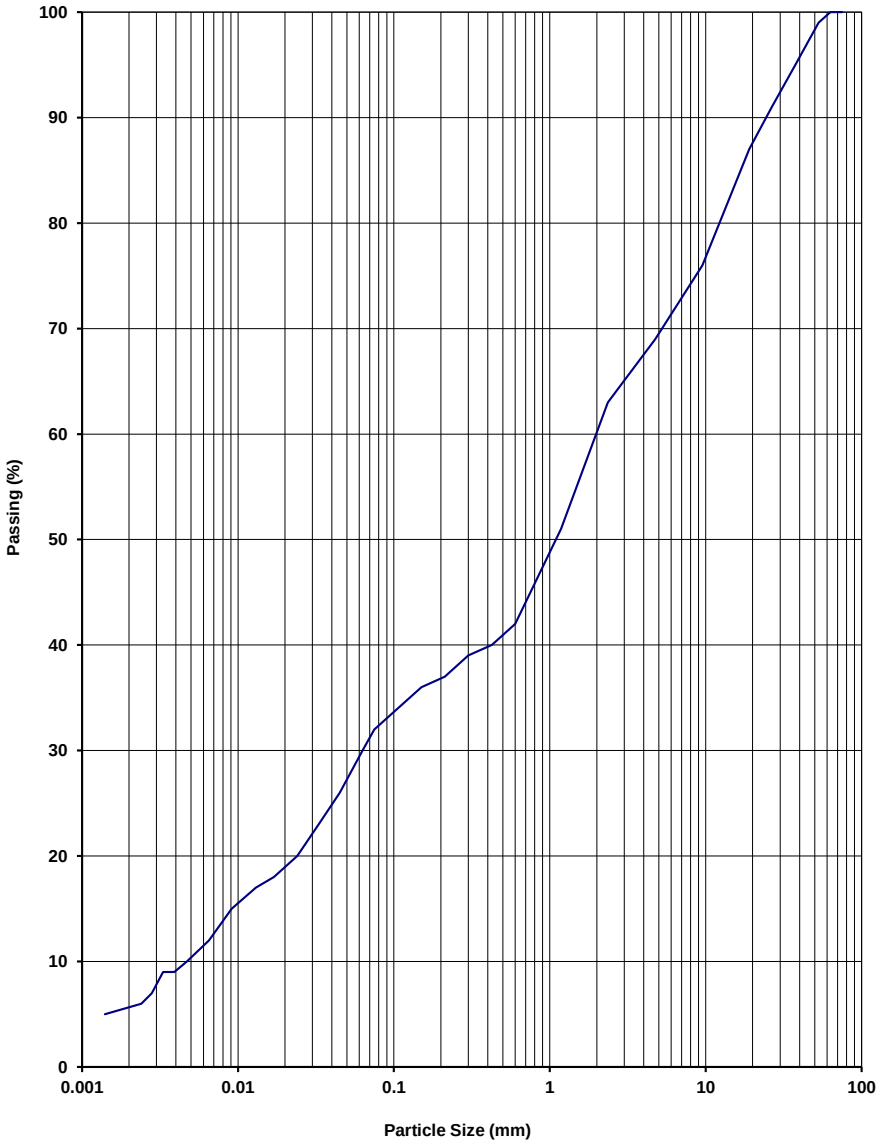
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120167-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	14/12/2021
		Report Date	12/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	17 - 2021044_C017	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	100
53.0	99
37.5	95
26.5	91
19.0	87
13.2	81
9.5	76
6.7	72
4.75	69
2.36	63
1.18	51
0.600	42
0.425	40
0.300	39
0.212	37
0.150	36
0.075	32
0.063	30
0.045	26
0.033	23
0.024	20
0.017	18
0.013	17
0.0091	15
0.0065	12
0.0047	10
0.0039	9
0.0033	9
0.0028	7
0.0024	6
0.0014	5



NOTES/REMARKS: -

Moisture Content 5.1% -2.36mm Soil Particle Density(t/m^3) 2.70

Sample/s supplied by the client

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Tested at Trilab Brisbane Laboratory

Authorised Signatory

Joshua Hawley

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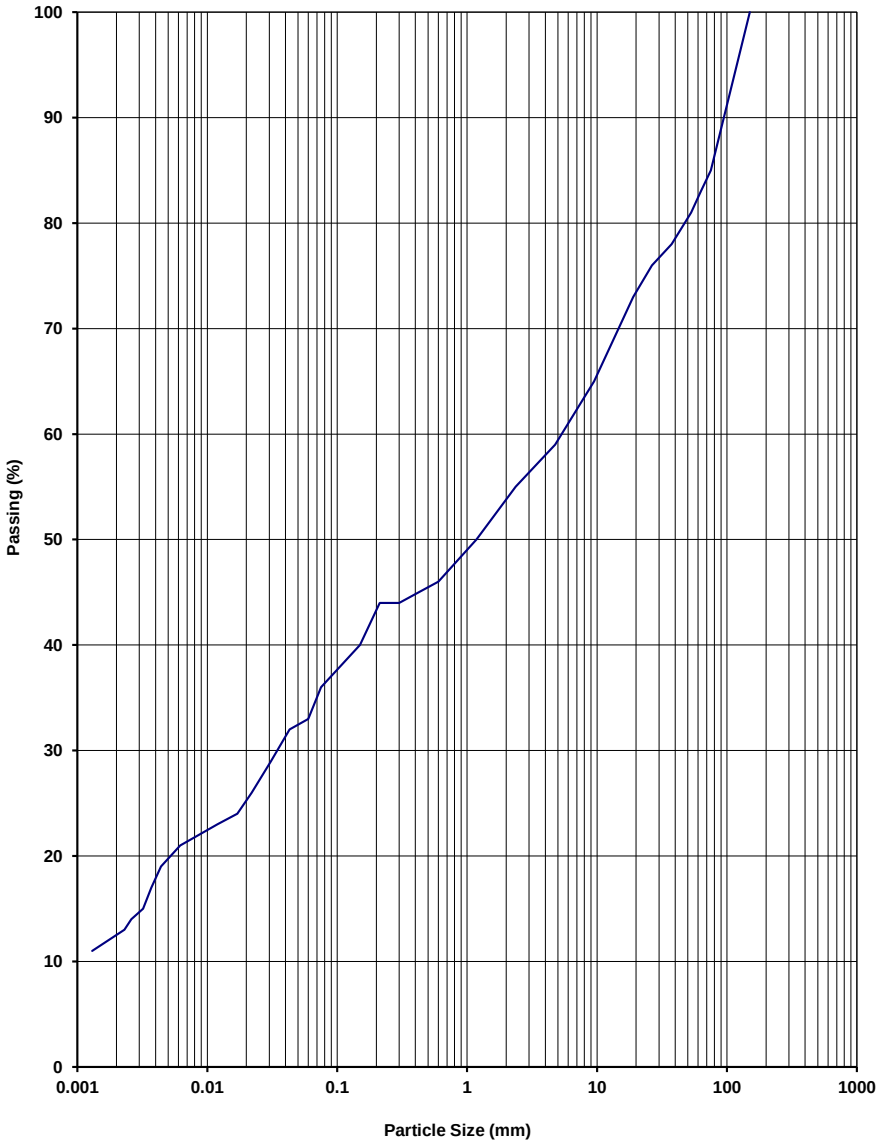
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120168-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	14/12/2021
		Report Date	12/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	18 - 2021044_C018	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	100
75.0	85
63.0	83
53.0	81
37.5	78
26.5	76
19.0	73
13.2	68
9.5	65
6.7	61
4.75	59
2.36	55
1.18	50
0.600	46
0.425	45
0.300	44
0.212	44
0.150	40
0.075	36
0.06	33
0.043	32
0.031	29
0.022	26
0.017	24
0.012	23
0.0086	22
0.0062	21
0.0044	19
0.0037	17
0.0032	15
0.0026	14
0.0023	13
0.0013	11



NOTES/REMARKS: -

Moisture Content 8.3% -2.36mm Soil Particle Density(t/m^3) 2.72

Sample/s supplied by the client

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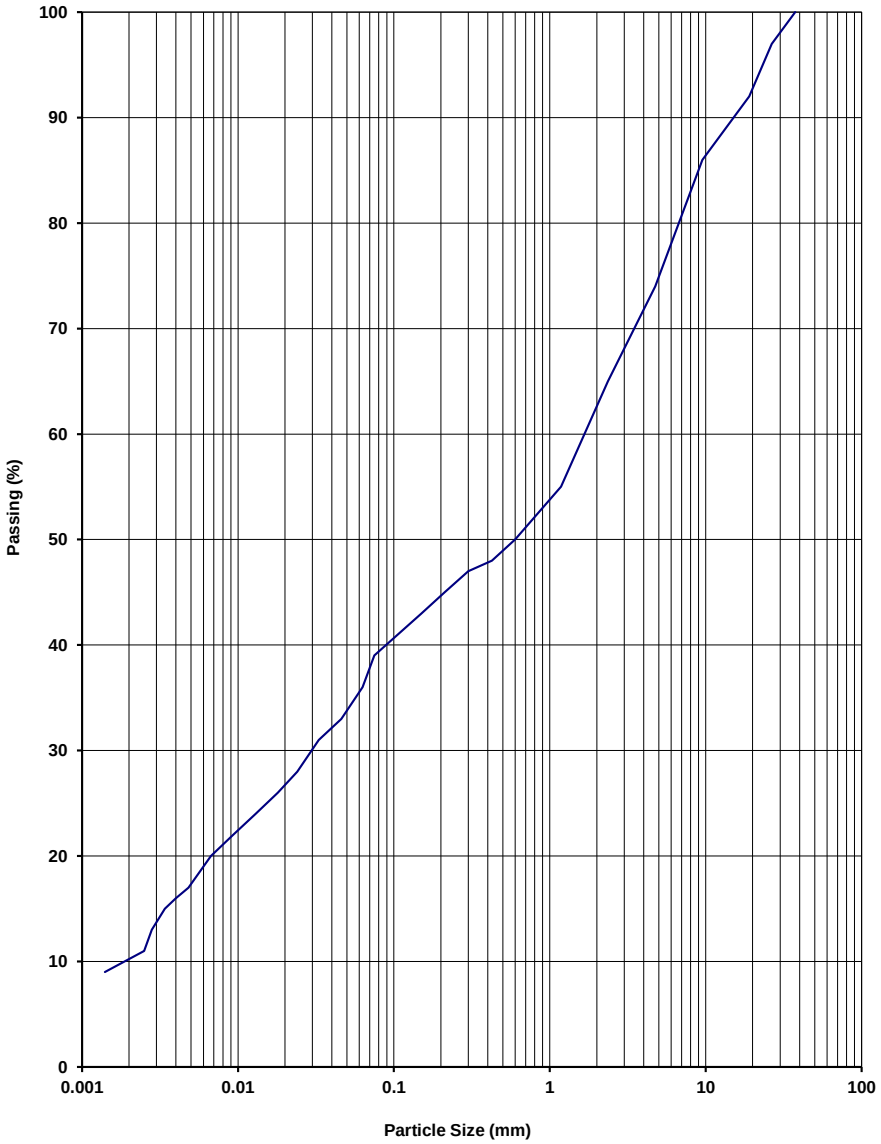
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Ph: +61 8 9258 8323

PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120170-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	15/12/2021
		Report Date	12/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	20 - 2021044_C020	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	
37.5	100
26.5	97
19.0	92
13.2	88
9.5	86
6.7	79
4.75	74
2.36	65
1.18	55
0.600	50
0.425	48
0.300	47
0.212	45
0.150	43
0.075	39
0.063	36
0.046	33
0.033	31
0.024	28
0.018	26
0.013	24
0.0093	22
0.0067	20
0.0048	17
0.004	16
0.0034	15
0.0028	13
0.0025	11
0.0014	9



NOTES/REMARKS: -

Moisture Content 6.9% -2.36mm Soil Particle Density(t/m^3) 2.54

Sample/s supplied by the client

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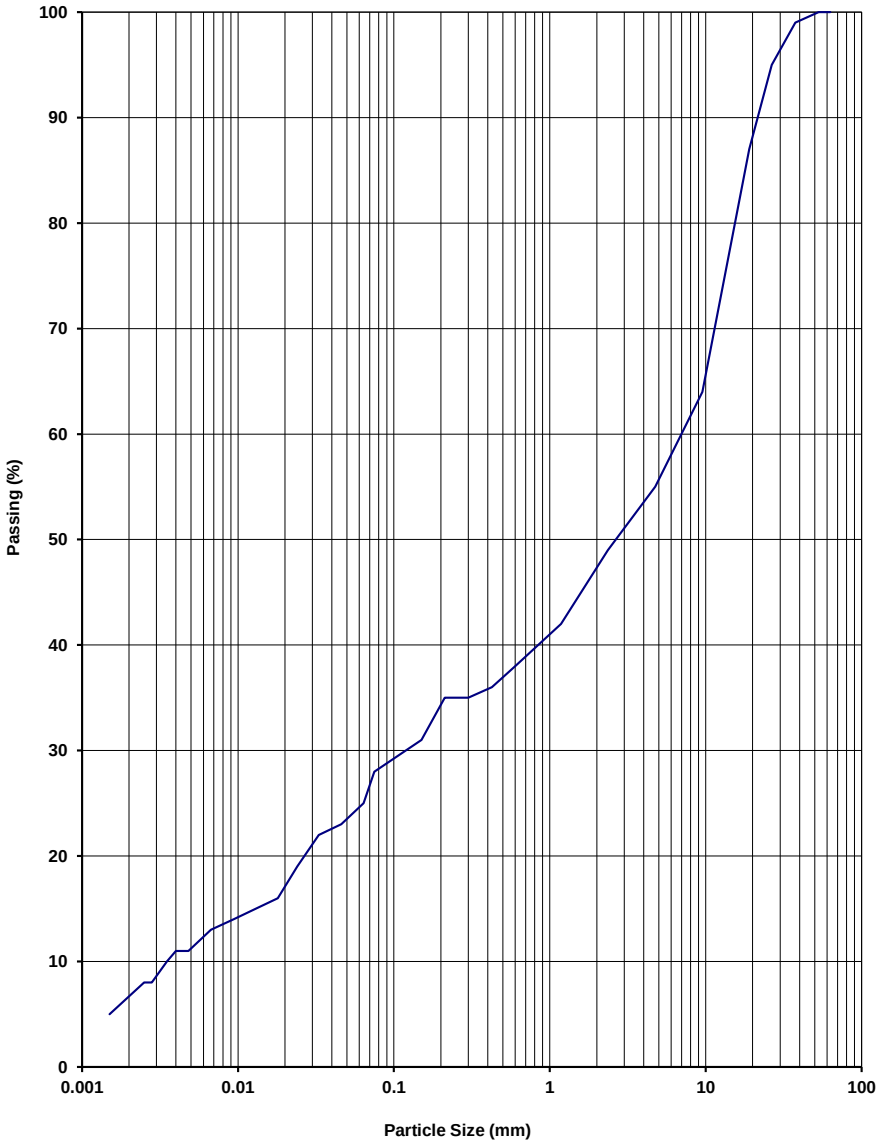
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120171-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	15/12/2021
		Report Date	12/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	21 - 2021044_C021	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	100
37.5	99
26.5	95
19.0	87
13.2	73
9.5	64
6.7	59
4.75	55
2.36	49
1.18	42
0.600	38
0.425	36
0.300	35
0.212	35
0.150	31
0.075	28
0.064	25
0.046	23
0.033	22
0.024	19
0.018	16
0.013	15
0.0094	14
0.0067	13
0.0048	11
0.004	11
0.0035	10
0.0028	8
0.0025	8
0.0015	5



NOTES/REMARKS: -

Moisture Content 5.1% -2.36mm Soil Particle Density(t/m^3) 2.55

Sample/s supplied by the client

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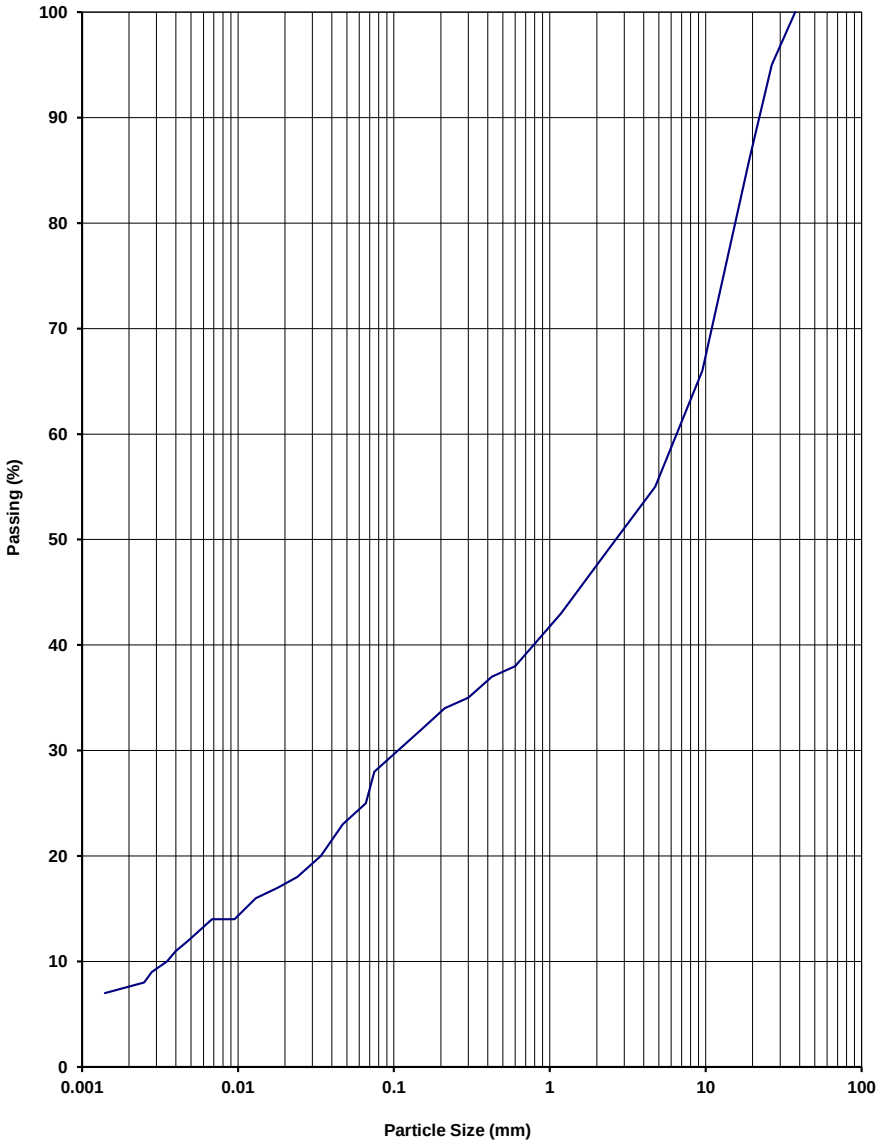
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120172-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	15/12/2021
		Report Date	12/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	22 - 2021044_C022	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	
37.5	100
26.5	95
19.0	86
13.2	76
9.5	66
6.7	61
4.75	55
2.36	49
1.18	43
0.600	38
0.425	37
0.300	35
0.212	34
0.150	32
0.075	28
0.066	25
0.047	23
0.034	20
0.024	18
0.018	17
0.013	16
0.0095	14
0.0068	14
0.0048	12
0.004	11
0.0035	10
0.0028	9
0.0025	8
0.0014	7



NOTES/REMARKS: -

Moisture Content 6.2% -2.36mm Soil Particle Density(t/m^3) 2.56

Sample/s supplied by the client

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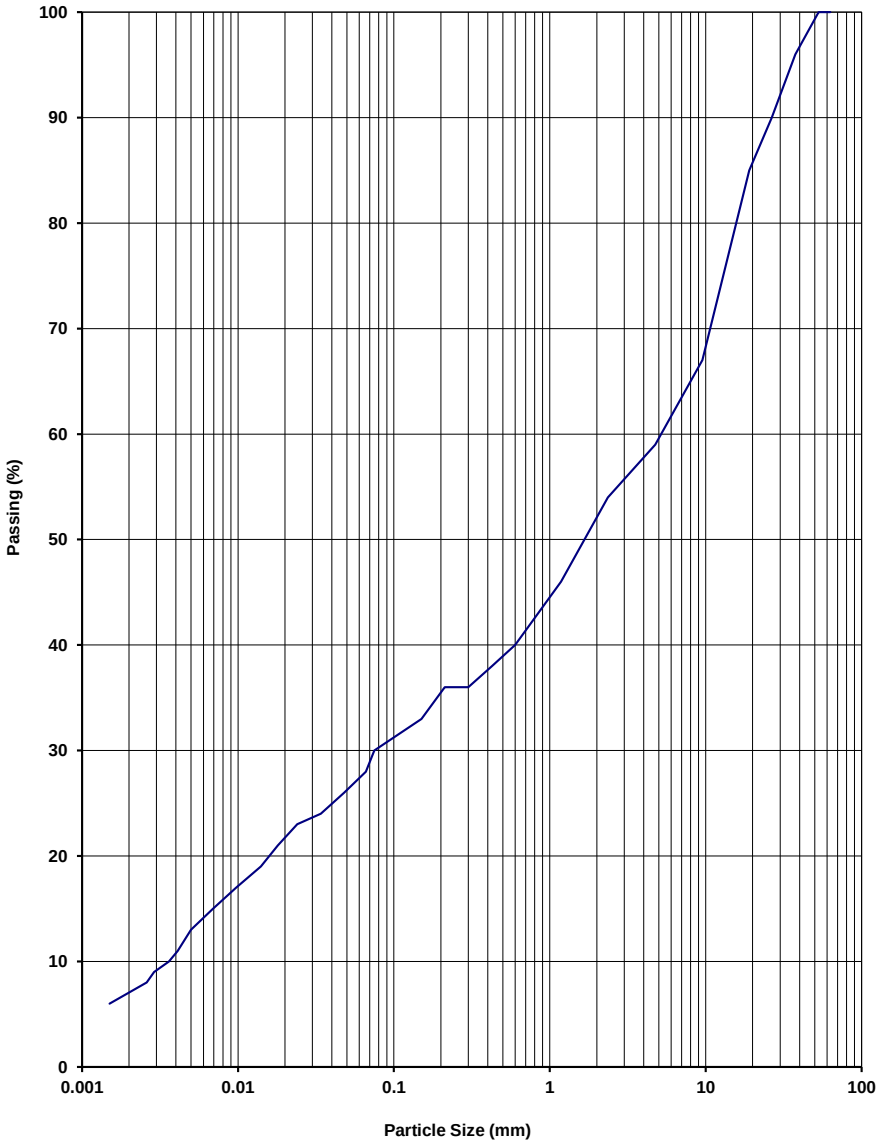
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120173-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	15/12/2021
		Report Date	12/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	23 - 2021044_C023	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	100
37.5	96
26.5	90
19.0	85
13.2	75
9.5	67
6.7	62
4.75	59
2.36	54
1.18	46
0.600	40
0.425	38
0.300	36
0.212	36
0.150	33
0.075	30
0.066	28
0.048	26
0.034	24
0.024	23
0.018	21
0.014	19
0.0097	17
0.0069	15
0.005	13
0.0041	11
0.0036	10
0.0029	9
0.0026	8
0.0015	6



NOTES/REMARKS: -

Moisture Content 9% -2.36mm Soil Particle Density(t/m^3) 2.46

Sample/s supplied by the client

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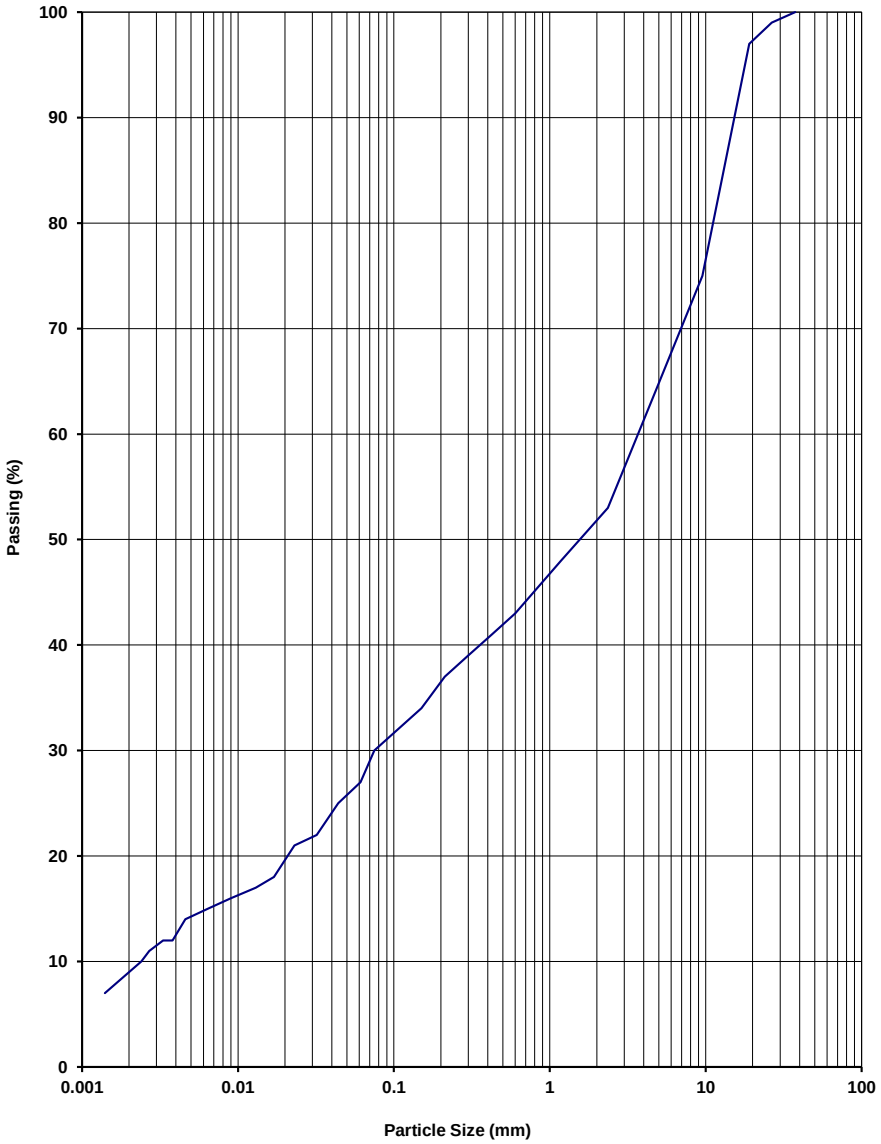
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PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120174-G
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	15/12/2021
		Report Date	12/1/2022
Project	2021044 - LLM RMSAP2		
Client ID	24 - 2021044_C024	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	
37.5	100
26.5	99
19.0	97
13.2	79
9.5	75
6.7	68
4.75	64
2.36	53
1.18	48
0.600	43
0.425	41
0.300	39
0.212	37
0.150	34
0.075	30
0.061	27
0.044	25
0.032	22
0.023	21
0.017	18
0.013	17
0.009	16
0.0064	15
0.0046	14
0.0038	12
0.0033	12
0.0027	11
0.0024	10
0.0014	7



NOTES/REMARKS: -

Moisture Content 9.3% -2.36mm Soil Particle Density(t/m^3) 2.67

Sample/s supplied by the client

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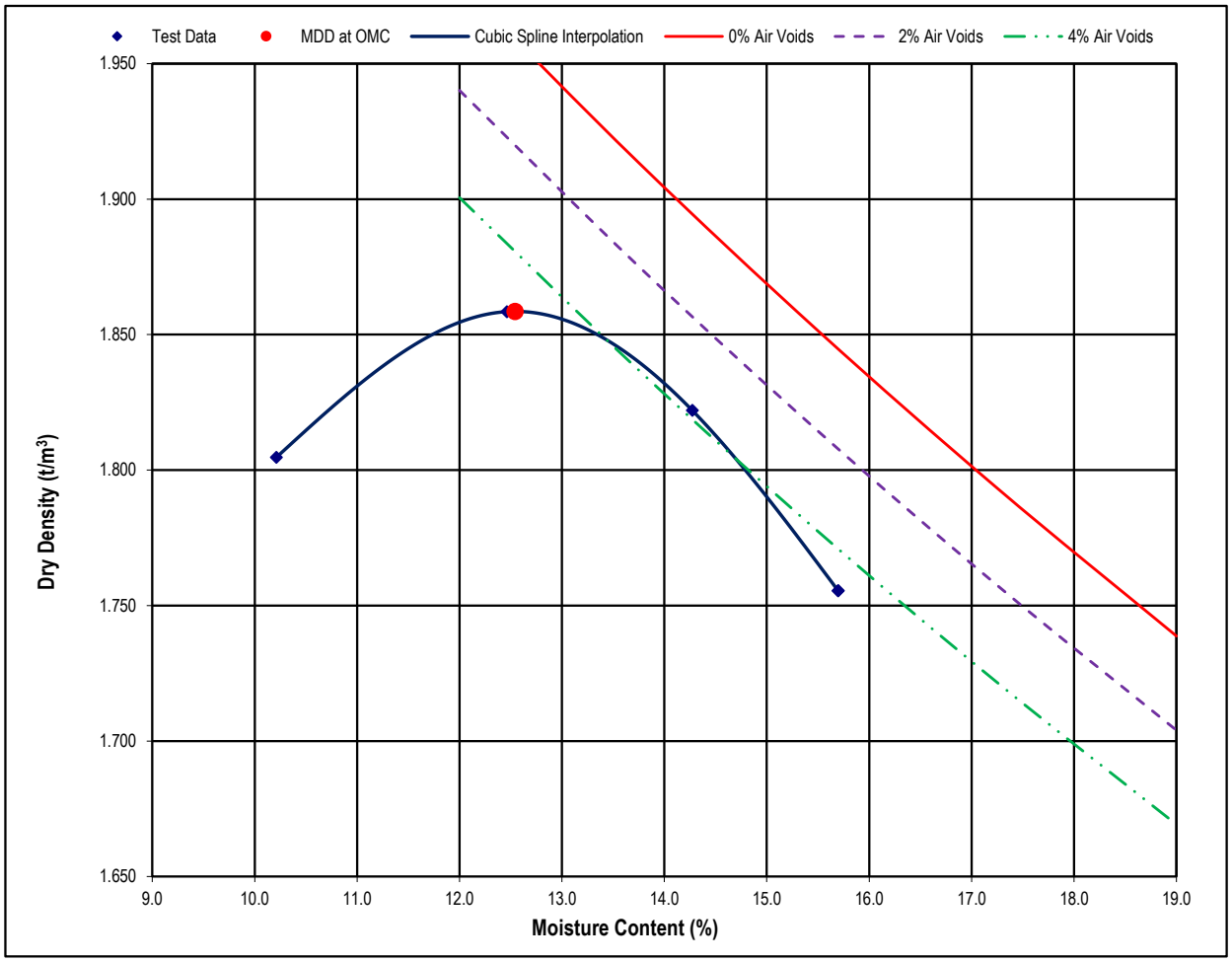
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120151-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	15/12/2021
		Report Date	16/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	1 - 2021044_C001	**Depth (m)**	Not Supplied
Description	Gravelly Clayey SILT - brown		



Maximum Dry Density (t/m^3)	1.86	**Optimum Moisture Content (%)**	12.5
Moisture Content (%)	9.4	**Percentage of Oversize/Sieve Size (mm)**	4.0 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.6

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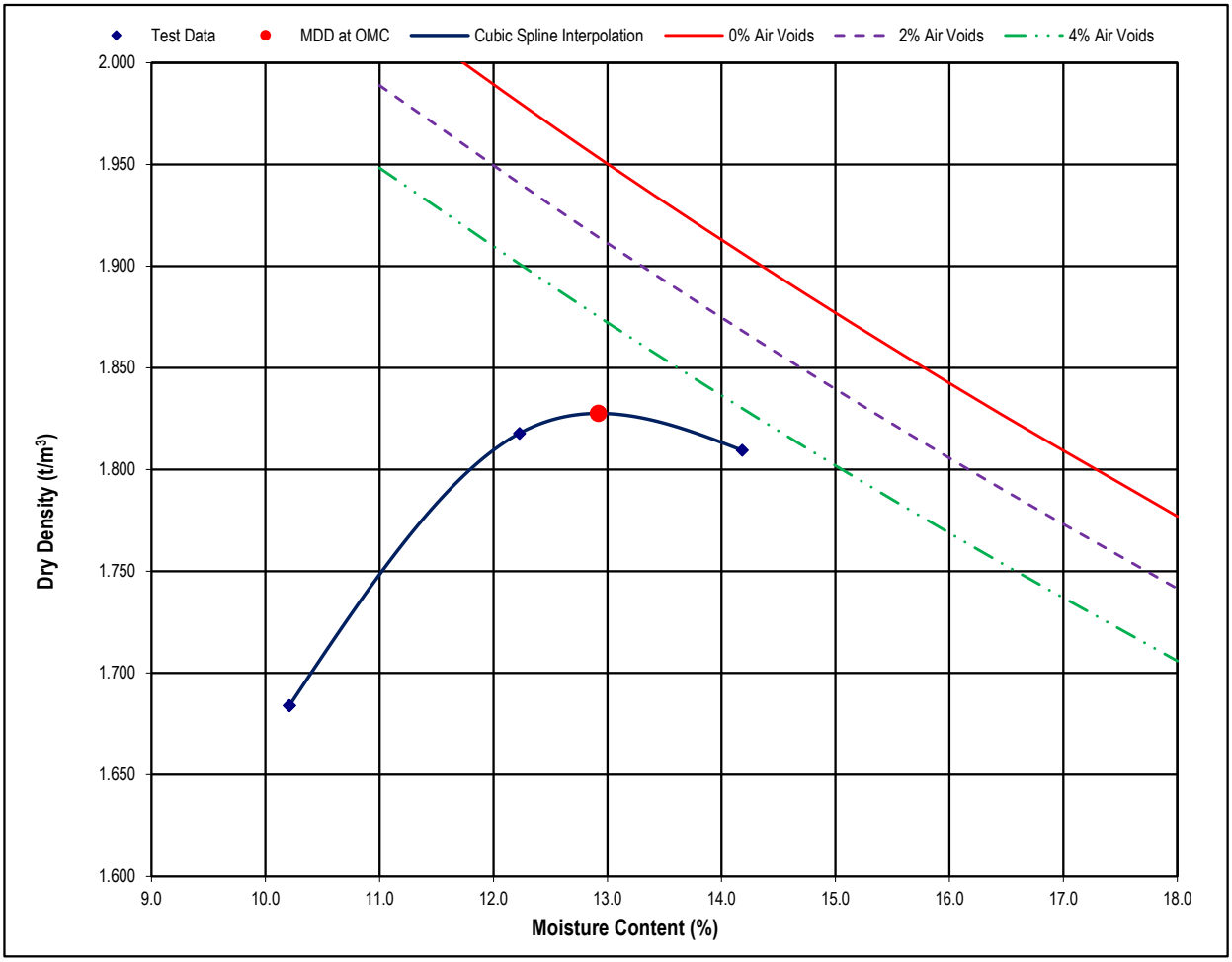
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120152-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	15/12/2021
		Report Date	16/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	2 - 2021044_C002	**Depth (m)**	Not Supplied
Description	Sandy SILT with gravel - brown		



Maximum Dry Density (t/m³)	1.83	**Optimum Moisture Content (%)**	12.9
Moisture Content (%)	9.4	**Percentage of Oversize/Sieve Size (mm)**	1.0 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.61

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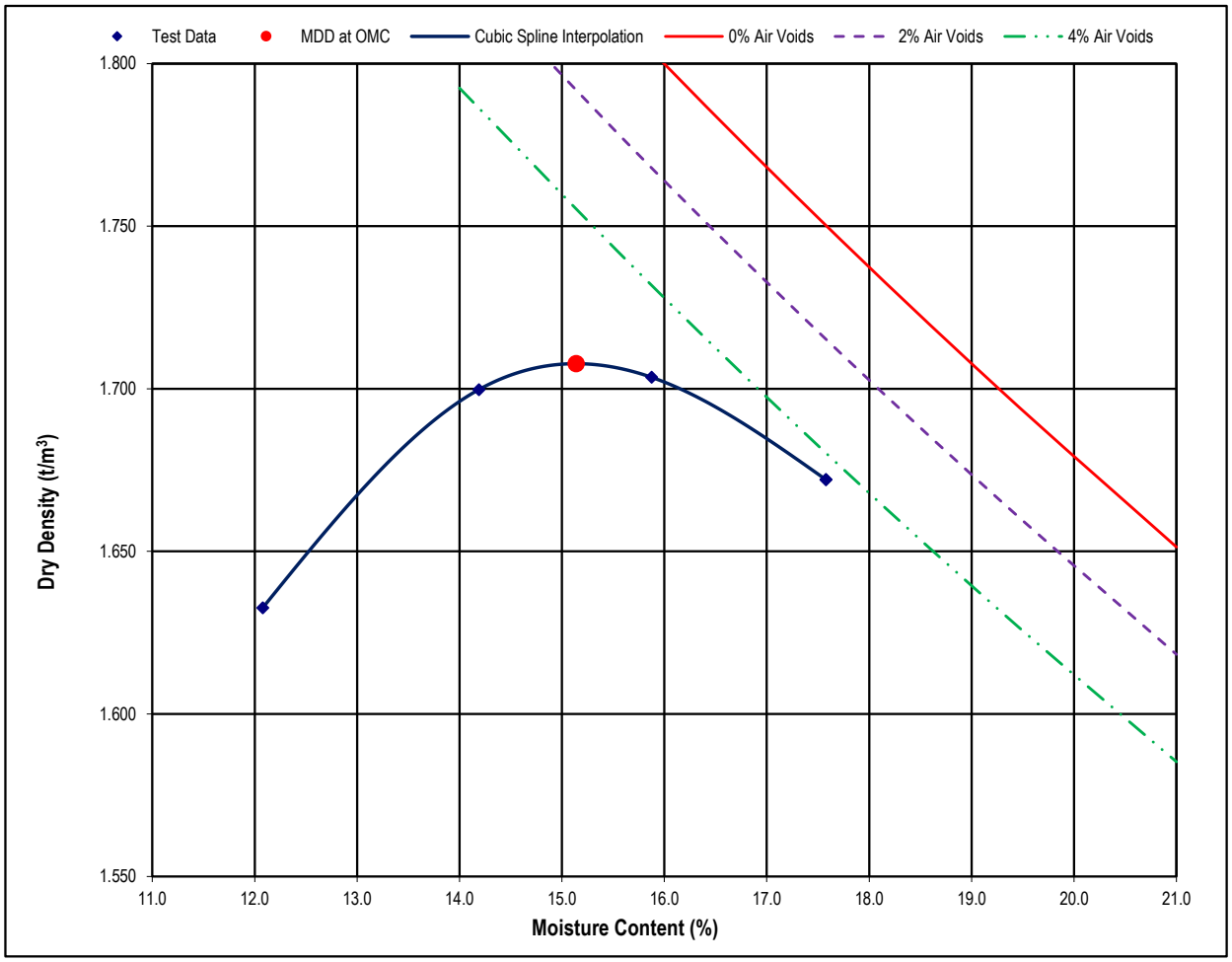
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120153-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	16/12/2021
		Report Date	17/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	3 - 2021044_C003	**Depth (m)**	Not Supplied
Description	Sandy SILT - brown/white		



Maximum Dry Density (t/m³)	1.71	**Optimum Moisture Content (%)**	15.1
Moisture Content (%)	6.8	**Percentage of Oversize/Sieve Size (mm)**	0 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.53

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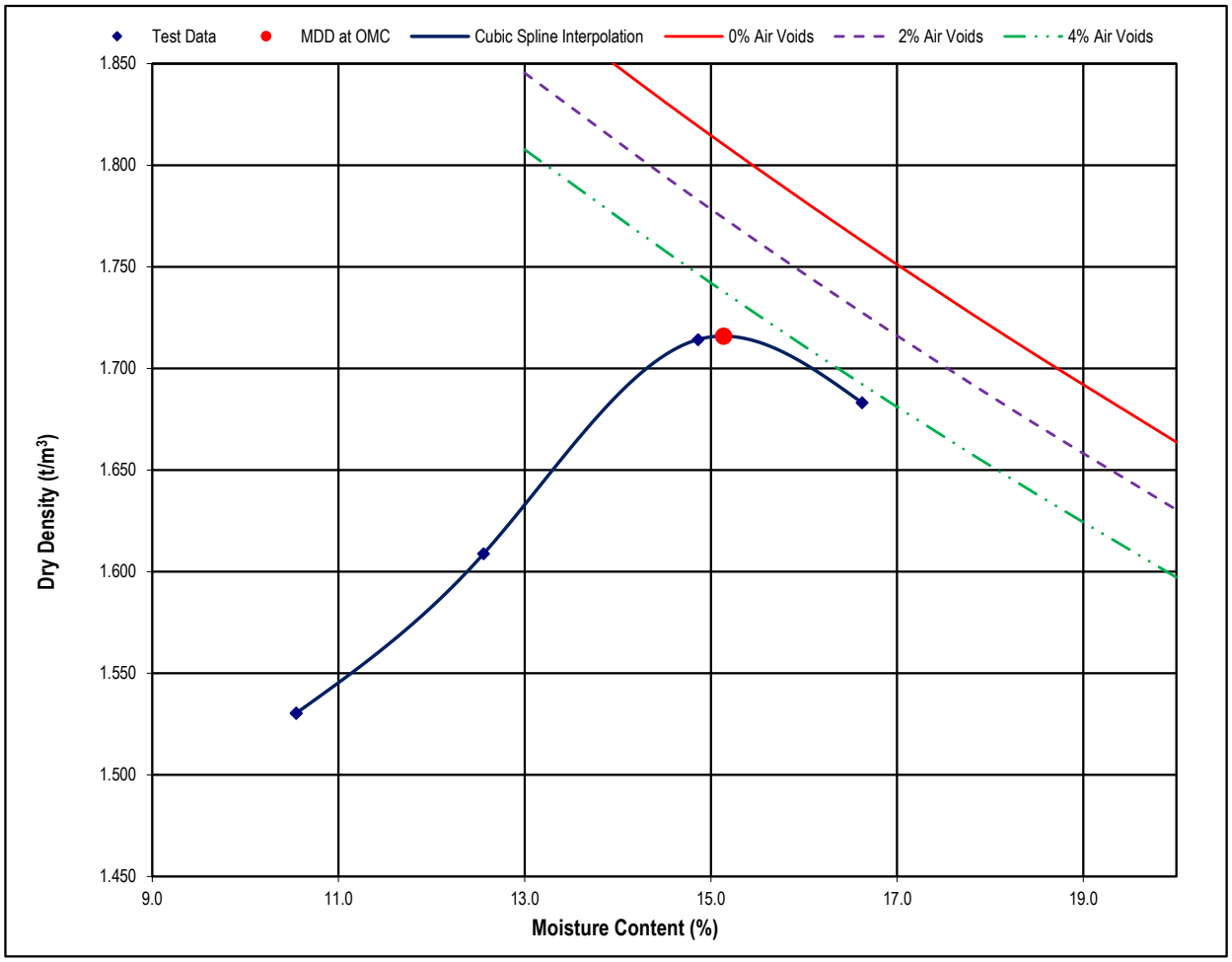
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120154-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	16/12/2021
		Report Date	17/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	4 - 2021044_C004	**Depth (m)**	Not Supplied
Description	Sandy SILT - brown/white		



Maximum Dry Density (t/m^3)	1.72	**Optimum Moisture Content (%)**	15.1
Moisture Content (%)	6.1	**Percentage of Oversize/Sieve Size (mm)**	0 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.49

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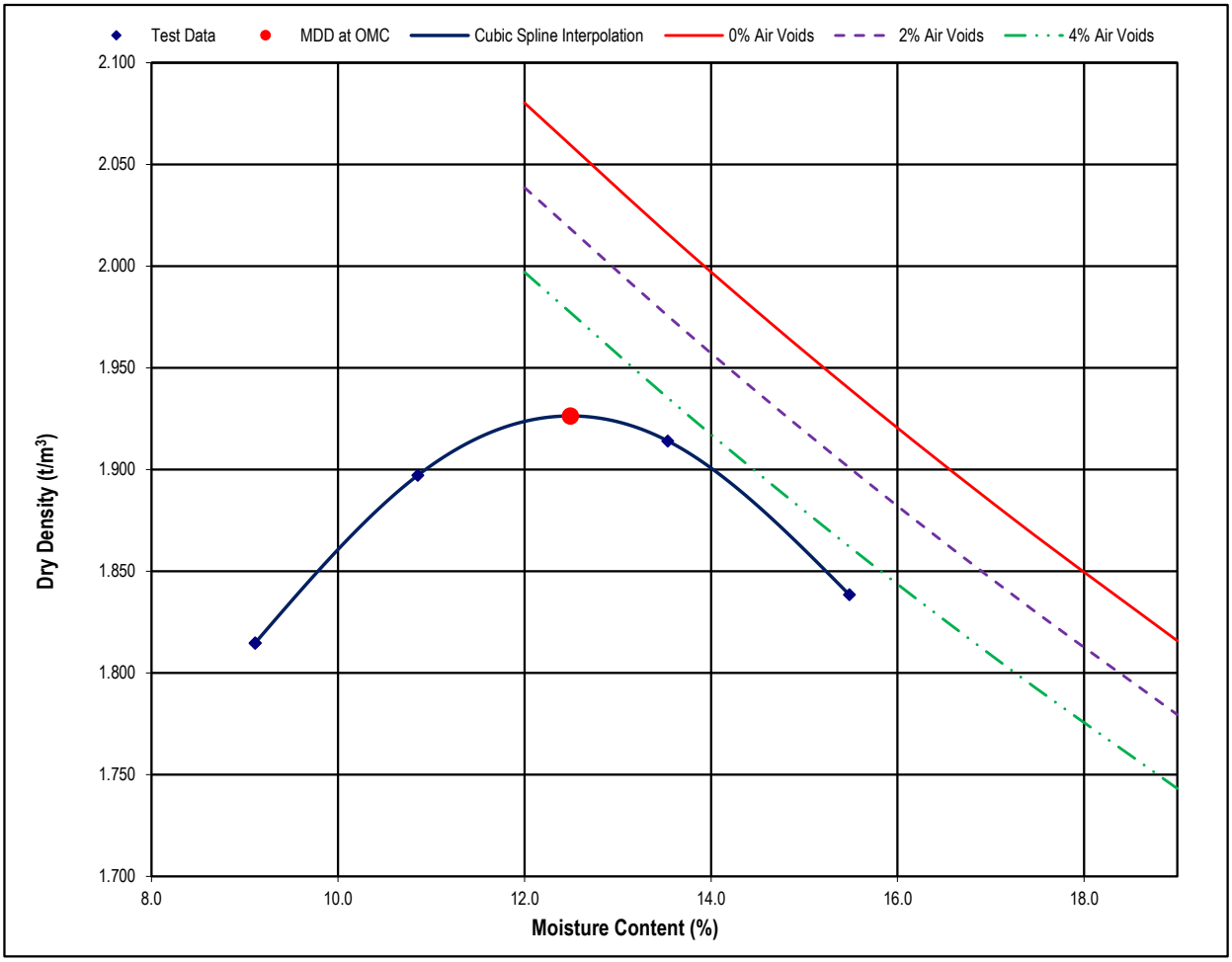
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120155-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	17/12/2021
		Report Date	18/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	5 - 2021044_C005	**Depth (m)**	Not Supplied
Description	Gravelly Sandy CLAY - brown		



Maximum Dry Density (t/m^3)	1.93	**Optimum Moisture Content (%)**	12.5
Moisture Content (%)	11.3	**Percentage of Oversize/Sieve Size (mm)**	2.0 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.77

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Authorised Signatory

Joshua Hawley

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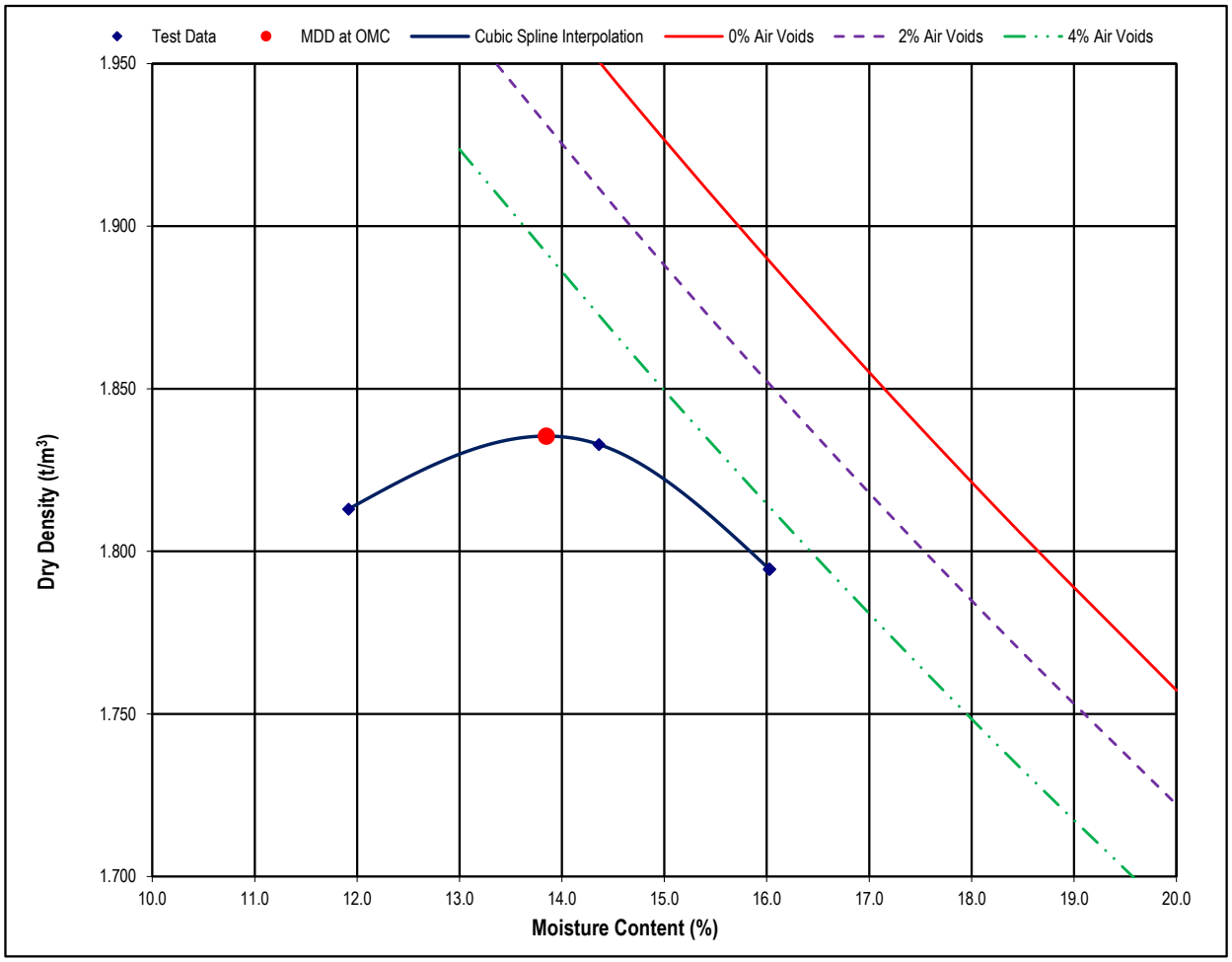
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120156-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	17/12/2021
		Report Date	18/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	6 - 2021044_C006	**Depth (m)**	Not Supplied
Description	Silty CLAY with gravel - brown		



Maximum Dry Density (t/m³)	1.84	**Optimum Moisture Content (%)**	13.8
Moisture Content (%)	8.1	**Percentage of Oversize/Sieve Size (mm)**	2.0 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.71

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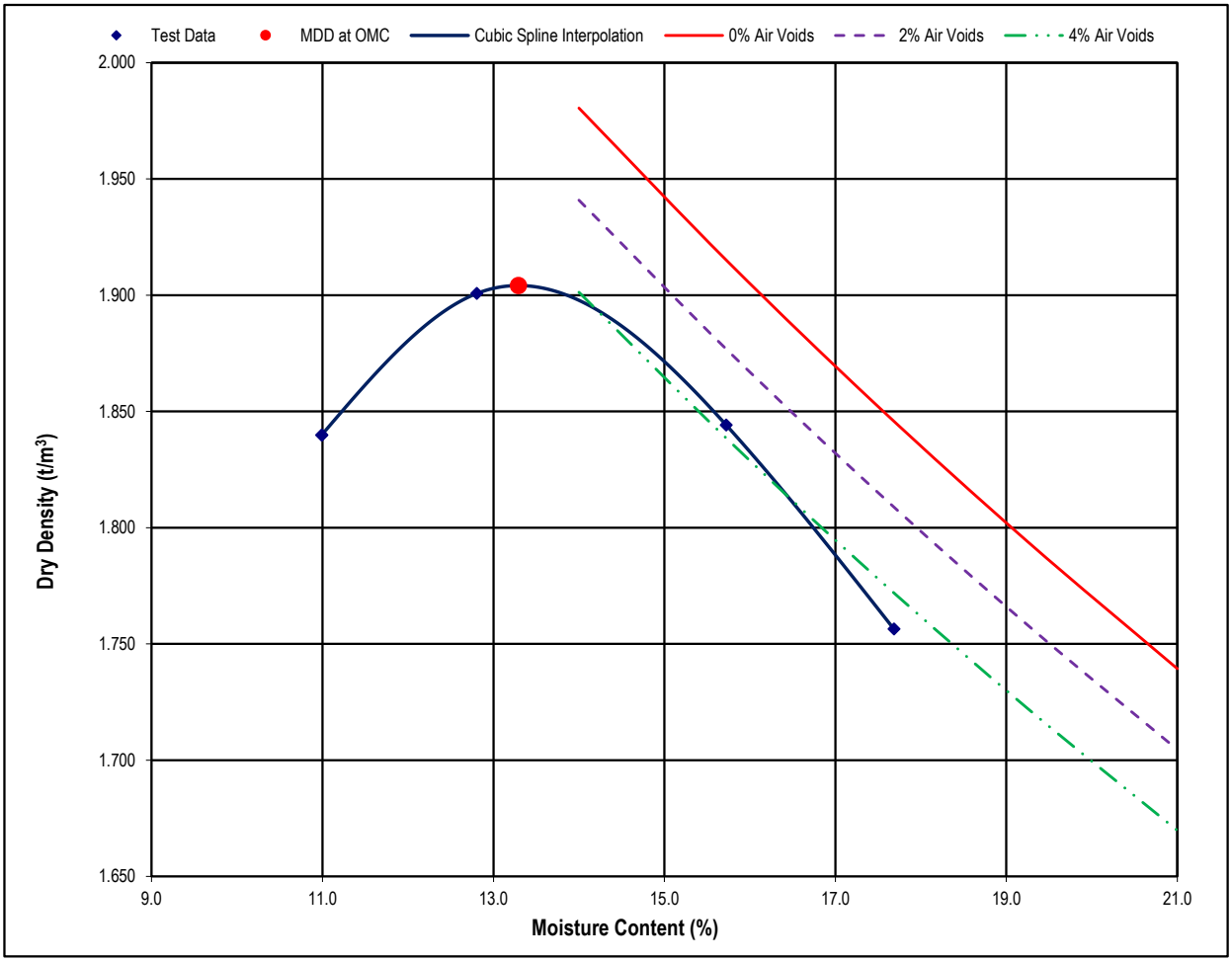
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120158-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	16/12/2021
		Report Date	17/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	8 - 2021044_C008	**Depth (m)**	Not Supplied
Description	Silty CLAY trace gravel - brown		



Maximum Dry Density (t/m^3)	1.90	**Optimum Moisture Content (%)**	13.3
Moisture Content (%)	10.7	**Percentage of Oversize/Sieve Size (mm)**	0 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.74

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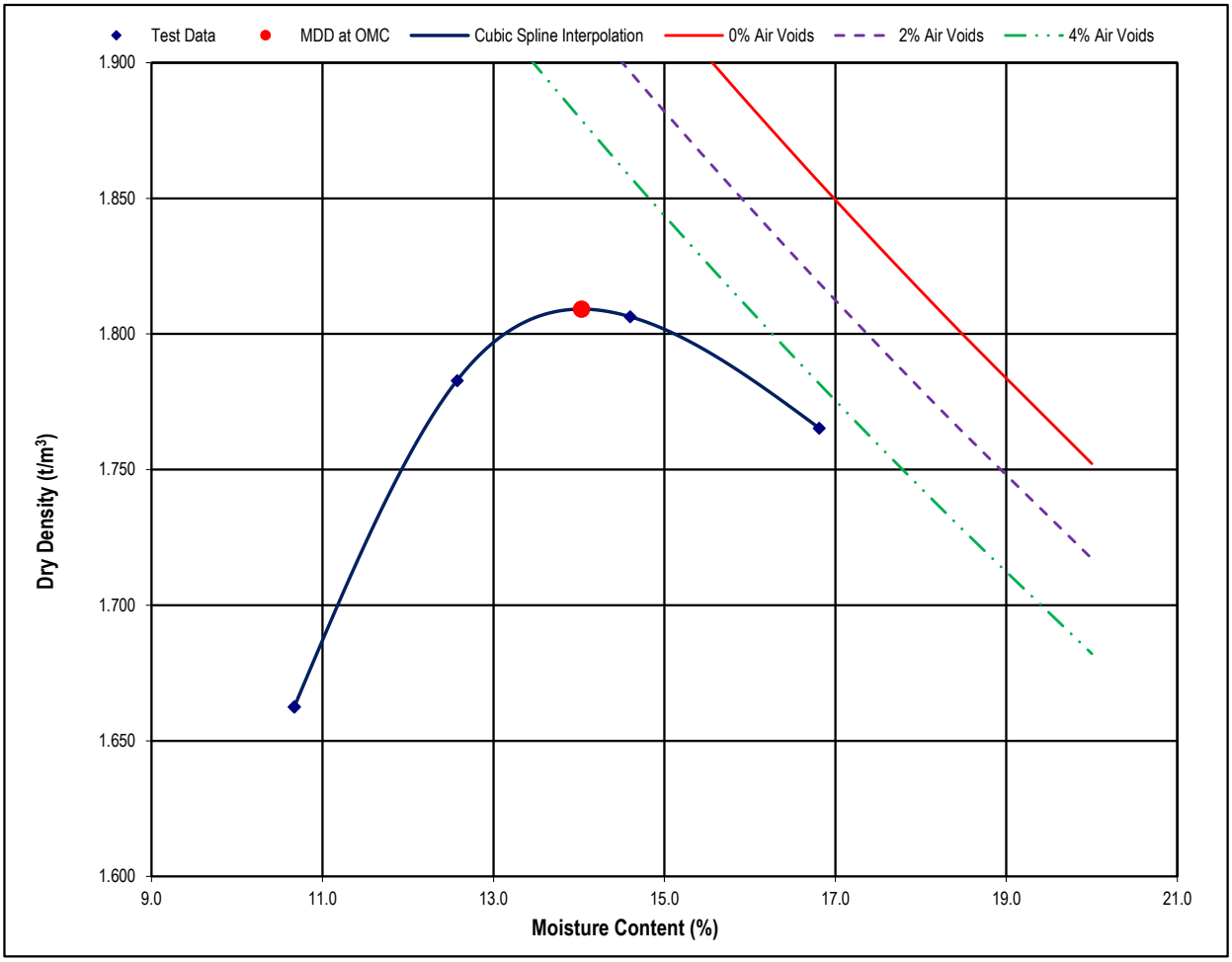
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120159-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	16/12/2021
		Report Date	17/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	9 - 2021044_C009	**Depth (m)**	Not Supplied
Description	Gravelly Silty CLAY - brown		



Maximum Dry Density (t/m^3)	1.81	**Optimum Moisture Content (%)**	14.0
Moisture Content (%)	8.3	**Percentage of Oversize/Sieve Size (mm)**	8.4 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.7

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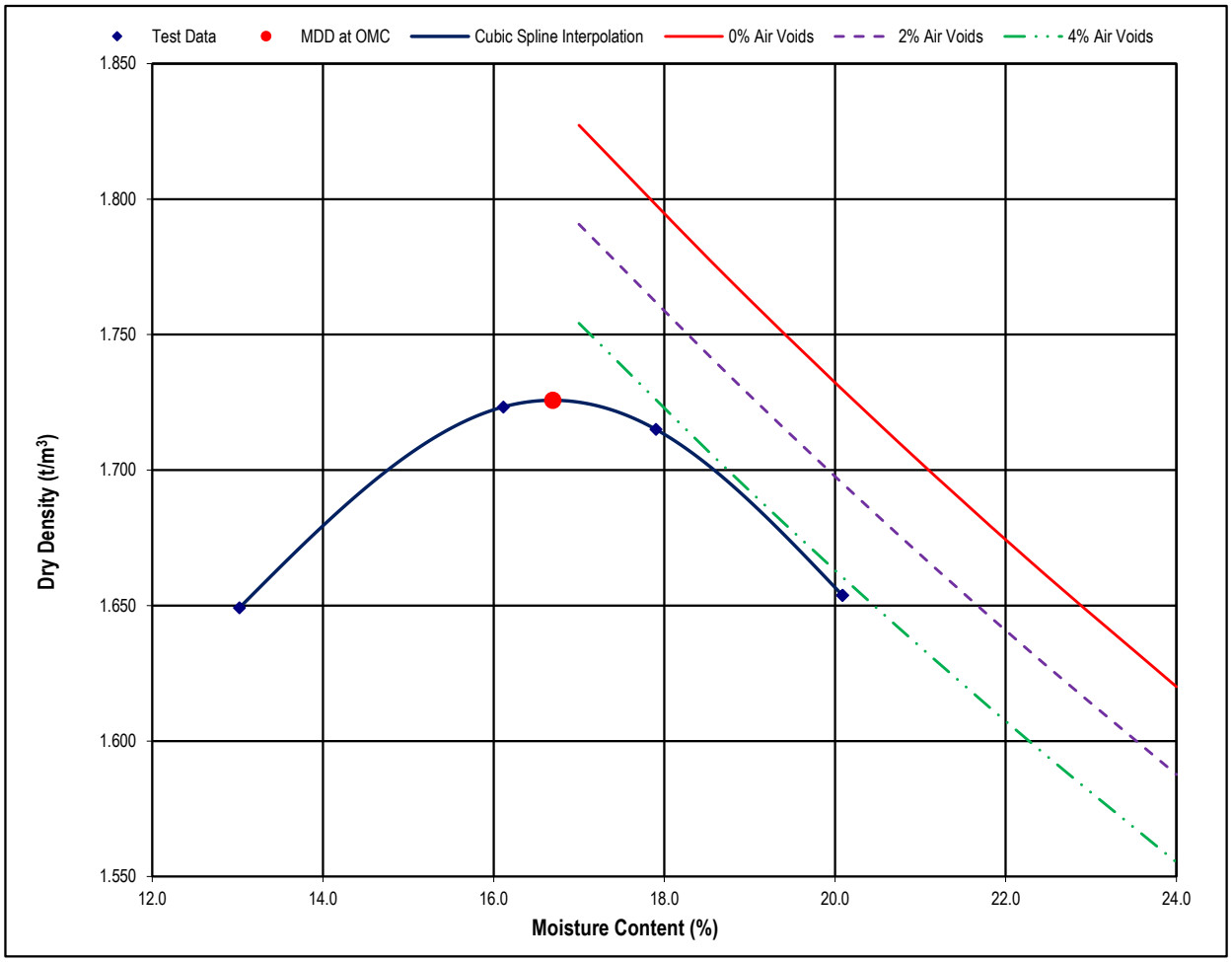
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120160-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	16/12/2021
		Report Date	17/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	10 - 2021044_C010	**Depth (m)**	Not Supplied
Description	SILT trace gravel - pale brown		



Maximum Dry Density (t/m³)	1.73	**Optimum Moisture Content (%)**	16.7
Moisture Content (%)	4.3	**Percentage of Oversize/Sieve Size (mm)**	31.0 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.65

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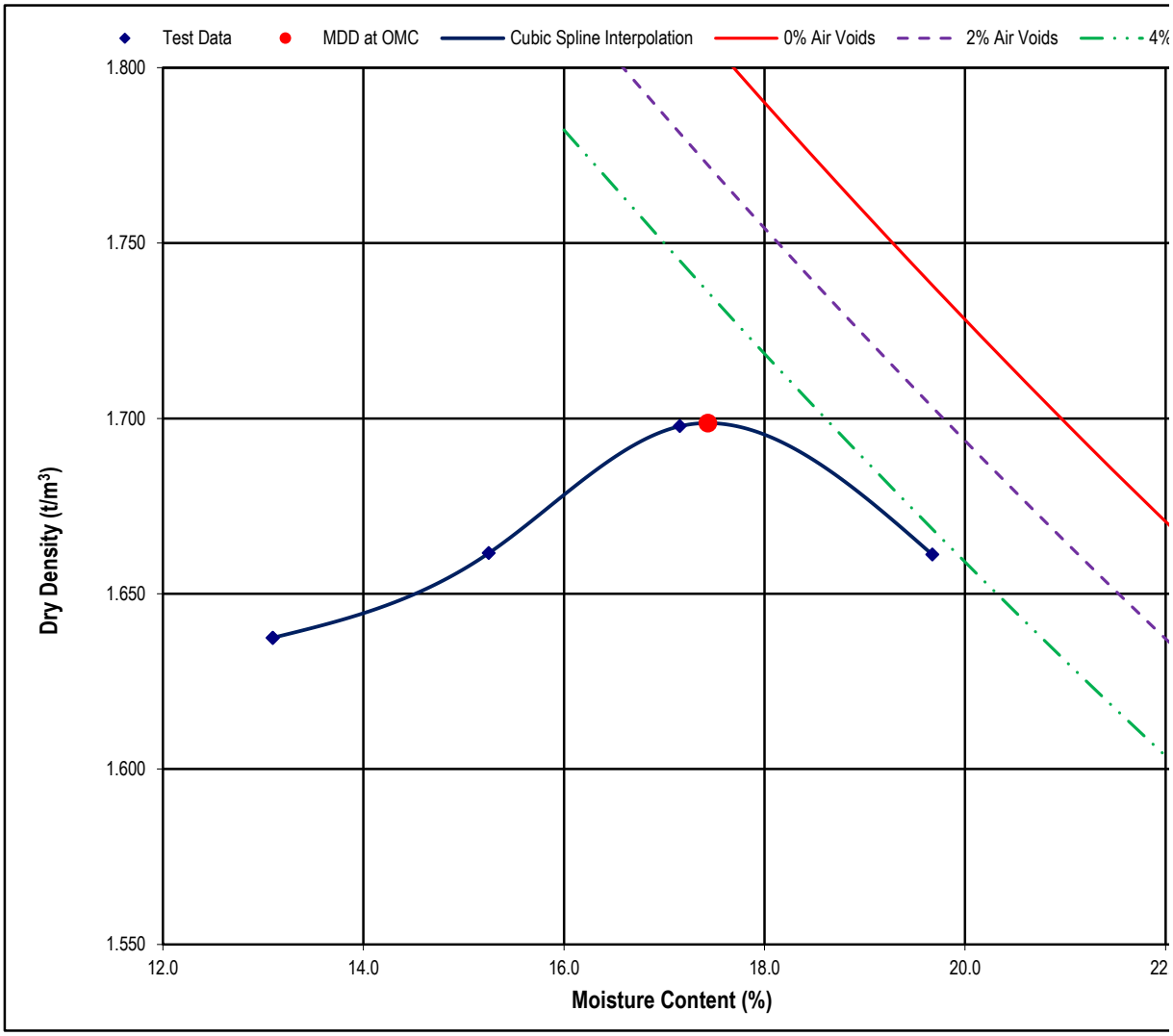
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	
		Workorder No.	
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	
		Report Date	
Project	2021044 - LLM RMSAP2		
Client ID	11 - 2021044_C011	**Depth (m)**	
Description	SILT with gravel - brown		



Maximum Dry Density (t/m^3)	1.70	**Optimum Moisture Content (%)**	
Moisture Content (%)	5.4	**Percentage of Oversize/Sieve Size (mm)**	

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.64

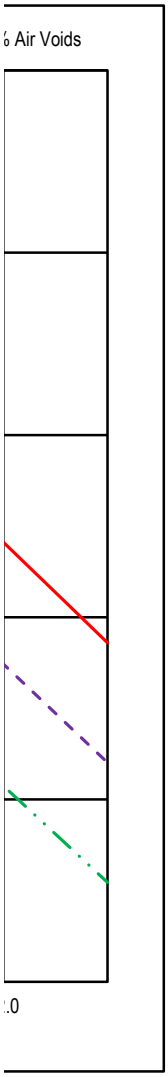
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0009363
17/12/2021
18/12/2021
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17.4
20.0 / 19

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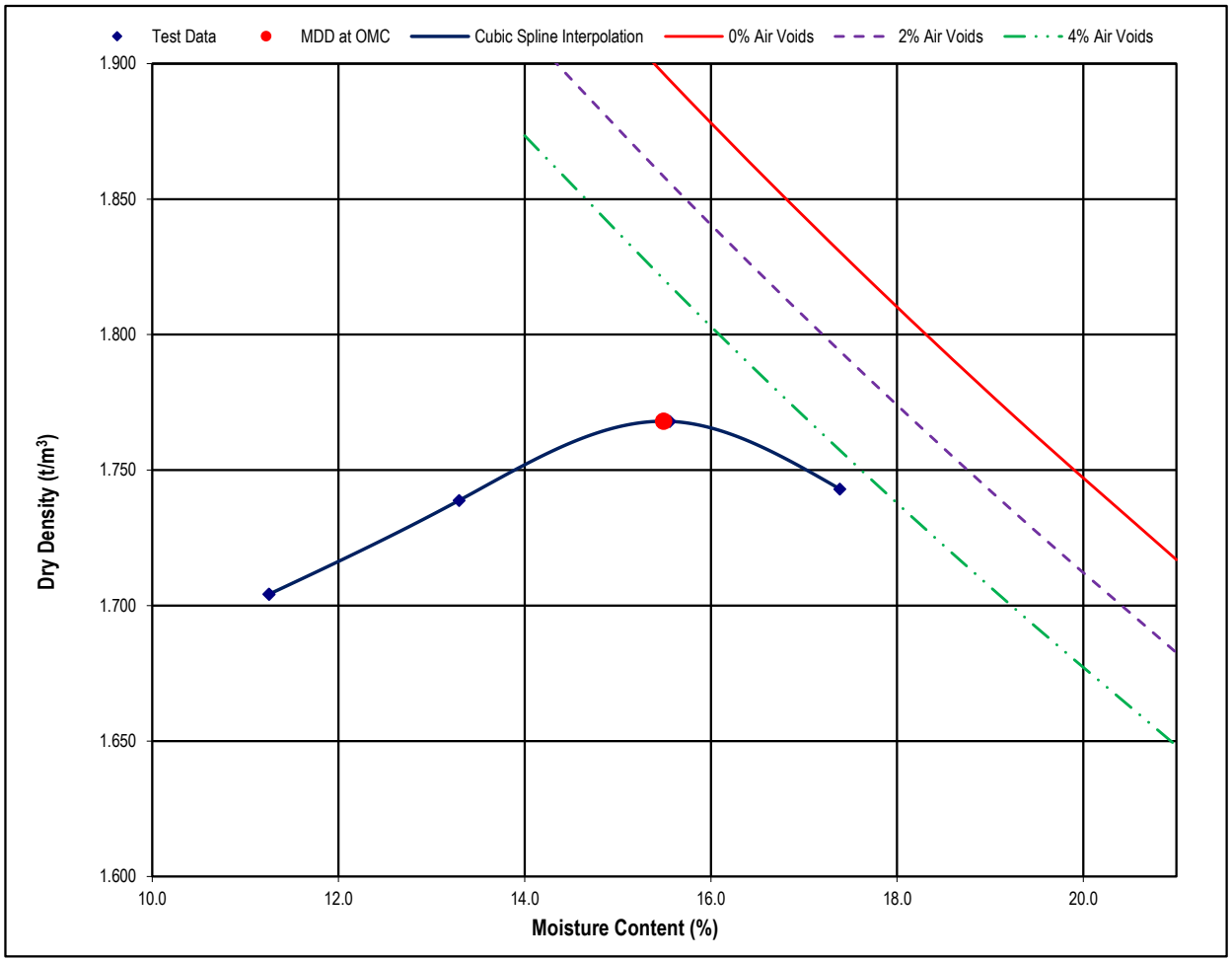
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120162-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	17/12/2021
		Report Date	18/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	12 - 2021044_C012	**Depth (m)**	Not Supplied
Description	Gravelly SILT - brown		



Maximum Dry Density (t/m^3)	1.77	**Optimum Moisture Content (%)**	15.5
Moisture Content (%)	7.4	**Percentage of Oversize/Sieve Size (mm)**	14.0 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.69

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ACCURATE QUALITY RESULTS FOR TOMORROW'S ENGINEERING

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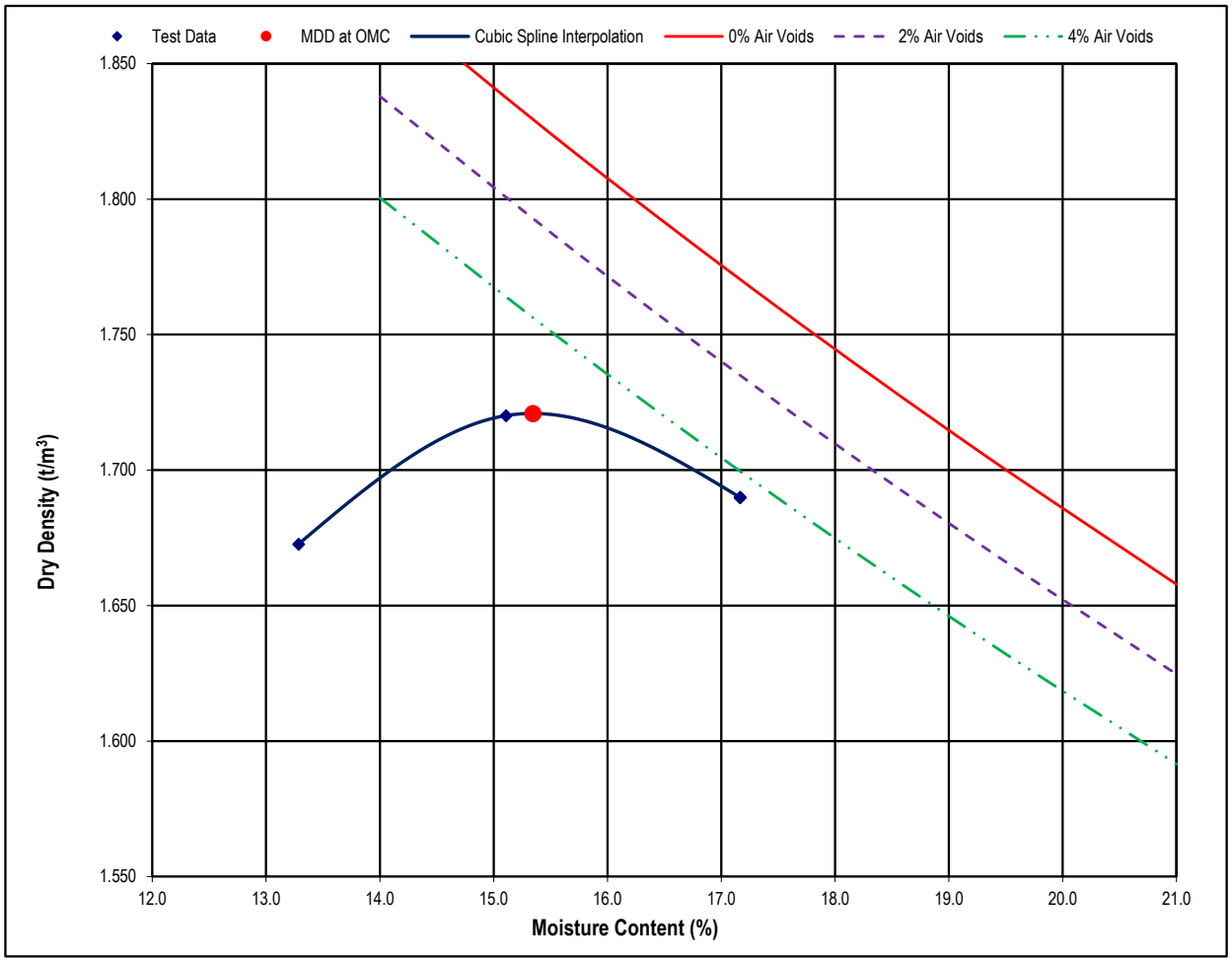
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120165-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	17/12/2021
		Report Date	18/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	15 - 2021044_C015	**Depth (m)**	Not Supplied
Description	Gravelly SILT - brown		



Maximum Dry Density (t/m³)	1.72	**Optimum Moisture Content (%)**	15.3
Moisture Content (%)	5.8	**Percentage of Oversize/Sieve Size (mm)**	11.0 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.54

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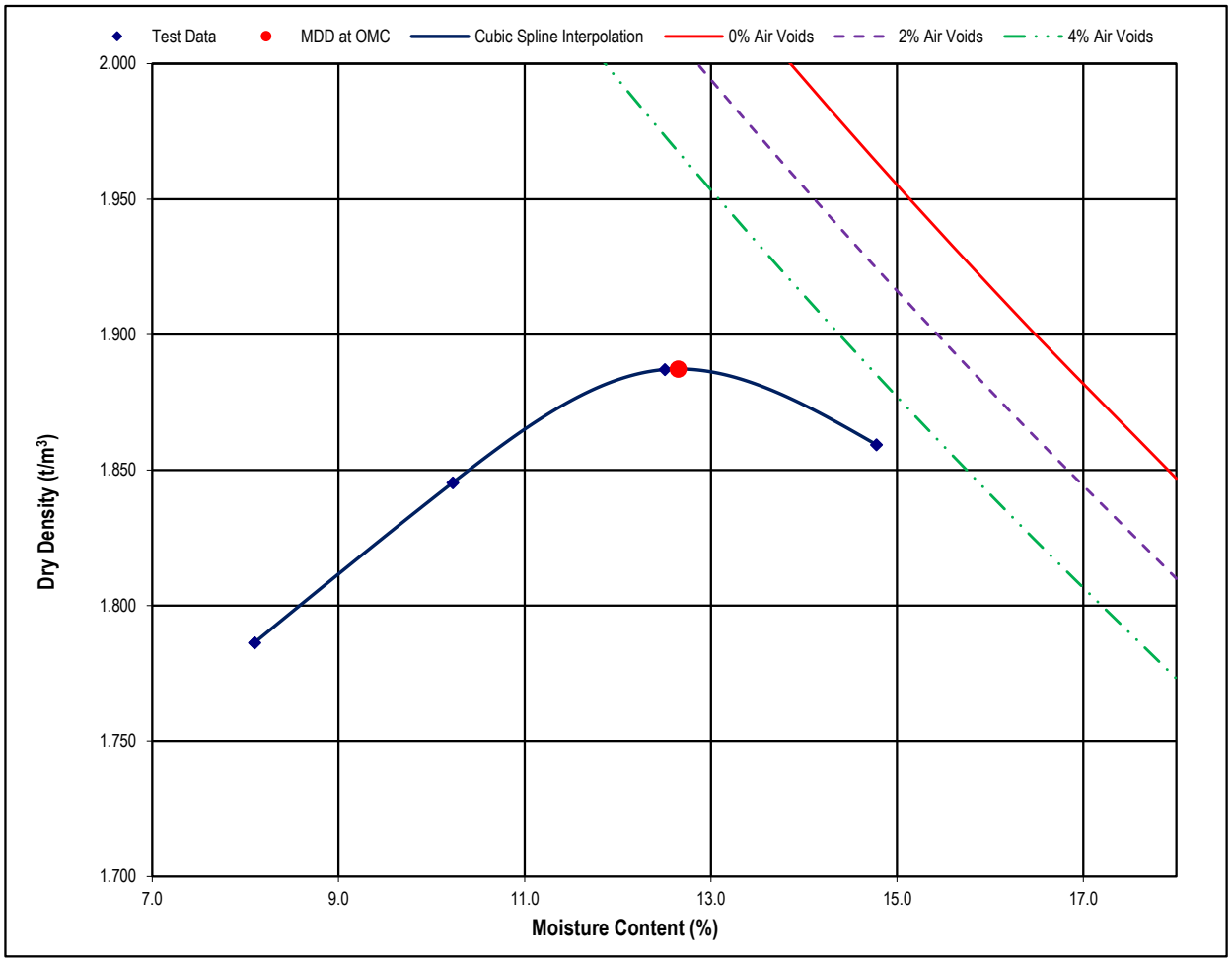
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120168-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	15/12/2021
		Report Date	16/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	18 - 2021044_C018	**Depth (m)**	Not Supplied
Description	Gravelly SILT - brown		



Maximum Dry Density (t/m^3)	1.89	**Optimum Moisture Content (%)**	12.6
Moisture Content (%)	8.3	**Percentage of Oversize/Sieve Size (mm)**	8.4 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.77

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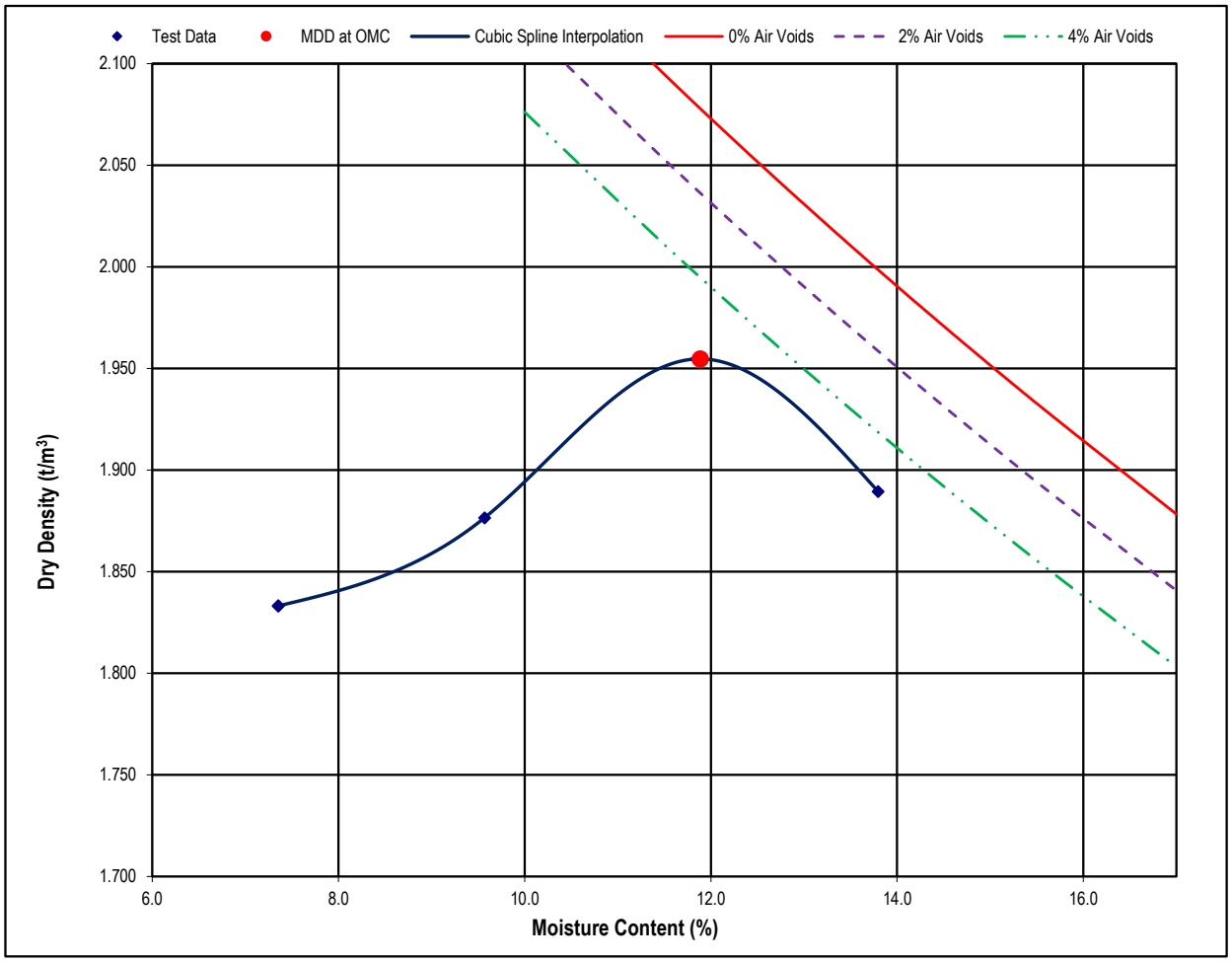
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120172-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	20/12/2021
		Report Date	21/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	22 - 2021044_C022	**Depth (m)**	Not Supplied
Description	Gravelly SILT - brown		



Maximum Dry Density (t/m^3)	1.95	**Optimum Moisture Content (%)**	11.9
Moisture Content (%)	6.2	**Percentage of Oversize/Sieve Size (mm)**	13 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.76

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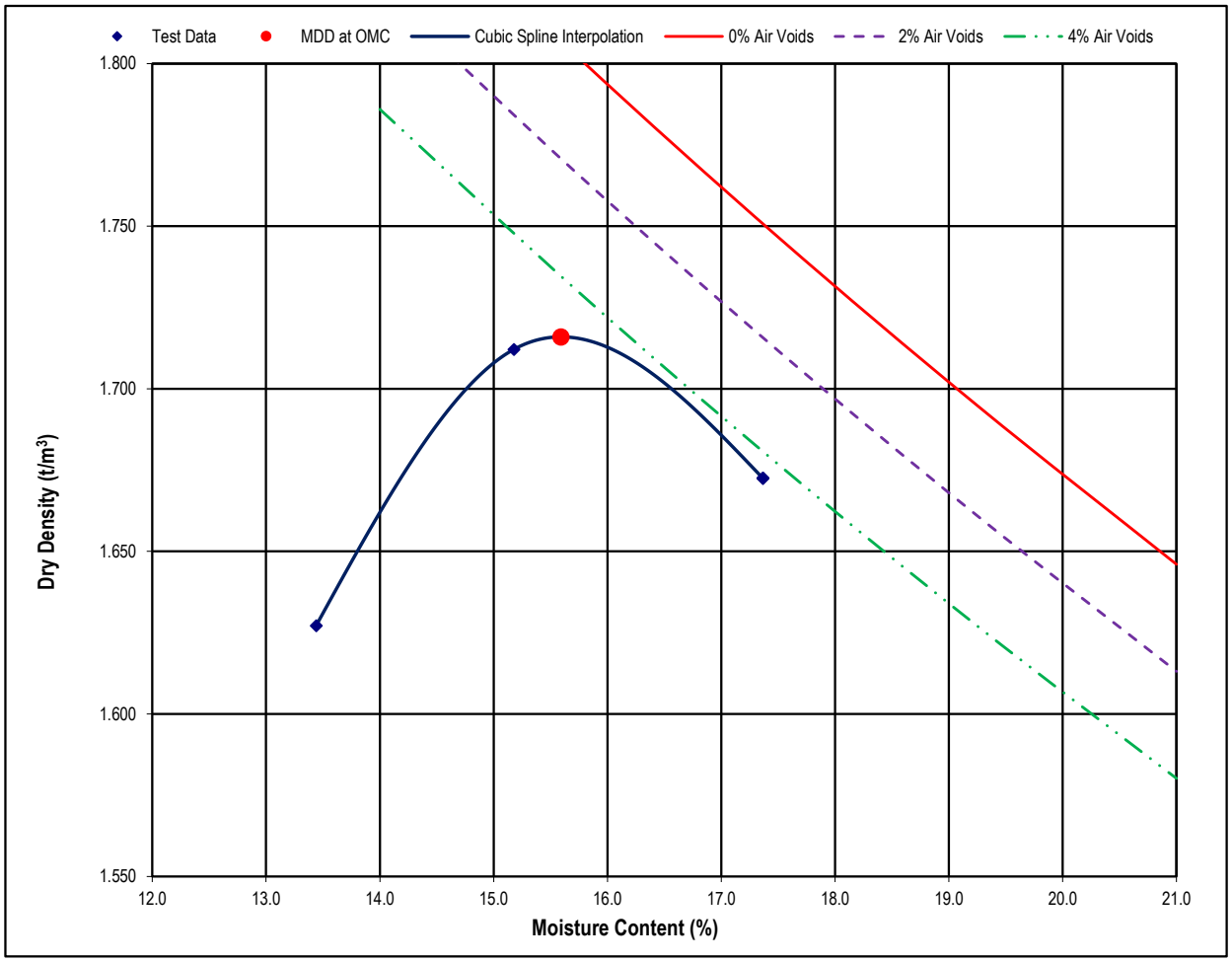
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120173-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	20/12/2021
		Report Date	21/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	23 - 2021044_C023	**Depth (m)**	Not Supplied
Description	Gravelly SILT - brown		



Maximum Dry Density (t/m^3)	1.72	**Optimum Moisture Content (%)**	15.6
Moisture Content (%)	9.0	**Percentage of Oversize/Sieve Size (mm)**	14 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.52

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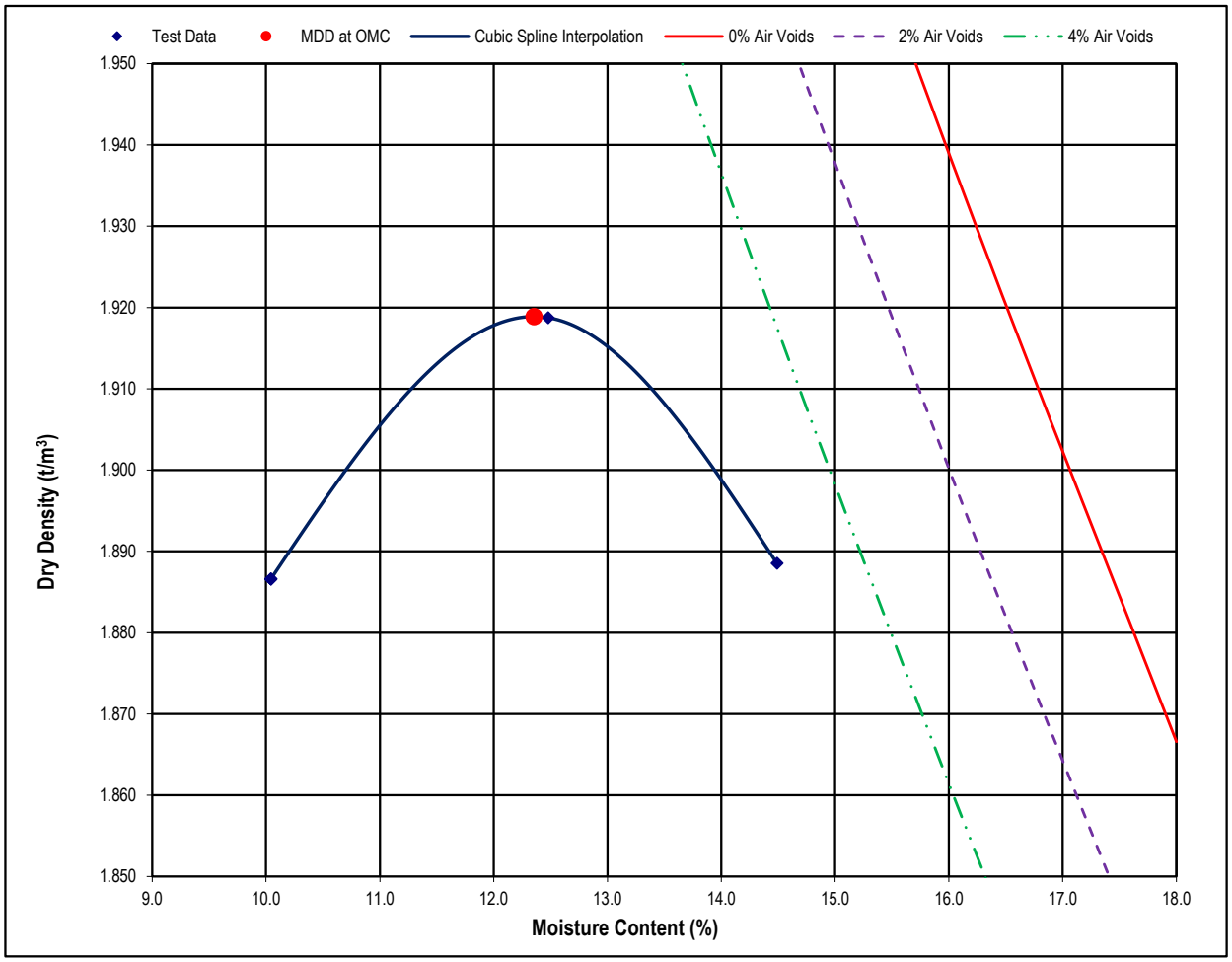
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MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120174-MDD
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	20/12/2021
		Report Date	21/12/2021
Project	2021044 - LLM RMSAP2		
Client ID	24 - 2021044_C024	**Depth (m)**	Not Supplied
Description	SILT with gravel - brown		



Maximum Dry Density (t/m³)	1.92	**Optimum Moisture Content (%)**	12.4
Moisture Content (%)	9.3	**Percentage of Oversize/Sieve Size (mm)**	3.0 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.81

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PERMEABILITY BY FALLING HEAD TEST REPORT

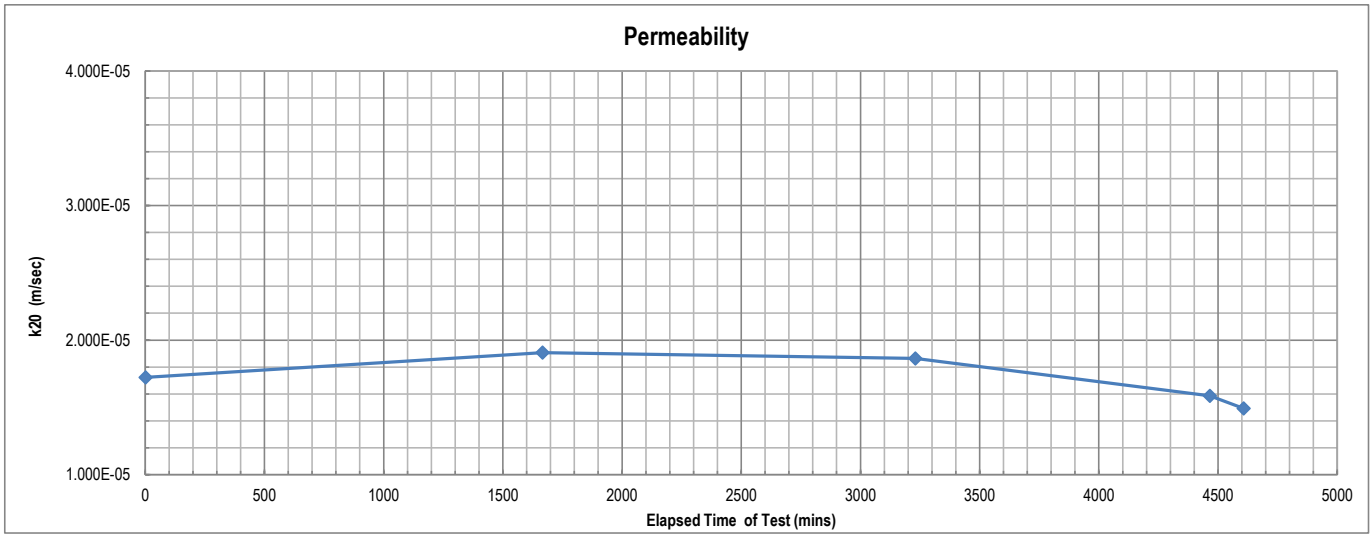
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120151-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	4/01/2022
		Report Date	10/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	1 - 2021044_C001	**Depth (m)**	Not Supplied
Description	Gravelly Clayey SILT - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.86**	Hydraulic Gradient	**9.5**
Optimum Moisture Content (%)	**12.5**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**12.0**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**95.9**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.86**	Percentage Material Retained/Sieve Size (mm)	**4 % /19 mm**
Density Ratio (%)	**89.3**	Sample Height and Diameter (mm)	**115.88 / 152.38 mm**

PERMEABILITY $k_{(20)} = 1.5 \times 10^{-05}$ **(m/sec)**



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client

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C. Purvis

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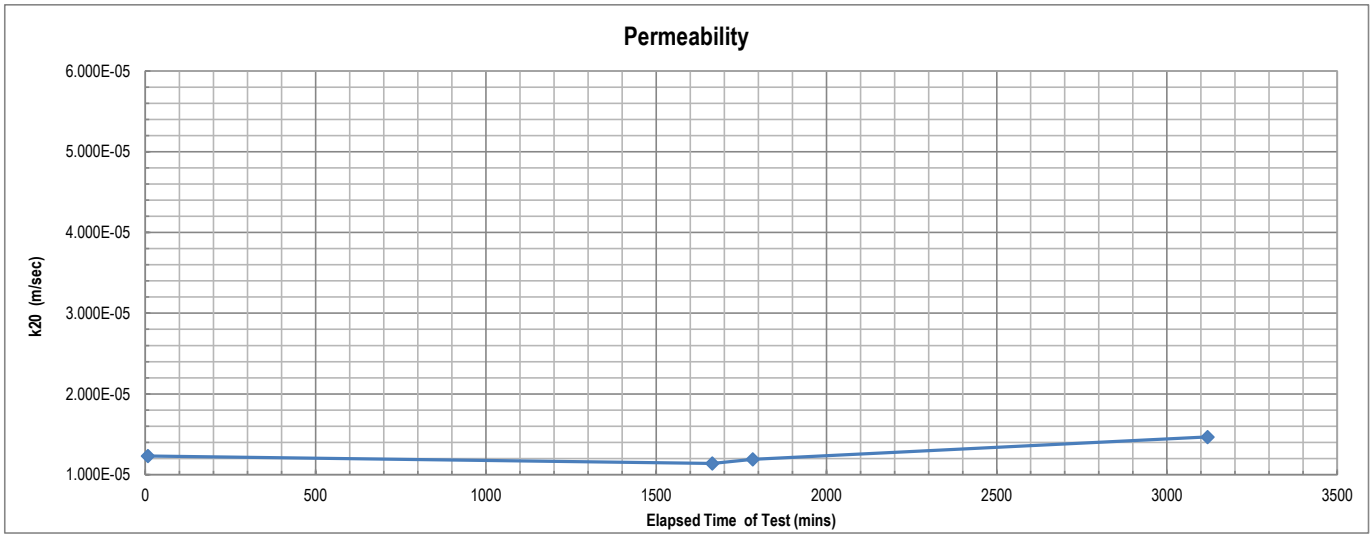
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120152-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	4/01/2022
		Report Date	7/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	2 - 2021044_C002	**Depth (m)**	Not Supplied
Description	Sandy SILT with gravel - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.83**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**12.9**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**13.0**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**100.6**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.86**	Percentage Material Retained/Sieve Size (mm)	**1 % /19 mm**
Density Ratio (%)	**89.9**	Sample Height and Diameter (mm)	**116.6 / 152.36 mm**

PERMEABILITY $k_{(20)}$ = 1.5 x 10^{-05} (m/sec)



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

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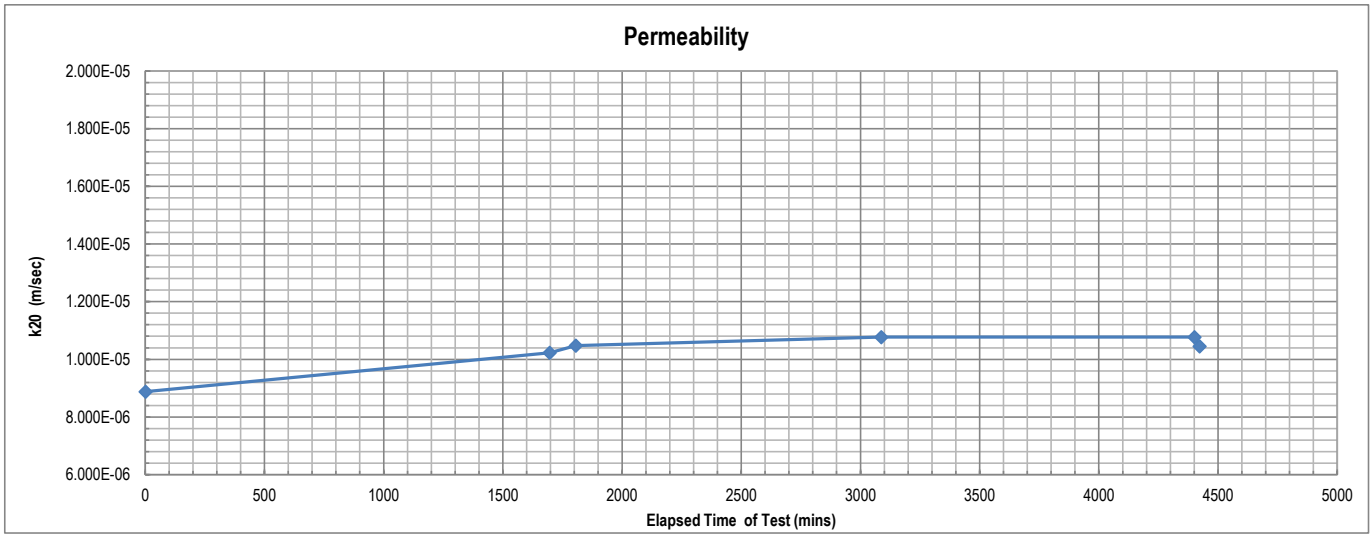
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120155-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	4/01/2022
		Report Date	10/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	5 - 2021044_C005	**Depth (m)**	Not Supplied
Description	Gravelly Sandy CLAY - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.93**	Hydraulic Gradient	**9.5**
Optimum Moisture Content (%)	**12.5**	Surcharge (kPa)	**3.6**
Placement Moisture Content (%)	**12.5**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**100.2**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.96**	Percentage Material Retained/Sieve Size (mm)	**2 % /19 mm**
Density Ratio (%)	**90.1**	Sample Height and Diameter (mm)	**116.1 / 152.47 mm**

PERMEABILITY $k_{(20)}$ = 1.1 x 10^{-05} (m/sec)



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

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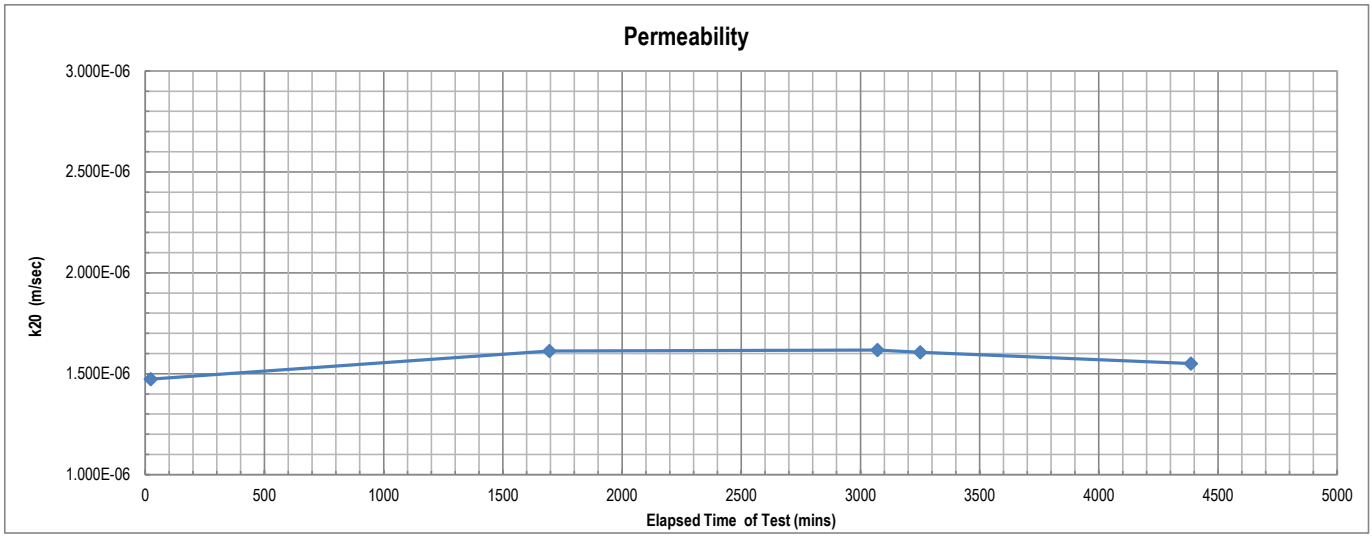
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120156-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	4/01/2022
		Report Date	14/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	6 - 2021044_C006	**Depth (m)**	Not Supplied
Description	Silty CLAY with gravel - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.84**	Hydraulic Gradient	**9.6**
Optimum Moisture Content (%)	**13.8**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**13.2**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**96.0**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.89**	Percentage Material Retained/Sieve Size (mm)	**2 % /19 mm**
Density Ratio (%)	**90.5**	Sample Height and Diameter (mm)	**115.07 / 152.47 mm**

PERMEABILITY $k_{(20)} =$ **1.6×10^{-06} (m/sec)**



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

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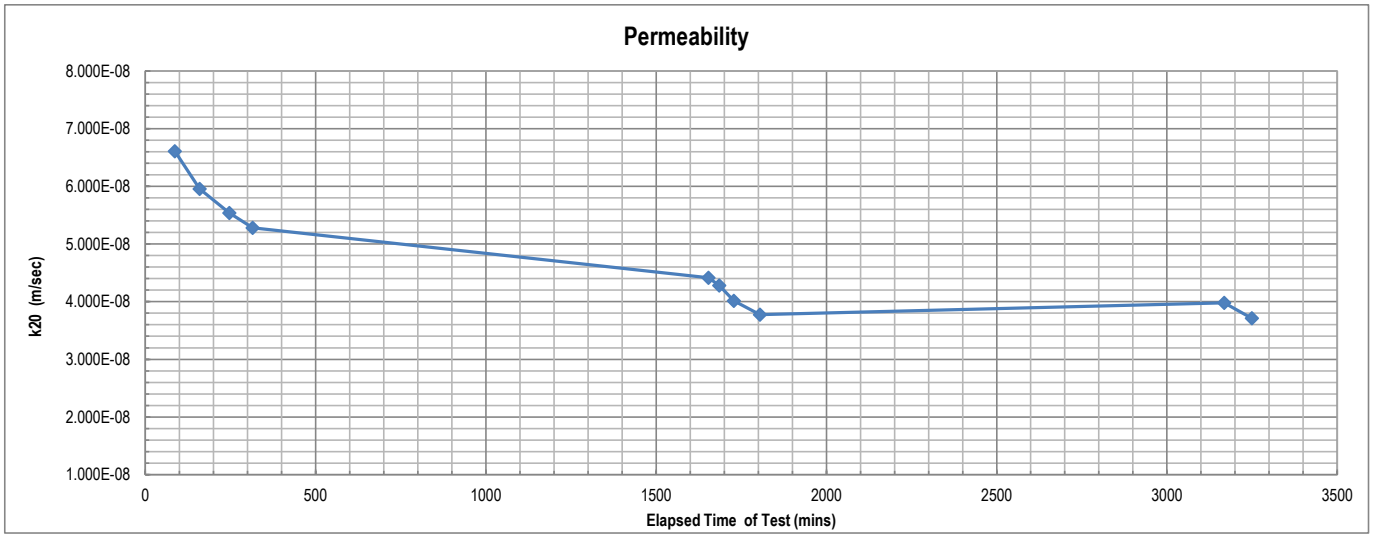
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120158-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	4/01/2022
		Report Date	14/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	8 - 2021044_C008	**Depth (m)**	Not Supplied
Description	Silty CLAY trace gravel - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.90**	Hydraulic Gradient	**9.5**
Optimum Moisture Content (%)	**13.3**	Surcharge (kPa)	**3.6**
Placement Moisture Content (%)	**13.5**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**101.6**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.94**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**89.9**	Sample Height and Diameter (mm)	**116.23 / 152.4 mm**

PERMEABILITY $k_{(20)}$ = 3.8×10^{-08} (m/sec)



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client | The compaction data was supplied by the client. | Tested as received | **Page: 1 of 1** | REP06301

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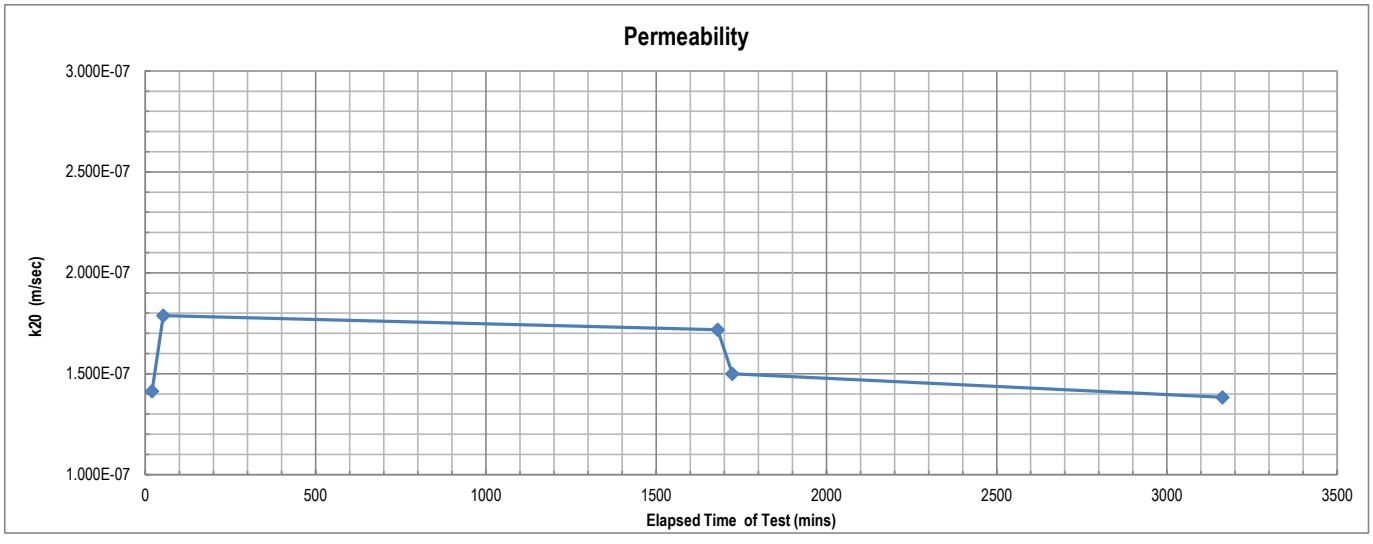
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120159-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	4/01/2022
		Report Date	14/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	9 - 2021044_C009	**Depth (m)**	Not Supplied
Description	Gravelly Silty CLAY - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.81**	Hydraulic Gradient	**9.5**
Optimum Moisture Content (%)	**14.0**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**14.5**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**103.6**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.86**	Percentage Material Retained/Sieve Size (mm)	**8.4 % /19 mm**
Density Ratio (%)	**89.6**	Sample Height and Diameter (mm)	**115.88 / 152.38 mm**

PERMEABILITY $k_{(20)}$ = 1.4 x 10^{-07} (m/sec)



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

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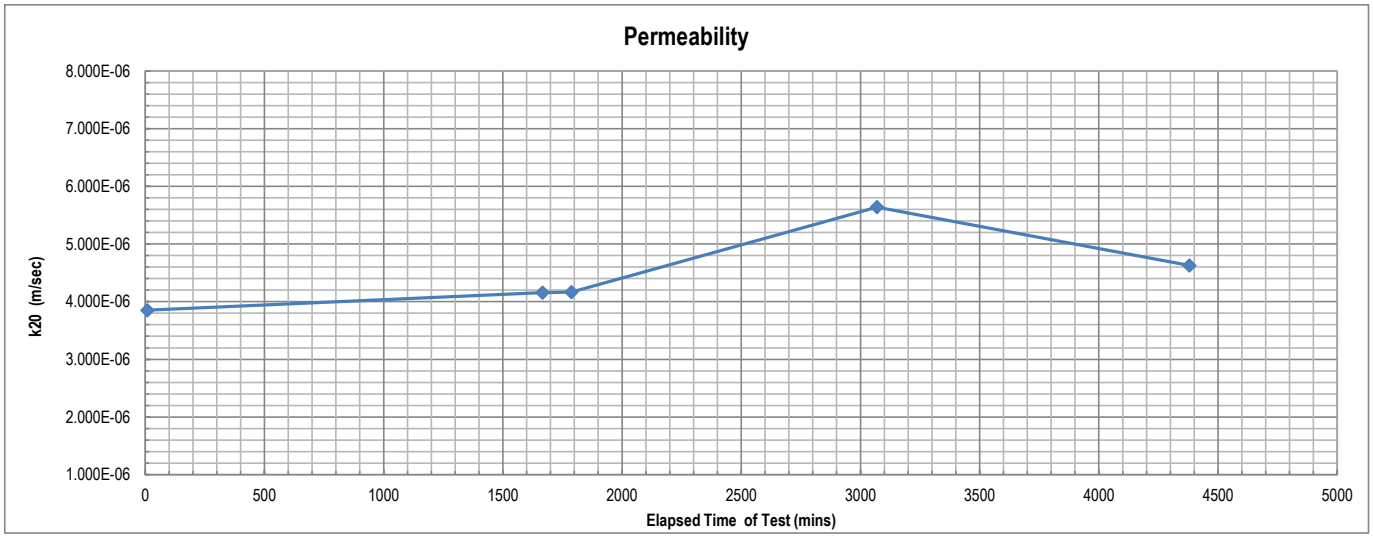
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120162-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	4/01/2022
		Report Date	14/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	12 - 2021044_C012	**Depth (m)**	Not Supplied
Description	Gravelly SILT - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.77**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**15.5**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**15.7**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**101.5**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.84**	Percentage Material Retained/Sieve Size (mm)	**14 % /19 mm**
Density Ratio (%)	**89.9**	Sample Height and Diameter (mm)	**116.47 / 152.22 mm**

PERMEABILITY $k_{(20)}$ = 4.6×10^{-06} (m/sec)



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

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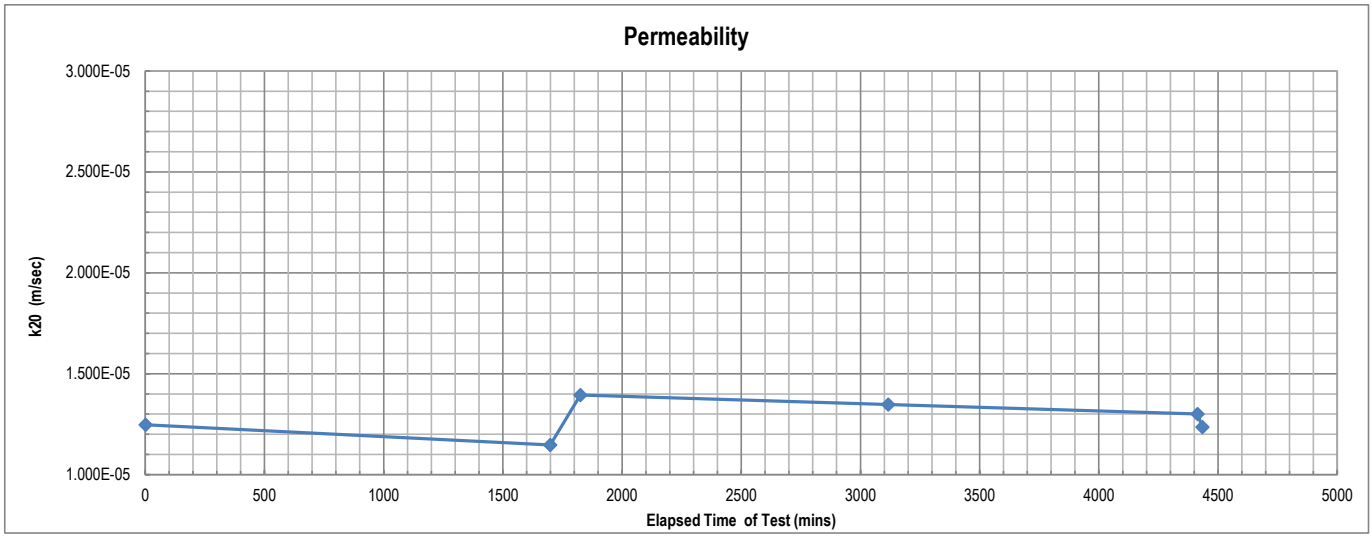
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120165-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	4/01/2022
		Report Date	14/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	15 - 2021044_C015	**Depth (m)**	Not Supplied
Description	Gravelly SILT - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.72**	Hydraulic Gradient	**9.5**
Optimum Moisture Content (%)	**15.3**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**15.4**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**100.4**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.79**	Percentage Material Retained/Sieve Size (mm)	**11 % /19 mm**
Density Ratio (%)	**90.0**	Sample Height and Diameter (mm)	**116.16 / 152.27 mm**

PERMEABILITY $k_{(20)}$ = 1.3×10^{-05} (m/sec)



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

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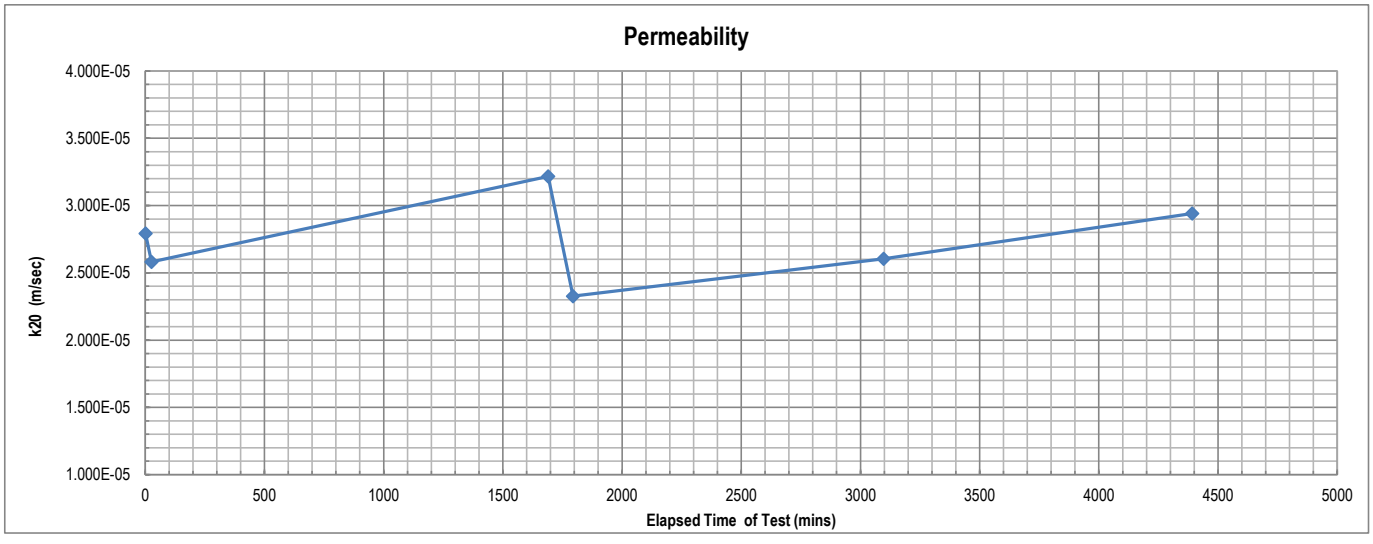
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120167-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	4/01/2022
		Report Date	10/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	17 - 2021044_C017	**Depth (m)**	Not Supplied
Description	SILT with gravel - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.79**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**15.4**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**15.1**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**97.7**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.86**	Percentage Material Retained/Sieve Size (mm)	**12 % /19 mm**
Density Ratio (%)	**90.3**	Sample Height and Diameter (mm)	**116.42 / 152.37 mm**

PERMEABILITY $k_{(20)} =$ **2.9×10^{-05} (m/sec)**



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

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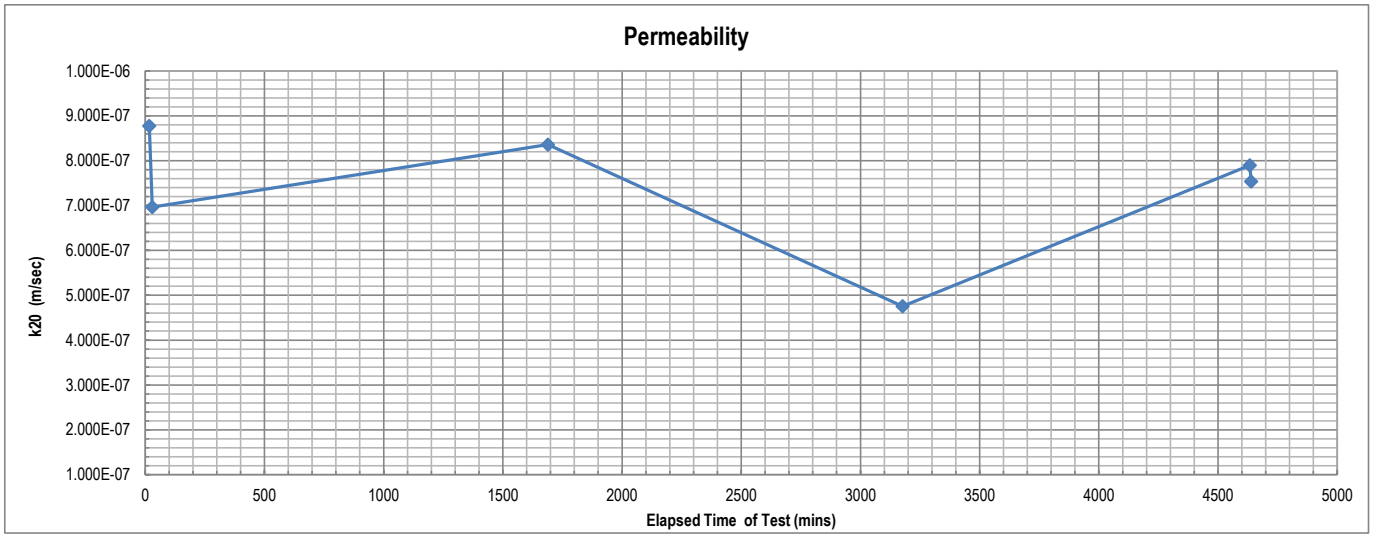
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120168-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	4/01/2022
		Report Date	14/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	18 - 2021044_C018	**Depth (m)**	Not Supplied
Description	Gravelly SILT - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.89**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**12.6**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**12.7**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**101.0**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.92**	Percentage Material Retained/Sieve Size (mm)	**8.4 % /19 mm**
Density Ratio (%)	**89.9**	Sample Height and Diameter (mm)	**116.67 / 152.22 mm**

PERMEABILITY $k_{(20)}$ = 7.7×10^{-07} (m/sec)



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

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PERMEABILITY BY FALLING HEAD TEST REPORT

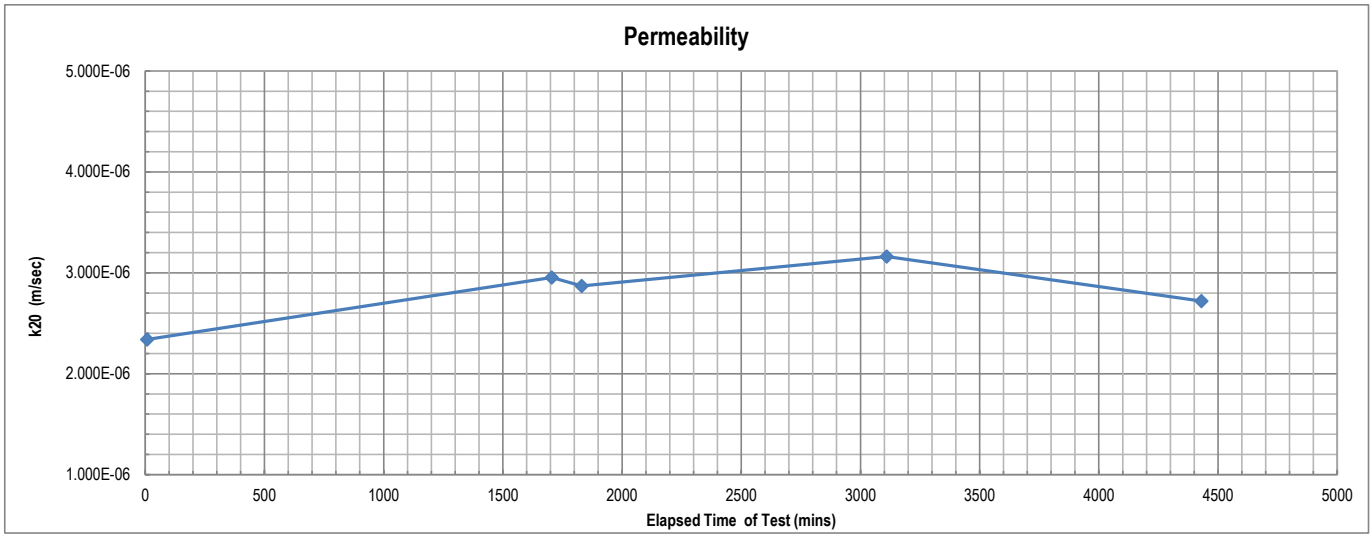
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120170-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	4/01/2022
		Report Date	7/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	20 - 2021044_C020	**Depth (m)**	Not Supplied
Description	SILT with gravel-brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.88**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**12.7**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**12.4**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**97.4**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.91**	Percentage Material Retained/Sieve Size (mm)	**7.3 % /19 mm**
Density Ratio (%)	**90.3**	Sample Height and Diameter (mm)	**116.5 / 152.23 mm**

PERMEABILITY $k_{(20)}$ = 2.7×10^{-06} (m/sec)



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client

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Tested at Trilab Brisbane Laboratory

Authorised Signatory
C. Purvis

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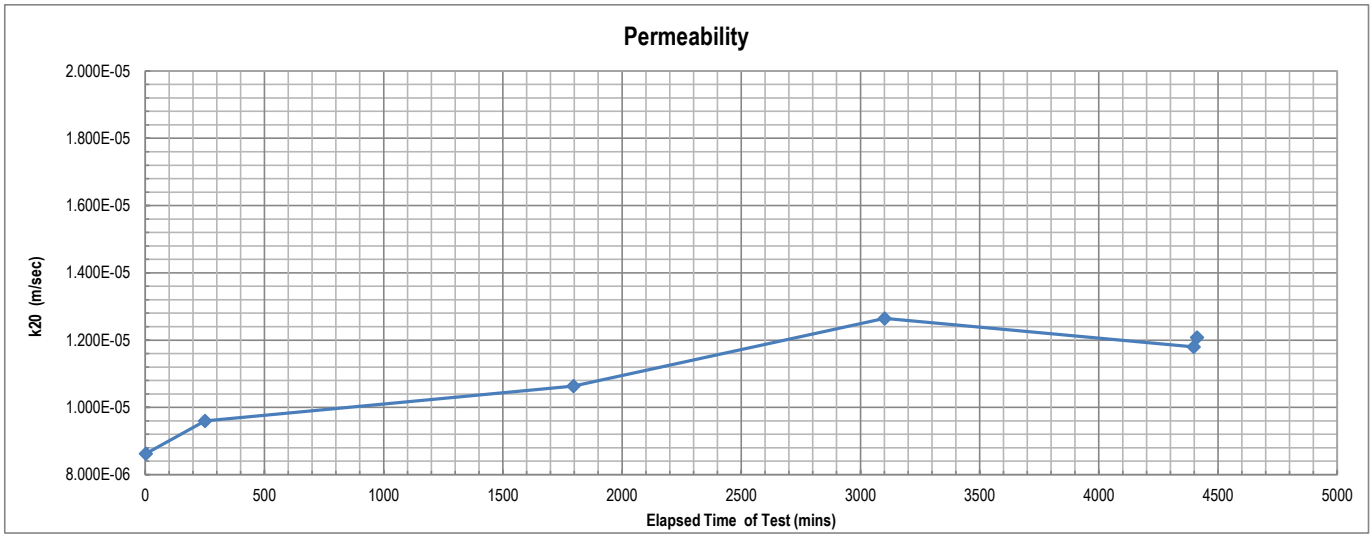
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120171-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	10/01/2022
		Report Date	14/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	21 - 2021044_C021	**Depth (m)**	Not Supplied
Description	GRAVELLY SILT -brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.82**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**14.0**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**14.4**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**103.1**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.87**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**89.6**	Sample Height and Diameter (mm)	**116.67 / 152.22 mm**

PERMEABILITY $k_{(20)}$ = 1.2×10^{-05} (m/sec)



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

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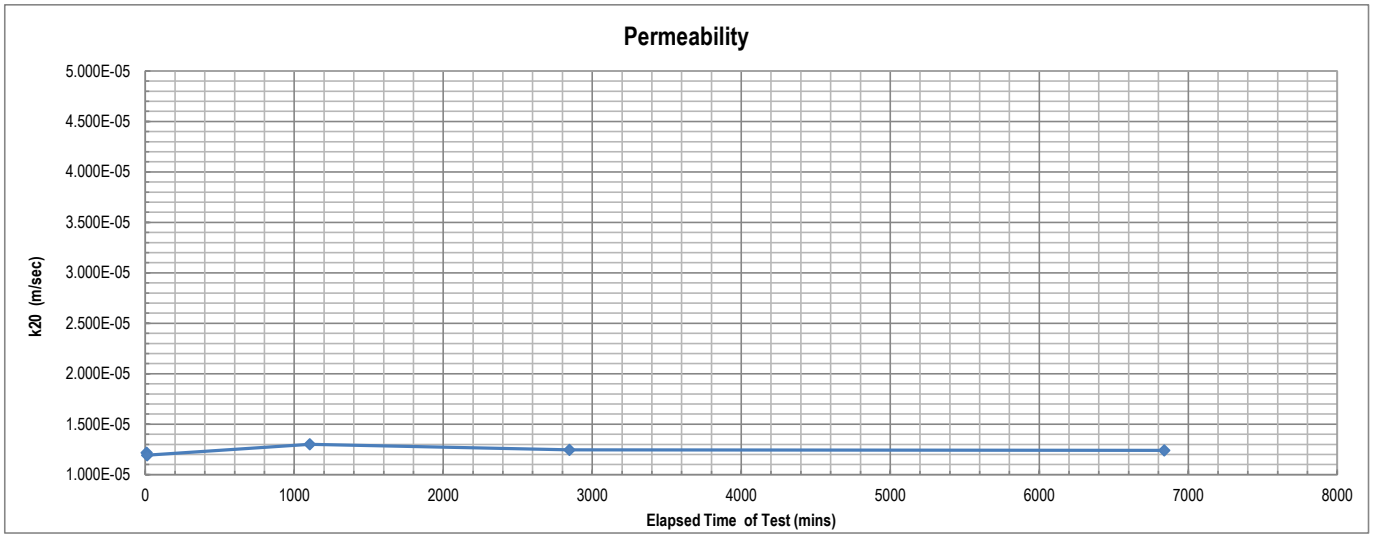
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120172-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	19/01/2022
		Report Date	2/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	22 - 2021044_C022	**Depth (m)**	Not Supplied
Description	SILTY GRAVEL - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.95**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**11.9**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**11.8**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**99.3**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.96**	Percentage Material Retained/Sieve Size (mm)	**14 % /19 mm**
Density Ratio (%)	**90.1**	Sample Height and Diameter (mm)	**116.41 / 152.4 mm**

PERMEABILITY $k_{(20)}$ = 1.2×10^{-05} (m/sec)



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client

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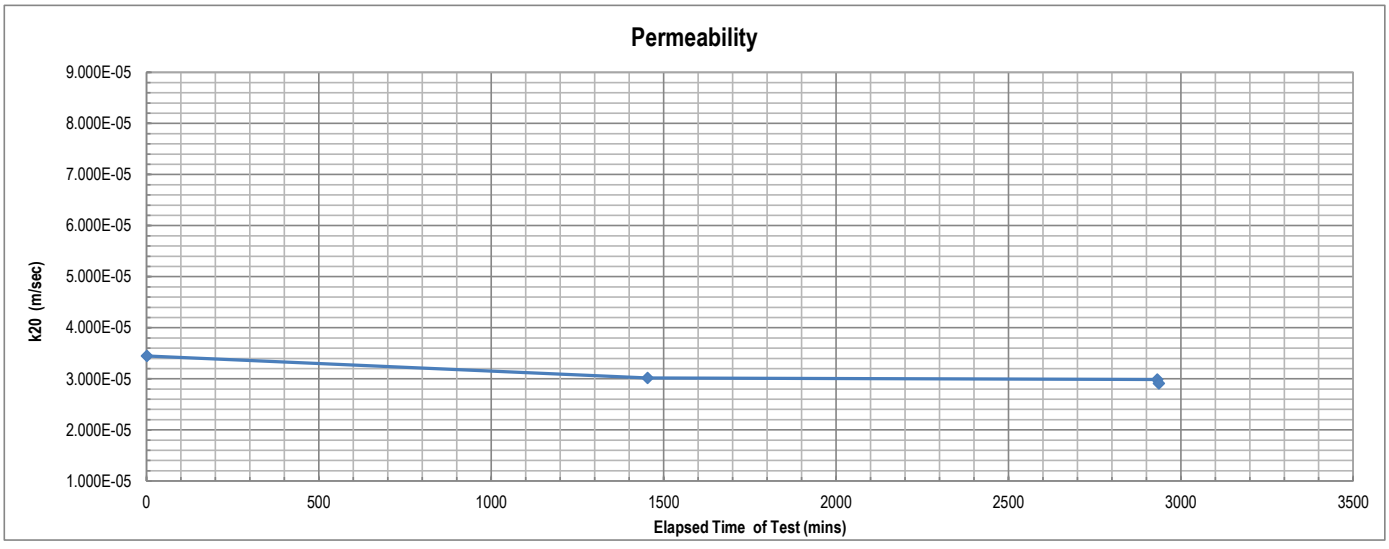
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120173A-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	28/02/2022
		Report Date	2/03/2022
Project	2021044 - LLM RMSAP2		
Client ID	23 - 2021044_C023	**Depth (m)**	Not Supplied
Description	Silty GRAVEL-brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.73**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**15.6**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**15.8**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**101.2**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.79**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**89.3**	Sample Height and Diameter (mm)	**116.75 / 152.35 mm**

PERMEABILITY $k_{(20)}$ = 2.9 x 10^{-05} (m/sec)



Remarks:	The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.
	This report replaces 21120173-FHPT issued on the 31/1/2022.

Sample/s supplied by client +19mm material crushed and added to sample prior to testing. **Page: 1 of 1** REP06301

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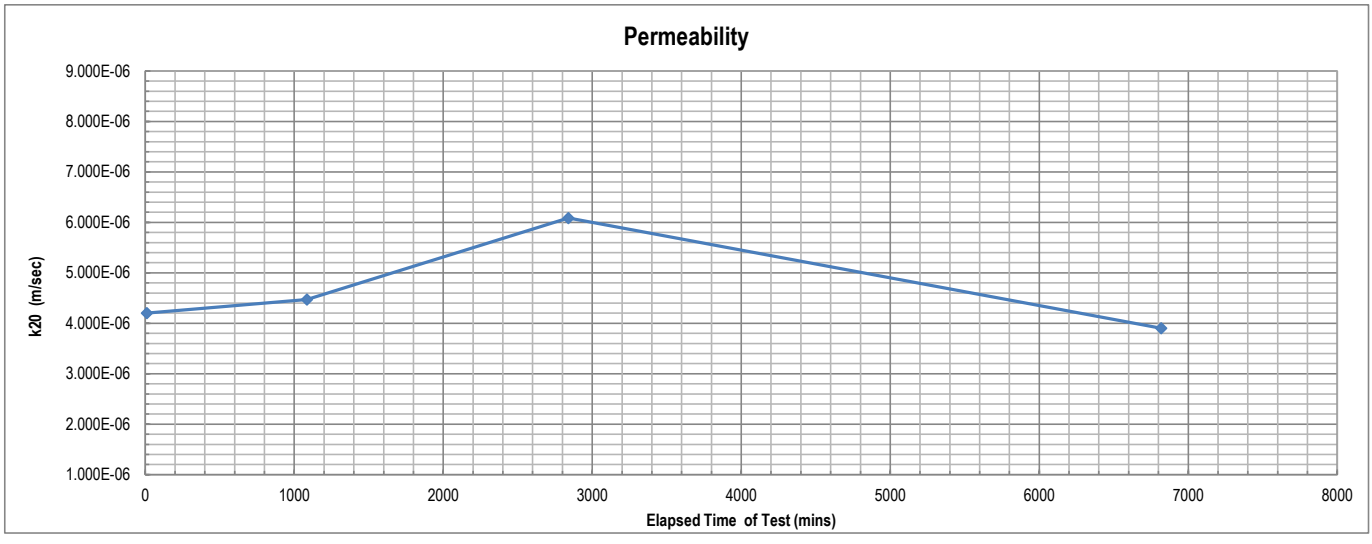
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120174-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	19/01/2022
		Report Date	31/01/2022
Project	2021044 - LLM RMSAP2		
Client ID	24 - 2021044_C024	**Depth (m)**	Not Supplied
Description	SILT with gravel - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.92**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**12.4**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**12.6**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**101.5**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.94**	Percentage Material Retained/Sieve Size (mm)	**3 % /19 mm**
Density Ratio (%)	**89.9**	Sample Height and Diameter (mm)	**116.5 / 152.23 mm**

PERMEABILITY $k_{(20)}$ = 3.9×10^{-06} (m/sec)



Remarks: The above specimen was remoulded to a target of 90% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client

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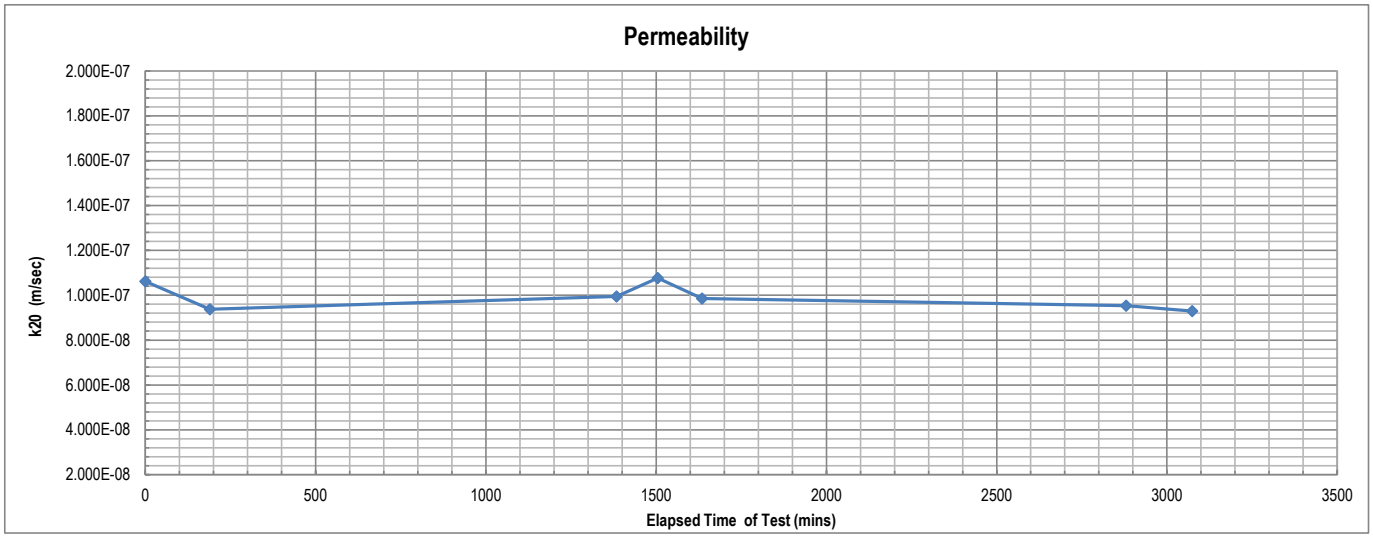
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120151-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	7/02/2022
		Report Date	15/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	1 - 2021044_C001	**Depth (m)**	Not Supplied
Description	SANDY SILTY GRAVEL - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.86**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**12.5**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**12.1**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**97.0**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.99**	Percentage Material Retained/Sieve Size (mm)	**4 % /19 mm**
Density Ratio (%)	**95.3**	Sample Height and Diameter (mm)	**116.67 / 152.22 mm**

PERMEABILITY $k_{(20)} = 9.4 \times 10^{-08}$ (m/sec)



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client

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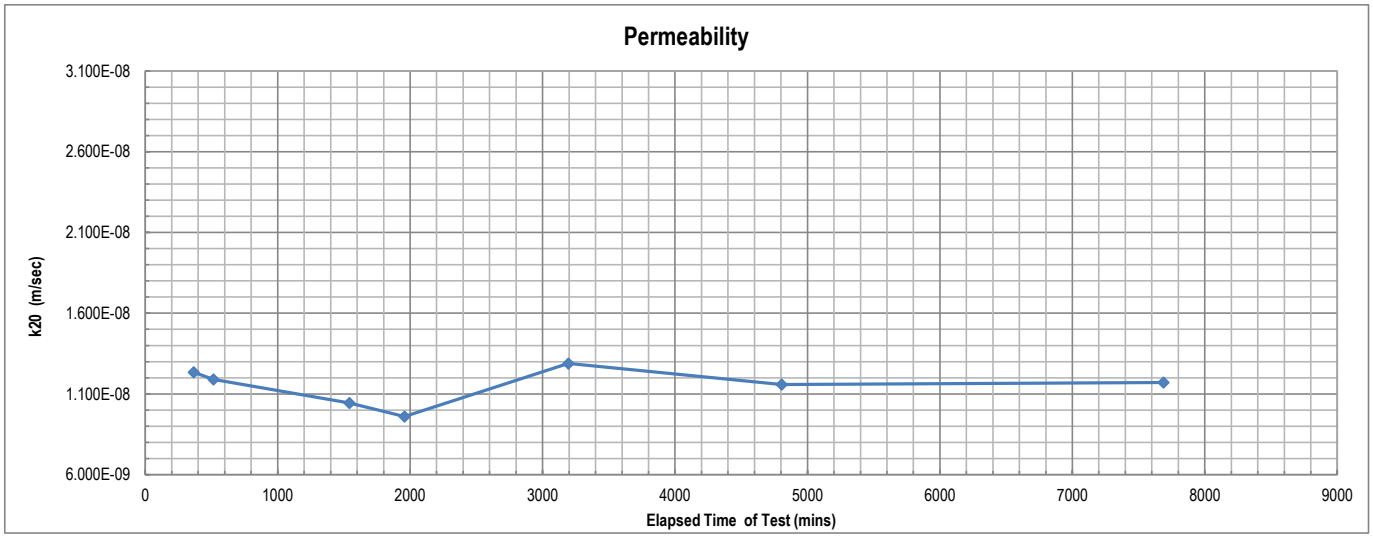
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120152-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	9/02/2022
		Report Date	16/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	2 - 2021044_C002	**Depth (m)**	Not Supplied
Description	Sandy SILT with gravel - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.83**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**12.9**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**12.8**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**99.3**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.96**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**95.1**	Sample Height and Diameter (mm)	**116.42 / 152.37 mm**

PERMEABILITY $k_{(20)}$ = 1.2×10^{-08} (m/sec)



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client +19mm material was crushed and added to sample prior to testing

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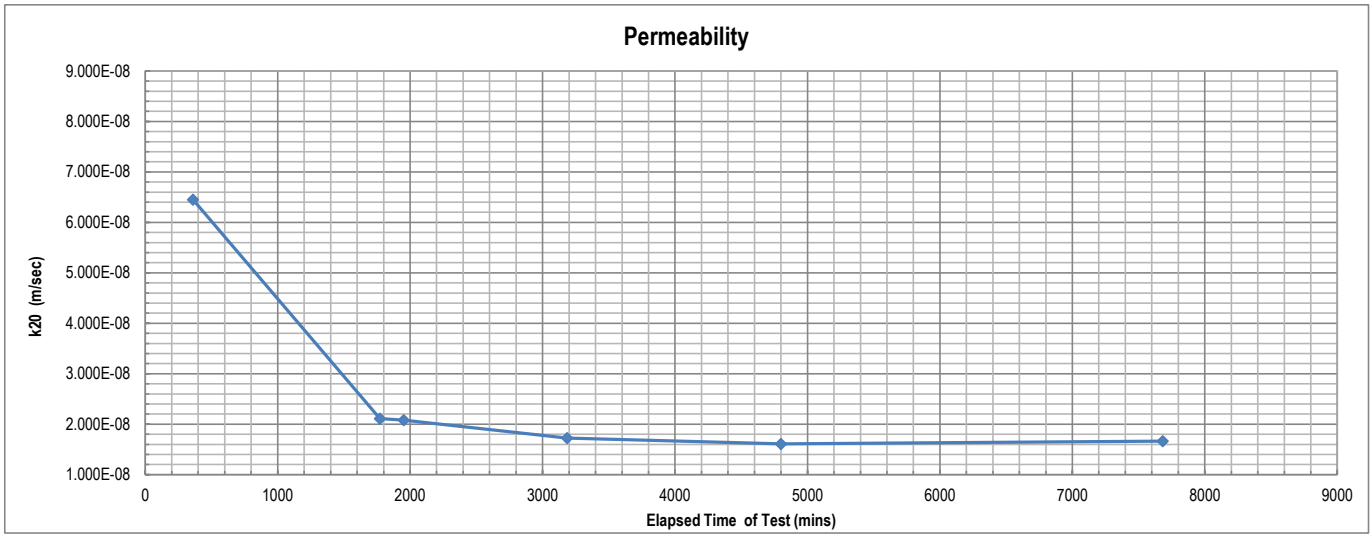
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120155-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	9/02/2022
		Report Date	17/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	5 - 2021044_C005	**Depth (m)**	Not Supplied
Description	Gravelly Silty CLAY - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.93**	Hydraulic Gradient	**9.5**
Optimum Moisture Content (%)	**12.5**	Surcharge (kPa)	**3.6**
Placement Moisture Content (%)	**12.5**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**100.2**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**2.06**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**95.0**	Sample Height and Diameter (mm)	**116 / 152.02 mm**

PERMEABILITY $k_{(20)} = 1.7 \times 10^{-08}$ (m/sec)



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client +19mm material crushed and added to sample prior to testing

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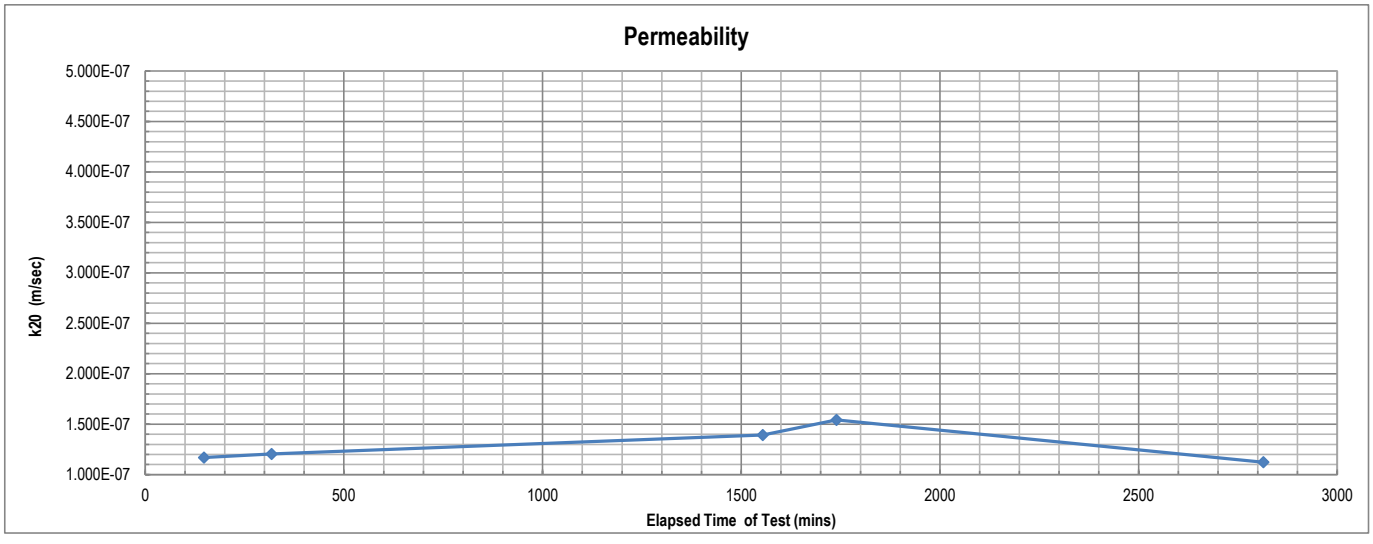
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120156-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	8/02/2022
		Report Date	17/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	6 - 2021044_C006	**Depth (m)**	Not Supplied
Description	GRAVELLY SANDY SILT- brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.84**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**13.8**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**13.7**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**98.9**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.99**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**95.2**	Sample Height and Diameter (mm)	**116.41 / 152.4 mm**

PERMEABILITY $k_{(20)} =$ **1.1×10^{-07} (m/sec)**



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client +19mm material crushed and added to sample prior to testing

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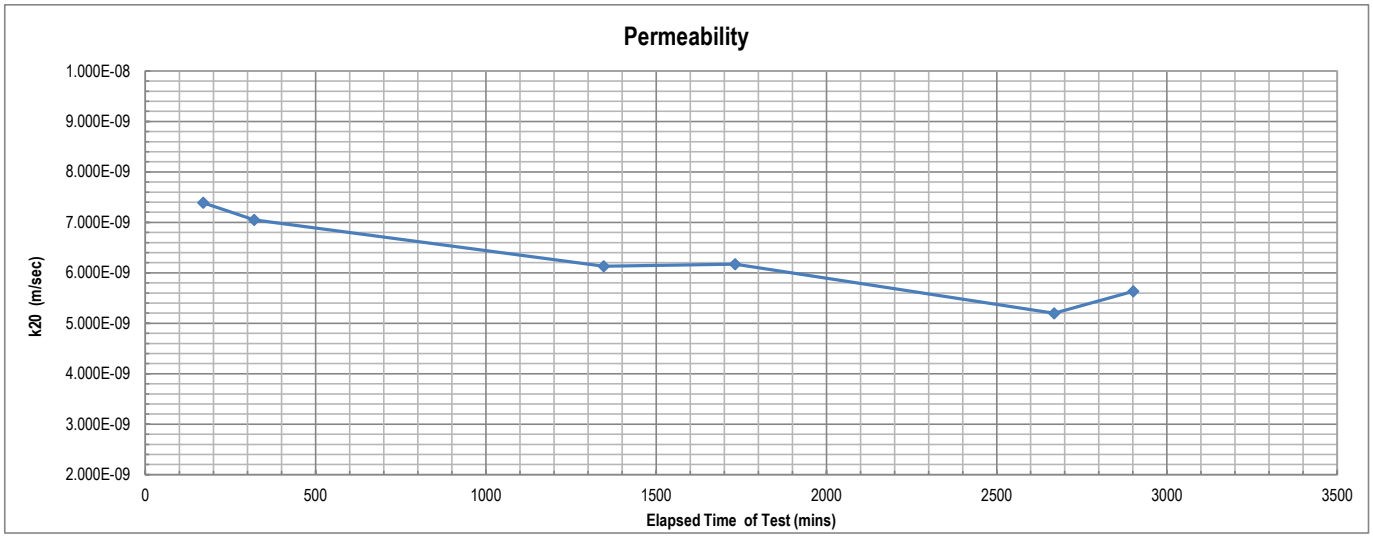
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120158-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	8/02/2022
		Report Date	11/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	8 - 2021044_C008	**Depth (m)**	Not Supplied
Description	Gravelly Clayey SILT - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.90**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**13.3**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**13.7**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**102.7**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**2.05**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**94.7**	Sample Height and Diameter (mm)	**116.5 / 152.23 mm**

PERMEABILITY $k_{(20)} =$ **5.4×10^{-09} (m/sec)**



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client +19mm material crushed and added to sample prior to testing

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Tested at Trilab Brisbane Laboratory

Authorised Signatory

C. Channon

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PERMEABILITY BY FALLING HEAD TEST REPORT

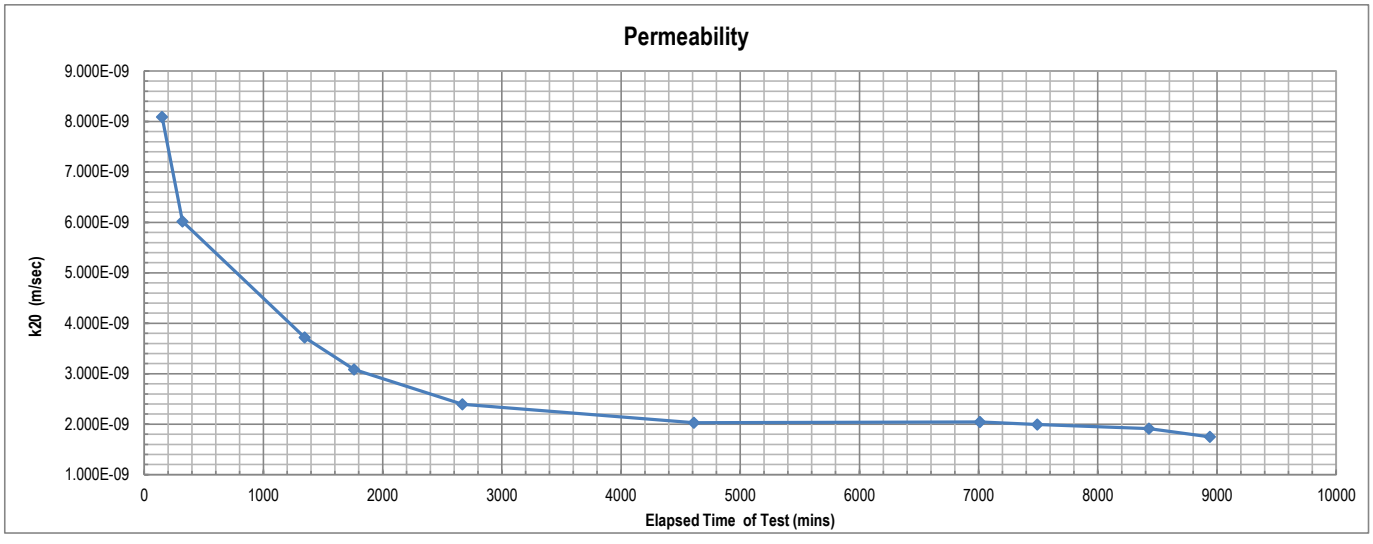
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120159-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	8/02/2022
		Report Date	17/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	9 - 2021044_C009	**Depth (m)**	Not Supplied
Description	Gravelly Clayey SILT -brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.81**	Hydraulic Gradient	**9.6**
Optimum Moisture Content (%)	**14.0**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**13.9**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**99.0**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.96**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**95.1**	Sample Height and Diameter (mm)	**115.07 / 152.47 mm**

PERMEABILITY $k_{(20)} = 1.8 \times 10^{-09}$ **(m/sec)**



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client +19mm material crushed and added to sample prior to testing

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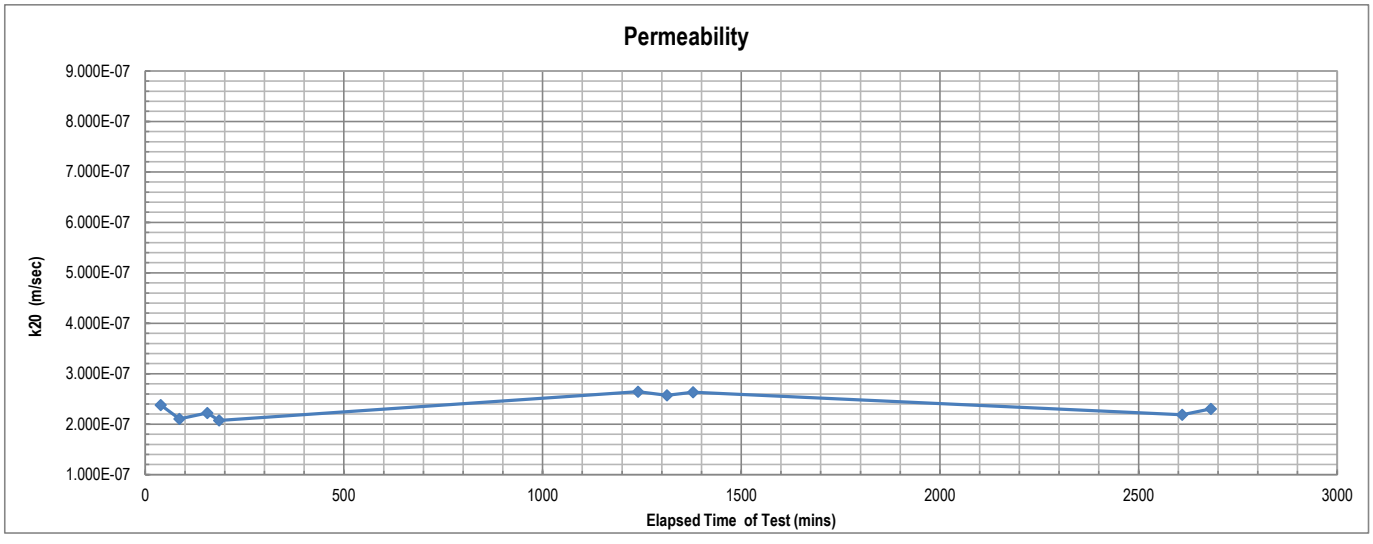
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120162-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	21/02/2022
		Report Date	25/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	12 - 2021044_C012	**Depth (m)**	Not Supplied
Description	Silty Sandy GRAVEL - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.77**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**15.5**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**15.1**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**97.3**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.94**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**95.4**	Sample Height and Diameter (mm)	**116.6 / 152.36 mm**

PERMEABILITY $k_{(20)} =$ **2.2×10^{-07} (m/sec)**



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client +19mm material crushed and added to sample prior to testing.

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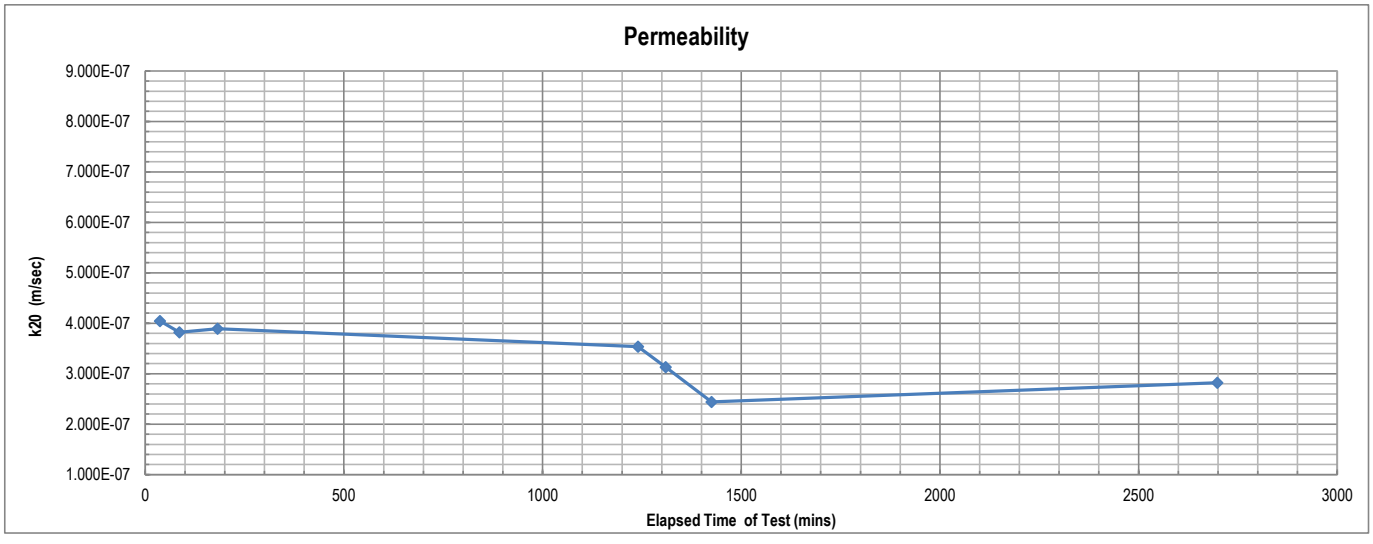
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120165-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/02/2022
		Report Date	23/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	15 - 2021044_C015	**Depth (m)**	Not Supplied
Description	Silty Sandy GRAVEL - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.72**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**15.3**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**14.9**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**97.5**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.88**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**95.4**	Sample Height and Diameter (mm)	**116.41 / 152.4 mm**

PERMEABILITY $k_{(20)} =$ **2.8×10^{-07} (m/sec)**



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client +19mm material crushed and added to sample prior to testing.

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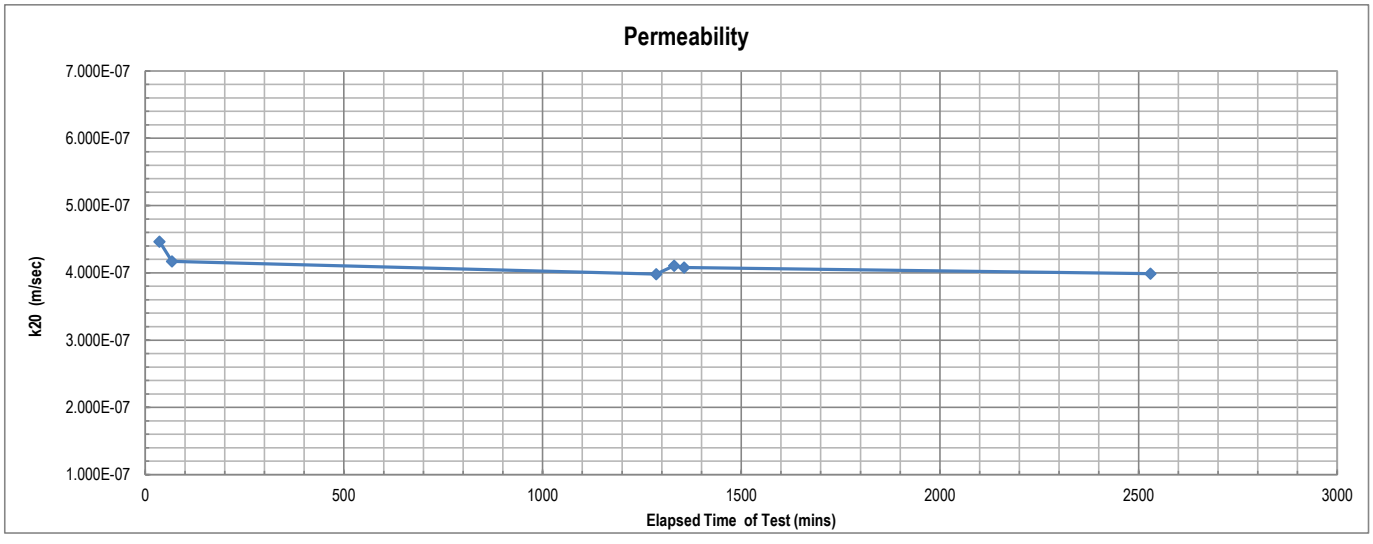
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120167-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/02/2022
		Report Date	24/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	17 - 2021044_C017	**Depth (m)**	Not Supplied
Description	Silty Sandy GRAVEL - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.79**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**15.4**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**16.0**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**103.7**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.96**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**94.6**	Sample Height and Diameter (mm)	**116.5 / 152.23 mm**

PERMEABILITY $k_{(20)} =$ **4.0×10^{-07} (m/sec)**



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client +19mm material crushed and added to sample prior to testing.

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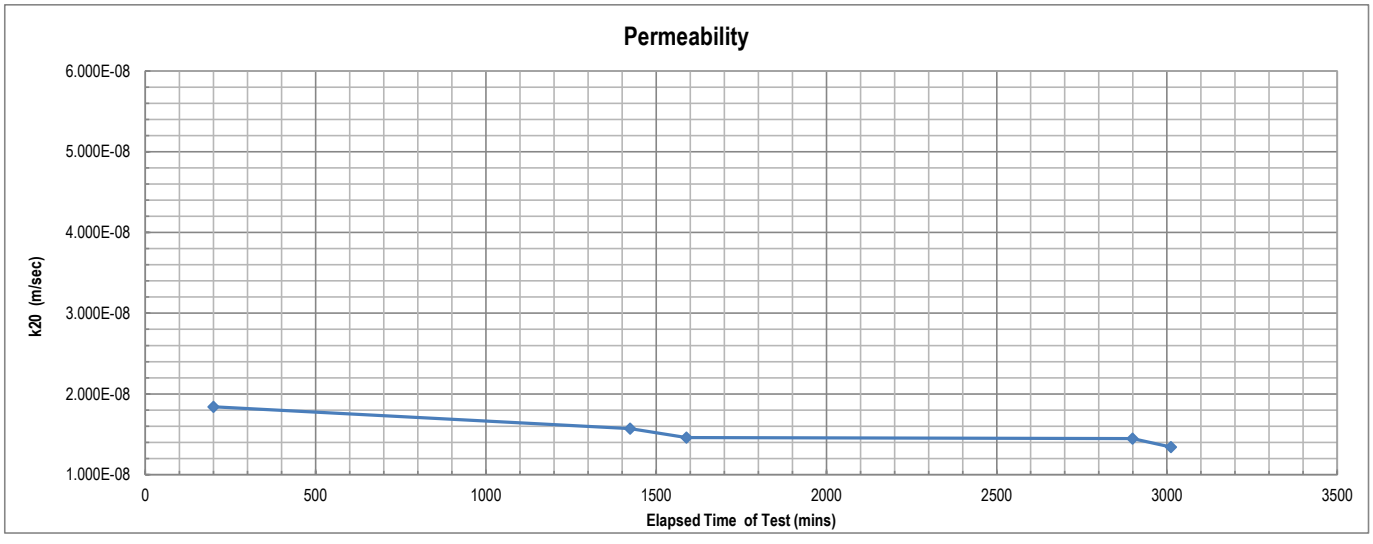
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120168-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/02/2022
		Report Date	24/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	18 - 2021044_C018	**Depth (m)**	Not Supplied
Description	Silty Sandy GRAVEL - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.89**	Hydraulic Gradient	**9.5**
Optimum Moisture Content (%)	**12.6**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**12.2**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**97.1**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**2.02**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**95.2**	Sample Height and Diameter (mm)	**116.16 / 152.27 mm**

PERMEABILITY $k_{(20)} = 1.4 \times 10^{-08}$ **(m/sec)**



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

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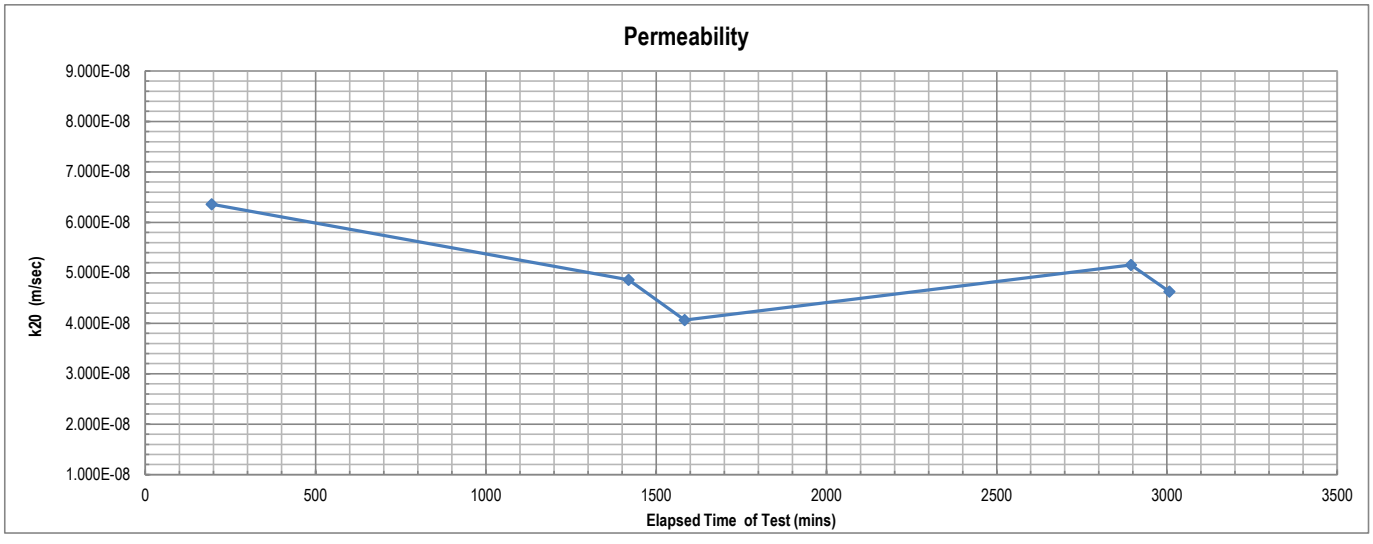
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120170-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/02/2022
		Report Date	24/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	20 - 2021044_C020	**Depth (m)**	Not Supplied
Description	Silty Sandy GRAVEL - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.88**	Hydraulic Gradient	**9.5**
Optimum Moisture Content (%)	**12.7**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**12.3**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**97.0**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**2.01**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**95.4**	Sample Height and Diameter (mm)	**115.88 / 152.38 mm**

PERMEABILITY $k_{(20)}$ = 4.9×10^{-08} (m/sec)



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

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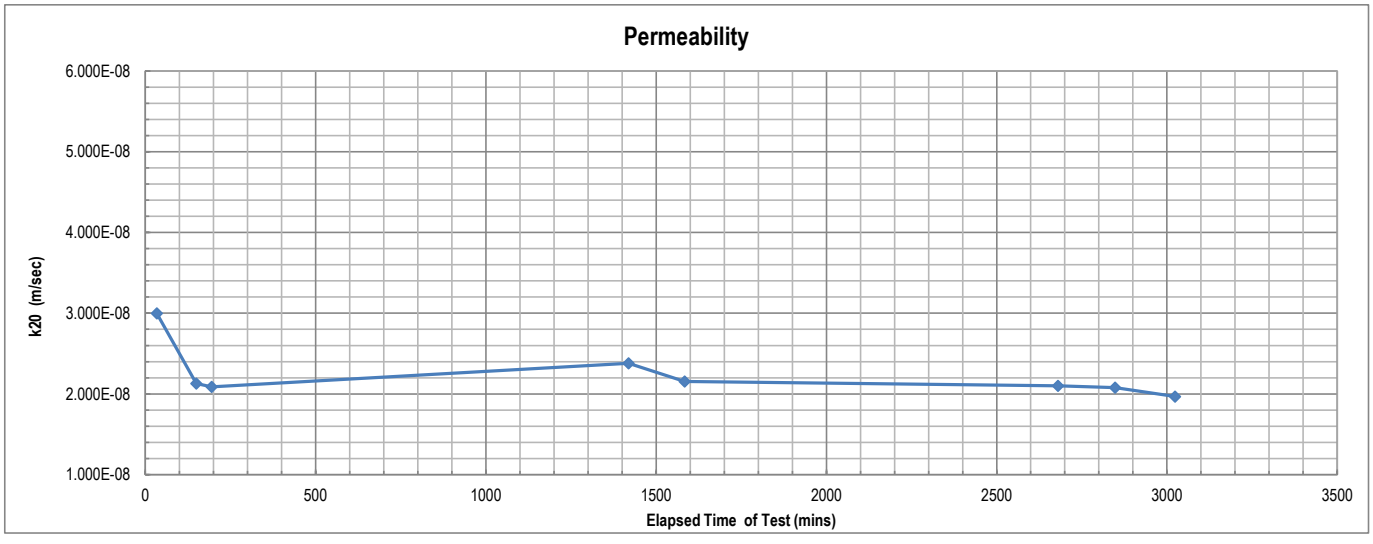
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120171-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	21/02/2022
		Report Date	25/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	21 - 2021044_C021	**Depth (m)**	Not Supplied
Description	Silty Sandy GRAVEL - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.82**	Hydraulic Gradient	**9.5**
Optimum Moisture Content (%)	**14.0**	Surcharge (kPa)	**3.6**
Placement Moisture Content (%)	**14.0**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**99.9**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.97**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**95.0**	Sample Height and Diameter (mm)	**116.23 / 152.4 mm**

PERMEABILITY $k_{(20)} =$ **2.0×10^{-08} (m/sec)**



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

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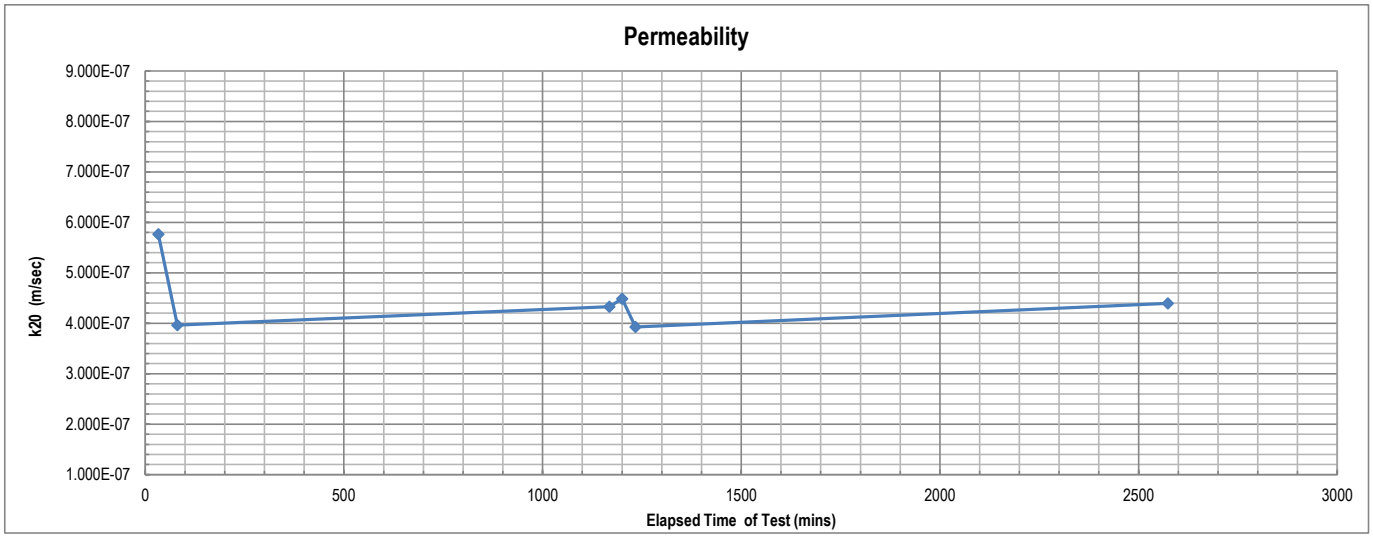
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120172-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/02/2022
		Report Date	24/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	22 - 2021044_C022	**Depth (m)**	Not Supplied
Description	Silty Sandy GRAVEL - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.95**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**11.9**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**12.0**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**101.0**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**2.07**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**94.9**	Sample Height and Diameter (mm)	**116.67 / 152.22 mm**

PERMEABILITY $k_{(20)} =$ **4.4×10^{-07} (m/sec)**



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client +19mm material crushed and added to sample prior to testing. **Page: 1 of 1** REP06301

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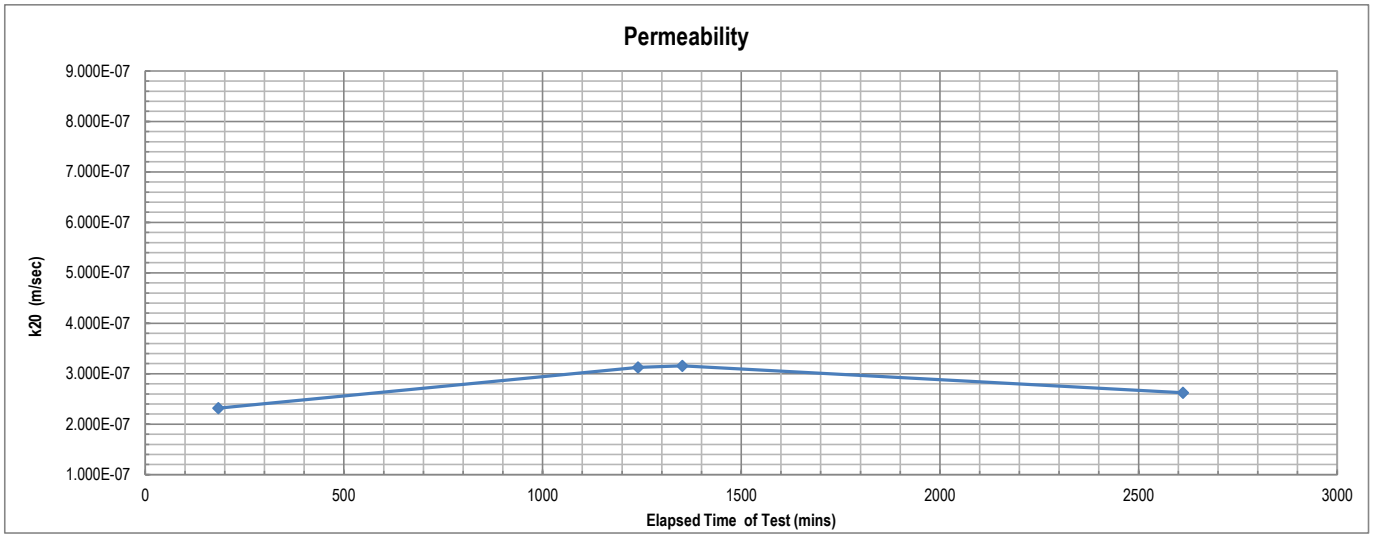
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120173-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	21/02/2022
		Report Date	3/03/2022
Project	2021044 - LLM RMSAP2		
Client ID	23 - 2021044_C023	**Depth (m)**	Not Supplied
Description	Silty GRAVEL - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.72**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**15.6**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**16.0**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**102.8**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**1.89**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**94.7**	Sample Height and Diameter (mm)	**116.75 / 152.35 mm**

PERMEABILITY $k_{(20)} =$ **2.6×10^{-07} (m/sec)**



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

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PERMEABILITY BY FALLING HEAD TEST REPORT

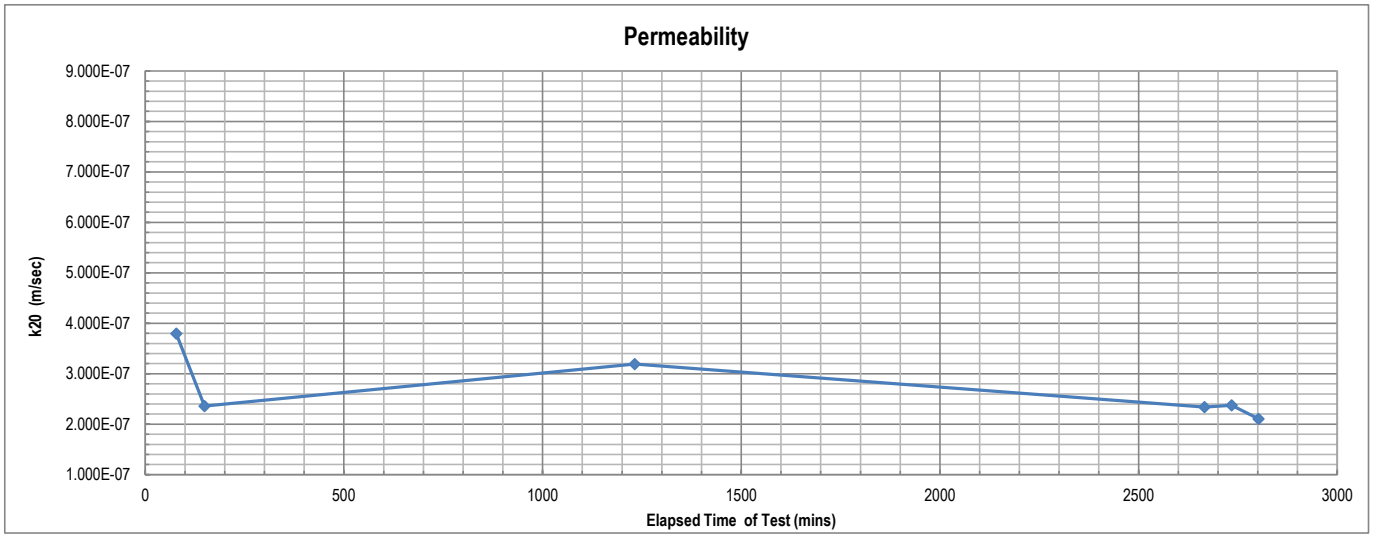
Test Method AS 1289 6.7.2, 5.1.1

Client	RGS Environmental Pty Ltd	**Report No.**	21120174-FHPT
		Workorder No.	0009363
Address	PO Box 3091, Sunnybank South QLD 4109	**Test Date**	18/02/2022
		Report Date	24/02/2022
Project	2021044 - LLM RMSAP2		
Client ID	24 - 2021044_C024	**Depth (m)**	Not Supplied
Description	Silty Sandy GRAVEL - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**1.92**	Hydraulic Gradient	**9.4**
Optimum Moisture Content (%)	**12.4**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**12.4**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**99.9**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**2.05**	Percentage Material Retained/Sieve Size (mm)	**0 % /19 mm**
Density Ratio (%)	**95.0**	Sample Height and Diameter (mm)	**116.47 / 152.22 mm**

PERMEABILITY $k_{(20)} =$ **2.3×10^{-07} (m/sec)**



Remarks: The above specimen was remoulded to a target of 95% of Standard Maximum Dry Density and at Optimum Moisture Content.

Sample/s supplied by client +19mm material crushed and added to sample prior to testing.

Accredited for compliance with ISO/IEC 17025 - Testing.
The results of the tests, calibrations, and/or measurements included in this document are traceable to Australian/National Standards.

Tested at Trilab Brisbane Laboratory

Authorised Signatory

C. Channon

NATA ACCREDITED FOR TECHNICAL COMPETENCE

Laboratory No. 9926

The results of calibrations and tests performed apply only to the specific instrument or sample at the time of test unless otherwise clearly stated.
Reference should be made to Trilab's "Standard Terms and Conditions of Business" for further details.
Trilab Pty Ltd ABN 25 065 630 506

ACCURATE QUALITY RESULTS FOR TOMORROW'S ENGINEERING

7.8 Attachment H: Soil Water Group Laboratory Certificates

SOIL WATER ANALYSIS (SWA)

soilwater GROUP
45 Gladstone St
East Perth WA 6006
(08) 9228 3060
(08) 9228 3210
admin@soilwatergroup.com
www.soilwatergroup.com

ANALYSIS REPORT

Water Retention (Pressure Plate Method)

Client:	Trilab Pty Ltd
Client Contact:	Chris Channon
Client Job Title:	2021044 - LLM RMSAP2
Client PO:	BNE 2212024
SWA Job No:	JN0774
Date of Analysis:	18 - 28 February 2022
No. Samples Submitted:	24

METHODOLOGY

- Pressure plate method used in accordance with McKenzie, N., Coughlan, K. and Cresswell, H. (2002). Soil Physical Measurement and Interpretation for Land Evaluation, CSIRO Publishing.
- Samples packed to a bulk density of 1.35 g/cm^3 on the pressure plates.
- Samples equilibrated for a 2 week period.

TEST RESULTS

SWA ID	Client ID	Water Retention Data (v/v)					van Genuchten parameters			
		0 kPa	10 kPa	33 kPa	100 kPa	1500 kPa	α [1/cm]	n [-]	Θ_s	Θ_r
774-01	C001	0.40	0.24	0.22	0.20	0.16	1.000	1.158	0.41	0.09
774-02	C002	0.44	0.25	0.22	0.20	0.15	1.000	1.157	0.44	0.07
774-03	C003	0.46	0.29	0.25	0.22	0.13	0.182	1.153	0.46	0.00
774-04	C004	0.46	0.31	0.26	0.22	0.13	0.080	1.174	0.46	0.00

SWA ID	Client ID	Water Retention Data (v/v)					van Genuchten parameters			
		0 kPa	10 kPa	33 kPa	100 kPa	1500 kPa	α [1/cm]	n [-]	Θ_s	Θ_r
774-05	C005	0.44	0.21	1.18	0.16	0.13	0.999	1.246	0.44	0.10
774-06	C006	0.46	0.21	0.19	0.18	0.14	1.000	1.263	0.47	0.11
774-07	C007	0.48	0.35	0.31	0.25	0.14	0.043	1.178	0.48	0.00
774-08	C008	0.48	0.23	0.20	0.19	0.17	1.000	1.334	0.48	0.16
774-09	C009	0.52	0.25	0.24	0.22	0.17	0.084	1.694	0.52	0.17
774-10	C010	0.48	0.36	0.30	0.24	0.14	0.038	1.192	0.48	0.00
774-11	C011	0.50	0.34	0.29	0.23	0.13	0.054	1.196	0.50	0.00
774-12	C012	0.49	0.32	0.28	0.23	0.15	0.149	1.154	0.49	0.00
774-13	C013	0.43	0.28	0.23	0.16	0.12	0.040	1.377	0.43	0.09
774-14	C014	0.38	0.20	0.18	0.15	0.09	0.487	1.157	0.38	0.00
774-15	C015	0.45	0.26	0.24	0.20	0.13	0.347	1.144	0.45	0.00
774-16	C016	0.52	0.34	0.27	0.20	0.10	0.046	1.248	0.52	0.00
774-17	C017	0.42	0.31	0.26	0.20	0.09	0.023	1.250	0.42	0.00
774-18	C018	0.46	0.26	0.23	0.20	0.15	1.000	1.146	0.46	0.05
774-19	C019	0.49	0.40	0.33	0.25	0.13	0.015	1.243	0.49	0.00
774-20	C020	0.41	0.28	0.24	0.20	0.13	0.123	1.148	0.41	0.00
774-21	C021	0.43	0.31	0.27	0.22	0.14	0.062	1.164	0.43	0.00
774-22	C022	0.42	0.25	0.23	0.19	0.12	0.258	1.147	0.42	0.00
774-23	C023	0.50	0.36	0.31	0.26	0.17	0.086	1.149	0.50	0.00
774-24	C024	0.45	0.22	0.20	0.19	0.13	1.000	1.193	0.45	0.08

*Test performed under controlled laboratory conditions.
Deviation from these results may occur in the field due to sample heterogeneity.



MINE WASTE AND
WATER MANAGEMENT

APPENDIX B MINE CLOSURE WATER BALANCE ASSESSMENT

ENGENY
WATER MANAGEMENT

LADY LORETTA
A GLENCORE COMPANY



Lady Loretta Mine

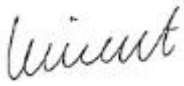
Mine Closure Water Balance Assessment

Water Balance Assessment Report

31 May 2022

M66000_099-REP-001-4

Job no. and Project Name: M66000_099 Lady Loretta Mine Water Balance Model
Doc Path File: \\online.com\files\Management\Projects\M66000 Glencore NQ\M66000_099 LLM Closure WBM\07 Deliv\2. Report\M66000_099-REP-001-4 LLM Closure WBM Assessment.docx

Rev	Date	Description	Author	Reviewer	Project Mgr.	Approver
0	21/03/2022	Draft Issue	Laura Vincent	Aaron Baldwin	Laura Vincent	Aaron Baldwin
1	04/05/2022	Client Issue	Laura Vincent	Aaron Baldwin	Laura Vincent	Aaron Baldwin
2	19/05/2022	Final Issue	Laura Vincent	Aaron Baldwin	Laura Vincent	Aaron Baldwin
3	20/05/2022	Final Issue	Laura Vincent	Aaron Baldwin	Laura Vincent	Aaron Baldwin
4	31/05/2022	Final Issue	Laura Vincent	Aaron Baldwin	Laura Vincent	Aaron Baldwin
Signatures						

DISCLAIMER

This Report has been prepared on behalf of and for the exclusive use of Lady Loretta Mine and is subject to and issued in accordance with Lady Loretta Mine instruction to Engeny Water Management (Engeny). The content of this Report was based on previous information and studies supplied by Lady Loretta Mine.

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1 INTRODUCTION

Engeny Water Management (Engeny) has been engaged to assist Lady Loretta Mine (LLM) to assess the water management system under a closure scenario to support the Progressive Rehabilitation and Closure Plan (PRCP). The assessment has been undertaken using the existing calibrated and routinely maintained operational water balance model. This report details the development and calibration of the water balance model as well as the proposed water management strategy for closure and the assessed system performance.

2 WATER BALANCE MODEL DEVELOPMENT AND CALIBRATION

2.1 WATER BALANCE MODEL

The LLM water balance model (WBM) is developed using the Goldsim model software and is used by site to assist with water management discission making. The WBM receives annual updates and recalibrations as part of the continuous improvement of effective site water management at LLM. The two previous updates were completed by SLR in 2020 and Engeny in 2021.

Goldsim is a software program developed by the GoldSim Technology Group and is capable of analysing complex time dependant systems. The model operates on a daily time step. For each scenario modelled, the model simulates 500 “realisations” derived using stochastic rainfall data developed for LLM from historical climate records on the Queensland Governments Scientific Information for Land Owners (SILO) Patch Point Data set. The stochastic data was produced from records from Jan 1960 to Dec 2018 and 500 replicates of 10 year rainfall data was developed. The first realisation uses climatic data commencing in 1960, the second commences with data from 1961 and the third with data from 1962 and so on. The results from all realisations are used to generate water forecasts including storage volume estimates, supply reliability and other relevant water balance statistics. This method effectively includes all recorded historical climatic events in the water balance model, including high, low, and median rainfall periods.

2.1.1 Water Management System

The LLM site WBM schematic is shown in Figure 2.1 and represents the site storages, movement of water, demands and inflows. The model consists of the four mine water storages on site representing the site’s water management system, which are shown on Figure 2.2 and listed below.

- Containment Dam A (CDA).
- Containment Dam B (CDB).
- Paste Plant Dam (PPD).
- Leachate Management Dam (LMD).

The WBM has been updated frequently since the initial development as part of the continuous improvement of effective site water management, based on the management strategies to control water risks at LLM. These are in line with the Lady Loretta Water Management Plan (LLM, 2021) and include:

- Operating and maintaining a water management network that:
  - diverts clean water away from operational areas;
  - directs mine affected water to containment structures; and
  - minimises risk to the receiving environment during the transfer and use of process water.
- Maximising available containment storage at all times;
- Conducting predictive modelling of water infrastructure performance in response to rainfall events;
- Implementing the LLM regulated dam Trigger Action Response Plan (TARP); and
- Managing and minimising land disturbance activities and soil erosion.

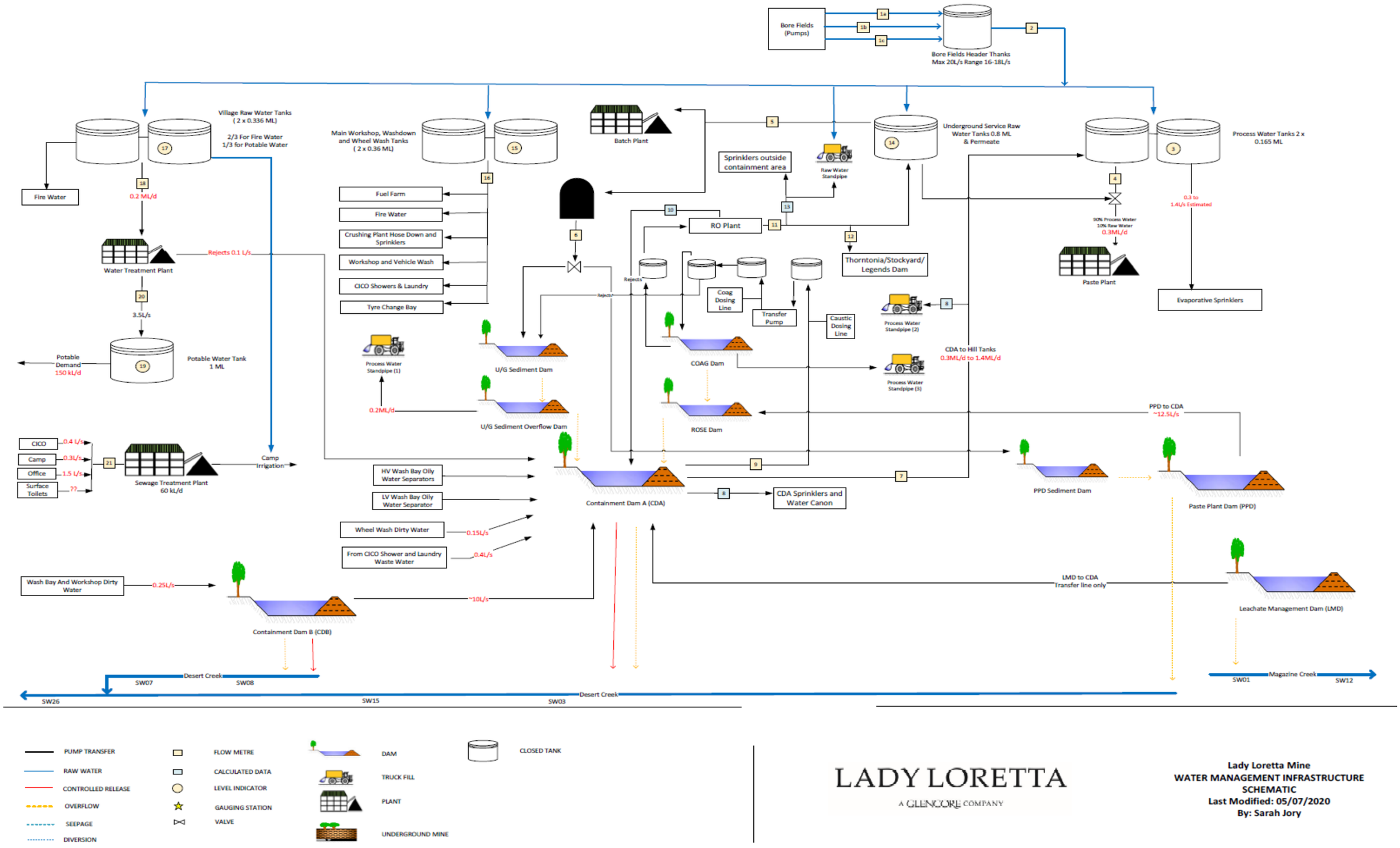


Figure 2.1: LLM Water Balance Model Schematic

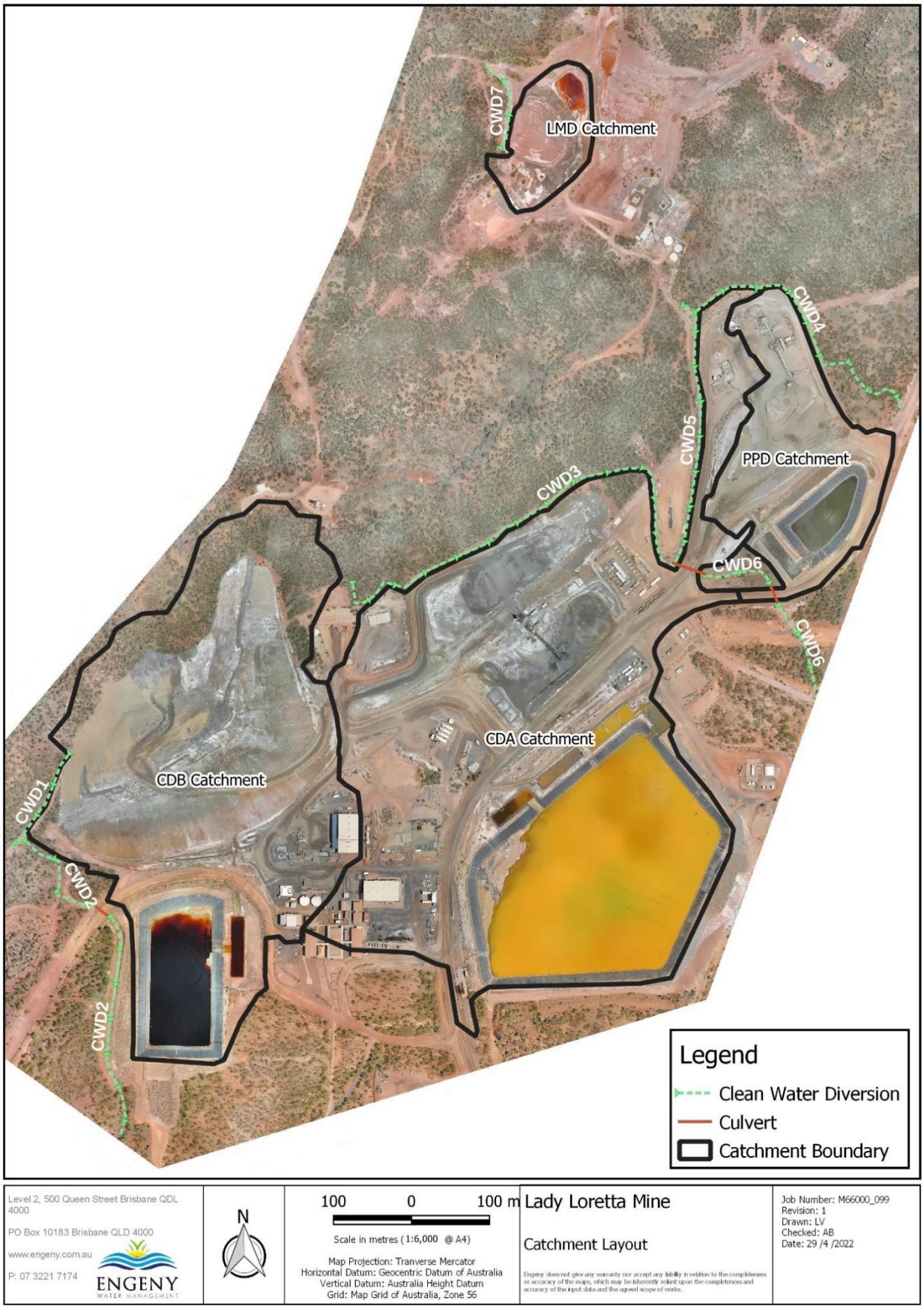


Figure 2.2: Catchment Layout

2.2 INPUT DATA

The following sections discuss the input to the water balance model.

2.2.1 Rainfall

The LLM model include two types of rainfall data:

- Stochastic daily rainfall data used to undertake forecast simulations; and
- Historical daily recorded rainfall data used for model calibration.

Stochastic rainfall data has been generated for the LLM WBM using the eWater CRC stochastic climate library. The rainfall data was sourced from the Queensland Governments Scientific Information for Land Owners (SILO) Patched Point Data set. The Patched Point Data set provides infilling of any missing data from nearby gauges based on relationships developed between the overlapping records of each gauge. The Patched Point Data used rainfall records from the Lady Annie Mine Gauge (029172), Calton Hills Station Gauge (029118) and Flora Downs Station Gauge (037055). The stochastic data was produced from records from Jan 1960 to Dec 2018. The stochastic rainfall data produced was for 500 replicates of 10-year rainfall data.

Historical daily rainfall data has been sourced from the LLM site rainfall gauge. Rainfall data was available from 1st of January 2017 until the 28th of May 2021. Figure 2.3 shows the rainfall recorded for this period. It shows distinct wet season periods between November and April each water year (1st of July to 30th of June each year).

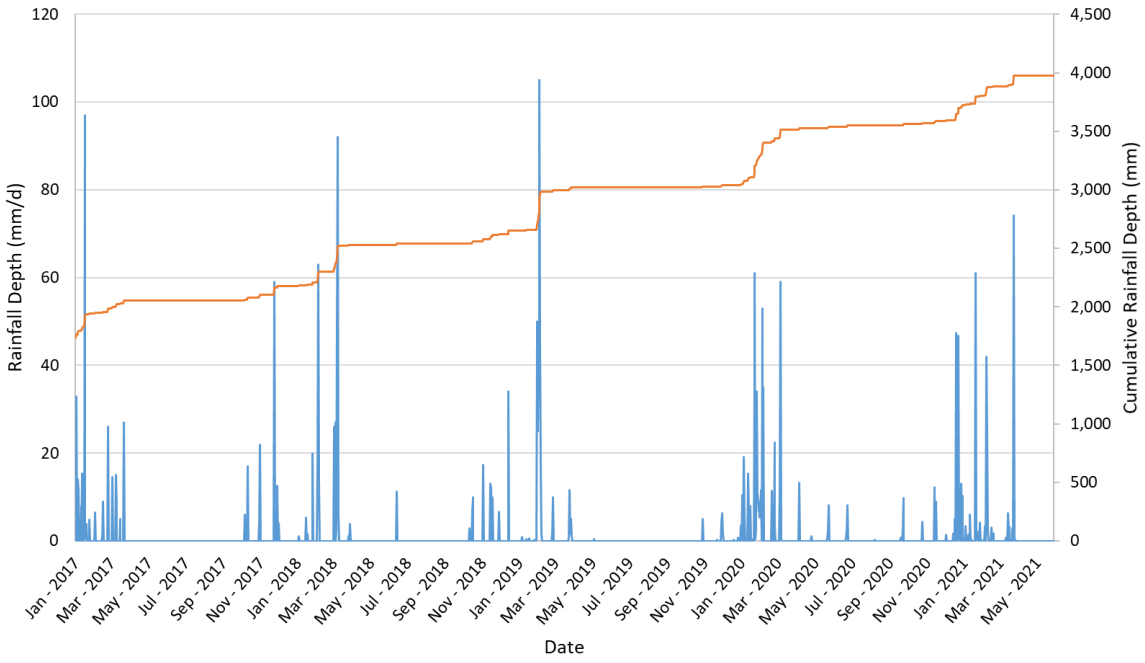


Figure 2.3: LLM Daily Recorded Rainfall

2.2.2 Runoff Modelling

The LLM WBM utilises the Australian Water Balance Model (AWBM) rainfall runoff module to simulate the rainfall and runoff inflows in each catchment. AWBM estimates catchment yield (flow) from rainfall and evaporation and is one of the most widely used rainfall-runoff models in Australia. The WBM simulates seven (7) different catchment types through separate AWBM modules, representing the runoff response for each of the following land use types:

- Natural.
- Dam.
- Hardstand.
- Paste Plant.

- Portal.
- Stockpile Crushing.
- Waste Dump.

The runoff simulated from the AWBM can be split into two forms:

- Surface runoff which travels overland to the destination; or
- Sub-surface which travels through the ground to reach the destination.

The focus of the 2021 model calibration is on verifying the calibrated AWBM and evaporation parameters used in the model to represent the rainfall and runoff response of the WBM.

2.2.3 Evaporation

The pan evaporation rates in the model were obtained from the SILO data base (Lat: -190.80°S Long: 139.05°E) and were generated based on interpolative methods using available Bureau of Meteorology (BoM) stations in the region. Due to limited number of stations in the region, long term average values were used in the WBM. Figure 2.4 shows the adopted daily evaporation rates per month. A pan factor of 0.85 was determined appropriate through model calibration (SLR, 2020) and applied to convert pan evaporation to lake evaporation.

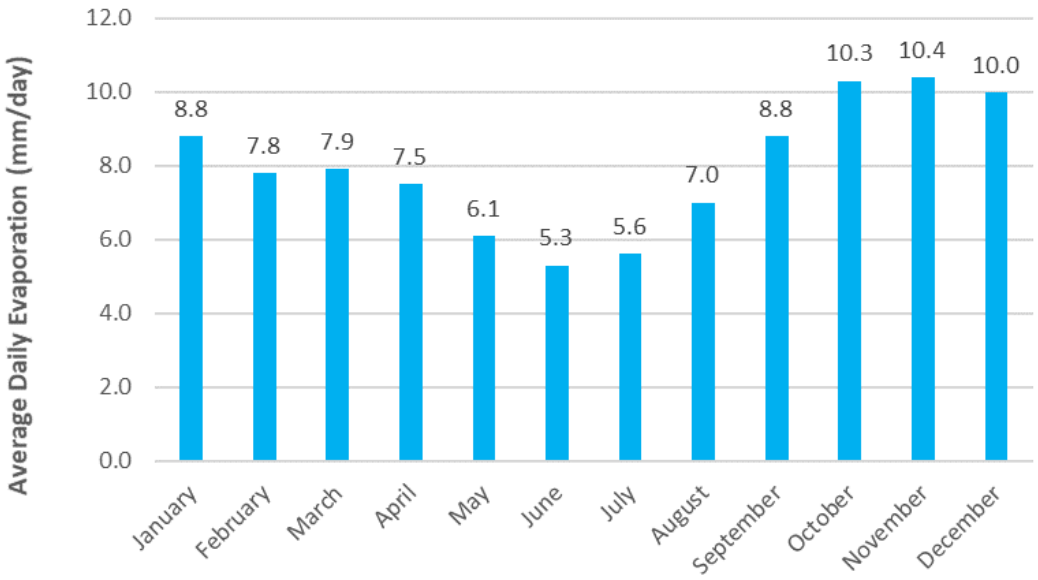


Figure 2.4: Adopted Evaporation Rates

2.2.4 Catchments

The four (4) catchments and landuse areas have been delineated based on recent aerial survey and imagery. Catchment areas are broken down into seven (7) separate landuse classifications which each have distinct runoff parameters effecting rainfall runoff yield. The current catchment boundaries are shown on Figure 2.1. Table 2.1 summarises the catchment and land use breakdown adopted in the existing WBM.

Table 2.1: Catchment Land Use Breakdown

Land Use	Area (ha)			
	CDA	CDB	PPD	LMD
Waste Dump	5.14	8.27	0.05	0.00
Stockpile Crushing	0.00	0.00	0.00	0.00

Land Use	Area (ha)			
	CDA	CDB	PPD	LMD
Dam	8.69	2.63	1.13	1.13
Paste Plant	0.00	0.00	0.69	0.00
Portal	0.00	0.00	0.00	0.00
Cleared or Hardstand	12.58	3.63	3.35	0.53
Natural / Rehabilitation	0.21	3.23	0.00	0.00
TOTAL	**26.61**	**17.76**	**5.22**	**1.66**

2.2.5 Process Inflows and Demands

LLM records the following process demands and inflows weekly (during the wet season) and monthly (outside of the wet season). Data provided for the period of 22nd June 2018 to 1st June 2021 was adopted in the model calibration (Engeny, 2021) and used as the basis of the adopted values in the assessment (refer to Sections 3.1, 4.1.1 and 4.2.1).

- Underground mine dewatering into CDA (Inflow).
- CDA to RO Plant (Demand).
- CDA to Sprinklers or Water Carts (Demand).
- CDA to Paste Plant (Demand).

It is noted that there are five minor wastewater inflows represented in the model that are estimates only. The following average site operation wastewater inflows have been adopted in the model, based on historical usage, as provided by LLM:

- Water Treatment Plant reject – 0.1 L/s.
- Wheel Wash Dirty Water – 0.15 L/s.
- CICO Shower and Laundry wastewater – 0.4 L/s.
- Light Vehicle and Heavy Vehicle Wash Bay wastewater – 0.25 L/s.
- Washbay Workshop wastewater – 0.25 L/s.

2.2.6 Operating Rules

The adopted storage capacities for the storages are based on storage curves provided by LLM and known spillway levels. The full supply volume (capacity) for each storage is summarised in Table 2.2.

Table 2.2: Storage Capacities

Storage	Storage Capacity (ML)
CDA	173.9
CDB	60.5
PPD	24.9
LMD (until ~2024)	5.3

The key operating rules and assumptions in the WBM include:

- Water management actively consolidates water to CDA.
- CDB transfers to CDA when the volume at CDB is greater than 10 ML and stops when CDA volume is greater than 100 ML.
- PPD transfers to CDA when volume at PPD is greater than 0.78 ML and stops when CDA volume is greater than 120 ML.
- LMD transfers to CDA when volume at LMD is greater than 1.92 ML and stops when CDA volume is greater than 145 ML.

2.3 AWBM PARAMETERS

Table 2.3 shows the AWBM parameters adopted in the 2021 WBM. These parameters were derived in the 2020 calibration update (SLR, 2020b) and confirmed in the 2021 review (Engeny, 2021). The performance of the WBM using the parameters in Table 2.3 are discussed in Section 2.4.

Table 2.3: AWBM Parameters

Parameter		Hardstand	Natural	Dam	Paste Plant	Stockpile	Waste Dump
Small storage capacity (mm)	C1	5	11	5	5	10	10
Medium Storage Capacity (mm)	C2	10	116	10	8	75	90
Large storage capacity (mm)	C3	25	232	15	18	110	130
Small partial area portion	A1	0.134	0.134	0.134	0.134	0.134	0.134
Medium partial area portion	A2	0.433	0.433	0.433	0.433	0.433	0.433
Large partial area portion	A3	0.433	0.433	0.433	0.433	0.433	0.433
Baseflow index constant	BFI	0.1	0.2	0.2	0.2	0.2	0.2
Baseflow recession constant	K	0.1	0.1	0.1	0.1	0.1	0.1
Daily streamflow recession constant	Ks	0.1	0.1	0.1	0.1	0.1	0.1

2.4 MODEL CALIBRATION

The WBM receives annual updates including recalibration as part of the continuous improvement of effective site water management. The model has most recently been calibrated for the period June 2018 to May 2021 and is discussed in detail in the *Lady Loretta Mine Water Balance Model Update and DSA Assessment* (Engeny, 2021).

The total recorded combined volume for the four storages against the calibration model results from the WBM are shown in Figure 2.5 (Engeny, 2021). The calibration results for this period show the model reproduces the site inventory trend well however there are some inconsistencies in peak volumes as well as rates of reduction. Inconsistencies in the model calibration are a function of the following:

- Runoff parameters.
- Demands applied as a constant historical average rate
- Spatial distribution of rainfall over the sites catchment not captured by the site's rainfall gauge.

Sensitivity analyses of the runoff parameters indicated that adopting parameters producing unrealistically high runoff did not significantly improve the match during the larger rainfall events (January 2019 and December 2020 events) and worsened the match for other parts of the calibration period. Recalibration of AWBM parameters was not undertaken during this calibration effort.

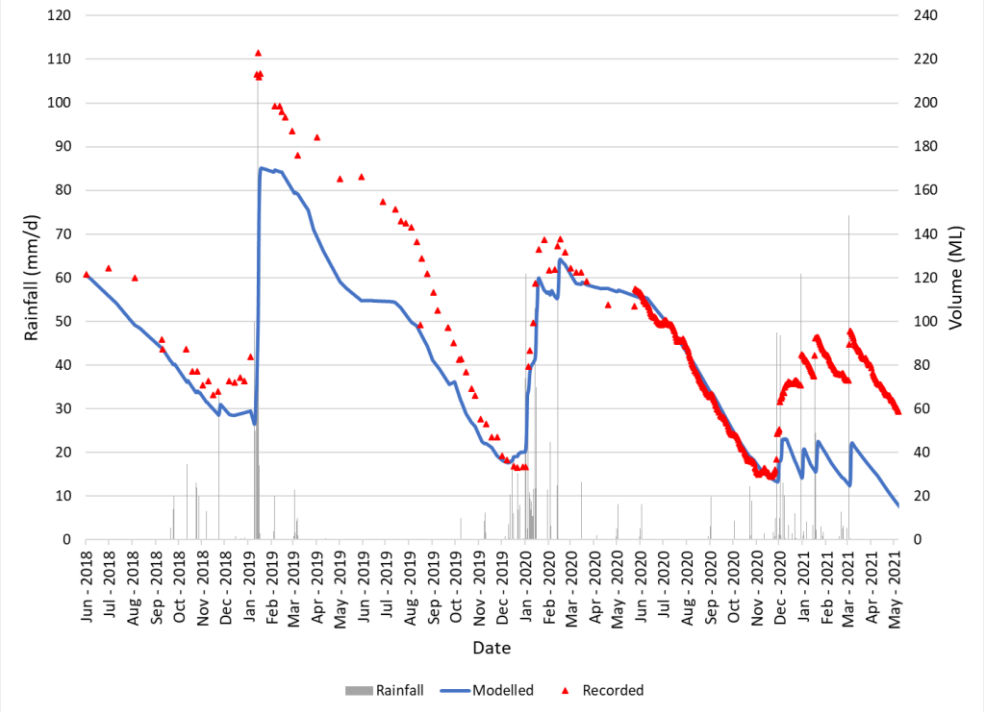


Figure 2.5: Total Site Inventory Calibration Results

3 EXISTING SYSTEM PERFORMANCE

An assessment of the existing water management system performance has been undertaken using the calibrated water balance model. The system performance is assessed based on containment performance of the water storages.

3.1 PROCESS INFLOWS AND DEMANDS

The following water sources and demands were used to assess the performance of the existing system and are based on data supplied by LLM on the long-term average source and demands whilst the site is in operation.

- Underground Mine Dewatering into CDA – 0.7 ML/d (Source).
- CDA to RO Plant – 0.3 ML/d (Demand).
- CDA to Sprinkler/Watercarts – 0.4 ML/d (Demand).
- CDA to Paste Plant – 0.3 ML/d (Demand).

3.2 ASSESSMENT METHODOLOGY

The operational water balance model was simulated over a 1 year forecast period for 500 realisations using stochastic climate data to determine the containment performance of each of the storages. The containment performance of the storages is assessed as the frequency of years overflow occurs from each storage. The operational performance target for all storages is achieving 1% Annual Exceedance Probability (AEP) of overflow or rarer.

3.3 ASSESSMENT RESULTS

The containment performance of the water containment storages at LLM are summarised in Table 3.1 and the total site inventory forecast for the assessment is shown in Figure 3.1. The total system initial volume (~50 ML) was adopted as it is representative of the typical volume prior to the start of the wet season, as predicted by model runs and based on historical dam inventories. The results show the dams have a very high containment standard with all dams overflowing 1% of years or less.

Table 3.1: Containment Assessment – Existing System

Storage	Capacity (ML)	Initial Volume (ML)	Annual Overflow Frequency (%)
CDA	173.9	30	0.2
CDB	60.5	15	1.0
PPD	24.9	5	0.4
LMD	5.3	0.25	0.4

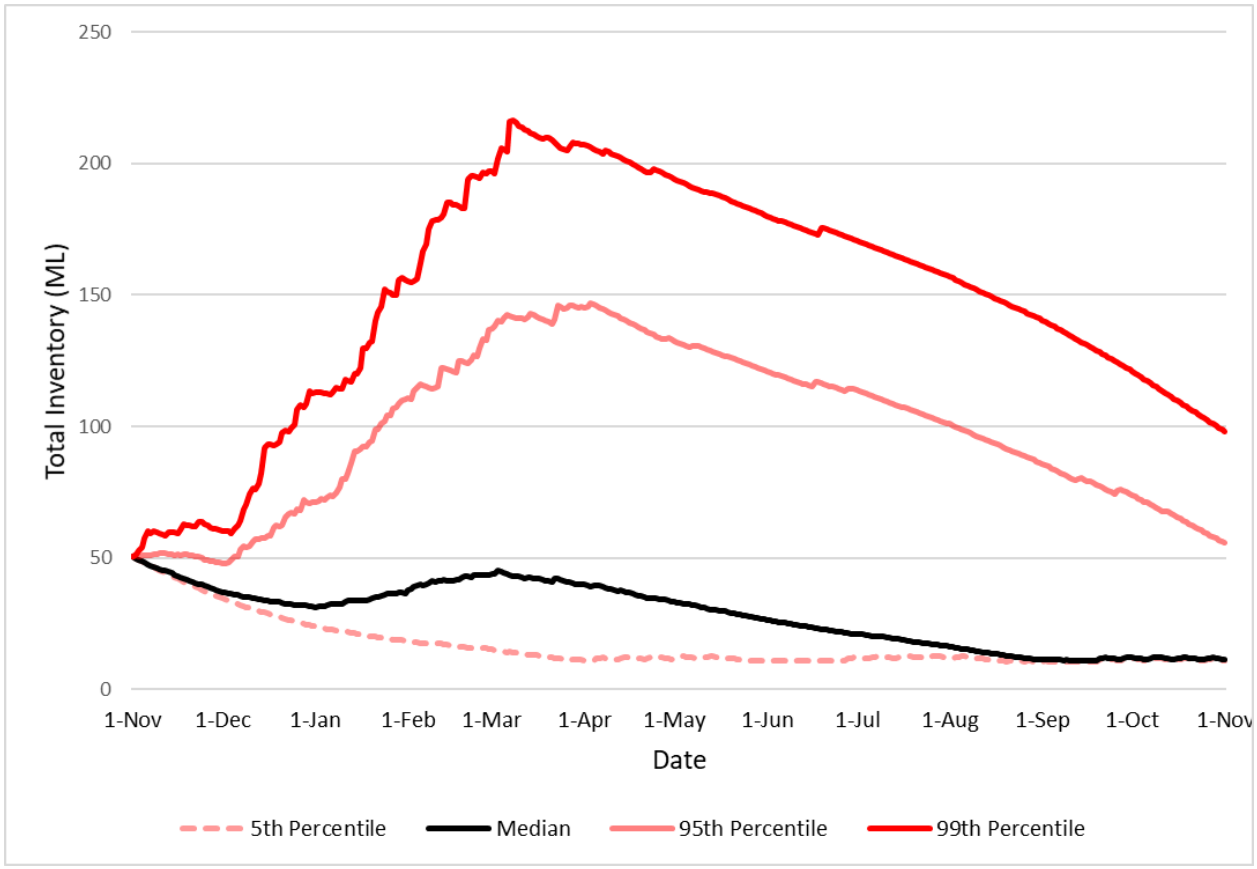


Figure 3.1: Total Site Inventory – Existing System

4 CLOSURE WATER MANAGEMENT ASSESSMENT

Lady Loretta Mine closure is planned to occur over two stages which have distinct water management strategies. These stages include:

Stage 1 – End of mining operations – the current campaign of mining is completed (2025) and minimal activities on site (years 2025 to 2032).

Stage 2 - End of commercial proposition – The LLM site undergoes rehabilitation, decommissioning and ongoing monitoring (From 2032).

This section outlines the water management system under the above two stages and the performance of the water management system.

Up until the end of Stage 1, it is expected there will be minimal changes to the LLM site catchments. The existing regulated dams will continue operating. There will be minimal landform design works and clean water catchments will remain in place, with the exception of LMD with planned decommissioning works prior to this stage (~2024). Following completion of the current mining campaign, LLM shall maintain the various fixed plant and infrastructure facilities in an operable condition to support future mining campaigns.

At the end of commercial proposition, full implementation of the decommissioning and rehabilitation program will occur and a post mining final landform that broadly reflects the pre-mining condition will be created. Demolition and rehabilitation works will commence and changes to the characteristics of the site catchment and runoff will occur as part of the post mining final landform design.

The three remaining regulated dams, once no longer required for management of the mine affected water inventory, will be converted to Erosion and Sediment Control (ESC) facilities to support the establishment of vegetation. Once this has been achieved, the ESC facilities will be available for decommissioning and the area reprofiled to complement the local terrain and made to be free draining.

It is anticipated, the three regulated dams will remain in place for 12 years after the end of commercial proposition. The most significant change of the post mining final landform will be the Waste Rock Emplacement which will comprise a steeply sloped batter and relatively flat crest plateau. Non-mineralised waste rock at the ROM pad will be partially relocated for underground backfill and the area recontouring to match the local topography and drainage lines. Revegetation works will occur across site whereby the land will be ripped and seeded which will alter runoff response across the catchments.

4.1 STAGE 1 – END OF MINING OPERATIONS

4.1.1 Process Inflows and Demands

The following water sources and demands were used to assess the performance of the Stage 1 – End of mining operations scenario and are based on data supplied by LLM.

Inflows

- Mine dewatering continues to CDA – 0.7ML/day (groundwater inflow rate).
- Workshop / vehicle wash down water to CDB – 0.0025 ML/day (1% of current activity).
- Wheel wash to CDA – 0.0015 ML/day (1% of current activity).
- CICO Laundry to CDA – 0.004 ML/day (1% of current activity).

Demands

- CDA RO plant runs as required when CDA level is above DSA – 0.8 ML/day (permeate transferred to third party).
- CDA to underground occurs as required when CDA level is above the mandatory reporting level (MRL) – 1 ML/day.
- CDA to dust suppression occurs as required when CDA level is above MRL – 0.3 ML/day.
- Paste plant not operational.

Based on data supplied by LLM, the underground void volume of ~600ML will remain at completion of the current Life of Asset (LOA); 2025.

4.1.2 Catchment Changes

LMD is proposed to be decommissioned in ~2024, before the beginning of the Stage 1 period, and its catchment is therefore not considered in the modelling for Stage 1 – End of mining operations. The catchment breakdown for CDA, CDB and PPD will remain as per Table 2.1 as minimal landform design works are proposed for the Stage 1 period.

4.1.3 Dam Transfer Rules

- Water is actively consolidated in CDA.
- CDB transfers to CDA when CDB volume > 20 ML, stops when CDA volume > 130 ML (~15 ML above CDA MRL).
- PPD transfers to CDA when PPD volume > 10 ML, stops when CDA volume > 120 ML (per current operations).
- LMD decommissioned (~2024).

4.1.4 Assessment Methodology

The Stage 1 – End of mining operations water balance model was simulated over a 7-year forecast period (2025 – 2032) for 500 realisations using stochastic climate data to determine the containment performance of each of the storages. The containment performance of the storages is assessed as the frequency of years overflow occurs from each storage. The operational performance target for all storages is less than 1% Annual Exceedance Probability (AEP) of overflow.

4.1.5 Assessment Results

The containment performance of the water containment storages at LLM are summarised in Table 4.1 and the total site inventory is shown in Figure 4.1. The results show after the end of mining operations all dams are expected to continue to achieve a containment standard better than 1% AEP (overflows is less than 1% of years) besides CDB which has a slightly increased overflow rate due to proposed changes to demands and dam transfer rules compared to the existing operational system. Contingencies are available to slow down underground mine dewatering rates and other approaches such as dam transfers and sending water back underground to reduce the annual overflow frequency below 1% at CDB.

The Stage 1 – End of mining operations containment modelling results indicate the following key conclusions:

- Under all climate scenarios (up to the 99th percentile), the total site inventory does not exceed the maximum available storage capacity (259 ML).
- The overall trend in storage inventory, including maximum volume, is relatively consistent across each year of the simulation. This indicates that LLM is not expected to accumulate water across the Stage 1 period.

Table 4.1: Containment Assessment – End of Mining Operations

Storage	Capacity (ML)	Initial Volume (ML)	Average Annual Overflow Frequency (%)
CDA	173.9	30	0.4
CDB	60.5	15	1.2
PPD	24.9	5	0.7
Total Volume	259	50	

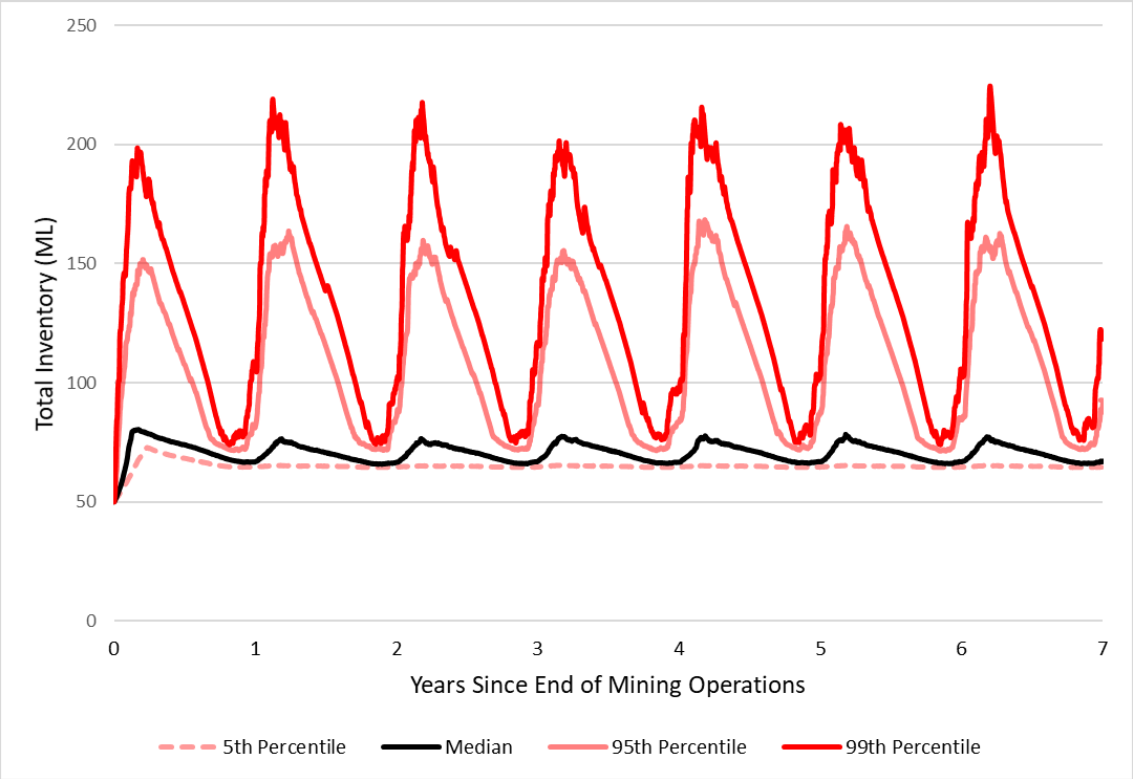


Figure 4.1: Total Site Inventory – End of Mining Operations

4.2 STAGE 2 – END OF COMMERCIAL PROPOSITION

4.2.1 Process Inflows and Demands

Following the end of commercial proposition stage, a 3-year decommissioning and rehabilitation phase will occur, followed by a nominal 25-year post-closure monitoring and maintenance phase. The first three years include water demands, transfers and catchment changes while the decommissioning and rehabilitation works are being undertaken. The following 5 years includes no water demands and transfers and the dam inventories are managed by evaporation only while the rehabilitation establishes (following this, the remaining regulated dams are proposed to be decommissioned). The following water sources and demands were used to assess the performance of the Stage 2 – End of commercial proposition scenario and are based on data supplied by LLM.

Inflows

- Mine dewatering continues to CDA – 0.7 ML/day for 6 months to allow removal of infrastructure.
- Workshop / vehicle wash down water to CDB – 0.25 ML/day for 12 months.

- Wheel wash to CDA – 0.15 ML/day for 12 months.
- CICO Laundry to CDA – 0.4 ML/day for 6 months.

Demands

- CDA RO plant runs as required when CDA inventory is above 10 ML – 0.8 ML/day for a 3-year decommissioning period.
- CDA to underground occurs as required when CDA level is above MRL – 1 ML/day.
- All other demands are no longer operational.

4.2.2 Catchment Changes

The three remaining regulated dams, once no longer required for management of the mine affected water inventory, will be converted to Erosion and Sediment Control (ESC) facilities to support the establishment of vegetation (i.e. 3-year decommissioning and rehabilitation phase). Following this phase, the modelling assumes full rehabilitation of all catchment areas reporting to the remaining regulated dams. This is highlighted in Table 4.2, based on the following timeline:

- 2032 = Beginning of decommissioning and rehabilitation phase.
- 2035 = Beginning of post closure maintenance and monitoring phase.

Table 4.2: Catchment Land Use Breakdown (Stage 2)

Stage	Area (ha)							
	Waste Dump	Stockpile Crushing	Dam	Paste Plant	Portal	Cleared or Hardstand	Natural / Rehabilitation	Total
CDA								
2032	5.15	0	8.69	0	0	12.58	0.21	26.61
2035	0	0	8.69	0	0	0	17.92	
CDB								
2032	8.27	0	2.63	0	0	3.63	3.23	17.76
2035	0	0	2.63	0	0	0	15.49	
PPD								
2032	0.05	0	1.13	0.69	0	3.35	0	5.22
2035	0	0	1.13	0	0	0	4.09	

It is anticipated that the dam areas will also be decommissioned and rehabilitated over the full post closure phase. As the focus of this assessment is on the containment performance of the regulated dams, the catchment changes post dam decommissioning have not been captured.

4.2.3 Dam Transfer Rules

- Dam rules as per Section 4.1.2 throughout a 3-year decommissioning period and then no transfers for the remaining 5 years (establishment period).
- Increased transfer rate from CDB to CDA – 10 L/s for the first three years.

4.2.4 Assessment Methodology

The Stage 2 – End of commercial proposition water balance model was simulated over a 8-year forecast period for 500 realisations using stochastic climate data to determine the containment performance of each of the storages. This includes the 3-year decommissioning and rehabilitation phase, followed by 5 years with no water demands or transfers and the dam inventories are managed by evaporation only. Following this 8-year period, rehabilitation is expected to be fully established, and

the performance of the water management system is not expected to change. The containment performance of the storages is assessed as the frequency of years overflow occurs from each storage. The operational performance target for all storages is less than 1% Annual Exceedance Probability (AEP) of overflow.

4.2.5 Assessment Results

The containment performance of the water containment storages at LLM are summarised in Table 4.3 and the total site inventory is shown in Figure 4.2. The results show after the end of commercial proposition all remaining dams are expected to continue to achieve a containment standard better than 1% AEP (overflows in less than 1% of years).

The Stage 2 – End of commercial proposition containment modelling results indicate the following key conclusions:

- Under all climate scenarios (up to the 99th percentile), the total site inventory does not exceed the maximum available storage capacity (259 ML). Figure 4.3 to Figure 4.5 show the modelled inventories against available capacity for individual dams.
- Following the first year, and full dewatering is achieved, the overall trend in storage inventory, including maximum volume, is relatively consistent across each year of the simulation. This indicates that LLM is not expected to accumulate water across the Stage 2 period.
- Once the regulated dams are decommissioned and repurposed as erosion and sediment control facilities, there will likely be between 2 ML (50th percentile climate scenario) and 50 ML (99th percentile climate scenario) of surface water runoff remaining in the storages.

Table 4.3: Containment Assessment – End of Commercial Proposition

Storage	Capacity (ML)	Initial Volume (ML)	Average Annual Overflow Frequency (%)
CDA	173.9	30	0.1
CDB	60.5	15	0.9
PPD	24.9	5	0.4
Total	259	50	

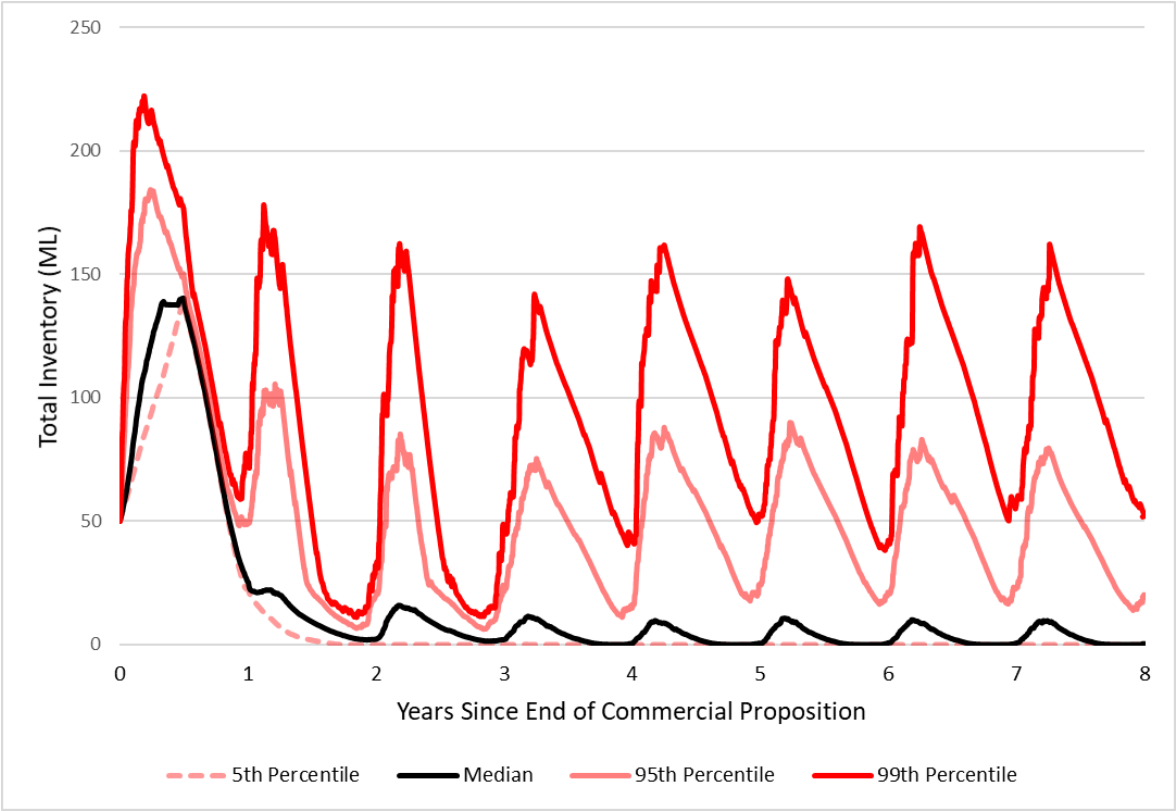


Figure 4.2: Total Site Inventory – End of Commercial Proposition

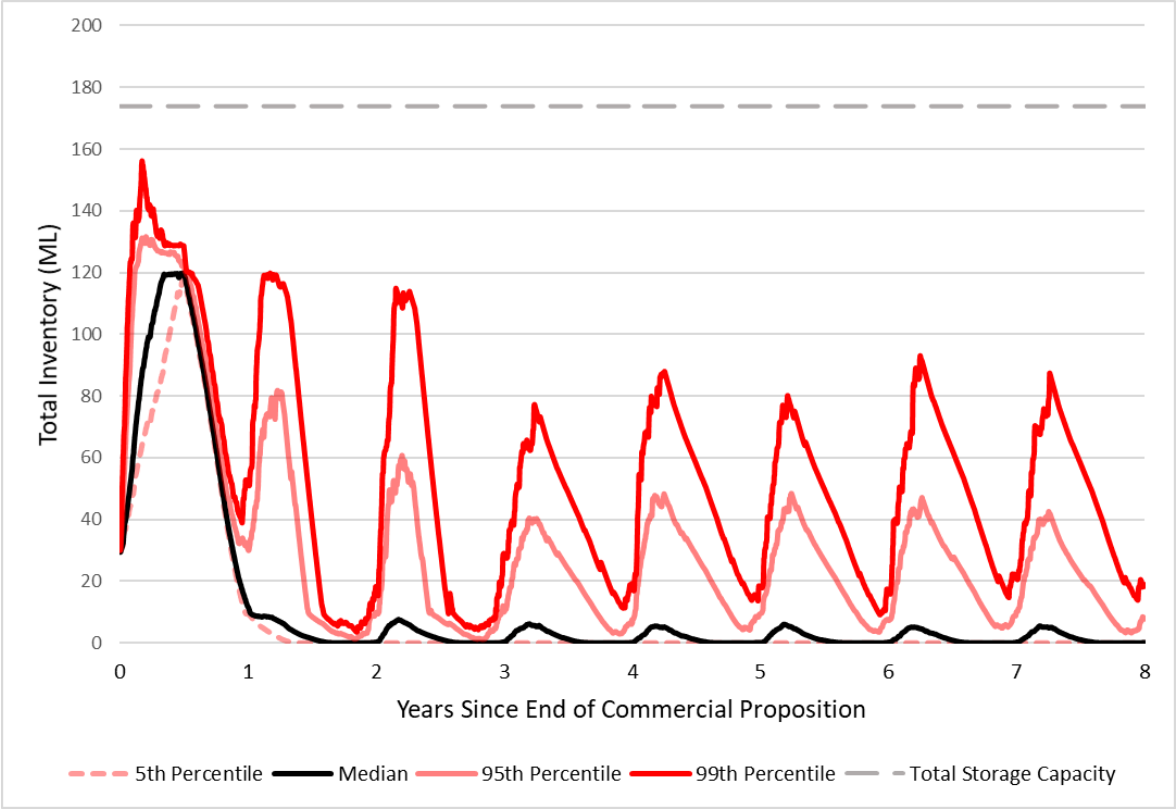


Figure 4.3: CDA Inventory – End of Commercial Proposition

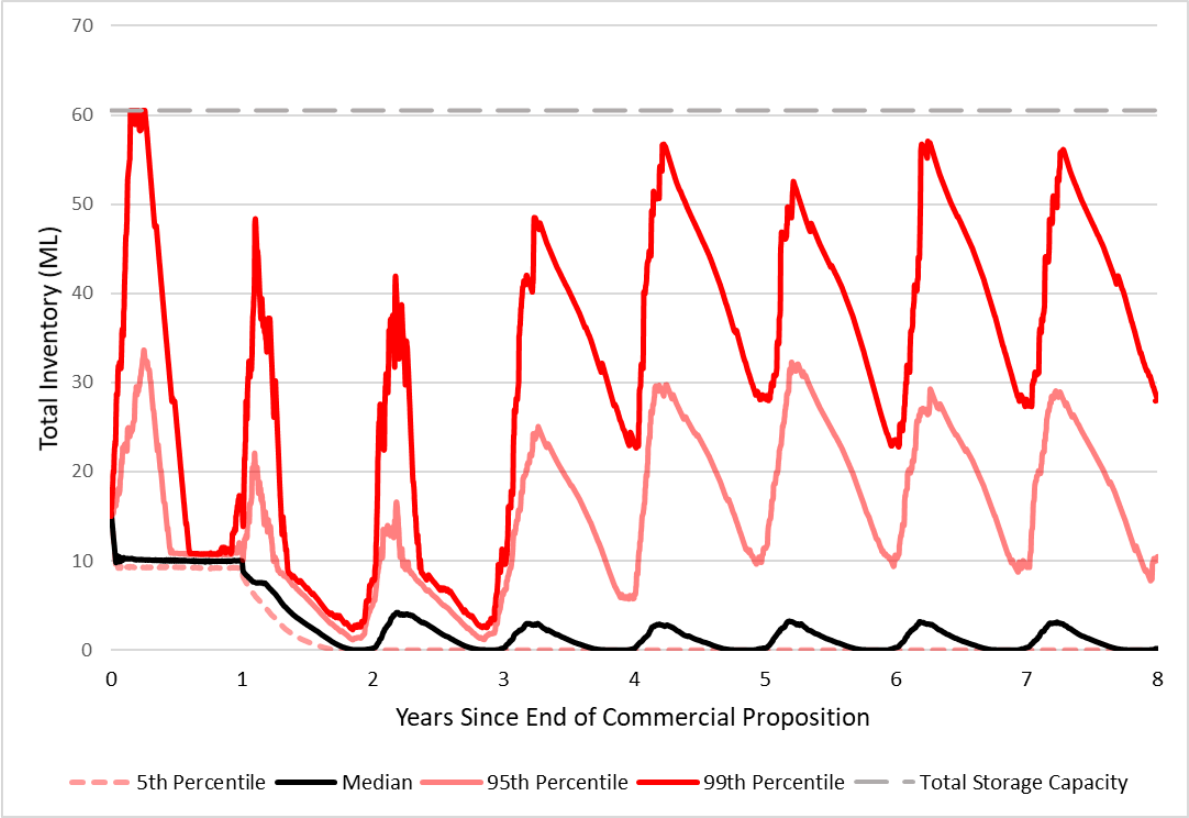


Figure 4.4: CDB Inventory – End of Commercial Proposition

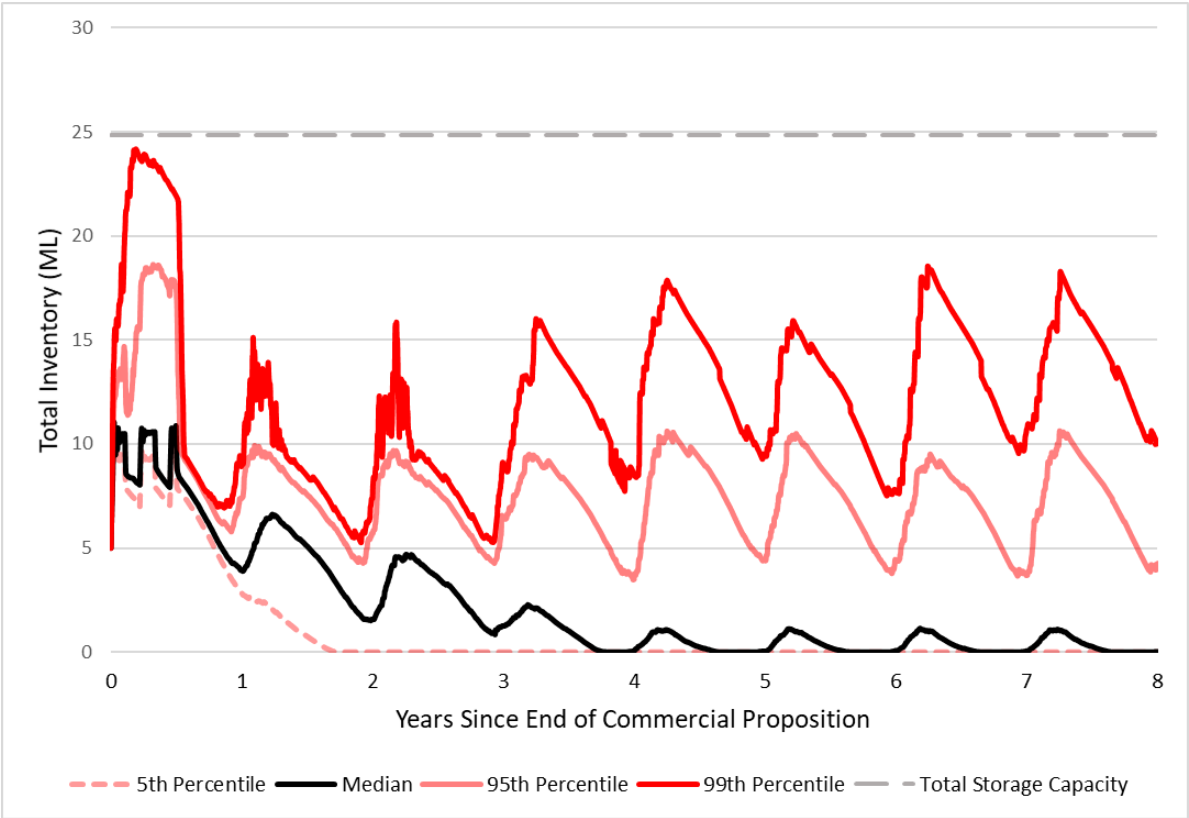


Figure 4.5: PPD Inventory – End of Commercial Proposition

5 CONCLUSIONS AND RECOMMENDATIONS

A containment assessment was undertaken on LLM's regulated dam structures to assess the performance of the site water management system under a closure scenario in support of the Progressive Rehabilitation and Closure Plan (PRCP). The assessment was undertaken using the existing calibrated and routinely maintained operational water balance model.

Two closure scenarios, representing the proposed progressive rehabilitation stages were assessed, including:

- Stage 1 – End of mining operations – the current campaign of mining is completed (2025), and minimal activities on site (years 2025 to 2032).
- Stage 2 - End of commercial proposition – The LLM site undergoes rehabilitation, decommissioning, and ongoing monitoring (From 2032).

The assessment indicated that during Stage 1 – End of mining operations, all dams are expected to continue to achieve a containment standard better than 1% AEP (overflows is less than 1% of years) besides CDB which has a slightly increased overflow rate (1.2%) due to proposed changes to the demands and dam transfer rules compared to the existing operational system. During Stage 2 – End of commercial proposition, all dams are expected to achieve a containment standard of 1% AEP or better.

The performance assessment for both stages indicate:

- Under all climate scenarios (up to the 99th percentile), the total site inventory does not exceed the maximum available storage capacity (259 ML).
- The overall trend in storage inventory, including maximum volume, is typically consistent across each year of the simulation. This indicates that LLM is not expected to accumulate water during the closure period.
- Once the remaining regulated dams (CDA, CDB and PPD) are decommissioned and repurposed as erosion and sediment control facilities, there will likely be between 2 ML (50th percentile climate scenario) and 50 ML (99th percentile climate scenario) of surface water runoff remaining in the storages.

The only impact identified by the performance assessment is the 1.2% overflow frequency (greater than the target 1%) from CDB during Stage 1 – End of mining operations. In order to reduce the annual overflow frequency below 1%, increased pumping capacity is required between CDB and CDA (approximately 10 L/s pump rate). Sufficient underground void volume (of ~600ML) will remain at completion of the current LOA and contingencies such as slowing down underground mine dewatering rates and transferring water back underground will be available.

6 QUALIFICATIONS

a) In preparing this document, including all relevant calculation and modelling, Engeny Water Management (Engeny) has exercised the degree of skill, care and diligence normally exercised by members of the engineering profession and has acted in accordance with accepted practices of engineering principles.

b) Engeny has used reasonable endeavours to inform itself of the parameters and requirements of the project and has taken reasonable steps to ensure that the works and document is as accurate and comprehensive as possible given the information upon which it has been based including information that may have been provided or obtained by any third party or external sources which has not been independently verified.

c) Engeny reserves the right to review and amend any aspect of the works performed including any opinions and recommendations from the works included or referred to in the works if:

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   ii) Engeny considers it prudent to revise any aspect of the works in light of any information which becomes known to it after the date of submission.

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g) This Report does not provide legal advice.

7 REFERENCES

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SLR. (2020b). *Lady Loretta Mine Water Balance Model Calibration* (Doc ref: 620.12436-MO1).

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APPENDIX C REHABILITATION AND REVEGETATION MILESTONE TECHNICAL MEMORANDUM

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1 March 2023

Ref: 0037

Alice Beer
Rehabilitation and Closure Advisor
Glencore Queensland Metals
Via email: Alice.Beer@glencore.com.au

Dear Alice,

Technical Memorandum: Further information on Waste Rock Emplacement (WRE) Rehabilitation and Rehabilitation Milestones

The Lady Loretta Mine (LLM) *Progressive Rehabilitation and Closure Plan* (PRCP, Version 1) was prepared by Glencore in May 2022. The PRCP was developed to meet the specific requirements of the Progressive Rehabilitation and Closure Plan Transition Notice (the PRCP Transition Notice) issued by the Queensland Department of Environment and Science (DES) on 18 September 2020, as well as requirements outlined in the LLM Environmental Authority EPML00982013 (the EA) and the Progressive Rehabilitation and Closure Plans Guideline (DES, 2021).

The Plan was also submitted to DES in May 2022. Since then, DES has issued a Request for Further Information (RFI, reference: EPML00982013 /101/0008765), with part of the RFI relating to landform design for the Waste Rock Emplacement (WRE) rehabilitation area, as well as the rehabilitation milestones outlined in Table 18 of the PRCP.

As part of developing a response to the RFI, Bower Ecology Pty Ltd was engaged to provide information on these matters. Specifically, this technical memorandum provides:

1. An assessment of the proposed seed mix for the WRE to help ensure cover integrity is not compromised by vegetation and that long-term compliance can be met. Specifically, consideration of root depth, growth medium properties and design of the cover system is assessed.
2. Commentary on Ecosystem Function Analysis (EFA) thresholds for the following Rehabilitation Milestones[1]:
    - RM10 – Achievement of surface requirements - Vegetation on Developmental Trajectory (Native Habitat areas);
    - RM11 – Achievement of surface requirements - Vegetation on Developmental Trajectory (Low Intensity Cattle Grazing areas);
    - RM13 – Achievement of post-mining land use to stable condition (Native Habitat areas); and
    - RM14 – Achievement of post-mining land use to stable condition (Low Industry cattle Grazing areas).

    To support this statistical analysis and benchmarking of existing monitoring data was undertaken. Commentary on how changing conditions may affect EFA results / rehabilitation success has also been contextualised alongside reasonable contingency measures.
3. A definition of 'low intensity grazing' and a framework against which this can be measured is also provided.

These three points are dealt with individually below.

[1] Rehabilitation Milestone (RM) reference numbers relevant to this memo have increased by one since DES conducted their review. I.e. RM9 is now RM10 etc.

Matter #1 – Assessment of the WRE Seed Mix

In their RFI (Item 7), DES has stated:

> *"The proposed Store and Release cover system includes the Infiltration Storage Layer which will be comprised of a 1.5m deep application of Rock Mulch intended to act as a growth medium for vegetation. Section 3.6.2.2* (of the PRCP) *describes this as "the growth media for a vegetation community dominated by trees." Table 16 (Section 3.6.8.4) includes a number of mid-storey species to be sown on the WRE Crest, including Mulga (Acacia aneura) as a priority species for the WRE crest. The department notes that some native species such as the Mulga have a taproot up to 3 meters."*

Further, DES have asked Glencore to:

> *"Confirm whether the species provided with Table 16 of the PRCP Plan are suitable and will not impact the integrity of the proposed WRE cover system."*

Presented below is a discussion of the species in the PRCP's seeding list and the potential of vegetation to penetrate the proposed WRE cover system, as well as a brief literature review. The proposed cover system on the crest (where the seed mix will be used) consists of Bituminous Geomembrane (BGM), protection material and an infiltration storage layer comprising of 1.5m of loosely placed rocky soil mulch.

Site summary

The site to be rehabilitated is in the Northwest Highlands bioregion (Bioregion 1), an area characterised by stony hills and ridges, dry semi-arid climate with monsoonal rainfall influences. Prior to mining works, the site was used for low intensity grazing and hosted 15 regional ecosystems spanning five different land zones.

Vegetation occurs on a continuum from sharp crests on metamorphic rocks (land zone 11) or ironstone crusts (land zone 7), some sedimentary rock outcrops (land zone 9), along upper erosional slopes of loamy and sandy plains (land zone 5) through to alluvium in valley floors (land zone 3). These mapped vegetation assemblages span from open sparse woodlands with spinifex understory (RE 1.7.7, 1.5.16, 1.5.3) through to grassy woodlands (RE 1.3.6, 1.3.7, 1.7.5). These theoretical pre-clear assemblages match well with what has been observed on site in the analogue vegetation monitoring sites per Umwelt (2021).

Rehabilitation area characteristics

Prior to disturbance, the area to be rehabilitated spanned the lower slopes of an ironstone cap dominated by a sparse spinifex and ghost gum woodland (RE 1.7.7a) that flowed through into a blended area of acacia woodland (RE1.7.5b) and drainage lines (RE1.3.7b).

Glencore intends to create robust vegetation cover on all areas that have been disturbed. These will be soils and meta-soils that have low structure and moisture holding capacity. This will include ten unique rehabilitation areas (RAs) spanning regular disturbed areas (e.g. roads and tracks), through to higher-risk modifications like decommissioned dams and the waste rock emplacement (WRE) areas (Figure 1). The WRE (RA1) is where moderate-high risk waste rock will be placed, secured, and contained and will comprise of a maximum footprint of 11ha. The WRE will be re-shaped with site-sourced rocky soil mulch and rock armour material for batter treatments and will include surface preparation to determine the requirement for ameliorants/other treatments necessary to achieve the PMLU. This will create a 'blank slate' on which revegetation can occur.

Rocky soil mulch is borrowed material from naturally occurring sedimentary deposits. It is intended to have fine and coarse particulars that will retain moisture whilst also resisting erosion. The intended mix for this site is a combination of moderate fine and coarse-grain sediments (including approximately 30% particles <2mm, 30% of particles >4.75mm).

Vegetation is proposed to play a key role in returning biodiversity to the site, and in stabilising the WRE. The WRE is composed of two areas with unique characteristics:

- Crest – flatter top (low slope area) made of a 1.5m deep layer of loosely placed rocky soil mulch that is intended to hold vegetation, underlain by an impermeable BGM and protection layers. The surface of the rocky soil mulch layer is intended to be dominated by vegetation. Further, the cover is considered a "Store

and Release" (SAR) system. I.e. the looseness of the soil will result in any rainwater being held within the layer and lost only to evaporation and evapotranspiration via the soil-surface and vegetation.

- Batter slopes – sloped sides built of compacted rocky soil mulch and covered with rock armour. This area is not proposed to be vegetated due to the slope and need for vehicular access along the benches.

The PRCP specifies a WRE seed mix (Table 1) designed to reflect existing vegetation communities and in the area, with consideration of commercial seed availability. The tree layer has been excluded due to the 1.5m depth of the rocky soil mulch. This is because strong tree roots (e.g. tap root and anchoring roots) can easily grow beyond the first 6-8m of the soil profile and even much deeper if the water table is deeper (Cook and Eamus 2018).

Table 1: Seeding list from the PRCP Version 2

Species	Common Name	Sowing Rate (g/ha)
Groundcover (Grasses, forbs and small shrubs)		
Aristida holathera	Kerosene grass	30
Aristida latifolia	Feathertop Wiregass	30
Aristida lazaridis	Wiregrass	20
Bothriochloa ewartiana	Desert Bluegrass	20
Cymbopogon bombycinus	Silk Grass	100
Eriachne mucronata	Mountain Wanderrie Grass	200
Paspalidium rarum	Bunch Paspalidium	200
Ptilotus clementii	Pussycats Tails	100
Ptilotus exaltatus	Mulla Mulla	100
Ptilotus fusiformis	Skeleton Bush	50
Ptilotus schwartzii	Horse Mulla Mulla	50
Schizachyrium fragile	Fire Grass	60
Senna notabilis	Cockroach Bush	60
Setaria surgens	Pigeon Grass	100
Triodia molesta	Buck Spinifex	620
Triodia longiceps	Giant Grey Spinifex	610
Triodia pungens	Soft Spinifex	650
Groundcover (TOTAL Sowing Rate)		**3kg/ha**
Midstorey Species (Shrubs)		
Acacia chisholmii	Turpentine	1000
Acacia holosericea	Silver Wattle	900
Acacia monticola	Hill Turpentine	900
Acacia retivenea	Net-veined Wattle	900
Acacia megalantha	None recorded	700
Acacia tenuissima	Broom Wattle	500
Atalaya hemiglauca	Whitewood	900
Flueggea virosa	White Currant	300
Gossypium australe	Native Cotton	300
Grevillea wickhamii	Wickham's Grevillea	300
Acacia cambagei	Gidgee	300
Midstorey (TOTAL Sowing Rate)		**7kg/ha**

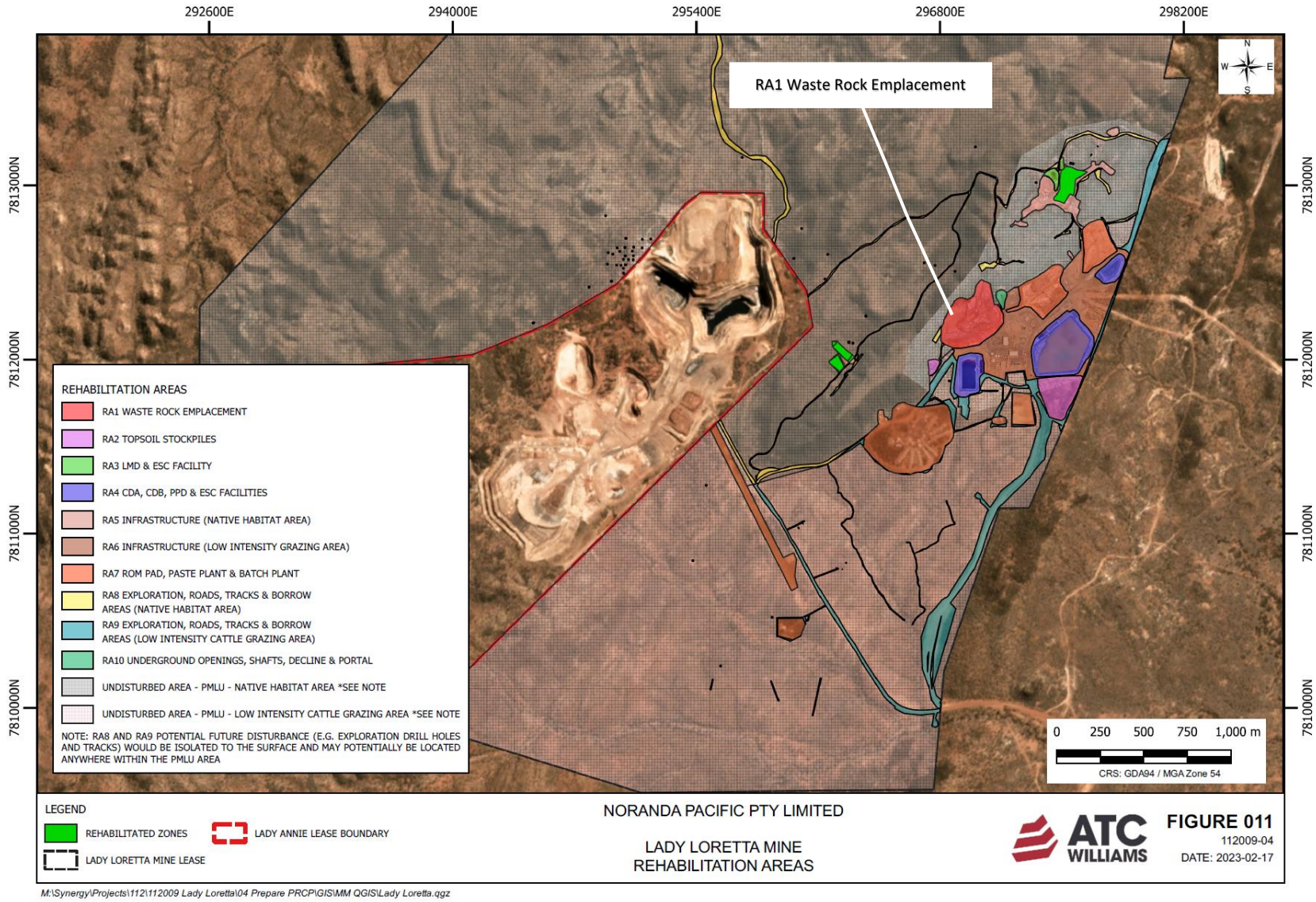


Figure 1: Proposed Rehabilitation Areas, per PRCP (c/o ATC Williams)

Review of the species list

A brief review of literature for root depths of potentially seeded species was conducted (Table 2). No peer reviewed or scientific literature was found for any of the specific species in the PRCP's proposed seeding list or with reference to other species within the regional ecosystems in the area.

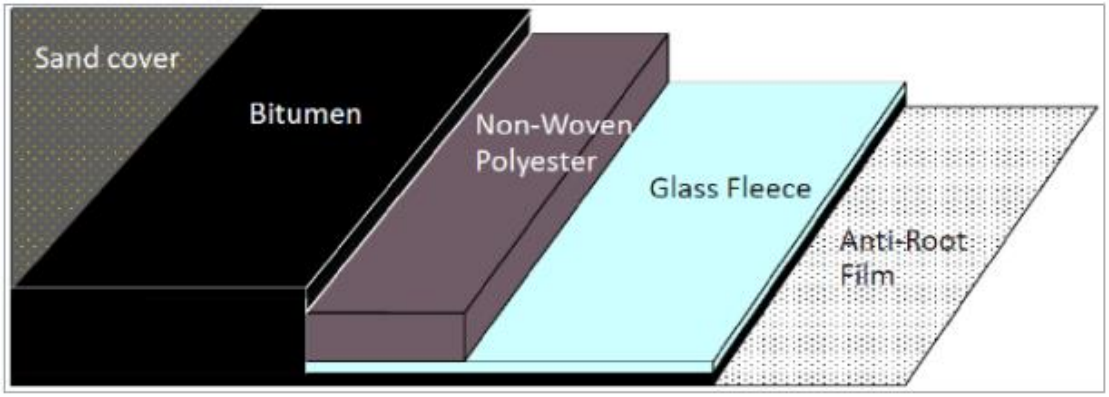
In arid environments, root depth is related to the search for water, as well as for plant stability. From the literature reviewed (Table 2), it is clear that the concern specific to *Acacia aneura* expressed by DES could be applied to all shrub species, and possibly some species in the groundcover layer (e.g. the deep rooted *Triodia* spp.) if the impermeable membrane is weak and water stress causes root systems to descend deeper in the search for water. There is evidence in the literature of shrub and tree species in these types of environments with root depths far beyond 1.5m, though several reviews conclude that across most functional groups the majority of roots are found at depths around <40-60cm (Table 2).

Relevant to this site, and mine rehabilitation sites in general, is the role of soil density and impermeable layers. Studies from South Africa of pasture and cropping species show that these shallow-rooted plants can have trouble permeating soil areas with high bulk density (Shoeman 2001) and would be unlikely to penetrate the BGM impermeable membrane proposed here. Whether that applies to woody species or species adapted for life on duricrusts, is not documented in the literature; however it is noted that the proposed BGM includes a root barrier layer specifically designed to prevent root penetration (see Figure 2 for a diagram of the BGM proposed). The polyester root-barrier film is considered an important consideration because bitumen is susceptible to root penetration.

Further, water will be readily available to plants on the WRE as the SAR is designed to capture all water. That is, water will collect in the rocky soil mulch area and evaporate via evapotranspiration and soil evaporation only; there are no overland flows to other areas proposed as part of the design. This design allows more water to be available to the vegetation and helps to prevent roots from needing to go deeply in search for water. Matric and osmotic suction also assist to help draw water upwards through the soil profile, making it available for plant roots. Shrubs will offer an improvement in water uptake (necessary for a SAR cover system) than grasses alone.

In the unlikely event that roots do pierce the BGM and associated root barrier, there are several factors that will limit the impacts to potentially contaminated water reaching external environments. These are that:

- A WRE design has been provided to restrict water percolating down into the buried waste rock, as this can lead to physical and chemical instability. Modelling shows that no water will flow through the cover system into the waste rock (ATC Williams 2023).
- The buried waste rock will be treated with lime (ATC Williams 2023). This hardens the material and helps to limit the permeability of the layer below the BGM (pers. comm JM at ATC Williams 24/11/20022).
- If any root penetration did occur, causing seepage into the buried waste rock, flow paths end in a containment dam ('CDB' in the PRCP) that has a water quality monitoring point. Hence, this provides a means to highlight potential issues, undertaken further assessment and provide adaptive management.
- Ongoing monitoring for contaminant mass flux out of the WRE to form part of a rehabilitation milestone.
- Rehabilitation (vegetation) monitoring will also be undertaken, providing a means to assist with the identification of any impacts of waste rock chemical constituents on the WRE vegetation and corrective actions where necessary.



A BGM is a composite material with several constituents to attain the desired overall material properties. They typically consist of non-woven geotextile and glass fleece layers impregnated with and encapsulated in elastomeric bitumen, with a sanded surface on one side for enhanced friction and an anti-root layer on the other. The geotextiles dictate the mechanical properties of the BGM, while the elastomeric bitumen provides waterproofing, chemical resistance and protection from ageing. The glass fleece is used for manufacturing purposes. It ensures stability of the geomembrane during impregnation of the geotextile with hot bitumen.

Figure 2: Diagram of the BGM, (adapted from Appendix H of McArthur River Mine's OMP Supplementary EIS [Glencore 2017])

There are also several benefits of retaining the shrub layer in the mix. Shrubs will add to the structural integrity of the rocky soil mulch, providing deeper and thicker roots than the grasses. A shrub layer akin to that naturally occurring on site will create a low-biomass grassy understorey with a far lower risk of carrying wildfire. There are also significant biodiversity and soil function benefits of including a shrub layer, particularly those with propensity to fix nitrogen through root associations (i.e. most Acacia species). Observations have been made by MRM that shrub roots did not permeate BGM on other sites, and instead ran parallel to the medium (pers. comm. S. Harris, Glencore).

Based on an assessment of the proposed seed mix and sowing rates stated in the PRCP Version 1, May 2022 submission, and the proposed WRE cover system design (offering a root limiting layer and the SAR concept), as well as the literature review undertaken, it is viewed as unlikely that the proposed seed mix will impact the long-term integrity of the WRE cover system. However, Glencore has chosen to remove the 300 grams per hectare of Mulga (*Acacia aneura*) from the seed mix for the WRE, based on the DES RFI. Increases in sowing rates to other shrubs have occurred to make up for the removal. I.e. 100 grams per hectare more of *Acacia holosericea*, *Acacia monticola* and *Acacia retivenea* based on a review of species recorded at analogue sites.

It should be noted, the proposed mid-storey sowing rate of 7kg/ha will remain unchanged, whereby the shrub layer will offer evapotranspiration necessary for the functioning of a SAR system. The revised seed mix will provide a reasonable and feasible approach and may require future refinement subject to ongoing seed availability, final properties of materials applied to the WRE, implemented application rates and conditions present leading up to, and during WRE revegetation.

Table 2: Results of a brief literature review on root depths in natural landscapes and mine rehabilitation landscapes globally.

Note: A focus was placed on the species and systems relevant to this site, though few sources were available with this level of specificity.

Source (full reference provided in reference section of this memo)	Relevant layers	Conclusions regarding maximum root depth
Cook, P., and Eamus D. 2018, https://depws.nt.gov.au/__data/assets/pdf_file/0004/498883/The-Potential-Use-for-Groundwater-Use-by-Vegetation-in-the-Aust.-Arid-Zone.pdf	Tree and shrub	Generally root depth is 6-8m but much deeper (e.g. 20m) if the ground water table is deeper.
Grigg et al 2008 https://www.researchgate.net/publication/230604150_Water_relations_and_mineral_nutrition_of_Triodia_grasses_on_desert_dunes_and_interdunes	Groundcover	*Triodia* species in natural contexts have root systems that range from 1 to 2m depth
Hutley et al 2001 https://besjournals.onlinelibrary.wiley.com/doi/full/10.1046/j.1365-2435.2000.00416.x	Tree	Eucalypts able to penetrate duricrusts with thick roots (>3cm) but most clustered above impenetrable layer <0.4m
Jackson et al 1996 https://link.springer.com/article/10.1007/BF00333714	All layers	Plants in drier areas have more roots >30cm depth but most plant systems have 75% of root matter <40cm depth
Maeght et al. 2013 https://www.frontiersin.org/articles/10.3389/fpls.2013.00299/full	All layers	Global averages are herbs 2.6m, shrubs 5.1m and trees 7.0m
	Trees	Tropical savannah has some of deepest root depths – average 15m up to 68m
Moore 2013 https://scholar.archive.org/work/po6zdng65zaepjiiklmljwetky/access/wayback/http:/joa.isa-arbor.com/request.asp?JournalID=1&ArticleID=3272&Type=2"	Trees	Majority of roots <60cm depth
Morris et al. 2011 https://onlinelibrary.wiley.com/doi/full/10.1111/j.1472-4642.2011.00802.x	Mid layer	*Acacia saligna* shown to root as deep as 2m
Ritcey 1989 https://www.osti.gov/biblio/7153930	Trees	Impermeable clay layer restricted tree root depth
Schoeman 2001 https://coaltech.co.za/wp-content/uploads/2019/10/Synopsis-of-agricultural-research-on-rehabbed-coal-mined-land-conducted-in-terms-of-the-Kraai-van-Niekerk-report-2001.pdf	Pasture grasses and maize	0.34 – 0.5m then roots stopped, but some sites reached as far as 0.8m for pasture grasses
Spain & Tibbett 2011 https://papers.acg.uwa.edu.au/p/1152_22_Spain/	Groundcover	Root penetration to 1m but most common stopped at 0.4m
Terrasim 2022 https://coaltech.co.za/wp-content/uploads/2022/01/Soil-covers-guideline_Mitigate-ARD-seepage-impact.pdf	Groundcover	0.3-0.4m
Terrasim 2022 https://coaltech.co.za/wp-content/uploads/2022/01/Soil-covers-guideline_Mitigate-ARD-seepage-impact.pdf	Tree	Up to 3m but dictated by the permeability of compacted layers below rock mulch
Versfeld 1998 https://www.wrc.org.za/wp-content/uploads/mdocs/413-1-98.pdf	Tree	*E. camaldulensis* rooted to 0.6-0.8m on rehabilitated mine site

Matter #2 – Commentary on EFA Thresholds

In their RFI (Item 19), DES has stated:

> *"Thresholds for the various Ecological Function Analysis (EFA) indices are proposed as milestone criteria (e.g., "Vegetation Dynamics >40% of reference").*
>
> *The Rehabilitation Planning Part does not currently justify the choice of thresholds. It is necessary to justify how the milestone criteria will demonstrate achievement of the relevant Rehabilitation Milestone which in turn achieves the required outcome of land in a stable condition."*

DES have asked Glencore to provide an updated PRCP that:

> *Justifies the choice of thresholds for EFA indices as sufficient to achieve the final outcome of land in a stable condition and discuss why these thresholds were chosen.*

Within the PRCP, the milestone criteria related to EFA include RM10, RM11, RM13 and RM14 (previously RM9, RM10, RM12 and RM13 in Version 1 of the PRCP). Each of these are addressed in turn below.

Generally however, the EFA indices proposed have been developed with the ultimate outcomes in mind – i.e. to achieve land in a stable condition that supports a viable vegetation community (per Table 7 of the PRCP).

EFA criteria relevant to each rehabilitation milestone are provided in Table 3.

Table 3: EFA criteria for each Rehabilitation Milestone (RM).

Milestone	Final Land Use	EFA Metric	Achievement of surface requirements - Vegetation on Developmental Trajectory (at 10 years)	Achievement of post-mining land use to stable condition (completion)
RM10 and RM13	Native Habitat areas	Metric:	RM10(c):	RM13(a):
		- Stability	>50% of reference	>80% of reference
		- Infiltration	>40% of reference	>60% of reference
		- Nutrient Cycling	>20% of reference	>60% of reference
		- Species Richness	>40% of reference	>60% of reference
		- Vegetation Dynamics	>20% of reference	>40% of reference
		- Habitat Complexity	>20% of reference	>40% of reference
RM11 and RM14	Low Intensity Cattle Grazing areas	Metric:	RM11(c):	RM14(b):
		- Stability	>50% of reference	>80% of reference
		- Infiltration	>40% of reference	>60% of reference
		- Nutrient Cycling	>20% of reference	>60% of reference
		- Vegetation Dynamics	>20% of reference	>40% of reference

Generally speaking, for mid-term EFA metrics (at 10 years, and per RM10 and RM11) reference values in Table 3 are lower than the final completion index score values of RM13/14 because they represent mid-term goals and are presumed to be tracking against an approximate sigmoidal curve per the Landscape Function Analysis Methods (Tongway and Hindley 2005). Further, it is acknowledged that this type of system is highly dependent on receiving good rainfall during the wet season, whilst recovery is generally slower compared to other bioregions in Qld due to arid conditions. Hence progress towards completion may occur in a step-wise fashion, experience occasional regression, or be slower than anticipated due to climatic conditions outside of Glencore's control.

What is most important for the mid-term EFA metrics, alongside achievement of the criteria, is demonstration of progress towards the end goal. This is what will be discussed in rehabilitation monitoring reporting, alongside any adaptive management requirements.

The intended way of measuring against the milestones is by averaging scores for representative analogue (reference) sites using data from the same monitoring event (or the most recent monitoring event, if all analogue

sites are to be considered in calculations). This method has been considered in the discussion of each EFA metric (column three of Table 3) below.

Stability

In EFA, stability is defined as the ability of the soil to withstand erosive forces, and to reform after disturbance (Tongway and Hindley 2005). For all RM, criteria are set at >50% of reference after 10 years and >80% of reference at completion (Table 3).

The mid-term milestone of >50% is set that way because some of the indicators the make up the stability score (Figure 3) take many years to develop evidence of presence/absence (such as cryptogram cover, crust broken-ness and deposited materials). Hence, these criteria allow for some time for the site to develop towards final completion.

Criteria are set at >50% and >80% because of the significant variation in stability scores within the reference sites themselves (Table 4 and Table 5). That is, if we use the lowest stability score amongst the analogue sites (84% of the average score), it is conceivable that a rehabilitation area may score just over 80% and still be in a comparable state to the analogue sites (Table 5). Likewise, with reference to the scores for each year's monitoring event, one standard deviation below the stability score average equates to between 84% and 95% (as a percent of the average scores) depending on the year (Table 5). Therefore 80% is considered reasonable given analogue sites are remnant ecosystems and we are comparing manufactured ecosystems against them.

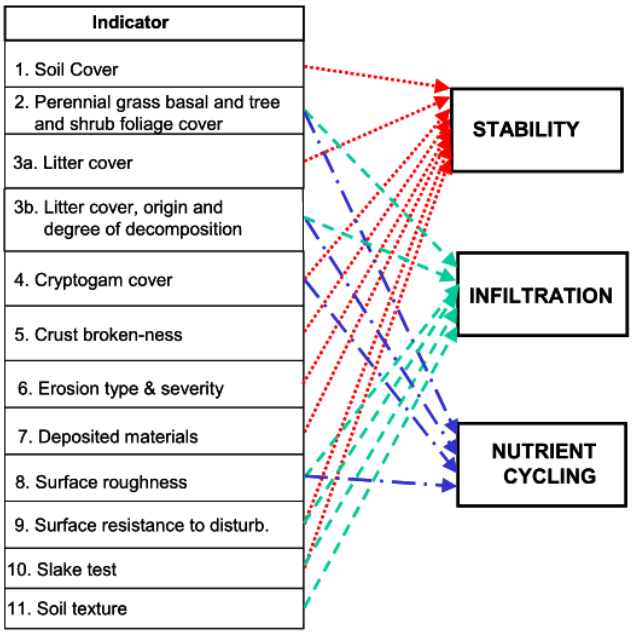


Figure 3: Indicators that make up the stability, infiltration and nutrient cycling scores within the EFA framework (from Tongway and Hindley 2005)

Infiltration

In EFA, infiltration is defined as how the soil partitions rainfall into soil-water (water available for plants to use), and runoff water which is lost from the local system, or may also transport materials away (soil, nutrients and seed) (Tongway and Hindley 2005). For all RM, criteria are set at >40% of reference after 10 years and >60% of reference at completion (Table 3).

Given the arid setting, indicators of infiltration such as perennial grass cover and litter cover (Figure 3) may take years to mature. Hence, the mid-term criterion of >40% has been defined.

Further, criteria is set relatively low compared to the average score for analogue sites because of the high variation in scores (Table 4). That is, if we take the lowest infiltration scores amongst the analogue sites, it is conceivable that a rehabilitation area may score just over 46% or 55% of the average score for that monitoring year (Table 5) and still

be comparable to the target analogue sites. Likewise, looking at the scores for each year's monitoring event, one standard deviation below the infiltration score average equates to between 46% and 95% (as a percent of the average scores) depending on the year (Table 5). Therefore 60% is considered reasonable given analogue sites are remnant ecosystems and we are comparing manufactured ecosystems against them.

Nutrient Cycling

In EFA, nutrient cycling is defined as how efficiently organic matter is cycled back into the soil (Tongway and Hindley 2005). For all RM, criteria are set at >20% of reference after 10 years and >60% of reference at completion (Table 3).

Again, the mid-term milestone is set relatively low because some of the indicators the make up the nutrient cycling score (Figure 3) take many years to develop evidence of presence/absence (such as grass cover, litter cover, cryptogram cover). Hence, these criteria give time for the site to develop towards final completion.

Criteria are set at >20% and >60% because of the significant variation in nutrient cycling scores within the reference sites themselves (Table 4 and Table 5). That is, if we take the lowest nutrient cycling scores amongst the analogue sites, it is conceivable that a rehabilitation area may score just over 38% / 40% of the average and still be comparable to the analogue sites (Table 5). Likewise, with reference to the scores for each year's monitoring event, one standard deviation below the nutrient cycling score average equates to between 13% and 90% (as a percent of the average scores) depending on the year (Table 5). Therefore >20% and >60% is considered reasonable given analogue sites are remnant ecosystems and we are comparing manufactured ecosystems against them.

Species Richness

This indicator applies to the native habitat end land uses only.

Species richness is the number of species within each site, as monitored via the Point-Centred Quarter method in the EFA methodology (Tongway and Hindley 2005). Again, there is significant variation around the minimum and maximum scores, with anywhere between 2 and 16 species found on each plot (Table 5). With reference to the existing dataset for all years, the average number of species is currently measured as 9.8. Hence 40% (at least for 4 species) and 60% benchmarks (at least 6 species) per Table 3 are considered appropriate, and will be similar to the condition of representative analogue sites.

Vegetation Dynamics

This indicator is measured by using two aspects of the vegetation dynamics scores within the EFA methodology (Tongway and Hindley 2005). This is the number of *canopy plants per ha*, and separately, the number of *understorey plants per ha* (i.e. shrubs)[2]. For all RM, criteria are set at >20% of reference after 10 years and >40% of reference at completion (Table 3).

With reference to the existing dataset for all years of **canopy plant counts**, the average number of plants is currently measured as 519 plants per ha, with a large standard deviation of 447 as the analogues span different types of vegetation community. Further, the analogue sites range from 44 canopy plants per ha, to 2020 canopy plants per ha in very thick Lancewood communities (Table 4). Hence 20% (at least 103 canopy plants per ha) and 40% benchmarks (at least 207 canopy plants per ha) are considered appropriate, and will be similar to the condition of representative analogue sites. For reference, analogue site A011 recorded 261 canopy plants per ha in 2021. An image of this community is provided in Figure 4 to give perspective.

With reference to the existing dataset for all years of **understorey plants** (and excluding the 3007 plants at A001 in 2018 as this is a statistical outlier), the average number of plants is currently measured as 326 plants per ha, with a large standard deviation of 208 plants per ha. This high standard deviation (relative to the mean) persists despite the exclusion of the largest outlier (3007 plants at A001 in 2018), demonstrating that variance within the system is naturally high. For information, the analogue sites range from 0 (or a few dozen) to 641 understorey plants per ha (excluding the 3007 plants outlier). Hence, the 20% (at least 66 plants per ha) and 40% benchmarks (at least 131

[2] Attributes related to perennial grass species are measured as part of the soil surface assessment and habitat complexity assessment in EFA. This will be assessed separately as part of the habitat complexity scoring discussed below.

plants per ha) are considered appropriate, and will be similar to the condition of representative analogue sites. For reference, analogue site A011 recorded between 143 and 199 understorey plants per ha in 2019 and 2021, respectively. An image of this community is provided in Figure 4 to give perspective.

Habitat Complexity

In EFA, habitat complexity (HC) is a relatively coarse method to calculate faunal habitat value. It is measured by scoring against the following metrics:

1) Canopy cover
2) Shrub cover
3) Ground vegetation cover
4) Litter, fallen logs and rocks (i.e. fauna microhabitat)
5) Free water availability

Scores against each of these five metrics are combined to give a final score out of 15. The analogue sites at LLM score relatively low, ranging from a HC score of 2 to 7, and averaging 4.1 (SD = 1.39) (Table 5).

For the native habitat RM, criteria were set at >20% (HC score of >1) of reference after 10 years and >40% (HC score of >2) of reference at completion (Table 3). These scores are considered low and based on this assessment are recommended to be increased to 40% and 60% respectively (i.e. both HC scores of >2). This will be considered appropriate given a score of 2 will be on par with at least 1 analogue site, and we are comparing remnant ecosystems against manufactured ecosystems.

Contingency Measures

Rehabilitation monitoring is likely to identify any serious issues related to construction/establishment during the first five years of monitoring. Five years is a standard assessment interval for tracking large-scale shifts in vegetated ecosystems under the Queensland BioCondition framework. Depending on local climatic conditions, 5 years allows a relatively high chance of capturing at least one wet year in an arid environment like that of the focal site. Such conditions are essential for measuring the true resilience and restoration potential for the site, as it is the trigger for natural recruitment, strong periods of growth for woody species and the expansion of functional attributes like cryptogram cover. For example, this will be identified via assessment of germination rates, soil condition; health of plants etc. Therefore, any rehabilitation construction/establishment issues that may jeopardise long-term compliance can be addressed early in the program. Due to the significant timeframes needed to reach completion, Glencore has significant resources devoted to ensure construction/establishment is done correctly; that any risks are mitigated during planning and implementation; and that any issues are identified and remedied early in the program.

Despite this, climatic changes between now and completion of the rehabilitation program poses a potential risk to achievement of the milestones. This includes (CSIRO 2020) a potential:

- increases in the number of hot days;
- increase in the number of dangerous fire weather days;
- increase in in rainfall during the wet season, storm intensity and flooding; and
- decreases in rainfall during the dry season, meaning less water may be available for plant growth/survival.

Nonetheless, these potential changes will also impact analogue sites. Therefore, reference values will also change depending on climatic conditions.

Any long-term changes will be contextualised and discussed within future rehabilitation reports. Based on an assessment undertaken of presented available data, the existing approach of EFA indices (stability, infiltration, nutrient cycling, species richness, vegetation dynamics) for relevant rehabilitation milestones and the proposed amendments to the habitat complexity scores for RM10 and RM13, will achieve conditions of analogue sites at completion, with allowance of mid-term metrics for adaptive management measures to be implemented, as required. The EFA indices as recommended in this memorandum are sufficient to achieve the outcome of land in a stable condition.

Table 4: Analogue Site Statistics

Year	Site	Stability Score	Water infiltration Score	Nutrient Cycling Score	Species Richness	Vegetation Dynamics - Canopy Plants per ha	Vegetation Dynamics - Understorey plants per ha	Habitat Complexity Score
2018	A001	50.2	36.1	21.8	NA	578	3007*	3
	A003	47.7	17.6	9.1	NA	97	13	3
	A007	56.9	27.9	24.7	NA	1456	0	4
	A008	44.6	13.2	9.5	NA	466	231	6
	A009	65.2	49.9	47.3	NA	937	0	4
2019	A002	53.1	26.5	16.4	13	634	201	5
	A004	54.3	25.9	15.9	8	388	33	2
	A005	51.9	27.4	15.6	8	250	400	4
	A006	57.4	24.7	17.9	10	349	86	3
	A010	58.3	28.4	20.3	2	559	19	2
	A011	54.5	26	17.1	14	281	143	3
2021	A002	54	27.2	19.5	16	634	201	5
	A004	47.5	31.5	18.6	6	276	38	3
	A005	54.2	33.6	29.7	10	272	224	5
	A006	54.2	33.6	29.7	15	388	173	7
	A010	51	34.6	26	6	324	28	4
	A011	46.4	26.3	17.7	15	261	199	4
2022	A001	57.4	13.9	9.5	11	403	89	4
	A003	57.4	20	20.9	11	44	192	3
	A007	64.9	29.6	38.1	8	2020	641	5
	A008	60.6	26.4	37.8	3	368	624	7
	A009	71.4	43.5	66.7	10	442	637	5

*3007 plants at A001 recorded in 2018 is a statistical outlier excluded from the assessment. See further discussion in text.

Table 5: Summary Statistics from Table 4

Year	Statistic	Stability Score	Water infiltration Score	Nutrient Cycling Score	Species Richness	Vegetation Dynamics - Canopy Plants per ha	Vegetation Dynamics - Understorey plants per ha	Habitat Complexity Score
2018	Max	65.2	49.9	47.3	NA	1456	3007*	6
	Min	44.6	13.2	9.1	NA	97	0	3
	Average	52.92	28.94	22.48	NA	706.8	650.2	4
	Range	20.6	36.7	38.2	NA	1359	3007	3
	Standard Deviation	8.22	14.73	15.56	NA	514.96	1321.15	1.22
	1 x SD below (% of Av.)	84%	49%	31%	NA	27%	-103%	69%
	Min score's (% of Av.)	84%	46%	40%	NA	14%	0%	75%
2019	Max	58.3	28.4	20.3	14	634	400	5
	Min	51.9	24.7	15.6	2	250	19	2
	Average	54.9	26.5	17.2	9.2	410.2	147.0	3.2
	Range	6.4	3.7	4.7	12	384	381	3
	Standard Deviation	2.47	1.29	1.73	4.31	154.16	141.45	1.17
	1 x SD below (% of Av.)	95%	95%	90%	53%	62%	4%	63%
	Min score's (% of Av.)	95%	93%	91%	22%	61%	13%	63%
2021	Max	54.2	34.6	29.7	16	634	224	7
	Min	46.4	26.3	17.7	6	261	28	3
	Average	51.2	31.1	23.5	11.3	359.2	143.8	4.7
	Range	7.8	8.3	12	10	373	196	4
	Standard Deviation	3.54	3.55	5.60	4.63	142.66	87.41	1.37
	1 x SD below (% of Av.)	93%	89%	76%	59%	60%	39%	71%
	Min score's (% of Av.)	91%	84%	75%	53%	73%	19%	64%
2022	Max	71.4	43.5	66.7	11	2020	641	7
	Min	57.4	13.9	9.5	3	44	89	3
	Average	62.3	25.1	25.0	9.0	570.0	295.5	4.5
	Range	14	29.6	57.2	8	1976	552	4
	Standard Deviation	5.93	11.17	21.63	3.36	779.07	272.82	1.48
	1 x SD below (% of Av.)	90%	56%	13%	63%	-37%	8%	67%
	Min score's (% of Av.)	92%	55%	38%	33%	8%	30%	67%
All years	Max	71.4	49.9	66.7	16	2020	641	7
	Min	44.6	13.2	9.1	2	44	0	2
	Average	55.1	28.4	24.1	9.8	519.4	326.3	4.1
	Range	26.8	36.7	57.6	14	1976	641	5
	Standard Deviation	6.48	8.51	13.56	4.10	447.36	208.27	1.39
	1 x SD below (% of Av.)	88%	70%	44%	58%	14%	36%	66%
	Min score's (% of Av.)	81%	47%	38%	20%	8%	0%	48%

*3007 plants at A001 recorded in 2018 is a statistical outlier excluded from the assessment. See further discussion in text.

Transect Start Photo A011 (2021)



Transect Finish Photo A011 (2021)



Figure 4: Photos of A011 in 2021

Matter #3 – Framework to describe and measure 'low intensity grazing'

The PRCP's rehabilitation milestone for RM14 is for the "*Achievement of post-mining land use to stable condition (Low Intensity Cattle Grazing areas)*", whilst the associated milestone criteria for RM14 requires "a*ssessment by suitably qualified and experienced person that pasture is sufficiently productive to support low intensity cattle grazing*".

As part of Item 19 of their RFI, DES has requested "*a definition for Low Intensity Grazing, sufficient to measure achievement of criterion RM13a"* (now RM14a).

The relationship between Grazing Rate, Land Types and Long-Term Carrying Capacity

It is acknowledged that the type of ecosystem within and surrounding the LLM mining lease has only supported 'low intensity grazing' in the past (in the context of grazing rates across Queensland) due to the low fertility, and low palatable biomass of the ground layer. Like anywhere, there are natural constraints on the long-term carrying capacity of the land. Ultimately, the level of 'low intensity grazing' may vary as the long-term carrying capacity of the land fluctuates with climate and resource availability.

Nonetheless, if the rehabilitation areas meet the associated rehabilitation milestones / EFA criteria in RM14, it could be assumed that the land will be fit for low intensity cattle grazing as it will reflect a pre-mining condition. This is because EFA measures and tracks Stability, Infiltration, Nutrient Cycling and Vegetation Dynamics – which are all relevant to the condition of grazing land.

Grazing capacity by ruminants such as cattle is measured in "Adult Equivalent" (AE), with a single AE being the pasture intake needed to sustain a 450kg steer. The Queensland Government provides guidance on the long-term carrying capacity of different ecosystems as part of their *Land types of Queensland Southern Gulf Region* publication (Queensland Government, 2011), and as part of the FORAGE reporting (2022). The proposed rehabilitation program will generally mimic the land types on site (see Figure 5). I.e.:

- SG07 – *Lancewood*
- SG10 - *Open Red Country*
- SG11 – *Rough Spinifex Hills*

See Appendix A for more information on each of these.

The long-term carrying capacity for these land types are shown below in Table 7, Table 8 and Table 9.

Further, the FORAGE Long-Term Carrying Capacity report (Appendix B) shows a maximum long-term carrying capacity of around 43.9 hectares per AE for land in the "A" condition. However, as mentioned above, this will vary over the long-term depending on land condition. For reference, "A" condition refers to the highest quality of habitat in a grazed landscape, with degraded conditions being assigned B, C or D as they worsen. "D" condition sites are overgrazed, lack grassy understories and have lowered ecosystem resilience and function. See Figure 6, Figure 7 and Figure 8 for example of the "A to D" land conditions associated with the three land types.

Therefore, "low intensity grazing" rates are considered to be equivalent to the long-term carrying capacities of the land (Table 7, Table 8 and Table 9). This is a function of pasture type, pasture growth, tree cover, weed cover and is variable subject to regional ecosystem type, climate, land/soil fertility and availability of palatable biomass for stock.

Further, the safe annual utilisation pasture growth rate is stated to be 15% for all three listed land types – by both the Queensland Government (2011) and the Southern Gulf NRM body (2016). A 'safe' pasture utilisation rate is defined as the proportion of annual forage growth that can be consumed by domestic livestock without adversely affecting land condition in the long term (Walsh and Cowley 2011).

Defining "Low Intensity Grazing"

With the above points in mind, the level of 'low intensity grazing' cannot be defined as a single number of hectares per AE because it will need to be flexible, and adapted to suit the fluctuations in carrying capacity of the land which will be impacted by natural events. In the absence of an on-ground assessment specific to the mining lease, the data within the FORAGE Long-Term Carrying Capacity report (Appendix B) is considered the most suitable available reference to provide a low intensity grazing rate for areas proposed for low intensity cattle grazing. The FORAGE report is more specific to the land than the *Land types of Queensland Southern Gulf Region* publication (Queensland

Government, 2011 – i.e. Table 7, Table 8 and Table 9) because the latter is calculated at a regional level whilst the FORAGE report looks specifically at the land in question. Table 6 outlines the long-term carrying capacity with reference to land types and condition and is based on data within the FORAGE Report (Appendix B). However, it is noted that the FORAGE Long-Term Carrying Capacity grazing rates used in Table 6 are based on, inter alia, computer models, weather data and satellite imagery. Hence, there is low confidence in the on-ground accuracy of this data. Until such time as a suitably qualified and experienced person undertakes an on-ground assessment (described below), and stakeholder engagement is undertaken, grazing rates in Table 6 should be used as a guide only, and they do not represent PCRP milestone criteria.

Table 6: Long-Term Carrying Capacity Grazing Rate

Land Type	Condition and Associated LTCC Grazing Rate (ha/AE)*			
	A	B	C	D
SG07 – *Lancewood*	21.9	29.2	49.1	110.4
SG10 - *Open Red Country*	55.5	73.5	123.5	272.7
SG11 – *Rough Spinifex Hills*	125.0	165.1	273.4	625.0

* Data based on Page 3 of Appendix B

Assessment by a suitably qualified and experienced person

The *Land Condition Guide* (Southern Gulf NRM 2016) provides an adaptive management framework for stocking rates based on the carrying capacity of the various land types. It utilises the same 'A to D' scoring system based on several land condition indicators, with stocking rates and other land management measures adapted to suit the land's condition.

As part of the milestone associated RM14a, an assessment by a suitably qualified and experienced person will be undertaken (on behalf of Glencore) to confirm the suitability of stocking rates. The assessment will be undertaken at the time of stocking - as part of the progressive rehabilitation of the mining lease area, and then also upon surrender to confirm achievement of the post mining land use to a stable condition.

The assessments will confirm if the pasture is sufficiently productive to support low intensity grazing and also recommend the most suitable rate of grazing. The 'safe' pasture utilisation rate and the *Land Condition Guide* (Southern Gulf NRM 2016) will also be referenced[3] to ensure sustainable grazing practices upon proposed surrender in 2060. Stocking rates will consider land use factors such as:

- land type and condition;
- climate;
- area available (paddock size) and evenness of use;
- available pasture at the commencement and end of grazing (dry mass per hectare);
- Feed accessibility due to water availability and geography;
- growth rates of pasture (seasonal considerations);
- Goals for animal production and land condition; and
- expected number of days grazing.

This is consistent with contemporary grazing practices and Meat and Livestock Australia (MLA 2021) recommendations for carrying capacity calculations.

The assessment under RM14 will also reference the EFA method and criteria as per Table 3, as well as EFA monitoring results, which enable tracking of elements relevant to long term carrying capacity (Stability, Infiltration, Nutrient Cycling, Vegetation Dynamics and basal area of vegetation). Again, it should be noted that if the relevant EFA milestones are met, the land will be representative of the pre-mining condition (as measured via analogue sites during the rehabilitation monitoring events) and therefore by definition will be able to support low intensity grazing.

[3] Due to the long-term nature of the PRCP, an equivalent framework may be used in the future, where it is considered to be an industry-recognised and credible method.

Conclusion regarding Low Intensity Cattle Grazing

A low intensity cattle grazing rate has been defined with reference to several credible sources mentioned above. Going forward, grazing rates will be assessed prior to the introduction of stock in areas that have been rehabilitated, and also as part of a final assessment upon surrender. Annual EFA monitoring will also assist to monitor the condition of the land, feeding back into decisions around stock rates and the long-term carrying capacity of the land.

The proposed program is considered adequate to track and confirm achievement of the post mining land use to a stable condition suitable for low intensity cattle grazing.



Figure 5: FORAGE Landtype (from Qld Government Spatial Services)

Table 7: Long Term Carrying Capacity for SG07 - Lancewood (from Queensland Government, 2011)

Based on fully watered area for 1AE = 450 kg animal consuming 8kg DM/day				
Median annual rainfall 398 – 761 mm				
Pasture type	Median tree cover (TBA m^2/ha) (FPC %)	Median annual pasture growth (DM kg/ha)	Safe annual utilisation pasture growth (%)	LTCC (ha/AE)
Native species	0 TBA/FPC	530 - 1740	15%	11 - 37
	8 TBA 20 FPC	230 - 680	15%	29 – 84

Table 8: Long Term Carrying Capacity for SG 10 – Red Country (from Queensland Government, 2011)

Based on fully watered area for 1AE = 450 kg animal consuming 8kg DM/day				
Median annual rainfall 398 – 831 mm				
Pasture type	Median tree cover (TBA m^2/ha) (FPC %)	Median annual pasture growth (DM kg/ha)	Safe annual utilisation pasture growth (%)	LTCC (ha/AE)
Native species	0 TBA/FPC	1080 - 2730	15%	7.1 - 18
	3 TBA 8 FPC	770 - 2410	15%	8.1 – 25

Table 9: Long Term Carrying Capacity for SG11 – Rough Spinifex Hills (from Queensland Government, 2011)

Based on fully watered area for 1AE = 450 kg animal consuming 8kg DM/day				
Median annual rainfall 398– 831 mm				
Pasture type	Median tree cover (TBA m^2/ha) (FPC %)	Median annual pasture growth (DM kg/ha)	Safe annual utilisation pasture growth (%)	LTCC (ha/AE)
Native species	0 TBA/FPC	220 - 960	15%	20 - 87
	4 TBA 10 FPC	130 - 560	15%	35 – 146

Acronyms for Table 9: AE = Adult equivalent; DM = Dry Mass; TBA = Total Basal Area ; FPC = Foliage Project Cover; LTCC = Long Term Carrying Capacity.

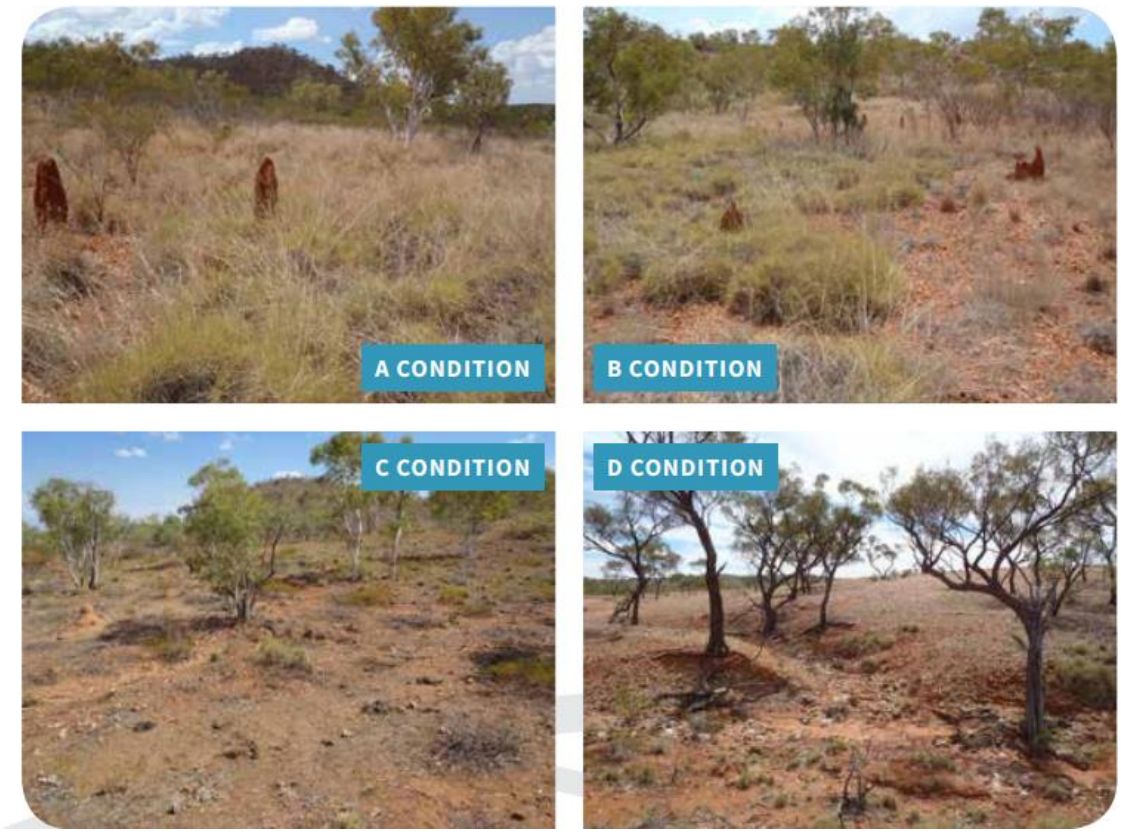


Figure 6: A to D Condition for Rough Spinifex Hills (From Southern Gulf NRM 2016).



Figure 7: A to D Condition for Lancewood (From Southern Gulf NRM 2016).

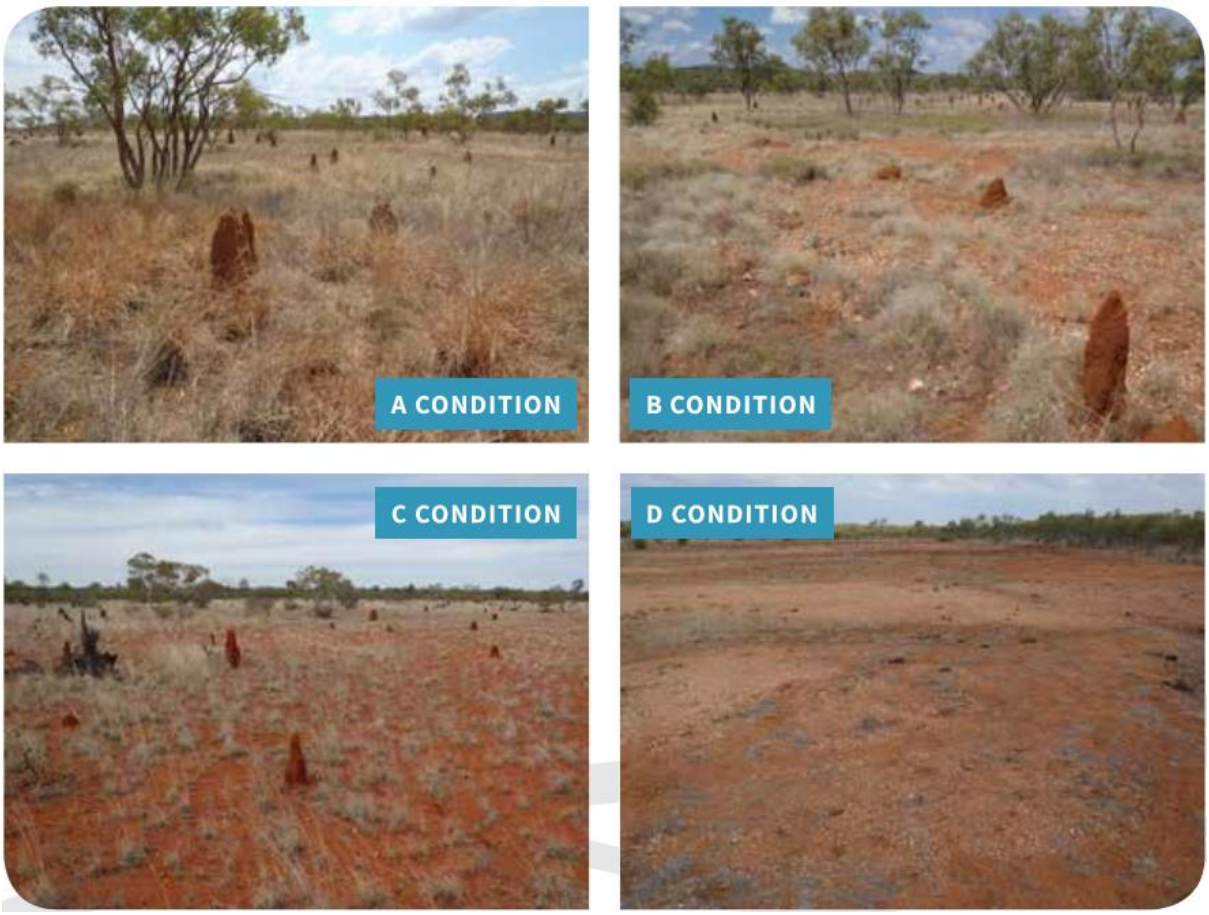


Figure 8: A to D Condition for Open Red Country (From Southern Gulf NRM 2016).

I trust this addresses RFI comments from DES. Please let me know if you require further information.

Regards,

Steve Jarman
Principal Ecologist

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Appendix A

Lancewood



Landform	Residual slopes, scarp retreats and adjacent tops of dissected plateaus and broken sandstone tablelands.
Woody vegetation	Lancewood woodland or low open woodland. Infrequently and sparsely associated with Normanton box.
Expected pasture composition	* *Denotes non-native "Expected Pasture Composition" species.*
Preferred	Golden beard grass, spinifex, kangaroo grass.
Intermediate	Wiregrasses, wanderrie grasses, curly windmill, bottlewashers.
Non-preferred	
Annual grasses	Fire grass, annual wiregrasses (including kerosene grass).
Common forbs	Sidas, potato bush, flannel weed.
Suitable sown pastures	Not suitable for sown pastures.
Introduced weeds	
Soil	Skeletal soils and shallow red earths; texture contrast soils and stony brown clays on steep slopes at the base of cliffs; often extensive rock outcropping.
Description	***Surface:*** Variable rock stone and gravel cover; ***Surface texture:*** sandy loam to none; ***Subsoil texture:*** weathered parent material.
Features	Extensive rock outcropping and/or extensive covers of rock, rubble, and gravel. Provides useful run-on to surrounding areas.

Water availability	Very low.
Rooting depth	Very shallow.
Infiltration	Very low. High proportion of run-off following 5 mm of rain, even under low intensity rainfall.
Fertility	Very low.
Salinity	Non-saline.
Sodicity	Non-sodic.
pH	Very acidic.

Long-term carrying capacity information (A condition)

Based on fully watered area for 1AE = 450 kg animal consuming 8kg DM/day				
Median annual rainfall 398 – 761 mm				
Pasture type	Median tree cover (TBA m^2/ha) (FPC %)	Median annual pasture growth (DM kg/ha)	Safe annual utilisation pasture growth (%)	LTCC (ha/AE)
Native species	0 TBA/FPC	530 - 1740	15%	11 - 37
	8 TBA 20 FPC	230 - 680	15%	29 – 84

Enterprise

Breeding.

Land use and management recommendations

- Sustainable harvesting of timber for fence posts and rails.
- Potential groundwater recharge area.
- Useful runoff areas for stock dams.

Land use limitations

- Generally unsuitable for grazing.
- Very low soil fertility and moisture storage.
- Steep broken slopes.

Conservation features and related management

- Protected area: Lawn Hill National Park.

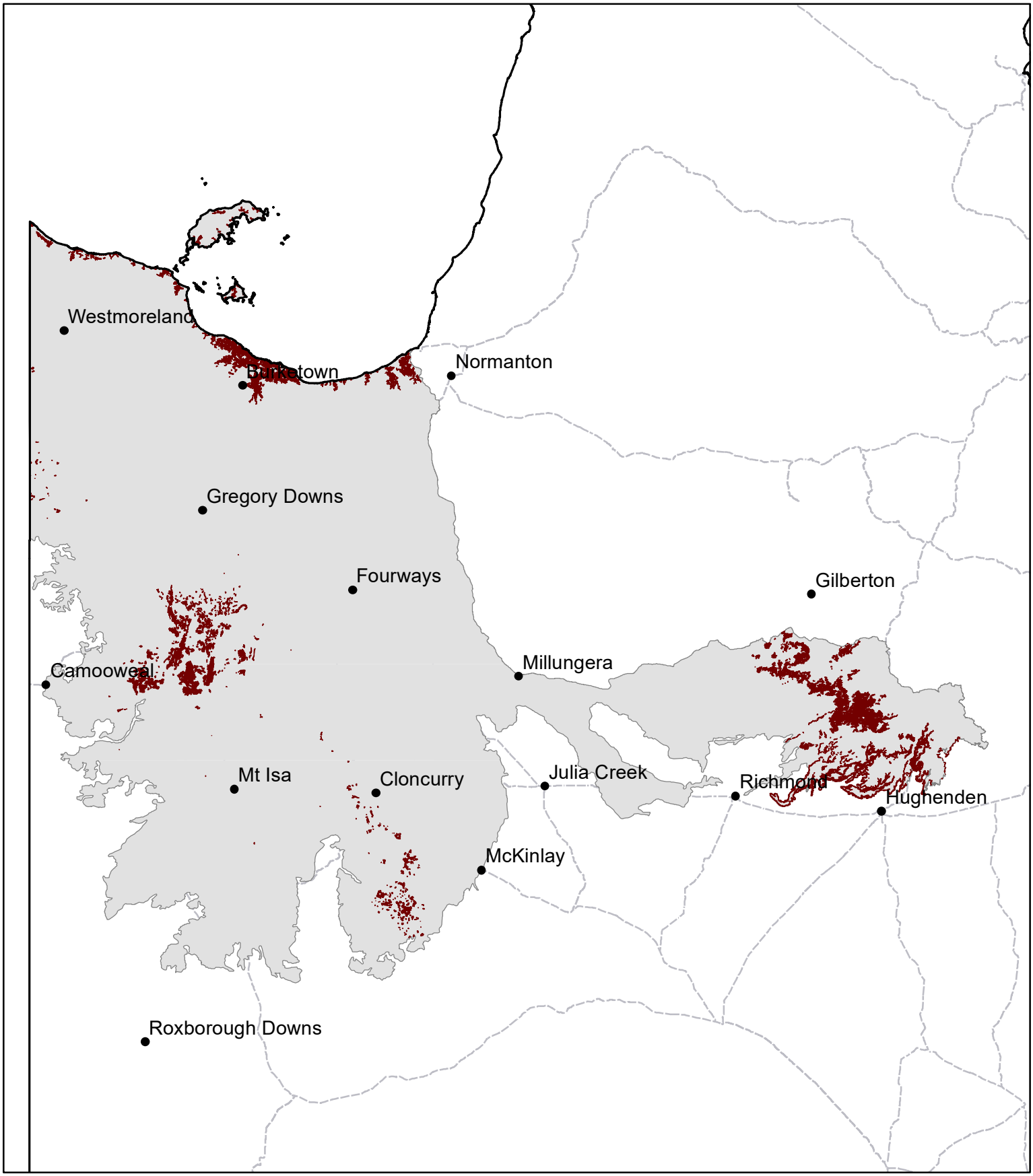
Regional Ecosystems

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Land Systems

Torwood(11), Hampstead (5) (Perry 1964).

SG07 Lancewood



Area of land type in region: 2%
Median rainfall (region): 233 – 831 mm
Average rainfall (region): 271 – 952 mm
Area of land type with FPC: 89%
Median FPC: 20%
Median TBA: 8 m2/ha

Queensland Government

Open red country



Landform	Outwash plains, erosional plains. Sometimes on gravelly alluvium or limestone ridges.
Woody vegetation	Open woodland including snappy gum, western bloodwood, Cloncurry box, silver-leaved box, gidgee and beefwood. Wattles, wait-a-while, cassia and currant bush shrubs are commonly found.
Expected pasture composition	** Denotes non-native "Expected Pasture Composition" species.*
Preferred	Kangaroo grass, forest bluegrass, desert bluegrass, black speargrass, Cloncurry buffel grass*.
Intermediate	Bottlewashers grasses, cotton panic, whitegrass, five-minute grass, soft spinifex, silky browntop, golden beard grass, silky oil grass.
Non-preferred	Wiregrasses.
Annual grasses	Button grass, wanderrie grasses, native couch, Australian dropseed, small burr grass, comb chloris, rare panic.
Common forbs	Foxtails, common bonamia, tickweed, tropical speedwell, sidas, pigweed, soft roly poly, gidgee burrs.
Suitable sown pastures	Buffel grass, shrubby stylos (e.g. Seca), Caribbean stylos (e.g Verano).
Introduced weeds	Calotrope, mesquite, parkinsonia, bellyache bush, kapok bush.
Soil	A variety of soils, the best being deep loamy red earths. Patches of red clays, texture contrast soils and some skeletal soils.
Description	***Surface***: Loamy with surface crusting and hard-setting; ***Surface texture***: silty loam; ***Sub-soil texture***: light to medium clays.

Features	Massive surface with soft consistency. Poor structure limits water infiltration during heavier rain. Contains small deposits of shallow skeletal soils. Impermeable surface horizon and hard sub soils.
Water availability	Low to moderate. Water holding capacity and internal drainage low to moderate.
Rooting depth	Low to moderate.
Infiltration	Low during heavier rainfall and moderate during lighter rainfall.
Fertility	Low. Particularly phosphorous.
Salinity	Low.
Sodicity	Low.
pH	Neutral to acidic, possibly changing at depth.

Long-term carrying capacity information (A condition)

Based on fully watered area for 1AE = 450 kg animal consuming 8kg DM/day				
Median annual rainfall 398 – 831 mm				
Pasture type	Median tree cover (TBA m^2/ha) (FPC %)	Median annual pasture growth (DM kg/ha)	Safe annual utilisation pasture growth (%)	LTCC (ha/AE)
Native species	0 TBA/FPC	1080 - 2730	15%	7.1 - 18
	3 TBA 8 FPC	770 - 2410	15%	8.1 – 25

Enterprise

Breeding.

Land use and management recommendations

- Use fire judiciously as management tool to control wattle, turpentine, and timber thickening.
- Maintenance of ground cover to minimise shrub invasion and erosion.

Land use limitations

- Areas of scalding due to overuse.
- Wattle thickening can limit productivity.

Conservation features and related management

- Includes some areas of Lawn Hill National Park.
- Changed fire regimes and heavy grazing can lead to changes in the floristics of the native vegetation.

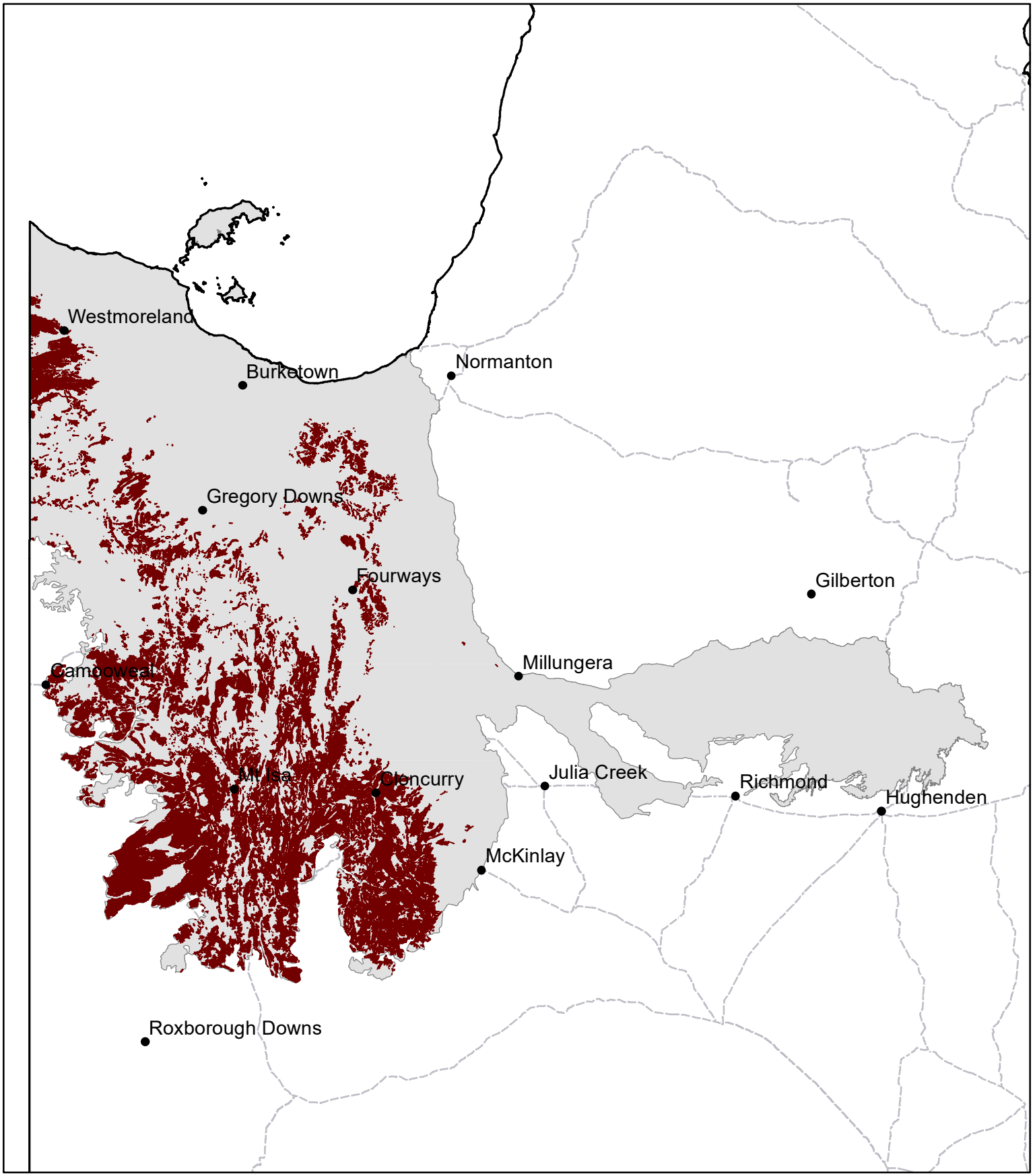
Regional Ecosystems

1.10.2, 1.10.3, 1.10.4a-b, 1.10.6, 1.11.2, 1.11.2a, 1.11.2h-j, 1.11.3a-b, 1.12.1, 1.12.1x5, 1.12.2, 1.5.15, 1.5.16, 1.5.17, 1.5.18, 1.5.19, 1.6.1, 1.9.5b, 2.10.1a, 2.10.4a-b, 2.10.4x3, 2.10.6, 2.10.6x2, 2.11.1a, 2.11.1c, 2.11.1x1, 2.12.1a-b, 2.5.10a-c, 2.5.23a-b, 2.5.35, 2.7.3, 2.7.3x1, 4.5.5b, 4.7.2x1, 4.7.7a-b.

Land Systems

Quamby (34), Percol (47) (Perry 1964).

SG10 Open red country



Area of land type in region: 15%
Median rainfall (region): 233 – 831 mm
Average rainfall (region): 271 – 952 mm
Area of land type with FPC: 64%
Median FPC: 8%
Median TBA: 3 m2/ha

Queensland Government

Rough spinifex hills



Landform	Rugged mountains, rocky plateaus and high plains, and hilly country.
Woody vegetation	Sparse low-woodland of snappy gum with scattered Cloncurry box, western bloodwood, winged nut tree, turpentine, wattles and cassias.
Expected pasture composition	** Denotes non-native "Expected Pasture Composition" species.*
Preferred	Soft spinifex, Cloncurry buffel grass*.
Intermediate	Bottlewashers, wanderrie grasses, hard spinifex, five-minute grass.
Non-preferred	Wiregrasses.
Annual grasses	Native couch, small burr grass, Australian dropseed, fire grass, slender wanderrie grass.
Common forbs	Gidgee burrs, foxtails, sidas, red spinach.
Suitable sown pastures	Not suitable for sown pastures.
Introduced weeds	Kapok bush.
Soil	Skeletal and rock outcrops poorly drained deeper soils along drainage lines.
Description	***Surface:*** Massive with varying stone cover; ***Surface texture:*** sandy loam to sandy clay loam; ***Sub-soil texture:*** clay.
Features	Deeper soils occur along drainage lines. Soils drain poorly at depth. Surface soil tends to seal. Generally, shallow soils less than 30cm are frequently stony and occur on steeper slopes.
Water availability	Very low to low.

Rooting depth

Low.

Infiltration

High on the steeper country until surface wets up after 10-15 mm of rain. On the deeper soils along drainage lines, light rain will be required to allow water to infiltrate down to the deeper clays once profile is wet, little through drainage is likely to occur, rest will run off.

Fertility

Low.

Salinity

Low, unknown at depth along the drainage lines.

Sodicity

Low, unknown at depth along the drainage lines.

pH

Neutral to acidic.

Long-term carrying capacity information (A condition)

Based on fully watered area for 1AE = 450 kg animal consuming 8kg DM/day				
Median annual rainfall 398– 831 mm				
Pasture type	Median tree cover (TBA m^2/ha) (FPC %)	Median annual pasture growth (DM kg/ha)	Safe annual utilisation pasture growth (%)	LTCC (ha/AE)
Native species	0 TBA/FPC	220 - 960	15%	20 - 87
	4 TBA 10 FPC	130 - 560	15%	35 – 146

Enterprise

Breeding.

Land use and management recommendations

- Maintenance of perennial pastures is required to allow infiltration in the deeper soils.
- Maintenance of ground cover to minimise shrub invasion and erosion.
- Mosaic burning for wildfire control, turpentine management and to improve access and grazing value of spinifex.

Land use limitations

- Steepness of slope may limit available grazing areas.
- Steepness of slope and shallow stony soils limit cultivation opportunities.
- Turpentine thickening can limit productivity.

Conservation features and related management

- Historic mining has potential to impact water quality.

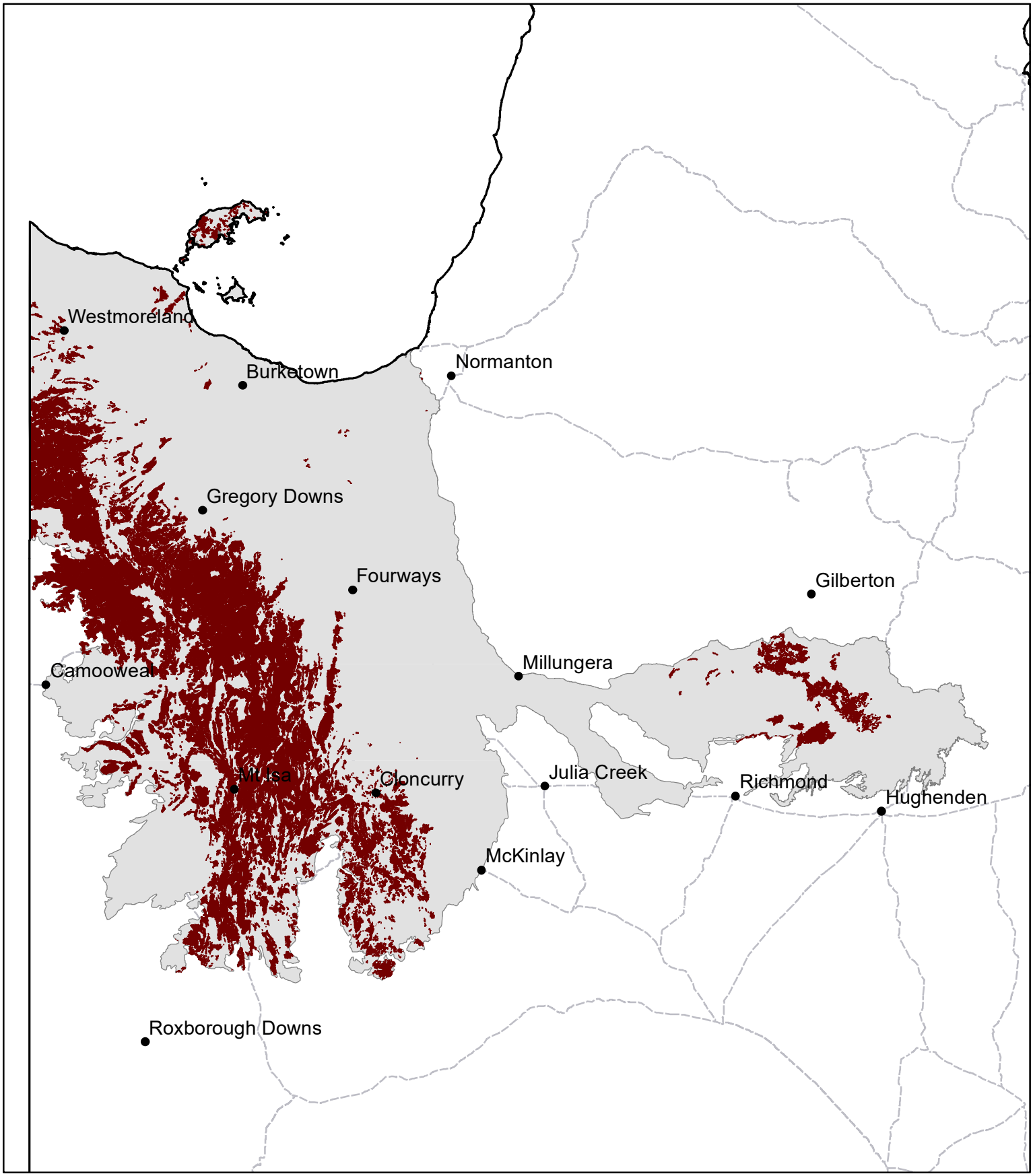
Regional Ecosystems

1.11.6, 1.11.8, 1.11.9, 1.12.3a, 1.7.1a, 1.7.7a, 1.9.10, 1.9.11a, 1.9.11c, 1.9.12, 1.9.13, 1.9.14, 1.9.4b-c, 2.3.20b, 2.3.37, 2.5.4, 2.5.9, 4.9.12x4a.

Land Systems

Kuridala (18), Argylla (8) Merlin (13) (Perry 1964).

SG11 Rough spinifex hills



Area of land type in region: 17%
Median rainfall (region): 233 – 831 mm
Average rainfall (region): 271 – 952 mm
Area of land type with FPC: 76%
Median FPC: 10%
Median TBA: 4 m2/ha

Queensland Government

Appendix B

FORAGE REPORT: LONG-TERM CARRYING CAPACITY (LTCC)

http://www.longpaddock.qld.gov.au/FORAGE 21/11/2022 Label: lady-loretta-ltcp Latitude/Longitude: -19.74/139.06 prototype v1.0

Queensland Government

Summary of estimated LTCC (fully watered)

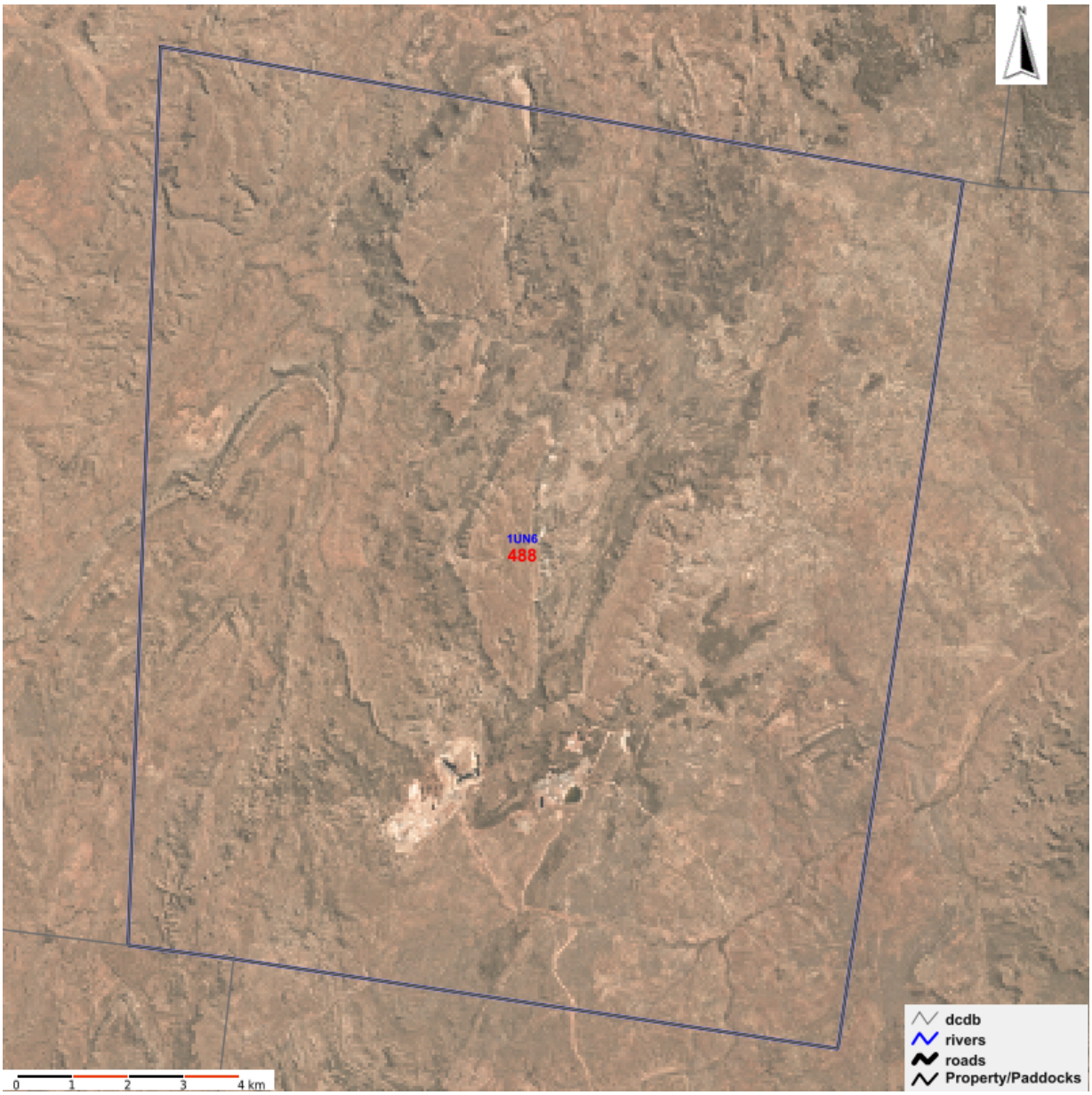
Land condition	LTCC (AE)	LTCC (Ha/AE)
A	488 (437 to 540)	43.9 (39.2 to 48.6)
B	366	58.5
C	220	109.7
D	98	219.5
User defined condition	N/A	N/A

Estimated long-term average feral animal and kangaroo equivalents for selected property or areas: 38 AE

Location map



Estimated LTCC (AE) for selected areas under best ('A') land condition



About the report

This report presents the estimated **"long-term carrying capacity" (LTCC)** for the property of interest. LTCC in this report refers to "number of livestock that a paddock or property can support over a long period (decades) without causing land degradation".

In this report, the LTCC is measured as the total adult equivalents (AEs; 450 kg cattle consuming 8kg DM/day) that can be safely carried for a paddock or property and is also shown as hectares required per AE unit. The calculation of the LTCC is based on a number of factors, including: the long-term median annual pasture growth; the safe utilisation rate of the pastures; the distance to watering points; topography and tree density. Pasture growth is calculated from the GRASP model using parameters for grazing land management (GLM) land types, the tree density on the property and the historical climate data for the property of interest (sourced from the SILO climate database - https://www.longpaddock.qld.gov.au/silo/).

Pasture utilisation by livestock is set at a rate that is not likely to cause long-term property degradation and to allow recovery after drought. For Mulga land types, livestock consumption of "topfeed" (i.e. feeding mulga leaves) is considered in the calculation of the LTCC. Introduced pasture species such as buffel grass will show an improved pasture response output if the buffel grass option is selected at request. However, stylos, pasture irrigation and fertiliser application are not considered in the pasture growth calculation. It is assumed that livestock have full water access adjacent to pastures. The annual feed intake for an AE is set as 2920 kg/year.

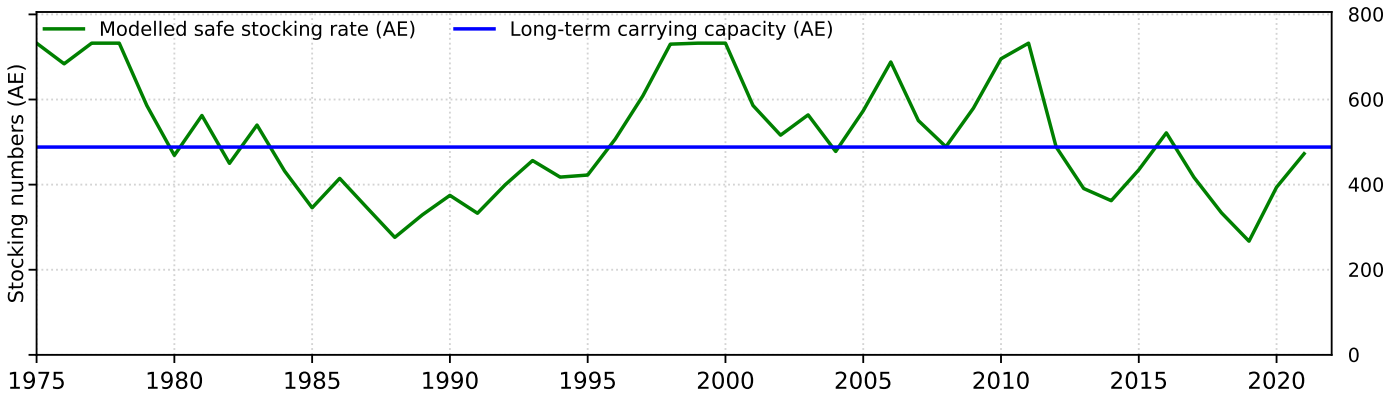
The purpose of the report is to provide an objectively estimated LTCC for the property which can be used as a starting point for discussion and to add input for further analysis (i.e. use spreadsheet supplied along with this report to improve the LTCC estimates). Values given for the LTCC are an indication only, significant management of property grazing pressure is still required on a season to season basis (i.e. forage budgeting).

FORAGE REPORT: LONG-TERM CARRYING CAPACITY (prototype v1.0)

http://www.longpaddock.qld.gov.au/FORAGE 21/11/2022 Label: lady-loretta-ltcp Latitude/Longitude: -19.74/139.06

Queensland Government

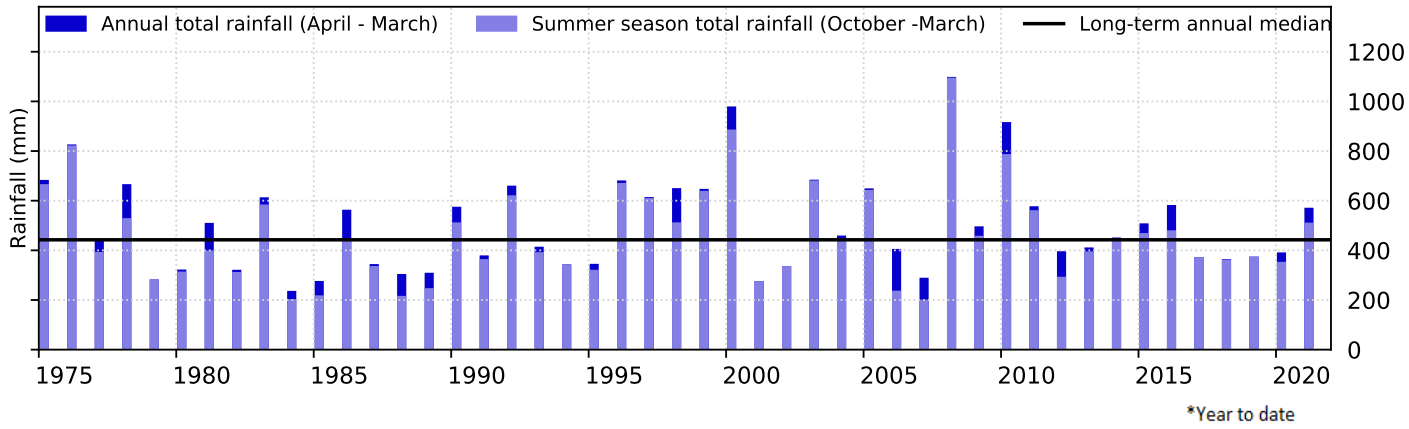
Modelled safe stocking rate under A condition



About the modelled safe stocking rate graph

The above graph shows the modelled historical annual (Apr-Mar) safe stocking rates for the property. The safe stocking rate calculations are based on a number of factors including: the modelled LTCC; the safe utilisation rate defined for each land type; and a set of rules to increase/decrease the stocking rate in response to changing climate.

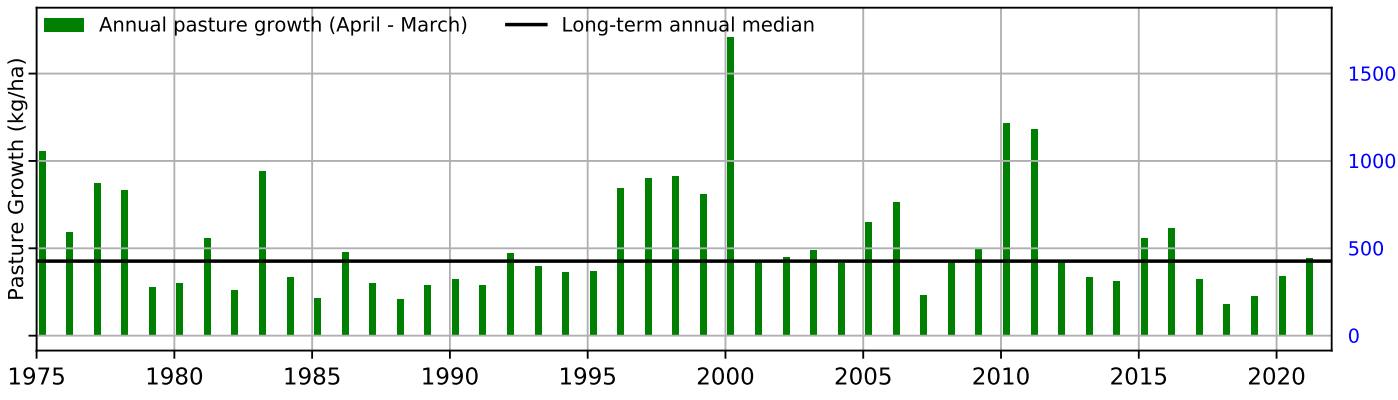
Historical annual and summer season rainfall



About the historical annual and summer season rainfall graph

The historical annual and summer season rainfall graph for the requested property is derived from the SILO database (https://www.longpaddock.qld.gov.au/silo/). Summer season rainfall is defined as rainfall during October to March. The long-term median rainfall is for a period from 1975 to the current year. The high year to year variability is a normal characteristic of Queensland rainfall.

Historical annual (April - March) pasture growth under A condition (kg/ha)



About the historical annual pasture growth graph

The historical annual pasture growth (April - March) is an area-weighted average across the property for each land type and foliage projective cover (FPC) level. The long-term median annual pasture growth is for a period from 1975 to the current year. The overall rainfall use efficiency for this property is approximately 1.1 kg DM/ha/mm rainfall.

FORAGE REPORT: LONG-TERM CARRYING CAPACITY (prototype v1.0)

Queensland Government

Long-term carrying capacity summary for paddocks/land parcels

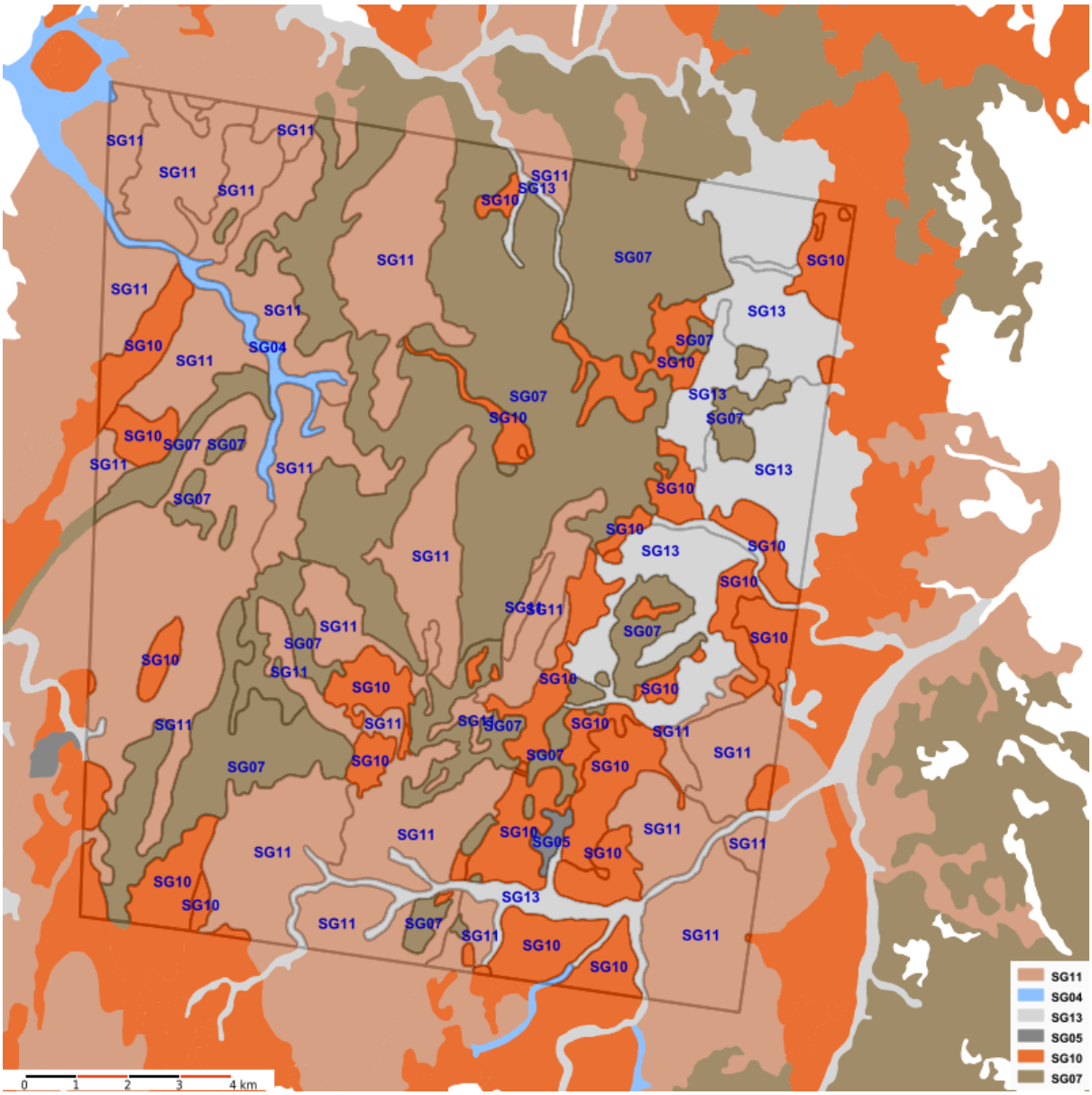
Paddock name	Total area (ha)	Area considered not grazed (ha)	LTCC (AE) A	LTCC (AE) B	LTCC (AE) C	LTCC (AE) D	LTCC (Ha/AE) A	LTCC (Ha/AE) B	LTCC (Ha/AE) C	LTCC (Ha/AE) D
1UN6	21433.9	0.0	488	366	220	98	43.9	58.5	97.6	219.5
Total/mean	21434	0	488	366	220	98	43.9	58.5	97.6	219.5

FORAGE REPORT: LONG-TERM CARRYING CAPACITY (prototype v1.0)

http://www.longpaddock.qld.gov.au/FORAGE 21/11/2022 Label: lady-loretta-ltcp Latitude/Longitude: -19.74/139.06

Queensland Government

Property land types



Summary of the land types and corresponding long-term carrying capacity

Land type code and name	Land type area (ha)	Percent area FPC<15	LTCC (AE) A	LTCC (AE) B	LTCC (AE) C	LTCC (Ha/AE) D	LTCC (Ha/AE) A	Median growth* (kg/ha/year)
SG04 - Frontage SG	188.5	31.3	16	12	7	3	11.6	1413
SG05 - Gidgee SG	47.2	38.4	3	3	2	1	13.7	1362
SG13 - Silver-leaved box	2370.6	56.9	119	89	53	24	20.0	812
SG10 - Open red country	3533.8	58.3	161	121	72	32	21.9	877
SG07 - Lancewood SG	6544.9	39.6	118	89	53	24	55.3	350
SG11 - Rough spinifex hills	8749.3	62.1	70	53	32	14	124.1	156
Total/mean	21434	N/A	488	366	220	98	43.9	421

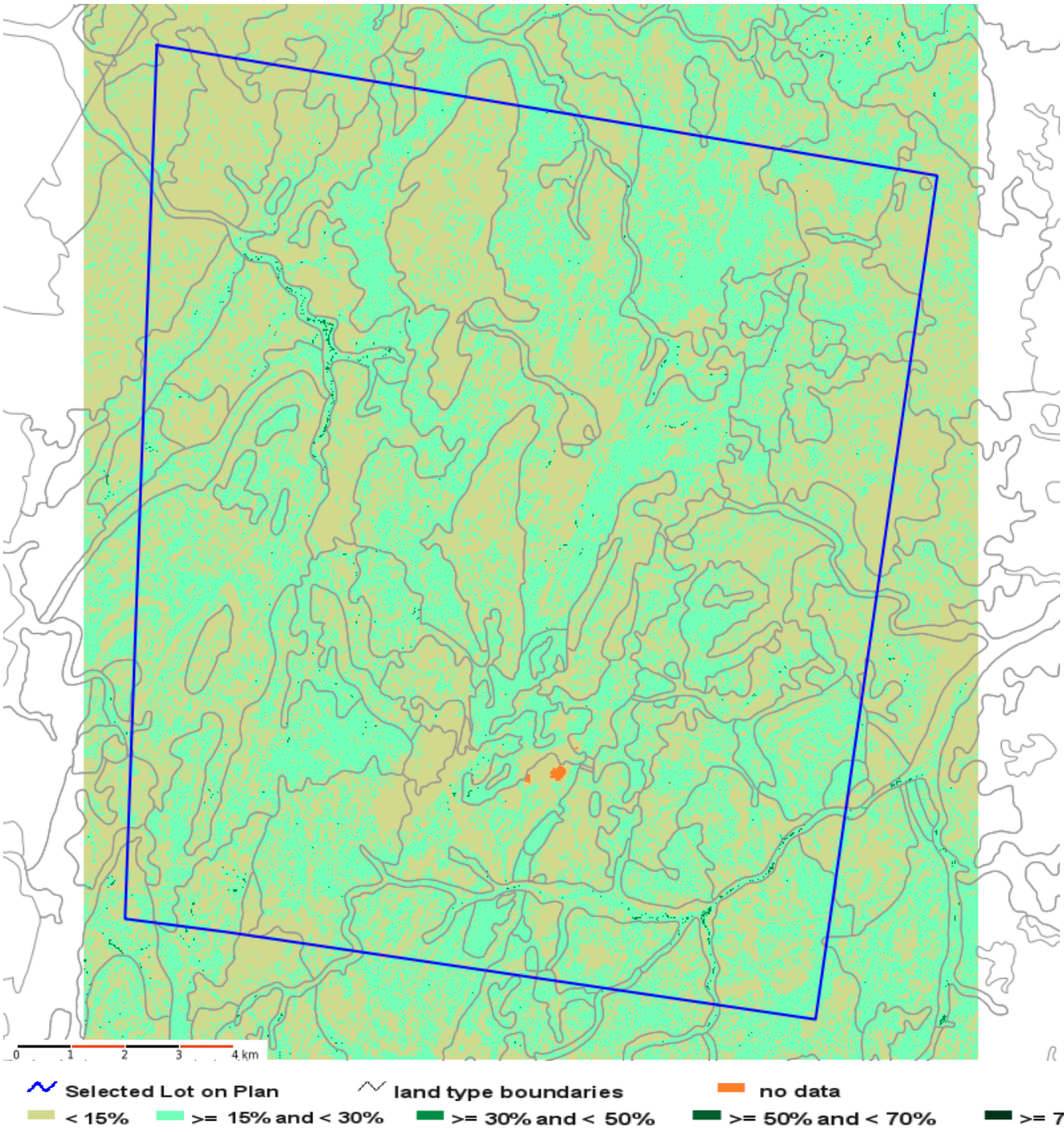
** Growth in any land type may be strongly impacted by local tree density.*

FORAGE REPORT: LONG-TERM CARRYING CAPACITY (prototype v1.0)

http://www.longpaddock.qld.gov.au/FORAGE 21/11/2022 Label: lady-loretta-ltcp Latitude/Longitude: -19.74/139.06

Queensland Government

Estimated foliage projective cover (FPC)



About the foliage projective cover (FPC) map

The map presents estimated FPC information obtained from satellite data (2019) for the selected paddocks/land parcels (for more information see FORAGE FPC report). The map shows both the different classes of FPC and the land type information for the area selected. Areas with greater than 15 percent FPC are classed as woody vegetation cover, whereas areas with less than 15 percent FPC are classed as non-woody vegetation cover. Users may be more familiar with tree density being expressed as tree basal area (TBA). As a guide, for mature tree communities, FPC thresholds of 15, 30 and 70 percent equate to tree basal area of approximately 6, 12 and 32 m^2/ha respectively.

Disclaimer

Limitation of liability: the State of Queensland, as represented by the Department of Environment and Science (DES) gives no warranty in relation to the data (including without limitation, accuracy, reliability, completeness or fitness for a particular purpose). To the maximum extent permitted by applicable law, in no event shall DES be liable for any special, incidental, indirect, or consequential damages whatsoever (including, but not limited to, damages for loss of profits or confidential or other information, for business interruption, for personal injury, for loss of privacy, for failure to meet any duty including of good faith or of reasonable care, for negligence, and for any other pecuniary or other loss whatsoever including, without limitation, legal costs on a solicitor own client basis) arising out of, or in any way related to, the use of or inability to use the data. ©The State of Queensland, 2022.

APPENDIX D FLOOD ASSESSMENT

Flood Assessment for the Progressive Rehabilitation and Closure Plan

Lady Loretta Mine

Gencore Limited
1636-03-B2, 25 May 2022

Report Title	Flood Assessment for the Progressive Rehabilitation and Closure Plan, Lady Loretta Mine
Client	Gencore Limited
Report Number	1636-03-B2

Revision Number	Report Date	Report Author	Reviewer
0	14 May 2022	JF	JO
1	23 May 2022	JF	JO
2	25 May 2022	JF	JO

For and on behalf of WRM Water & Environment Pty Ltd
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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

1.1 BACKGROUND

Glencore Limited (Glencore) is currently preparing the Progressive Rehabilitation and Closure Plan (PRCP) for final landforms associated with the Lady Lorretta Mine (LLM). Figure 1.1 shows the site location and drainage characteristics. Figure 1.2 shows the locations of the PRCP related infrastructure, which includes the rehabilitated waste rock emplacement, rehabilitated dams, and rehabilitated infrastructure areas and associated drainage. The site is proposed to be fully rehabilitated, and no Non-Use Management Areas (NUMAs) such as final voids are proposed.

Glencore engaged WRM Water & Environment Pty Ltd (WRM) to undertake hydrologic and hydraulic modelling for these LLM final landforms in support of the PRCP preparation.

The Department of Environment and Science's (DES) *Guideline – Progressive rehabilitation and closure plans* (PRC plans) (DES, 2019) require a flood plain model report to be included in the rehabilitation planning part of the PRCP, the intent of which is to:

- represent the flood plain under removal of all temporary structures or features;
- assess the flooding susceptibility and influence across the site; and
- confirm the final landform to be stable.

The PRCP guidelines require flood plain modelling to be undertaken in accordance with the Australian Rainfall and Runoff (ARR) guidelines and excluding artificial features on the site. Artificial features under the PRCP schedule are defined as structures or features that are temporary, that will require a level of maintenance greater than the level of maintenance that would be required had the schedule not been carried out, or that interfere with or affect relevant watercourses of the natural flow of water. Such features will be identified and excluded from the flood modelling.

DES (2019) defines a "relevant watercourse" as a watercourse that, under the Strahler method, is a stream ordered as a fourth order stream or higher. It is noted that lower ordered streams also require assessment against the decision criteria in the EP Act.

Hydrologic and hydraulic modelling for the 50% Annual Exceedance Probability (AEP), 1% AEP, 0.1% AEP event and Probable Maximum Flood (PMF) was undertaken to assess flooding characteristics at the LLM under final landform conditions as per the DES (2019 & 2020) requirements.

1.2 PURPOSE OF REPORT

This flood modelling report provides a description of the adopted assessment methodology and the key modelling results for the assessment of flooding at the LLM. The contents of this report may be used as input to the PRCP.

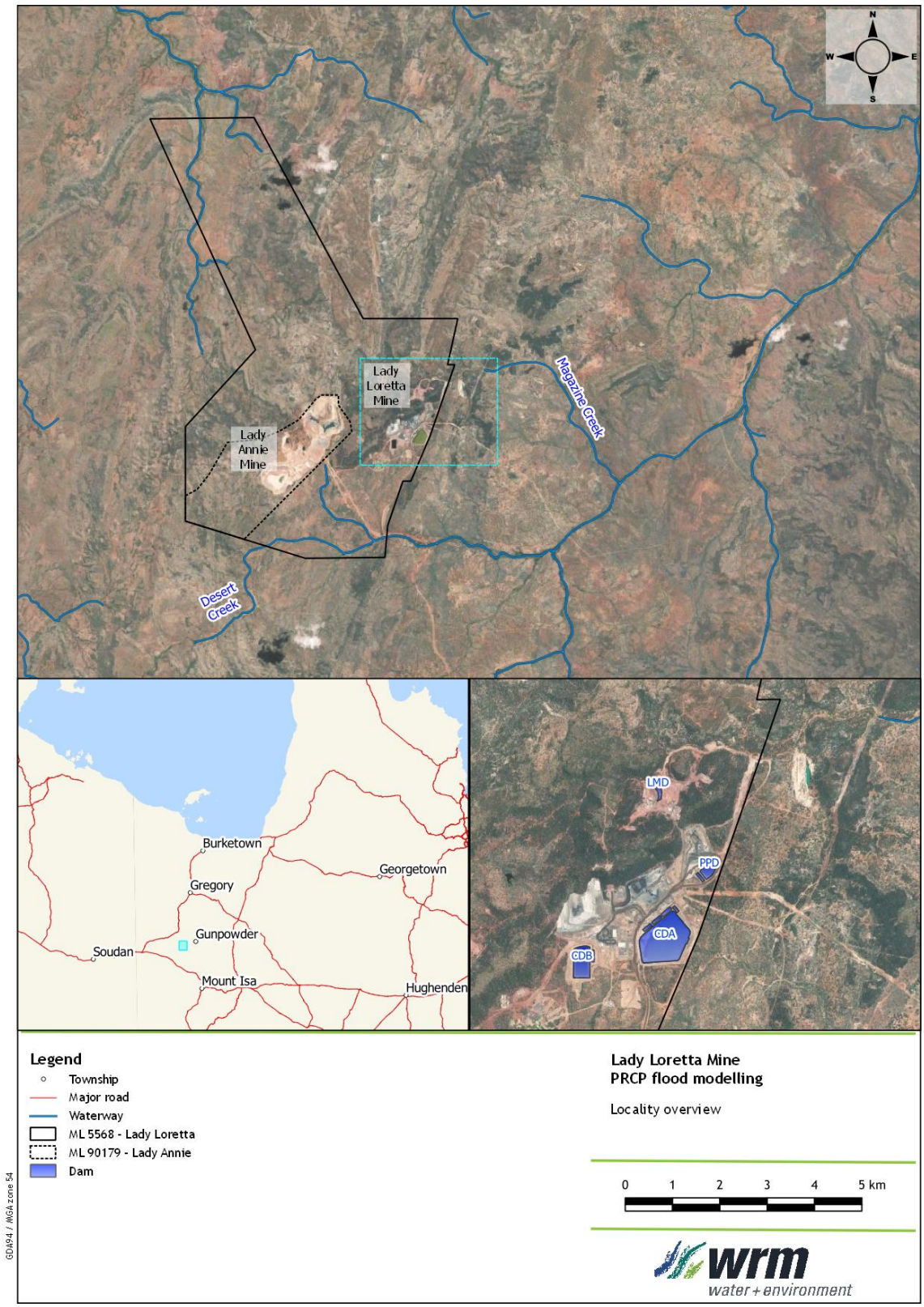


Figure 1.1 – Locality and key drainage features

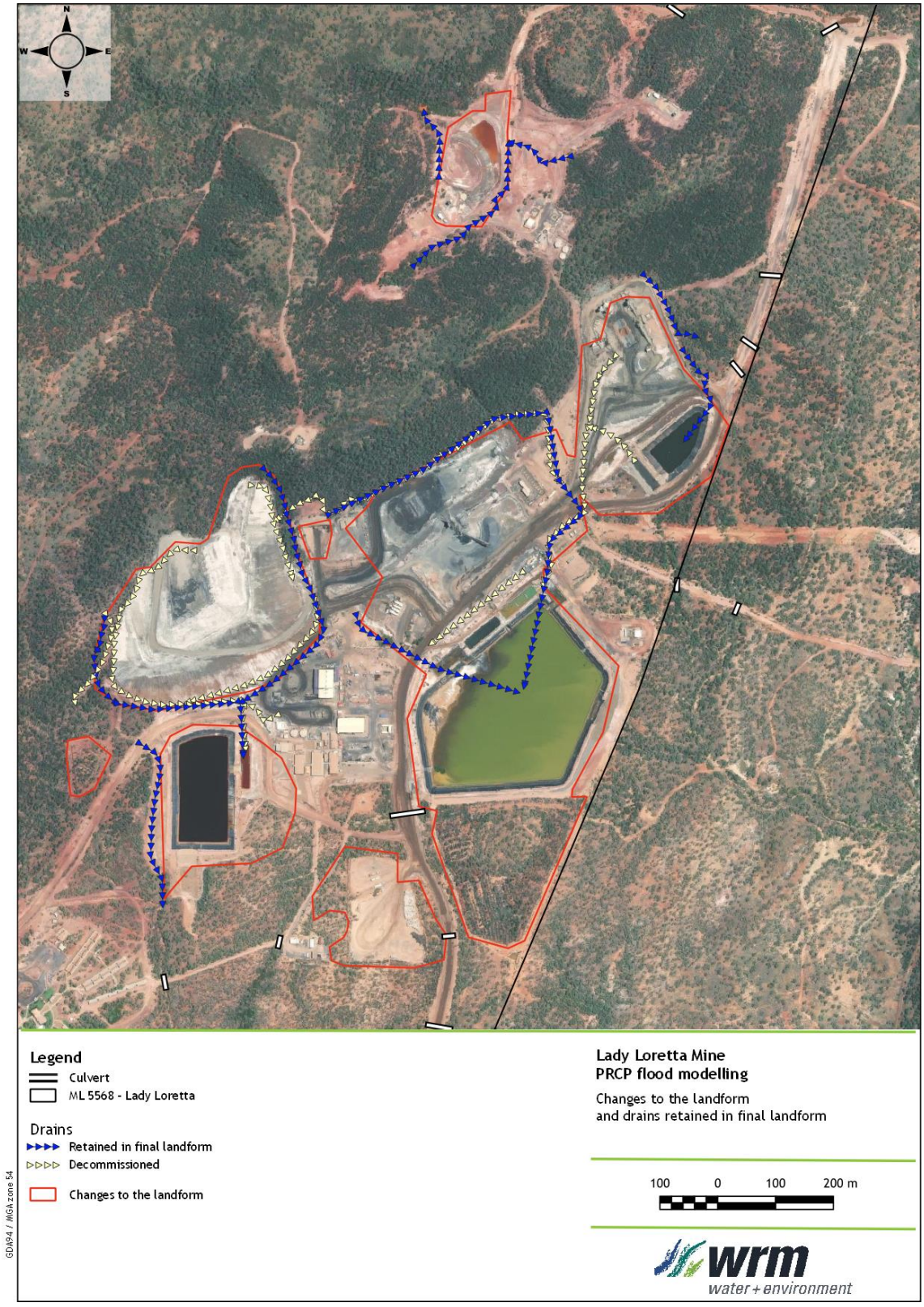


Figure 1.2 – Site overview, proposed changes to the landform and drains

2 Regional and local catchments

Figure 2.1 shows the catchments and key drainage features in the vicinity of LLM. The following sections describe the existing catchments and drainage features in the vicinity of the site.

2.1 REGIONAL TOPOGRAPHY AND CATCHMENTS

The LLM operation is located within the Leichhardt River catchment at the headwaters of Magazine and Desert creeks. The southern part of the LLM site is located within the Desert Creek catchment. The northern part of the LLM site is located within the Magazine Creek catchment. The nearby Lady Annie operation is in the Desert Creek catchment upstream of LLM.

Based on the GeoScience Australia dataset, the upper headwaters of Magazine and Desert Creeks are characterised by steep first and second order watercourses (see Figure 2.1). These upstream catchments have been modified within the Mine site to allow for mining operations.

Magazine Creek remains a first stream order classification from its northern headwaters and past the northeastern mine lease boundary and is a second order stream at its confluence with Desert Creek. The Desert Creek stream order classification ranges between first order streams in the upper southwestern headwater to a fourth order watercourse at the downstream southeastern boundary of the mine lease. Desert Creek is of fifth stream order classification at its confluence with Magazine Creek approximately 6.2 km downstream of the LLM mine lease boundary. The following catchment areas are of note:

- Desert Creek has a catchment area of approximately 29.7 km^2 to the downstream mine lease boundary and an additional 107.7 km^2 upstream of the Magazine Creek confluence; and
- Magazine Creek has a catchment area of approximately 1.5 km^2 to the downstream mine lease boundary and 10.5 km^2 upstream of the Desert Creek confluence.

2.2 SITE DRAINAGE

The Mine site is located at the headwaters of Magazine and Desert creeks. Little external catchment drains to the Mine, with only first order watercourses intersecting the site (see Figure 2.1).

Several drains direct runoff around the mine site, a number of which are proposed to be retained in the final landform (see Figure 1.2).

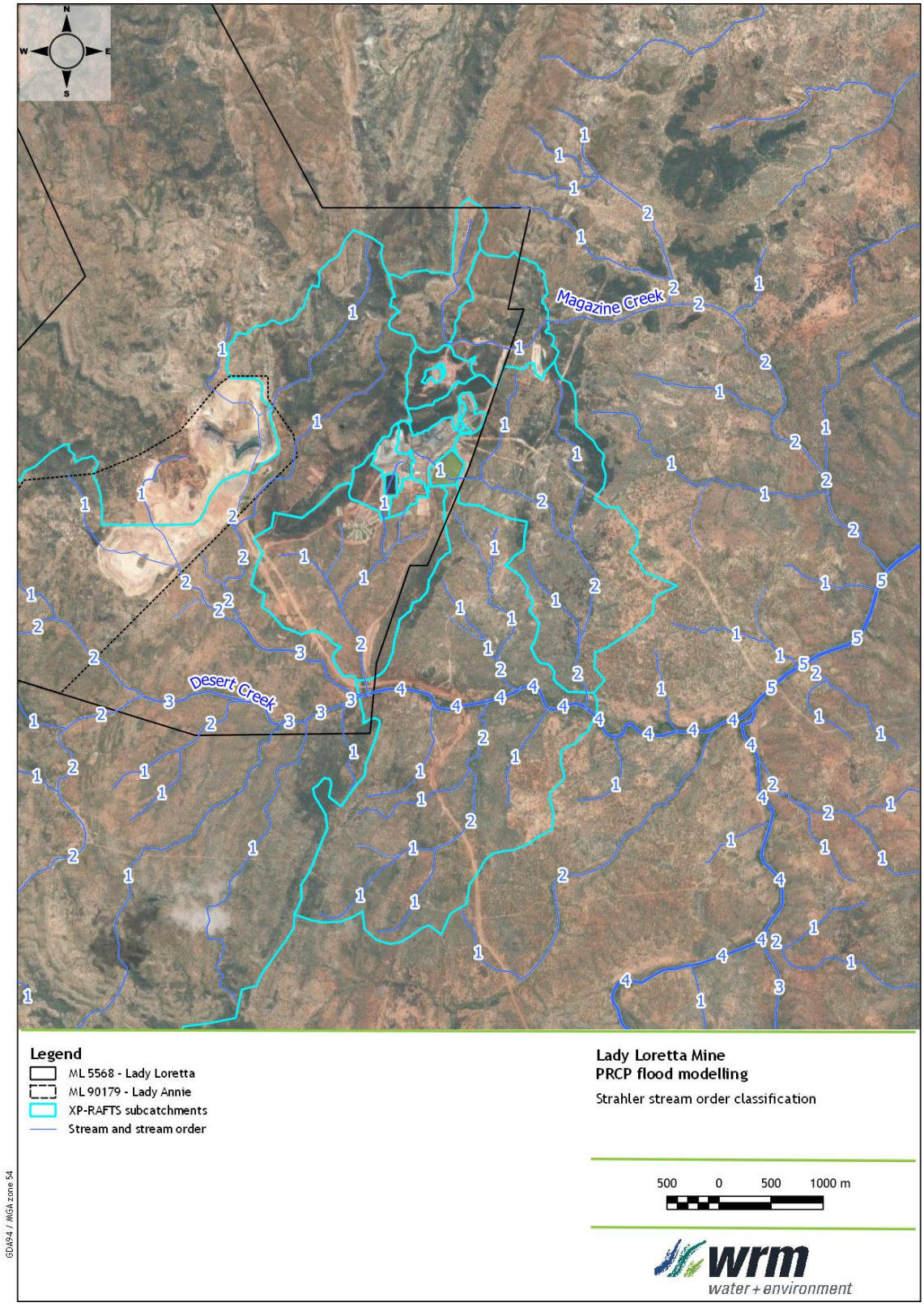


Figure 2.1 – Regional and local catchments and Strahler stream order classification

3 Available data

3.1 FLOODPLAIN TOPOGRAPHIC DATA

Figure 3.1 shows the extents of available topographic data for the study. The topographic data was used to develop a XP-RAFTS hydrologic model (refer to Section 5) and Two-Dimensional Unsteady Flow (TUFLOW) hydraulic model (refer to Section 6) developed for this study. The following topographic data was available for use in this study:

- Light Detection and Ranging (LiDAR) data provided as 199 American Standard Code for Information Interchange (ASCII) tiles merged to a grid with 1 m resolution covering the hydraulic model extent including the existing waste rock emplacement, mine infrastructure area, mine water dams and around the camp and Sewage Treatment Plant (STP) within the LLM mine lease;
- the final landform surface “Post Mining Final Landform.tif”, which had a grid resolution of 5 m, was provided as by ATC Williams on 28 March 2022. It was assumed for the purpose of this assessment the landform surface provided only included permanent features and temporary features were removed; and
- SRTM data for the remaining areas, used to define the hydrologic model where higher resolution data was unavailable.

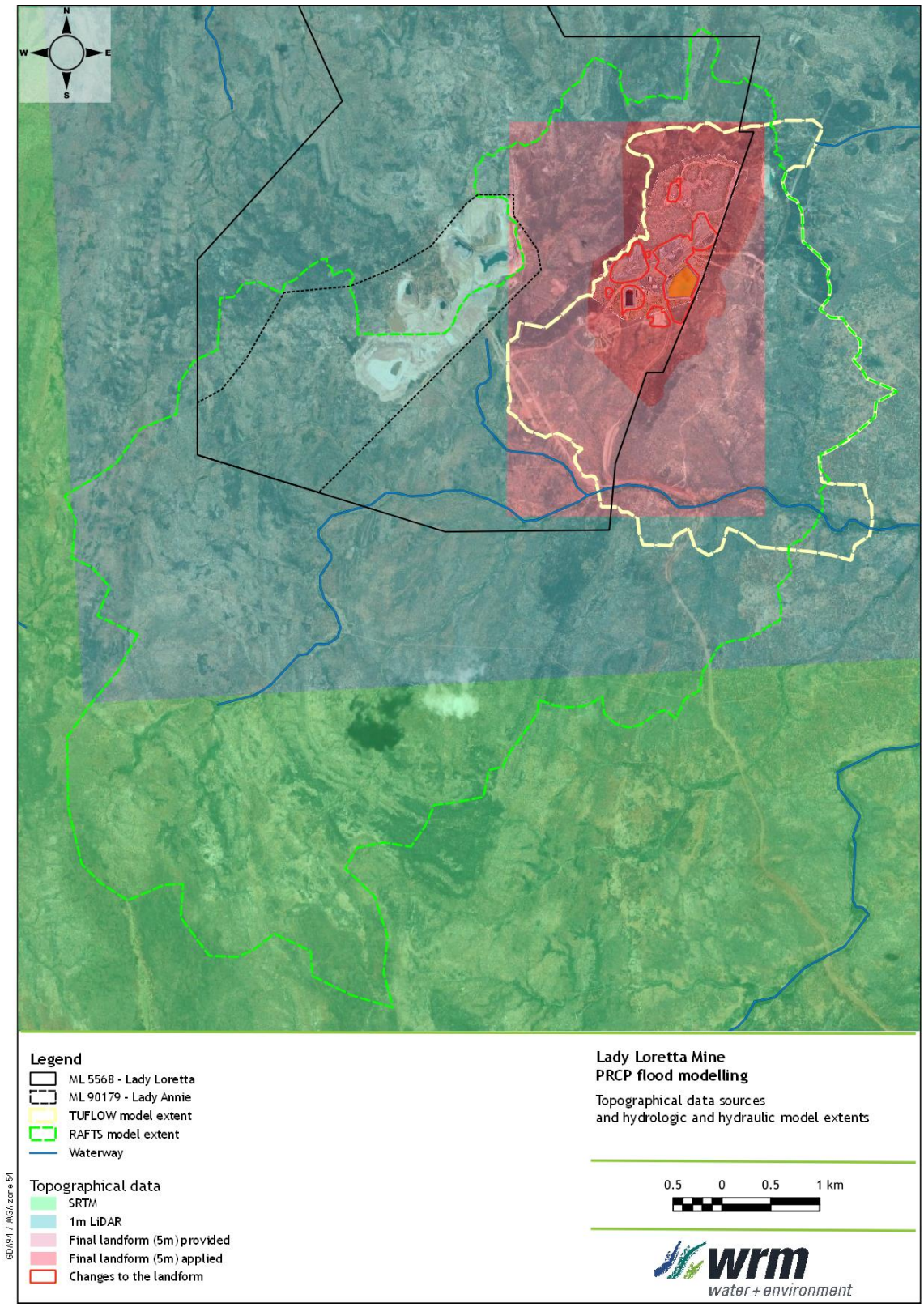


Figure 3.1 – Topographical data availability

4 Final landform configuration

The available topographic data described in Section 3 was combined with the post-mining landform data provided by ATC Williams to develop the final landform topography at the LLM site. The final landform topography was used as the basis for hydrologic and hydraulic modelling. Figure 4.1, Figure 4.2 and Figure 4.3 show the modelled final landform configuration for CDA, CDB, PPD, LMD, mine infrastructure area and waste rock emplacement.

The portal box cut, infrastructure areas including the Run of Mine (ROM), Paste Plant area and dams will be regraded where required to be free draining and rehabilitated. It is proposed to retain the rehabilitated waste rock emplacement, haul roads and associated drainage in the final landform, subject to landholder engagement. There are no residual voids associated with the final landform of the LLM site.

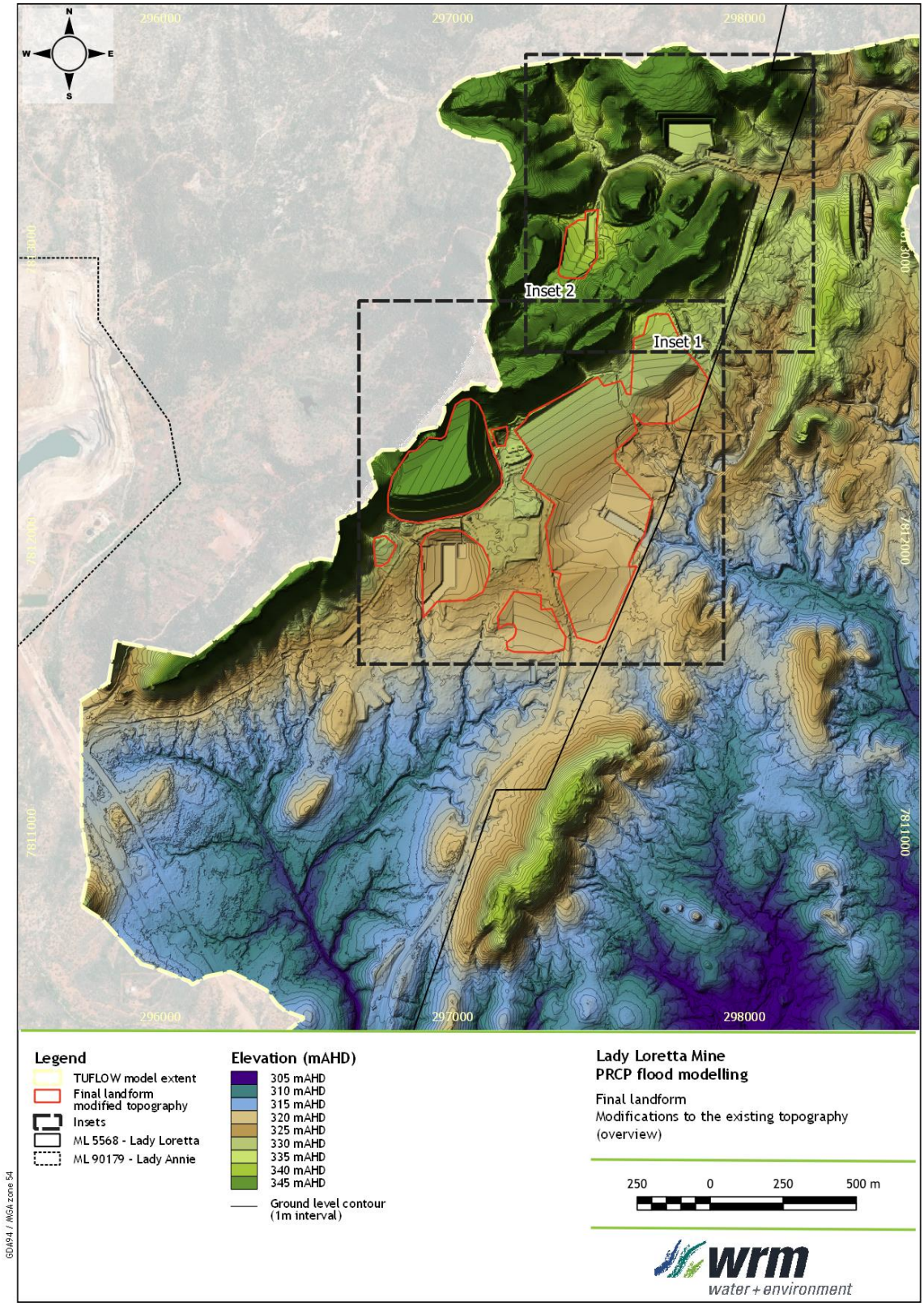


Figure 4.1 – Final landform configuration, overview



Figure 4.2 – Final landform configuration, LMD (inset 1)

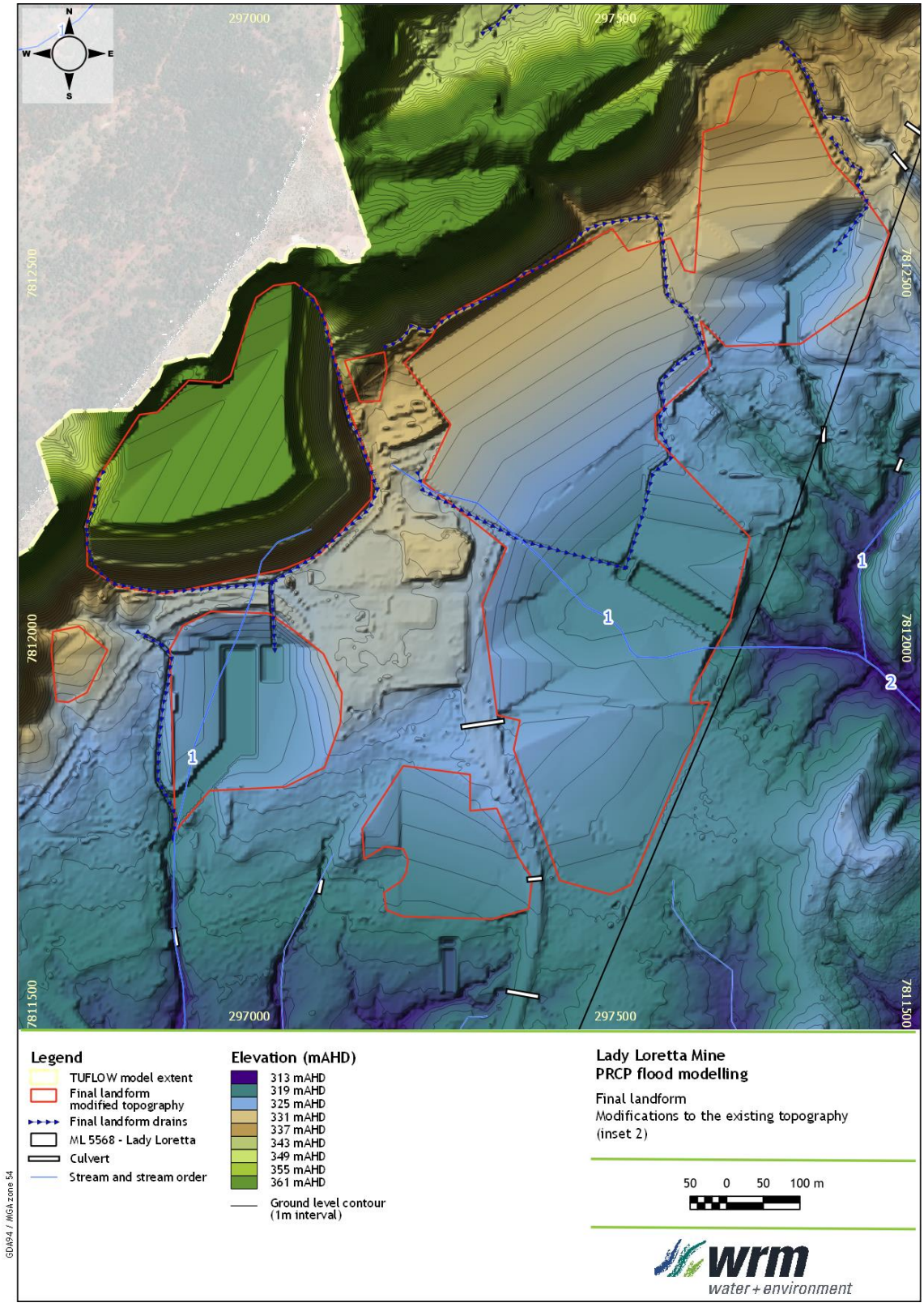


Figure 4.3 – Final landform configuration, CDA, CDB, PPD, WRE, Infrastructure Areas and ROM / Paste Plant (inset 2)

5 Estimation of discharges

5.1 OVERVIEW

An XP-RAFTS runoff-routing model (Innovyze, 2018) was developed to estimate design discharges for Desert Creek and Magazine Creek and the local catchments draining the LLM site for the 50% (1 in 2) AEP, 1% (1 in 100) AEP and 0.1% (1 in 1,000) AEP design flood events. The model was also used to produce design discharge hydrographs for the PMF event.

The XP-RAFTS model was validated for the 50% AEP, 2% AEP and 1% AEP design events against the Rational Method and the Regional Flood Frequency Estimation (RFFE) (see Section 5.2). The validated XP-RAFTS model was then used to estimate design discharges in the creeks and the local catchments using the Australian Rainfall and Runoff (ARR) 2019 guidelines (Ball et al., 2019) for the 0.1% AEP design event as well as the Probable Maximum Flood (PMF) event for a range of storm durations up to 6 hours to determine the critical storm durations at key locations. The derived hydrographs were used as inputs to the TUFLOW hydraulic model.

Figure 5.1 shows the Desert Creek hydrologic model configuration. The model covers the entire Desert Creek and Magazine Creek catchments to their common confluence and consists of 15 sub-catchments. Table 5.1 provides a description of each catchment as well as the adopted catchment parameters.

A uniform rainfall depth and temporal pattern were assumed over the entire catchment. Rainfall losses (initial loss /continuing loss) across the catchment were assumed to be uniform.

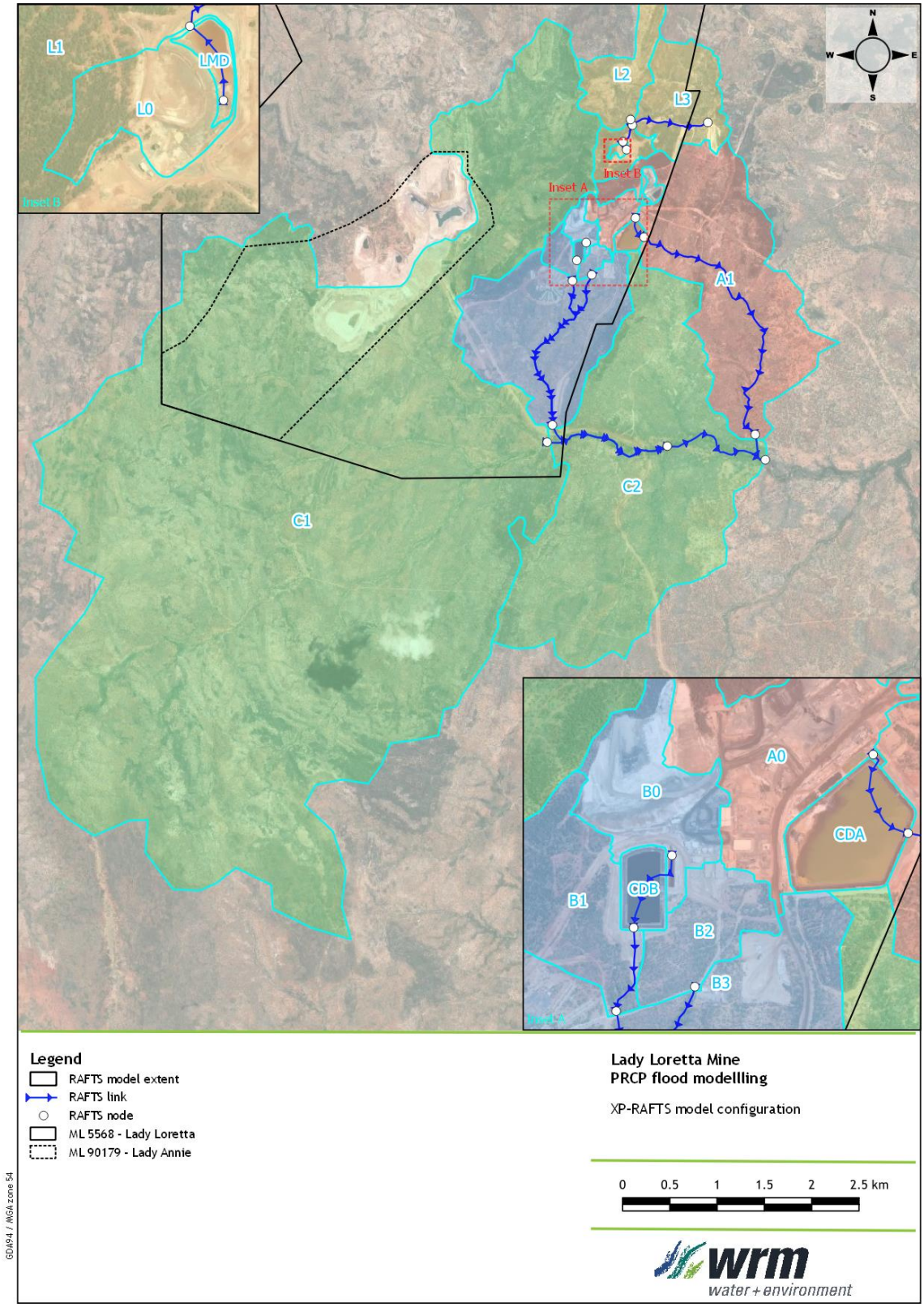


Figure 5.1 – XP-RAFTS hydrologic model configuration

5.1.1 XP-RAFTS subcatchment parameters

Table 5.1 shows the adopted XP-RAFTS model sub-catchment parameters. A PERN 'n' of 0.05 was adopted throughout the model. The percentage impervious for the dam catchments and former dams was assumed to be 10% for the post mining landform. The remaining catchments were assumed to be natural with 0% imperviousness.

The sub-catchment slopes were determined as area-weighted slopes based on SRTM and confirmed against the higher resolution LiDAR where available. Slopes in the dam catchments were determined based on the final landform surface.

Table 5.1 – Adopted XP-RAFTS model subcatchment parameters

Node ID	Description	Area (ha)	PERN 'n'	% Impervious	Slope (%)
A0	CDA catchment	22.3	0.05	10	7.74
CDA	CDA surface	8.0	0.05	10	2.64
B0	CDB catchment	12.1	0.05	10	9.51
CDB	CDB surface	2.5	0.05	10	3.72
L0	LMD catchment	2.0	0.05	10	12.51
LMD	LMD surface	0.4	0.05	10	4.28
A1	PPD catchment and natural catchment between sewerage treatment plant and creek	336.5	0.05	0	3.14
B1	Natural catchment upstream camp	13.9	0.05	0	12.02
B2	Natural catchment upstream sewerage treatment plant	7.6	0.05	0	2.14
B3	Natural catchment between camp and creek	219.8	0.05	0	3.49
C1	Catchment of Desert Creek	2962.2	0.05	0	3.63
C2	Residual natural catchment to creek	632.0	0.05	0	2.91
L1	Natural catchment around LMD	23.9	0.05	0	9.91
L2	Natural catchment downstream LMD	61.8	0.05	0	6.90
L3	Natural catchment downstream LMD	90.1	0.05	0	9.04

5.1.2 Dam configuration

The dams will be decommissioned. Hence, they were not represented in the XP-RAFTS model as storages.

5.1.3 Design rainfalls

Design rainfall depths were obtained from the Bureau of Meteorology (BoM) intensity frequency duration data system (2016 IFD) on 3 May 2022. For the estimation of design discharges, design rainfalls were obtained for the centroid of the Mine (at -19.774 latitude and 139.065 longitude).

Probable Maximum Precipitation (PMP) rainfall depths for durations up to 6 hours were estimated using the methodology given in *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method - GSDM* (BoM, 2003).

Table 5.2 shows the adopted depths for the modelled design events.

Table 5.2 – Adopted PMP design rainfall depths

Storm Duration (minutes)	PMP (mm)	0.1% AEP (mm)	1% AEP (mm)	50% AEP (mm)
20	-	-	57.1	23.4
25	-	-	63.7	26.1
30	-	-	69.1	28.5
45	-	-	80.9	33.6
60	500	137	89.2	37.1
90	-	-	101	41.9
120	640	169	110	45.2
180	730	190	123	49.7
270	-	-	138	54.2
360	890	235	151	57.6

5.1.4 Design losses

The following is of note for the adopted design rainfall losses:

- For the 50%, and 1% AEP events, an initial loss of 20 mm and a continuing loss of 3.2 mm/hr were adopted based on the validation against the Rational Method and RFFE (see Section 5.2);
- for the 0.1% AEP event, an initial loss of 6.9 mm and a continuing loss of 1.6 mm/hr were adopted based on the linear interpolation on a log-log frequency plot between the losses adopted for the 1% AEP event and the losses adopted for the PMP event as recommended in the ARR guidelines; and
- for the PMP event, a 0 mm initial loss and 0 mm/hr continuing loss were adopted.

5.1.5 Areal reduction factor

No areal reduction factors were applied to the design rainfalls.

5.1.6 Temporal patterns

Temporal patterns for the 0.1% AEP and PMP events and for durations up to and including 6 hours were obtained from the *Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method (GSDM)* (BoM, 2003) as per the recommendation in ARR 2019.

Design rainfall temporal patterns for the more frequent events were derived using the ensemble approach outlined in the ARR 2019 guidelines (Ball et al., 2019). Using this approach, an 'ensemble' of 10 temporal patterns was run for each storm duration for each event. The critical storm duration was selected based on the duration which produces the highest average peak discharge at the location of interest. As recommended in the guidelines, the temporal pattern of the duration producing the next higher discharge was selected for the analysis.

To illustrate the variation in peak discharges from the ensemble of 10 temporal patterns for each storm duration, Figure 5.2 provides box and whisker plots (box plots) showing the distribution of peak discharges in Desert Creek for the 1% AEP event. For each duration, the rectangle box represents the 25%ile and 75%ile (1st and 3rd quartile, the interquartile range or IQR) bound of the estimate. The horizontal lines at the top and bottom (whiskers) represent the upper and lower estimates for 1.5 times the IQR. The horizontal line within the box is the median value and the "X" represents the mean value, the value of which is shown above the box plots (critical in green).

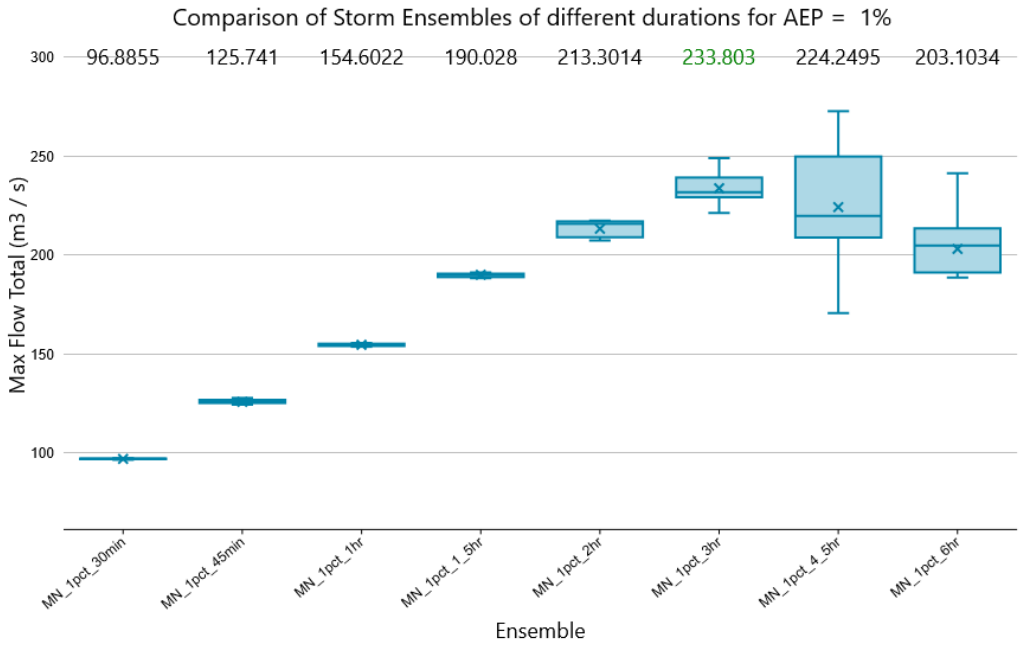


Figure 5.2 – Distribution of 1% AEP design peak discharges at Desert Creek

By comparing the critical temporal pattern derived following the above approach at three key locations, i.e., downstream of CDA, downstream of CDB, and downstream of LMD, a representative temporal pattern was selected for each duration ranging from the 10 minutes to the 6 hours storm for the 50% AEP and 1% AEP design event, respectively. The critical duration for these events was determined using the hydraulic model by superimposition of the result grids. Table 5.3 outlines the representative temporal pattern chosen for the modelled design events.

Table 5.3 – Representative temporal pattern selected per duration

Duration	2% AEP	1% AEP	0.1% AEP	PMF
10min	-	1	GSDM	GSDM
15min	-	4	GSDM	GSDM
20min	1	10	GSDM	GSDM
25min	5	9	GSDM	GSDM
30min	9	8	GSDM	GSDM
45min	6	7	GSDM	GSDM
1hr	4	8	GSDM	GSDM
1.5hr	5	6	GSDM	GSDM
2hr	6	5	GSDM	GSDM
3hr	10	10	GSDM	GSDM
4.5hr	10	10	GSDM	GSDM
6hr	10	2	GSDM	GSDM

5.1.7 Local catchment design discharges

The XP-RAFTS model was run for the 50% AEP, 1% AEP, 0.1% AEP and PMP flood events for the 10-minute hour to 6 hour storm durations to determine the catchment design hydrographs. Table 5.4 summarises the XP-RAFTS model predicted peak discharges at key locations for each event (refer to Figure 5.1).

The XP-RAFTS model results show that the critical storm duration is:

- Between 20 and 30 minutes for local headwater tributaries within the LLM site;
- approximately 3 hours for Desert Creek; and
- approximately 1 hour for Magazine Creek.

Table 5.4 – XP-RAFTS model predicted PMP flood peak discharges

Reporting Location	50% AEP		1% AEP		0.1% AEP		PMF	
	Peak discharge (m^3/s)	Critical duration in hours (TP)	Peak discharge (m^3/s)	Critical duration in hours (TP)	Peak discharge (m^3/s)	Critical duration in hours	Peak discharge (m^3/s)	Critical duration in hours
CDA	2.17	1 (4)	10.1	0.5 (10)	14.978	1	58.61	1
CDB	1.34	1 (4)	5.7	0.5 (7)	7.571	1	28.65	1
LMD	0.3	1 (4)	1.14	0.33 (10)	1.281	1	4.94	1
C1	39.5	6 (2)	236.3	3 (2)	477.813	2	2616.5	2
A1	8.83	3 (3)	43.92	2 (9)	85.564	1	451.89	1

TP – temporal pattern

5.2 XP-RAFTS DESIGN DISCHARGE VALIDATION

The XP-RAFTS design discharges estimated in Section 5.1.7 for Desert Creek (node C1 in Figure 5.1) were validated to design discharges estimated using two methodologies:

- The regional flood frequency estimation (RFFE) methodology recommended for ungauged catchments in the ARR 2019 guidelines (Ball et al., 2019); and
- the Rational Method as described in QUDM (2017).

As per the ARR (2019) guidelines, the Rational Method is valid only up to and including the 1% AEP event. Validation was carried out for the 50% AEP, 2% AEP and 1% AEP event and additionally confirmed against a RFFE assessment. A summary of the validation assessments undertaken is shown in Table 5.5 and Figure 5.3. A good agreement with the peak discharges predicted by the Rational Method was achieved. Therefore, the adopted model parameters are considered suitable for this assessment.

Table 5.5 – Rational Method and RFFE discharge validation for Desert Creek

Annual exceedance probability (% AEP)	XP-RAFTS peak discharge (m^3/s)	RFFE discharge (m^3/s)	Dif (%)	RM Bransby Williams Eq. peak discharge (m^3/s)	Dif (%)	RM Modified Friends Eq. peak discharge (m^3/s)	Dif (%)
50	39	25.5	55%	63	-37%	65	-39%
2	200	167	20%	193	3%	210	-5%
1	236	220	7%	223	6%	244	-3%

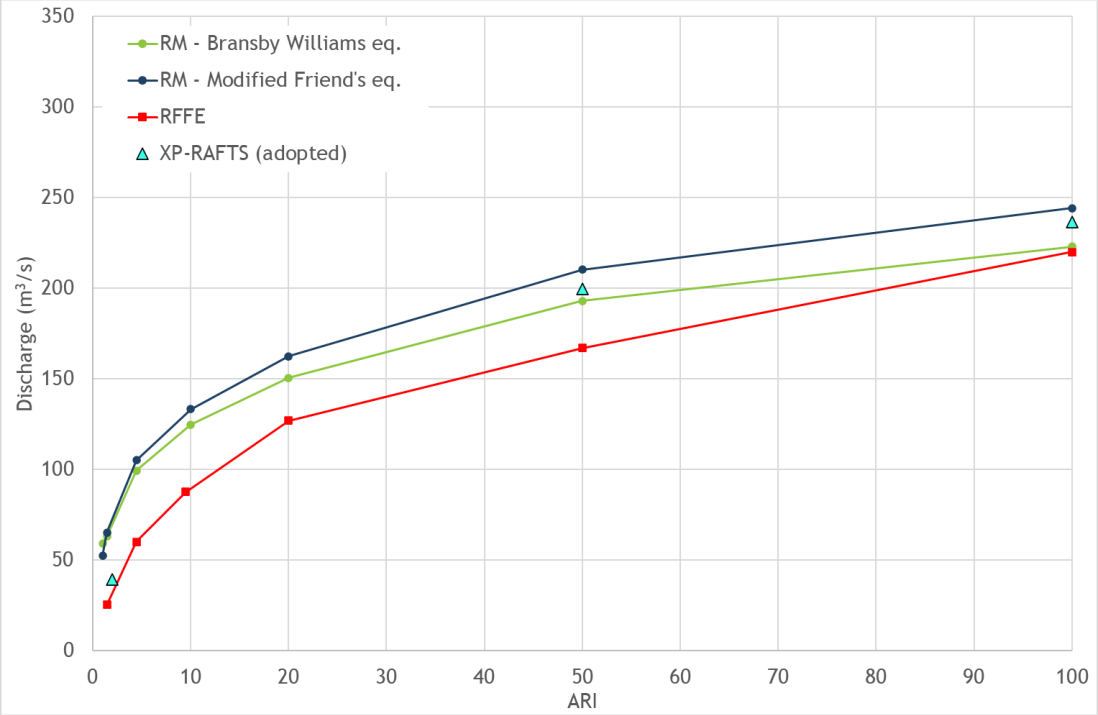


Figure 5.3 - Rational Method and RFFE discharge validation for Desert Creek

6 Hydraulic model development

6.1 OVERVIEW

A TUFLOW two-dimensional hydraulic model (BMT, 2019) was developed to simulate the runoff behaviour in the Mine catchments using the discharge hydrographs estimated in XP-RAFTS as inflows (refer to Section 5). The TUFLOW hydraulic model was used to estimate peak flood extents, depths and velocities in the vicinity of the Mine for the 50% AEP, 1% AEP and 0.1% AEP design events and the PMF.

6.2 MODEL EXTENT AND CONFIGURATION

Figure 6.1 shows the spatial extent and configuration of the TUFLOW hydraulic model developed for this study. The model covers an area of 10.93 km^2 and extends:

- Approximately 1.5 km upstream and 3.2 km downstream of the mine lease boundary along Desert Creek; and
- Approximately 750 m upstream and 900 m downstream of the mine lease boundary along Magazine Creek.

The model was configured as HPC-GPU (high-performance computing graphics processing unit) model with a 2 m fixed grid resolution and solved using the TUFLOW model version 2020-10-AB.

6.3 TOPOGRAPHY

The following topographic data was incorporated in the hydraulic model:

- LiDAR data provided as 199 ASCII tiles merged to a grid with 1 m resolution covering the entire hydraulic model extent; and
- the final landform surface “Post Mining Final Landform.tif”, which had a grid resolution of 5 m, was provided as by ATC Williams on 28 March 2022, clipped to the mine area as shown in Figure 3.1 (refer also Figure 4.2 and Figure 4.3) overlying the LiDAR data.. It was assumed for the purpose of this assessment the landform surface provided only included permanent features and temporary features were removed.

6.4 INFLOW AND OUTFLOW BOUNDARY CONDITIONS

The discharge hydrographs estimated using XP-RAFTS were applied at 16 inflow locations throughout the model. Figure 6.1 shows the locations of the inflow polygons. The regional inflow boundary for Desert Creek was configured as a 2D boundary condition (BC) at the code boundary to the west. The local model inflow boundaries were configured using 2D surface area (SA) polygons. Inflow hydrographs at these locations were applied equally distributed across all active cells within a given subarea, effectively applying runoff to all areas within the model extent. The model inflow approach was validated by comparing design discharges against those estimated by the hydrologic model. Peak flows were found to be generally similar (less than 5% to 10% difference). These small differences were expected to occur and were considered acceptable when accounting for storage and breakout flows represented in the hydraulic model that were not represented in the hydrologic model.

Four outflow boundaries were included in the model:

- The Desert Creek outflow boundary was located approximately 3.2 km downstream of the mine lease boundary at a normal depth slope of 0.2%.
- The Magazine Creek outflow boundary was located approximately 900 m downstream of the mine lease boundary at a normal depth slope of 1.0%.
- A western outflow boundary at a normal depth slope of 2%.

- A northern outflow boundary at a normal depth slope of 1.0%.

6.5 ADOPTED MANNING'S 'N' VALUES

The TUFLOW model uses Manning's 'n' values to represent hydraulic resistance of different material types. For the final landform modelling, a uniform Manning's 'n' value of 0.060 was adopted to represent natural and rehabilitated areas. A Manning's 'n' value of 0.050 was assumed for waterways and for the drains retained in the final landform.

6.6 HYDRAULIC STRUCTURES

Figure 6.1 shows the locations of key hydraulic structures included in the TUFLOW model. Details of the hydraulic structures are based on information and photographs provided by LLM personnel and the available topographic information as well as aerial imagery.

The modelled culverts were represented as 1D structures in the model. Table 6.1 shows the details adopted for the culverts in the TUFLOW model.

Table 6.1 – Adopted culvert details

ID	Location	Type	Barrels	Width or Dia (m)	Height (m)	Manning's 'n'	Block (%)	U/S invert* (mAHD)	D/S invert* (mAHD)
1	Camp	CMP	2	0.75		0.02	0	316.0	315.5
2	STP	CMP	2	0.6		0.02	30	319.0	318.5
3*	DS LMD	CMP	1	1.05		0.02	0	329.7	329.2
4*	DS LMD	CMP	2	0.75		0.02	0	325.7	325.5
10*	North PPD	CMP	1	0.6		0.02	0	328.5	326.8
11*	North PPD	CMP	1	0.6		0.02	0	330.3	329.0
12*	North PPD	CMP	1	0.6		0.02	0	330.3	328.7
13*	DS PPD	CMP	1	1.05		0.02	0	320.2	319.1
14*	DS PPD	CMP	1	1.05		0.02	0	317.4	317.1
15	Haul road	CMP	1	0.6		0.02	90	324.6	323.8
16	Haul road	Cattle grid	1	1.8	0.3*	0.02	80	321.6	321.6
17	Haul road	CMP	1	0.9		0.02	5	318.0	317.0
18	Haul road	CMP	1	1.05		0.02	5	318.8	318.0
19	Haul road	CMP	1	1.05		0.02	0	319.1	318.0
20	Haul road	CMP	1	1.05		0.02	0	318.0	317.2
22*	Desert Creek	RCBC	2	1.2	1.2	0.013	0	302.8	302.3
23*	Desert Creek	RCBC	2	2.4	1.2	0.013	0	302.1	302.0

*estimated

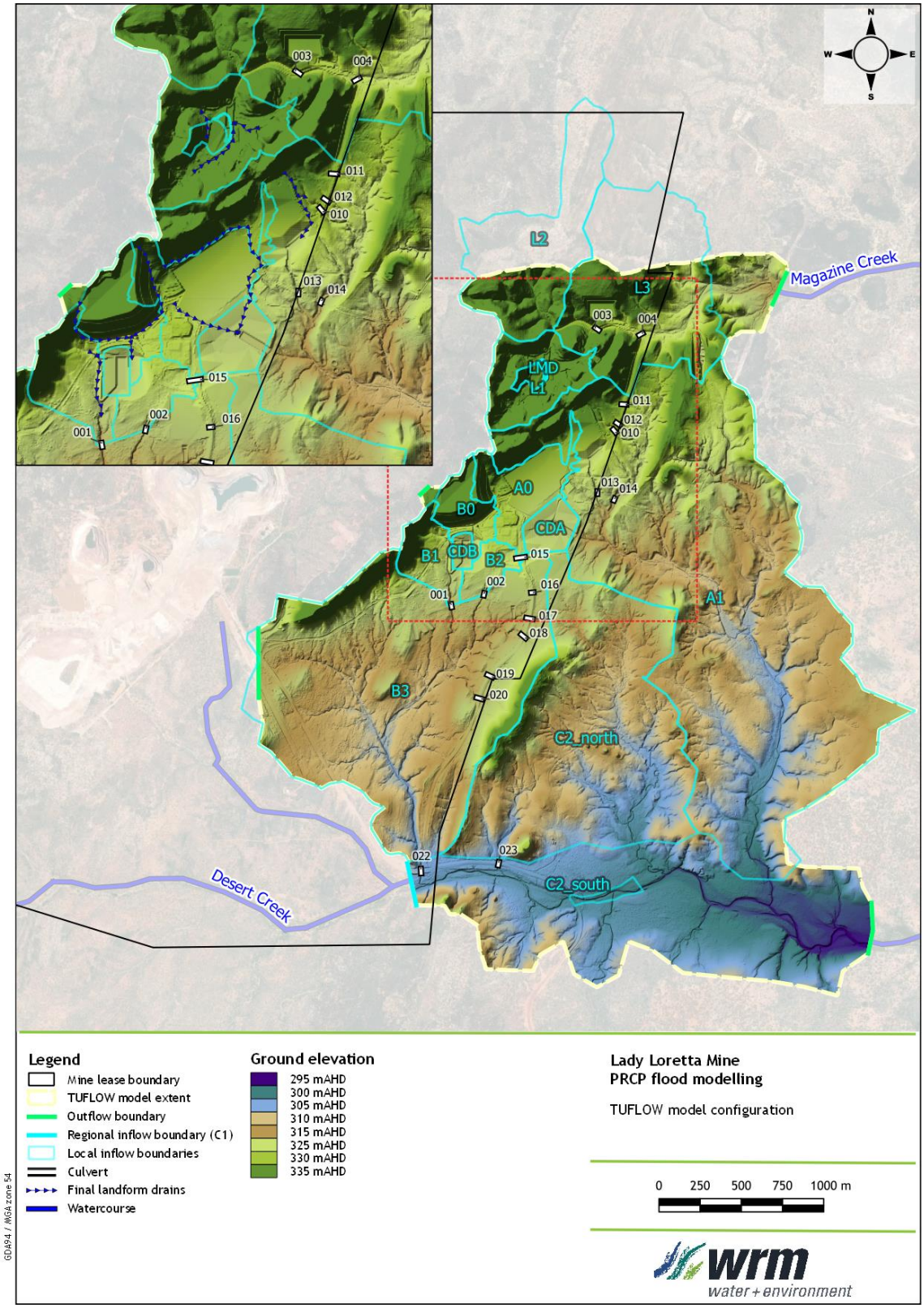


Figure 6.1 – TUFLOW hydraulic model configuration (final landform)

7 Hydraulic model results

Figure 7.1 shows the TUFLOW model predicted 50% AEP peak flood depths and extents in the vicinity of the Mine under post-mining conditions. Figure 7.2 shows the corresponding peak velocities.

Figure 7.3 shows the TUFLOW model predicted 1% AEP peak flood depths and extents in the vicinity of the Mine under post-mining conditions. Figure 7.4 shows the corresponding peak velocities.

Figure 7.5 shows the TUFLOW model predicted 0.1% AEP peak flood depths and extents in the vicinity of the Mine under post-mining conditions. Figure 7.6 shows the corresponding peak velocities.

Figure 7.7 shows the TUFLOW model predicted PMF peak depths and extents in the vicinity of the Mine under post-mining conditions. Figure 7.8 shows the corresponding peak velocities.

In general, the following is of note:

- Final landforms at the Mine are not affected by a “relevant watercourse” as per the DES (2019) definition. That is, final landforms at the Mine are not affected by Desert Creek flooding.
- The proposed final landform is not inundated by flood waters from streams draining through the site.
- Runoff through the former CDA, CDB, PPD, and LMD as well as the Paste Plant Area, ROM, Infrastructure Area and the WRE is conveyed from the proposed final landform to the receiving waters in a similar manner to pre-mining conditions. The final landform is free draining.
- Flooding in the vicinity of the Mine is characterised by shallow sheet flow across the majority of the Mine. Increased depths are predicted in the narrow and steep channelised landforms, resulting in elevated velocities in some drainage paths. The design of these drains should include adequate erosion protection in drainage paths to consider elevated velocities, if not already in place.
- Flood velocities are naturally high in streams within and downstream of the mine due to the steam topography.
- The proposed final landforms will not significantly modify stream catchments downstream of the mine. Hence, the risk of the final landform contributing to flooding or erosion in the downstream environment is low.
- For the 50% AEP and 1% AEP events:
  - Peak velocities within the proposed dam landforms generally do not exceed 1 m/s.
  - Peak velocities of up to 1.3 m/s (50% AEP) and 2.65 m/s (1% AEP) are predicted along the proposed final landform drain west of the Waste Rock Emplacement, and the steep drain into the former sediment dam at CDB.
  - Peak velocities exceeding 1.5 m/s (1% AEP) are predicted along the proposed final landform drain east of the Waste Rock Emplacement. Peak velocities in the 50% AEP design event remain below 1 m/s along the proposed drain east of the Waste Rock Emplacement.
  - Peak velocities of up to 2 m/s (1% AEP) are predicted downstream of the former LMD in the flowpath towards Magazine Creek. Except for localised exceedances, peak velocities in the 50% AEP design event remain below 1 m/s.
  - Peak velocities in the proposed final landform drains upstream of LMD exceed 1 m/s in the 1% AEP design event.

- For the 0.1% AEP event:
  - Peak flood depths within the Mine are generally low (less than 0.05 m) with shallow sheet flow across the landforms. Increased depths occur within the drains but are generally contained. Localised ponding occurs along haul roads but will be conveyed by the local cross drainage structures. The post-mining landform remains free draining.
  - Predicted peak velocities within the proposed dam landforms do not exceed 1 m/s, except for the transition between the former sediment dam at CDB and parts of the dam landform itself.
  - Peak velocities in the natural drainage line downstream of CDB towards the former Camp exceed 1.5 m/s.
  - Peak velocities are predicted along the proposed final landform drain west of the Waste Rock Emplacement of up to 2.7 m/s, and the steep drain into the former sediment dam at CDB with localised peaks of up to 3 m/s.
  - Peak velocities along the proposed final landform drain east of the Waste Rock Emplacement are up to 1.5 m/s.
  - Peak velocities in the natural drainage line downstream of the LMD landform are up to 2.0 m/s.
- For the PMF event:
  - Peak flood depths within the Mine are generally low (less than 0.05 m) with shallow sheet flow across the steep landforms. Increased depths occur within the drains but are generally adequately contained. While peak depths within the dam landforms may exceed 1 m, the landform remains free draining.
  - Peak velocities within the proposed dam landforms generally remain below 1.2 m/s, except for the transition between the former sediment dam at CDB and the parts of the dam landform itself, with predicted peak velocities of up to 2.4 m/s.
  - Peak velocities in the natural drainage line downstream of CDB towards the former Camp exceed 2.5 m/s.
  - Peak velocities exceed 2 m/s at the western batter of the Waste Rock Emplacement plateau before entering the final landform drainage.
  - Peak velocities are predicted along the proposed final landform drain west of the Waste Rock Emplacement of up to 4.5 m/s, and the steep drain into the former sediment dam at CDB with localised peaks of up to 4.0 m/s.
  - Peak velocities along the proposed final landform drain east of the Waste Rock Emplacement are up to 2.5 m/s.
  - Peak velocities in the natural drainage line downstream of the LMD landform are up to 2.5 m/s.

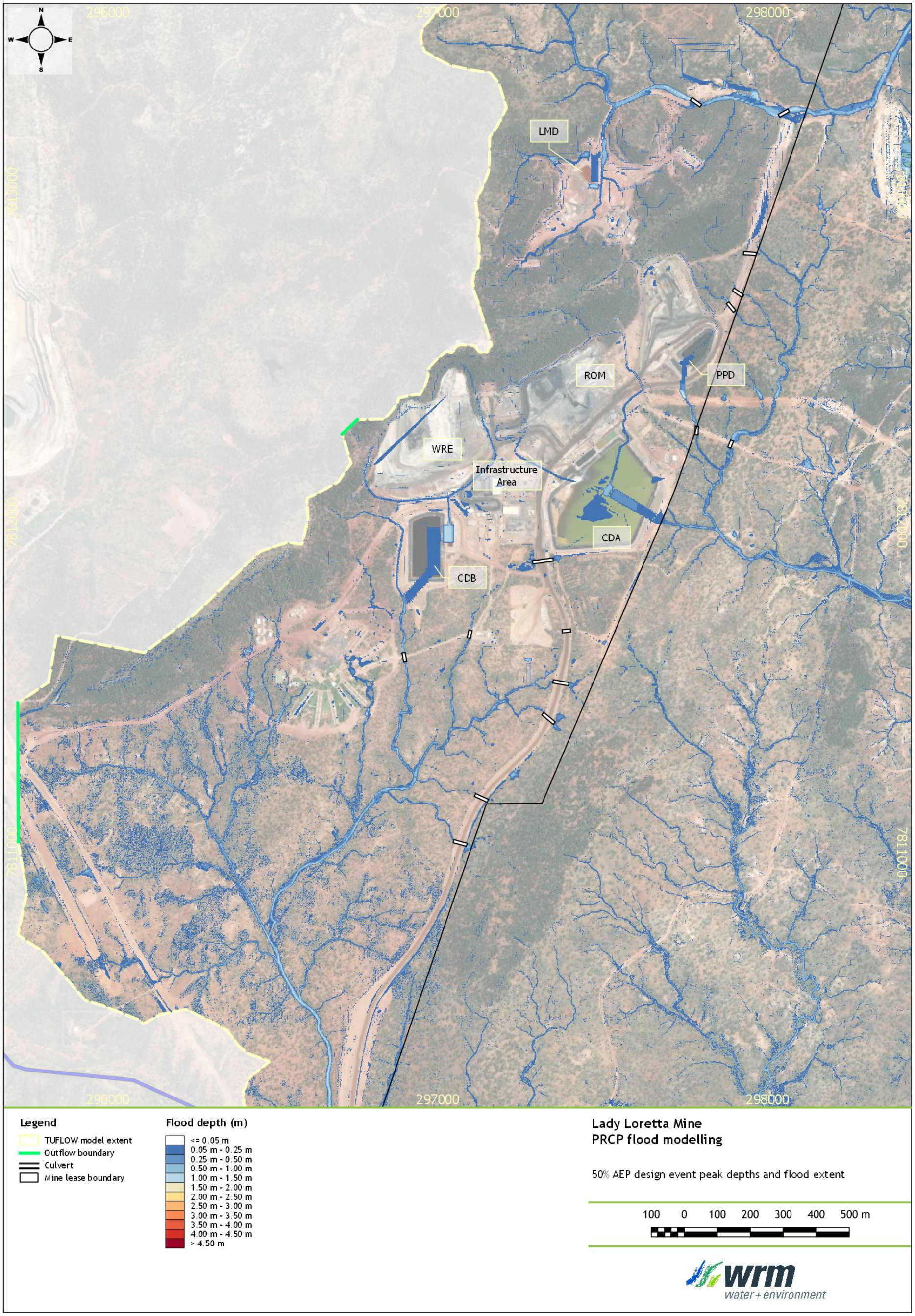


Figure 7.1 – Predicted 50% AEP peak flood depths in the vicinity of the Mine for post-mining conditions



Figure 7.2 – Predicted 50% AEP peak flood velocities in the vicinity of the Mine for post-mining conditions

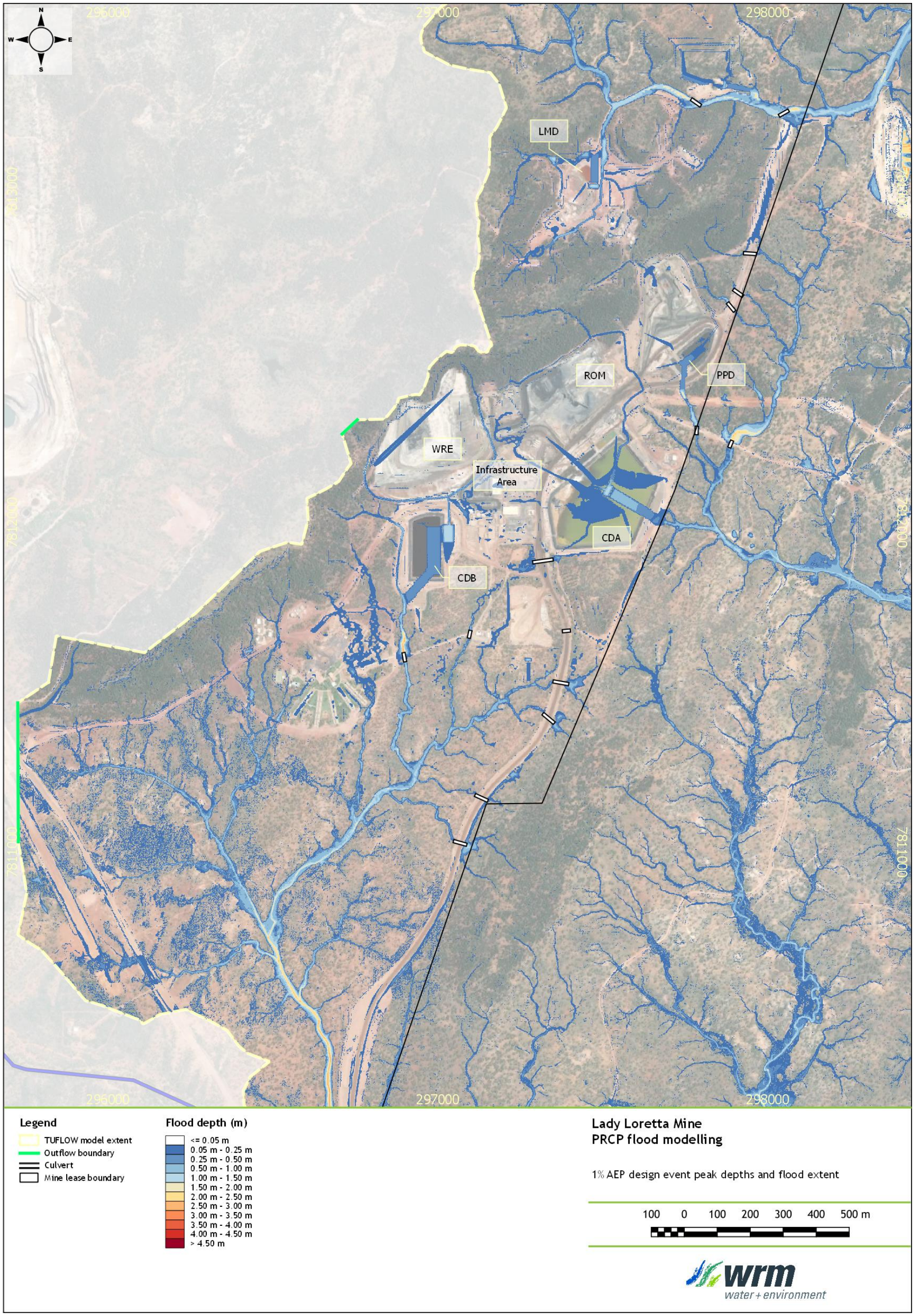


Figure 7.3 – Predicted 1% AEP peak flood depths in the vicinity of the Mine for post-mining conditions



Figure 7.4 – Predicted 1% AEP peak flood velocities in the vicinity of the Mine for post-mining conditions

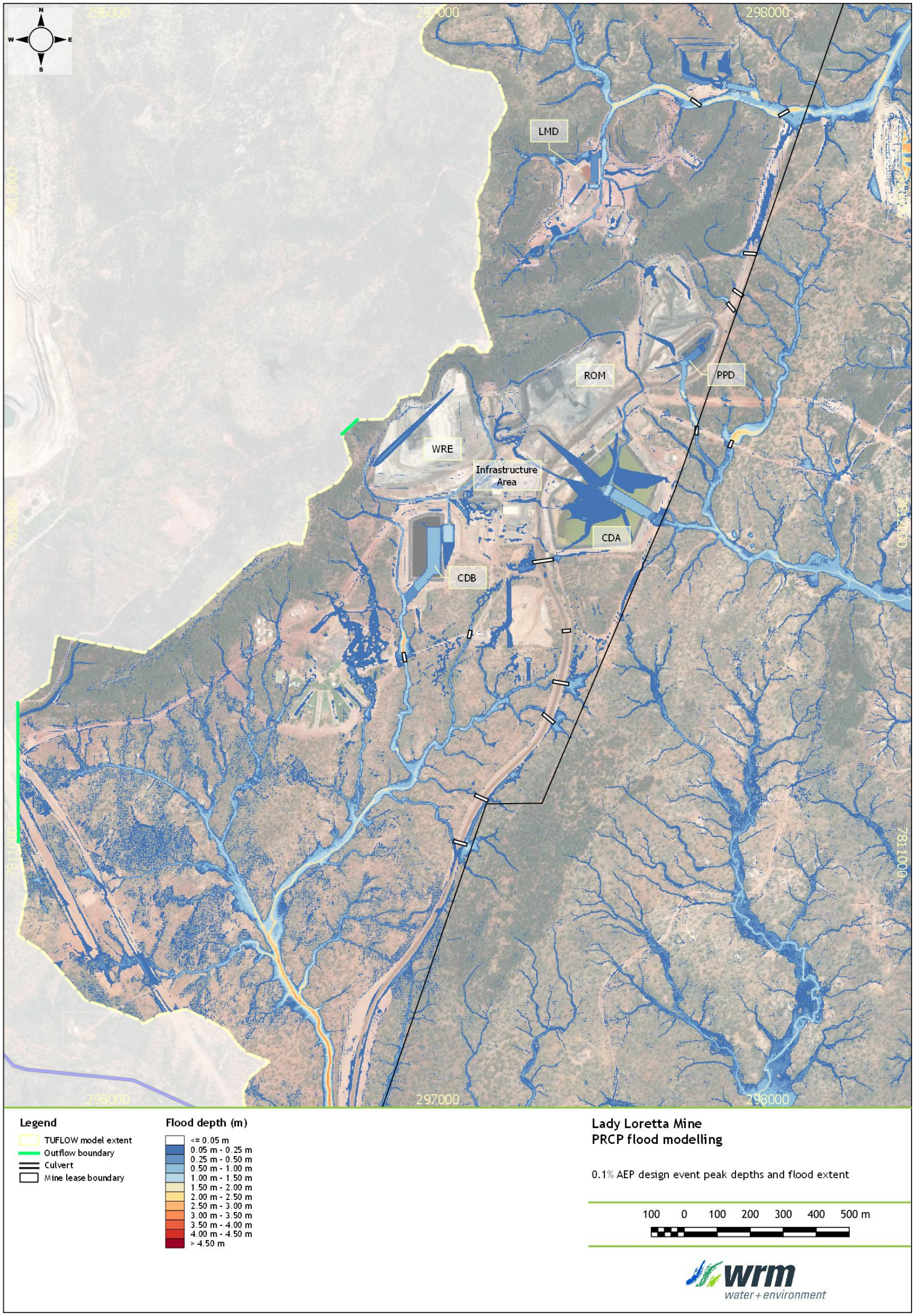


Figure 7.5 – Predicted 0.1% AEP peak flood depths in the vicinity of the Mine for post-mining conditions



Figure 7.6 – Predicted 0.1% AEP peak flood velocities in the vicinity of the Mine for post-mining conditions

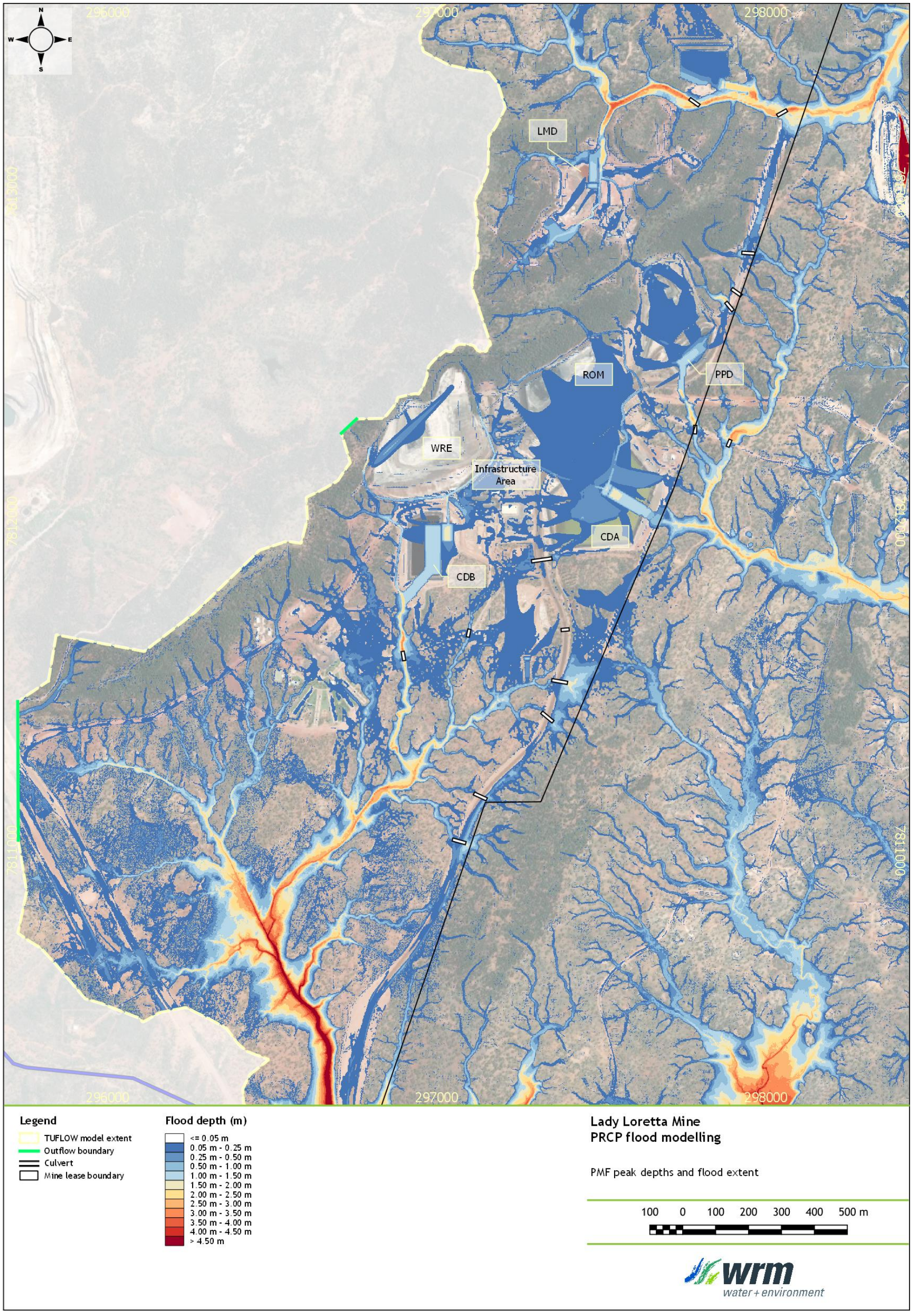


Figure 7.7 – Predicted PMF peak flood depths in the vicinity of the Mine for post-mining conditions

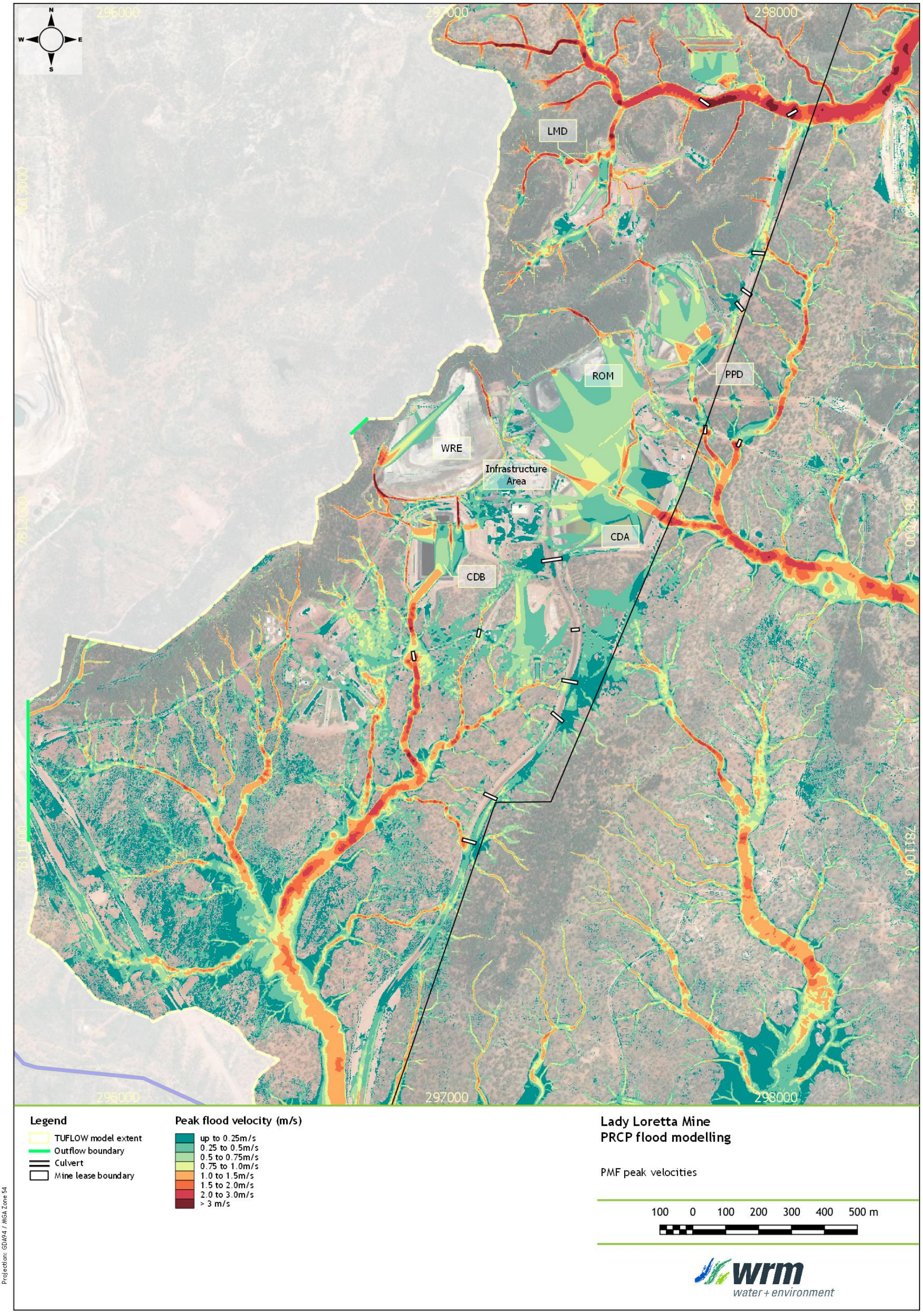


Figure 7.8 – Predicted PMF peak flood velocities in the vicinity of the Mine for post-mining conditions

8 Summary of findings

Hydrologic and hydraulic modelling was undertaken for Lady Loretta Mine to assess the flooding characteristics for the 50% AEP, 1% AEP and 0.1% AEP design flood event as well as the PMF as per the DES (2019 & 2020) requirements.

The portal box cut, infrastructure areas, including the ROM, Paste Plant area and dams will be regraded where required to be free draining and rehabilitated. It is proposed to retain the rehabilitated waste rock emplacement, haul roads and associated drainage in the final landform. There are no residual voids associated with the final landform of the LLM site.

In summary, the proposed final landforms will not significantly modify stream catchments downstream of the mine and the risk of flooding is very low. Hence, the risk of the final landform contributing to flooding or erosion in the downstream environment is low and final landform stability will not be impacted from a flooding perspective. The following is of note:

- Only minor first order streams intersect the Mine. On this basis, the Mine would not be located within the flood extent of a "relevant watercourse" as defined by DES (2019). Only a minor part of Desert Creek where it intersects the south-eastern corner of the mine lease is classified as a fourth order stream. This section of Desert Creek does not impact on any post-mining landform.
- No part of the Mine's post-mining landform is located within the 0.1% AEP flood extent of Magazine or Desert Creek, with only the latter considered to be a "relevant watercourse" according to DES (2019). There are no voids located within the 0.1% AEP flood extent.
- Drains retained within the final landform are generally steep, with elevated velocities predicted in the drains. Careful consideration should be given to ensure adequate erosion protection during the design and construction phases to ensure the drains and receiving streams remain stable.
- Flooding in the vicinity of the Mine is characterised by shallow sheet flows across the majority of the Mine. Increased depths are predicted for the narrow and channelised flows due to the steep topography in the upstream catchments. With steep upstream catchments and no higher order watercourses, peak flood levels at the Mine are generally low and contained within drainage paths. Hence, the proposed LLM final landform is not at risk of flooding.
- Peak 0.1% AEP flood depths within the mine are generally less than 0.05 m, with shallow sheet flow occurring across the majority of the Mine and greater depths confined to narrow but steep channels.

9 References

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APPENDIX E FINAL LANDFORM 3D MODEL- DIGITAL SUBMISSION

APPENDIX F WRE CLOSURE CONCEPT DESIGN REPORT

REPORT

Noranda Pacific Pty Ltd

Lady Loretta Mine
WRE Closure Concept Report

112009.04 R05
March 2023

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EXECUTIVE SUMMARY

This report consolidates recent assessment and design work completed to support closure planning for the waste rock emplacement (WRE) at Lady Loretta Mine (LLM). The objective of this report is to present the proposed final landform design details, summarise the engineering decision-making process and present technical assessment supporting the adopted WRE closure design.

The WRE final landform design incorporates Glencore's closure objectives and has been developed to meet the specific requirements of the Progressive Rehabilitation and Closure Plan Transition Notice (the PRCP Transition Notice) issued by the Queensland Department of Environment and Science (DES) on 18 September 2020, as well as requirements outlined in the LLM Environmental Authority EPML00982013 (the EA) and the *Progressive Rehabilitation and Closure Plans Guideline* (DES, 2021).

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 (PMLU). These three components of stability are the general rehabilitation goals for all areas disturbed by mining in Queensland.

The post-closure WRE final landform design addresses these rehabilitation goals through cover system and batter slope design that considers:

- The local climatic conditions
- Reactivity of the LLM mine waste material
- Seepage to groundwater and exposure of contaminants to the receiving environment through erosion and seepage
- Landform footprint and approved disturbance area
- Capacity to hold all planned Life of Mine (LoM) waste volume
- Available construction materials to minimise erosion, environmental harm and sustain the PMLU of native habitat.

Assessments demonstrating the cover system and batter slope design effectiveness at achieving the WRE rehabilitation goals, i.e., safe, stable and non-polluting, include:

- **Seepage modelling** – Precipitation infiltration is a key driver of post-closure seepage-related groundwater impacts due to ongoing saturation of potentially acid-forming (PAF) waste and continued downward migration of contaminants into groundwater and the receiving environment. The adopted cover system design minimises potential environmental harm by preventing ongoing seepage following closure.
  - Seepage modelling results indicate that downward seepage (and upward capillary flow) through the cover system into the underlying waste material is negligible due to the presence of the bituminous geomembrane (BGM) liner.
  - The final WRE batter has the primary objective of withstanding erosion. The risks of infiltration when compared to the plateau are reduced due to the steep slopes and high rates of runoff. Notwithstanding, a zone of NAF fill would be required to ensure moisture which did infiltrate is captured and does not percolate into the PAF waste.
- **Stability modelling** – The WRE landform has been designed to be structurally stable with batter slope angles which consider the LoM waste volumes and adoption of a footprint maintained within the current approved disturbance area (thus avoiding an increase in future disturbance areas).
  - Various stability controlling failure modes and loading conditions are considered for the WRE. Slope stability modelling results indicate that the proposed final landform is structurally stable for all loading conditions analysed, with factors of safety greater than those recommended by ANCOLD (2019) guidelines.

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- **Landform evolution modelling** – Long-term landform stability was assessed through estimating the soil loss across the landscape and WRE over a 1,000-year period. Long-term erosion through multiple erosion mechanisms (sheet wash and rill or gully formation) have potential to expose PAF waste material and discharge contaminants into the receiving environment if the cover system design is not resistant to long-term erosion risks. The thickness of the proposed WRE cover system and batter slope geometry will not be adversely impacted by long-term erosion, and therefore the design is considered appropriate based on the long-term erosion risk.

  - Erosion rates were estimated using Water Erosion Prediction Project (WEPP) while multiple erosion mechanisms were evaluated using SIBERIA Landform Evolution Model. While the adopted design is suitable for closure, key factors critical to the success of the final landform stability are:

    - Avoiding concentrated flow which has generally been achieved by the conceptual final landform design presented in the PRCP.
    - The establishment of vegetation through appropriate surface preparation, seeding, and grazing management.
    - Monitoring and maintenance of drainage controls and assessment of the causes of localised scour until stability is established.

Adopted WRE Design

Key design elements of the WRE final landform were defined through a series of options assessments to identify and evaluate multiple options for the cover system, batter slopes and landform geometry as well as trade-offs. Design elements were identified through consultation with relevant guidelines (i.e., best practice guidelines such as International Network for Acid Prevention's *Global Acid Rock Drainage (GARD) Guide* (the GARD Guide), ANCOLD guidelines and other literature), ATC Williams (ATCW) technical experience, and Glencore's previously adopted WRE conceptual closure design.

The initial options assessment was completed in 2021 followed by a multiple accounts analysis (MAA) to select the preferred landform design. MAA criteria included:

- Cost
- Environmental protection
- Technical viability/constructability
- Cover design effectiveness

The preferred WRE conceptual design for the final landform geometry was to construct the batters at the maximum allowable slope whist maintaining acceptable factors of safety for geotechnical stability. Further revisions to the landform geometry were undertaken to achieve operational requirements for waste rock disposal, as follows:

- Additional storage capacity to store current WRE volume (as at October 2022) plus 370,000 m³ (Loose Cubic Metres).
- Batter slopes of 1V:2.5H
- Bench spacing (vertical increments) of 15 m
- Bench width of 9m to allow for vehicle access on benches.
- Maintain less than 11ha disturbance area (per EA).

The plateau and batter cover system designs are described below:

- **Cover System**: The proposed cover system is comprised of a bituminous geomembrane (BGM) liner overlain by an Infiltration Storage Layer (ISL) made up of 1.5m rocky mulch. The BGM liner is an ultra-low-permeability layer (1 x 10^{-9} m/s) which prohibits seepage reporting through the cover system and capillary rise. The ISL provides a plant growth medium and

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protects the BGM liner. The final surface will have a slope of less than (<)1V:20H (5 percent (%)) on the plateau would be loose and hummocked to increase plant available moisture.

- **Batter Slopes**: re-contouring (waste re-handle) of the waste rock inventory to achieve batter slopes of 1V:2.5H, with:
  - non-acid forming (NAF) rind and placement of batter elements
  - 3 m horizontal compacted PAF waste over entire batter area
  - 3 m horizontal compacted non-acid forming (NAF) protection layer using rock mulch over entire batter area
  - 2 m of rock armour protection layer.

The WRE final landform presented in this design report has changed from the original design adopted by Glencore as part of their 2018 Lady Loretta PMLU Plan (Glencore, 2018) to accommodate additional LoM waste volume estimates completed in 2022. The increased waste required an increase in WRE height, which resulted in steeper batter slopes to maintain a footprint within the approved disturbance area.

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1 INTRODUCTION

This report consolidates recent assessment and design work completed to support closure planning for the waste rock emplacement (WRE) at Lady Loretta Mine (LLM). The objective of this report is to present the proposed final landform design details, summarise the engineering decision-making process and present technical assessment supporting the adopted WRE closure design.

The WRE final landform design incorporates Glencore's closure objectives and has been developed to meet the specific requirements of the Progressive Rehabilitation and Closure Plan Transition Notice (the PRCP Transition Notice) issued by the Queensland Department of Environment and Science (DES) on 18 September 2020, as well as requirements outlined in the LLM Environmental Authority EPML00982013 (the EA) and the Progressive Rehabilitation and Closure Plans Guideline (DES, 2021).

1.1 Preface

Glencore Zinc Australia, via its subsidiary Noranda Pacific Pty Limited (Glencore), owns and operates the Lady Loretta Mine (LLM), located some 140 km north-north-west of Mount Isa, in north-west Queensland. Underground operations on the mining lease (ML5568) commenced in 2013 and have occurred intermittently in response to global zinc prices. The current campaign of mining commenced in 2018 and is scheduled to reach conclusion in 2025. The underground workings are supported by various surface infrastructure, including:

- Ore stockpiles and primary crushing facilities;
- Paste-fill plant and batch plant;
- Run of Mine (ROM) Pad;
- Waste Rock Emplacement (WRE);
- Water management infrastructure including four regulated dams;
- Workshop, warehouse and administration facilities;
- Ventilation equipment; and
- Accommodation camp.

Glencore have commissioned ATC Williams Pty Ltd (ATCW) to assist with the preparation of the Progressive Rehabilitation and Closure Plan (PRCP) required under the Queensland Government's Mined Land Rehabilitation Policy. As part of these works, a closure assessment has been completed for the WRE, as detailed in this report.

1.2 Scope and Structure

This report has been developed to provide background to the WRE, define closure objectives, and detail the assessments undertaken to demonstrate closure objectives are achieved. This report also provides a summary of post closure monitoring and maintenance undertaken. Report sections are summarised as follows:

Section 2: Existing status of the WRE and history of the structure.

Section 3: Details closure objectives and regulatory background. Additionally presents the outcomes of the options assessment undertaken to define the closure concept adopted.

Section 4: Summarises geotechnical and geochemical investigations to date for waste rock and proposed cover materials.

Section 5: Details cover system modelling for the preferred cover system including inputs, methodology and outcomes from modelling.

Section 6: Schedule of quantities for the proposed WRE cover design.

Section 7: Describes the stability modelling undertaken for the WRE cover design.

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Section 8: Provides details on erosion assessment undertaken.

Section 9: Details the post closure monitoring and maintenance plan.

Supporting documentation is provided within the Appendices.

1.3 PRCP Requirements

This report has been developed to meet the landform and cover system components required under the PRCP guideline administered by the Department of Environment and Science (DES) (DES, 2021 ESR 2019/4964). Attention is also brought to the Progressive Rehabilitation and Closure Plan (PRCP) (Glencore Reference: Z-LLM-HSEC-PLN) which addressed additional components required for closure and the LLM Waste Rock and Spoil Management Plan (WRSMP) (Glencore, 2023), required by Environmental Authority EPML00982013 (EA).

TABLE 1 identifies the key PRCP Guideline requirements for landform design and a reference to where the relevant requirements in relation to the WRE are addressed in this report (and elsewhere).

TABLE 1: PRCP GUIDELINE REPORT SECTIONS

PRCP Guideline Requirement	Where addressed
Landform Design	
3D design plans of final landform	PRCP
Method of determining landform design	Section 3
Modelling predicting the long-term stability of the final landform design	Section 7.4 Section 8
Method of construction and Quality Assurance / Quality Control (QA/QC) requirements	WRSMP
Trial methodology to verify the predicted success of the final landform design	PRCP
Structure location, footprint and height (including proposed lift heights)	Section 3.6.3
Structure requirements for lining for seepage minimisation	Section 3.6.1
Identification of landform as ‘water-retaining’ or ‘water- shedding’ considering rainfall and composition and texture of the waste	Section 3.6
Identification of materials available for landform rehabilitation including ability to achieve landform design outcomes	Section 4.2
Erosion assessments to determine landform heights, gradients, profiles, and material placement	Section 8
Slope profile design considering the interactions between soil erodibility, rainfall erosivity, landform height gradient and vegetation cover to identify acceptable erosion rates over a long-term average	Section 3.6.2 Section 3.6.3 Section 8.2
Settling and subsidence over time, which may impact the availability of areas for rehabilitation	Section 9.4

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PRCP Guideline Requirement	Where addressed
Hydrological and hydrogeological assessments	PRCP
A waste placement strategy developed to mitigate environmental and rehabilitation risks during construction and decommissioning phase	WRSMP
Specific landform requirements committed to in stakeholder consultation, mine planning or other sources, which could include rock incorporation, designed flow paths, aesthetic considerations, non-linear batter slopes and targeted placement of materials	Section 3.5 Section 3.6
Monitoring to determine performance of control measures (i.e. liners or seepage collection systems)	Section 9
Cover Design	
Results from geochemical characterisation	Section 4 WRSMP
Type and physical characteristics of the material being covered (from the material balance developed for the site)	PRCP
Site conditions	Section 2
Availability of suitable cover materials (both quality and quantify)	PRCP
Criteria for discharge (i.e. to protect environmental values)	PRCP
Suitable vegetation	PRCP
Identification and specification of the objectives of the cover system	Section 3.2
Detailed description of the design including thickness of each layer	Section 3.6
Detailed description of construction methodology including any proposed staging of the cover system	WRSMP
A quantitative assessment that identifies the location and quantity of proposed capping material available on site	PRCP
Proposed QA/QC for the construction of the cover system including timely implementation of corrective actions where deviations from the design are identified	WRSMP/PRCP

1.4 Related Documentation

The overarching document for closure at LLM is the PRCP, which should be read in conjunction with this report. Additional documents which are relevant to closure and rehabilitation of the WRE are listed as follows:

- ATC Williams, 2020. Lady Loretta Operations – Geotechnical Investigation of the Waste Rock Dump and Potential Capping Materials. Ref. 112009.03. November 2020.

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- ATC Williams, 2022. Lady Loretta Mine – WRE Batter Construction Method Specification. Ref. 112009.09 R01. December 2022.
- DES, 2021. Guideline Progressive Rehabilitation and Closure Plans (PRCPs). ESR/2019/4964 Version 2.00. 17 March 2021. Queensland Department of Environment and Science.
- Glencore, 2022. Lady Loretta Z-LLM-OPS-PLN-Water Management Plan, 2022.
- Glencore, 2023. Lady Loretta Z-LLM-OPS-PLN Waste Rock and Spoil Management Plan. 2023.
- RGS, 2021. Factual Report Phase 1 – Rehabilitation Material Sampling and Analysis Program (RMSaAP). July 2021.
- RGS, 2023. Factual Report Phase 2 – Rehabilitation Material Sampling and Analysis Program (RMSaAP). March, 2023.

2 EXISTING SITE CONDITIONS

2.1 Project History and Development

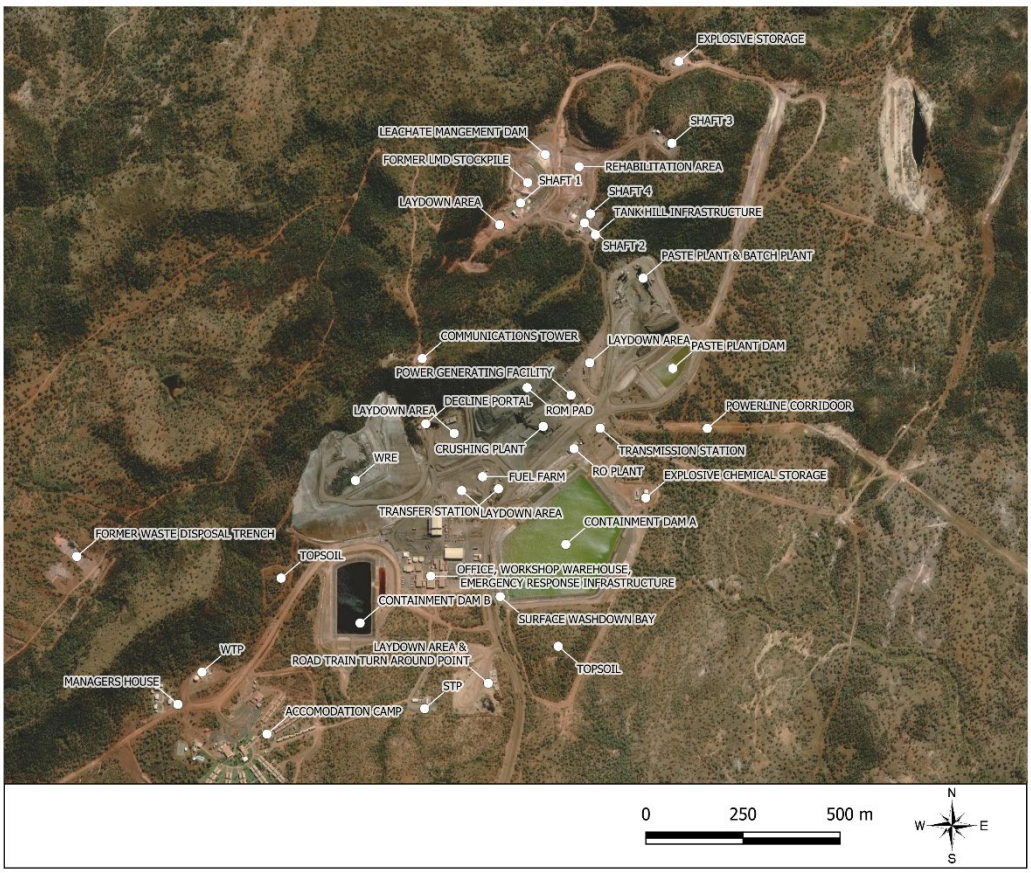
The Lady Loretta deposit was discovered in 1969. Exploration activities at LLM commenced in the late 1980s. Mining activities commenced in 2011 with the mine subsequently being placed into care-and-maintenance from Quarter 4 2015 to Quarter 1 2018. The current mine plan extends mining operations to 2025.

At commencement, the Lady Loretta highly mineralised deposit was host to an estimated 12.7 million tonnes reserve that consists of 14.2% zinc, 4.8% lead, and 84 grams of silver per tonne. Full production at LLM is in the order of 1.6 million tonnes of ore per annum.

Ore is mined from LLM by blast hole stoping to fragment the rock surrounding the ore. Ore is then loaded into underground haulage trucks and transported via the decline to the run of mine (ROM) stockpile. From there, ore is crushed on site before being trucked to the Glencore Zinc Mount Isa Mines (MIM) for further processing. After the ore is processed at MIM, a proportion of the tailings are transported back to LLM and used in the production of cemented paste-fill for backfilling open stopes (voids) underground.

Other waste rock removed during underground excavations and construction is characterised and selectively handled depending on its geochemical and geophysical properties. Non-acid forming (NAF) waste rock removed during the construction of the decline in 2011 was transported to the surface forming construction of the ROM Pad. Non-NAF material is placed in the purposely designed Waste Rock Emplacement (WRE). A second, smaller potential acid-forming (PAF) waste rock stockpile was created during exploration phases between 1986 and 1987 (during the construction of Shaft 1) and stored adjacent to the leachate management dam (LMD). This stockpile has recently been removed and transported to the WRE. The current site layout is shown in **MAP 1**.

MAP 1: SITE LAYOUT



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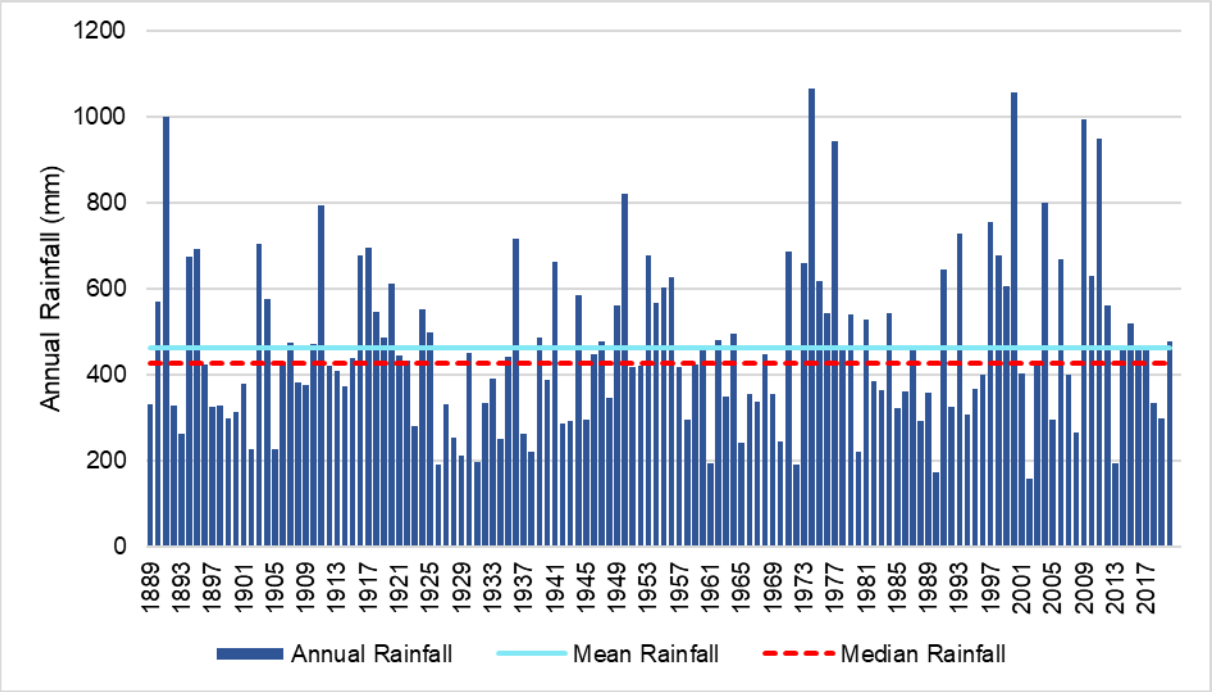
2.2 Climate

2.2.1 Regional Context

The regional climate is classified as semi-arid, with highly variable annual rainfall. DES provides an enhanced SILO (Scientific Information for Land Owners) climate database that holds Australian climate data from 1889. The interpolated climate data is stored on a regular 0.05° latitude x 0.05° longitude grid (approximately 5 km x 5 km). This database was used to obtain long-term geostatistically determined climate records at the nearest grid point to Lady Loretta.

The SILO Data Drill annual rainfall and evaporation totals based on the available historical record (noting that evaporation data is only available from 1968) are presented in **DIAGRAM 1** and **DIAGRAM 2**.

DIAGRAM 1: TOTAL ANNUAL RAINFALL



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DIAGRAM 2: TOTAL ANNUAL EVAPORATION

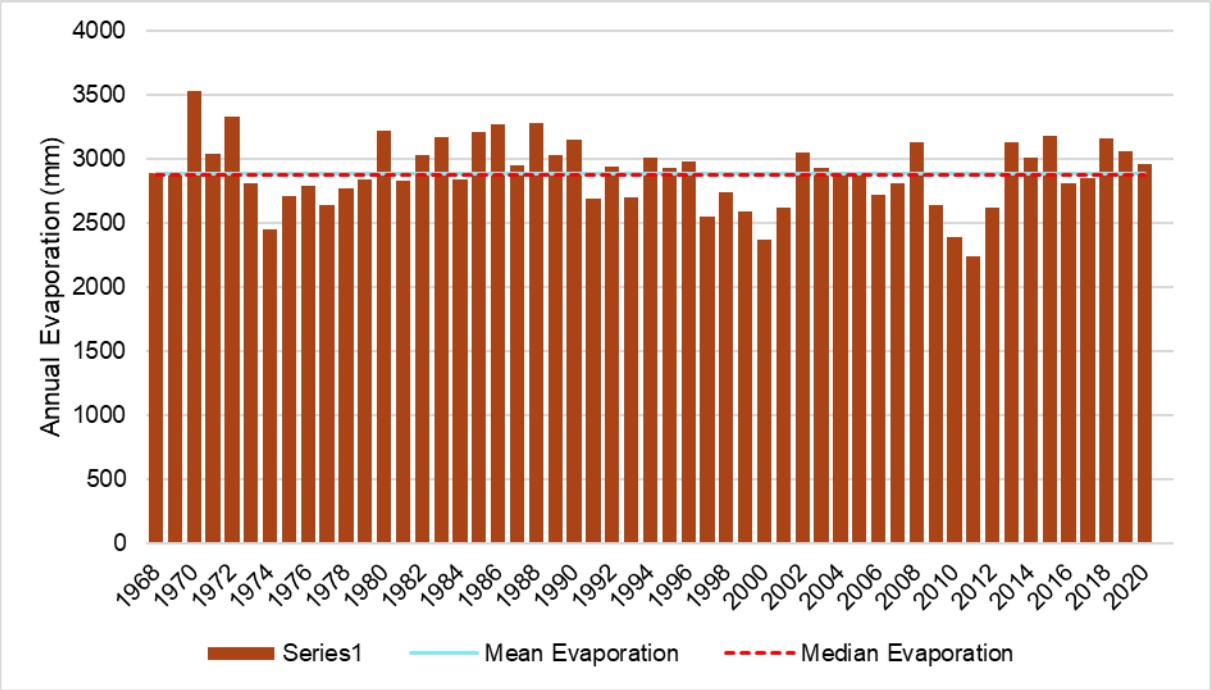
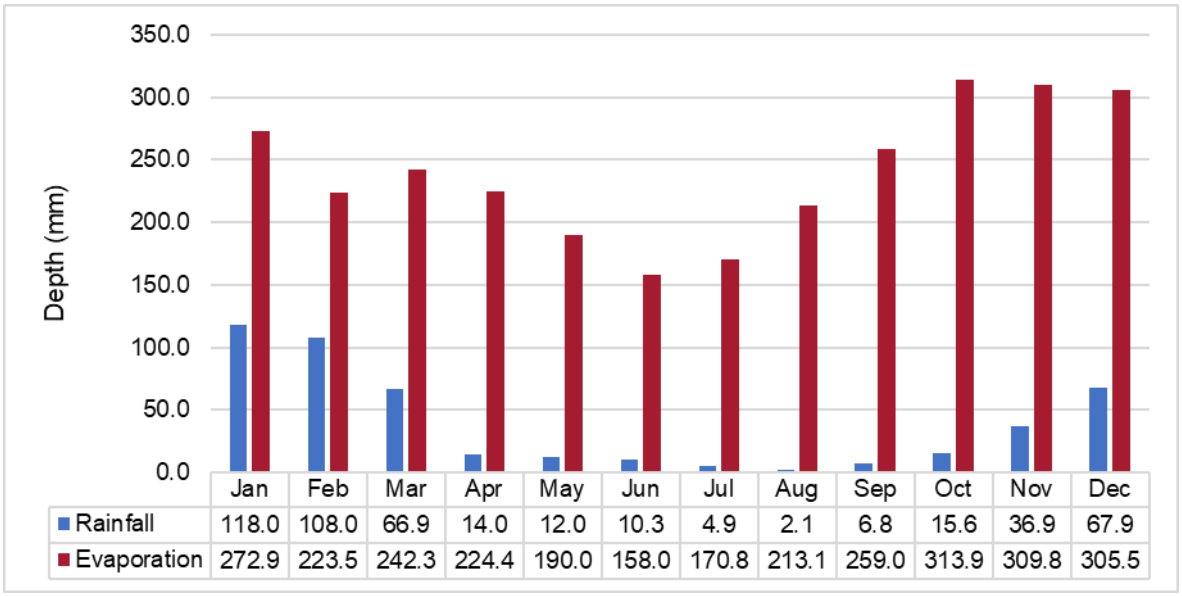


DIAGRAM 1 shows that annual rainfall is extremely variable, and has historically ranged between 160 mm and 1,070 mm, with the long-term average in the order of 460 mm. **DIAGRAM 2** shows that annual evaporation has ranged between approximately 2,700 mm and 3,500 mm, with average annual evaporation (2,880 mm) exceeding average annual rainfall by a factor of approximately 6.2.

The SILO Data Drill average monthly rainfall and pan evaporation are presented in **DIAGRAM 3**.

DIAGRAM 3: MONTHLY AVERAGE RAINFALL AND PAN EVAPORATION



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	118.0	108.0	66.9	14.0	12.0	10.3	4.9	2.1	6.8	15.6	36.9	67.9
Evaporation	272.9	223.5	242.3	224.4	190.0	158.0	170.8	213.1	259.0	313.9	309.8	305.5

DIAGRAM 3 shows that the site is characterised by marked seasonal rainfall. On average most of the rainfall (85%) occurs between November and March. Average evaporation also significantly exceeds average rainfall for all months of the year.

Rainfall statistics are presented as box and whisker plots in **DIAGRAM 4**. The box and whisker plot depicts the following:

- Minimum value

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- Second quartile (values below which the lower 25% of the data are contained)
- Median value
- Third quartile (values below which the upper 25% of the data are contained)
- Maximum value

DIAGRAM 4: RAINFALL STATISTICS (SILO DATA DRILL)

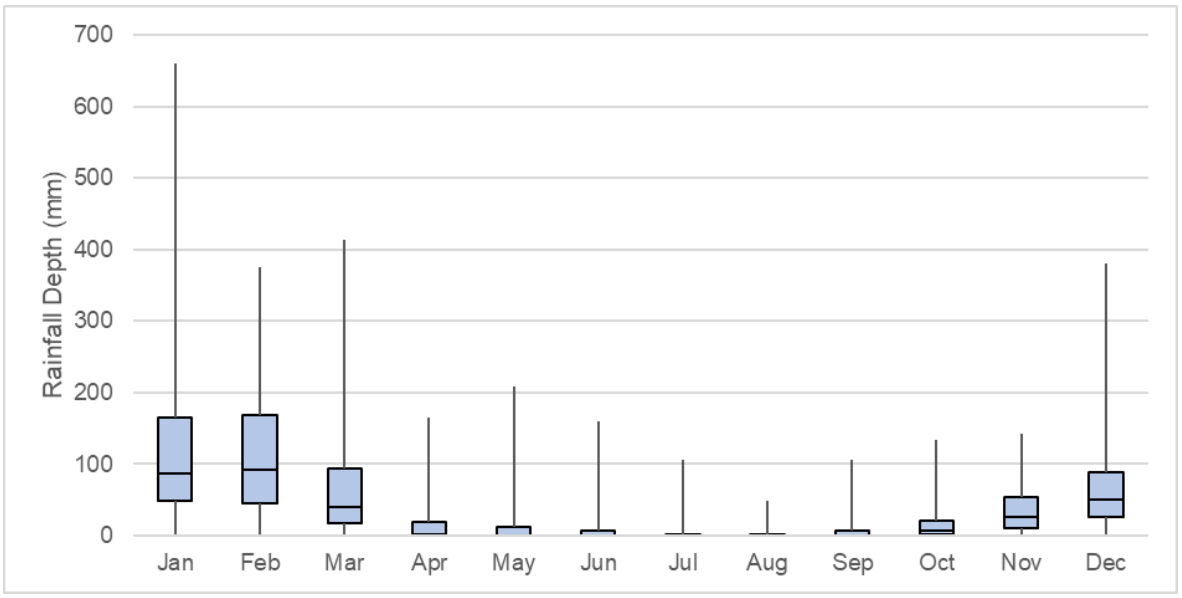


DIAGRAM 4 shows that monthly rainfall over the wet season months (December to March) is highly variable.

Evaporation statistics are presented as box and whisker plots in **DIAGRAM 5**.

DIAGRAM 5: EVAPORATION STATISTICS (SILO DATA DRILL)

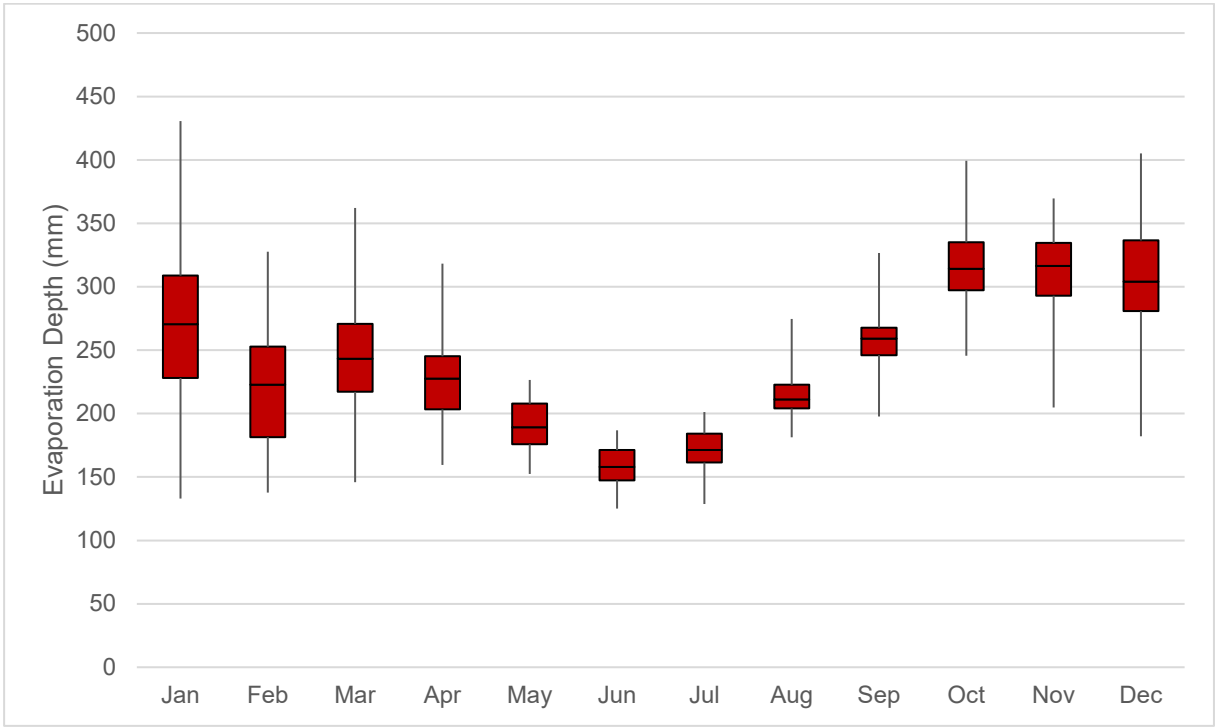


DIAGRAM 5 shows monthly variability in evaporation is similarly pronounced over the wet season month, compared to the winter months.

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In general, based on precipitation and evaporation data presented above, the site climate is characterised as water deficient, which is typical of a semi-arid environment.

2.2.2 Climate Change Considerations

In considering the implications of climate change on design specifications, guidance is taken from the *Australian Rainfall and Runoff Guidelines* (Commonwealth of Australia, 2019), which has identified the following five aspects likely to be impacted by climate change in relation design flood estimation:

- rainfall Intensity Frequency Duration (IFD) relationships;
- rainfall temporal patterns;
- continuous rainfall sequences;
- antecedent conditions and baseflow regimes; and
- compound extremes (e.g. riverine flooding combined with storm surge inundation).

The magnitudes of the likely impacts on any of the aspects listed above have not been subject to comprehensive study either nationally or internationally (Commonwealth of Australia, 2019). Notwithstanding, failure to account for potential climate hazards can lead to poor decisions, particularly when the exposure risk to climate change is medium to high. In these circumstances, a reasonable approach is to make a decision that is robust against a range of plausible futures.

The Australian Climate Futures Tool, developed by the CSIRO, is a decision-support tool developed to assist understanding and application of climate change projections for impact assessment and adaptation planning. It includes projections from global and regional climate models as well as statistically downscaled results. The global climate model (GCM) data are from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) that informed the Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report as well as those used for the earlier Fourth Assessment Report (CSIRO, 2021). Maximum GCM consensus cases for Representative Concentration pathways (RCPs) 4.5 and 8.5 (moderate and high) are considered appropriate choices for the design setting (Commonwealth of Australia, 2019) on the basis that these represent what are considered more conservative as well as worst-case emissions scenarios.

GCM estimates for changes to annual rainfall at the site location are provided in **TABLE 2**, with the rating for the consensus on models described in **TABLE 3**. For RCP 4.5, there is high consensus of little change (-5 to +5%) to annual rainfall. For RCP 8.5, there is low consensus for changes to the annual rainfall, however the highest percentage (26%) of models also indicate little change.

TABLE 2: GCM ESTIMATED CHANGES TO RAINFALL (CSIRO CLIMATE FUTURES TOOL)

Annual Change to Rainfall	RCP 4.5	RCP 8.5
Much Drier (< -15.00%)	8 of 68 (12%)	14 of 70 (20%)
Drier (-15.00 to -5.00%)	15 of 68 (22%)	16 of 70 (23%)
Little Change (-5.00 to 5.00%)	32 of 68 (47%)	18 of 70 (26%)
Wetter (5.00 to 15.00%)	11 of 68 (16%)	14 of 70 (20%)
Much Wetter (> 15.00%)	2 of 68 (3%)	8 of 70 (11%)

TABLE 3: GCM CONSENSUS

Consensus	Proportion of models
Not projected	No models
Very Low	< 10%

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Low	10% - 33%
Moderate	33% - 66%
High	66% - 90%
Very High	> 90%

In conclusion, the majority of climate change models indicate little change (+/- 5%) in estimated annual rainfall at LLM under possible future climate change (emissions) scenarios. However, there is also sufficient variability observed in the model outcomes to highlight that Glencore should continue to allow for contingencies in terms of climate and ecology when costing likely resourcing and maintenance items. These include bushfire potential as well as weed and pest control.

2.3 Site Topography

Topography of the mine is dominated by the 'Big Syncline' and 'Small Syncline'. The eastern limb of both synclines forms the main ridgeline at LLM. The ridgeline is orientated in a north-east to south- west direction. Elevations across the mine site vary from approximately 320 m Australian Height Datum (AHD) to 380 m AHD.

Most of the mine infrastructure is located on the edge of a ridgeline occupying levels between 325 m AHD and 335 m AHD at typically low gradients, less than 3% slope. The steepest gradients found at LLM are approximately 40% to 50% on the hill slopes of the 'Big Syncline'. To the east, south-east and north-east of LLM, the topography flattens and is dominated by undulating plains with occasional lower hills and ridgelines (Noranda Pacific, 2000).

2.4 Geology

The deposit targeted by the LLM is a Pb-Zn-Ag deposit within the Mount Isa Inlier, with the ML within the Lady Loretta Formation. The deposit is considered a classic sediment-hosted base metal deposit. Sediments hosting the deposit comprise freely bedded siltstone, sandstone, interclastic dolomite, carbonaceous and pyritic shale. The ore horizon is a distinctive finely banded massive sulphide lens up to 50 m thick and contains pyrite, sphalerite, galena and in places barite (Noranda Pacific, 2000).

The Mount Isa Soil Landscape Province is a dissected plateau of Precambrian igneous, metamorphic and sedimentary rocks. Lithosols (stony or gravelly soils lacking horizon development, other than an A1 horizon) are the dominant soils and have formed either in situ on the near vertically bedded shales, or from eroded material deposited on the lower slopes and along waterways. Lithosols typically consist of a shallow gravelly layer, containing minor silt and sand content, up to 1 m thick which grades into a fine to medium grained sandy loam (0.5 to 1 m thick). In some areas the gravelly layer grades into a silty clay loam or a silty clay (0.5 to 2 m depth). (Noranda Pacific, 2000). The soil horizons within LLM generally contain a large proportion of coarse textured material, as well as iron and manganese nodules. Some sections (particularly the north-eastern part) have a 30 cm layer of very fine-grained chert (Noranda Pacific, 2000). Soils along the laterite ridge above the site have naturally elevated concentrations of lead, zinc and silver associated with surface outcrops of the underlying ore horizon and associated pyrite bed (TropWATER, 2021).

2.5 Land Use

The Mt Isa Land System, where LLM lies, has a naturally low stock carrying capacity, low pastoral potential and minimal agricultural potential. Broadly, the system consists of undulating country with spinifex pastures covering large areas, and smaller regions of woodland. The land use is restricted to exploration/mining and very low intensity stock grazing.

The Environmental Management Overview Strategy (EMOS) (Noranda Pacific, 2000) reports the Lady Loretta area to be predominantly land capability class VI on the flatter plains to the east of the deposit and the valley floors between ridgelines. On the slopes and ridges the land capability class is reported as VII due to steepness of the slopes and generally shallow, rocky soils.

Emery (1985) describes capability class VI as:

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- Land not suited to any type of cultivation but best used for grazing; and
- Generally comprising land with a range of physical or climatic limitations which may include shallow soils, high rock content, excess salt concentration, steep or awkward slope gradients.

Capability class VII is described as:

- Land best to remain under green timber owing to its high soil erosion hazard and severe site restrictions; and
- Generation areas of steep slopes, shallow soils and/or rock outcrop.

2.6 Drainage

The LLM mining lease is located on the catchment divide for two major catchments draining north into the Gulf of Carpentaria, the Leichhardt River catchment and the Nicholson River catchment. The lease area is intersected by a number of ephemeral drainage lines which discharge to numerous small ephemeral creeks (including Magazine Creek and Desert Creek), which in turn discharge into Battle Creek, and ultimately into Gunpowder Creek (a major tributary of the Leichhardt River). It should be noted that Desert Creek and its tributaries also receive runoff from the Lady Annie Mining Lease (ML 90179). Gunpowder Creek has a catchment area of approximately 3,600 km^2 and Battle Creek has a catchment of approximately 475 km^2. ML5568 occupies less than 1% of either of these catchment areas. There are no permanent natural surface water bodies in the LLM operational area.

There is also no permanent surface water flow within the LLM lease; flows are typically short, discrete events that coincide with rainfall events (Glencore, 2019). Flow gauging stations installed in Magazine and Desert Creek identified streams within the LLM lease generally experience flows lasting one to three hours. Further downstream, in Desert Creek, flow events last, on average, 33 hours (Noranda Pacific, 2018).

2.7 WRE Existing Conditions

2.7.1 Geometric Configuration

At the time of writing, reshaping works on the WRE were ongoing to construct the landform discussed in **Section 3.4.3**. The geometry as of late 2022 (recognising some aspects have changed due to current construction activities) is summarised as follows:

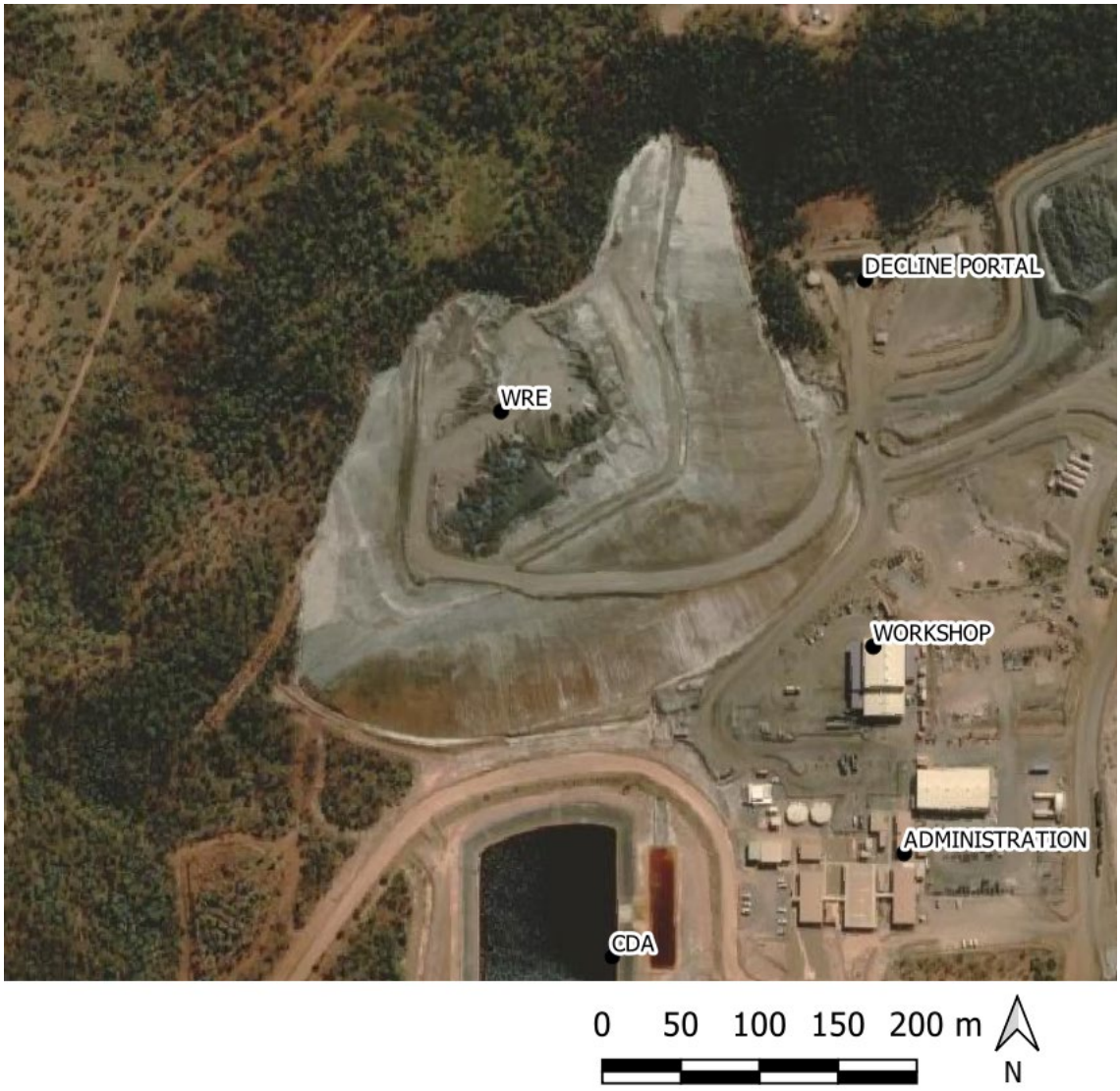
Maximum height:	52m
Average batter slope:	1V:3.5H
Footprint:	9.7ha

A clean water diversion drain exists around the northern and western perimeter, diverting the upstream catchment, unimpacted by mining activities. Surface water runoff from the WRE reports to Containment Dam B, located to the south.

The current layout of the WRE and Containment Dam B is shown in **MAP 2**.

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MAP 2: WRE EXISTING LAYOUT

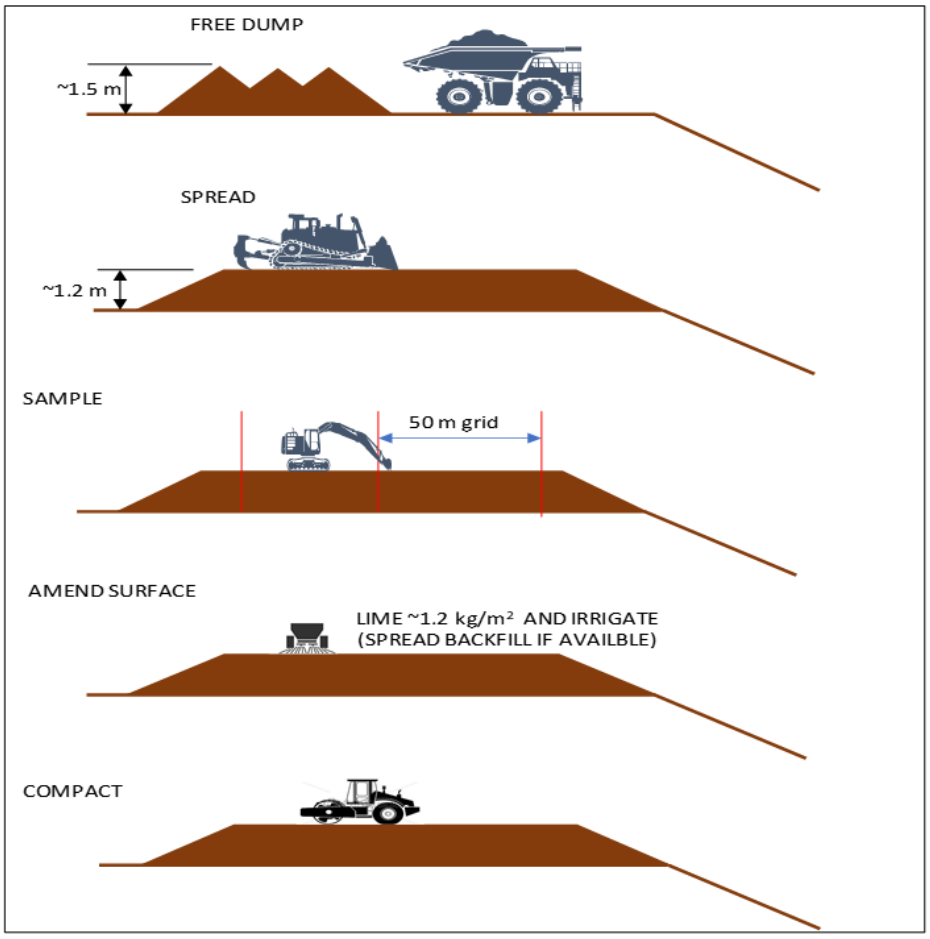


2.7.2 Waste Rock Management

Waste Rock is trucked from the decline along the access road, up the ramp currently located along the southern face of the WRE. Key management requirements have been established for the management of PAF material to manage and minimise leachate from the WRE and limit the risk of spontaneous combustion. The material is free-dumped in 1.5 m piles and then pushed out and levelled by dozer every several days or weekly at a minimum, resulting in a layer thickness of approximately 1.2 m. Hydrated lime is then applied to the surface using an excavator at a rate of 1.2 kg/m^2 to assist in neutralising acidity. The area is then moisture conditioned and compacted using a padfoot roller. This waste rock placement methodology is depicted in **DIAGRAM 6**.

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DIAGRAM 6: METHOD OF CONSTRUCTION



2.7.3 Foundation Conditions

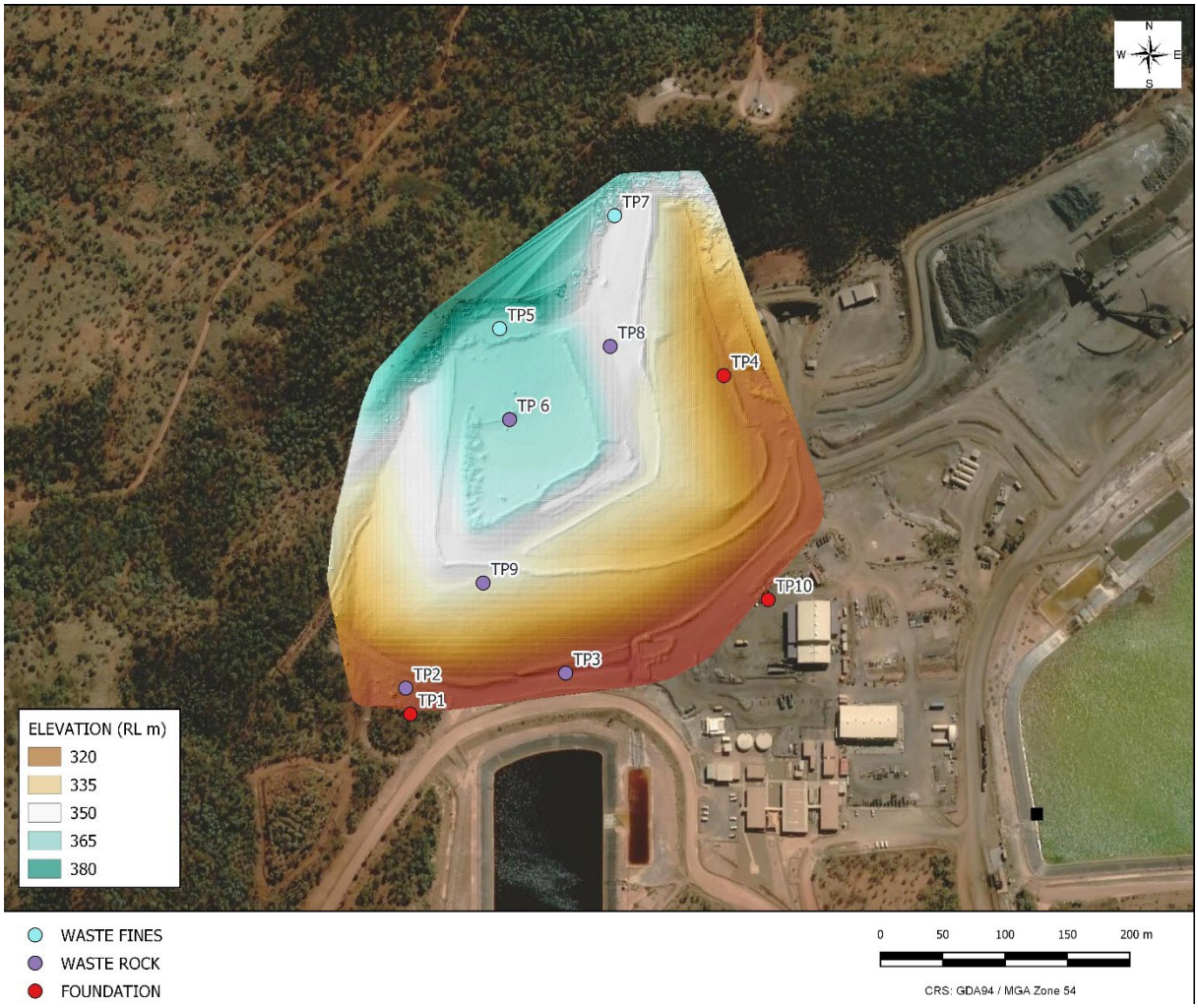
The foundation conditions for the entirety of the WRE are unconfirmed. ATCW completed an investigation for the expansion of WRE footprint (ATCW, 2020). The remainder of the foundation conditions are assumed to be generally consistent with observations from SRK (2019):

> *LLM indicated that the topsoil was stripped from the base of the WRE footprint area; however, the extension of the material upslope of the hillside indicated that the topsoil in these parts had not been removed. SRK therefore assumed for the purposes of the stability assessment, that the topsoil against the hillside had not been removed.*
>
> *LLM also indicated that a 100 mm thick clay/ fine-grained material layer had been installed or constructed at the base of the WRE following removal of the topsoil. The purpose of this layer is to limit seepage and contaminant ingress into the foundation. Based on site observations, it is assumed that this layer does not extend up the hillside (Figure 3-1). For the purpose of the geotechnical stability analyses, SRK assumed that the clay liner extends across the base of WRE footprint only. A description of the soil landscape is presented in the Erosion and Sediment Control Plan (LLM, 2016) and details on the site geology can be found in the WRSMP (KBR, 2018). Based on the geology and regional soil description, it is unlikely that the foundation materials would settle or heave, and there is no potential for chemical dissolution. However, a geotechnical investigation must be carried out to validate these assumptions.*
>
> *SRK noted during the site inspection that the channel foundation material appears to become more competent with depth. However; it appeared that excavator refusal had not yet been achieved at the depth to which the trench invert had been developed. The observed material is characterised as being highly fractured rock.*

ATCW (2020) undertook test pitting of the foundation prior to the proposed footprint expansion as part of separate works as shown in **MAP 3** (test pit locations TP1, TP4 and TP10).

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MAP 3: WRE TEST PITTING LAYOUT



A summary of soil types encountered during the test pitting at foundation sites is summarised as follows:

TP1: 0.5 m of topsoil (mostly fines, red-brown) was encountered at surface, with material below comprising sedimentary rock (fine grained, highly weathered, medium strength). The test pit was terminated at 1.1 m

TP4: Similar conditions to TP1 with topsoil to 0.1 m, material becoming medium strength at 0.4 m and refusal at 1.3 m

TP10: Similar conditions to TP4 with topsoil to 0.05 m, with material becoming medium strength and refusal at 0.3 m

Testing of geotechnical and geochemical parameters of samples retrieved from the three test pits confirmed that the foundation materials should be suitable for use in development of cover systems appropriate for the local weather environment as well as the environmental risk posed by the WRE (ATCW, 2020).

The other test pits shown on **MAP 3** (TP2, TP3 and TP5 to TP9) were excavated into the waste rock and waste fines (also known as paste fill). Material properties for waste rock are discussed further in **Section 4**.

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3 CLOSURE CONCEPT

3.1 Background

In consultation with LLM, ATCW (2021) completed an initial options assessment, evaluating the WRE landform geometry and cover systems for closure. The objective of the options assessment was to:

- Define closure objectives;
- Identify regulatory requirements;
- Identify potential landform configurations, and cover systems suitable for the WRE; and
- Undertake a high-level assessment for each combination of landform and cover system to identify the preferred conceptual landforms and cover systems to be progressed for further analysis (modelling).

3.2 Closure Objectives

Closure objectives are outlined below which provide a basis for assessing and comparing closure options identified. Identified options are assessed against these closure objectives in the following sections to determine the suitability of options identified.

The objective is to return land disturbed by the mining activities to pre-mining land use of low intensity grazing and pre-mining capability class of native habitat. As stipulated in the PRCP and land outcome document; Post Mine Land Use Plan (PMLUP), 2018, the Post-Mining Land Use (PMLU) for the WRE is proposed as Native Habitat.

For the WRE final landform to meet the above land use requirements, overall objectives for rehabilitation of the WRE is to create a landform that is:

- Non-polluting (i.e. does not contribute to any deterioration of the receiving environment);
- Geotechnically stable in the long term; and
- Environmentally sustainable, related to long term compatibility with the surrounding topography and final land use.

In addition to the above, high-level closure objectives are as follows:

Non-Polluting

- Limited seepage due to low water flux into waste
- No capillary rise

Physically Stable

- Mass stability under static and earthquake condition
- Permanent containment with low rates of erosion
- Key elements are resilient to cyclic wetting and drying

Sustains Agreed Land Use

- Sufficient plant available moisture on the crest (whilst avoiding saturation/flux through cover system to waste rock)
- Supports Native Habitat (including sufficient soil nutrition that promote vegetation establishment on the crest and surfaces that create habitat for native fauna)

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3.3 Legislative Requirements

3.3.1 Mineral Resources Act 1989

Resource activities are regulated through a 'resource authority' under the *Mineral Resources Act 1989* (MR Act). This provides resource companies with the right to enter land and undertake the approved activity. The MR Act applies to mining leases and informs the requirement for surrender.

3.3.2 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 requires that all areas of disturbed land within the relevant mining tenure be rehabilitated to support a suitable Post-Mining Land Use (PMLU) or managed as a Non-Use Management Area (NUMA). Sections 126C and 126D stipulate the requirements for PRCPs and 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 PRCP approvals. The EP Act also prescribes the requirements for surrendering an EA, including the preparation of final rehabilitation reports and post-mining management reports.

3.3.2.1 EA Requirements

LLM operates under EA EPML00982013, with likely future amendments made prior to closure of LLM to reflect contemporary PRCP standards.

Note the Post Mine Land Use Plan referenced under Schedule E of the EA will be superseded by PRCP requirements in accordance with the Queensland Governments mining rehabilitation reforms.

Requirements under the PRCP is that a suitable landform and cover system design for a WRE is achieved. Reference to DES PRCP Guideline has been made to ensure key components for LLM WRE closure design are met.

3.3.3 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 an EA holder fails to meet their environmental and rehabilitation obligations. This act also amended the EP Act to require mining companies to develop PRCPs.

3.4 2021 Options Assessment

In consultation with LLM, ATCW (2021) completed an initial options assessment, evaluating the WRE landform geometry and cover systems for closure. The cover system for the batters was considered separately to the plateau. The following sections summarise the cover systems and final landform options assessed.

3.4.1 Plateau Cover Systems

Potential cover systems were identified and assessed against functional objectives discussed in **Section 3.2**. Cover system options identified are summarised as follows:

Cover A: Capillary Break (DES default capping option)

Cover B: Bituminous geomembrane liner

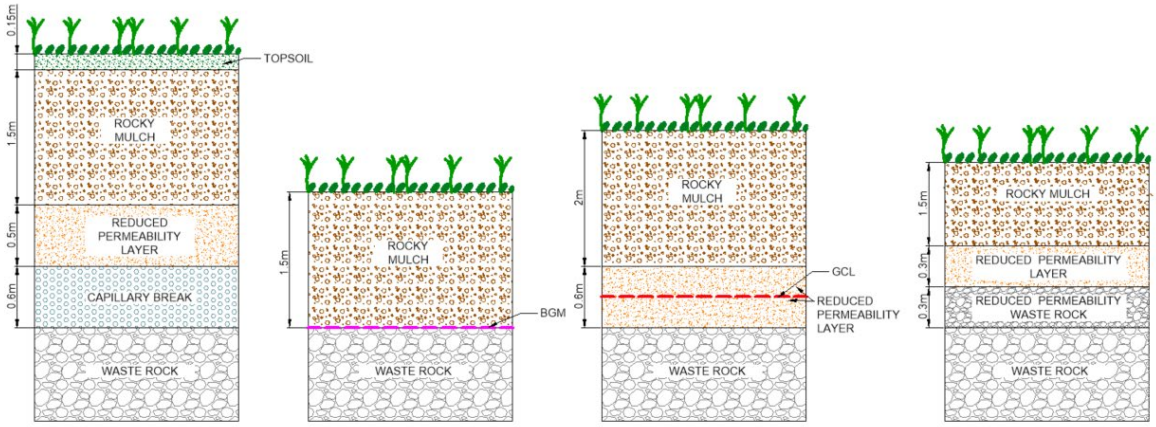
Cover C: Geosynthetic clay liner (GCL)

Cover D: Store and release

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Typical profiles for each of these cover options are shown in **DIAGRAM 7**. All cover system options were deemed plausible with modelling recommended (as detailed in **Section** Error! Reference source not found.) to assess performance against closure objectives.

DIAGRAM 7: COVER SYSTEM OPTIONS



A – Capillary Break **B – BGM Liner** **C – GCL** **D – Store and Release**

3.4.2 Batter Treatment

The final WRE batter has the primary objective of withstanding erosion. The risks of infiltration when compared to the plateau are reduced due to the steep slopes and high rates of runoff. Notwithstanding, a zone of NAF fill would be required to ensure moisture which did infiltrate is captured and does not percolate into the PAF waste.

No closure objectives with respect to vegetation have been assigned for the NAF Rind. Consideration of vegetation establishment on the batters is summarised as follows:

- Steep batters will have a high proportion of rainfall runoff (low infiltration); thus moisture content will be low.
- Construction materials (primarily rock armour material) are less desirable for vegetation growth, however, are required for erosion protection.
- Unvegetated (or low vegetated) batters would be comparable to natural rocky outcrops, common in the region and possibly suitable habitat for purple-necked rock wallabies.

Similar cover systems to those identified for the plateau were initially considered; however, were discounted with fatal flaws identified as follows:

- With average batter slopes of 1V:3.5H, the current landform (nominated as Landform 1) is expected to be too steep for the capillary break, store and release cover systems.
- The GCL was discounted as seasonal wetting and drying is likely to cause cracking and desiccation of the liner. The cracking and desiccation would be expected to impact the hydraulic performance of the liner such that it would no longer perform adequately.
- Construction of a reduced permeability layer (RPL) with a thickness of 0.3 m would not be feasible on a slope. Noting that compaction of this layer is required to achieve the desired material properties, options incorporating a thin RPL were discounted.

A batter treatment option including a bituminous geomembrane (BGM) liner was considered with the following profile:

- Compacted PAF waste
- BGM liner
- Cushion Layer (for protection of BGM)
- Rock Armour (for erosion protection)

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This option was not progressed, given the following:

- Steep slopes will result in high velocities and low infiltration of runoff. The function of a BGM is to prevent infiltration through the cover system into the PAF waste rock, therefore the requirement for a BGM would be negligible.
- Minimal benefits with respect to reducing the volume of earthworks material required, noting the width of the cushion layer and rock armouring would need to be constructable.
- Benches may need to be widened to allow for installation of the BGM (anchor trench plus width for vehicle access for installation).
- A veneer stability analysis would be required to determine if adopted batter slopes would support the BGM without slippage of the liner. Subject to the outcome of this assessment, batter slopes may need to be flattened.

A final option comprising a NAF Rind was identified as follows:

- 1.2 m compacted PAF waste
- 1.2 m compacted NAF waste
- 0.9 m rock armour

This option was deemed to achieve closure objectives and address geometric constraints imposed by the steep batter slopes and was selected as the preferred option. The NAF Rind is depicted in **DIAGRAM 10 (Section 3.6.2)**.

3.4.3 Landform Options

To ensure the final landform was optimised to meet closure objectives, three landform options were identified for assessment, as follows:

Landform 1: Cover the existing landform without reshaping the existing waste rock (adopting the current batter slopes of 1V:3.5H).

Landform 2: Construct a containment rind around the perimeter of the WRE, allowing the landform to be steepened, thereby increasing the area of low slope at the plateau. The batter slope for the containment rind (refer **Section 3.6**) was assigned at 1V:2.5H.

Landform 3: Increase the footprint of the storage thereby increasing the plateau area (low slope) while leaving current batters at around 1V:3.5H. Landform 3 is considered halfway between Landform 1 and Landform 2.

Early concepts for each of these landform options are depicted in **MAP 4** to **MAP 6**. It is noted that further development of the preferred option was undertaken as discussed in **Section 3.4.4**.

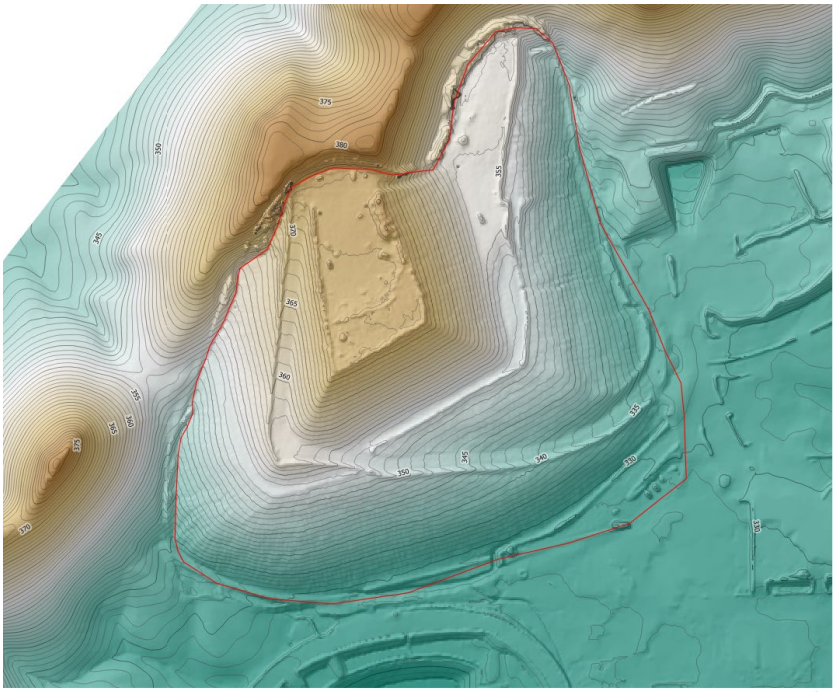
A summary of the assessment for each of the landform options is provided as follows:

Landform 1

The existing landform did not allow for the required volume of mine waste for the life of mine (LOM). This was considered a fatal flaw for Landform 1 and this option was therefore discarded.

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MAP 4: LANDFORM 1



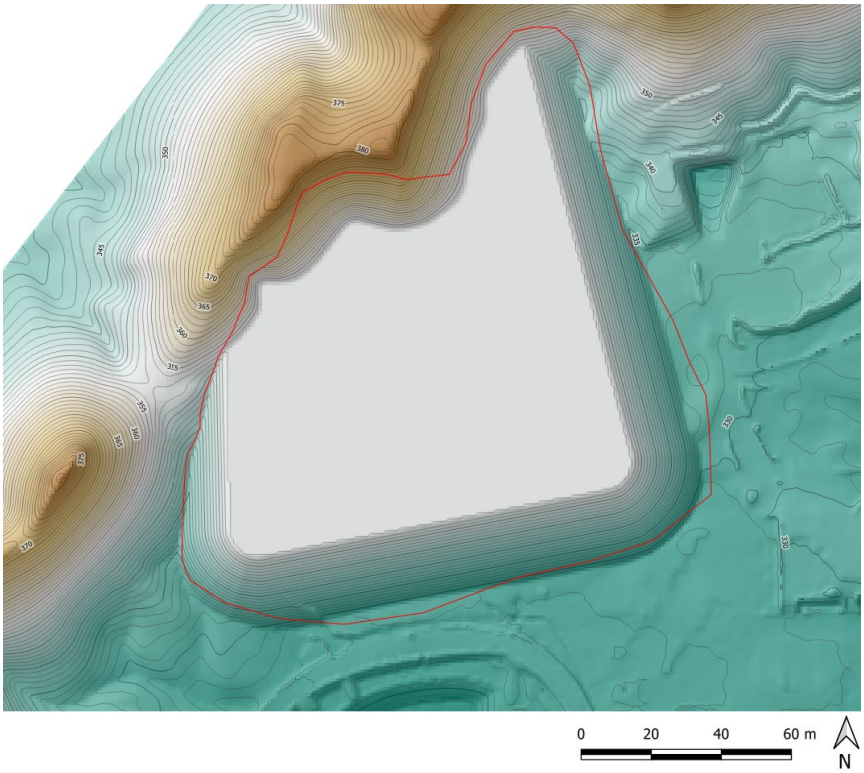
Landform 2

Landform 2 was developed with the steepest slopes possible while maintaining constructability and the required factors of safety with respect to geotechnical stability (refer **Section** Error! Reference source not found.). Considerations for Landform 2 were as follows:

- Revegetation of the plateau created for Landform 2 is expected to be more successful than vegetation on slopes (e.g., for the current landform).
- Rock lined, steep batters are comparable conditions to rocky slopes, commonly observed in the surrounding landscape.
- Construction of Landform 2 during operations maximises the storage capacity available for future mine development.

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MAP 5: LANDFORM 2



Landform 3

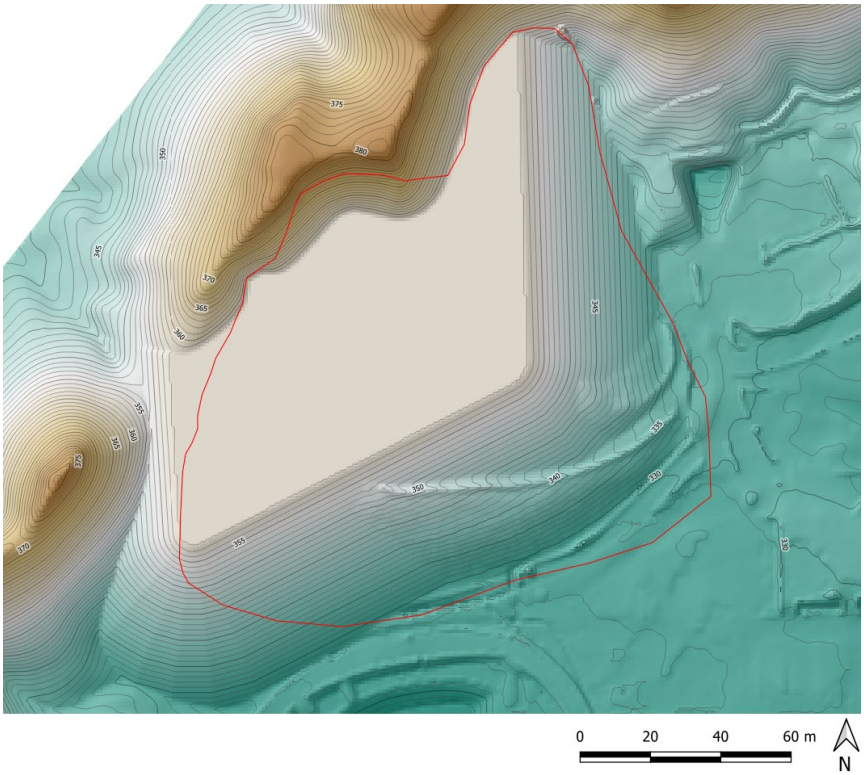
Landform 3 was discarded noting the following:

- Compared to Landform 2, Landform 3 consumes a greater footprint than required to contain the same volume.
- The increased footprint exceeded the approved footprint area in the EA of 11ha.
- Flatter batters (1V:3.5H) provide limited benefit over the adopted steeper batters (1V:2.5H) with respect to vegetation establishment and will still require rock armouring. Therefore, the additional footprint required by Landform option 3 is not justified.

Based on the assessment undertaken, Landform 2 was adopted as the preferred option for further assessment. It is noted that further development of the conceptual landform shown in **MAP 5** was undertaken to meet LOM waste volume requirements.

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MAP 6: LANDFORM 3



3.4.4 Preferred Options

Based on the 2021 Options Assessment undertaken, feasible combinations for each of the plateau cover systems, batter treatments and landform options are provided in **TABLE 4**.

TABLE 4: SUMMARY OF OPTIONS ASSESSED

Cover	Landform 1	Landform 2	Landform 3
Cover A - Capillary Break	Landform does not provide sufficient airspace for life of mine.	2A To be assessed	Not Assessed as Landform is a combination of Landform 1 and 2
Cover B – BGM		2B To be assessed	
Cover C – GCL		2C To be assessed	
Cover D – Store and Release		2D To be assessed	

Note: Options shaded in red not considered viable based on a high-level review. Green options considered potentially viable pending further assessment.

3.5 2022 Options Workshop

A workshop was undertaken between 1st and 2nd November 2022, assessing proposed cover systems under the Multiple Account Analysis (MAA) approach. The MAA approach is used to support decision making with respect to cover designs and provides a reliable basis that allows for better refinement of options, identifies appropriate value management initiatives, and considers reasonable and feasible engineering solutions. The MAA approach was adopted to allow refinement of the WRE cover options

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and to provide further information relating to the final landform design of the WRE. The workshop was facilitated by SGM Environmental and attended by Glencore and a representative from ATCW.

For the plateau, the cover systems identified in **Section 3.4** were further assessed, including minor variations to Cover Option A to include a double capillary break, protective layer for Cover Option B (BGM), in addition to the Hybrid Store and Release Cover system (Cover Option E) previously proposed in the LLM PMLUP. Each of the cover systems identified were assessed against the following criteria:

- Environmental (i.e., potential for seepage, surface water management requirements, prevention of capillary rise, potential for dust generation, compatibility with surrounding landscape, unsafe and unsustainable landform, ecological considerations)
- Financial (i.e., costs associated with cover installation, sourcing borrow material, post closure monitoring and maintenance, susceptibility to market volatility)
- Technical Viability (i.e., geotechnical instability, slippage / friction at cover interface, cover elements tolerance; to cracking / desiccation of liner and infiltration of fines, duration of construction)
- Cover Design Considerations (i.e., cover performance to wet / dry cycling, susceptibility to climate regimes, cover installation complexity, requirement for benches and borrow materials)
- Other (i.e., stakeholder and regulatory considerations)

Results for the assessment on the plateau are summarised as follows:

- Cover Option B (BGM on Plateau) ranked best for all criteria.
- Cover Option D (Store and Release system) had the second highest ranking for all criteria.
- Cover Option C (GCL) and Cover Option E (hybrid store and release cover system) had the third/fourth highest ranking subject to criteria. Cover Option E ranked fourth for environment, cover design and other.
- Cover Option A (CB) ranked lowest.

Options assessed for the batter treatment comprised the NAF Rind, in addition to 3 alternative options including BGM liners. The configuration of the options assessed are shown in **DIAGRAM 8**.

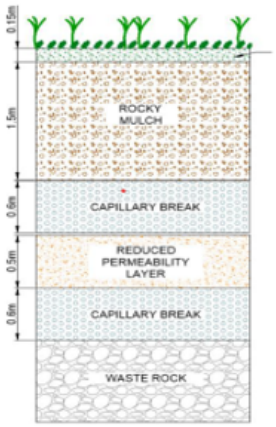
Results for the assessment on the batter are summarised as follows:

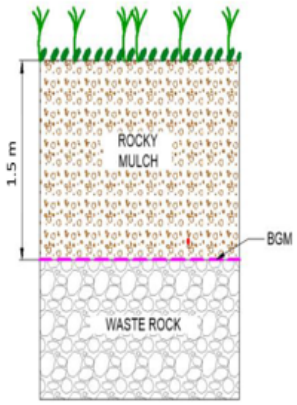
- Batter Option 4 (NAF Rind) ranked best for all areas except technical viability.
- Batter Option 3 (BGM bottom-up build) ranked second for general and other, and third for all other criteria.
- Batter Option 1 (BGM no cover) ranked similar to batter option 3 having second/third highest ranking subject to criteria. It ranked first for technical viability. This score is associated with no cover material i.e., easier to install because there is no capping treatment on batters.
- Batter Option 2 (BGM crest tip) ranked lowest.

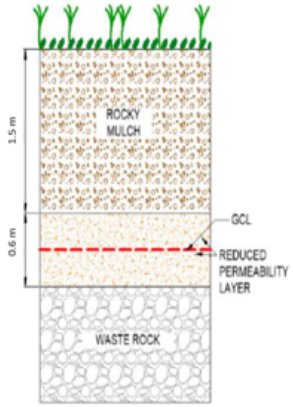
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DIAGRAM 8: MAA PLATEAU COVER SYSTEM OPTIONS

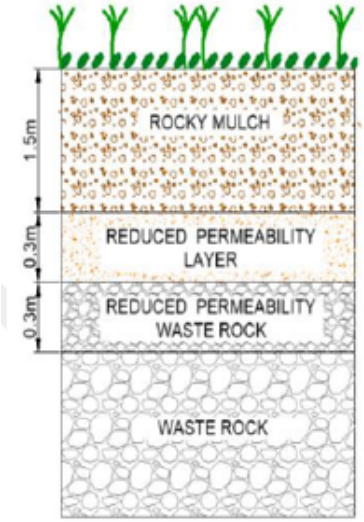
Cover option A	Cover option B	Cover option C
Double capillary break (CB)[1]	**Bituminous geomembrane liner (BGM)**	**Geosynthetic clay liner (GCL)**
• 0.1-0.2 m growth media; • 1.5 m ISL (rocky mulch); • 0.6 m capillary break; • 0.5 m RPL (fine oxide); and • 0.6 m capillary break.	• 1.5 m ISL (rocky mulch); and • 0.3 m protective layers above (graded/crush and screen) BGM (ie free issue).	• 1.5 m ISL (rocky mulch); • 0.3 m protective layer above GCL (ie RPL fine oxide); and • 0.3 m protective layer below GCL.

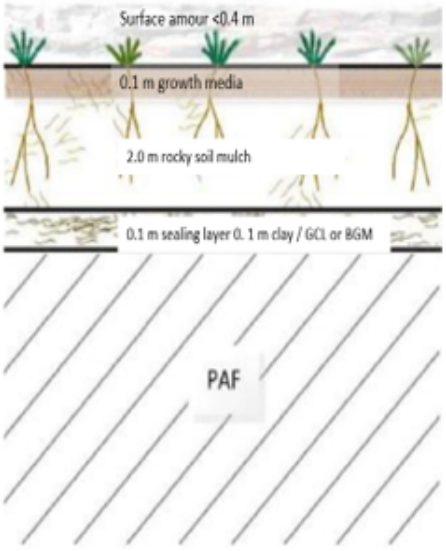






Cover option D	Cover option E
Store and release cover (S&R system)	**Hybrid SRC system (hybrid cover system)**
• 1.5 m ISL (rocky mulch); • 0.3 m RPL (fine oxide); and • 0.3 m RPL (in-situ PAF waste rock).	• 0.4 m surface armour; • 0.1 m growth media; • 2 m rocky mulch; and • 0. 1 m clay / GCL or BGM.

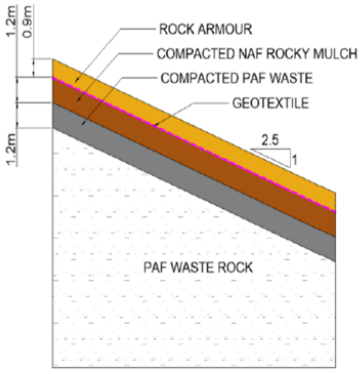




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DIAGRAM 9: MAA BATTER TREATMENT OPTIONS

Batter option 1	Batter option 2	Batter option 3	Batter option 4
BGM (no cover)	**BGM crest tip**	**BGM bottom-up build**	**NAF rind**
• compacted PAF waste to reduce infiltration; and • BGM liner.	• 1.2 m rocky mulch.	• 1.8 m rocky soil mulch; and • 0.9 m rock armour.	• 1.2m compacted PAF waste (to reduce infiltration); • 1.2 m compacted NAF rocky mulch (graded rocky / gravelly fill to reduce infiltration in the PAF waste); • Geotextile (to reduce erosion of the compacted NAF rocky mulch); and • 0.9 m rock armour (erosion resistance layer of fresh durable rock fill).



3.6 Adopted Landform and Cover System

Based on the outcomes of the 2021 options assessment and the 2022 workshop, the adopted configuration for the plateau cover system, batter treatment and final landform is discussed in the following sections.

3.6.1 Plateau Cover System

The preferred option for the plateau cover system is the BGM with an Infiltration Storage Layer (ISL) comprising of 1.5m rocky mulch. The purpose of the rocky mulch layer is to provide a medium for plant growth and to protect the BGM liner. The final surface on the crest would be loose and hummocked to increase plant available moisture. The purpose of the BGM is to provide a low permeability layer, minimising seepage reporting through the cover system and prohibiting capillary rise. It is recognised that the maximum tap-root depth of some plant species may potentially reach the proposed BGM liner at 1.5 m. On this basis, a BGM to be used would require a root barrier. BGM manufacturer, Coletanche, has demonstrated a range of products (ES, XP and Axter TP4) that are resistant to roots based on the European standard test method for determining resistance to roots (EN 14416). Notwithstanding, material specifications, including root resistance, will be verified as part of future Project phases as per commitments made by Glencore.

It is highlighted that during the detailed design phase, liner protection testing would be undertaken to confirm the final requirements for liner protection layers, with the intent of these works being to ensure liner integrity and to reduce the risk of puncturing. If required, additional liner protection layers would be expected to comprise up to a 0.3 m layer of low permeability (e.g. clay) fill — with options to place this material both above and beneath the liner should this be required.

Material properties and performance of the cover system are provided in **Section 5**.

3.6.2 Batter Cover System

The preferred option for the batter treatment is the NAF Rind.

It is noted that after the initial options assessment, it was identified that concept options should also consider a drainage geotextile beneath the rock armouring. This has been considered to reduce the risk of undercutting the proposed Rock Armour layer and subsequently leading to potential erosion of the proposed compacted Rocky Mulch layer. Specification and performance requirements for the

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geotextile would be developed during future Project phases to validate appropriate strength/grading of the geotextile material.

The proposed configuration for the NAF Rind is depicted in **DIAGRAM 10**. The cover thickness is shown in **DIAGRAM 11**. A description of the target properties for the layers of the NAF rind are as follows:

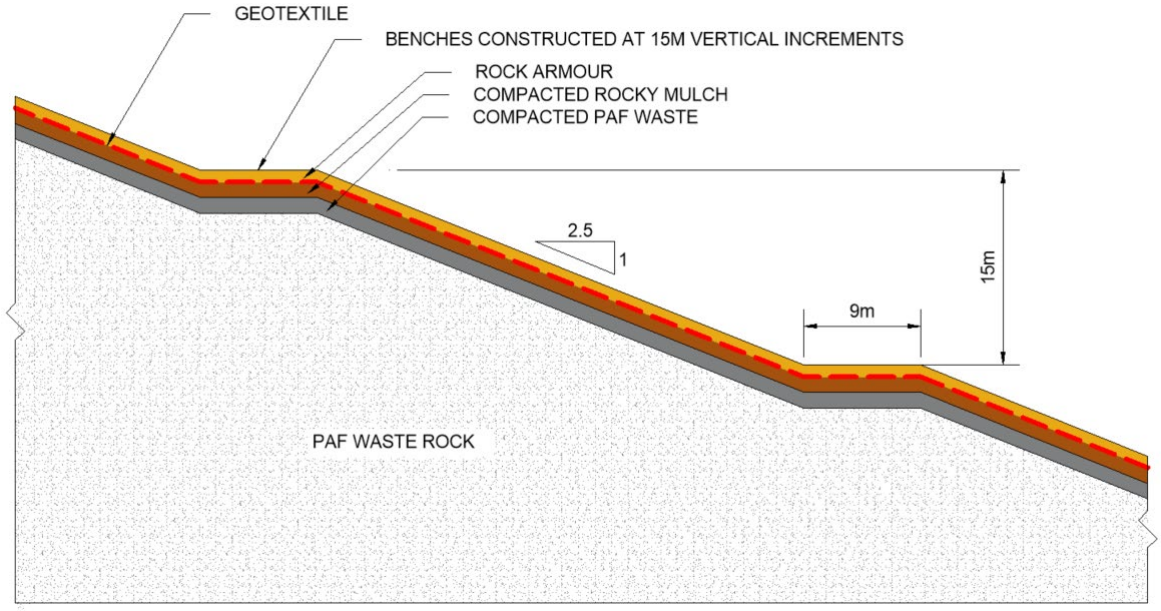
Compacted PAF waste:	Compacted PAF zone to allow for a working layer on which to construct the Compacted Rocky Mulch. It is recognised the entirety of the PAF waste would be compacted (based on the method of waste rock placement, spreading and compaction); however, a higher level of construction quality assurance, (comprising compaction testing) is expected to be implemented on the outer layer of PAF waste.
Compacted Rocky Mulch:	Compacted rock and soil blend to limit moisture ingress to PAF waste.
Geotextile:	Separation layer comprising geotextile to reduce internal erosion/piping risk at the interface of the Rock Armour and compacted Rocky Mulch layers.
Rock Armour:	Fresh, angular rock, provided as the erosion resistant surface.

The adoption of 3 m width for the compacted PAF and Rocky Mulch layers was based on the minimum working width for a compactor (assuming material will be placed in horizontal lifts). Compaction for these layers is critical for limiting infiltration and optimising erosion and geotechnical (slope) stability.

The rockfill thickness is based on achieving two to three layers of D_{50} diameter of rock armouring (best practice), as discussed in **Section 8**. The material will need to comprise a well graded material including boulders derived from hard, dense and durable rock of sufficient diameter (anticipated maximum size of 300 to 450 mm) to ensure erosion from surface water runoff does not occur. Smaller particles (anticipated size of 30 to 100 mm) will also be required to provide structural stability and limit infiltration.

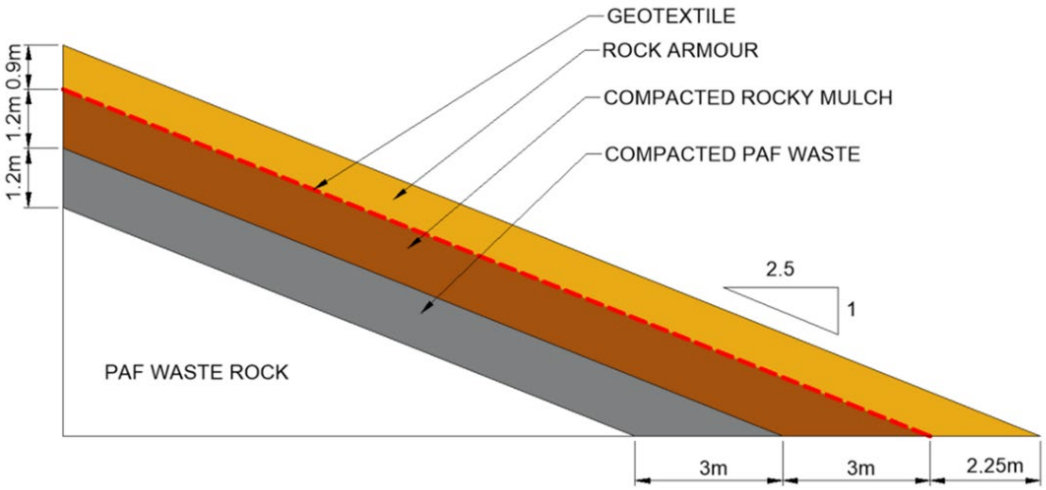
Any rainfall infiltrating through the rock armour, has potential to erode fines in the Rocky Mulch layer thereby undercutting the Rock Armour. The geotextile will limit the risk of erosion, by limiting the potential of fines washing out of Rocky Mulch layer underlying the Rock Armour.

DIAGRAM 10: NAF RIND



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DIAGRAM 11: NAF RIND PROFILE



Note: Rock Armour is to extend across the benches. Gravel sheeting may be required for trafficability, however this would be assessed during Detailed Design.

3.6.3 Final Landform Geometry

The preferred conceptual option for the final landform geometry (Landform Option 2) was to construct the batters at the maximum allowable slope whist maintaining acceptable factors of safety for geotechnical stability. Subsequent to the development of the Landform Option 2 concept, further revisions to the landform geometry were undertaken in order to achieved operational requirements for waste rock disposal, as follows:

- Additional storage capacity to store current WRE volume (as at October 2022) plus 370,000m³ (Loose Cubic Metres).
- Batter Slopes of 1V:2.5H
- Bench spacing (vertical increments) of 15m
- Bench width of 9m to allow for vehicle access on benches.
- Crest slope of less than 20 H:1 V (5%).
- Maintain less than 11ha disturbance area (per EA).
- Maximum height of WRE not exceeding natural ridgeline to the north.

The geometry of the conceptual final landform developed is shown in **MAP 8** (refer **Section 6)**.

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4 MATERIAL PROPERTIES AND CHARACTERISATION

4.1 Waste Rock

In 2020, ATCW undertook an investigation to determine the geotechnical characteristics of the waste rock. The investigation comprised excavation of 12 tests pits into the WRE, foundation and ROM pad. Tests pits were distributed across the full extent of the landform, along the toe, crest and batters. Test pits were logged and photographed, with samples collected for geotechnical and geochemical analysis. A summary of test work undertaken is described in sections below.

During the investigation, a range of materials were observed. The primary material comprised a coarse shale waste rock. The waste rock was covered by a mixture of paste-fill and finer/more weathered shales/siltstones/sandstone material. The finer material ranged in depth between 0.3 m and greater than 1.5 m (maximum test pit depth) on the crest of the landform.

4.1.1 Geotechnical

Geotechnical samples were prepared in the field by hand picking and discarding particles exceeding 100mm in diameter, using the fine fraction to fill a 20kg sample bags.

All testing was completed pursuant to NATA ISO/IEC 17025 and samples were analysed for the following parameters:

- Moisture content
- Particle size distribution
- Atterberg limits
- Permeability

The waste rock is generally comprised of well graded material, comprising 40-62% gravel and a fines fraction representing 15-44% fine material (silt/clay). A portion of samples taken were predominantly Paste Fill that had been remined and mixed with the Waste Rock stream during dumping. The Waste Rock materials not mixed with Paste Fill were found to contain a significant coarse component (75-80%) and generally less than 7% fines.

The permeability of the waste rock varied from rapid to moderate, varying with the fines ratio and the compaction. Permeability test results are provided in **TABLE 5** and were completed at 95% compaction ratio.

TABLE 5: COMPACTION AND PERMEABILITY RESULTS (ATCW, 2020)

Sample Name	Optimum Moisture Content	Max Dry Density (t/m³)	Permeability @20C (m/s)	Final Moisture Content
TP2	12.5	2.09	6.44×10^{-6}	13.3
TP9	12.5	2.45	3.60×10^{-6}	13.5

4.1.2 Geochemical

As outlined in the Waste Rock and Spoil Management Plan (WRSMP) (Glencore, 2023), waste rock has historically been sampled and characterised for environmental geochemistry parameters (including Acid Base Accounting and Net Acid Generation parameters) in four sampling campaigns:

- Pre-operation:
  - Stewart Miller and Associates (1996/87); and
  - Resource Strategies (2000)

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- Operation
  - Sampling of decline and near-ore samples in 2013/14; and
  - WRE drilling in April 2016.

A summary of observations from these sampling campaigns is as follows (Glencore, 2023):

- PAF rock occurs predominately near the ore zone and includes the Pyritic Ore Horizon (material not taken as ore), Massive and Cyclic lithological units
- NAF rock appears to be associated with the Lower Dolomite lithological unit in the mine footwall, and interbedded dolomitic sandstone/siltstone of the Cyclic Unit in the mine decline
- Waste rock in the WRE is predominately PAF, with Chromium Reducible Sulphur (CRS) and water leachable concentration of cadmium, lead, and zinc likely to exceed contaminant release limits; and
- Waste rock drainage chemistry as represented by water quality present in the CDB containment dams during the mine's care-and-maintenance period was characterised by acidic pH and exceeded release limits for electrical conductivity, aluminium, cadmium, cobalt, copper, lead, nickel and zinc.

Recognising the WRE constitutes the most significant post mining landform and moderate-high risk waste rock inventory, a suitable cover system is required to minimise moisture ingress and seepage. These objectives and the performance of the proposed cover system is discussed further in **Section 5**.

4.2 Borrow Materials

4.2.1 General

Between 2020 and 2021, RGS Environmental Consultants Pty Ltd (RGS) undertook an investigation to identify suitable materials for closure and rehabilitation, referred to as Phase 1 and Phase 2. The purpose of the investigation was to verify if soil, regolith and rock from proposed borrow areas at LLM would be suitable for rehabilitation, and to then quantify the material balance for each type of material.

4.2.2 Material Required

Material types and quantities required for closure of the WRE were determined based on the Landform and Cover Option selection for closure. The required material qualities for different material types are outlined in **TABLE 6**.

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TABLE 6: BORROW MATERIALS REQUIRED PROPERTIES

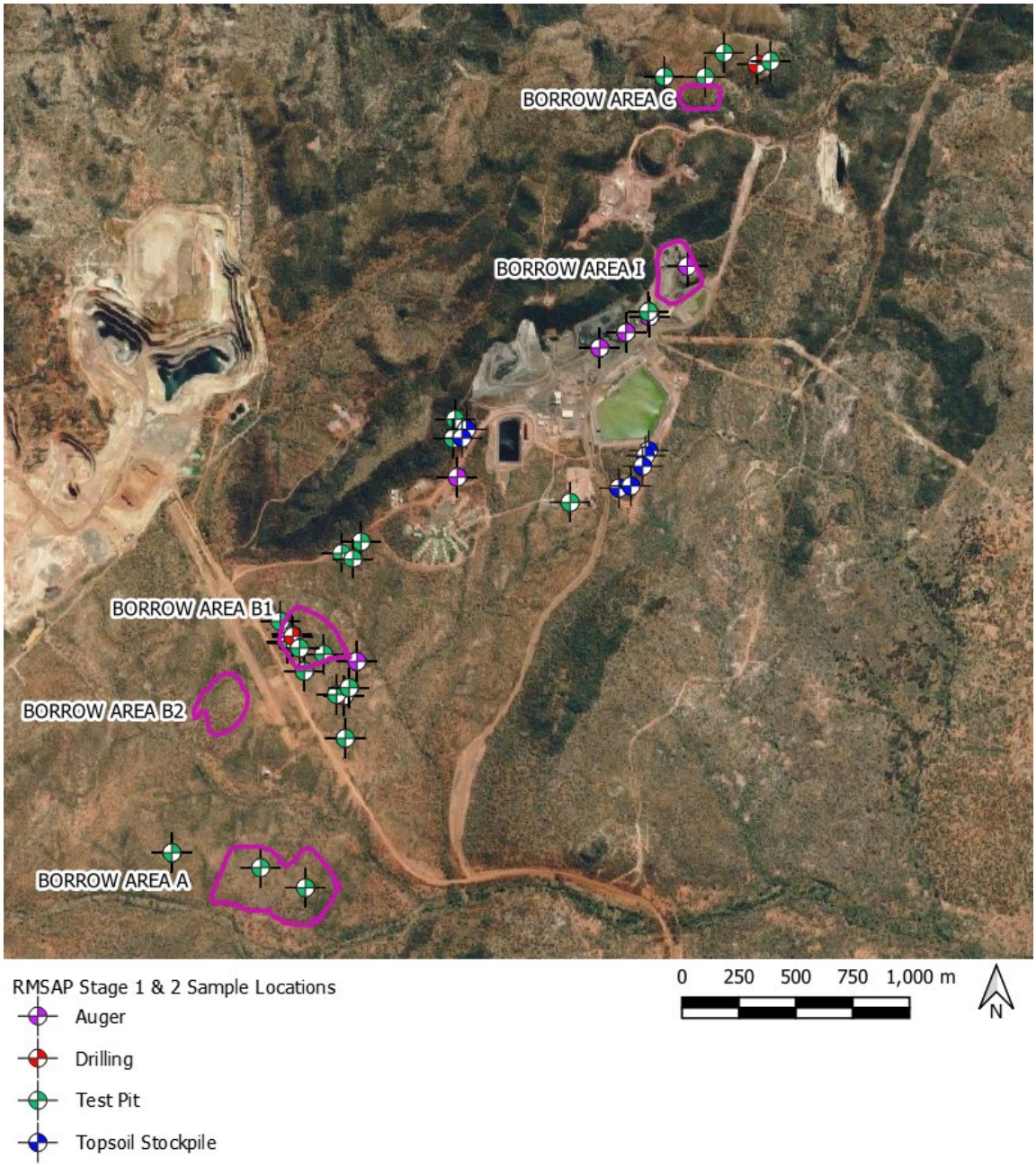
Material Type	Material Application	Required Qualities
Rocky Soil Mulch	Infiltration Storage Layer (ISL) on plateau	• Be Non-Acid Forming • Not prone to generating neutral/saline drainage • Exhibit suitable moisture holding capacity • Exhibit suitable nutrition characteristics to support vegetation growth (or amelioration/treatment, as required) • Non-dispersive (or treated dispersive soils) / non sodic
Rocky Soil Mulch	Reduced Permeability Layer (NAF Rind)	• Be Non-Acid Forming • Form a low permeable layer when compacted to specification requirements
Competent Rock	Rock Armour (NAF Rind)	• Be Non-Acid Forming • High strength and durable • Mix of boulders and smaller particles

4.2.3 Borrow Areas

The RGS Phase 2 works involved an investigation of borrow areas and included revised borrow material volumes and material balances. Based on Phase 1 and 2 works, the optional borrow sites are presented in **MAP 7** (RGS, 2023). Borrow Area A, B1 or B2 (as single borrow sites) and borrow area C will meet the required material types, qualities and volumes (rocky soil mulch and rock armour respectively) to construct the WRE cover system. Borrow Area I, whilst containing suitable rocky soil mulch will only achieve approximately half of the required volumes for the WRE. It is noted not all borrow areas are required to meet material demands.

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MAP 7: OPTIONAL BORROW AREAS AND INVESTIGATION LOCATIONS



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RGS undertook various geotechnical and geochemical testing on cover soils. Relevant to this investigation are the geotechnical parameters used in Vadose modelling (refer **Section 5**). Relevant data is summarised in the following sections.

These geotechnical parameters describe engineering properties for soils used to evaluate moisture movement and storage within the cover system materials. Soil water characteristic curves describe the unsaturated flow characteristics, permeability describes how water flows through the material pore spaces and Atterberg Limits describe the critical water contents of fine-grained soils as they transform from solids to liquids and how the material may behave under load.

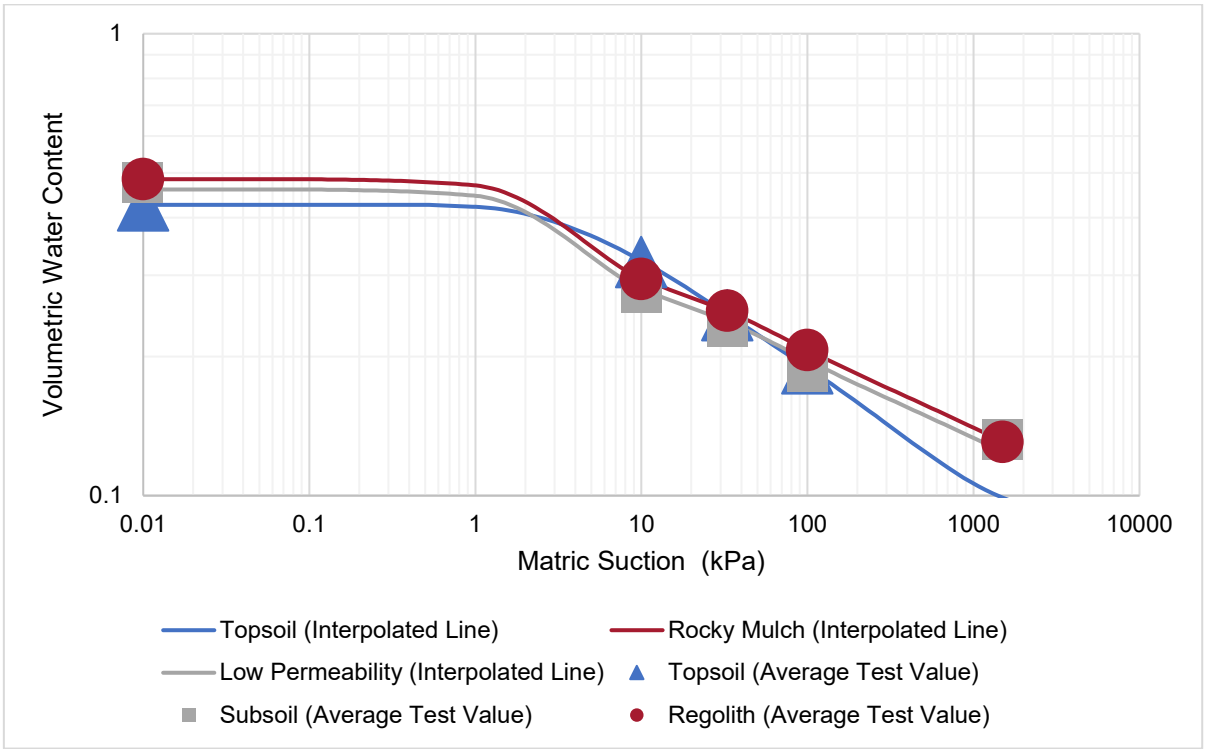
4.2.4 Soil Water Characteristic Curves

A soil-water characteristic (SWC) curve describes the amount of water retained in a soil (expressed as volumetric water content or VWC) under equilibrium at a given matric potential and is used to predict soil water storage. The matric potential is the potential energy of water that is attributed to the attraction of the soil matrix to water, or the capillary and adsorptive forces; i.e. the "suction" pressure or the matric pressure. The matric potential decreases as the VWC increases and the soil becomes saturated. Matric suction is the pressure dry soil exerts on the surrounding soils to equalise the moisture content in the overall soil mass and is defined as the difference between pore water pressure and pore air pressure. In short, the higher the matric suction, the drier the material.

Topsoil, Subsoil and Regolith (Saprolite) were tested for soil water characteristics. A total of 9 samples were tested during Phase 1 works, three each from the topsoil, subsoil and regolith. A further 15 samples were tested during Phase 2. Available data at the time of writing this report included both Phase 1 and Phase 2 results.

The volumetric water content was tested at 0, 10, 33, 100 and 1,500 kpa as plotted in **GRAPH 1** below. For the purposes of modelling, a line was interpolated within the data points, also shown in **GRAPH 1**. With reference to the pressures tested in the soil water characteristic curve, 33 kpa is considered the field capacity, with 1,500kpa being the permanent wilting point. The amount of water available to plants is the difference between the field capacity and the wilting point.

GRAPH 1: SOIL WATER CHARACTERISTIC CURVES



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4.2.5 Permeability

Composite samples (topsoil, subsoil and regolith) within the preliminary borrow sites were tested for permeability as summarised in **TABLE 7**. Permeability was tested at 95% and 90% standard compaction. Whilst it is recognised that low permeability is desirable to limit infiltration, increased compaction will be detrimental to plants. Therefore 90% compaction is assumed for the final cover on the plateau, recognising that some compaction will occur from spreading plant. Compaction of the rocky mulch on the batters would be undertaken to reduce permeability. The required permeability for the batters would be determined in the detailed design phase.

TABLE 7: COVER SOILS: PERMEABILITY TEST RESULTS

Area	Constant Head Method (m/s)		Falling Head (m/s)	
	k_{sat} 95%	k_{sat} 90%	k_{sat} 95%	k_{sat} 90%
Borrow Area A	3.7×10^{-9}	2.9×10^{-5}	2.7×10^{-8}	7.3×10^{-8}
Borrow Area B	1.1×10^{-9}	1.2×10^{-5}	1.6×10^{-9}	8.5×10^{-9}
Borrow Area I	Not tested		1.9×10^{-9} 5.6×10^{-9}	

4.2.6 Atterberg Limits

Atterberg Limits were undertaken for samples from Borrow areas A and B. Test results are shown in **TABLE 8**.

TABLE 8: COVER SOILS: ATTERBERG LIMITS

Parameter	Borrow B				Borrow I	
	Topsoil	Topsoil	Subsoil	Subsoil	Topsoil	Subsoil
Liquid Limit (%)	25	28	31	39	26	29
Plastic Limit (%)	11	10	13	11	18	13
Plasticity Index (%)	14	18	18	28	8	16
Linear Shrinkage (%)	7	8	7	11	2	8
Parameter	**Borrow A**			**Borrow B**		
	Topsoil	**Subsoil**	**Regolith**	**Topsoil**	**Subsoil**	**Regolith**
Liquid Limit (%)	22	30	30	22	29	31
Plastic Limit (%)	16	15	19	15	15	20
Plasticity Index (%)	6	15	11	7	14	11
Linear Shrinkage (%)	2	5.5	3.5	2	6	3.5

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5 VADOSE MODELLING

5.1 Overview

Modelling has been undertaken to assess the performance of cover systems identified. The performance Cover options A, B and D (refer **Section 3.4.1**) has been assessed against the closure objectives discussed in **Section 3.2**, with key outputs and performance criteria summarized as follows:

Water Balance:	The fate of rainfall being lost through surface water runoff, evaporation or infiltrating into the cover system.
Plant Available Moisture:	Available moisture within the cover profile to support vegetation growth
Flux:	The movement of moisture though the cover profile, in both directions:
Downward flux:	Infiltration through the cover system into the waste rock, potentially reporting as seepage or to groundwater.
Upward flux:	Upwards migration of moisture through drying of surface layers and capillary action. Potentially transporting contaminants upwards into cover soils.

Modelling was undertaken with SEEP/W, a computer-based, finite element package used for numerical modelling of saturated and unsaturated flow within soils. Model results include climatic inputs such as rainfall and evaporation, with the balance reporting as net infiltration through the model profile.

Modelling was undertaken using a one-dimensional column through the proposed cover system profile extending 20 metres into the waste rock profile. A daily time step was modelled for a 10-year period with climatic data sourced from a SILO data drill.

The batters were not modelled noting the following:

- The total cover depth of NAF material over PAF waste rock is in the order of 2.1m (vertical thickness). This depth limits the risk of infiltration and deep percolation into waste rock.
- Due to the steep batters (1V:2.5H), high runoff rates would be expected with limited infiltration into cover soils.
- Rates of capillary rise are expected to be negligible due to the low moisture content of waste rock.
- Waste rock will be compacted further limiting the risk of moisture ingress and achieving required geotechnical factors of safety (as discussed in **Section** Error! Reference source not found.).

5.2 Model Development

5.2.1 Boundary Conditions

The geometric configuration of the model comprises a 1-dimensional column, comprised of 20m of waste rock overlain by the cover system. It is recognised that the thickness of the waste rock exceeds 20m however model results indicate climatic factors are not observed at the base of the 20m. Therefore, modelling additional material would have no impact on the outcome of the model, with 20m being modelled.

Other boundary conditions are outlined as follows:

Climatic Conditions:	Applied to the surface of cover system. Further detail is provided in **Section 5.2.4**.
Initial Gradient (free drainage):	Applied at the base of the model to allow seepage from the model. Seepage rates are calculated assuming the downward flux is equal to the hydraulic conductivity at that point.

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Vegetation was not included in the modelling. It is recognised that vegetation will form an important component of the final cover system on the plateau; however, for the purpose of modelling, exclusion of vegetation will achieve conservative outcomes by ignoring moisture losses through evapotranspiration effects.

It is noted that the model comprises a 1-dimensional column and does not account for surface texture which may result in over estimating surface water runoff. Notwithstanding, this limitation is addressed by adjusting material parameters as discussed in later sections.

5.2.2 Model Scenarios

Based on the options assessment discussed in **Section 3.5**, three cover systems were modelled. The capillary break was modelled as the DES default cover profile for high-risk structures. Two store and release covers with varying thickness of the infiltration storage layer (ISL) were modelled in addition to the BGM. Each of these cover systems were modelled under average (50th percentile), dry (10th percentile) and wet (90th percentile) climatic conditions. A total of 12 scenarios were therefore modelled as summarised in **TABLE 9**.

TABLE 9: VADOSE MODEL SCENARIOS

Option		10th Percentile Rainfall	50th Percentile Rainfall	90th Percentile Rainfall
Capillary Break	DES Default	✓	✓	✓
Store and Release	1.5m ISL	✓	✓	✓
	2m ISL	✓	✓	✓
BGM	1.5m ISL	✓	✓	✓
Scenarios				**12**

5.2.3 Soil-Water Characteristic Curves

Model inputs for the hydraulic characteristics of soils comprise the volumetric water content and matric suction curve (soil water characteristic curve) in addition to the hydraulic conductivity vs water content (permeability curve).

Material characteristics were generally adopted from laboratory testing (refer **Section 4**) except for Topsoil. The final surface of the capped WRE (surface of the Rocky Mulch) would be loose and hummocked, as a result, runoff would be minimal. Due to inability to model surface texture, initial model runs with material properties for Lady Loretta soils indicated high runoff rates. As a result, the hydraulic conductivity of the top 0.1m of rocky mulch was increased to promote infiltration and more accurately represent the water infiltration characteristics of a hummocked final surface. This increased permeability layer was modelled for all cover options to reduce runoff.

The volumetric water content curves were adopted as follows:

Topsoil: Typical curve adopted for silty sand (refer above)

Rocky Mulch (ISL): Average values for the saprolite regolith from borrow areas A and B. This material will comprise a mixture of saprolite material, NAF rock as well as topsoil and subsoil layers. It is recognised that the NAF rock would have some impact on the hydraulic characteristics however limitations on soil particle size for the soil water characteristic curve (SWCC) means that it would not be possible to test the mixed rocky mulch. Notwithstanding, the magnitude of change not expected to be material to the outcomes of this investigation and as such the SWCCs for the saprolite are considered suitable for this study.

Low Permeability (RPL): Average values for subsoil (generally containing higher fraction of clay) adopted from the RGS 2021 Investigation

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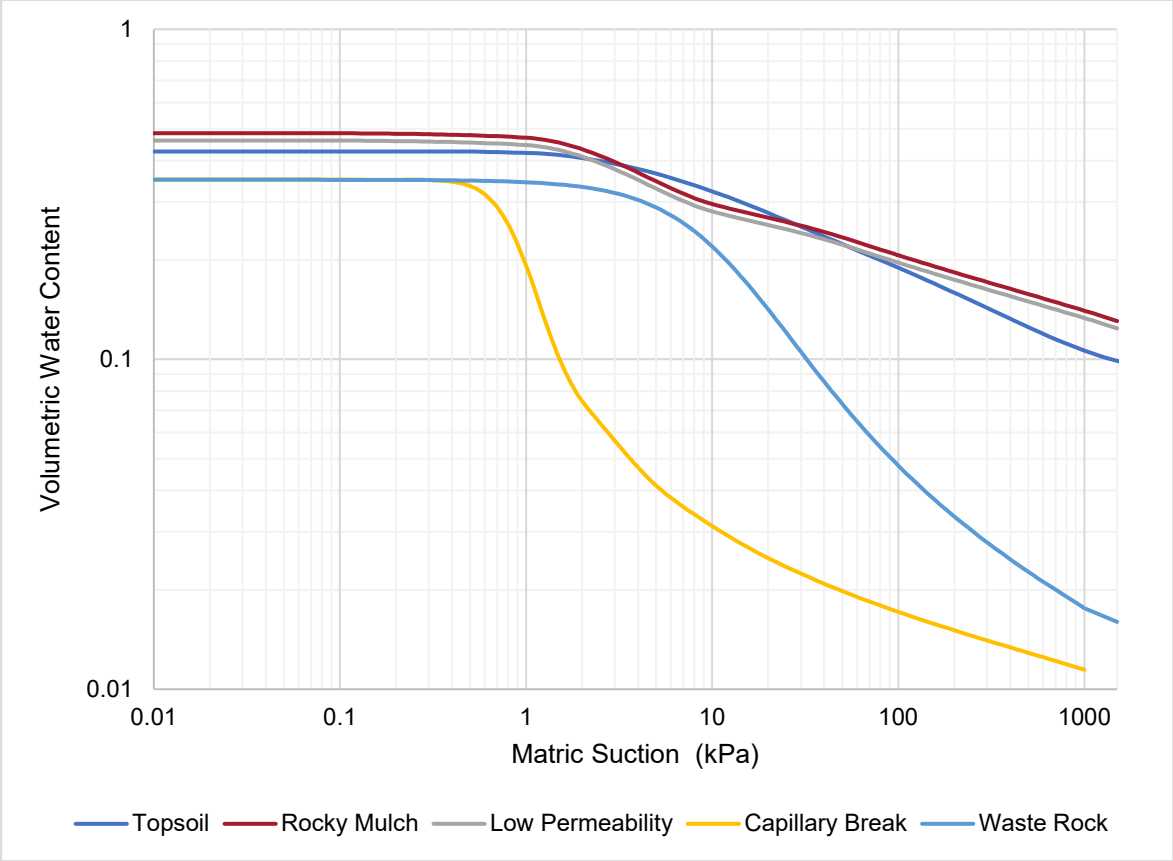
Capillary Break: Samples of the capillary break were not available at the time of writing this report as this material would be crushed and screened on site when required. As such, Seep/W default curves for gravel were adopted.

Waste Rock: The soil water characteristic curves were not determined for the waste rock. It is understood there are limitations in particle size with the laboratory, making the testing of rocky material difficult. Parameters were therefore estimated using geotechnical test data from ATCW (2020).

The permeability curves were estimated using Seep/W's inbuilt Van Genuchten model, using the soil water characteristic curves discussed above.

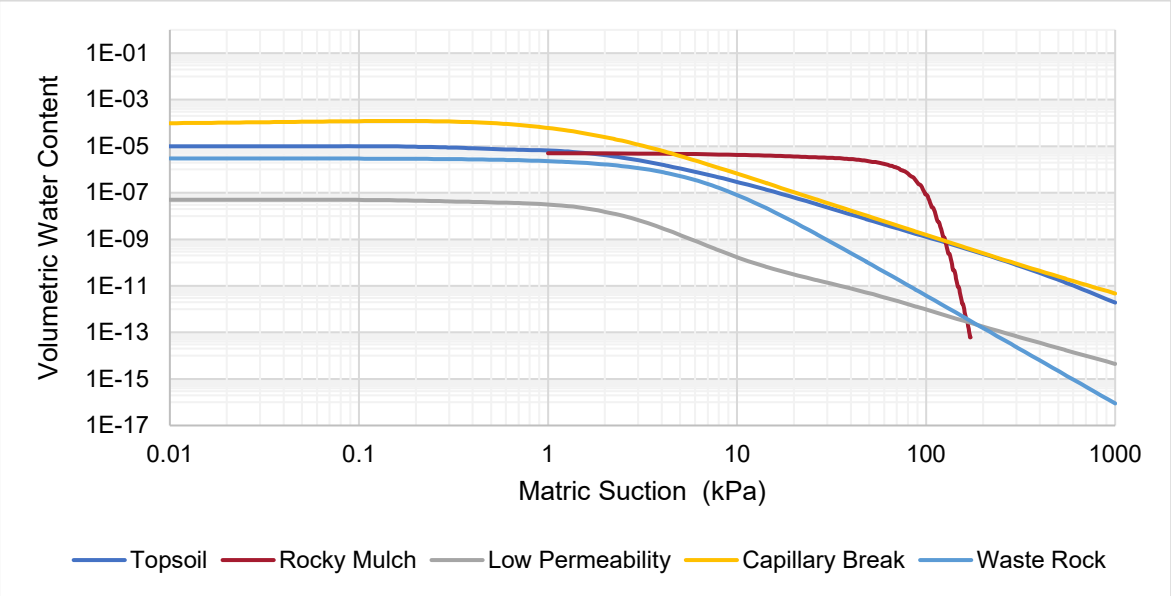
Generated soil water characteristics curves and permeability curves are depicted in **GRAPH 2** and **GRAPH 3** respectively.

GRAPH 2: SOIL WATER CHARACTERISTIC CURVES



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GRAPH 3: PERMEABILITY CURVE



5.2.4 Climate Data

Climatic data was sourced from a SILO Data Drill as outlined in **Section 2.2**. Three climate scenarios were assessed for each of the cover options, to simulate wet, dry and average rainfall conditions. Each of the climate scenarios were adopted by ranking annual rainfall depths from 1889 to 2020 in 10-year periods. These are shown in **TABLE 10**.

TABLE 10: CLIMATIC DATA SETS ADOPTED

Rainfall Years	Percentile	Total 10-year Rainfall Depth
July 1979 to July 1989	9th percentile (closest 10-year period to 10th percentile	3,774 mm
July 2010 to July 2020	55th (closest 10-year period to 50th percentile)	4,714 mm
July 1968 to July 1978	89th percentile (closest 10-year period to 90th percentile	5,635 mm

Other climatic data required for the model, adopted from the SILO Data Drill are summarised as follows:

- Humidity (daily maximum and minimums)
- Radiation (total daily)
- Temperature (daily maximum and minimums)

5.3 Results

5.3.1 Overview

The performance of each cover system has been assessed against the closure objectives discussed in **Section 3.2**. Results are depicted in **GRAPH 4** to **GRAPH 15**, with the significance of results summarised as follows:

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Water Balance

The water balance shows cumulative balance of moisture within the modelled profile. Results which form part of the water balance are:

Rainfall: Rainfall depth occurring for the modelled period

Runoff: Rainfall runoff not infiltrating into the cover system, reporting as surface water runoff to report off the WRE structure.

Evaporation: Evaporation loss from the cover profile

Net infiltration: The balance of rainfall (input) runoff and runoff (subtracting from the rainfall depth).

Volumetric Water Content

The volumetric water content gives an indication of the plant available moisture. Between 33kpa (field capacity) and 1,500kPa (permanent wilting point) moisture is available for uptake from plants. Above the wilting point, the porewater pressure no longer allows for uptake of moisture from plants.

The volumetric water content results are based on average climatic conditions. The wet and dry conditions are not plotted however it is noted that the outcomes for these scenarios were not materially different.

Flux

Moisture flux gives an indication of the direction and rate of movement of moisture within the cover profile. Values are reported at the base of the cover system and the top of the waste rock. An objective of the cover system is to minimise downward flux at the interface of the cover system with excess flux potentially contributing to seepage reporting at the base of the structure.

Upwards flux with moisture transferring from the waste rock into the cover system has the potential to transport contaminants within the waste rock to the surface. The adopted cover system should therefore minimise flux at the interface between the cover system and the waste rock in both directions.

5.3.2 Cover A – Capillary Break

Model results (refer **TABLE 11**) indicate 9% and 14% of the rainfall reports as runoff for the dry and average rainfall conditions respectively. The runoff rate for the wet conditions is higher at around 34%, with higher intensity rainfall events producing more runoff compared to model scenarios with lower rainfall. The net infiltration for the dry and average scenarios is less than zero, meaning all rainfall infiltrating the cover system is lost through evaporation. The net infiltration for the wet scenario is slightly greater than zero due to a large rainfall event at the end of the model. Based on similar, high rainfall events occurring throughout the modelled period, it is likely this volume (around 0.3m) would be lost through evaporation within the following year.

TABLE 11: WATER BALANCE – CAPILLARY BREAK

Parameter	10th percentile	50th percentile	90th percentile
Runoff	-9%	-14%	-34%
Net Infiltration	-5%	-3%	4%
Evaporation	-91%	-86%	-70%

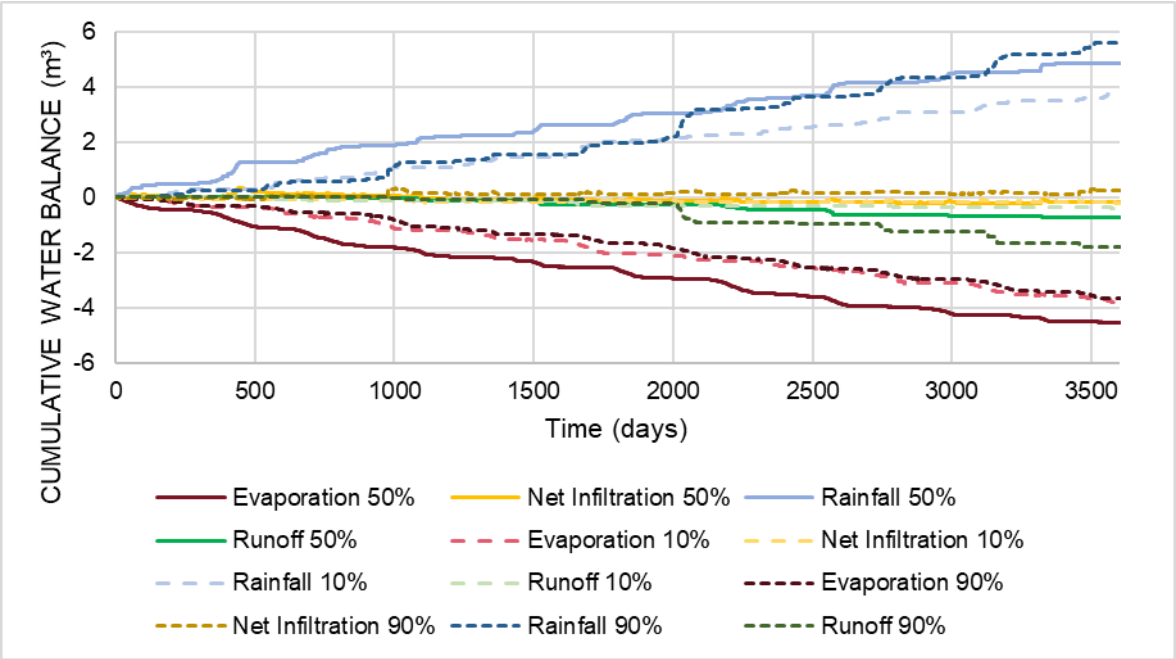
Note: values do not necessarily add up to 100% due to initial moisture conditions

Plant available moisture near the surface is seasonally available following rainfall. Subsequent evaporation losses reduce the water content below the wilting point during the dry season. Due to the initial porewater pressure conditions in the model, the initial water content is high at 0.5m depth and at the base of the rocky mulch. Throughout the model period however, the plant available moisture reduces and does not exceed the wilting point again. The implications of low moisture are discussed further in **Section 5.3.6**.

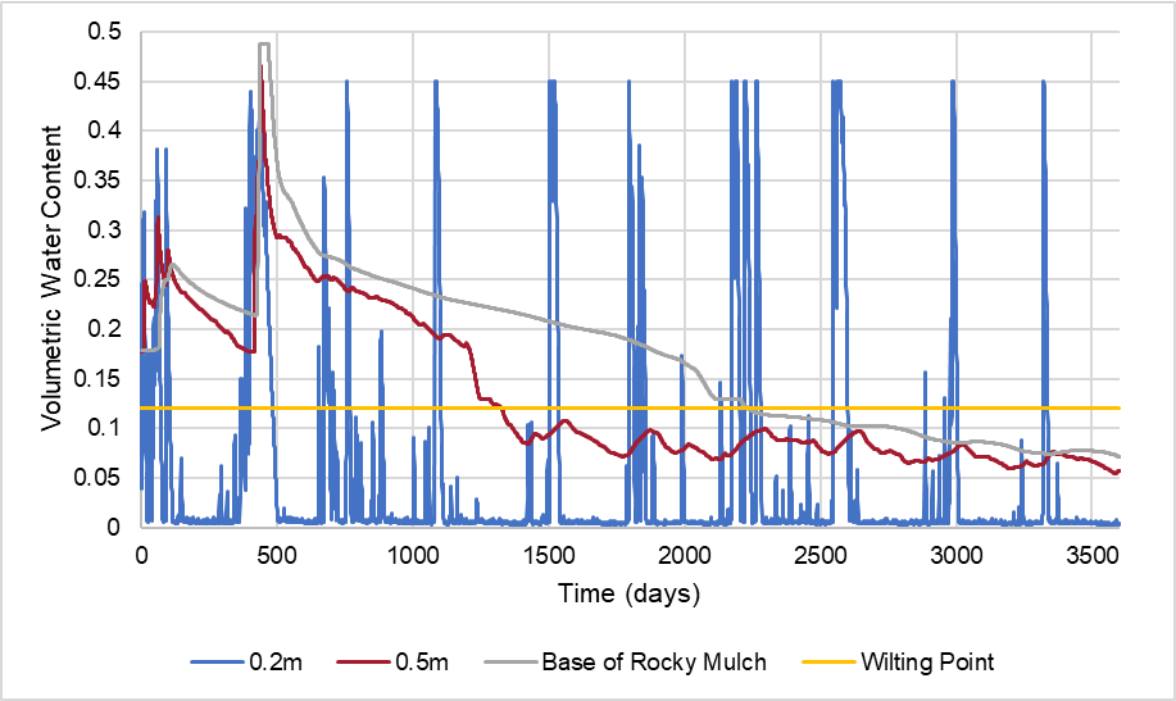
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Model results indicate zero flux through the base of the cover system into the waste rock, similarly no upward flux is measured.

GRAPH 4: CAPILLARY BREAK: WATER BALANCE

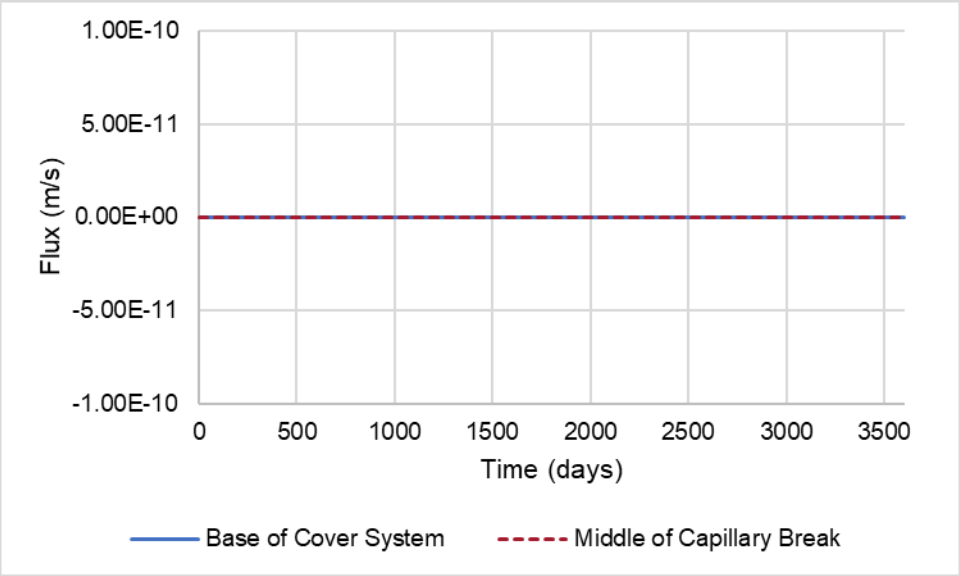


GRAPH 5: CAPILLARY BREAK: VOLUMETRIC WATER CONTENT (50TH PERCENTILE)



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GRAPH 6: CAPILLARY BREAK: FLUX THROUGH COVER SYSTEM (50TH PERCENTILE)



5.3.3 Cover B – BGM

Model results (refer **TABLE 12**) indicate approximately 35.9% and 35.6% of the rainfall reports as runoff for the dry and average rainfall conditions respectively. The runoff rate for the wet conditions is significantly higher at around 58%, with more frequent, higher intensity rainfall events producing more runoff than is generated for model scenarios with lower rainfall. The net infiltration for all scenarios is less than zero, meaning all rainfall infiltration is lost through evaporation rather than seeping through the model profile. The evaporative losses as a percentage of total rainfall are high for the dry and average scenarios (around 69 and 66% respectively), with a lower percentage for the wet scenario (44%). It is noted that the total evaporation depth for each scenario is similar, with the difference in percentage due to the higher rainfall depth of the wet scenario.

TABLE 12: WATER BALANCE – BGM

Parameter	10th percentile	50th percentile	90th percentile
Runoff	-36%	-36%	-58%
Net Infiltration	-5%	-2%	-2%
Evaporation	-69%	-66%	-44%

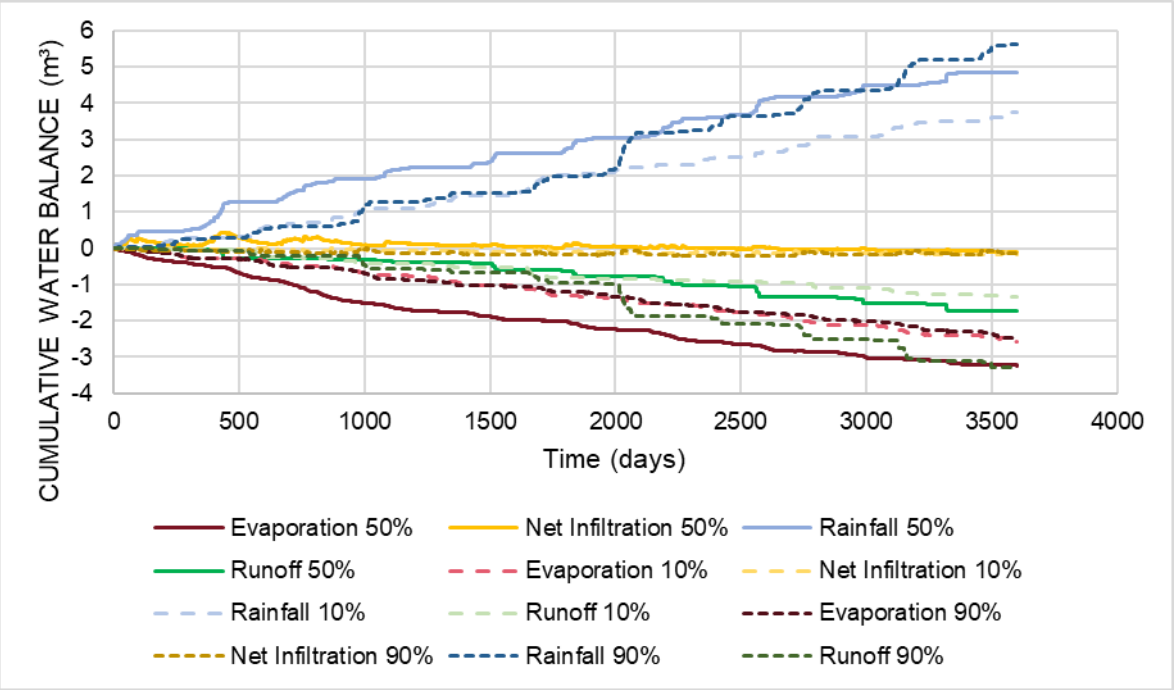
Note: values do not necessarily add up to 100% due to initial moisture conditions

Plant available moisture near the surface is seasonally available following rainfall. Subsequent evaporation losses reduce the water content below the wilting point during the dry season. Due to the initial porewater pressure conditions in the model, the initial water content is high at 0.5m depth and at the base of the rocky mulch. Throughout the model period however, the plant available moisture reduces and does not exceed the wilting point again within the modelled period. The implications of low moisture are discussed further in **Section 5.3.6**.

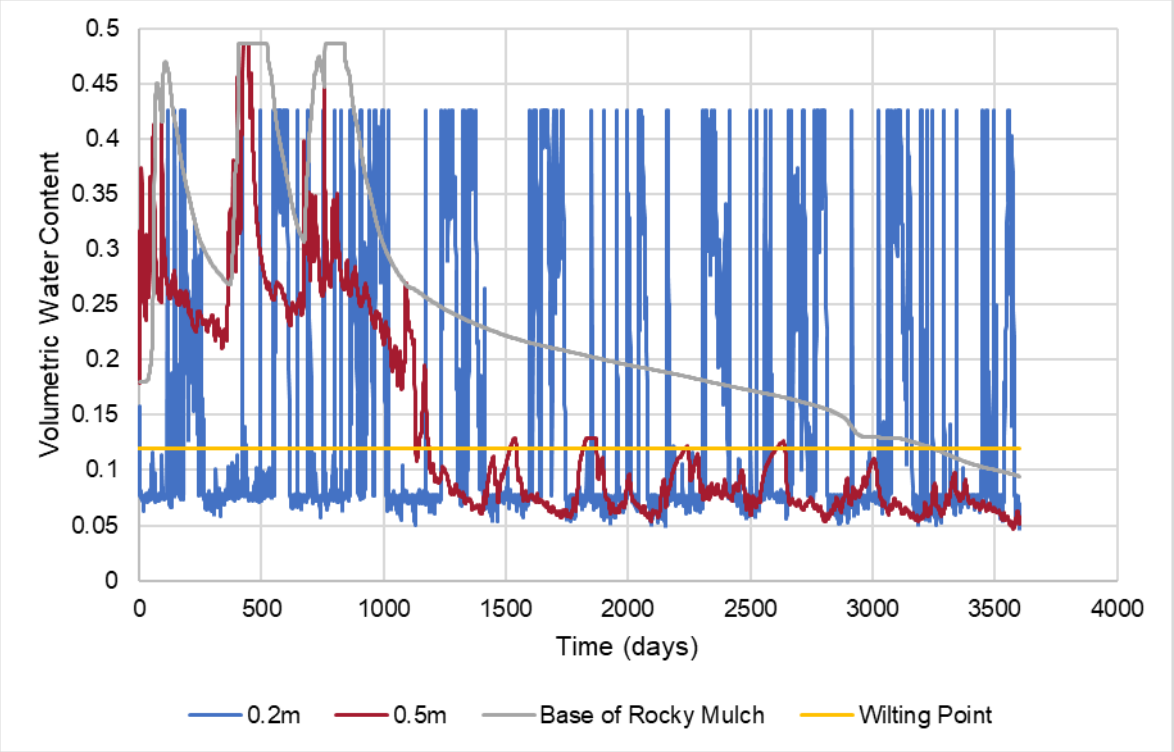
Model results indicate zero flux through the base of the cover system into the waste rock, similarly no upward flux is measured.

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GRAPH 7: BGM: WATER BALANCE

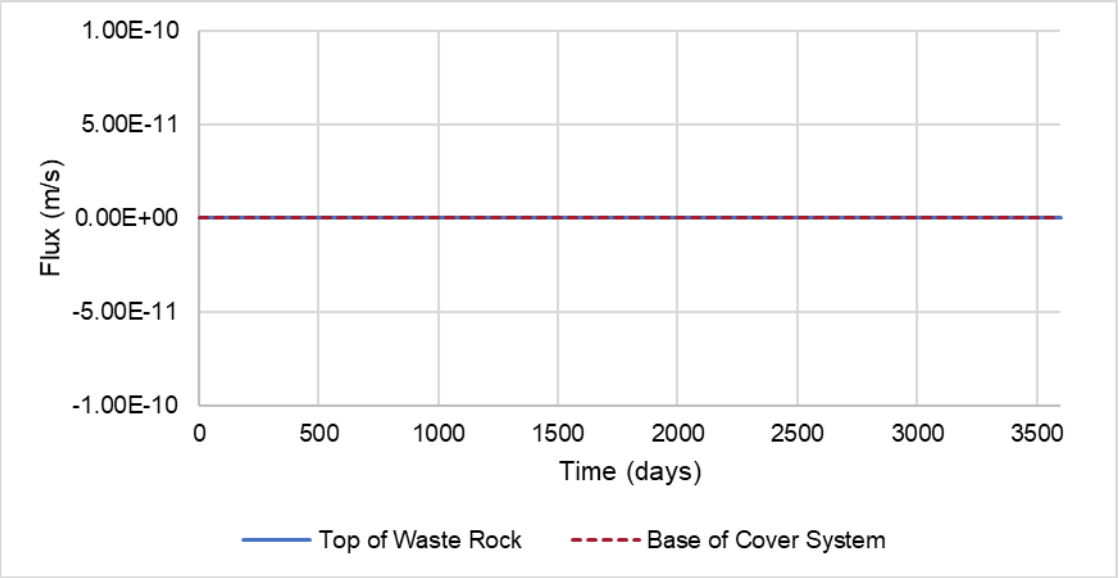


GRAPH 8: BGM: VOLUMETRIC WATER CONTENT (50TH PERCENTILE)



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GRAPH 9: BGM: FLUX THROUGH COVER SYSTEM (50TH PERCENTILE)



5.3.4 Cover D1 – Store and Release Cover – 1.5m Rocky Mulch)

Model results (refer **TABLE 13**) indicate some 12% and 14% of the rainfall reports as runoff for the dry and average rainfall conditions respectively. The runoff rate for the wet conditions is significantly higher at around 40%, with more frequent, higher intensity rainfall events producing more runoff than is generated for model scenarios with lower rainfall. The net infiltration for all scenarios is low meaning the majority of all rainfall infiltration is lost through evaporation rather than seeping through the model profile. The evaporative losses as a percentage of total rainfall are high for the dry and average scenarios (around 80%), with a lower percentage for the wet scenario. It is noted that the total evaporation depth for each scenario is similar, with the difference in percentage due to the higher rainfall depth of the wet scenario.

TABLE 13: WATER BALANCE – STORE AND RELEASE COVER (1.5M ROCKY MULCH)

Parameter	10th percentile	50th percentile	90th percentile
Runoff	-12%	-14%	-40%
Net Infiltration	-6%	1%	-1%
Evaporation	-82%	-86%	-58%

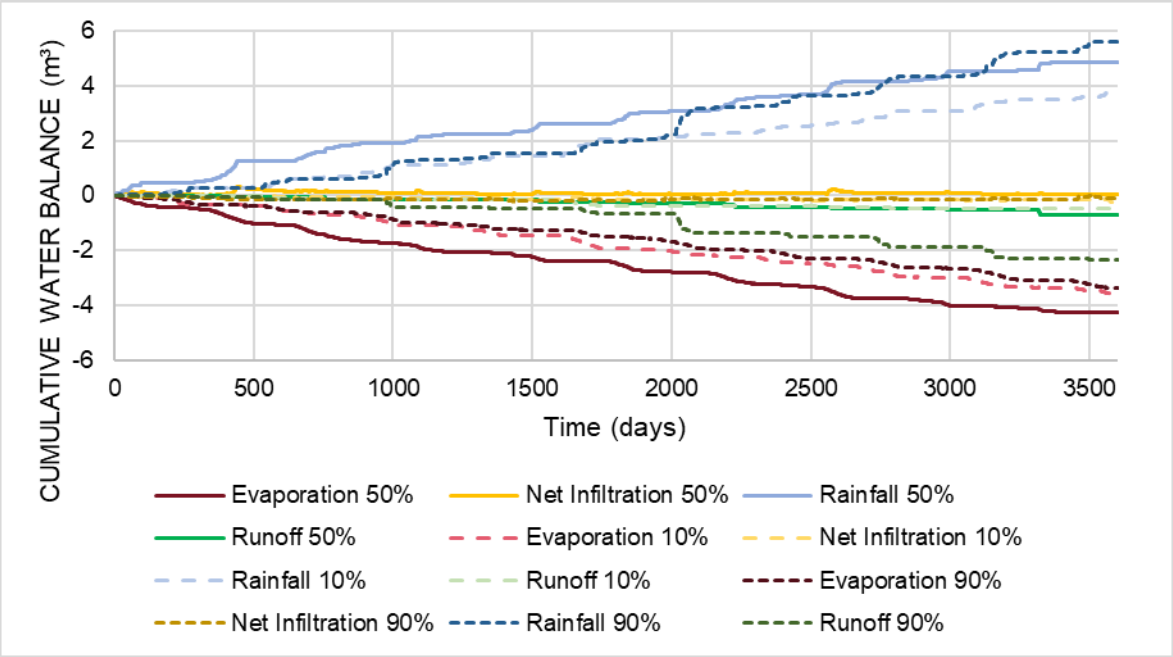
Note: values do not necessarily add up to 100% due to initial moisture conditions

Plant available moisture near the surface is seasonally available following rainfall. Subsequent evaporation losses reduce the water content below the wilting point during the dry season. Due to the initial porewater pressure conditions in the model, the initial water content is high at 0.5m depth and at the base of the rocky mulch. Throughout the model period however, the plant available moisture reduces and does not exceed the wilting point again within the modelled period. The implications of low moisture are discussed further in **Section 5.3.6**.

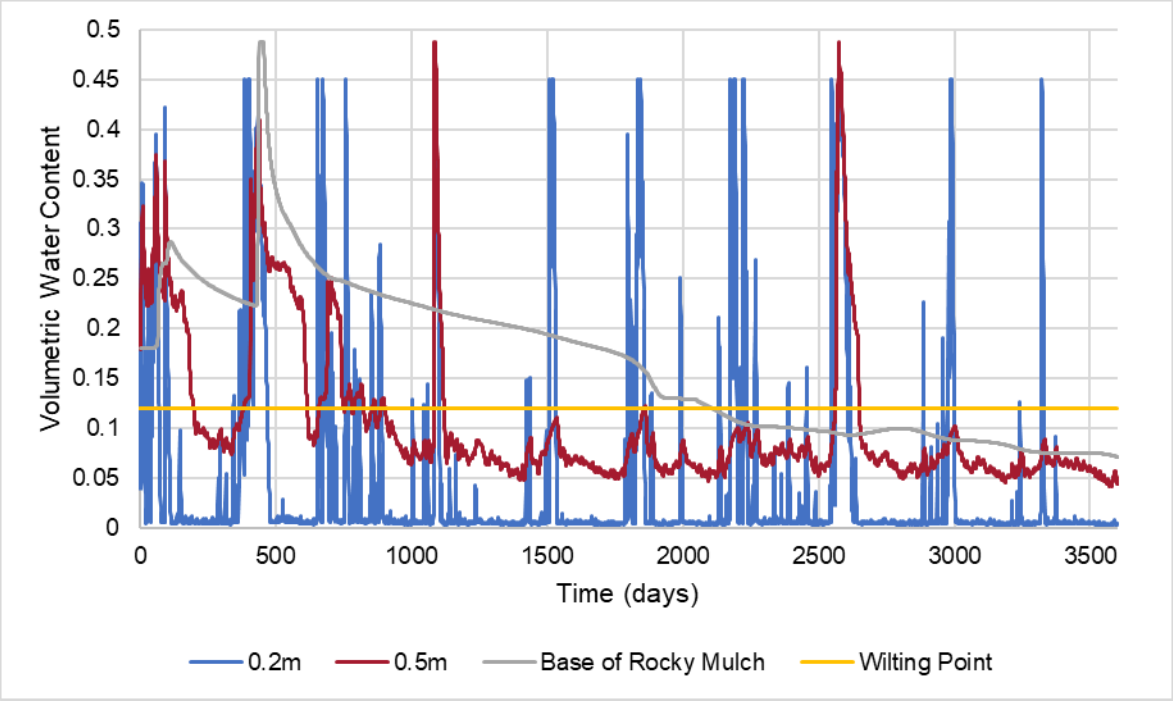
Initially infiltration through the cover system into the waste rock occurs (negative flux), corresponding to high rainfall events. The infiltration occurs at the beginning of the model period where the initial moisture content within the modelled period may impact these results. Towards the end of the modelled period, model results indicate a positive flux, meaning moisture from the waste rock transfers to the cover profile. The positive flux occurs at low rates (around 5 x 10^{-11} m/s).

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GRAPH 10: STORE AND RELEASE 1.5M: WATER BALANCE

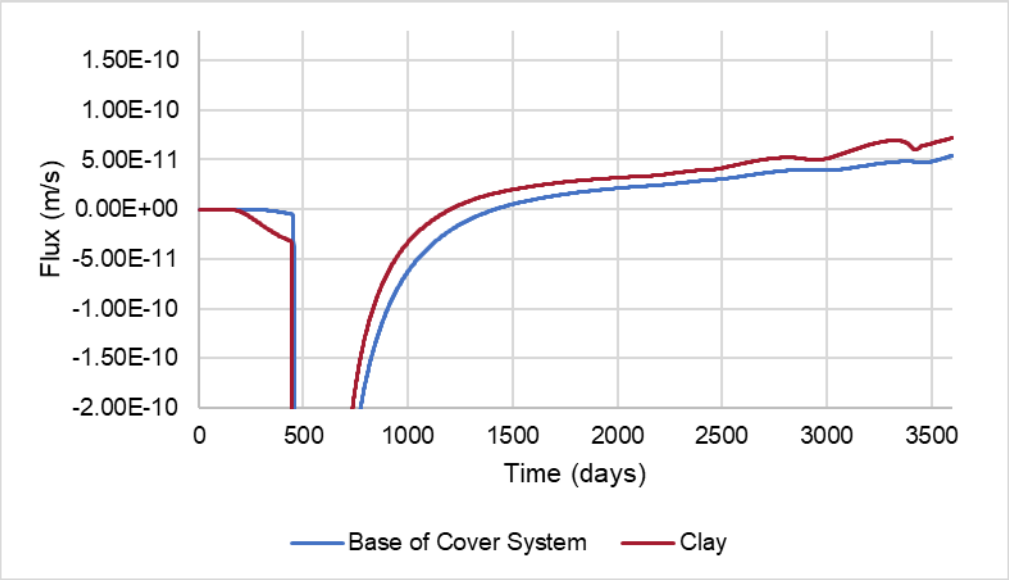


GRAPH 11: STORE AND RELEASE 1.5M: VOLUMETRIC WATER CONTENT (50TH PERCENTILE)



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GRAPH 12: STORE AND RELEASE 1.5M: FLUX THROUGH COVER SYSTEM (50TH PERCENTILE)



5.3.5 Cover D2 – Store and Release Cover (2m Rocky Mulch)

Model results (refer **TABLE 14**) indicate approximately 9% and 17% of the rainfall reports as runoff for the dry and average rainfall conditions respectively. The runoff rate for the wet conditions is significantly higher at around 38%, with more frequent, higher intensity rainfall events producing more runoff than is generated for model scenarios with lower rainfall. The net infiltration is minimal for all scenarios is meaning the majority of all rainfall infiltration is lost through evaporation rather than seeping through the model profile. The evaporative losses as a percentage of total rainfall are high for the dry and average scenarios (around 85% to 78%), with a lower percentage for the wet scenario (62%). It is noted that the total evaporation depth for each scenario is similar, with the difference in percentage due to the higher rainfall depth of the wet scenario.

TABLE 14: WATER BALANCE – STORE AND RELEASE COVER (2M ROCKY MULCH)

Parameter	10th percentile	50th percentile	90th percentile
Runoff	-9%	-17%	-38%
Net Infiltration	-6%	-5%	1%
Evaporation	-85%	-78%	-62%

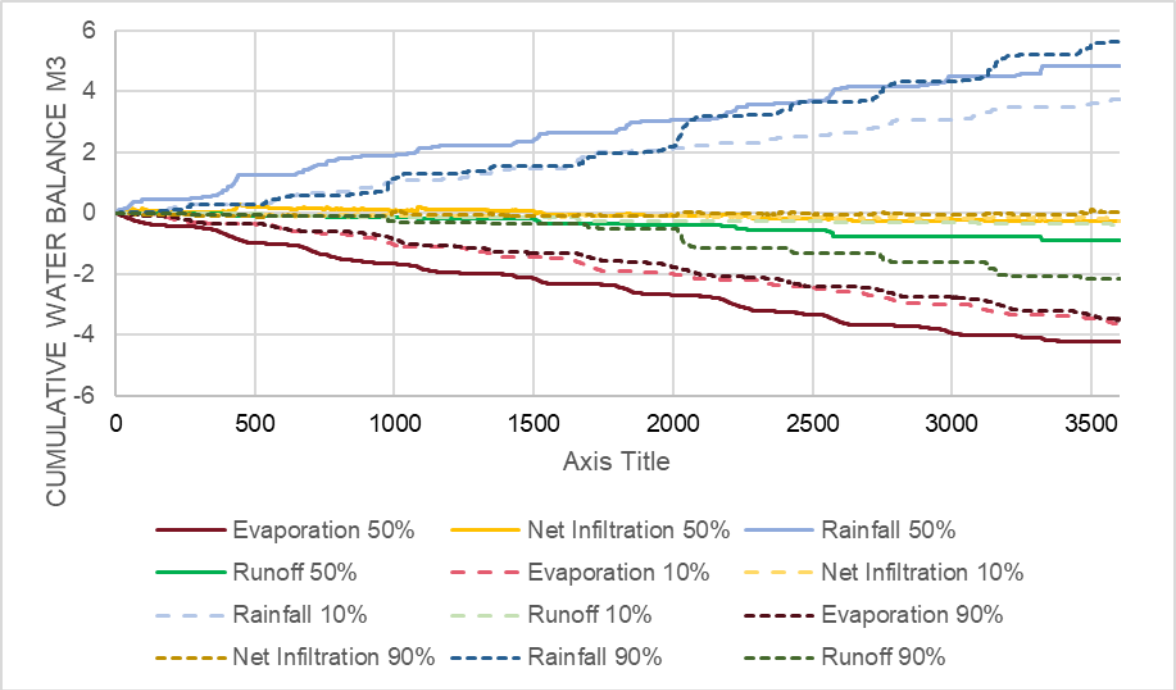
Note: values do not necessarily add up to 100% due to initial moisture conditions

Plant available moisture near the surface is seasonally available following rainfall. Subsequent evaporation losses reduce the water content below the wilting point during the dry season. Due to the initial porewater pressure conditions in the model, the initial water content is high at 0.5m depth and at the base of the rocky mulch. Throughout the model period however, the plant available moisture reduces and does not exceed the wilting point again within the modelled period. The implications of low moisture are discussed further in **Section 5.3.6**.

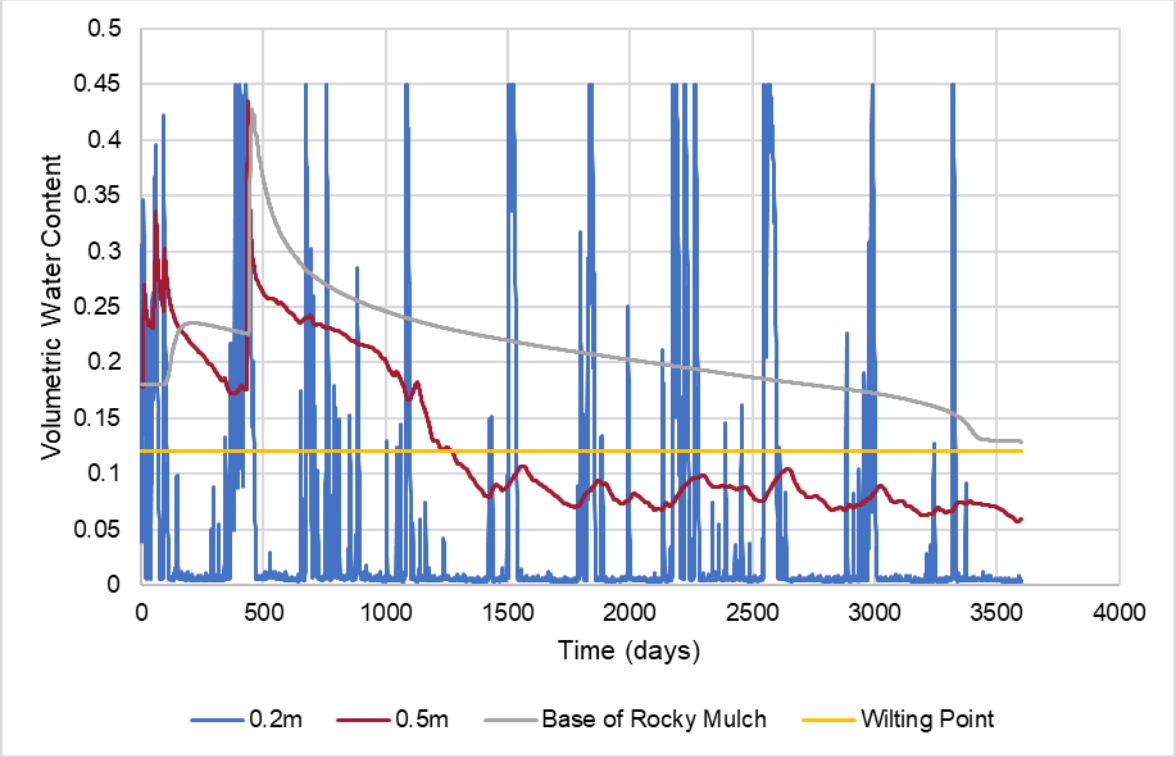
Initially infiltration through the cover system into the waste rock occurs (negative flux), corresponding to high rainfall events. The infiltration occurs at the beginning of the model period where the initial moisture content within the modelled period may impact these results. Towards the end of the modelled period, model results indicate a positive flux, meaning moisture from the waste rock transfers to the cover profile. The positive flux occurs at low rates (around $1x10^{-11}$ m/s).

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GRAPH 13: STORE AND RELEASE 2M: WATER BALANCE

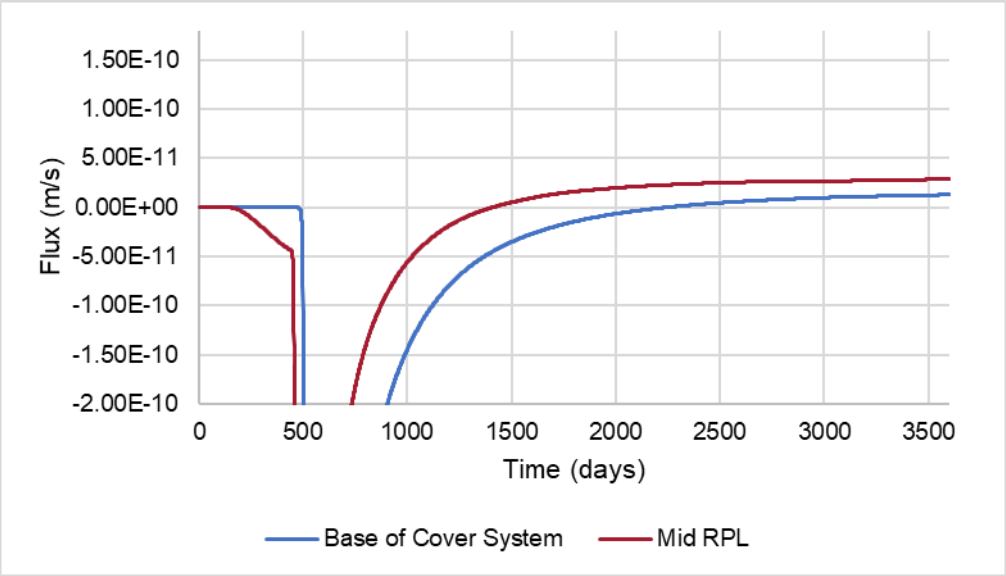


GRAPH 14: STORE AND RELEASE 2M: VOLUMETRIC WATER CONTENT (50TH PERCENTILE)



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GRAPH 15: STORE AND RELEASE 2M: FLUX THROUGH COVER SYSTEM (50TH PERCENTILE)



5.3.6 Summary of Results

The performance of all cover systems with respect to the water balance is similar. Owing to the regional climate conditions, being low in rainfall and high in evaporation, for all cover options most of the rainfall infiltrating the cover system is lost through evaporation. This outcome is favourable for preventing seepage though the cover system; however, is less favourable for plant growth.

For all scenarios, moisture for plant growth in the surface (<300mm) is available for some time (ranging from days to months depending on the rainfall depth) after rainfall however with subsequent evaporation, surface layers dry out. The impacts of rainfall are greatest at the surface with reduced impact at 0.5m depth, with the majority of moisture evaporated prior to reaching this depth. Moisture at the base of the rocky mulch is not impacted by individual rainfall events and controlled by the moisture contained within the entire cover profile.

The moisture throughout the cover profile is generally low (below wilting point, corresponding to a volumetric water content of 0.12) due to low rainfall conditions. Notwithstanding, the conditions observed are expected to be similar to that of background environmental conditions, suitable for native vegetation endemic to this area.

Model results indicate capillary rise is possible for the store and release cover system, irrespective of the depth for the ISL. This is likely observed due to the high fines content of the waste rock retaining moisture and allowing for capillary rise. No capillary rise is observed for the capillary break layer or the BGM liner system with the capillary break performing as per the design intent and the BGM providing a hydraulic barrier sufficient to prevent moisture transmission.

TABLE 15 provides a summary of results, compared to closure objectives discussed in **Section3.2**.

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TABLE 15: PERFORMANCE OF COVER OPTIONS SUMMARY

Cover Option	Prevents seepage into waste rock	Provides Plant Available Moisture	Prevents Capillary Rise
Cover A Capillary Break	Yes	Average	Yes
Cover B BGM	Yes	Average	Yes
Cover D1 Store and Release Cover 1.5m Depth	Yes	Average	Marginal
Cover D2 Store and Release Cover 2m Depth	Yes	Average	Marginal

In reference to the conclusions drawn in the above table, the following is noted:

- All cover system options minimise infiltration into the waste rock. This is observed in the following results:
  - Net infiltration is generally zero or negative. For the scenarios with positive net infiltration this is a result of a rainfall event occurring during the end of the modelled period. This moisture is held within the cover soils (rather than the waste rock) and would evaporate in the following days.
  - Flux measured at the base of the cover system is near zero. Negative flux (indicating infiltration) was not observed as a response to rainfall, indicating moisture is stored within cover soils prior to being evaporated.
- For all scenarios, Plant Available Moisture (PAM) is seasonally available. It is highlighted that this is related to the regional climate, where annual rainfall is typically low. It is expected that plant available moisture in the cover system would be similar to natural soil profiles around the site, where during the wet season vegetation growth would occur followed by natural die back during the dry season. The modelled performance of all cover systems with respect to plant available moisture was similar.
- The Capillary Break and BGM cover systems prevent capillary rise with no positive flux rates observed in model results. Some positive flux rates are observed in the store and release cover systems, however these rates low (in the order of 1e-11m/s). A 'Marginal' classification is given acknowledging that whilst these results are extremely low, cover systems did not prevent capillary rise altogether.

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6 ADOPTED CONFIGURATION AND SCHEDULE OF QUANTITIES

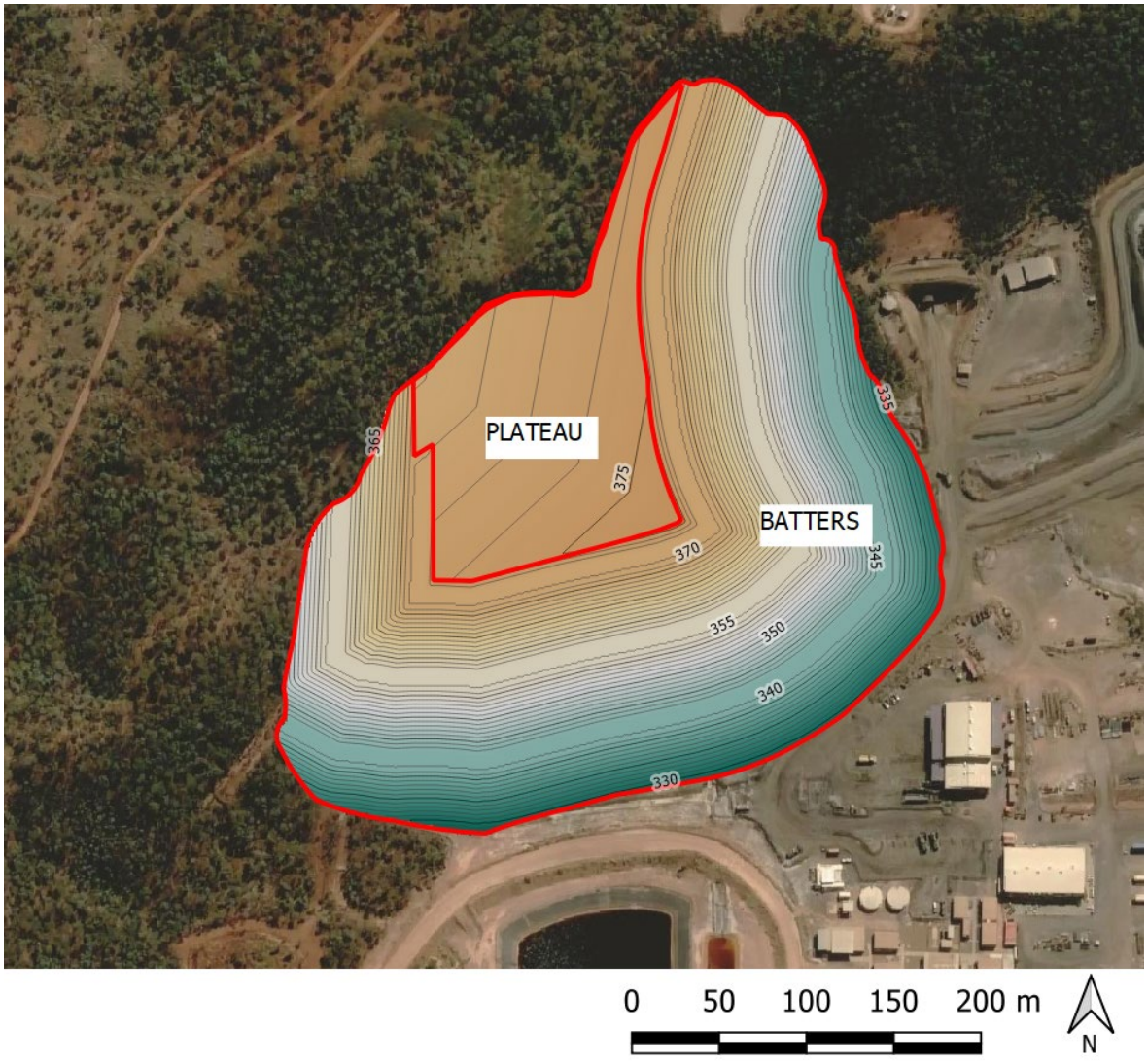
Based on available information, modelling undertaken and discussions with LLM, the preferred closure configuration for the WRE is as follows:

Landform: Landform 2 comprising reshaping of the WRE landform and constructing a NAF Rind.

Cover System: Cover B comprising BGM liner overlain by 1.5m of rocky mulch.

A schedule of quantities is provided in **TABLE 16** based on the adopted final conceptual landform configuration shown in **MAP 8**.

MAP 8: PLATEAU AND BATTER AREAS



Areas used for volume estimates are as follows:

Plateau Area: 1.7 ha

NAF Rind Area: 9.01 ha

It its noted that the areas shown are slope areas. The total plan area of the landform is 10.4ha (slope area 10.71ha).

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TABLE 16: SCHEDULE OF QUANTITIES

Item	Element	Quantity[1]
NAF Rind	Compacted PAF Waste Rock (1.2m vertical depth over entire batter area)	100,000 m³
	Compacted Rocky Soil Mulch (1.2m vertical depth over entire batter area)	100,000 m³
	Rock Armour (0.9m vertical depth over entire batter area including benches), this layer includes a geotextile underlay	76,000 m³
Plateau	BGM (Installed over total plateau area) [2]	21,000 m²
	Rocky Soil Mulch (1.5m (minimum) depth over entire plateau area) [3]	42,000 m³

Notes:

1. All quantities in LCM and have been rounded to the nearest 1,000m² or 1,000m³
2. 10% contingency included for overlapping and wastage.
3. Conservatively includes 0.3 m subgrade and liner protection layers above and below the BGM liner. Detailed design will confirm if these additional protection layers are required for the BGM. Rocky Mulch layer will be graded at 1% towards a central drain, shaped convexly towards the extremities to increase the cap thickness to a minimum depth of 2 m.

6.1 Post Closure Water Management

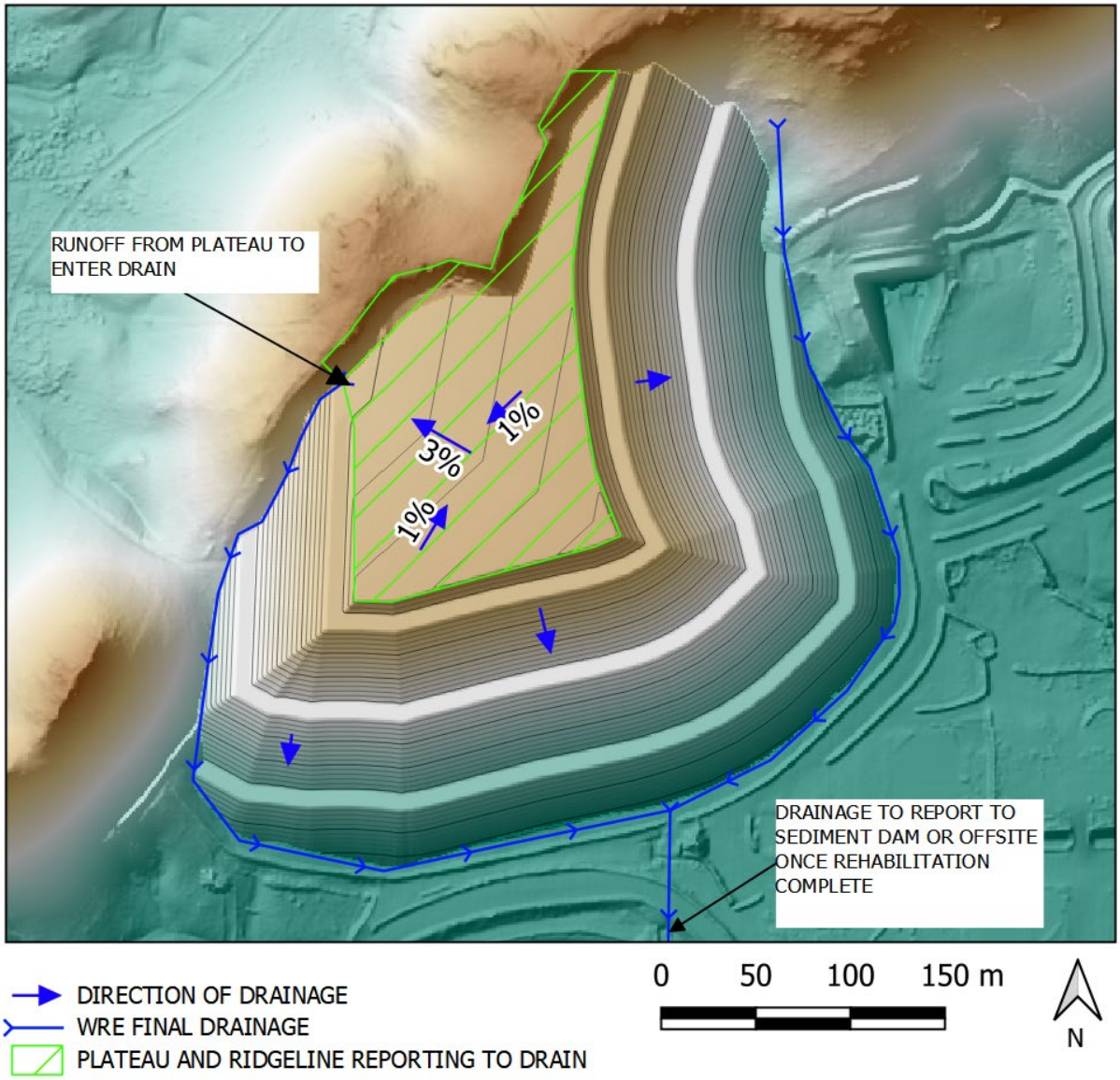
The post-closure water management objective for the final landform is to divert surface water runoff from the structure without causing undue erosion and scouring. The general arrangement for final drainage of the WRE is shown in **MAP 9**.

Batters will be rock lined and resistant to erosion, as discussed in **Section 8**. To avoid areas of concentrated flow, no internal drains are proposed for the batters, with rainfall runoff reporting downslope to the toe. A perimeter drain at the toe will divert clean water runoff off site, once it is demonstrated runoff meets contaminant release criteria defined in the EA.

The final grade of the plateau will facilitate drainage towards the centre of the structure at 1%. A central drain grades south-east to north-west to a central drain. At the outlet of the central drain, flows would report to a chute, to divert flows to the toe of the WRE. The chute would be excavated into natural sequences. Based on observations at site, it is assumed that the base of the drain would comprise rock. Any local areas of unsuitable material (soil, etc.) would be removed and replaced with appropriate rock armouring.

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MAP 9: FINAL DRAINAGE



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7 STABILITY ANALYSIS

7.1 Preface

As outlined in **Section 3.4.4**, the preferred WRE configuration comprises steepened batters, maximising the plateau area. To meet the design objective of maximising the plateau area, stability modelling was undertaken to determine the maximum batter slope which would meet the minimum required factors of safety.

7.2 Basis of Design

7.2.1 Australian Guidelines Documentation

Industry standards and guidelines defining design criteria and minimum factors of safety are generally targeted at water and tailings dams. Notwithstanding, as design standards generally adopt a risk-based approach to minimum factors of safety and seismic design criteria, they are considered suitable for the WRE design.

Criteria for engineering of the LLM WRE are based on the following key references:

- DES, 2016. Manual for Assessing Consequence Categories and Hydraulic Performance of Structures.
- ANCOLD, 2019. Guidelines on Tailings Dams- Planning, Design, Construction, Operation and Closure – Revision 1 (July 2019).
- ANCOLD, 2019. Guidelines for Design of Dams and Appurtenant Structures for Earthquake (May 2019).

7.2.2 Stability Design Criteria

Design of the WRE landform has been undertaken in accordance with the ANCOLD (2019) guidelines. Minimum Factors of Safety (FoS) to be achieved for the WRE landform are summarised in **TABLE 17**.

TABLE 17: ANCOLD RECOMMENDED MINIMUM SLOPE STABILITY FACTORS OF SAFETY

Loading Condition	Minimum FoS	Shear Strength Criteria
Long-term drained	1.50	Effective Strength
Short-term drained (potential loss of containment)	1.50	Consolidated Undrained Strength
Post-Seismic	1.10 (Range between 1.0 and 1.2)	Post Seismic Shear Strength*

As summarised above, the minimum recommended FoS for the post-seismic loading condition ranges between 1.0 and 1.2. ANCOLD (2019) recommends this range to be related to the confidence in the adopted residual shear strength values, where 1.0 may be adequate for use with lower bound results. ATCW adopted a value of 1.1 for this analysis based on the limited geotechnical data (residual shear strength values) for existing materials.

7.2.3 Earthquake/Seismic Criteria

The Operating Basis Earthquake (OBE) and Safety Evaluation Earthquake (SEE) scenarios require an earthquake ground acceleration to be applied to the WRE profile. For the purposed of the assessment the design criteria in **TABLE 18** have been adopted including the interpreted PGA coefficients adopted.

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TABLE 18: SEISMIC LOADING DESIGN CRITERIA

Design Scenario	Design Criteria (AEP)	Peak Ground Acceleration (PGA)
OBE	1 in 1,000	0.06
SEE	1 in 10,000	0.25

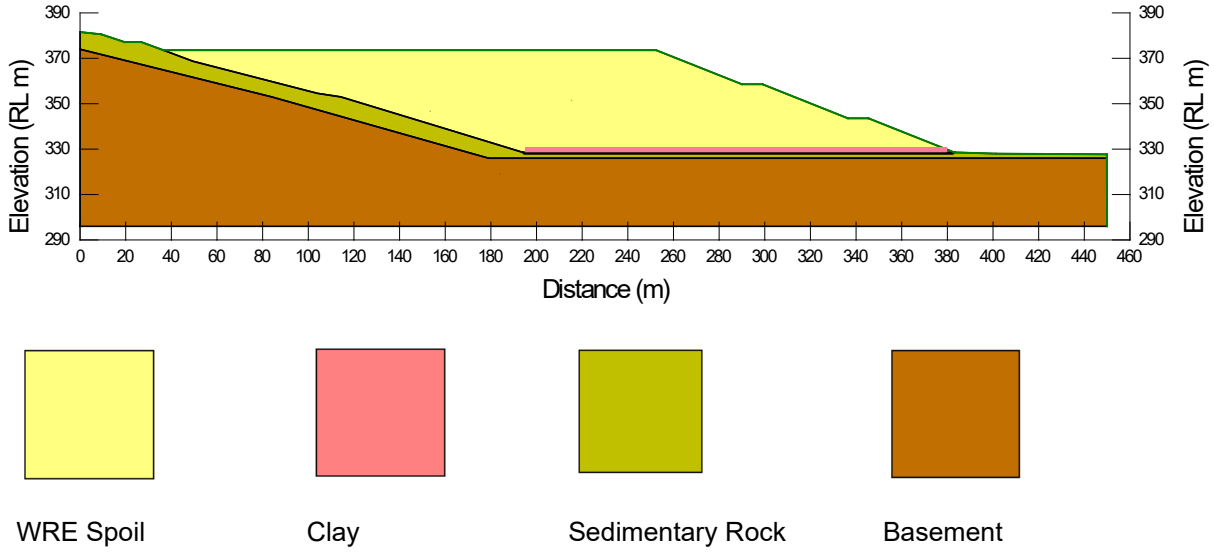
Peak ground accelerations (PGA) for the site were from the following seismic map sources:

- (Leonard, M., Burbidge, D. and Edwards, M. 2013). Atlas of seismic hazard maps of Australia: seismic hazard maps, hazard curves and hazard spectra. Record 2013/41. Geoscience Australia: Canberra.
- Burbidge, D.R. (ed.), 2012. The 2012 Australian Earthquake Hazard Map. Record 2012/71. Geoscience Australia: Canberra.
- Australia, G., 2020. Interactive Maps. [online] Maps.ga.gov.au. Available at: <http://maps.ga.gov.au/interactive-maps/#/theme/hazards/map/earthquakehazards> [Accessed 20 July 2021]

7.3 WRE Geometric Configuration

The Geometric configuration for modelling is as shown in **DIAGRAM 12**.

DIAGRAM 12: WRE CONFIGURATION



7.4 Slope Stability Analysis

7.4.1 General

The slope stability analysis was performed using the software SLOPE/W, developed by GeoSlope International Inc. SLOPE/W is a two-dimensional computer program that performs slope stability computations using limit equilibrium methods. The Morgenstern-Price method (Morgenstern and Price, 1965) with a half-sine function for interslice forces was selected for performing the computations in SLOPE/W. The method uses both circular and non-circular shear surfaces and satisfies both moment and force equilibrium.

Various stability controlling failure modes and loading conditions are considered for the WRE. The analysis cases and target design factors of safety for various conditions are discussed in **Section 7.2.2.** The analysis considers various phreatic surfaces using drawn phreatic surfaces using

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the pore water pressure (PWP) conditions from piezometric surfaces option within Slope/W. Stability evaluations are completed for potential downstream (DS), failures to the toe/foundations for varying conditions upon completion of the WRE landform.

Slip surfaces were defined using the entry/exit method. This method has been set to evaluate the impact of failures initiating along the slope or crest of the WRE external face and extending into the foundation materials. This is considered consistent with ANCOLD recommendations to select critical failure surfaces that would cause significant damage should failure occur (ANCOLD, 2019) **[2].**

7.4.2 Material Properties

As shown in Diagram 12, four material types were considered for the stability analysis, including the waste material, in addition to foundation sequences. The source of material properties for each of the material types is as follows:

Waste Rock: In lieu of test results, inference of material strength for the waste rock was based on the Simmons et al. (2004), whereby based on a series of case histories of dumped spoil slopes to categorise waste rock materials and provide shear strength design parameters for varying conditions. These categories are as illustrated in **TABLE 19** and **DIAGRAM 13.**

Clay: Inferred from general classification test work (permeability, particle size distribution, Atterberg limits) undertaken for the WRE expansion (ATCW, 2020).

Sedimentary Rock: Conservative values adopted based on test pit logs from the WRE expansion (ATCW, 2020).

Basement: Assumed to be impenetrable.

Recognising some parameters are assumed from published values or inferred, sensitivity cases were included to verify outcomes of the assessment. Details of sensitivity cases included are summarised as follows:

Sensitivity Case 1 (SC1): Strength parameters reduced by 20% for the waste rock for the seismic analysis to assess the impact of lower strengths of the waste to the factor of safety.

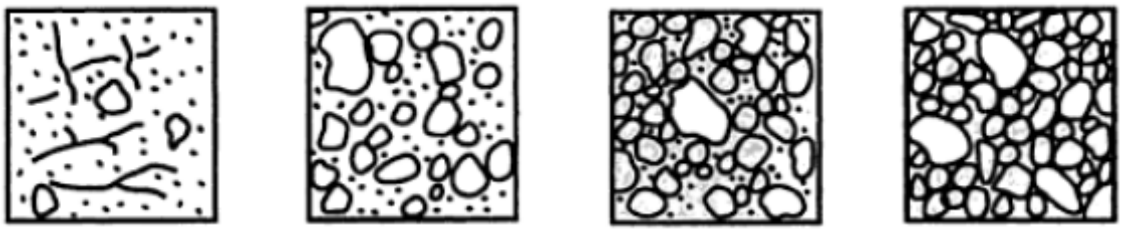
Sensitivity Case 2 (SC2): Assumes a higher phreatic surface, and therefore saturated conditions for the waste at the base of the WRE. This scenario accounts for any entrained water in the WRE accumulating at the base, potentially leading to a saturated zone. The phreatic surface adopted is appears conservative.

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TABLE 19: SPOIL CATEGORIES AND ATTRIBUTES

Category		1	2	3	4
Description Attributes	**Weighting (excl. Age)**	**Fine-grained clay-rich high plasticity**	**Fine-grained low plasticity with larger clasts**	**Larger clasts with fine matrix, low plasticity**	**Large blocks, minor fines, minor slaking**
Predominant Particle Size	3/31 = 9.7% (11.6%)	Clay	Sand	Gravel	Cobbles
Consistency: cohesive cohesionless	7/31 = 22.6% (26.9%)	Soft to Firm Loose	Stiff Med. Dense	Hard Dense	XLS+ rock Very Dense
Structure	7/31 = 22.6% (26.9%)	Matrix Only	Matrix Supported	Framework supported	Framework only
Liquid Limit	9/31 = 29.0% (34.6%)	High (>50)	Intermediate (35-50)	Low (20-35)	Not Plastic (<20)
Age	5/31 = 16.1%	0-2y	2-10y	10-30y	>30y
Note: XLS+ rock refers to rock of extremely low strength, or higher					

DIAGRAM 13: SPOIL STRUCTURE CONTROL RANKING (USE WITH TABLE 19)



Category 1 – Matrix Only **Category 2 – Matrix supported** **Category 3 – Framework supported** **Category 4 – Framework only**

Given the variability quality of the waste rock and laboratory testing including the PSD and Falling-Head permeability testing (refer **Section 4.1**), Category 2 is the inferred best fit for the waste rock conditions and is considered appropriate for the onsite material.

Based on the above, the following design parameters were adopted as shown in **TABLE 20** (Simmons et. al).

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TABLE 20: STRENGTH PARAMETERS FOR CATEGORIES AND MOBILISED MODES

Category	Unsaturated			Saturated			Remoulded Parameters
	γ (kN/m³)	c' (kPa)	ϕ'(deg)	γ (kN/m³)	c' (kPa)	ϕ'(deg)	c' = 0 kPa, ϕ'(deg)
1	18	20	25	20	0	18	18
2	**18**	**30**	**28**	**20**	**15**	**23**	**18**
3	18	50	30	20	20	25	18
4	18	50	35	20	0	30	28

Note: Category 2 is the adopted parameters for this assessment.

The strength parameters used in the slope stability review are as shown in **TABLE 21**.

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TABLE 21: MATERIAL STRENGTH PARAMETERS

Layer Description	Saturated Parameters			Saturated Parameters					Post-Seismic Parameters				
	Bulk Density, γ (kN/m³)	Cohesion, c' (kPa)	Friction Angle, φ (°)	Bulk Density, γ (kN/m³)	Cohesion, c' (kPa)	Friction Angle, φ (°)	Undrained Shear Strength, S_u (kPa)	SHANSEP (Tau/Sigma)	Bulk Density, γ (kN/m³)	Cohesion, c' (kPa)	Friction Angle, φ (°)	Undrained Shear Strength, S_u (kPa)*	SHANSEP (Tau/Sigma)
Waste Rock	18	30	28	20	15	23	-	-	20	0	18	-	-
Clay	18	2	28	18	-	-	25	0.28	18	-	-	20	0.224
Sedimentary Rock	20	0	32	20	0	32	-	-	20	0	25.6	-	-
Basement	Bedrock (Impenetrable)												

Note: - = not applicable

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7.4.3 Stability Analyses Scenarios

7.4.3.1 Long Term Stability Analysis

This case represents conditions after construction has been completed (nominally to be completed in 2037), and it is assumed that excess pore water pressures (i.e. the difference between measured hydrostatic pressure and equilibrium piezometric pressure) due to construction of the WRE have dissipated and thus no B-bar pressures were applied. Dissipation of piezometric pressure could take between several months to several year to occur and is the result of reduced infiltration of precipitation through the cover following installation.

For this case, three materials characterisation scenarios were considered:

1. Undrained

   In the undrained scenario, undrained strengths were adopted for clay fill, and waste material below the estimated phreatic surface. All undrained strengths were capped at their drained strengths for the reasons described above. This is considered consistent with ANCOLD Guidelines which also note that "*long-term stability analyses must consider all materials that are contractive and generate pore pressures on shearing. These materials should always be modelled in accordance with the Undrained Strength Analysis (USA*)" (ANCOLD, 2019a) **[2]**.

2. Drained

   In the drained scenario, all materials were characterised using drained (effective) strengths. This is considered consistent with ANCOLD Guidelines for "drained" analyses which note that, for this loading condition, all materials are characterised with effective stress drained shear strength.

3. Post-Seismic

   In the post-earthquake scenario, all materials were characterised using large strain shear strengths for the post-seismic loading condition. Cyclically reduced undrained /drained shear strengths have been used as presented in **TABLE 21**. It is assumed that the WRE landform is not liquefiable based on the particle size, limit of moisture content and compaction undertaken during construction.

7.5 Results of Geotechnical Analyses

The results of the slope stability analyses from the cross sections analysed are presented in **TABLE 22.** The figures for reference are as shown in **Appendix A**.

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TABLE 22: SUMMARY OF SLOPE STABILITY FACTORS OF SAFETY

Design Case	Recommended Factor of Safety (FoS)	Achieved Factor of Safety (FoS)	Appendix A Figure Number
Effective Drained - Global	≥1.50	2.04	A1
Effective Drained – Local 1	≥1.50	2.11	A2
Effective Drained – Local 2	≥1.50	2.25	A3
Undrained - Global	≥1.50	1.60	A4
Undrained – Local 1	≥1.50	1.82	A5
Undrained – Local 2	≥1.50	1.98	A6
Post Seismic - Global	≥1.10	1.38	A7
Post Seismic – Global (SC1)	≥1.10	1.19	A8
Post Seismic – Local	≥1.10	1.37	A9
Post Seismic – Local 1 (SC1)	≥1.10	1.21	A10
Post Seismic – Local 2	≥1.10	1.32	A11
Post Seismic – Local 2 (SC1)	≥1.10	1.18	A12
Undrained Global (SC2)	≥1.50	1.50	A13
SC Undrained – Local 1 (SC2)	≥1.50	1.56	A14
SC Undrained – Local 2 (SC2)	≥1.50	1.55	A15

Note: SC refers to Sensitivity Case.

The results indicate that for all loading conditions analysed, the factors of safety are greater than the recommended factors of safety as provided by ANCOLD, 2019 **[2]**.

In addition, the Waste Rock factor of safety was assessed based on the following equation:

$$FoS = \tan(\varphi 1) \,/\, \tan(\varphi 2) \qquad \textbf{[Eq. 1]}$$

Where:

$\varphi 1 = angle\ of\ material\ parameter$

$\varphi 2 = angle\ of\ slope$

The WRE has been designed to a slope of 2.5(H):1(V) and based on a material parameter of 28°, the factor of safety equals 1.52.

7.6 Seismic Deformation

A seismic deformation analysis was undertaken for the WRE, being a requirement of ANCOLD. It is recognised that ANCOLD focus on dams, where seismic deformation has the potential to reduce embankment height and freeboard, potentially leading to failure of the structure through overtopping. In the context of the WRE, the structure is not required to contain water and is therefore not subject to the same failure mechanisms. Notwithstanding, seismic deformation estimates are useful to determine the order of magnitude for potential settlement, and potential impacts to the closure objectives.

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ANCOLD (2019) notes that pseudo-static method as a screening tool for earthquake stability is no longer recommended but rather recommend following a more realistic approach to estimate the deformations due to earthquake shaking. A pseudo-static analysis would only be carried out to compute yield acceleration and assess if the computed pseudo-static factor of safety is less than 1.0 under design earthquakes. To this end, a seismic deformation calculation was undertaken to determine potential deformation.

Seismic displacement of the WRE landform was computed using methods described by Pells & Fell (2002) and Swaisgood (2003) as no probabilistic seismic hazard assessment has been undertaken. The results are as shown in **TABLE 23.**

TABLE 23: SEISMIC DISPLACEMENT RESULTS

Design Event	PGA	Magnitude (Assumed)	Pells & Fell (2002)		Swaisgood (2003) (m)
			LB (m)	UB (m)	
SEE	0.25	7.5	0.095	0.238	0.052

The results in **TABLE 23** illustrate that the seismic displacements of the WRE material calculated using both the Pells & Fell and Swaisgood methods indicated similar amounts of potential deformation.

Generally, the results indicate similar displacements/deformations with the Swaisgood values residing within the lower and upper bounds of the Pells & Fell method. The largest potential deformation from the two methods analysed is 0.238 m. In the context of the final closure objectives, the following commentary is provided:

- As noted above, the seismic analysis has been undertaken being a requirement of ANCOLD, however seismic deformation does not have the same design implications on the WRE which would be relevant to a dam. Notwithstanding, excessive settlement has the potential to impact the performance of the structure, by impacting drainage or impacting the cover system.
- As a percentage of total height the estimated deformation of 0.238m is around 0.5% of the total WRE height.
- Given the magnitude of potential settlement is low, this would not be expected to impact the performance of the cover system or drainage. Notwithstanding, detailed design of the cover system and final landform should confirm that deformation or differential settlement does not have the potential to impact the BGM liner on the plateau, or impact surface water drainage.

7.7 Summary of Stability Analysis

The stability analysis undertaken assesses the proposed final geometry of the WRE against minimum factors of safety to be achieved in accordance with ANCOLD guidelines. Based on the model outcomes, the factors of safety achieved exceed the minimum required values for all scenarios.

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8 EROSION ASSESSMENT

8.1 Plateau

Erosion modelling was undertaken on the proposed final landform using WEPP and SIBERIA. The erosion assessment is reproduced as **Appendix C**.

The Water Erosion Prediction Project (WEPP) is a 2-dimensional erosion simulation model used to predict and calculate estimates of soil detachment and deposition as well as simulation of the hydrologic and erosion processes on small watersheds. The purpose of WEPP modelling is to estimate the soils loss, based on site climate, soil characteristics, expected vegetation conditions and catchment geometry.

SIBERIA is a soil erosion and landform evolution model that can predict type of erosion (that is, sheet wash and/or gullying) and to predict gully initiation and evolution (Hancock and Evans; 2006, 2010; Hancock, Willgoose and Lowry, 2013). Estimated soil loss rates generated using WEPP were input along with other parameters to estimate the severity of erosion and estimate the final landform surface, at defined intervals.

The landform evolution model was undertaken for 1,000 years, with landform outputs generated at the following intervals:

- 100 years
- 200 years
- 500 years
- 1,000 years

Model results indicate expected rates of erosion are unlikely to impact the performance of the cover system. Based on the modelling outcomes, the thickness of the proposed cover system in addition to the proposed geometry is suitable for closure and the closure objectives of 'permanent containment with low rates of erosion is achieved. As detailed in **Appendix C**, whist modelling indicates satisfactory performance of the cover system, the following key factors are critical to the success of the final landform are:

- Avoiding concentrated flow which has generally been achieved by the conceptual final landform design presented in the PRCP.
- The establishment of vegetation through appropriate surface preparation, seeding, and grazing management.
- Monitoring and maintenance of drainage controls and assessment of the causes of localised scour until stability is established.

Erosion modelling is intended to identify the scale erosion on the rehabilitated WRE landform over a prolonged period, to confirm the proposed landform geometry, grades and cover system thickness are suitable.

This model is not intended to provide precise estimates for soil loss rates, particularly over short-duration, high intensity rainfall events. Notwithstanding, the average annual soil loss rates generally account for these events, with the objective of modelling met through establishing estimated long term soil loss rates.

The key model limitations are that soil and vegetation parameters are based on laboratory test results, empirical formulas and published literature. Flume testing (Laboratory erosion testing) could be undertaken at a later project stage, once borrow areas are accessible, to reduce uncertainty and calibrate models with respect to erosion parameters. It is noted that flume testing requires large quantities of soil (more than 1m³), which would need to be prepared in the same way Rocky Mulch will be prepared for construction. Flume testing is not expected to materially chance the outcomes of erosion model results.

8.2 Batters

As described in **Section 3**, steep batters have an increased erosion risk. To reduce this risk, WRE batters will be rock armoured. Objectives of the rockfill are to:

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- Resist gradual degradation and erosion by weathering and transport of fine particles.
- Resist short term erosion and scouring caused by high intensity rainfall bursts.

To achieve the first objective, batters will be rock lined with fresh, competent rock fill which is resistant to weathering. The rock layer will be less prone (compared to a soil) to sheet erosion, whereby fine particles (sand, silt, clay) are gradually detached and transported after successive years of typical rainfall. As the underlying rocky mulch will contain a portion of fines, a geotextile will be placed under the Rock Armour to protect fines from washing out.

High intensity, short duration storm events present the greatest risk to rock armouring, where these rainfall events have the potential to generate high flow rates and steam velocity reporting down the batters. To achieve the section objective, rock sizing has been undertaken to ensure the proposed material can resist flows up to 0.01% AEP.

It is noted that the objective of landform evolution modelling (WEPP and SIBERIA) is to predict the gradual erosion of surfaces through the loss of fine particles, with inbuilt formula based on soils. As such, erosion assessment using these programs for the batters is not appropriate. Instead a hydraulic assessment has been undertaken to determine the required diameter (D50) of the rockfill. The method adopted comprised the Witter at. Al (1990), with the required rock sizing is determined as follows:

$$d_{50} = \frac{1.25 \times SF \times K_1 \times K_2 \times {S_o}^{0.5} \times q^{0.5} \times y^{0.25}}{s_r - 1}$$

D_{50}: Required D_{50} diameter (mm) of rock armouring

K_1: correction factor for rock shape

K_2: correction factor for rock grading

q: flow rate (m^3/s)

s_r: specific gravity of rock (t/m^3)

S_o: bed slope (m/m)

SF: factor of safety

Adopted parameters are provided in **Table 23**.

TABLE 24: ROCK SIZING ADOPTED PARAMETERS

Parameter	Value adopted
K_1	Adopted value of 1.0 based on fresh, angular rock
K_2	Adopted 1.05 based on well graded rock
q	Refer below
S_r	2.6t/m³ based on typical density of granite/quartz
S_o	Based on design batter angle of 1V:2.5H
SF	1.5 adopted based on high risk structure

Flow rates used for the assessment adopted the 0.01% AEP (1 in 1,000 year ARI) with 5 min duration assuming 100% runoff (no infiltration). Flow rates were estimated assuming settlement of a 50 m wide section across the benches, resulting in concentrated flows reporting to a 2 m wide section down the batter slope. 50 m is conservative as the bench width is only 9 m wide and unable to convey flows for such a distance.

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Recognising flow rates will increase from the top to the base of the batters, each of the benches was considered separately (Refer **MAP 10**). Estimated flow rates and parameter used to estimate rock sizes are provided in **TABLE 25**.

TABLE 25: ROCK SIZING ADOPTED PARAMETERS

Bench No.	1	2	3
Rainfall intensity*	404 mm/hr	404 mm/hr	404 mm/hr
Time of concentration	5min	5min	5min
Cumulative Slope length (including batters)	47m	93m	140m
Cumulative catchment Area	930m²	1,860m²	2,730m²
Slope	1V:2.5H	1V:2.5H	1V:2.5H
Calculated Discharge	0.26m³/s	0.52m³	0.78m³/s

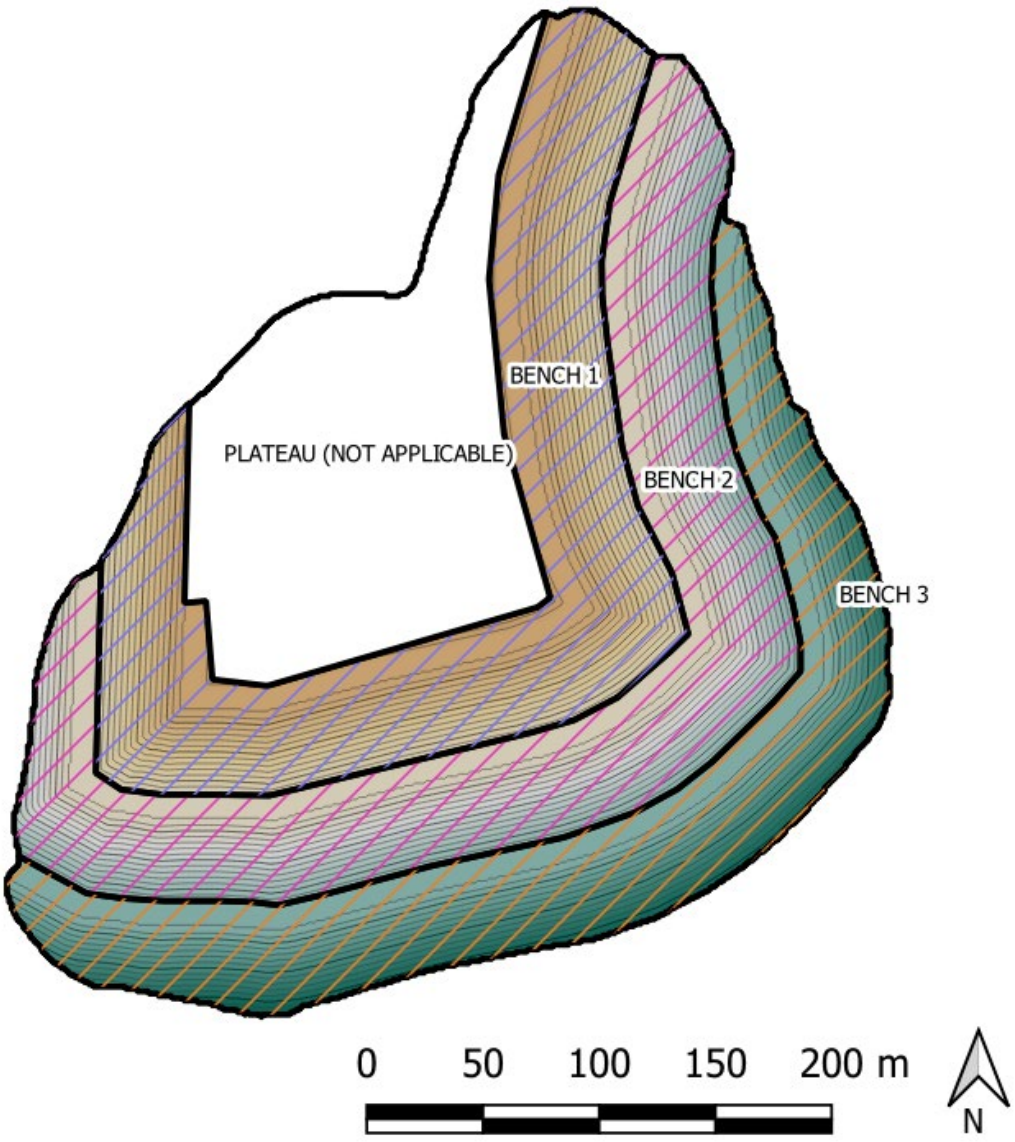
*based on BOM Intensity Frequency Duration Table generated for the site location.

TABLE 26: CALCULATED ROCK SIZING

Bench	Calculated D50mm Rock Diameter
1	300mm
2	400mm
3	450mm

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MAP 10: BATTER AREAS



The exact extents for the rock armouring would be determined during detailed design. This would include consideration around rock aprons at the toe, trafficability of the benches, number of layers and grading envelope to achieve interlocking and fill voids in between D50 rock. These aspects would be confirmed during detailed design.

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9 POST CLOSURE MONITORING AND MAINTENANCE

Decommissioning and rehabilitation of the WRE will include the application of low water flux covers to the crest and batters. These will act to resist the infiltration of meteoric water into the contained waste rock and thereby remove the mechanism that may act to transport contaminants into the receiving environment. In addition, the crest and batter treatments have been designed to provide functions such as resistance to erosion and storage of water to support plant growth.

Following construction of the WRE cover system, inspection and reporting will be completed to provide assurance that rehabilitation activities were completed in accordance with approved designs. Upon completion of physical works, the cover system construction works will have as-constructed plans prepared and certified by a suitably qualified person. Deviations between design and construction are to be identified. Records to be kept include:

- Chemical and physical properties of all cover materials (including lab-based material characterisation results)
- Surface and sub-surface preparation requirements including any available information related to the base layer under the BGM liner (for example, ripping, compacting, establishing bunds) (including evidence, photos, records of any tests conducted)
- Amelioration requirements (for example gypsum/lime etc, rate, spreading/layer application) (including lab-based material characterisation results)
- Details of installation methodology
- Monitoring equipment installation.

Monitoring for conditioning under the BGM liner is not recommended due to risk of puncturing the BGM liner and causing preferential flow paths for seepage.

Quality Assurance/Quality Control testing will be completed to demonstrate the cover system construction has met the design criteria. Analysis will comprise of the following:

- Depth of rock mulch layer on the crest
- Depth of compacted PAF and compacted NAF on the batters
- Maximum hydraulic conductivity of the compacted PAF and compacted NAF layer on the batters is to specified design
- Manufacturer's quality assurance/quality control testing results and specifications for the BGM liner, including maximum hydraulic conductivity
- No PAF material is present within the cover material.

Revision of the monitoring program may be required as new information becomes available or performance issues identified during regular inspections.

9.1 Instrumentation

Instrumentation would be installed to monitor the performance of the cover system against rehabilitation objectives.

Recommended instrumentation for closure is as follows:

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Weather station:	Climatic data will be useful for calibrating vadose models and for analysis of matric suction measurements. The following climatic data would be required: • Rainfall • Evaporation • Relative humidity • Wind strength • Wind direction and • Air temperature.
Fredlund thermal conductivity sensor: (or similar matric suction sensor)	A Fredlund thermal conductivity sensor measures matric suction. Measurement of matric suction in the cover system will provide an indication of the fate of moisture within the cover system to include the base of the cover soils and the surface of the PAF waste material, measured from the batter instrumentation only
Piezometer	It would be beneficial to install vibrating wire piezometers (VWPs) within the WRE to monitor the phreatic surface within the WRE post closure.

Installation of instrumentation would depend on final site conditions.

9.2 Monitoring

Monitoring of the WRE water balance will demonstrate the performance of the cover system, including the bituminous geo-membrane liner to prevent infiltration into the contained waste. Because the BGM liner is a manufactured material with a very low hydraulic conductivity ($1x10^{-9}$ m/s), any penetration of the liner will compromise its integrity. As such, the cover system water balance will be used to evaluate the rate of infiltration (or lack of infiltration) into the waste material. Monitoring will be completed using a network of four (4) instrumented monitoring stations located in both the crest and batter treatment areas, two within the crest and two within the batter. Each station will comprise paired sensor arrays monitoring volumetric moisture content and matric suction located at strategic levels in the capping media. A weather station will also be maintained at the WRE. An automatic on-site weather station will assess the water balance of the landform including:

- Storage,
- Losses to runoff,
- Losses to evapo-transpiration, and
- Net losses to infiltration.

Erosion

Cover system performance assessment will occur to include erosion extent primarily through visual assessments during on-site routine inspections and as a component of the rehabilitation monitoring program. Direct measurements of erosion depths can be collected. Visual assessment of prolonged surface water ponding and surface water runoff on the crest may indicate potential for erosion of embankments and instability issues.

As the WRE batters will be constructed using rock armour erosion of the surface is not anticipated. However, instability risks at the compacted NAF and rock armour interface can be measured. Surface water runoff and sediment loss will be monitored through the installation of sediment capture flumes at the base of the embankments.

The geotechnical stability risk for the cover system will also be measured at primary monitoring locations (established in representative locations). This will comprise of vibrating wire piezometers (VWPs) installed in the embankment below the rock armour following completion of the reshaping of the final

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landform. This will allow direct measurement of the phreatic surface within the embankment which will be used to evaluate both stability risk and water flux out of the landform as well as an indirect indicator of infiltration through the cover system.

Water Flux into contained waste

Water flux into the contained waste is to be less than 10% of rainfall and appropriate flux monitoring sites to be installed. The cover system water balance will be used to evaluate water flux in the contained waste. The in-situ monitoring stations (4 in total as mentioned above) will be installed to measure available water holding capacity of the cover soil profile and moisture in the profile, nominally to be installed within the upper 30% and at the base of the cover profiles on the crest and batters. The surface of the PAF waste material will also be measured on the baters to determine water infiltration into the underlying waste. Appropriate locations and depths will be determined during detailed design. These measuring devices will also provide an indication of any potential erosion and instability risks of the embankments.

Monitoring for the condition of the interface at the BGM and NAF layer is not recommended due to risk of puncturing the BGM liner and preferential flow paths for seepage. BGM is a manufactured product and the permeability of the BGM (measured at maximum hydraulic conductivity) will be demonstrated through appropriate QA/QC.

VWP data will be used as an indirect indicator of infiltration through the cover system. As the cover system prevents infiltration into the waste, the phreatic surface is expected to decrease over time.

Contaminant Mass Flux out of WRE

Cover system performance will also be measured through contaminant mass flux monitoring out of the WRE. This can be achieved via installation of a V-notch weir installed at an appropriate location to assess seepage out of the WRE. An appropriate and representative location will be determined during detailed design phase.

The VWP data will be used as an indicator of infiltration through the cover system. As the cover system prevents infiltration into the waste, the phreatic surface is expected to decrease over time, which will reduce contaminant mass flux out of the WRE due to the reduced hydraulic head within the WRE

Mass contaminant flux out of the WRE will also be interpreted through ongoing groundwater monitoring, pursuant to the requirements of the EA.

Instrumentation and sensors used in the monitoring program will be calibrated to the material type being monitored using the manufacturers specifications and installed, operated and maintained by an appropriately qualified person.

9.3 Inspections

Site inspections of rehabilitated surfaces should occur annually following mine site closure. Inspections are also recommended following significant rainfall events. The site inspections shall include assessment of the integrity of the following aspects:

- Cover material and batter slopes
  - Erosion/scour
  - Surface water ponding/ seepage
  - Vegetation establishment
  - Weed control
  - Settlement inspection
  - Condition & access
- Surface water drains
  - Sediment or debris build up in drainage lines

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- Erosion/scouring of drainage lines
- Ponding of surface water

An inspection checklist should be completed during each inspection. This inspection checklist would form a record for tracking the condition and rehabilitation and maintenance requirements of the site.

9.4 Maintenance

To performance of the final cover system is maintained, inspections would need to identify areas of settlement, erosion, scour, vegetation loss or ponding of surface water. Settlement shall also be monitored routinely in order to measure and assess any consolidation and effects on the surface drainage. Settled areas within the rehabilitated surface should be repaired by reprofiling and filling with cover soils to facilitate surface water run-off toward designed swales or drainage channels and ultimately to prevent ponding. In general, BGM liners are highly flexible and adaptable to settlement deformation of up to 50 to 60% strain rate with no cracking. Settlement analysis completed at McArthur River Mine for the closure of their Overburden Emplacement Facility predicts a range of long-term creep and strain settlement of 450 to 4,350 mm (Glencore, 2017). The predicted liner strain ranges from 1 to 11%, which is well within the BGM liner's capacity for deformation.

Vegetation management requirements include maintenance of established vegetation and establishment of new vegetation following any maintenance works. Weed management should also be undertaken for the site as required.

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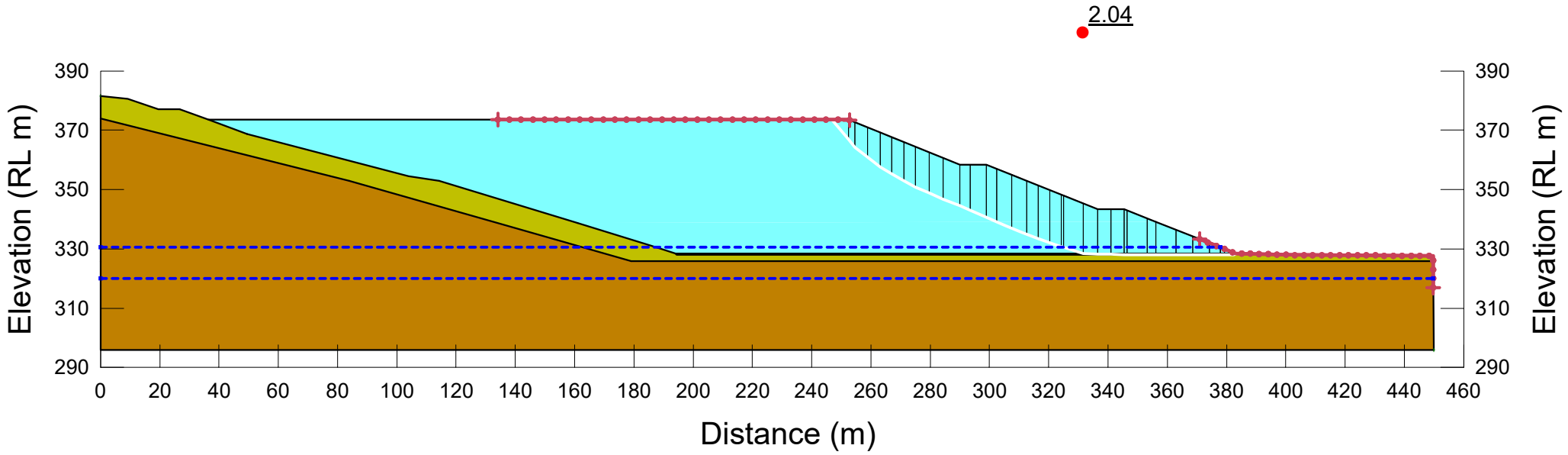
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APPENDICES

APPENDIX A – GEOTECHNICAL MODELLING RESULTS

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Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Piezometric Surface
	Basement (Imp)	Bedrock (Impenetrable)				1
	Clay	Mohr-Coulomb	18	2	28	2
	Sedimentary Rock	Mohr-Coulomb	20	0	32	1
	WRD (Simmons et al. 2017 - Unsaturated)	Mohr-Coulomb	18	30	28	2



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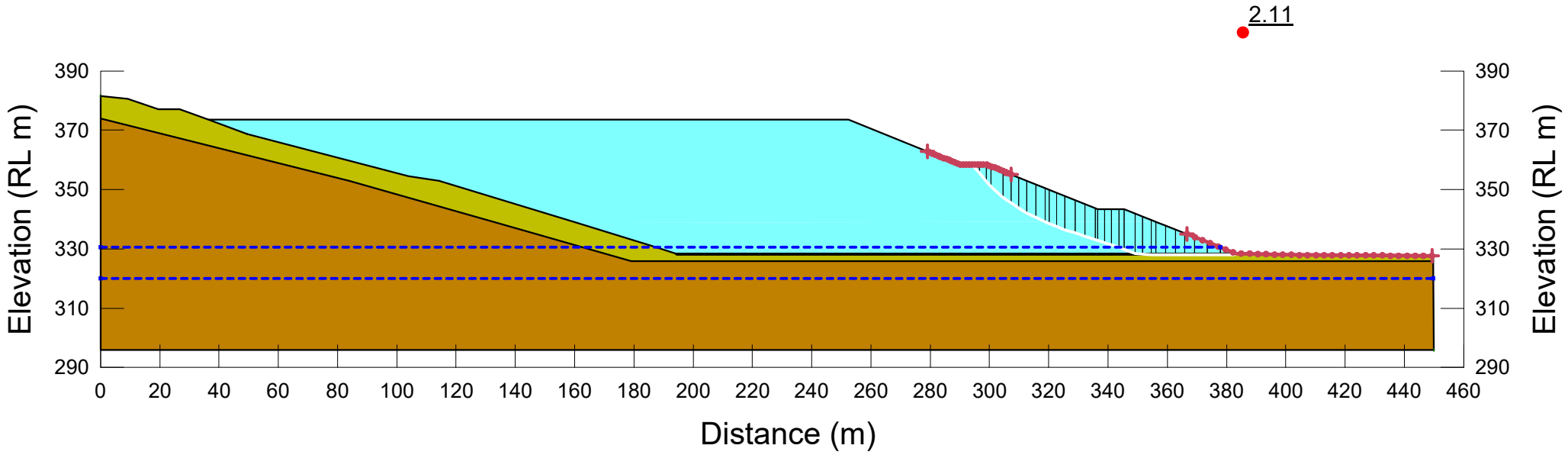
LADY LORETTA MINE - WASTE ROCK DUMP STABILITY ANALYSIS

Effective Drained - Global

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Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Piezometric Surface
	Basement (Imp)	Bedrock (Impenetrable)				1
	Clay	Mohr-Coulomb	18	2	28	2
	Sedimentary Rock	Mohr-Coulomb	20	0	32	1
	WRD (Simmons et al. 2017 - Unsaturated)	Mohr-Coulomb	18	30	28	2



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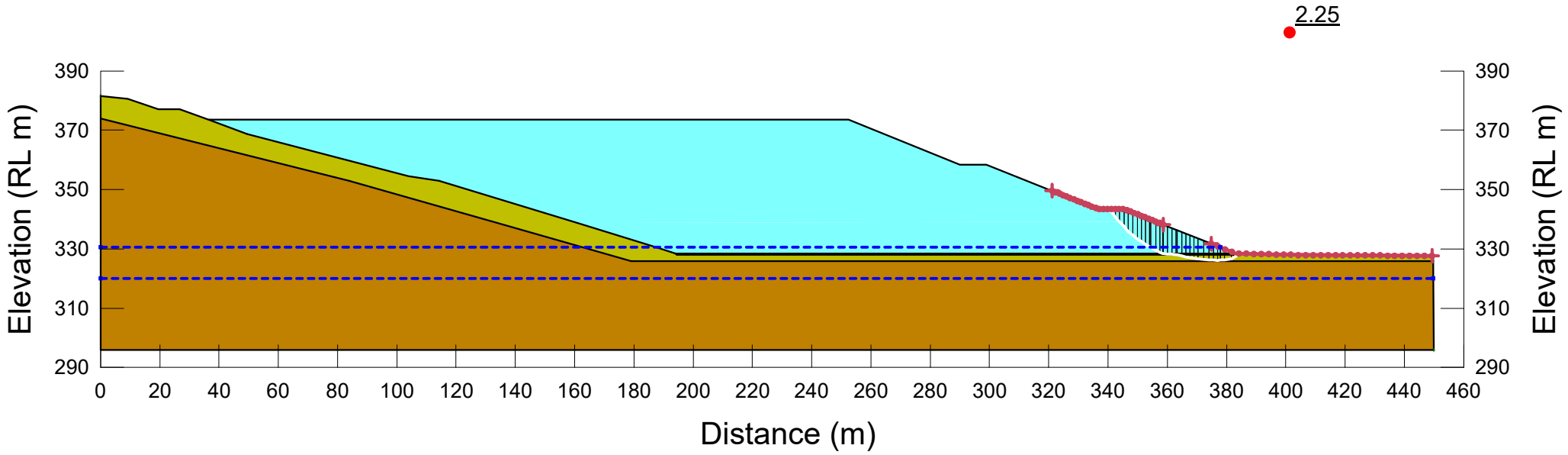
LADY LORETTA MINE - WASTE ROCK DUMP STABILITY ANALYSIS

Effective Drained - Local 1

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Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Piezometric Surface
	Basement (Imp)	Bedrock (Impenetrable)				1
	Clay	Mohr-Coulomb	18	2	28	2
	Sedimentary Rock	Mohr-Coulomb	20	0	32	1
	WRD (Simmons et al. 2017 - Unsaturated)	Mohr-Coulomb	18	30	28	2



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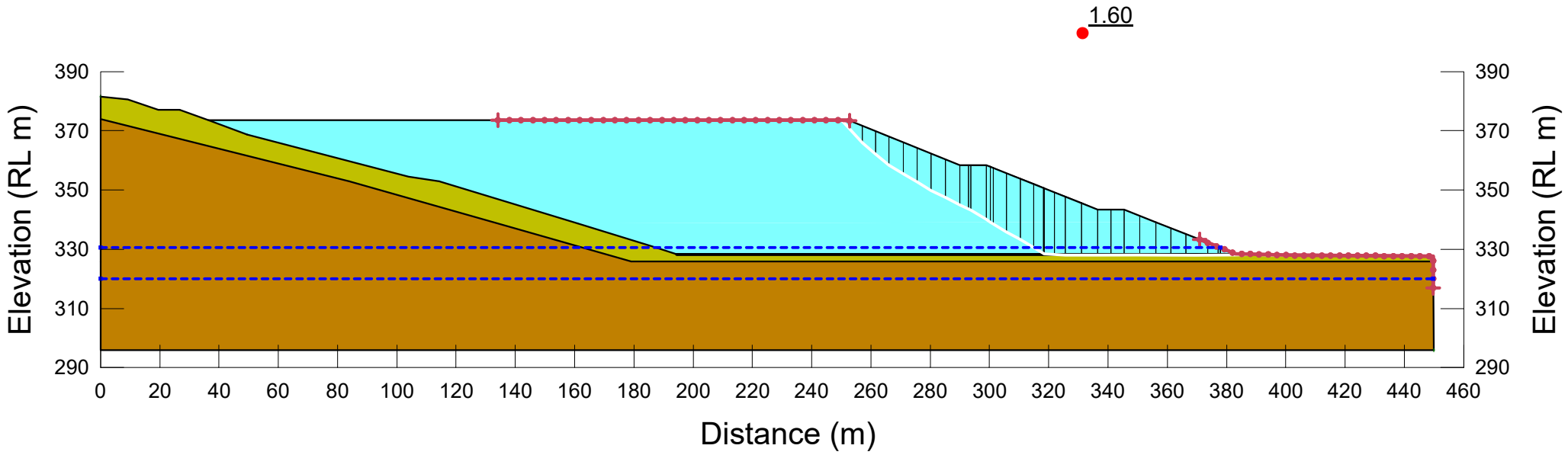
LADY LORETTA MINE - WASTE ROCK DUMP STABILITY ANALYSIS

Effective Drained - Local 2

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Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Minimum Strength (kPa)	Tau/Sigma Ratio	Piezometric Surface
	Basement (Imp)	Bedrock (Impenetrable)						1
	Clay (UD)	SHANSEP	18			25	0.245	1
	Sedimentary Rock	Mohr-Coulomb	20	0	32			1
	WRD (Simmons et al. 2017 - Unsaturated)	Mohr-Coulomb	18	30	28			2



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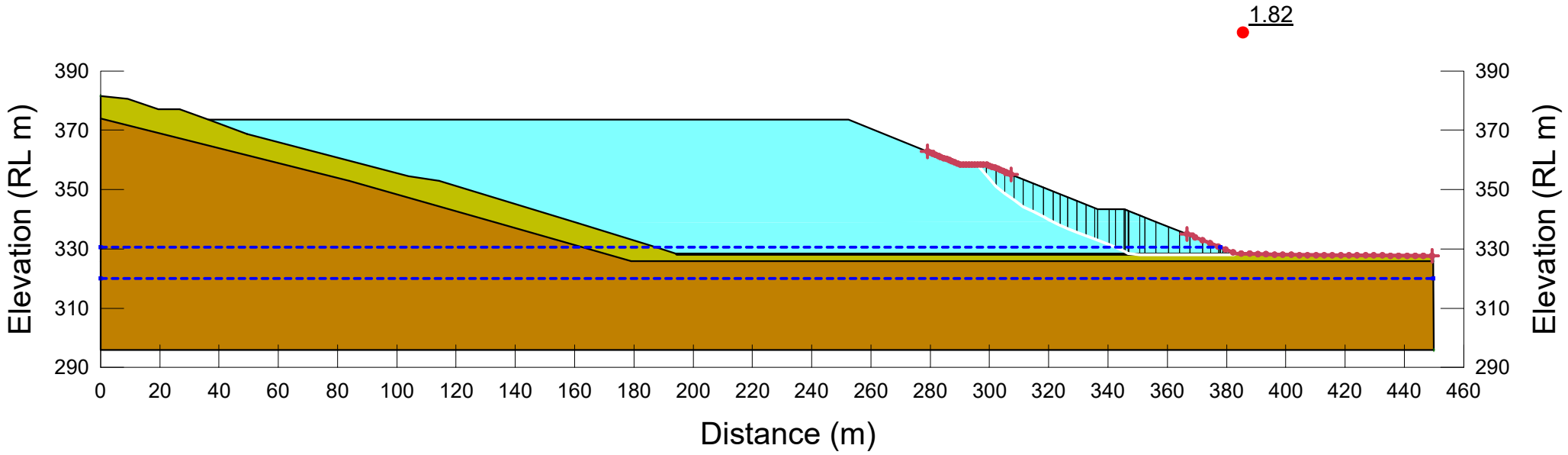
LADY LORETTA MINE - WASTE ROCK DUMP STABILITY ANALYSIS

Effective Drained/Undrained - Global

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	Basement (Imp)	Bedrock (Impenetrable)						1
	Clay (UD)	SHANSEP	18			25	0.245	1
	Sedimentary Rock	Mohr-Coulomb	20	0	32			1
	WRD (Simmons et al. 2017 - Unsaturated)	Mohr-Coulomb	18	30	28			2



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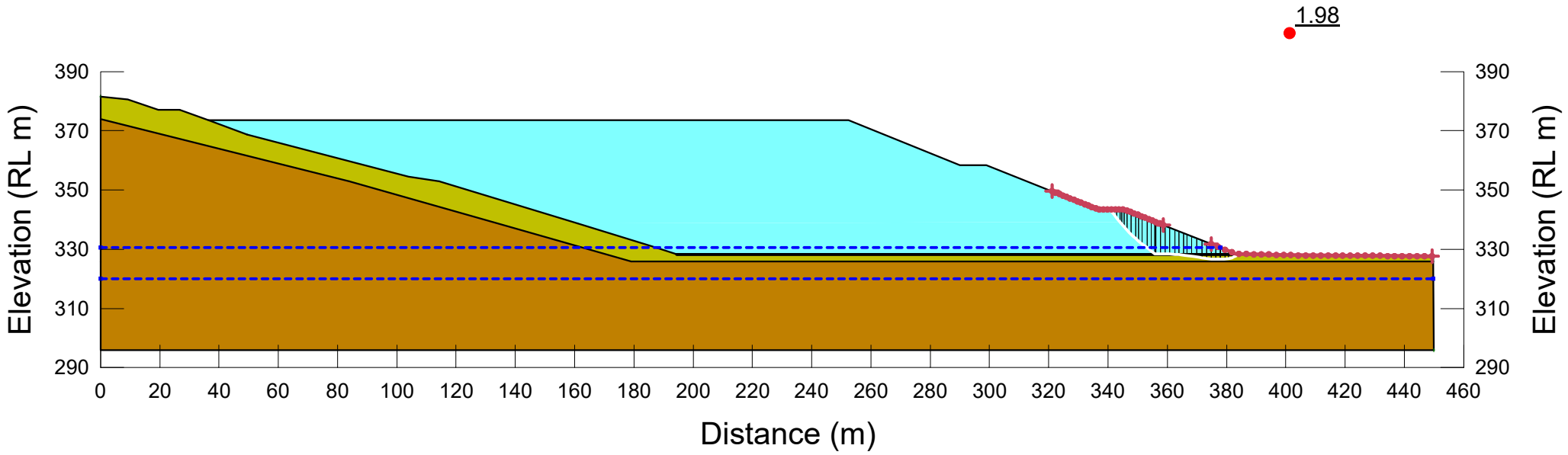
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Effective Drained/Undrained - Local 1

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	Basement (Imp)	Bedrock (Impenetrable)						1
	Clay (UD)	SHANSEP	18			25	0.245	1
	Sedimentary Rock	Mohr-Coulomb	20	0	32			1
	WRD (Simmons et al. 2017 - Unsaturated)	Mohr-Coulomb	18	30	28			2



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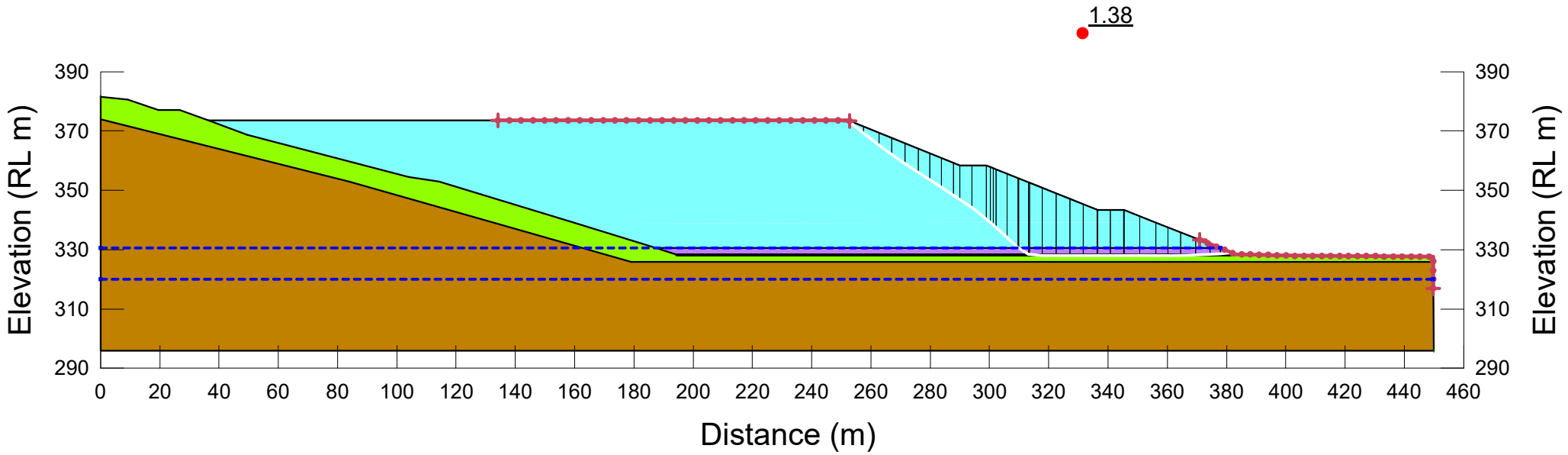
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Effective Drained/Undrained - Local 2

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	Basement (Imp)	Bedrock (Impenetrable)						1
	Clay (PS UD)	SHANSEP	18			20	0.196	2
	Sedimentary Rock (PS)	Mohr-Coulomb	20	0	25.6			1
	WRD (Simmons et al. 2017 - Remoulded)	Mohr-Coulomb	20	0	18			2
	WRD (Simmons et al. 2017 - Unsaturated)	Mohr-Coulomb	18	30	28			2



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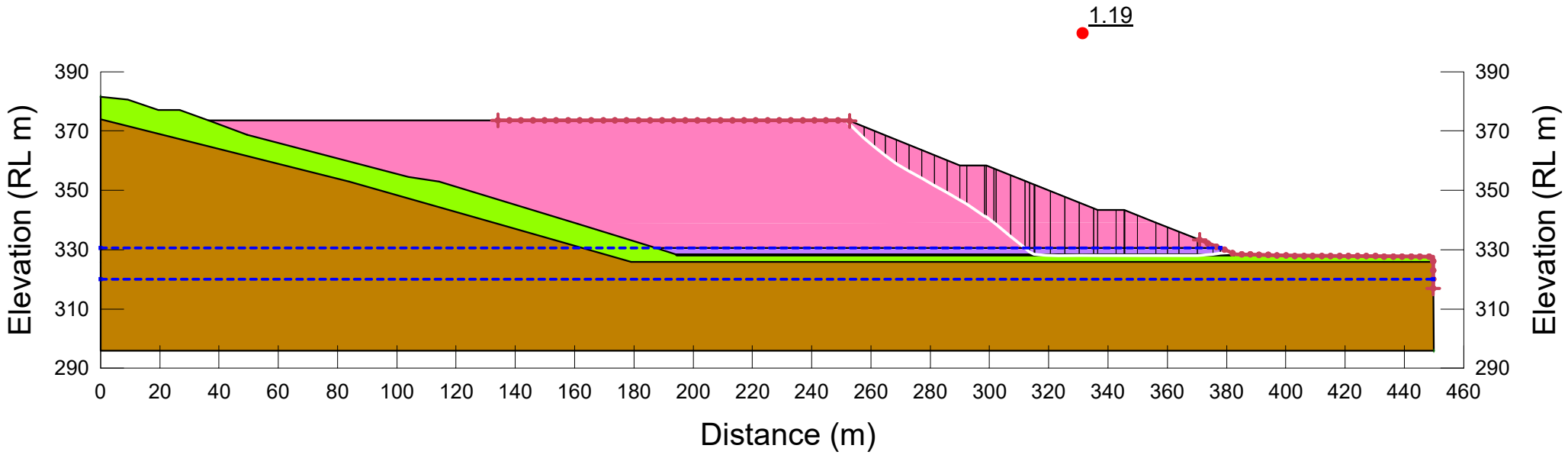
LADY LORETTA MINE - WASTE ROCK DUMP STABILITY ANALYSIS

Post Seismic - Global

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	Basement (Imp)	Bedrock (Impenetrable)						1
	Clay (PS UD)	SHANSEP	18			20	0.196	2
	Sedimentary Rock (PS)	Mohr-Coulomb	20	0	25.6			1
	WRD (Simmons et al. 2017 - Remoulded)	Mohr-Coulomb	20	0	18			2
	WRD (Simmons et al. 2017 - Unsaturated) (SR)	Mohr-Coulomb	18	24	22.4			2



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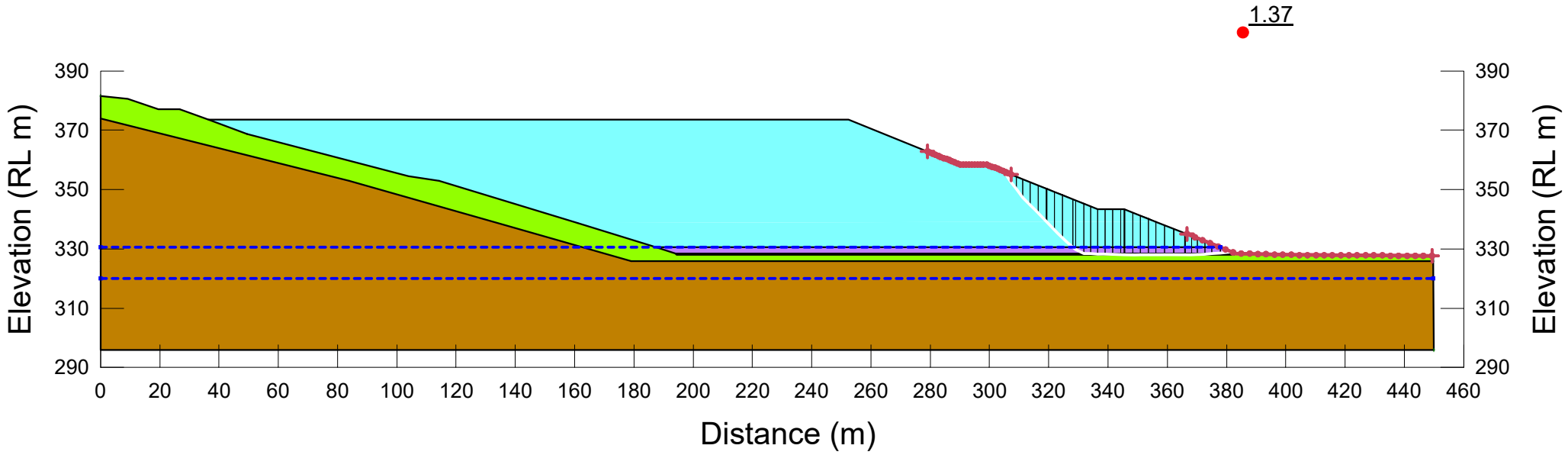
LADY LORETTA MINE - WASTE ROCK DUMP STABILITY ANALYSIS

Post Seismic - Global (Sensitivity 1)

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	Basement (Imp)	Bedrock (Impenetrable)						1
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	Sedimentary Rock (PS)	Mohr-Coulomb	20	0	25.6			1
	WRD (Simmons et al. 2017 - Remoulded)	Mohr-Coulomb	20	0	18			2
	WRD (Simmons et al. 2017 - Unsaturated)	Mohr-Coulomb	18	30	28			2



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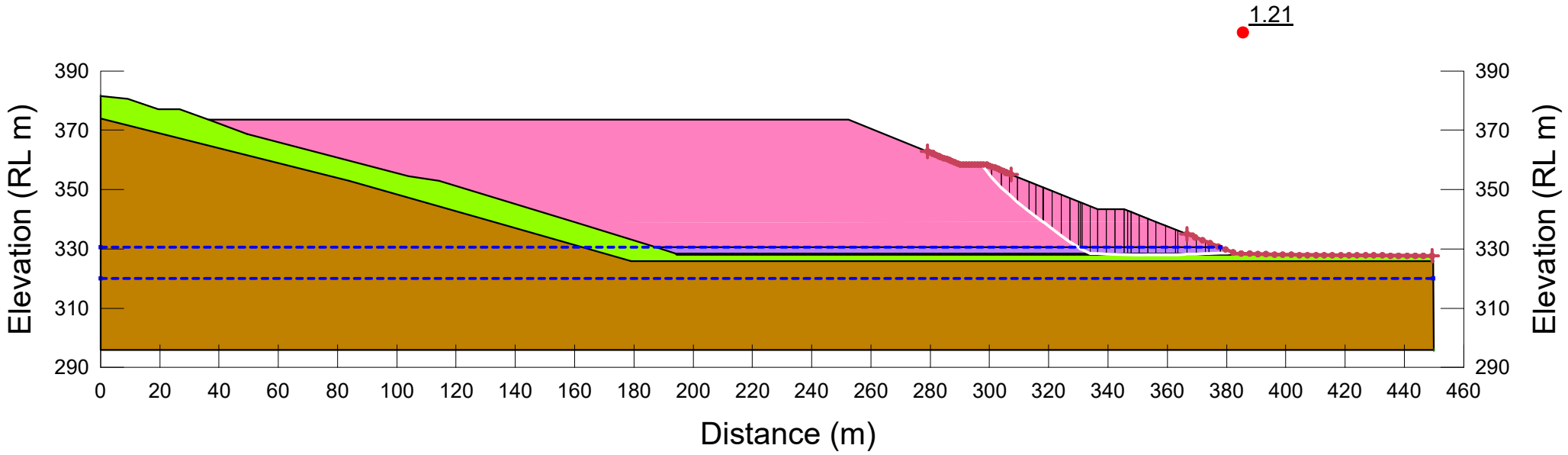
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	Basement (Imp)	Bedrock (Impenetrable)						1
	Clay (PS UD)	SHANSEP	18			20	0.196	2
	Sedimentary Rock (PS)	Mohr-Coulomb	20	0	25.6			1
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	WRD (Simmons et al. 2017 - Unsaturated) (SR)	Mohr-Coulomb	18	24	22.4			2



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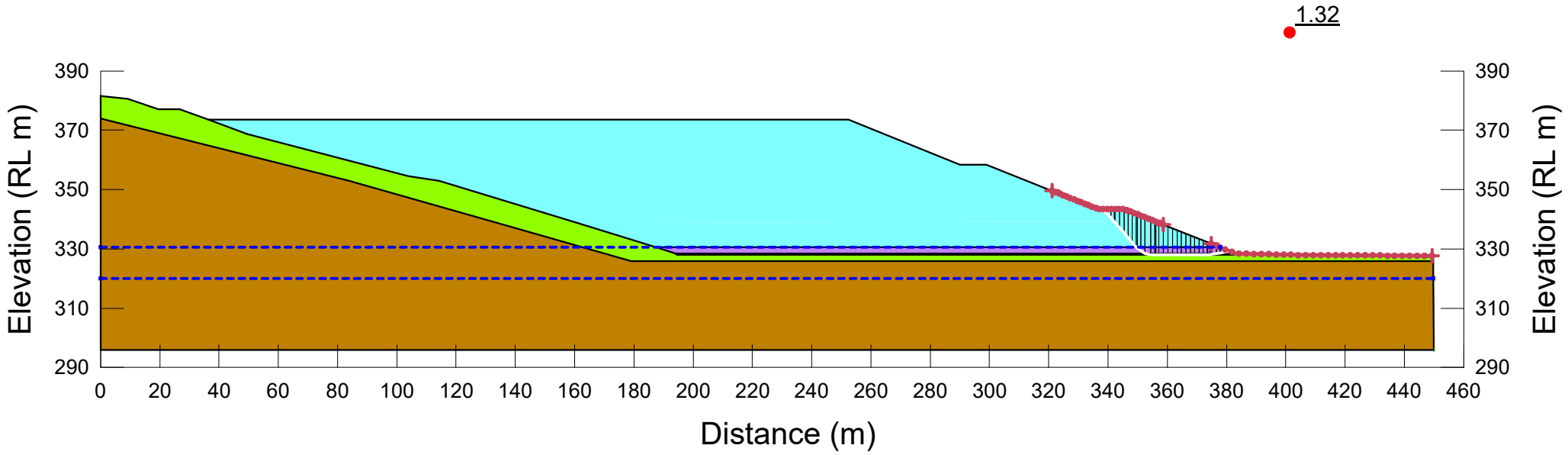
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	Basement (Imp)	Bedrock (Impenetrable)						1
	Clay (PS UD)	SHANSEP	18			20	0.196	2
	Sedimentary Rock (PS)	Mohr-Coulomb	20	0	25.6			1
	WRD (Simmons et al. 2017 - Remoulded)	Mohr-Coulomb	20	0	18			2
	WRD (Simmons et al. 2017 - Unsaturated)	Mohr-Coulomb	18	30	28			2



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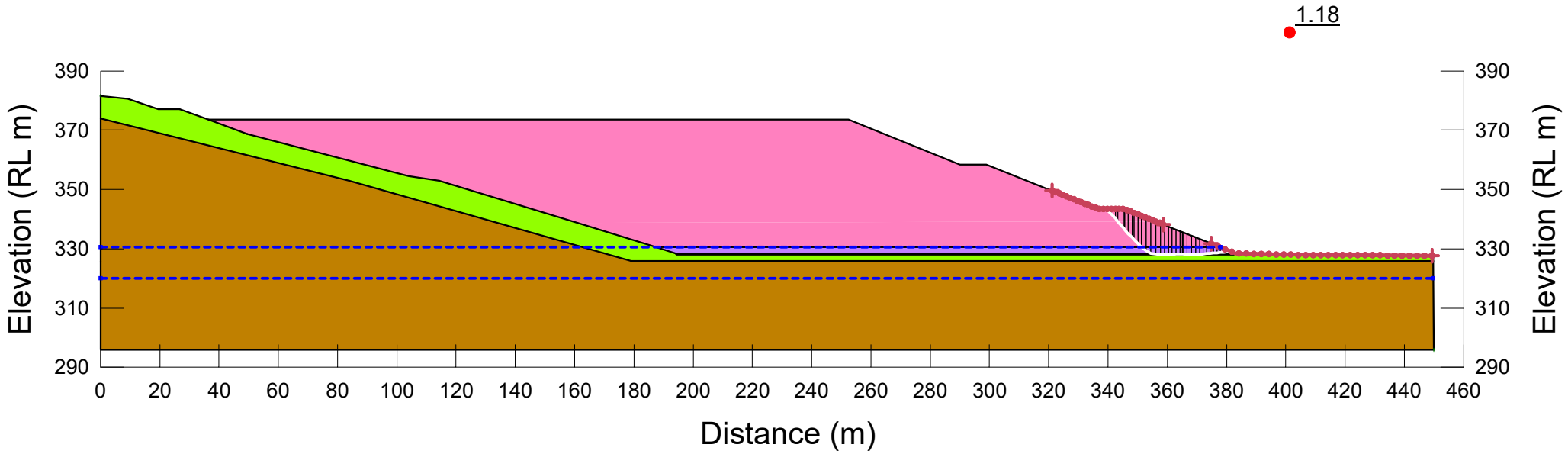
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	Basement (Imp)	Bedrock (Impenetrable)						1
	Clay (PS UD)	SHANSEP	18			20	0.196	2
	Sedimentary Rock (PS)	Mohr-Coulomb	20	0	25.6			1
	WRD (Simmons et al. 2017 - Remoulded)	Mohr-Coulomb	20	0	18			2
	WRD (Simmons et al. 2017 - Unsaturated) (SR)	Mohr-Coulomb	18	24	22.4			2



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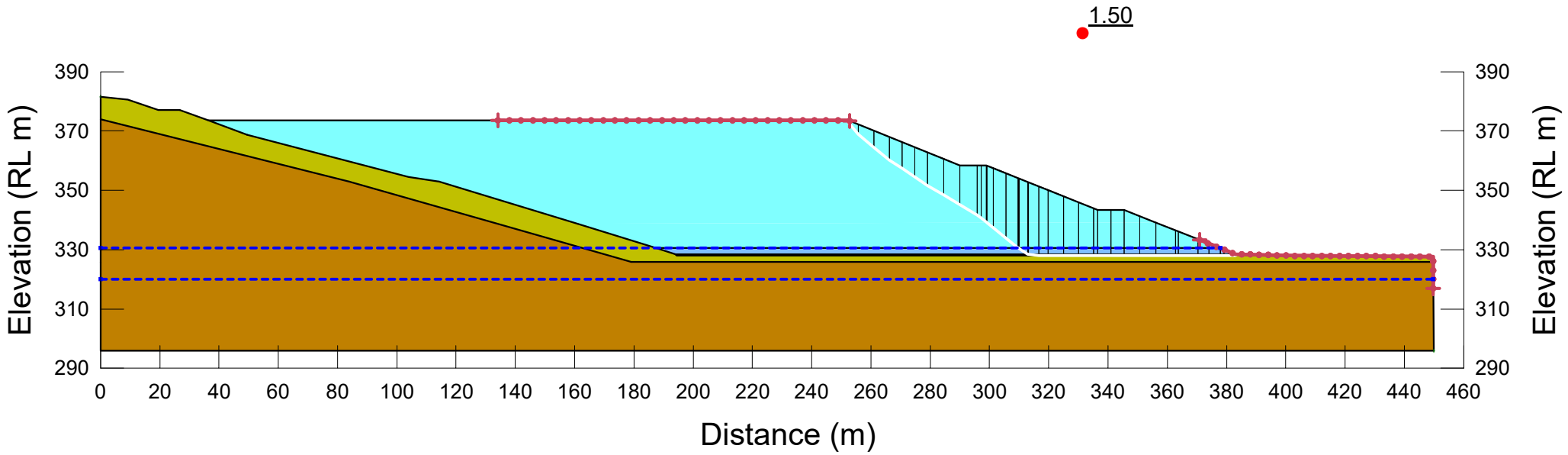
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Post Seismic - Local 2 (Sensitivity 1)

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	Basement (Imp)	Bedrock (Impenetrable)						1
	Clay (UD)	SHANSEP	18			25	0.245	2
	Sedimentary Rock	Mohr-Coulomb	20	0	32			1
	WRD (Simmons et al. 2017 - Saturated)	Mohr-Coulomb	20	15	23			2
	WRD (Simmons et al. 2017 - Unsaturated)	Mohr-Coulomb	18	30	28			2



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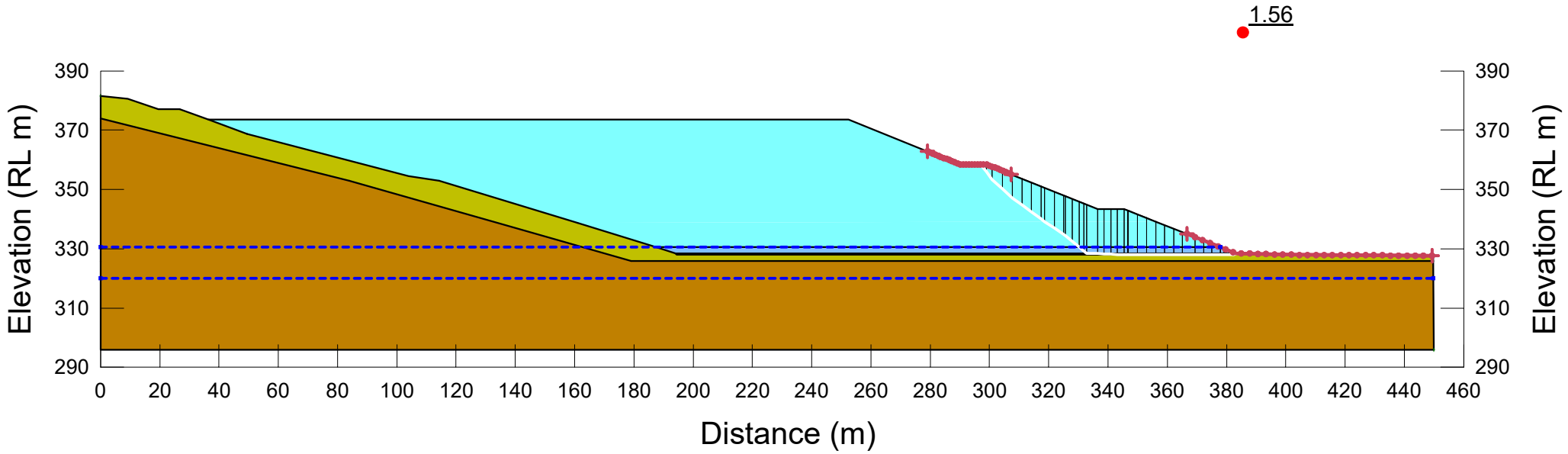
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Undrained - Global

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	Basement (Imp)	Bedrock (Impenetrable)						1
	Clay (UD)	SHANSEP	18			25	0.245	2
	Sedimentary Rock	Mohr-Coulomb	20	0	32			1
	WRD (Simmons et al. 2017 - Saturated)	Mohr-Coulomb	20	15	23			2
	WRD (Simmons et al. 2017 - Unsaturated)	Mohr-Coulomb	18	30	28			2



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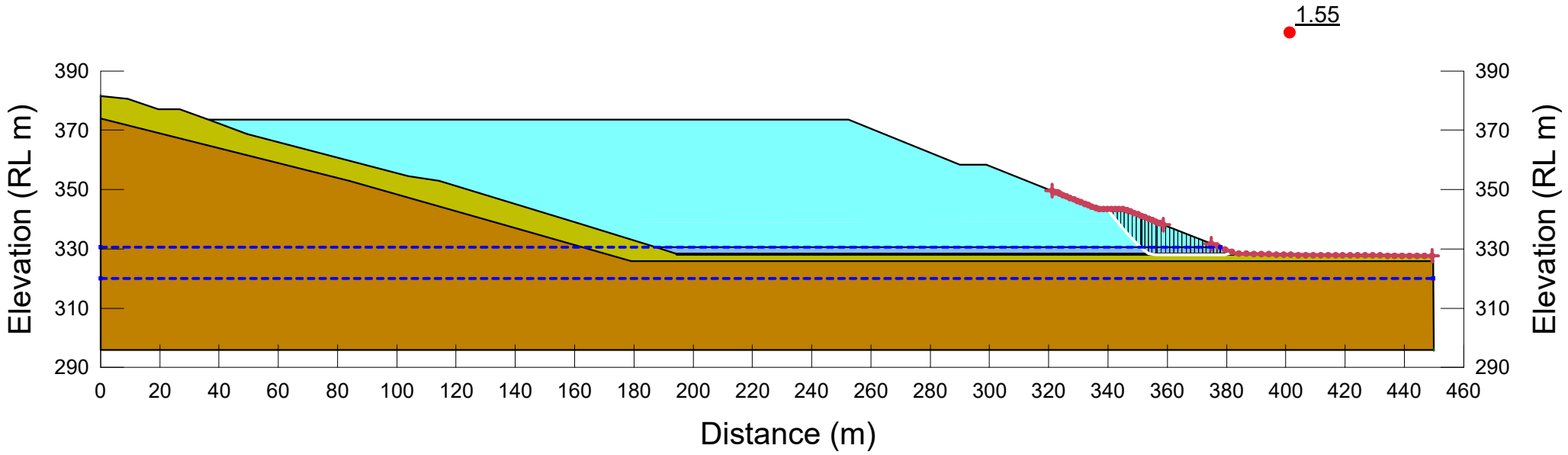
LADY LORETTA MINE - WASTE ROCK DUMP STABILITY ANALYSIS

Undrained - Local 1

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Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Minimum Strength (kPa)	Tau/Sigma Ratio	Piezometric Surface
	Basement (Imp)	Bedrock (Impenetrable)						1
	Clay (UD)	SHANSEP	18			25	0.245	2
	Sedimentary Rock	Mohr-Coulomb	20	0	32			1
	WRD (Simmons et al. 2017 - Saturated)	Mohr-Coulomb	20	15	23			2
	WRD (Simmons et al. 2017 - Unsaturated)	Mohr-Coulomb	18	30	28			2



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LADY LORETTA MINE - WASTE ROCK DUMP STABILITY ANALYSIS

Undrained - Local 2

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APPENDIX B – EROSION ASSESSMENT

1 INTRODUCTION

1.1 Background

This document has been prepared as an addendum to the WRE conceptual closure design report (ref 112004.R04) to document the erosion landform evolution modelling inputs and results.

The proposed cover system for the plateau will comprise rocky mulch, a well graded material possessing both coarse rock and fines. Rock armouring will be constructed on the batters.

Erosion modelling has been undertaken for the Plateau to confirm the proposed depth of the cover system is sufficient to prevent scouring to the base of the rocky mulch layer. Although it is recognised that a BGM will be installed at the base of the rocky mulch layer (preventing exposure of the PAF waste), maintenance of the rocky mulch layer is critical for both vegetation and protection of the BGM.

Modelling has been undertaken using the Water Erosion Prediction Project (WEPP) and SIBERIA Landform Evolution Model. The background to these models, inputs and outcomes from these models are detailed in the following sections.

WEPP and SIBERIA have been developed to assess the long-term erosion of soils. Rock armouring to be installed on the batters will comprise fresh, unweathered rockfill, designed to withstand high intensity rainfall events. The material properties are therefore resistant to long-term fluvial erosion which WEPP and SIBERIA assess. On this basis, erosion modelling has not been undertaken on the WRE batters, however hydraulic calculations were used to determine the suitability of proposed rockfill, as detailed in the conceptual closure report.

2 WEPP MODELLING

2.1 Background

The Water Erosion Prediction Project (WEPP) is a 2-Dimensional erosion simulation model used to predict and calculate estimates of soil detachment and deposition as well as simulation of the hydrologic and erosion processes on small watersheds.

The purpose of WEPP modelling is to estimate the soils loss, based on site climate, soil characteristics, expected vegetation conditions and catchment geometry.

2.2 Inputs

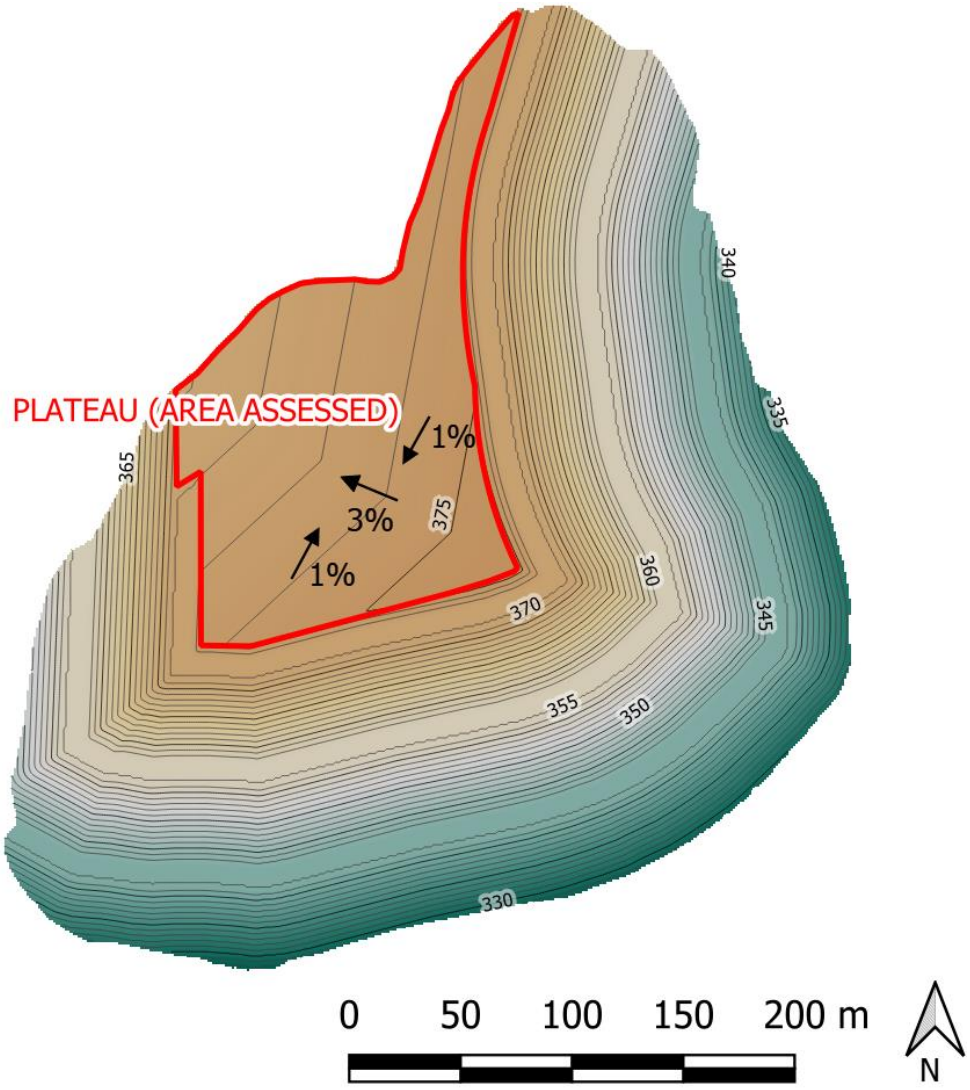
2.2.1 Final Landform Geometry

The final geometry of the WRE plateau is shown in **Figure 1**. Key aspects to the design are summarised as follows:

- 3% fall with central drain.
- 1% surface grade falling towards the central drain.
- Bunds constructed around the perimeter to prevent rainfall runoff reporting over the edges of the landform.
- Drainage chute to divert runoff from the plateau to the toe and off the WRE.

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Figure 1: Landform Geometry



2.2.2 Model Duration

A model duration of 20 years was adopted for the WEPP model, to establish baseline erosion rates. This time period is considered an appropriate model duration noting the following:

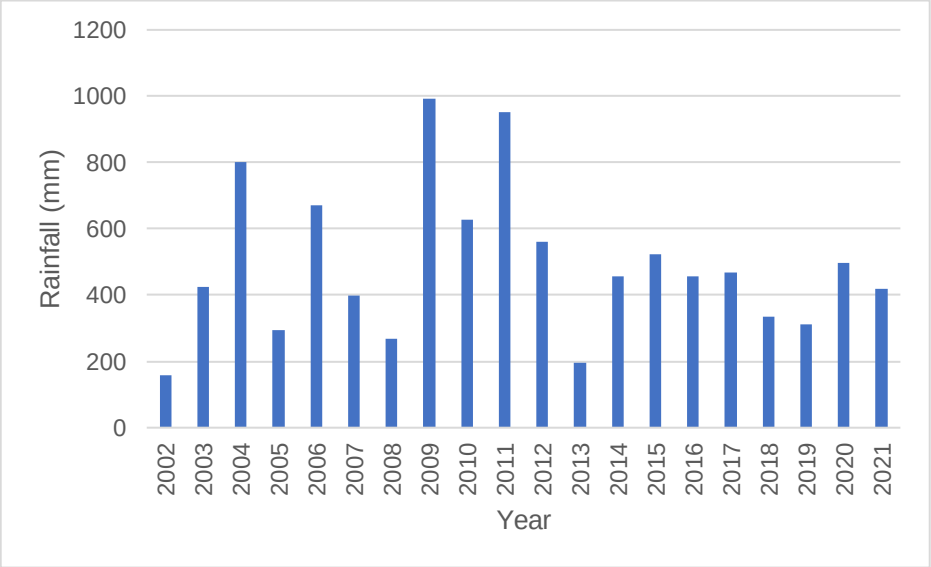
- Vegetation is assumed to be established at the model start time. Erosion control structures will remain in place until sufficient ground cover is established (refer **Section 2.5.3**).
- The 20 year period adopted includes years of high and low rainfall, allowing assessment of loss rates for varying climatic conditions.
- Expected erosion rates are not expected to expose soil multiple horizons, whereby the soil loss rates vary over time.
- Erosion rates are not expected to expose soil multiple horizons such that loss rates will vary over time. The cap / cover soil will be one soil type. The cap will be consistent with the surrounding land in that the arid nature of the soil results in no definable topsoil layer.
- Results indicate erosion loss rates fluctuate annually depending on rainfall and generally did not trend upwards or downwards.

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2.2.3 Climate Data

Twenty years of SILO data for Mt Isa, from the years 2002 to 2021, was used in the simulation. The annual rainfall for the years 2002 to 2021 are shown in **Figure 19**. The modelled period includes years of low rainfall (2002, 160mm) and high rainfall (2009, 992mm),

Figure 2: Annual Rainfall



2.2.4 Soil Parameters

Typical soil parameters for the site were obtained from RGS (2022), however the percentage of rock was increased to represent the blended material. It is noted that the percentage of rock may vary however 40% is deemed as conservative. Key soil test data used for the WEPP analysis is outlined in **Table 1**.

Table 1: WEPP Soil Input Parameters

Sand (%)	Clay (%)	Rock (%)	Organic (%)	CEC (meq/100g)
32	28	40	1	5

Using the above soil parameters, WEPP uses inbuilt empirical equations to determine soil loss rates, with key formula provided as follows:

Interrill Erodibility

Interrill Erodibility the susceptibility of the soil detachment by raindrop impact and shallow flows

For soils with 30% or more sand:

Ki = 2728000 + 1921000*VFS

Where VFS is very fine sand percentage (≤40%)

For soils less than 30% sand:

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Ki = 6054000 – 55130*CLAY

Where CLAY is percentage clay in surface soil (≤40%)

Rill Erodibility

Rill erodibility reflects the susceptibility of the soil the shear detachment by water flowing in rills

For surface soils containing 30% or more sand, the equation for Kr is:

Kr = 0.00197+0.0003*VFS+0.03863e-1.84ORGMAT

Where VFS is very fine sand in the surface soil (≤40%)

ORGMAT is percentage of organic matter in the surface soil (≥0.35)

For surface soils containing less than 30% sand the equation for Kr is:

$Kr = 0.0069 + 0.134e^{-0.20CLAY}$

If clay is less than 10%, 10% is used in the equation for Kr for soils containing less than 30% sand.

Critical Shear

Critical shear is a threshold value, under which rill detachment does not occur

For soils containing 30% or more sand, the equation is

TAUc = 2.67 + 0.065*CLAY-0.058*VFS

For soils with less than 30% sand:

TAUc = 3.5

Effective Hydraulic Conductivity

For soils with ≤ 40% clay content

Kb = -0.265 + 0.0086*SAND^1.8+11.46*CEC^-0.75

For soil with >40%

Kb = 0.0066exp(244/CLAY)

2.2.5 Vegetation

The final land use for the WRE is defined as Native Habitat, as detailed in the PCRP document and as discussed in the WRE conceptual closure report. Vegetation parameters adopted for the erosion analysis is summarised in **Table 2**.

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Table 2: Vegetation Parameters

Parameter	Units	Native Habitat
In-row plant spacing	cm	100
Plant stem diameter at maturity	cm	25
Maximum canopy height	cm	250
Maximum leaf area index	-	6
Maximum root depth	cm	200
Percent of growing season when leaf area index starts to decline (0-100%)	%	25
Percent canopy remaining after senescence (0-100%)	%	50

2.3 WEPP Outputs

Based on the inputs and assumptions of the WEPP model, an average soil loss rate of around 5/t/ha/y are expected.

3 SIBERIA MODELLING

SIBERIA is a soil erosion and landform evolution model that has the ability to predict type of erosion (that is, sheet wash and/or gullying) and to predict gully initiation and evolution (Hancock and Evans; 2006, 2010; Hancock, Willgoose and Lowry, 2013).

Estimated soil loss rates generated using WEPP were input along with other parameters generated for the WRE (as detailed in the following section) to estimate the severity of erosion and estimate the final landform surface, at defined intervals. Inputs, assumptions and model outcomes are detailed in the following sections.

3.1 Inputs

Key model inputs used for SIBERIA Modelling are detailed in **Table 3**.

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Table 3: Vegetation Parameters

Parameter	Assumption
Model run duration	The landform evolution model was undertaken for 1,000 years, with landform outputs generated at the following intervals: • 10 years • 100 years • 200 years • 500 years • 1,000 years
Landform	The final WRE design was adopted. The plateau has been designed with a 3% central drain, and 1% surface grade towards the central drain.
Grid size	A grid size of 0.5m was adopted. This grid size was determined using trial and error to achieve the smallest grid size within the model limitations. It was determined that 0.25m exceeded the number of points SIBERIA could process.
Sediment transport Parameters	SIBERIA adopts the Einstein-Brown sediment transport model defined as: $q_s = \beta_1 \times q^{m_1} \times S^{n_1}$ Where: B_1= sediment transport coefficient Q = discharge (m3/y) M_1 = discharge exponent S = slope N_1 = slope exponent Values for B1, M1 and N1 were calibrated against WEPP results with adopted as follows: B_1 = 0.002 M_1 = 1.5 N_1 = 2.0
Soil Parameters	Bulk density of soil = 1.6t/m^3 Vegetation cover factor = 0.4

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3.2 Results

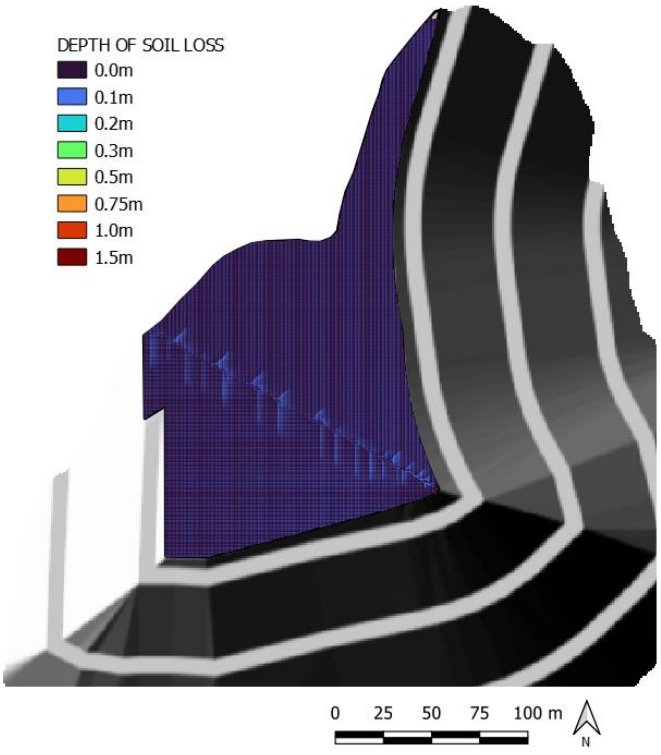
As outlined in **Section 1.2.2**, the key objective with respect to erosion of the WRE cover system is preventing exposure of the underlying PAF waste material. **Figures 3** to **7** depict the SIBERIA model results. Key observations for the modelling results are provided in **Table 3**.

Based on model results, sheet erosion is minimal, with the cover system performing well for 1000 years. Results indicate a maximum rill depth of around 0.1m after 100 years, with an average soil loss in the order of 0.02m. Results after 500 years indicate an average loss of around 0.06m and maximum depth of 0.36m. the maximum rill depth after 1000 years is 0.57m, being less than half the thickness of the cover system.

Table 4: Modelled Erosion Depths

Years	Average	Maximum
100	0.02m	0.10m
200	0.03m	0.18m
500	0.06m	0.36m
1000	0.11m	0.57m

Figure 3: WRE PLATEAU – 100Y EROSION



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Figure 4: WRE PLATEAU – 200Y EROSION

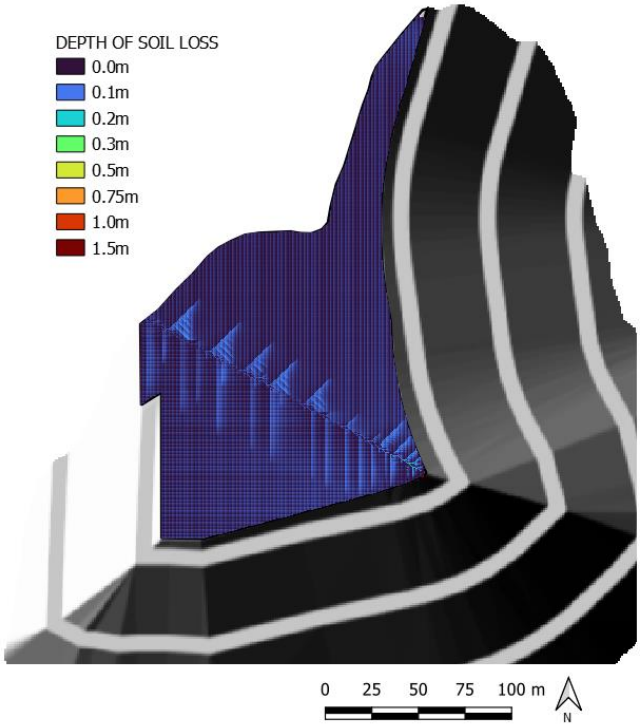
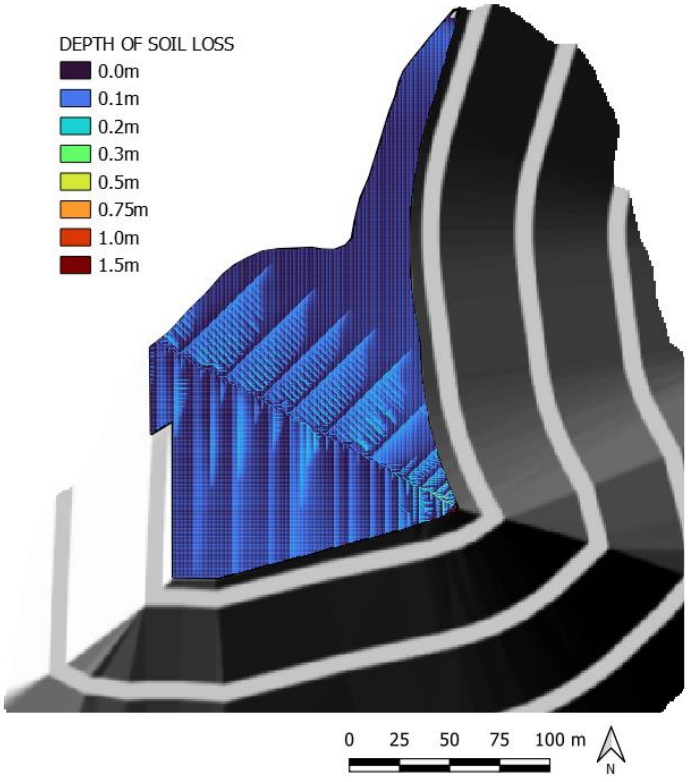
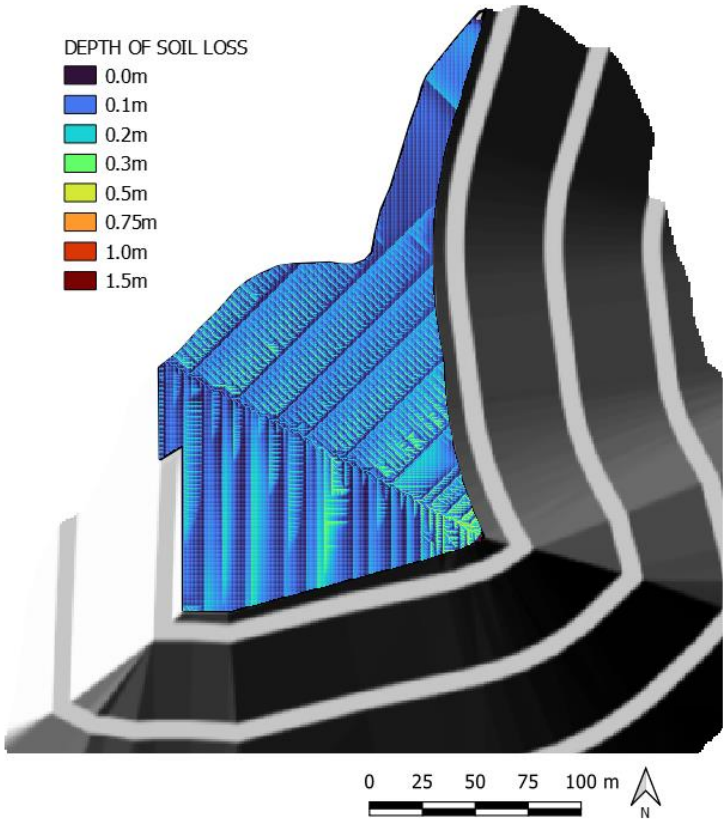


Figure 5: WRE PLATEAU – 500Y EROSION



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Figure 6: WRE PLATEAU – 1,000Y EROSION



4 CONCLUSIONS

Model results indicate expected rates of erosion are unlikely to impact the performance of the cover system. Based on the modelling outcomes, the thickness of the proposed cover system in addition to the proposed geometry is suitable for closure. It is further noted that the SIBERIA model assumes a uniform surface and does not account for surface texture, created at closure. Creating a loose, hummocky surface is critical to minimising surface runoff and erosion.

The above notwithstanding, key factors to the success of the final landform are:

- Avoiding concentrated flow which has generally been achieved by the conceptual final landform design presented in the PRCP.
- The establishment of vegetation through appropriate surface preparation, seeding, and grazing management.
- Ongoing maintenance of drainage controls and assessment of the causes of localised scour.
- The desired long-term outcomes of the cover system can be achieved through high quality construction and vegetation establishment, ongoing maintenance and monitoring.
- LLM should have a maintenance contingency that accounts for both likely maintenance and catastrophic events such as bushfire.

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APPENDIX G FINAL LANDFORM EROSION ASSESSMENT

REPORT

Noranda Pacific Pty Ltd

Lady Loretta Mine
Final Landform Erosion Assessment

112009.04 R08
March 2023



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1 INTRODUCTION

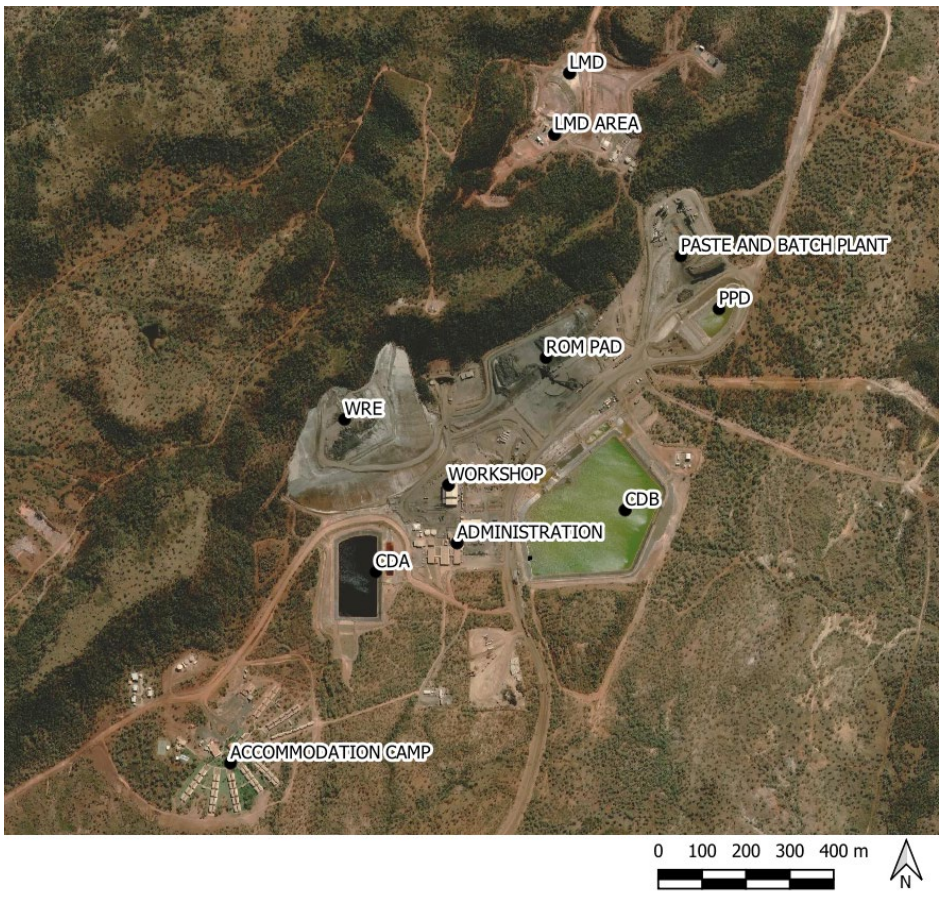
1.1 Preface

Glencore Zinc Australia via its subsidiary Noranda Pacific Pty Limited (Glencore) owns and operates the Lady Loretta Mine (LLM), located some 140 km north-north-west of Mt Isa, Northern Queensland. Underground operations at the Site commenced in 2013 and have occurred intermittently. The current campaign of mining commenced in 2018 and is scheduled to conclude in 2025. The underground workings are supported by various surface infrastructure including:

- ROM Pad
- Paste-fill plant
- Waste Rock Emplacement (WRE)
- Regulated structures (CDA, CDB, PPD, LMD)
- Ventilation equipment
- Workshop & administration
- Accommodation camp

The general site layout is shown in **DIAGRAM 1**.

DIAGRAM 1: SITE LAYOUT



LLM commissioned ATC Williams Pty Ltd (ATCW) to assist with the development of the Progressive Rehabilitation and Closure Plan (PRCP) for the Lady Loretta Mine Site. As part of this work, ATCW has

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completed an erosion assessment for areas to be reshaped as part of closure works. The purpose of this assessment is to confirm if erosion rates of the final landform comparable to pre-mining conditions and identify any erosion control measures required or changes to the proposed landform design to mitigate erosion risks.

1.2 Scope

This document has been prepared to detail the erosion risk and mitigation strategies for the final landform at LLM. The scope of the assessment undertaken is as follows:

- Review of regional climatic conditions, vegetation and geology.
- Review of site-specific soil information.
- Assessment of predicted long-term erosion loss rates for rehabilitated areas using the Water Erosion Prediction Project Model (WEPP).
- Identification of erosion controls required or if changes to final landform are required.

Assessment of the Waste Rock Emplacement (WRE) has been undertaken using SIBERIA landform evolution model. Outcomes of this assessment are provided in as Appendix C to the WRE Closure Concept Report (ATCW, 2023).

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2 BACKGROUND

2.1 Assessment Setting and Context

This report has been written as a standalone report. This section is provided to define the landform assessment setting and context.

The landform erosion assessment commences on Day One following the completion of the decommissioning, closure and rehabilitation phases of LLM. The rehabilitated (vegetated) landform will be reshaped as discussed in **Section 2.6**. Day One starts when the erosion and sediment control facilities have been decommissioned from the nominated landform (assessment) area. As **DIAGRAM 12** (refer **Section 2.6.1**) shows, LLM has been broken into landform areas based on mining and operational activities within particular catchments. It is important to note that decommissioning, closure and rehabilitation may occur at different times between different nominated assessment areas.

Further details relating to the closure and rehabilitation of LLM are described within the Lady Loretta Progressive Rehabilitation and Closure Plan (PRCP) ref: Z-LLM-HSEC-PLN.

2.2 Climate

2.2.1 Climate Summary

The regional climate is classified as semi-arid with highly variable annual rainfall. The Department of Environment and Science (DES) provides an enhanced climate database SILO (Scientific Information for Land Owners) that holds Australian climate data from 1889. The interpolated climate data is stored on a regular 0.05° latitude x 0.05° longitude grid, which is approximately 5 km x 5 km. This database was used to obtain long-term geostatistically determined climate records at the nearest grid point to Lady Loretta.

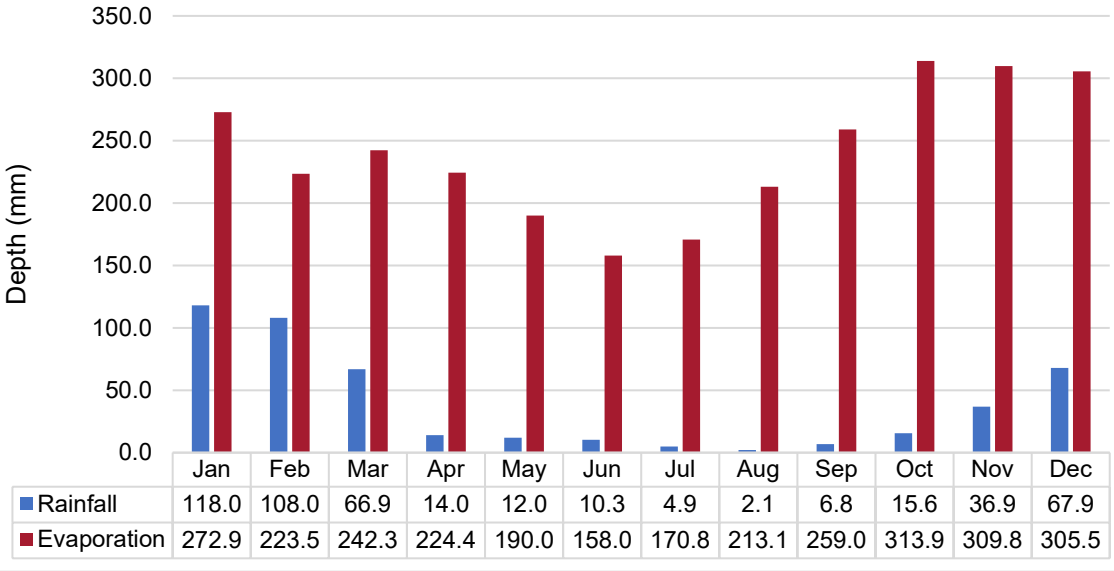
DIAGRAM 2 shows median monthly rainfall and pan evaporation. The annual and monthly statistics of rainfall is shown in **DIAGRAM 3** and **DIAGRAM 4**. **DIAGRAM 5** and **DIAGRAM 6** display evaporation records and statistics.

Annual rainfall is extremely variable (160 mm to 1,070 mm), with long-term average annual rainfall in the order of 460mm. From **DIAGRAM 2** and **DIAGRAM 3** it is evident that the site is characterised by marked seasonal rainfall. On average most of this rainfall (85%) occurs between November to March. The mean number of days with rainfall during the wet season ranges from 5.8 to 7.9 per month, with a corresponding mean wet season monthly rainfall of 72 to 115 mm. Rainfall primarily occurs as thunderstorms forming due to intense heating during the summer months as well as the inland trough that channels moisture from the northern coastal areas into the interior. Remnants of tropical cyclones occasionally bring heavy and prolong rain resulting from an extension of the monsoonal trough form northern Australia (BoM, 2023).

The average annual evaporation (2,880 mm) exceeds mean annual rainfall by a factor of 6.2 and on average is greater than rainfall for all months of the year (**DIAGRAM 3**). In general, based on precipitation and evaporation data presented in this section, the regional climate is water deficient, which is typical of a semi-arid environment.

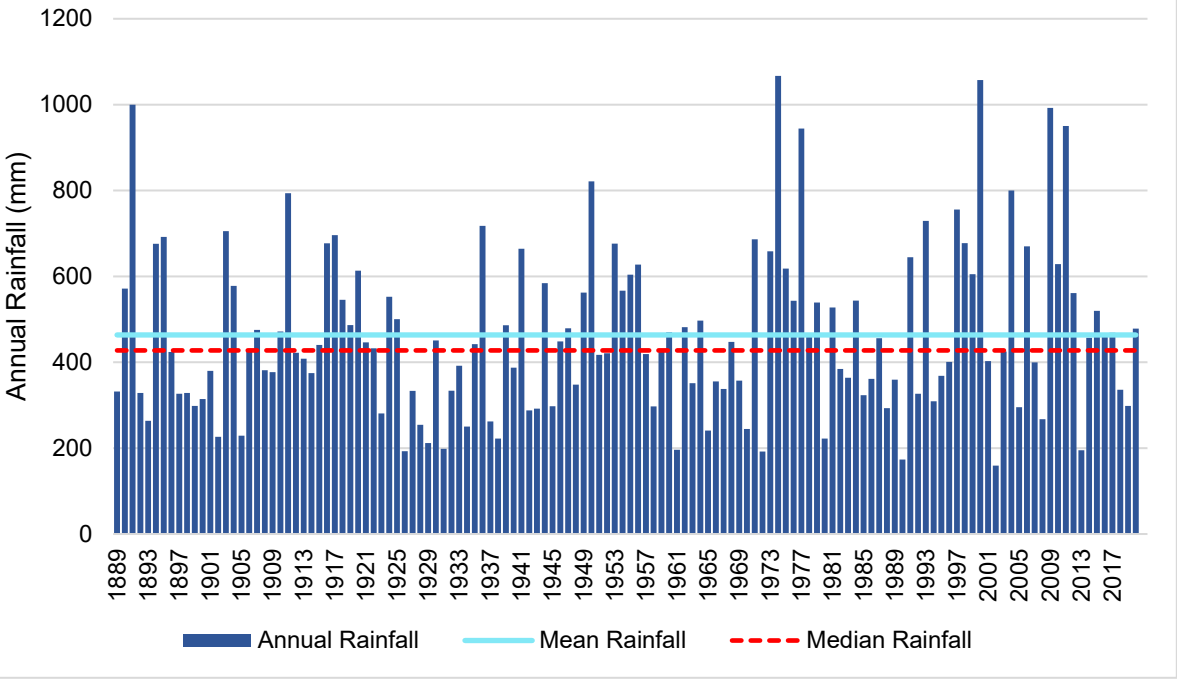
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DIAGRAM 2: MONTHLY AVERAGE RAINFALL AND EVAPORATION



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	118.0	108.0	66.9	14.0	12.0	10.3	4.9	2.1	6.8	15.6	36.9	67.9
Evaporation	272.9	223.5	242.3	224.4	190.0	158.0	170.8	213.1	259.0	313.9	309.8	305.5

DIAGRAM 3: ANNUAL RAINFALL TOTALS (SILO DATA DRILL)



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DIAGRAM 4: RAINFALL STATISTICS (SILO DATA DRILL)

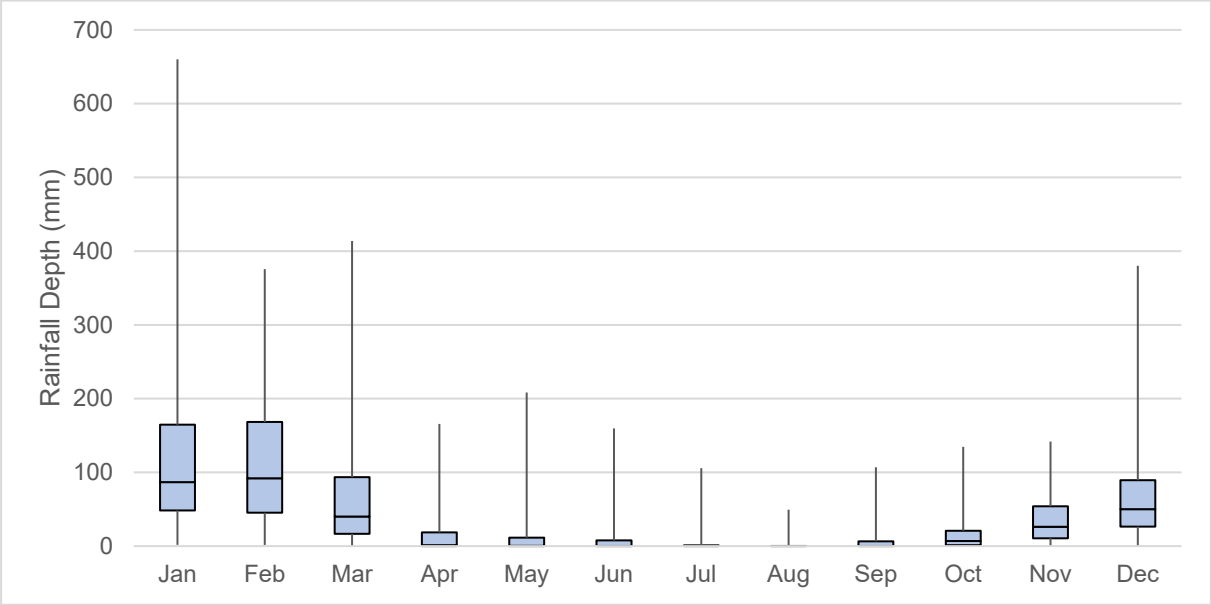
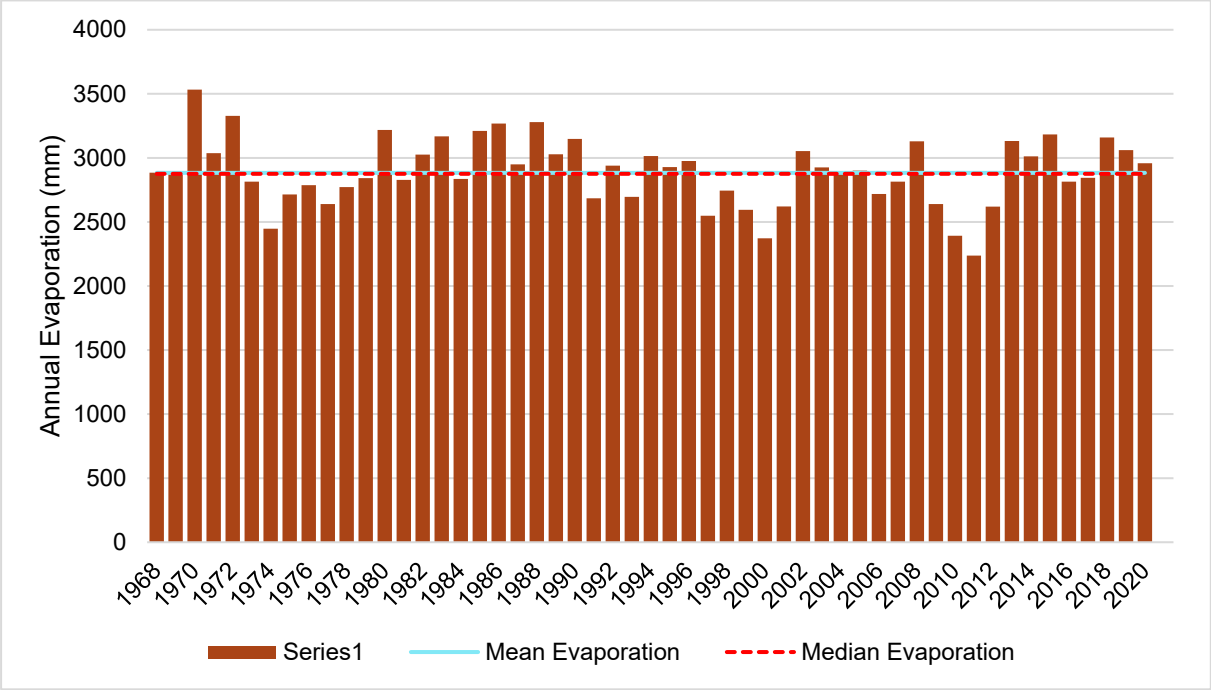
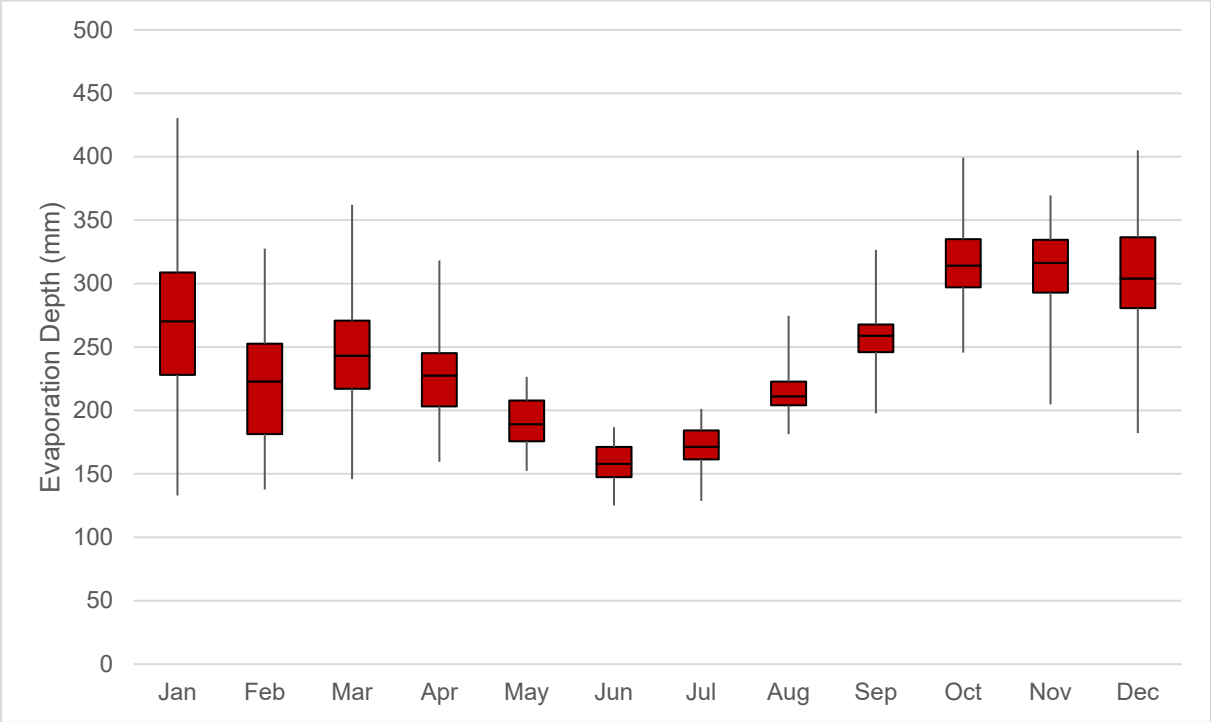


DIAGRAM 5: ANNUAL EVAPORATION TOTALS (SILO DATA DRILL)



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DIAGRAM 6: EVAPORATION STATISTICS (SILO DATA DRILL)



2.2.2 Climate Change Considerations

In considering the implications of climate change on design specifications, guidance is taken from the *Australian Rainfall and Runoff Guidelines* (Commonwealth of Australia, 2019), which has identified the following five aspects likely to be impacted by climate change in relation design flood estimation:

- rainfall Intensity Frequency Duration (IFD) relationships;
- rainfall temporal patterns;
- continuous rainfall sequences;
- antecedent conditions and baseflow regimes; and
- compound extremes (e.g. riverine flooding combined with storm surge inundation).

The magnitudes of the likely impacts on any of the aspects listed above have not been subject to comprehensive study either nationally or internationally (Commonwealth of Australia, 2019). Notwithstanding, failure to account for potential climate hazards can lead to poor decisions, particularly when the exposure risk to climate change is medium to high. In these circumstances, a reasonable approach is to make a decision that is robust against a range of plausible futures.

The Australian Climate Futures Tool, developed by the CSIRO, is a decision-support tool developed to assist understanding and application of climate change projections for impact assessment and adaptation planning. It includes projections from global and regional climate models as well as statistically downscaled results. The global climate model (GCM) data are from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) that informed the Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report as well as those used for the earlier Fourth Assessment Report (CSIRO, 2021). Maximum GCM consensus cases for Representative Concentration pathways (RCPs) 4.5 and 8.5 (moderate and high) are considered appropriate choices for the design setting (Commonwealth of Australia, 2019) on the basis that these represent what are considered more conservative as well as worst-case emissions scenarios.

GCM estimates for changes to annual rainfall at the site location are provided in **TABLE 1**, with the rating for the consensus on models described in **TABLE 2**.

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For RCP 4.5, there is high consensus of little change (-5 to +5%) to annual rainfall. For RCP 8.5, there is low consensus for changes to the annual rainfall, however the highest percentage (26%) of models also indicate little change.

TABLE 1: GCM ESTIMATED CHANGES TO RAINFALL (CSIRO CLIMATE FUTURES TOOL)

Annual Change to Rainfall	RCP 4.5	RCP 8.5
Much Drier (< -15.00%)	8 of 68 (12%)	14 of 70 (20%)
Drier (-15.00 to -5.00%)	15 of 68 (22%)	16 of 70 (23%)
Little Change (-5.00 to 5.00%)	32 of 68 (47%)	18 of 70 (26%)
Wetter (5.00 to 15.00%)	11 of 68 (16%)	14 of 70 (20%)
Much Wetter (> 15.00%)	2 of 68 (3%)	8 of 70 (11%)

TABLE 2: GCM CONSENSUS

Consensus	Proportion of models
Not projected	No models
Very Low	< 10%
Low	10% - 33%
Moderate	33% - 66%
High	66% - 90%
Very High	> 90%

In conclusion, the majority of climate change models indicate little change (+/- 5%) in estimated annual rainfall at LLM under possible future climate change (emissions) scenarios. However, there is also sufficient variability observed in the model outcomes to highlight that Glencore should continue to allow for contingencies in terms of climate and ecology when costing likely resourcing and maintenance items. These include bushfire potential as well as weed and pest control.

2.3 Geology and Soils

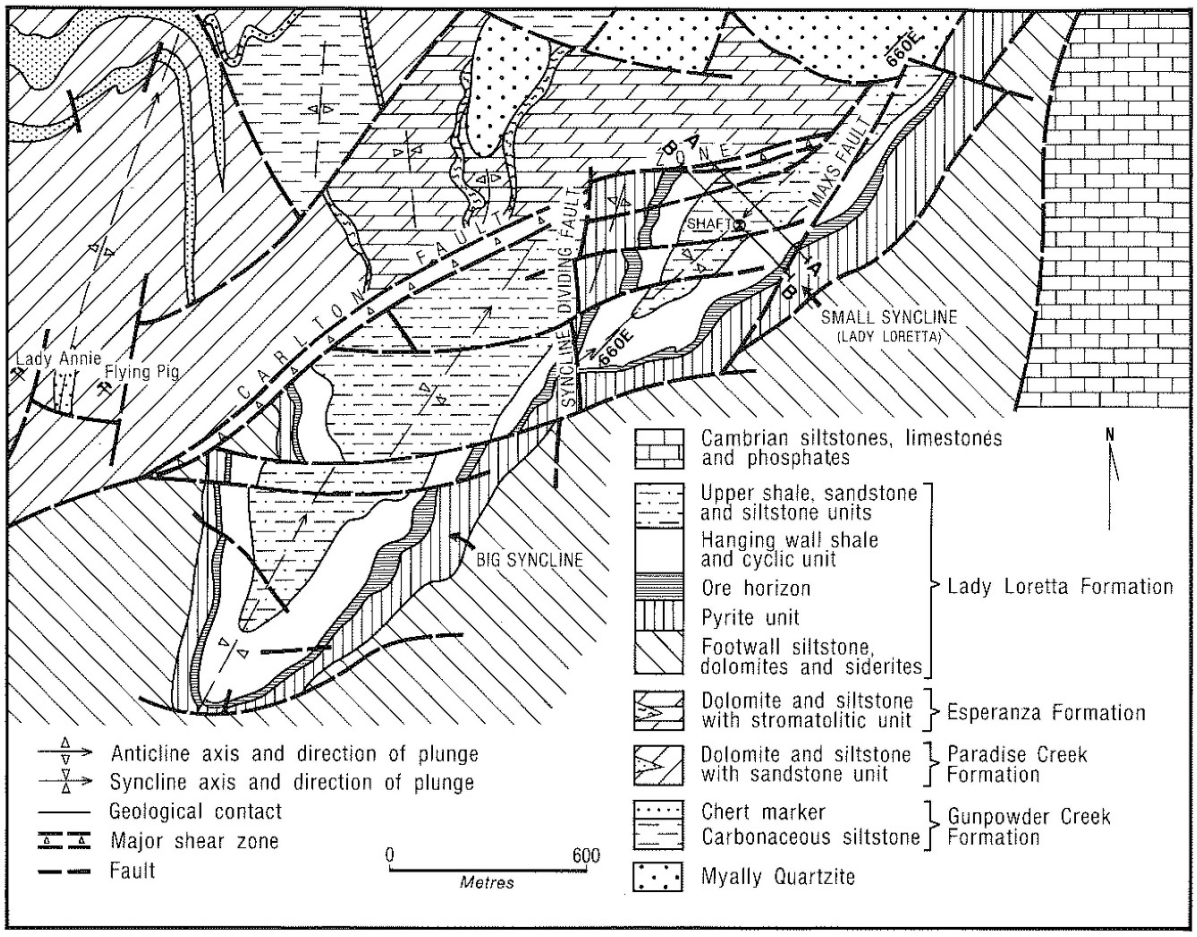
2.3.1 Regional Context

LLM is situated in the Western Fold Belt of the Mt Isa Inlier. The deposit targeted by the LLM is a Pb-Zn-Ag deposit within the Mount Isa Inlier, with the ML within the Lady Loretta Formation. The deposit is considered a classic sediment-hosted base metal deposit. Sediments hosting the deposit comprise interbedded bedded siltstone, sandstone, interclastic dolomite, carbonaceous and pyritic shale. The ore horizon is a distinctive finely banded massive sulphide lens up to 50 m thick and contains pyrite, sphalerite, galena and in places barite (Noranda Pacific, 2000).

The deposit is hosted within the Palaeoproterozoic Lady Loretta formation, which is the uppermost outcropping unit of the McNamara Group (Valenta, 2018) within the keel of the Small Syncline, a tight north-east trending fold. The Small Syncline as well as the Big Syncline are heavily faulted with a series of north-east and south trending faults. Local geology is shown in **DIAGRAM 7**.

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DIAGRAM 7: REGIONAL GEOLOGICAL MAP (HANCOCK AND PURVIS, 1990)



The Mount Isa Soil Landscape Province is a dissected plateau of Precambrian igneous, metamorphic and sedimentary rocks. Lithosols (stony or gravelly soils lacking horizon development, other than an A1 horizon) are the dominant soils and have formed either in situ on the near vertically bedded shales, or from eroded material deposited on the lower slopes and along waterways. Lithosols typically consist of a shallow gravelly layer, containing minor silt and sand content, up to 1m thick which grades into a fine to medium grained sandy loam (0.5 to 1m thick). In some areas the gravelly layer grades into a silty clay loam or a silty clay (0.5 to 2m depth) (Noranda Pacific, 2000). The soil horizons within the LLM generally contain a large proportion of coarse textured material, as well as iron and manganese nodules. Some sections (particularly the north-eastern part) have a thick 30cm layer of very fine-grained chert (Noranda Pacific, 2000). Soils along the laterite ridge above LLM site have naturally elevated concentrations of lead, zinc and silver associated with surface outcrops of the underlying ore horizon and associated pyrite bed (TropWATER, 2021).

The Mount Isa Land System, where LLM lies, has a relatively low stock carrying capacity, low pastoral potential and minimal agricultural potential. Broadly, the system consists of undulating country with spinifex pastures covering large areas, and smaller regions of woodland. The land use is restricted to exploration/mining and very low intensity stock grazing.

The Environmental Management Overview Strategy (EMOS) (Noranda Pacific, 2000) reports the Lady Loretta area to be predominantly land capability class VI on the flatter plains to the east of the deposit and the valley floors between ridgelines. On the slopes and ridges the land capability class is reported VII due to steepness of the slopes and generally shallow, rocky soils.

Emery (1985) describes capability class VI as:

(i) Land not suited to any type of cultivation but best used for grazing, and

(ii) Generally comprising land with a range of physical or climatic limitations which may include shallow soils, high rock content, excess salt concentration, steep or awkward slope gradients.

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Capability class VII is described as:

(iii) Land best to remain under green timber owing to its high soil erosion hazard and severe site restrictions, and

(iv) Generation areas of steep slopes, shallow soils and/or rock outcrop.

The strategy identifies the objective to return land disturbed by the mining activities to pre-mining land use of low intensity grazing and pre-mining capability class.

2.3.2 Site Soils

A soil sampling program was undertaken by RGS between 2020 and 2021 (RGS, 2022), which included surface (grab) sampling of soils, test pitting, auguring and core drilling. The purpose of this Rehabilitation Material Sampling and Analysis Program (RMSaAP) was to identify available soil and rock types and quantities from borrow areas that will be suitable for rehabilitation of areas disturbed by mining operations. Based on observed conditions during the investigation, the following soil horizons were identified (RGS, 2023):

Topsoil - top layer of the native soil profile recognised by higher organic carbon content, some development of soil structure, the presence of plant roots, and typically containing the soil seed bank.

Subsoil - soil layer underlying the native topsoil, typically identified by a decrease in organic carbon content and fewer (and finer) roots. The characteristics of subsoil materials vary markedly depending on the soil type. Subsoils that are not acidic, saline or sodic are a valuable resource suitable for use during the rehabilitation program. Together, topsoil and subsoil constitute growth medium as a Major RM_{UNIT}.

Weathered clay - typically massive heavy clays with low permeability, high plasticity and increased soil strength. The characteristics of these materials vary markedly depending on the clay mineralogy and the presence of salts in the landscape. Weathered clay that is not sodic may be suitable for use as a subsoil during the rehabilitation program due to its capacity to retain water.

Saprolite - typically weathered-rock materials identified by the presence of iron and aluminium oxides. Depending on the chemistry, these materials may be suitable for use as a subsoil or rocky soil mulch layer during the rehabilitation program due to its more favourable physical characteristics when compared to the heavy clay overburden.

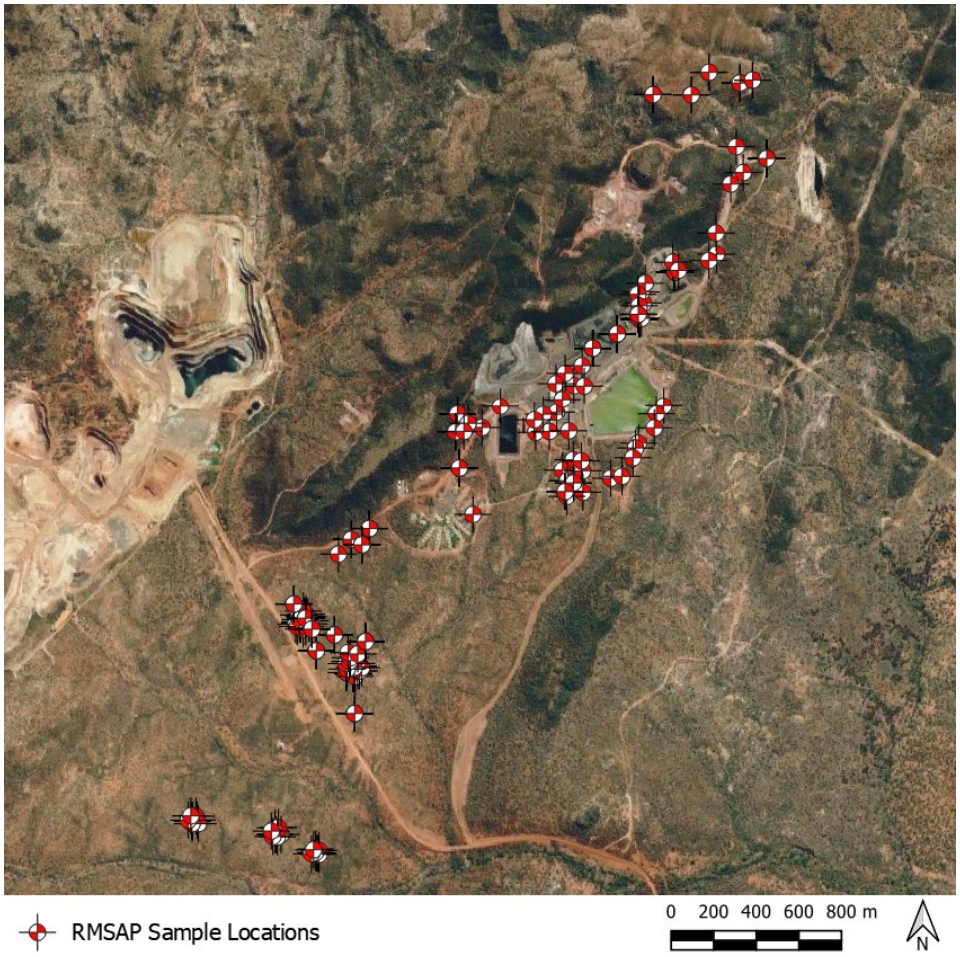
Saprock - typically weathered materials and partially weathered rock identified by the presence of fines (< 2 mm particle size distribution (PSD) comprising iron and aluminium oxides and residual rock fragments (from gravel to cobble size rock). Together, saprolite and saprock are generally classified as rocky soil mulch as a Major RM_{UNIT}.

Fresh rock (bedrock) – depending on various physical characteristics and benign chemistry, fresh rock may be suitable for use during the rehabilitation program as rock mulch or surface rock armouring. Fresh rock is usually classified as competent rock as a Major RM_{UNIT}.

Soils relevant to erosion modelling generally comprise the topsoil and subsoil unit. A summary of laboratory test results, which are relevant to WEPP modelling as outlined in RGS (2022) is provided below. The location of test samples is shown in **DIAGRAM 8**.

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DIAGRAM 8: SAMPLE LOCATIONS



Dispersion

Emerson class testing was undertaken during the RMSaAP with results summarised as follows:

- 60% were Emerson Class 2: these tests are done on soil peds and samples have some dispersion
- 20% were Emerson Class 3: this is a sub class of Class 7 that has no dispersion from a soil ped and after remoulding samples have some dispersion
- 20% were Emerson Class 5: this is a sub class of Class 7 that has no dispersion from a soil ped and after remoulding samples have minor dispersion attributed to gypsum or carbonate minerals (RGS, 2021).

Further Emerson class testing undertaken identified:

- 2% are Emerson Class 1: a single sample of saprolite is both slaking and dispersive
- 19% are Emerson Class 2: these tests are done on soil peds and samples have some dispersion
- 49% are Emerson Class 3: this is a sub class of Class 7 that has no dispersion from a soil ped and after remoulding samples have some dispersion
- 15% were Emerson Class 4: this is a sub class of Class 7 that has no dispersion from a soil ped and after remoulding samples have minor dispersion attributed to gypsum (4g) (n=6) or carbonate (4c) (n=1) minerals
- 15% were Emerson Class 6: this is a sub class of Class 7 that has no dispersion from a soil ped and after remoulding samples remain aggregated (flocculated) (RGS, 2023).

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Particle Size distribution

Excluding gravels, soils from borrow areas are generally 40 – 60% sand, 20 – 40% silt and 30 – 50% clay. Soils from infrastructure areas are generally 45 – 60% sand, 30 – 50% silt and 0 – 30% clay.

Organic (%)

Soil nutrients such as organic matter, phosphorous and cation exchange capacity are naturally low in the soils and saprolite but nevertheless support native flora and can be used for rehabilitation of mine areas. Total organic carbon (TOC) was 0.3% to 10.6% with a median of 0.3% and total organic matter (OM) was 0.3% to 6.1% with a median of 0.3%. TOC and OM are highest in topsoil (0.0 – 0.5 m) samples from all borrow and infrastructure areas.

CEC (meq/100g)

The cation exchange capacity (CEC) results from borrow areas were 0.9 to 21.2 meq/100g with a median of 4.9 meq/100g and are sufficient to support native vegetation. Based on the results, the CEC is higher in topsoil and subsoil due to their higher clay content and lower in saprolite samples, verifying that topsoil and subsoil have a better ability to provide nutrients. The exchangeable sodium percentage (ESP) results were 0.1% to 73% with a median value of 6%. The ESP tests verify 49% of the samples are sodic and strongly sodic based on agricultural classification (Hazelton and Murphy, 2016) and were found in topsoil, subsoil and saprolite samples.

2.4 Topography and Land Use

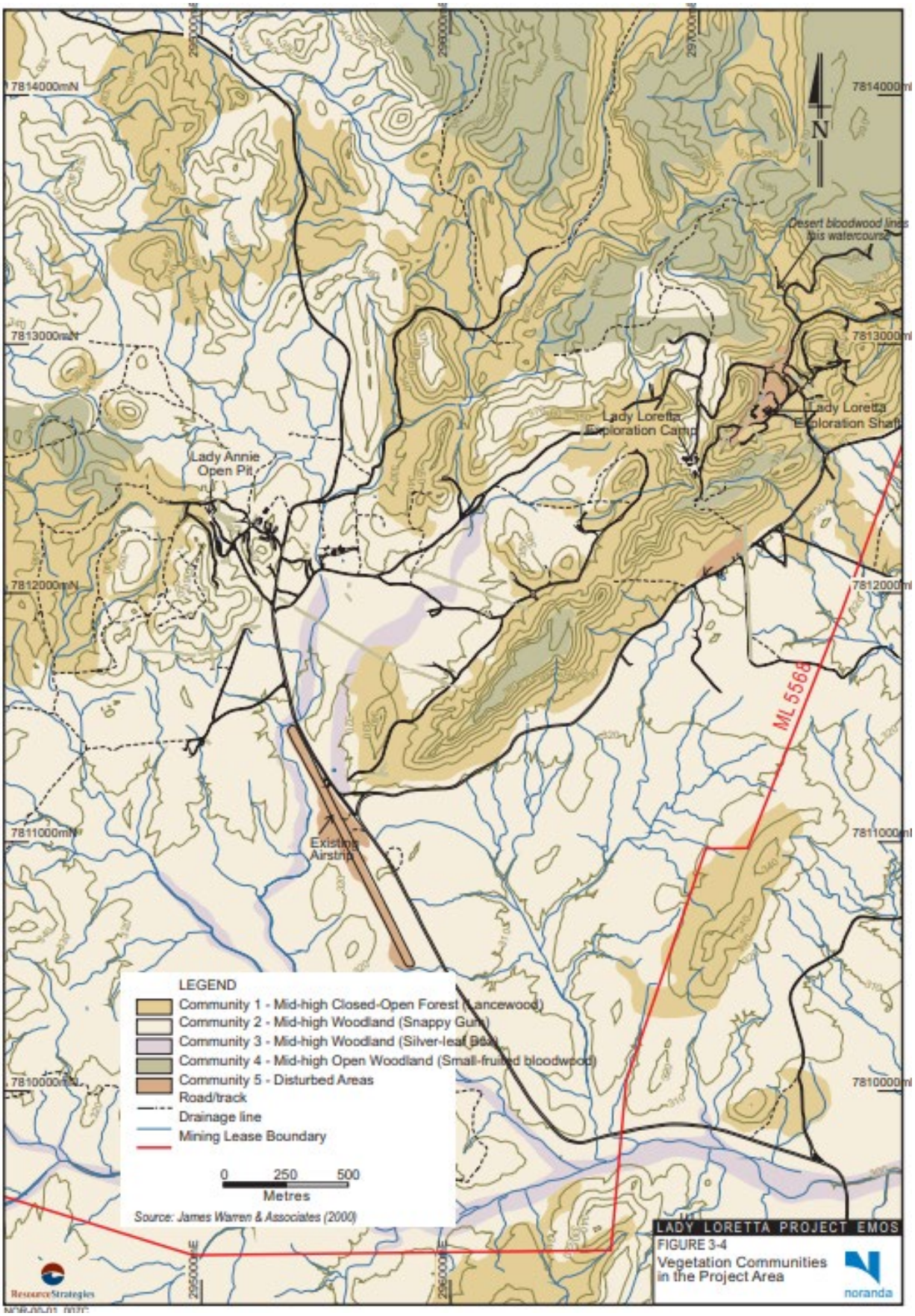
Topography of the mine is dominated by the “Big Syncline”. The eastern limb of this syncline forms the main ridgeline at LLM. The ridgeline is orientated in a north-east to south-west direction. Elevations across the mine vary from approximately 380 m Australian Height Datum (AHD) to 320 m AHD.

Most of the mine infrastructure is located on the edge of a ridgeline, occupying levels between 325 m and 335 m AHD at typically low gradients, less than 3% slope. The steepest gradients found at LLM are approximately 40% to 50% on the hill slopes of the Big Syncline. To the east, south-east and north-east of LLM the topography flattens and is dominated by undulating plains with occasional lower hills and ridgelines (Noranda Pacific, 2000).

A plan showing the pre-disturbance vegetation types is presented in **DIAGRAM 9**.

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DIAGRAM 9: PRE-DISTURBANCE VEGETATION MAP



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Land use types at LLM can be broadly characterised as Lowland Plain or Steep Ridges. A description of each of these areas is provided below.

2.4.1 Lowland plain

Much of the fixed plant and surface infrastructure at the Site has been developed on a lowland plain bordered by the eastern boundary of the ML and the ridge that hosts the Lady Loretta orebody. The alluvial plain is relatively flat with slopes typically less than 8%. Although nutrient poor, soils and sub-soils have developed by a combination of in-situ weathering of the underlying strata and/or accumulations of sediments transported from the nearby ridges. Vegetation on this terrain type comprises Regional Ecosystems 1.11.2a and 1.3.6a. The EMOS described them as:

(i) Community 2 - Mid-High Woodland (Snappy gum).

Prior to mining, the lowland plain was utilised by livestock as a component of a low intensity cattle grazing land use.

2.4.2 Steep ridges

The Lady Loretta orebody is hosted in a ridge that runs north-east to south-west. The ridge comprises siliceous sediments that have been folded to form a dipping syncline. The folding has resulted in typical slopes of 15% but scree slopes of 40% are common. The shales and mudstones are relatively tight and resist percolation of meteoric water into the groundwater system except in areas of heavy fracturing. The sloped terrain and low rates of infiltration results in high rates of surface runoff and naturally high rates of erosion. Soils are typically sparse and nutrient poor.

The pre-mining vegetation on this terrain type reflects Regional Ecosystem; 1.11.2 (found on rocky hills), 1.7.5a and 1.7.5b (formally known as 1.7.1x1 and 1.11.2x2a respectively) and was described in the EMOS as:

(i) Community 1 - Mid-High Closed-Open Forest (Lancewood), and

(ii) Community 4 - Mid-High Open Woodland (Small fruited bloodwood).

Prior to mining, the steep ridges were available for grazing of livestock but is unlikely that cattle utilised the grasses available due to their relative sparseness and lack of available drinking water. The pre-mining land use was Native Ecosystem for native fauna.

2.5 Stable Non-Polluting Landform Criteria and Objectives

Successful rehabilitation and closure of LLM will result in a stable non-polluting landform. A stable non-polluting landform from an erosion perspective is one that mimics the pre-development conditions. Success criteria for LLM landform erosion modelling is to be set based on both quantitative and qualitative criteria. The quantitative success criteria are to be based on achieving a soil loss rate similar to that of the surrounding land; whilst the qualitative success criteria will be based on how the proposed landform adopts similar topographical features to that of the surrounding land.

2.5.1 Regional Erosion Rates

Establishing a baseline for regional erosion rates is important to quantify rehabilitation objectives and success criteria. Soil erosion rates are notoriously difficult to measure, due to the number of variables including, but not limited to surface grade, rainfall, soil type, vegetation cover and land management.

Given that there are currently no established guidelines, criteria or objectives for erosion rates, typical regional conditions have been considered for the purposes of this assessment.

Lu et al (2001) presents a national hillslope erosion loss estimate as depicted in **DIAGRAM 10** based on empirical soil loss equations. Based on this diagram, soil loss rates within the LLM region are in the order of 20 to 50 t/ha/yr.

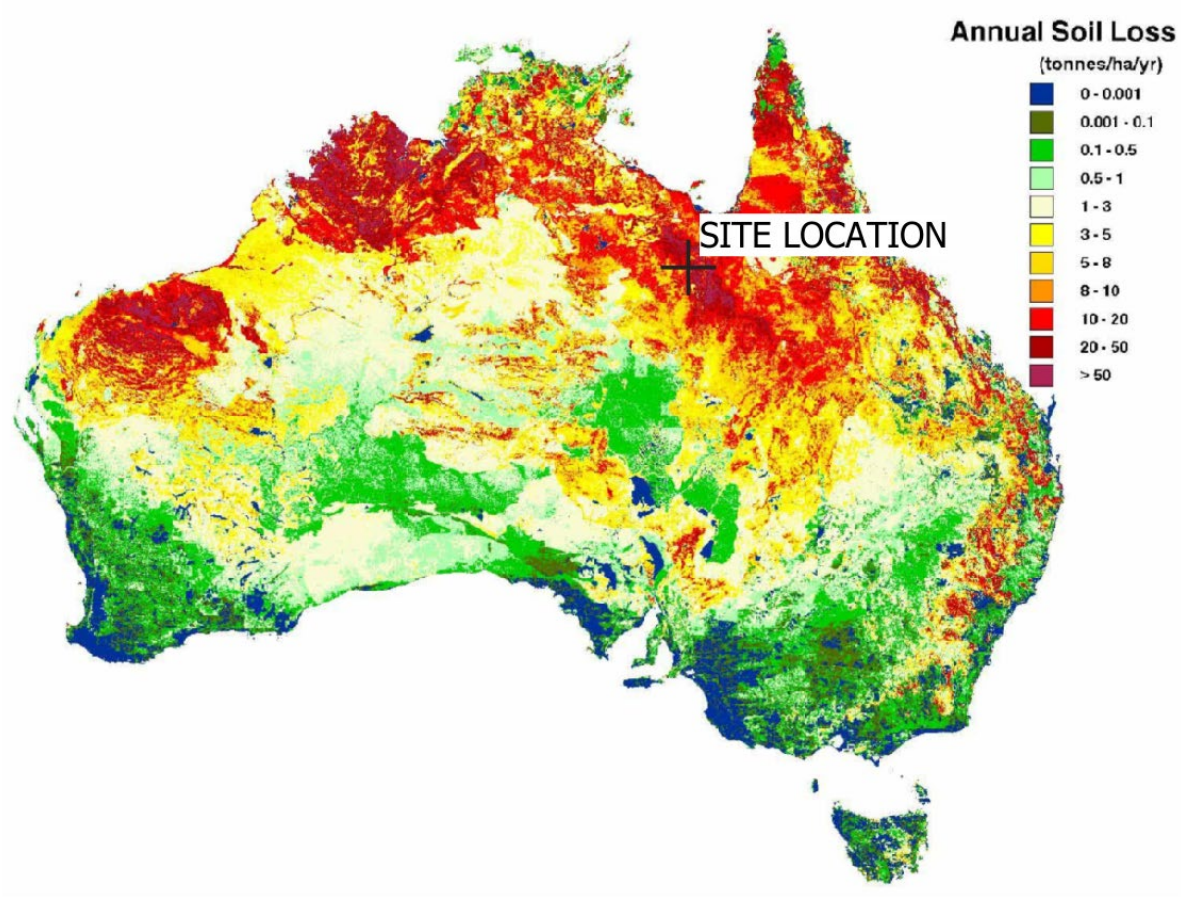
Recognising natural soil loss rates presented by Lu et. al. (2001), climatic conditions limiting vegetation growth and moderate dispersivity of site soils can be found, a maximum average annual erosion loss rate of 30t/ha/yr (nominally about 2 mm/yr) is deemed appropriate for rehabilitated landforms at LLM and therefore has been adopted as the threshold for drainage controls. The adopted maximum average

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annual erosion rate of 30t/ha/year accounts for natural replenishment from upgradient sources and is based on contemporary published literature and will provide a reasonable and feasible approach to demonstrating long-term stability and consistency of the final landform with pre-mining conditions.

It is important to note that the presented values are annual averages that are considered over the long-term and that measured erosion rates in any one year will vary due to temporal climatic conditions.

DIAGRAM 10: AUSTRALIAN SOIL LOSS RATES



2.5.2 Example Landform

To characterise the local natural topography and drainage conditions, an example landform similar in scale to the LLM rehabilitation areas has been mapped. The chosen landform appears to be generally undisturbed by mining or other human activities. The landform is located approximately 800m south east of the site and includes both steep ridges and lowland plains as shown in **DIAGRAM 11**.

Steep ridges have minimal drainage features owing to surfaces generally comprised of weathered rock, with higher resistance to erosion. Lowland plains have a high density of drainage features (incised gullies), with spacing generally ranging from 15m to 50m, depending on the surface grade (ranging from 15% to <3%). In reviewing the example landform and other landforms surrounding LLM, the maximum overland flow length is generally 100m. This means that surface flows are only conveyed up to a maximum of 100m or so before their flow depth and velocity create a drainage path. Based on observations of site soils, the high density of incised gullies is likely a result of moderately dispersive of site soils (refer **Section 2.3.2**) and typically low vegetation density. This chosen example landform is therefore a great point of reference to determine whether the success criteria for stable and non-polluting is achieved for the LLM assessment areas.

Based on observations of the example landform, considerations for final landforms are as follows:

- Steep, rocky faces are a natural occurrences and are likely to withstand erosion and scouring, provided insitu materials are comprised of competent rock.

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- Lowland plains require drainage features to control conveyance flow volumes and velocities and to confine deposition, erosion and scouring. Without constructed drainage features to reduce the length of overland flow paths, incised gullies will likely form through erosion and scouring, with the severity increasing based on soil type, vegetation cover, slope and contributing catchment area. During this process the landform is unlikely to be considered stable as there is a risk of undercutting steep batter slopes and scouring which potentially could change the landform and surface hydrology. By defining the locations of drainage features the final landform will be stable at Day One of completion of the rehabilitation.

DIAGRAM 11: REFERENCE SITE

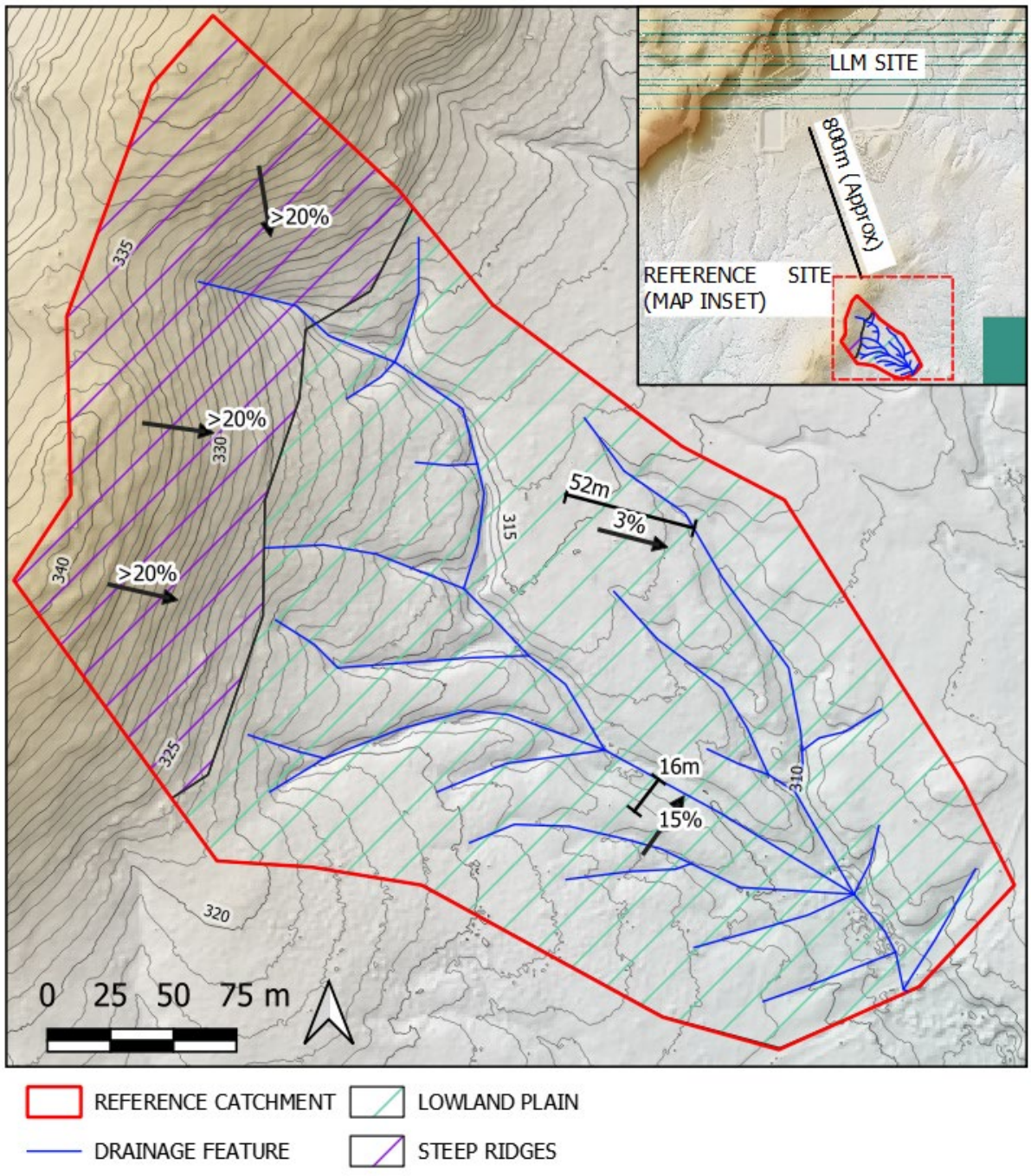


DIAGRAM 11 above shows steep batters only form drainage paths to convey flows from upstream contributing catchments. Whilst within the lowland plain areas, drainage paths are formed with a separation distance of 20m where surface slopes are steep and a separation distance of 50m or more where surface slopes are flat.

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2.5.3 Vegetative Cover

Similar to **Section 2.5.2**, the target vegetative cover is to mimic two vegetation types defined in **Section 2.4**, with snappy gum woodland on lowland plains and open woodland to open-forest of *acacia shirleyi* on steep ridges. An example photo of both the low land plains and steep batters are shown in **DIAGRAM 12** and **DIAGRAM 13.**

DIAGRAM 12: NATIVE HABITAT/STEEP BATTERS



DIAGRAM 13: LOW INTENSITY CATTLE GRAZING/ LOWLAND PLAINS



2.5.4 Adopted Criteria

The adopted stable non-polluting landform criteria and description are listed below:

TABLE 3: ADOPTED CRITERIA

Criteria	Description
Soil Loss Rate	30 t / ha / yr (max. annual average)
Cover soil type	Steep Ridges - Rocky Mulch Lowland Plain – Topsoil and/or Subsoil
Vegetative Cover	Refer to example **DIAGRAM 12** and **DIAGRAM 13** Trees on steep ridges whilst lowland plain areas containing spinifex.
Drainage Pathways and Features	Limit drainage pathways (all areas). Steep Ridges - Only provide batter chutes for the conveyance of upstream catchments, provide bunds at top of batters to reduce surface flows across batters. At the detailed design stage provide rock armouring in areas to assist in slowing flows and reducing scour. Lowland Plains – Limit overland flow length to less than 100m. Provide furrows at set spacings to ensure that the target soil loss is not exceeded. Based on the example landform, gullies will likely vary between 20m to 70m.

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2.6 LLM Final Landform

2.6.1 Geometry

Landform geometry adopted for modelling is based on the final landform model in the PRCP. General reshaping of areas will occur during closure as shown in **DIAGRAM 14** and summarised as follows:

ROM Area:	External batters graded to 1V:4H. Surface graded at 1% to the back of the natural hill. It is understood growth media will be applied to the entire surface of the ROM. Two separate sections were modelled in WEPP, with the batters and plateau considered separately. A diagram of the modelled conditions for the ROM is depicted in **DIAGRAM 15**.
Paste and Batch Plant Area, CDA and CDB:	These areas will be reshaped to ensure no slopes steeper than 25% and are free draining. This area includes the reprofiled batters of the decommissioned Erosion and Sediment Control (ESC) Facilities. It is understood that no growth media in these areas would be required as the underlying subsoil is suitable for supporting vegetation growth.
LMD Area:	Area to be reshaped to ensure no slopes steeper than 25%. No growth media would be applied as the underlying subsoil is suitable for supporting vegetation growth.
Borrow Areas:	Five conceptual borrow areas have been developed and provided by LLM for assessment. These borrow pits comprise borrow pits A, B1, B2, C and I (as shown in **DIAGRAM 14**). It is understood that likely not all of these borrow pits would be required. Growth media will be applied to base on pits.

Geometry for each area modelled is provided in **TABLE 4** and shown in **DIAGRAM 14**.

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TABLE 4: SOIL UNITS

Area		Maximum Slope Length	Average Grade	Plan Area
ROM	XS1 (Plateau)	80m	25%	2ha
	XS2 (Batter)	50m	1%	1ha
Paste and Batch Plant		230m	8%	9.2ha
CDA Area		160m	4%	16.5ha
CDB Area		120m	3%	5.6ha
LMD Area		280m	4%	3.2ha
Borrow Areas*	A	250m	Batters: 25% Floor: 1%	6.9ha
	B1	330m	Batters: 25% Floor: 1%	5.2ha
	B2	230m	Batters: 25% Floor: 1%	4.1ha
	C	130m	Batters: 200% Floor: 1%	1.3ha
	I	280m	Batters: 25% Floor: 1%	4.0ha

*Note: all borrow area options included however not all will be required.

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DIAGRAM 14: FINAL LANDFORM

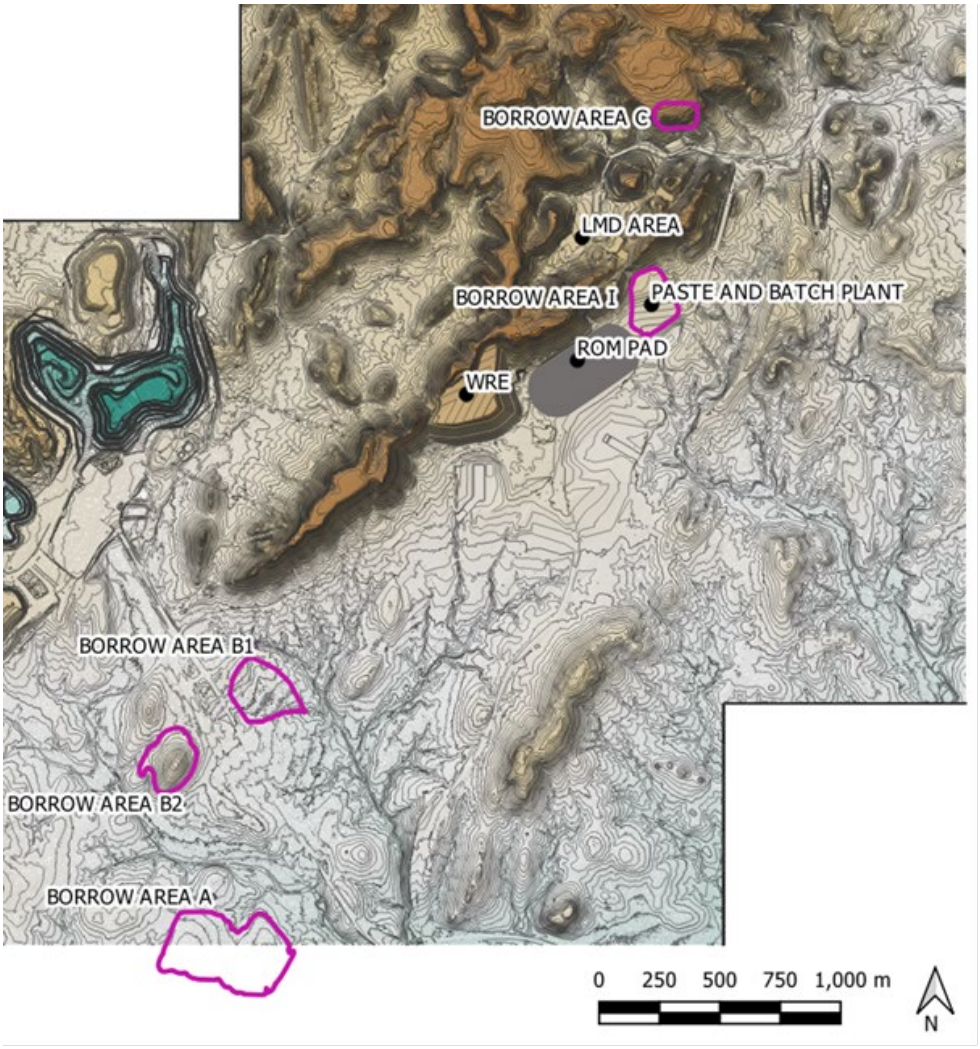
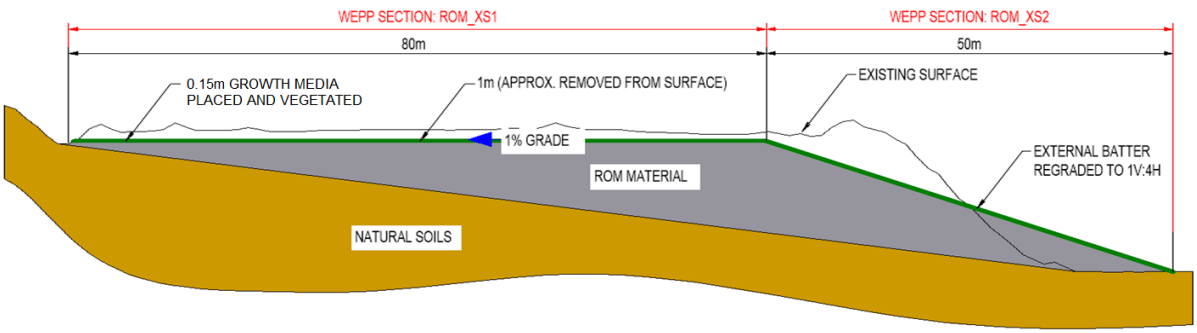


DIAGRAM 15: ROM FINAL PROFILE



2.6.2 Drainage Control

The proposed final landform comprises long, unbroken overland flow paths, drainage features are therefore required to reduce the overland flow paths. This will be achieved through the construction of contour furrows. Contour furrows are proposed to reduce the overland flow path length of rehabilitated

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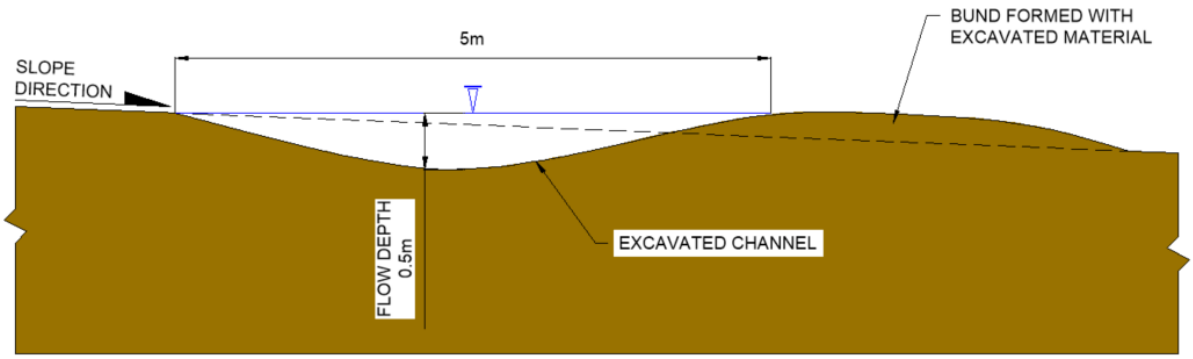
catchments. The function of the furrows is to limit erosion loss during rainfall events by reducing sheet flow potential through shorter flow pathways and lower flow velocities. The furrows reduce the energy associated with sheet flow thus limiting the sediment carrying capacity. During extreme rainfall events, runoff overtopping the furrows could induce sheet flow; however, flow velocity would be lower than that of unfurrowed ground surfaces, thus reducing erosion impacts.

The general concept for a contour furrow is presented in **DIAGRAM 16** and summarised as follows:

- The majority of the furrow is to be formed through excavation, which will reduce the risk of failure through piping or overtopping) by eliminating embankments and associated failure risk.
- Furrows generally constructed parallel to the ground slope, as to minimise longitudinal grade.
- Excavated material from channel used to form a bund on the downstream side of the channel to increase hydraulic capacity.
- Gentle slopes (eg: 1V:5H) on channel and bund batters.
- Maximise base width compared to channel depth, which in turn minimises flow depth, flow velocities and erosion, a typical ratio of 10V:1H could be applied.
- Drainage furrows to report to a central drain.
- Where excavation exposes dispersive, sodic or highly sodic soils, additional measures may be required such as treatment of soils (lime dosing or similar), rock armouring, or excavation and replacement of unsuitable soils.
- At future project phases, a review of drainage furrows conveyance shall be undertaken to confirm flow depths and velocities will not result in significant erosion or scouring. Additional erosion control including rock armouring (or other suitable treatment) may be required. Rock size or other treatment details will be determined based on site-specific factors).

DIAGRAM 17 shows an example catchment utilising furrows. The proposed furrow spacings presented in **Section 3** (and WEPP modelling) adopts a similar methodology for erosion control.

DIAGRAM 16: CONTOUR FURROW TYPICAL DETAIL



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DIAGRAM 17: CONTOUR FURROW EXAMPLE LAYOUT



2.6.3 Vegetation

Two land types are proposed for the rehabilitated site, comprised of low intensity cattle grazing and native habitat. The description of the vegetation type(s) for each of these areas is provided below. Delineation of these areas, with respect to areas to be rehabilitated are discussed in **Section 3.7**.

Low intensity Cattle Grazing:

Open woodlands dominated by *Eucalyptus leucophloia* and native grasses including spinifex. Some improved pasture species will be used to improve the palatability of the grasses present.

Native Habitat:

The species mix applied to the Native Habitat area will reflect the woodlands dominated by Lancewood and the small-fruited bloodwood. The species mixes have been designed to give due regard to availability as well as to milestone criteria as outlined in the PRCP. Specific mixes may be modified slightly to account for variations in the environmental features of a particular rehabilitation area.

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3 WEPP MODELLING

3.1 Background

The Water Erosion Prediction Project (WEPP) is a 2-Dimentional erosion simulation model used to predict and calculate estimates of soil detachment and deposition as well as simulation of the hydrologic and erosion processes on small watersheds.

The purpose of WEPP modelling is to estimate the soils loss for rehabilitated areas, based on site climate, soil characteristics, expected vegetation conditions and catchment geometry.

The performance objective for rehabilitated areas is to achieve similar erosion loss rates to analogous locations around the site, undisturbed by mining. Analogous locations would be defined as areas with similar surface grades and soil types. As such, the objective of this assessment is to estimate erosion rates for the proposed landform design, confirm that the predicted rates are within the range of natural erosion rates for similar local landscapes and where predicted erosion rates are determined to be unacceptable, identify mitigation measures to reduce erosion loss. Evaluation of erosion rates over the long-term is an appropriate approach for assessing post-closure landform stability and erosion risk, noting that temporal erosion rates will vary from year to year due to temporal climatic conditions.

WEPP (Version 2012.8) has been used to estimate soil loss for the final landform within the following site locations (assessment areas):

- Paste and Batch Plant Area
- ROM Area
- CDA Area
- CDB Area
- LMD Area
- Borrow Areas A, B1, B2, C, and I

It is noted that the WEPP model adopts a typical section across each landform, which may not include features such as drains or access roads). Notwithstanding, as WEPP results are used to estimate soil loss from the entire catchment, adopted geometry is deemed to represent average catchment conditions.

3.2 Closure Objectives

As outlined in **Section 2.5.1**, target maximum annual average soil loss rates are less than 30t/ha/yr. Additional landform closure objectives with respect to soil loss from the final landforms is to achieve grades similar to natural, undisturbed land, achieve suitable vegetation cover and appropriate land management. Details of these objectives are detailed in the PRCP.

3.3 Final Landform Geometry

For each of the assessment areas (refer **Section 3.1**), a 2d section was derived from the final landform model is presented in **Appendix B**.

3.4 Model Duration

A model duration of 20 years was adopted for all sections. This time period is considered an appropriate model duration noting the following:

- Vegetation is assumed to be established at the beginning of the model start time, as erosion control structures would remain in place until sufficient ground cover was established, nominally to be established by a construction and rehabilitation works completion date of 2038 (refer **Section 2.5.3**).

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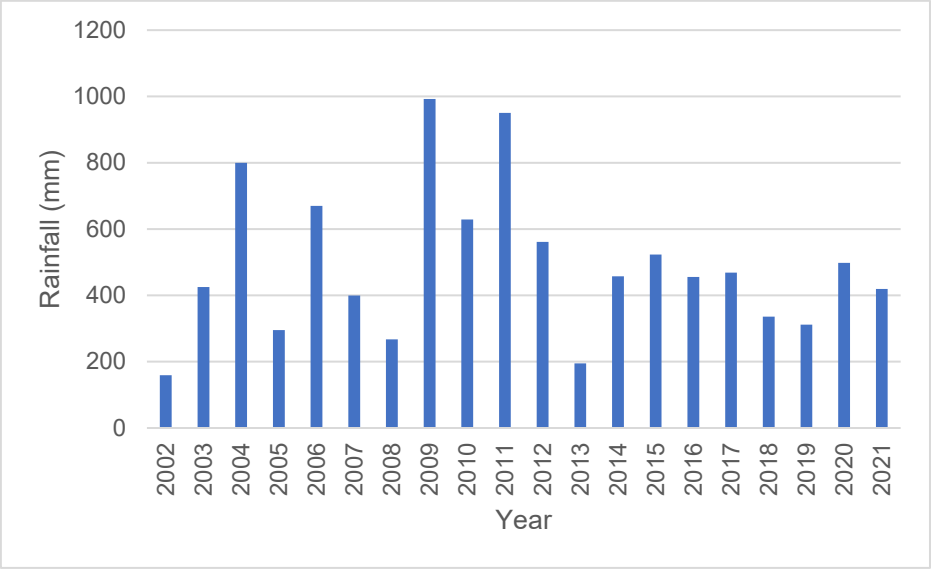
- The 20-year period adopted includes years of high and low rainfall, allowing assessment of loss rates for varying climatic conditions.
- Although annual or seasonal short term soil loss rates will vary over time, predicted erosion rates are not expected to expose soil multiple horizons (i.e. erosion into the subsoil).
- Results indicated erosion loss rates (across the 40 modelled scenarios to range from <1t/ha/yr in dry years to around 100t/ha/yr in wet years) fluctuated annually depending on rainfall and generally did not trend upwards or downwards (model in state of equilibrium).

If modelled duration were different than the adopted 20-year duration, the ability to represent long-term climate influence is reduced and modelled erosion rates could be affected. If model duration was shorter, then erosion rates could be higher in "wetter" than average climate dataset or lower if the adopted climate conditions were "dryer" than average. Because the model predictions show a stable erosion rate over the 20-year period, longer model durations would be expected to be similar to the current model predictions, thus demonstrating that the model sensitive to climate and a representative climate record is necessary for accurate prediction.

3.5 Climate Data

Twenty years of SILO data for Mt Isa, from the years 2002 to 2021, was used in the simulation. The annual rainfall for the years 2002 to 2021 are shown in **DIAGRAM 18**. The modelled period includes years of low rainfall (2002, 160mm) and high rainfall (2009, 992mm), compared to a mean annual rainfall of 464mm (refer **DIAGRAM 3**).

DIAGRAM 18: ANNUAL RAINFALL



3.6 Soil Parameters

Soil input parameters to WEPP were estimated using laboratory test results obtained during the RMSAP (RGS, 2021) and empirical formulas. Noting, the final profile will generally comprise in-situ soils in cut areas and likely blended soils in areas of fill, no rainfall simulation or flume testing was undertaken. As discussed in Section 2.5.2 the proposed rehabilitation landform features are similar to the surrounding landscape. There are sufficient nearby natural landscapes with similar topographic features to qualitatively confirm the modelled assessment area landform results. By performing a visual calibration check of the final stable landform, to the surrounding natural landscapes, both the WEPP model results and adopted soil loss threshold can be said to be verified.

Key soil test data used for the analysis is outlined in **TABLE 5**.

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TABLE 5: WEPP SOIL INPUT PARAMETERS

Layer	Depth (mm)	Sand (%)	Clay (%)	Rock (%)	Organic (%)	CEC (meq/100g)
Topsoil	155	40	10	25	1.1	10
Subsoil	682	43.5	28	2	1	5

WEPP uses inbuilt empirical equations to determine soil loss rates, with key formula provided as follows:

Interrill Erodibility

Interrill Erodibility the susceptibility of the soil detachment by raindrop impact and shallow flows.

For soils with 30% or more sand:

Ki = 2728000 + 1921000*VFS

Where VFS is very fine sand percentage (≤40%)

For soils less than 30% sand:

Ki = 6054000 – 55130*CLAY

Where CLAY is percentage clay in surface soil (≤40%)

Rill Erodibility

Rill erodibility reflects the susceptibility of the soil the shear detachment by water flowing in rills.

For surface soils containing 30% or more sand, the equation for Kr is:

Kr = 0.00197+0.0003*VFS+0.03863e-1.84ORGMAT

Where VFS is very fine sand in the surface soil (≤40%)

ORGMAT is percentage of organic matter in the surface soil (≥0.35)

For surface soils containing less than 30% sand the equation for Kr is:

$Kr = 0.0069 + 0.134e^{-0.20CLAY}$

If clay is less than 10%, 10% is used in the equation for Kr for soils containing less than 30% sand.

Critical Shear

Critical shear is a threshold value, under which rill detachment does not occur.

For soils containing 30% or more sand, the equation is

TAUc = 2.67 + 0.065*CLAY-0.058*VFS

For soils with less than 30% sand:

TAUc = 3.5

Effective Hydraulic Conductivity

For soils with ≤ 40% clay content

Kb = -0.265 + 0.0086*SAND^1.8+11.46*CEC^-0.75

For soil with >40%

Kb = 0.0066exp(244/CLAY)

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3.7 Vegetation

The post mine land use for areas modelled is based on the land descriptions provided in the PRCP and summarised in **TABLE 6**. Vegetation parameters used in the modelling are provided in **TABLE 7**, based on aerial and visual inspections of background sites, a sensitivity analysis of these parameters was undertaken by increasing and decreasing plant density. Results were not materially impacted by changes to the plant parameters within the practical limits of the semi-arid climate type.

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TABLE 6: POST MINE LAND USE

Area		Post Mine Land Use
ROM	S1 (Plateau)	Low Intensity Cattle Grazing
	S2 (Batter)	
Paste and Batch Plant		Low Intensity Cattle Grazing
CDA		Low Intensity Cattle Grazing
CDB		Low Intensity Cattle Grazing
LMD		Native Habitat
Borrow Areas	A	Low Intensity Cattle Grazing
	B1	Low Intensity Cattle Grazing
	B2	Low Intensity Cattle Grazing
	C	Native habitat area
	I	Low Intensity Cattle Grazing

TABLE 7: VEGETATION PARAMETERS

Parameter	Units	Spinifex	Native Habitat
In-row plant spacing	cm	0.6	100
Plant stem diameter at maturity	cm	0.5	25
Maximum canopy height	cm	60	250
Maximum leaf area index		6	6
Maximum root depth	cm	100	200
Percent of growing season when leaf area index starts to decline (0-100%)	%	85	25
Percent canopy remaining after senescence (0-100%)	%	70	50

3.8 WEPP Outputs

The primary output from WEPP is the estimated soil loss rate (t/ha/yr). The modelled average annual soil loss rates are provided in **TABLE 8**. As discussed in **Section 2.5.2**, a key feature of the natural landscape (particularly low-lying areas) is a high density of incised gullies, reducing the sheet flow lengths for rainfall runoff. In the final landform, to reduce erosion rates drainage furrows are required to reduce sheet flow lengths as discussed in **Section 2.6.2**. The spacing of drainage furrows is based on achieving an annual average soil loss rate of 30t/ha/yr. The general alignment for drainage furrows is presented in figures in **Appendix A**. Soil loss rates for each of the rehabilitation areas if no furrows were implemented and with furrows is presented in **TABLE 8**. Performance of each of the final landform is as follows:

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CDA

The gradient for the rehabilitated footprint of the CDA area generally ranges from 2% to 4%. A maximum sheet flow length of some 250m would exist without contour furrows, resulting in a modelled soil loss rate of around 160t/ha/yr. Through the implementation of contour furrows at 30m, a reduced soil off rate of around 28t/ha/yr is achieved.

Recognising the relatively low gradients of the rehabilitated areas, satisfactory erosion rates are achieved with the implementation of drainage furrows at frequencies shown in **Appendix A**.

CDB

The rehabilitated footprint of the CDB area comprises variable slopes, generally ranging from 2% to 12%. Sheet flow lengths for CDB are reduced compared to CDA, which facilitates lower soil loss rates.

Within the steepest section of CDB (gradient of around 12%), the sheet flow length is around 40m. Flatter sections (2% grade) have overland flow paths up to 100m long. Due to the higher gradients in CDB, closer spacing of drainage furrows is required, with results indicating 20m required. Without furrows, soil loss rates up to 121t/ha/yr are expected.

Paste and Batch Plant

The rehabilitated footprint of the paste and batch plant comprises variable slopes, generally ranging from 1% to 14%. The northern most portion of the area comprises flatter surfaces (1 to 4%), with the steeper segment located to the south (up to 14%). Unbroken sheet flow length of up to 400m would exist without the implementation of drainage controls. For the implementation of furrows the northern area (segment 1) requires furrow spacing of 50m to achieve soil loss rates of 19t/ha/yr. The southern portion (segment 2) requires furrow spacing of 30m to achieve soil loss rates of around 29t/ha/yr.

ROM Pad

The surface of the ROM pad achieves acceptable erosion rates without furrows due to low gradient (1%) and maximum sheet flow length of around 80m. The batters require drainage controls at 15m spacing due to a surface gradient of 25%. On the ROM batters it would be recommended to construct a series of benches on the batters, rather than install drainage furrows. The general configuration of the ROM batters would therefore comprise 2 x 5m wide benches at around 15m horizontal increments.

LMD Area

The profile of the final LMD area generally comprises low gradient slopes, in the order of 3 to 4%. Unbroken flow path lengths of up to 300m would exist without drainage controls. Through the implementation of furrows at 60m spacing, an estimated soil loss rate of around 22t/ha/yr is achieved, which is below the adopted annual average erosion rate.

Borrow areas

The floor of all borrow areas have been designed at 1% grade. The proposed spacing of contour furrows at 100m achieves a soil loss rate of 29t/ha/yr.

Batters for borrow areas A, B1, and I have been designed at 1V:4H. The maximum slope length for the batters of B1 is around 15m, which achieves erosion rates of around 26t/ha/yr. Batter lengths for borrow pits A and I are around 30m and 25m respectively. Model results indicate a soil loss rate of some 49t/ha/yr based on a slope length of 30m. Whist this does not achieve target soils loss rates, the solution is SFAIRP (so far as is reasonably practicable). No furrows are proposed on the batters noting the following:

- Furrows would be difficult to construct on batters and result in the steepening of batters, thus potentially increasing local erosion along the batter slope.
- If batters were flattened, to achieve the required borrow volume, the batter footprint area would increase, which would increase the disturbance area for each borrow pit or reduces the volume of available borrow material if the current borrow pit footprint were to be maintained.
- Soil loss rates are maintained below maximum regional soil loss rates of 50t/ha/yr as discussed in **Section 2.5.1**, recognising that undisturbed catchments contain natural steep slopes which have inherently more erosion potential than flatter slopes.
- Batters exceeding 15m in length, comprise less than 10% of the total landform footprint.

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Batters for Borrow Quarry C have been designed at 2V:1H. It is assumed that the in-situ soils on the batters would comprise quartz rock and would therefore be resistant to erosion. Furrows are shown on the floor of the Borrow Quarry C, however, may not be required if the exposed floor is competent rock, being resistant to erosion. This would be confirmed during the construction phase. Borrow area B2 does not have batters or areas steeper than 1%, with the estimated erosion rate of 29t/ha/yr applicable to the entire borrow area.

TABLE 8: AVERAGE ANNUAL SOIL LOSS RATES (T/HA/YR)

Area	Without Furrows	With Furrows	Furrow Spacing
CDA – Seg 1	160 t/ha/yr	28 t/ha/yr	30m
CDB – Seg 1	121 t/ha/yr	25 t/ha/yr	20m
Batch Plant – Seg 1	159 t/ha/yr	19 t/ha/yr	50m
Batch Plant – Seg 2		23 t/ha/yr	30m
LMD Area	70t/ha/yr	22 t/ha/yr	60m
ROM – Seg 1	140 t/ha/yr	29 t/ha/yr	15m
ROM – Seg 2	24 t/ha/hr	NA	None
Borrow Areas Floor	54 t/ha/yr	29 t/ha/yr	100m
Borrow Area Batters	30m length: 49 t/ha/yr 15m length: 26 t/ha/yr	NA	None

Qualitatively, proposed furrow spacing is generally consistent with the frequency of incised gully formation in undisturbed catchments as discussed in **Section 2.5.2**. Therefore, the design criteria set out in **Section 2.5** is achieved.

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4 CONCLUSIONS AND RECOMMENDATIONS

For modelling, an average soil loss rate of 30t/ha/yr was deemed acceptable based on regional soil loss rates and the following observations from the region:

- The regional climate is characterised by relatively low rainfall (average 460mm/year) with a distinct wet season characterised by thunderstorms and occasional ex-tropical cyclones bringing intense heavy rainfall for prolonged periods. Average monthly days of rainfall during the wet season ranges from 5.8 to 7.9 days per month. Variance of rainfall across the average is on the order of 20 to 25% (BoM, 2023).
- Local soils are generally moderately dispersive.
- Slopes are generally low (typically 2 to 4%, with short batters, typically less than 20m in length, at 25%) and comparable to the surrounding landscapes.

Based on the assessment undertaken, the final landform requires drainage controls to reduced sheet flow lengths. Without these drainage controls, high erosion rates would likely occur, with incised gullies forming resulting in sediment laden runoff. Model results indicate once the furrows are implemented, acceptable soil loss rates are achievable, nominally set with a maximum average loss rate of 30t/ha/yr. A qualitative review of furrow spacing compared to undisturbed areas, indicates similar spacing between drainage features. Expected soil loss rates are comparable to catchments undisturbed from mining activities.

On this basis, the proposed landform, with required controls, is suitable as a final landscape and can achieve soil loss performance objectives, including limiting landform erosion and sediment transport off-site, no change in sediment deposition in existing downgradient creeks and no material change to suspended sediment loads above natural levels. .

The above notwithstanding, key factors to the success of the final landform are:

- Avoiding concentrated flow (having the potential to cause significant erosion and scouring, i.e. reducing sheet flow to <10 mm in depth and avoiding channelised flow) which has generally been achieve with the conceptual final landform design presented in the PRCP.
- The establishment of vegetation through appropriate surface preparation, seeding, and grazing management for varying post mine land uses adopted for site.
- Monitoring and maintenance of drainage controls should be implemented until stabilisation is established to verify the landform design is appropriate and functioning according to the design. Monitoring and maintenance activities including inspection of sediment build up post wet season, removing debris and inspection of gully-forming erosion should be undertaken in accordance with the PRCP monitoring and maintenance plan.

Final landform to be consistent with surrounding landscape, with respect to surface gradient, vegetation and drainage features. .This model is intended to identify the scale erosion on post closure landforms over a prolonged period, as a comparison to natural, undisturbed catchments adjacent to mine affected areas. It is also intended to identify where erosion controls are required to reduce overland flow distances and erosion risk.

This model is not intended to provide precise estimates for soil loss rates, particularly over short-duration, high intensity rainfall events. Notwithstanding, the average annual soil loss rates generally account for these events, with the objective of modelling met through establishing estimated long term soil loss rates.

The key model limitations are as follows:

- Soil and vegetation parameters are based on empirical laboratory test results, empirical formulas and published literature. Site information for the scale of this assessment would be impractical to obtain, due to variability in landform geometry, soils, vegetation density, climatic factors and other factors.
- Models adopts a typical 2D section, recognising that variability in slope distances and grades are present.
- The model considers a portion of the entire catchment, whereby sediment deposition from upstream catchments may not be considered. Similarly, the point of deposition from sediment runoff from the catchment modelled may be downstream of the modelled section.

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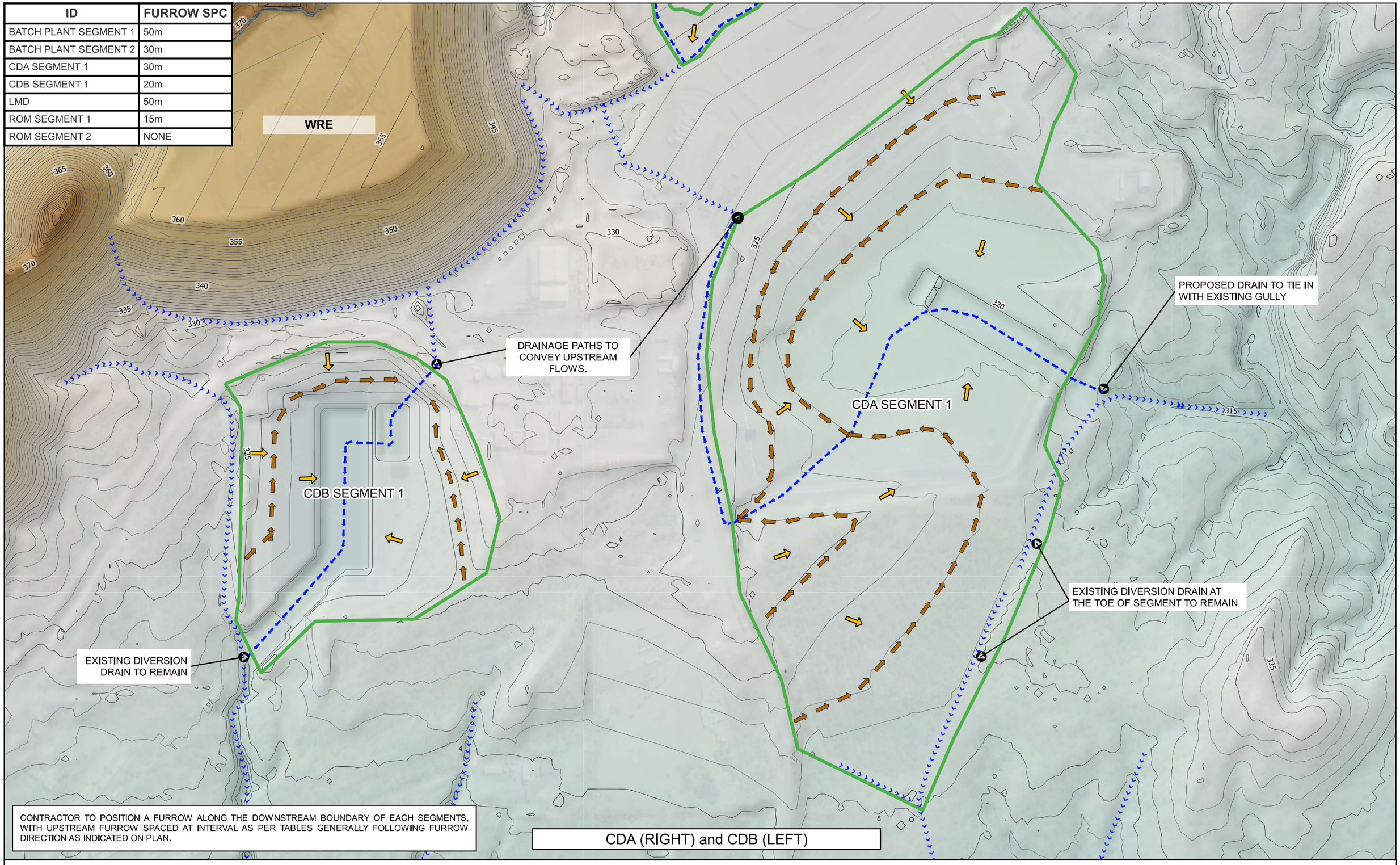
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APPENDICES

APPENDIX A – FIGURES

ID	FURROW SPC
BATCH PLANT SEGMENT 1	50m
BATCH PLANT SEGMENT 2	30m
CDA SEGMENT 1	30m
CDB SEGMENT 1	20m
LMD	50m
ROM SEGMENT 1	15m
ROM SEGMENT 2	NONE



0 60 120 180 240 m

LEGEND:

- ASSESSMENT AREA
- EXISTING DRAINS
- PROPOSED DRAIN
- FURROW DIRECTIONAL ALIGNMENT (NTS)
- FLOW ARROW

FIGURE 001
LADY LORETTA MINE - FINAL LANDFORM EROSION ASSESSMENT

CONCEPT GEOMETRY & DRAINAGE CONTROLS
(SHEET 1 / 4)

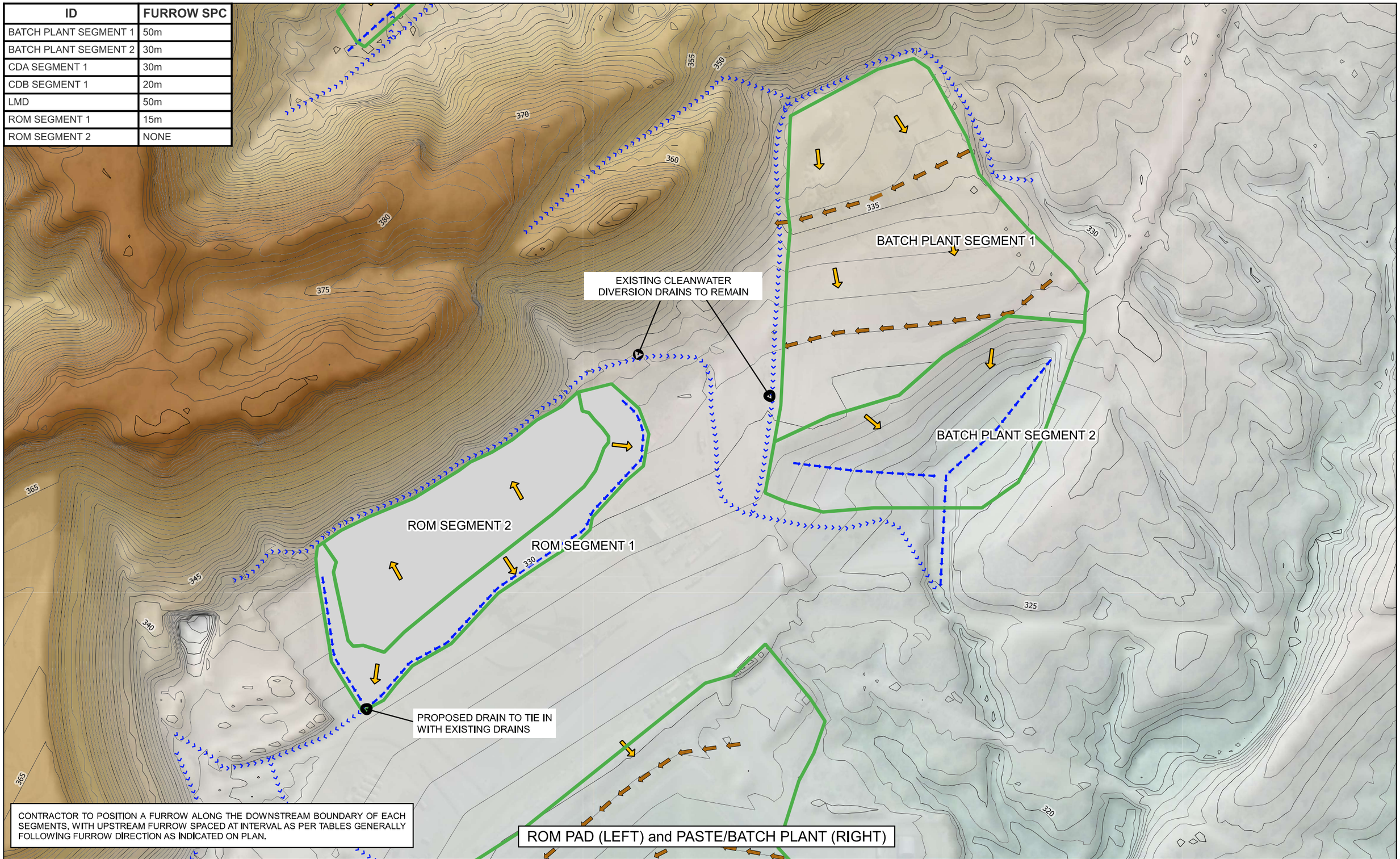
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ID	FURROW SPC
BATCH PLANT SEGMENT 1	50m
BATCH PLANT SEGMENT 2	30m
CDA SEGMENT 1	30m
CDB SEGMENT 1	20m
LMD	50m
ROM SEGMENT 1	15m
ROM SEGMENT 2	NONE



0 60 120 180 240 m

LEGEND:

- ASSESSMENT AREA
- EXISTING DRAINS
- PROPOSED DRAIN
- FURROW DIRECTIONAL ALIGNMENT (NTS)
- FLOW ARROW

FIGURE 002
LADY LORETTA MINE - FINAL LANDFORM EROSION ASSESSMENT

CONCEPT GEOMETRY & DRAINAGE CONTROLS
(SHEET 2 / 4)

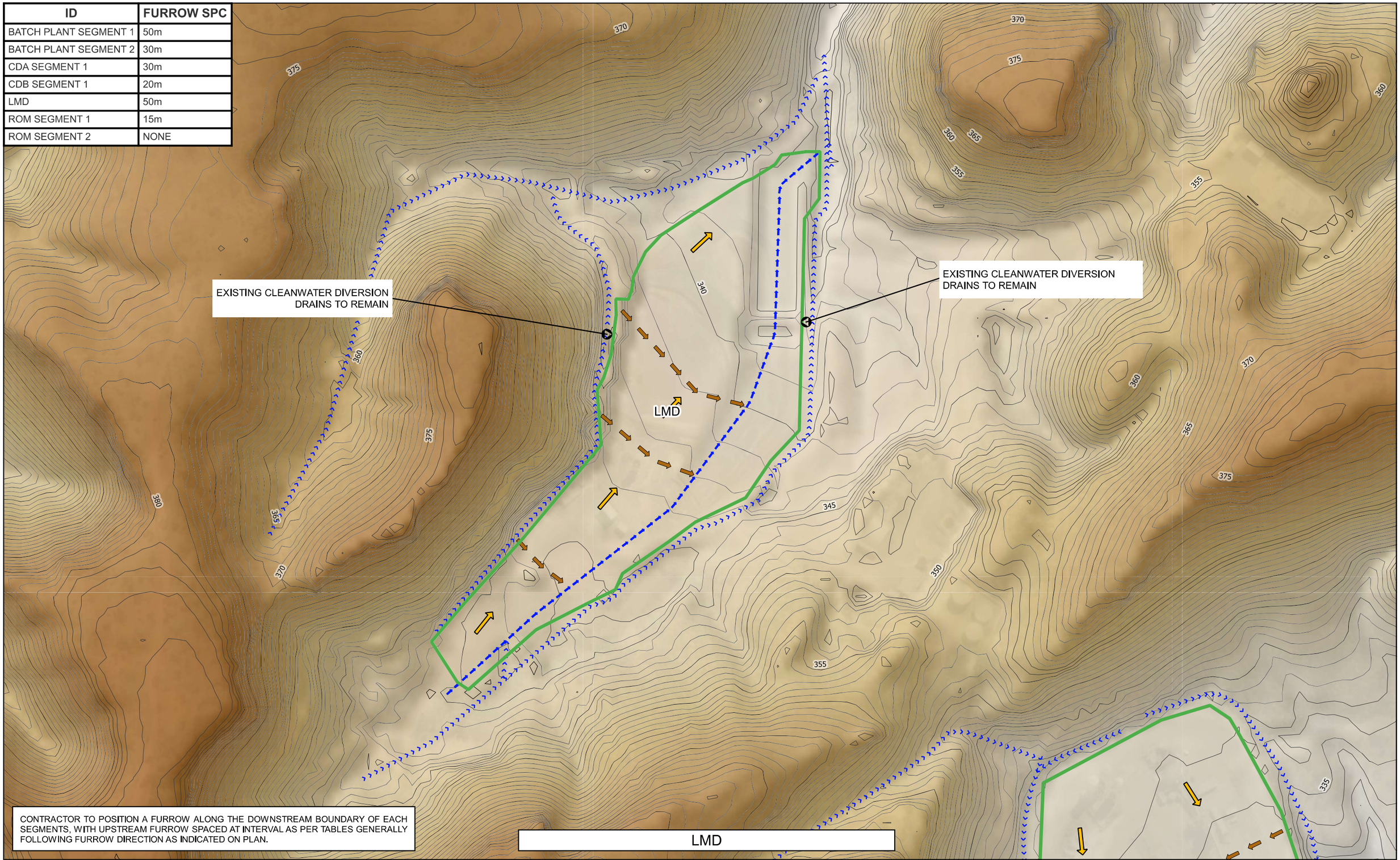
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ID	FURROW SPC
BATCH PLANT SEGMENT 1	50m
BATCH PLANT SEGMENT 2	30m
CDA SEGMENT 1	30m
CDB SEGMENT 1	20m
LMD	50m
ROM SEGMENT 1	15m
ROM SEGMENT 2	NONE



0 50 100 150 200 m

LEGEND:

- ASSESSMENT AREA
- EXISTING DRAINS
- PROPOSED DRAIN
- FURROW DIRECTIONAL ALIGNMENT (NTS)
- FLOW ARROW

FIGURE 003
LADY LORETTA MINE - FINAL LANDFORM EROSION ASSESSMENT

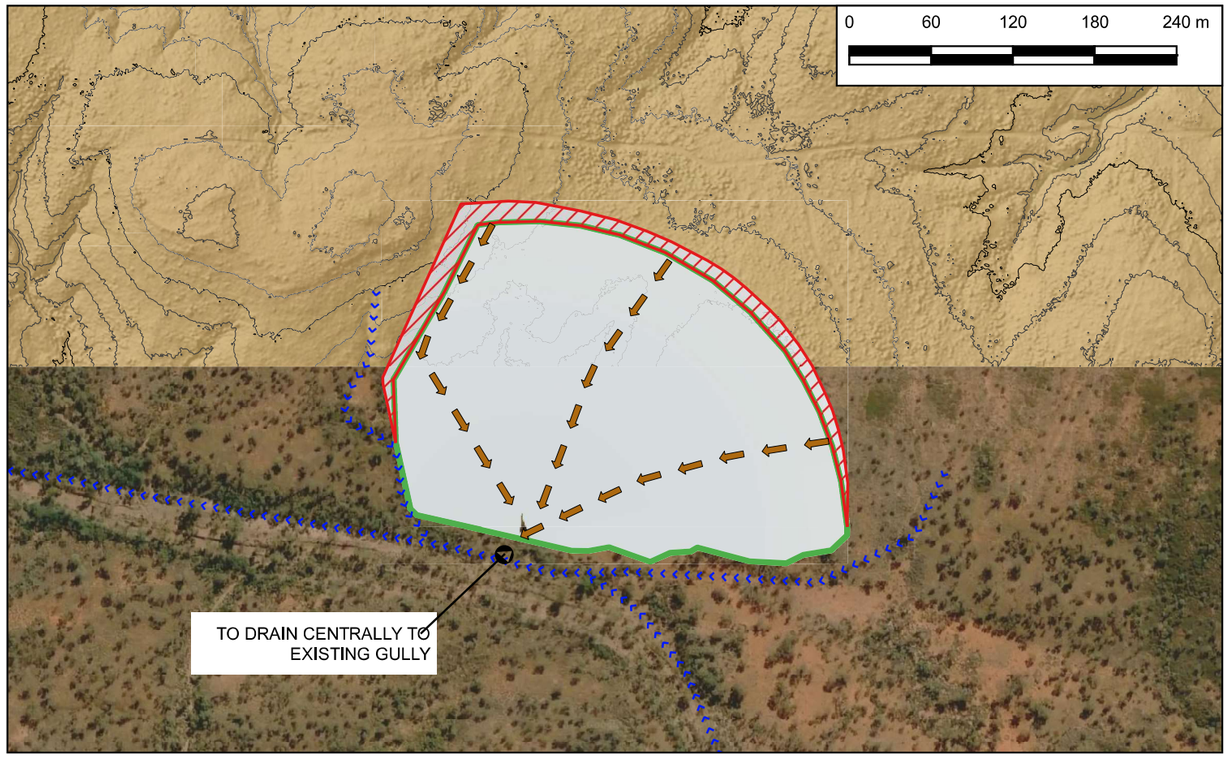
CONCEPT GEOMETRY & DRAINAGE CONTROLS
(SHEET 3 / 4)

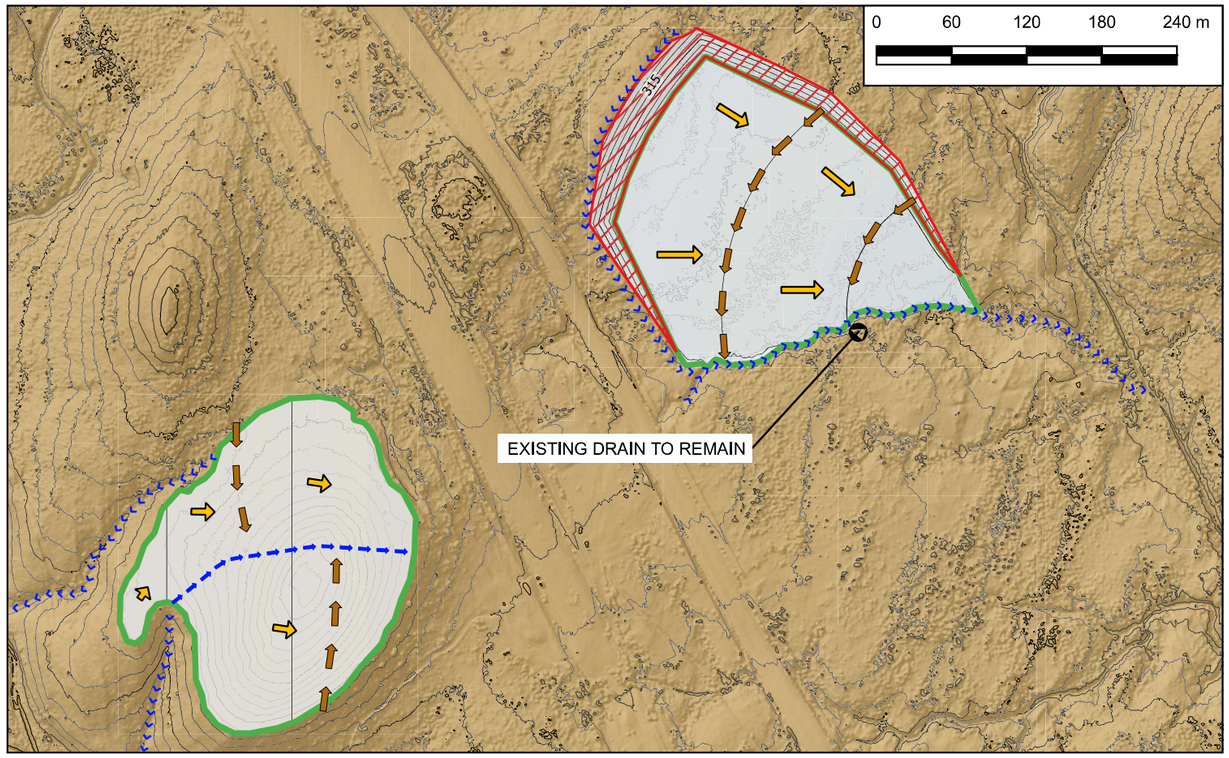
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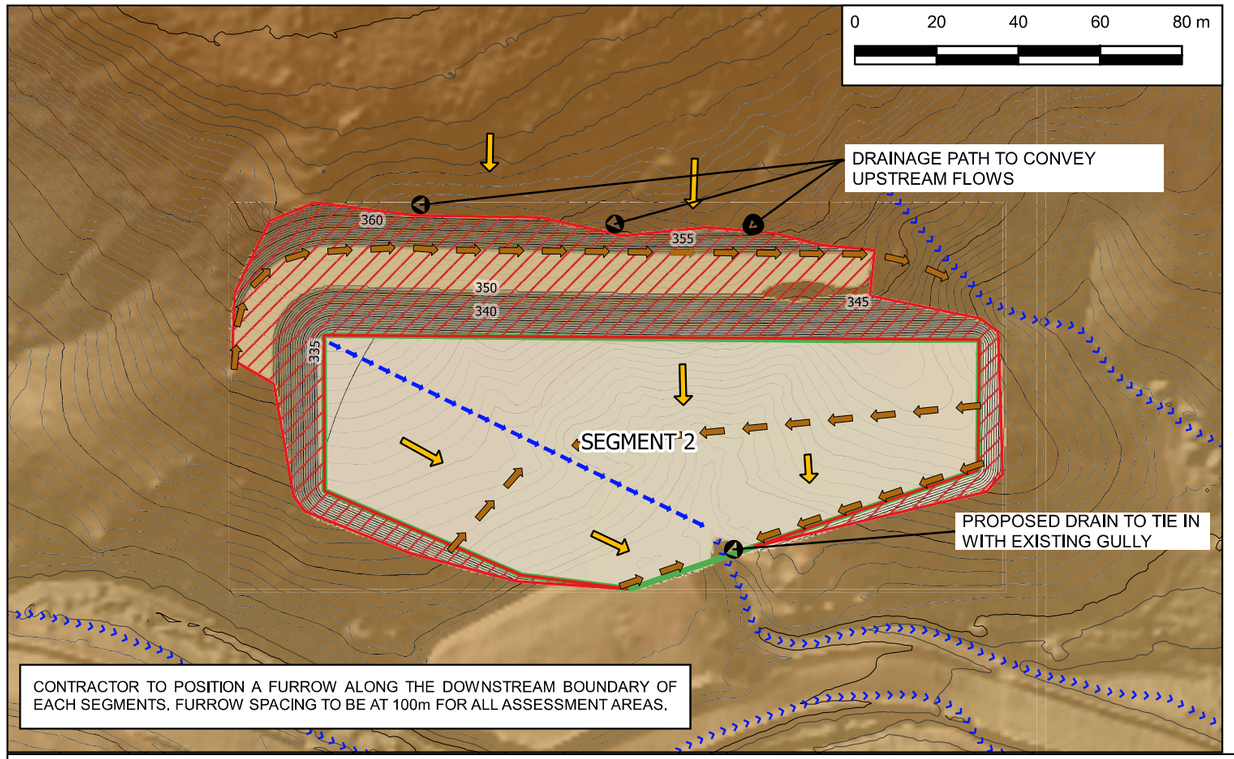
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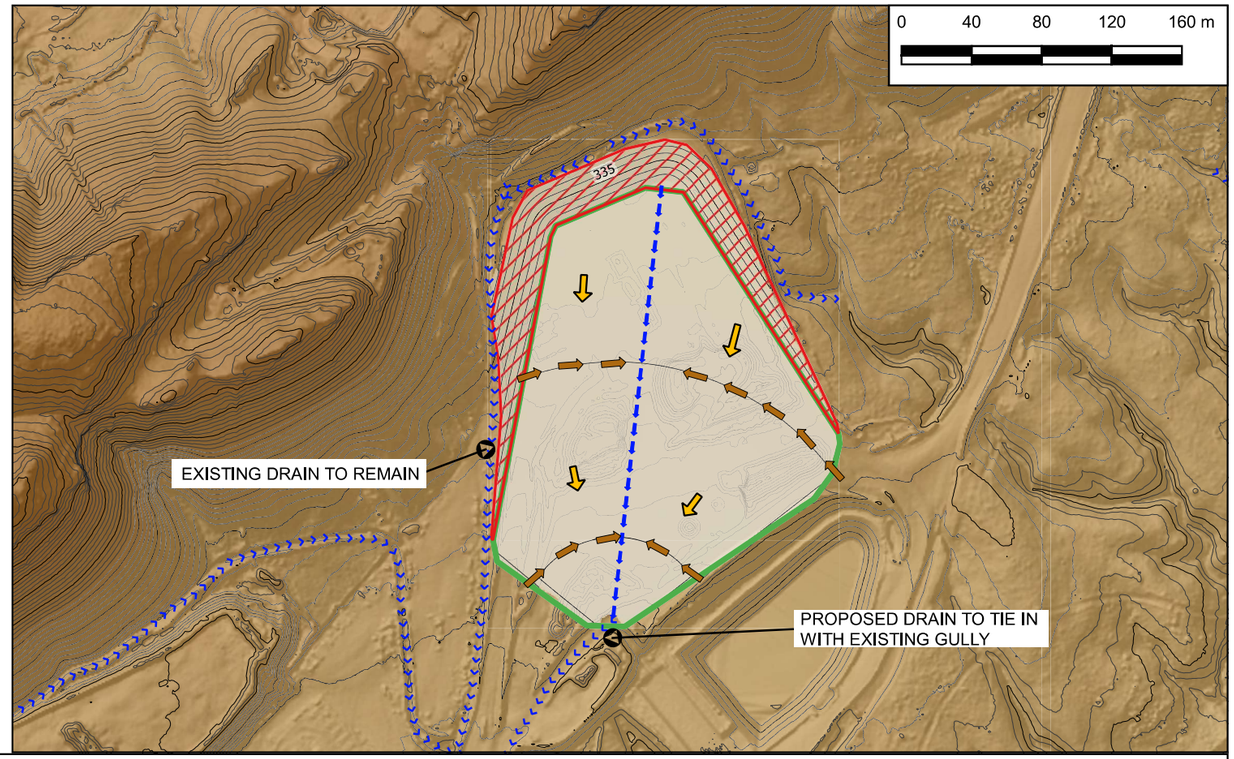
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LEGEND:

- ASSESSMENT AREA
- PROPOSED DRAIN
- EXISTING DRAINS
- FURROW DIRECTIONAL ALIGNMENT (NTS)
- BATTER
- FLOW ARROW

FIGURE 004
LADY LORETTA MINE - FINAL LANDFORM EROSION ASSESSMENT

CONCEPT GEOMETRY & DRAINAGE CONTROLS
(SHEET 4 / 4)

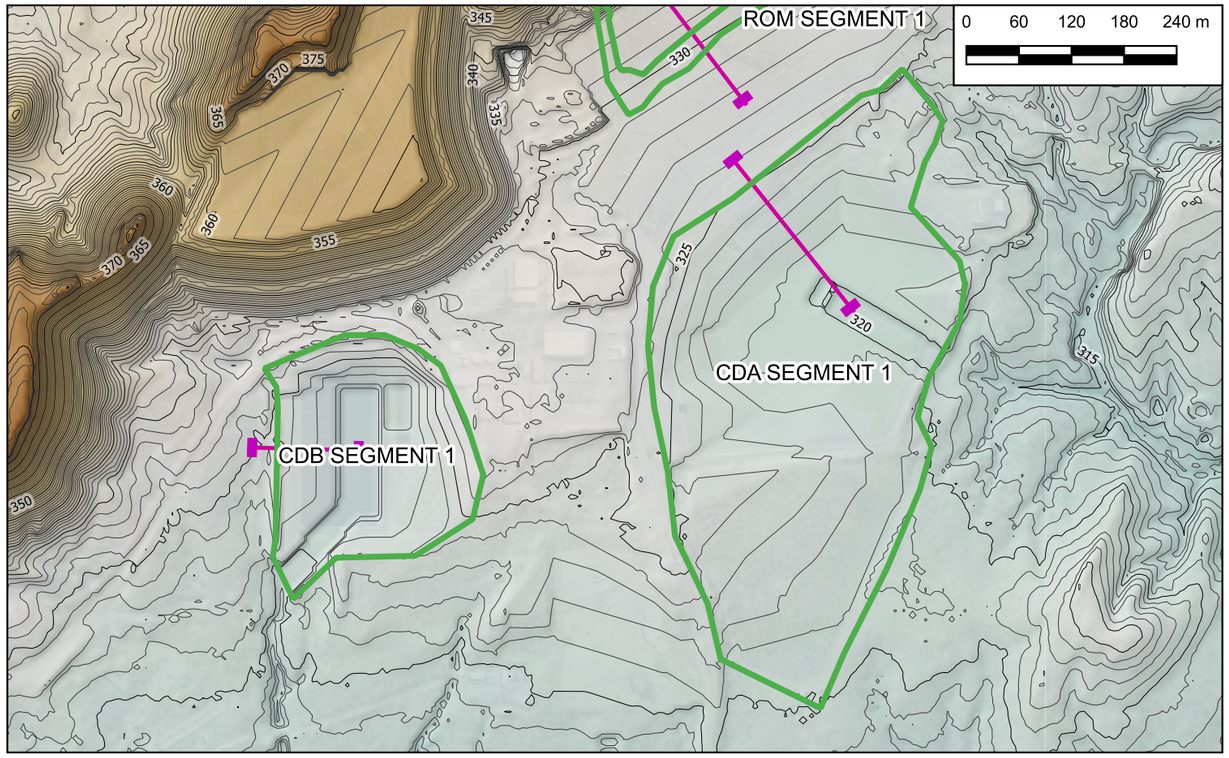
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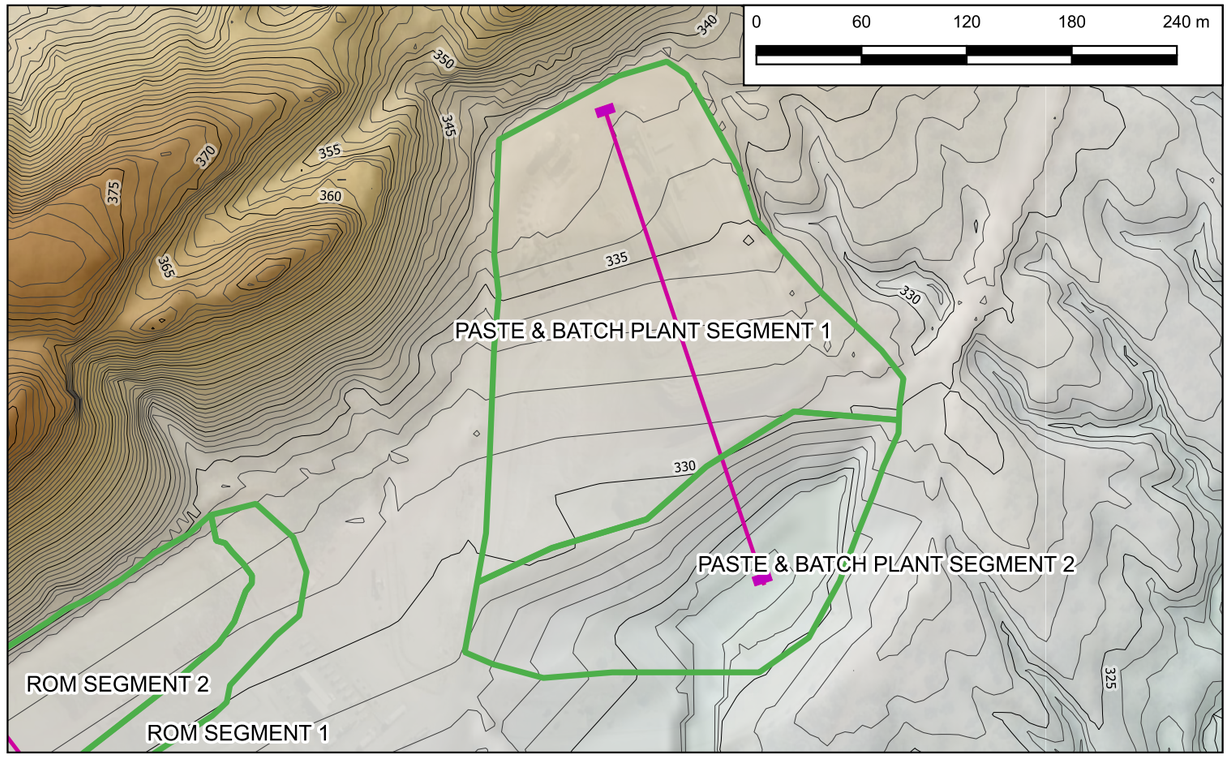
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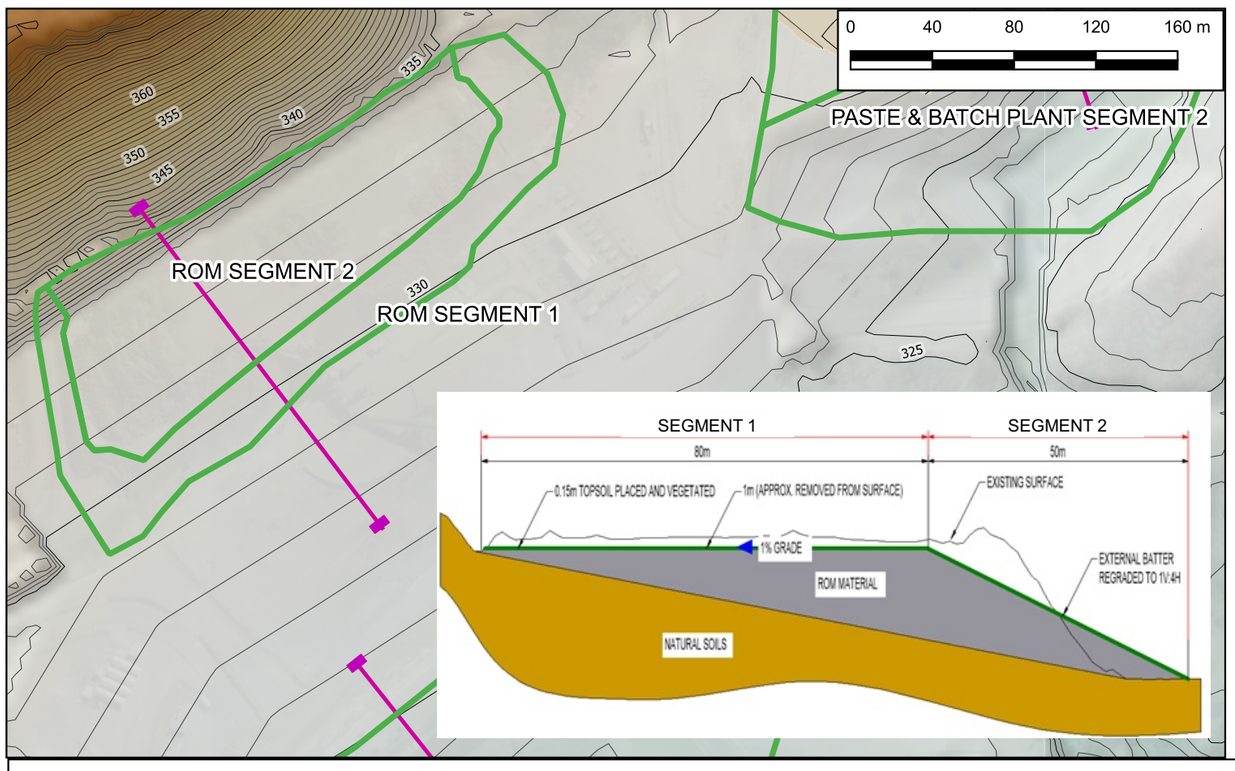
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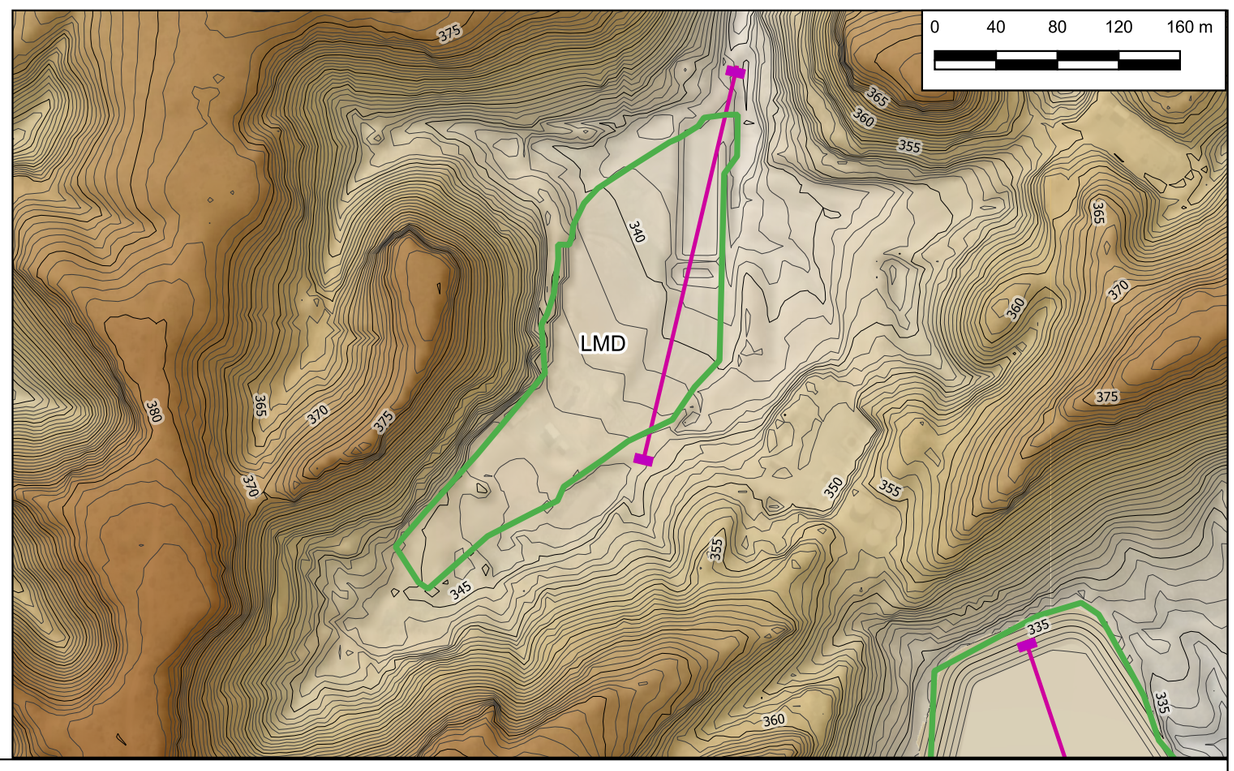
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APPENDIX B – 2D PROFILES









LEGEND:

ASSESSMENT AREA

SECTION LOCATIONS

FIGURE 001

LADY LORETTA MINE - FINAL LANDFORM EROSION ASSESSMENT

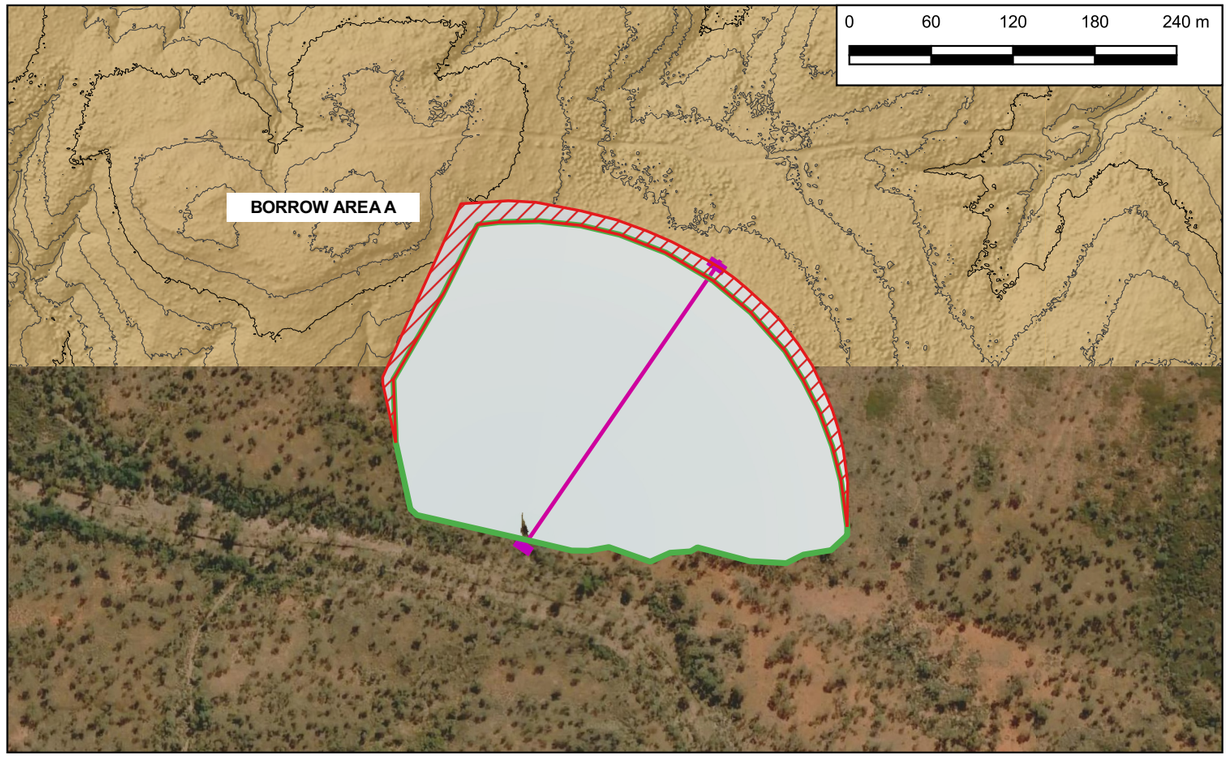
ASSESSMENT AREA SECTION LOCATIONS

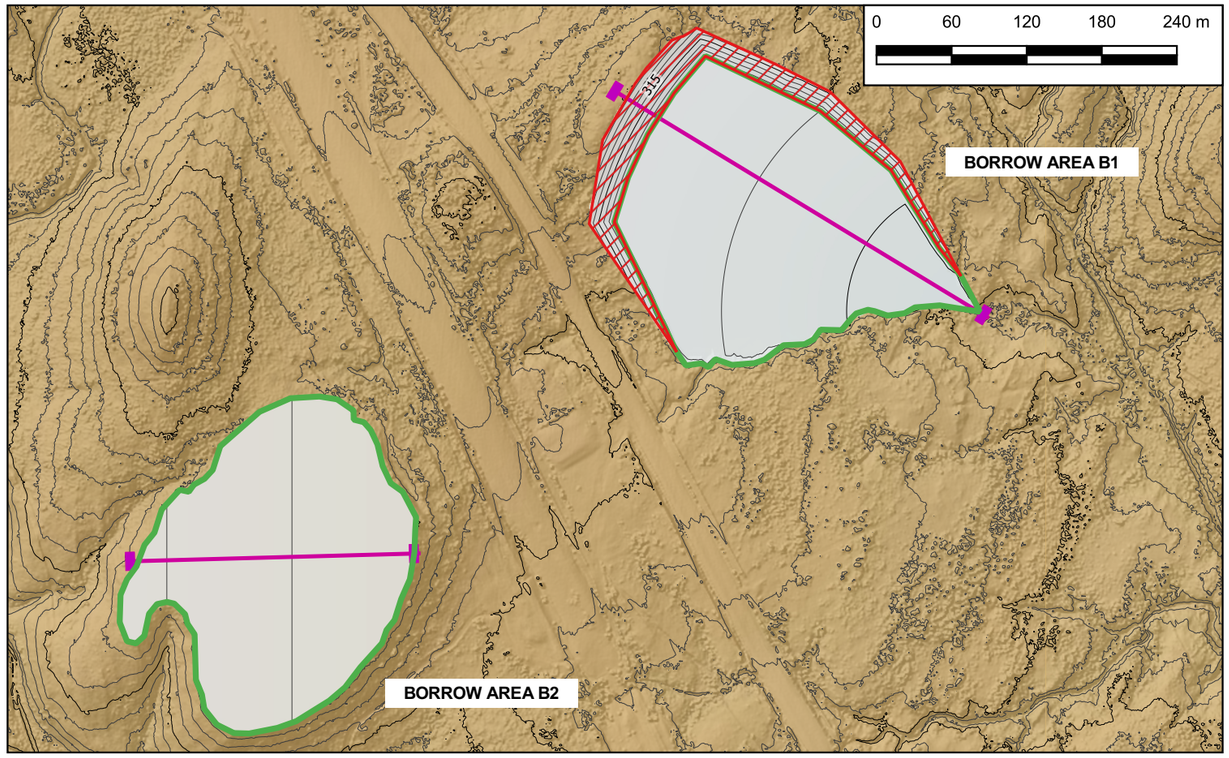
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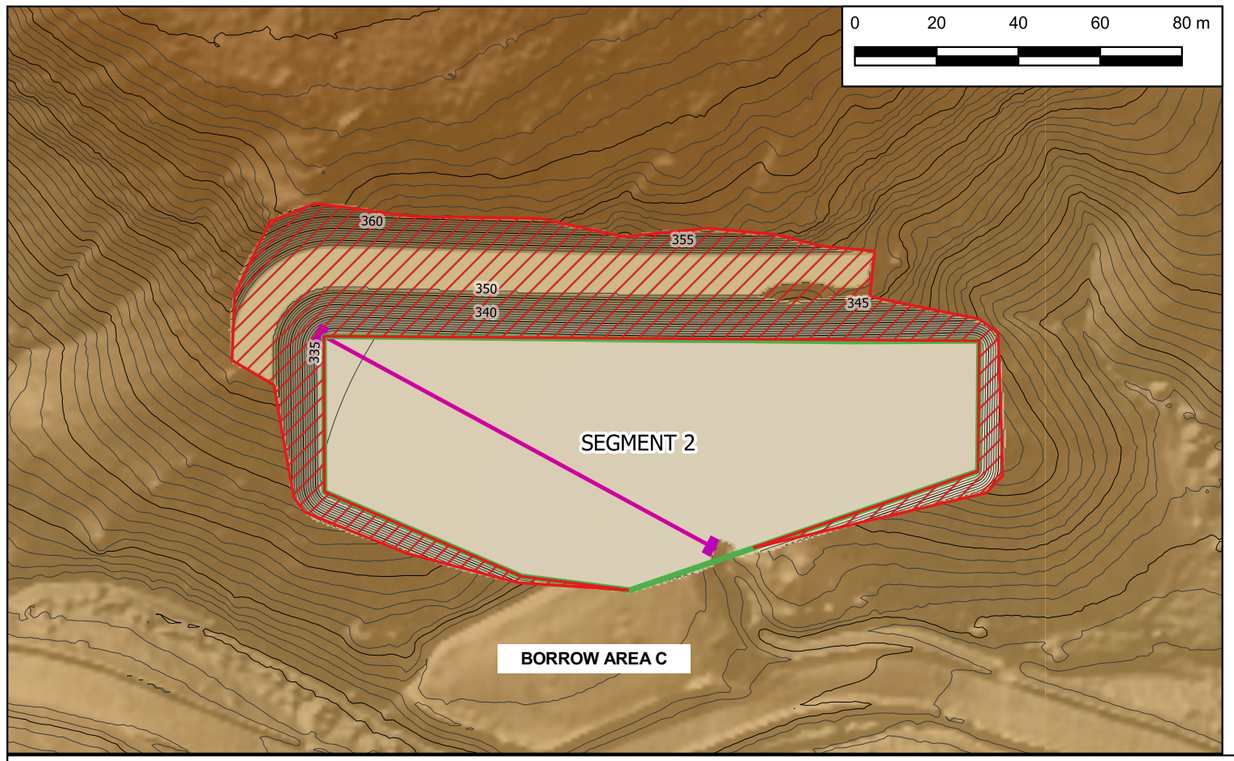
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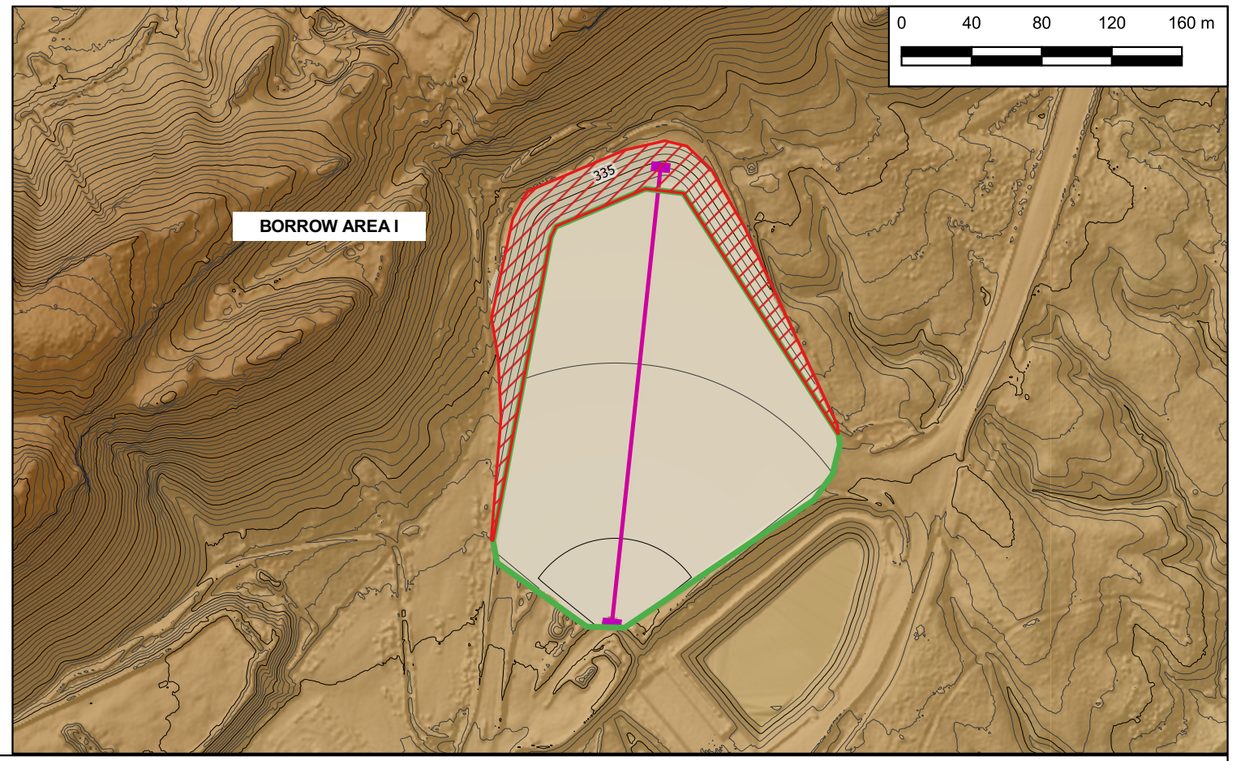
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LEGEND:

- ASSESSMENT AREA
- SECTION LOCATIONS

FIGURE 002
LADY LORETTA MINE - FINAL LANDFORM EROSION ASSESSMENT

ASSESSMENT AREA SECTION LOCATIONS

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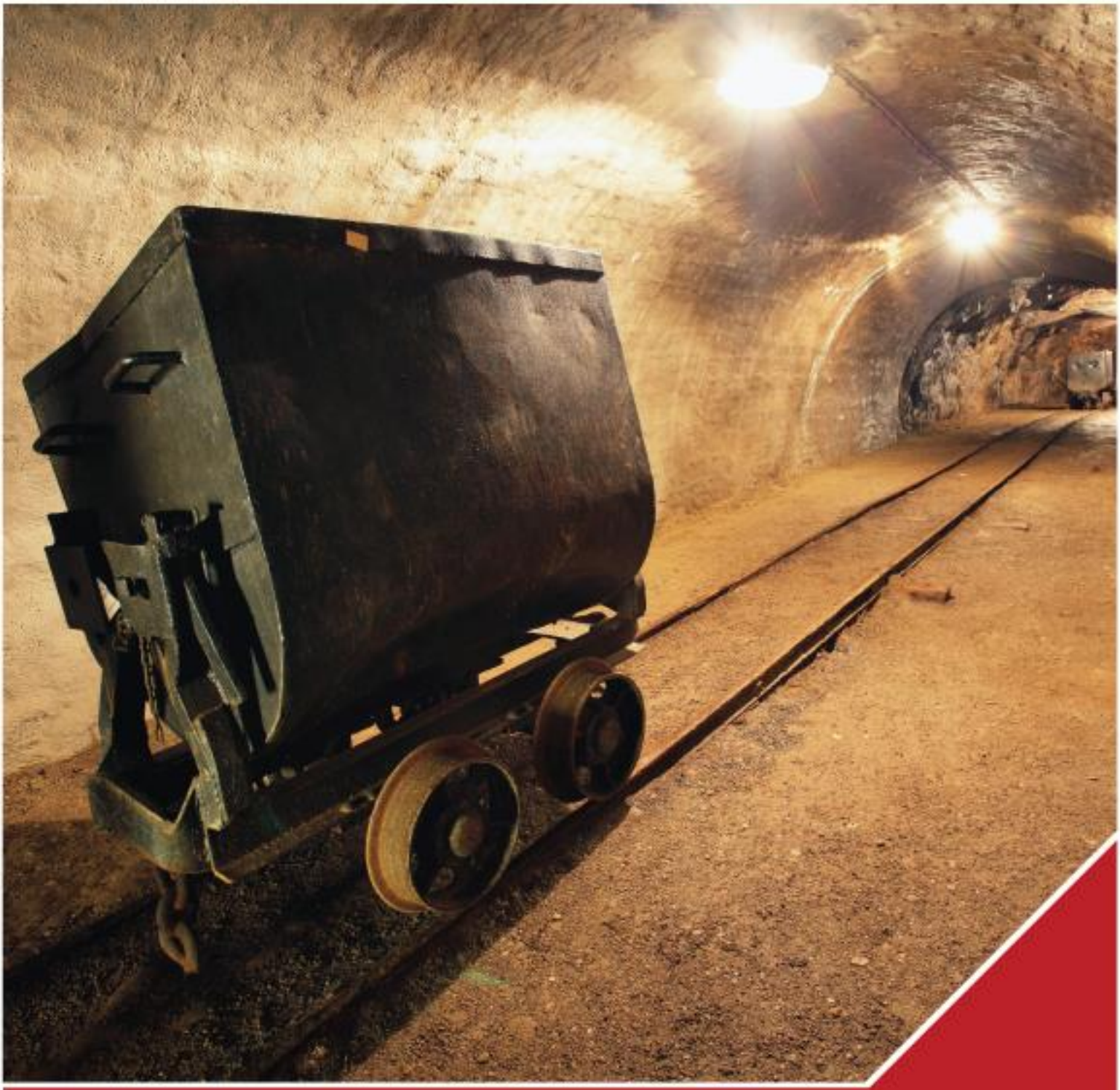
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APPENDIX H CLOSURE GEOTECHNICAL STUDY

MEC MINING

TRUSTED EXPERTISE. PROVEN OUTCOMES.



Glencore - Lady Loretta Mine

Mine Closure Geotechnical Study

7th April 2022

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EXECUTIVE SUMMARY

Glencore's Lady Loretta Mine (LLM), located in Northwest Queensland, 140 km NNW from Mount Isa is preparing for closure. The Progressive Rehabilitation and Closure Plan (PRCP) for Lady Loretta Mine requires a geotechnical assessment of the long-term risk of underground mine subsidence and its control.

This report presents a geotechnical data discovery review, geotechnical modelling and assessment, and geotechnical recommendations for closure considerations. The geotechnical investigation and assessment focusses on failure and subsidence risk of the upper Decline, underground stopes, and shafts. Methods of assessment used includes empirical and numerical modelling. The report also considers long term deterioration of concrete and ground supporting elements, backfilling requirements, and monitoring recommendations.

All ground voids constitute elements of weakness within a rock mass, and any stope crowns that are not tight filled, upper Declines, and shaft failures, can create a significant geohazard. The natural consequence of ground failure is upward void migration, which may reach the surface and cause varying levels of subsidence. Subsidence could be dangerously instantaneous or could occur slowly over many years. Two controls that will mitigate subsidence risk after mine closure are backfilling and mine flooding.

A stability assessment of crown pillars in the Eastern Limb, Western Limb, and North Ore Body (NOB) left by mining found that caving failure will occur in some scenarios, with the collapsed rock mass occupying voids left my mining. An empirical analysis using the Scaled Span Method for the crown pillars, revealed an acceptable factor of safety (FoS) for the most likely scenario of ground and water condition. Most scenarios using the poorer ground conditions (1st quartile Q), which have a low likelihood of occurrence and cannot be completely discounted, had unacceptable FoS, and service life. In consideration of the critical cases FoS can be as low as 0.9, but generally around 1.3. This corresponds to a service life of generally 2-5 years. In real terms, this assessment considers the void backs in the 1200 level are unsupported, so at such time when ground support has deteriorated beyond its usefulness, the backs will begin to unravel in (critical case) 2-5 years.

Exploring the Scaled Span Method critical cases, all crown pillars were assumed to fail, and a bulking of failure analysis was undertaken. This assessment indicated that any and all upward ground collapse will be arrested prior to reaching the surface for all crown pillar areas. Failure propagation would reach 38 m below ground level (bgl) for the Eastern Limb and 92 m bgl for the Western Limb. Since NOB has been tight filled, there is no void to allow propagation of failure. The empirical assessment concluded that although crown pillar failure could occur, it would not cause settlement on the surface.

2D modelling of the crown pillar was conducted using Rocscience RS2® for representative sections in the Eastern Limb, Western Limb, and NOB. The results are summarised in Table E1. At final stages of mining, modelling suggests minor subsidence in the Eastern Limb and the North Ore Body and small uplift in the crown pillar above

the Western Limb due to the buoyance effect. These vertical movements would likely go unnoticed by visual observations. The 2D modelling is supported by the empirical assessment.

Table E1- Surface displacement at various stages from 2D Analysis

	At Final Stage of Mining (Dry Mine)	Buoyancy Effect (Mine Recharged)	Net subsidence from pre-mining
Eastern Limb	20 cm ↓	18 cm ↑	2 cm ↓
Western Limb	20 cm ↓	32 cm ↑	12 cm ↑
NOB	19 cm ↓	9 cm ↑	10 cm ↓

The stability assessment for the upper Decline, where composed of weathered rock mass, was undertaken using an empirical bulking failure analysis. Results indicate that ground failure would arrest by choking at depths lower than 60 m below surface. Above this depth from surface, subsidence will occur, and the Decline requires backfilling to chainage 460 m from portal. It is estimated that a total volume of around 20,500 m^3 of waste will be required to backfill the upper Decline and the boxcut.

There are four shafts linked to surface which were deemed unstable during construction and thus supported over their entire length. There is one additional historical shaft which was unsuccessful in excavation and has been backfilled. The existing concrete lining support is anticipated to deteriorate over time, and ground collapse will occur if shafts are not backfilled for post closure stability. It is estimated that a total of 12,000 m^3 of waste will be required to backfill the four shafts.

Backfill material should be sourced primarily from the ROM pad due to its larger coarser fraction and limited fines. Only ROM pad material should be used to backfill the shafts. Material from the waste rock dump can be used in the Decline after ROM material has been exhausted.

Areas above the portal, upper level of the Decline and around the shafts must be barricaded and sign posted as future subsidence can occur atop these areas. Surface monitoring is recommended of these areas and proactively above the crown pillar.

1 INTRODUCTION

Glencore Lady Loretta Mine (LLM) engaged MEC Mining (MEC) to conduct a geotechnical study of the Lady Loretta Mine Closure. This report presents:

- Overview of geotechnical nature of the LLM,
- Review of mine operations and management of subsidence risk, and
- Assessment (including modelling) of long-term geotechnical risk and recommendations for controls following cessation of operations.

2 LADY LORETTA MINE (LLM) OVERVIEW

This section provides a summary of the geotechnical setting associated with Lady Loretta Mine upon reviewing of supplied documents. Also presented are geotechnical, geological, and hydrogeological settings, and known geotechnical performance history.

2.1 Documents Supplied and Reviewed

In conjunction with the Lady Loretta Mine Ground Control Management Plan (GCMP), key reports and other documentations that were reviewed include:

- AMC Consultants, 2000. Lady Loretta Feasibility Study Geotechnical Review. AMC Project 300026, October 2000.
- AMC Consultants, 2020. Lady Loretta Numerical Modelling. AMC Project 220083, 30 October 2020.
- ATC Williams, 2020. Lady Loretta Operations Geotechnical Investigation of the Waste Rock Dump and Potential Capping Materials, November 2020.
- Australasian Groundwater and Environmental Consultants (AGE, 2020). Lady Loretta Mine Hydrogeological Conceptual Model 2020 Update. Project G1834H, 01 September 2020.
- Beck Engineering 2012. LADY LORETTA Global Back fill deformation, 25 May 2012.
- Brummer, R 2006. Geotechnical review of the Lady Loretta Mine project. Unpublished report Itasca, 19 September 2006.
- Bieniawski, Z. T., 1989. Engineering rock mass classifications. New York: Wiley.
- Carter TG 2014. Guidelines for use of the Scaled Span Method for Surface Crown Pillar Stability Assessment; Golder and Associates.
- C.M Jewel & Associates 2006. Hydrogeological Study Lady Loretta, QLD for Noranda Pacific, September 2006.
- Douglas Partners 2012. Development of a Dewatering Strategy & Groundwater Management Plan for Lady Loretta Mine, July 2012.
- Entwisle, D, Lee, K A, and Lawley, R S. 2015. User guide for 'BGS Civils' - a suite of engineering properties datasets. British Geological Survey Internal Report, OR/15/065.
- EUROPEAN COMMISSION DIRECTORATE-GENERAL RESEARCH, 2013. Mine Shafts: improving security and new tools for the evaluation of risks.
- Koski, John A., 1994. Sealing Abandoned Mine Shafts with Concrete. PUBLICATION #J941015, Copyright © 1994, The Aberdeen Group.
- Lady Loretta Mine Backfill Management Plan 2021. Including Bulkhead Design, Paste Design and Paste Reticulation.

- McCracken, A. & Stacey, T.R., 1989, Geotechnical risk assessment of large-diameter raise-bored Shafts, IMM, *Proceedings Shaft Engineering Conference*, pp 309-316.
- MineGeoTech 2018. Lady Loretta Mine Domaining Project, 31 October 2018.
- Mining One 2011. Lady Loretta Box Cut Geotechnical Mapping, September 2011.
- Mining One 2012. Lady Loretta Geotechnical Factual Report Proposed Decline and Shaft, February 2012.
- Progressive rehabilitation and closure plans (PRC plans) 2021. Guideline–Progressive rehabilitation and closure plans (PRC plans), Department of Environment and Science (Queensland Government), Last reviewed on 17 March 2021.
- Sandy, M. P., 2000. Lady Loretta feasibility study geotechnical review. Unpublished report AMC300026, October 2000.
- Wolkersdorfer C 2008. Water Management at Abandoned Flooded Underground Mines. Springer 2008 465 pages. ISBN 978-3-540-77330-6.
- Work Health and Safety Regulation 2011 (Qld) – Part 4.4 Falls https://www.legislation.qld.gov.au/view/html/inforce/current/sl-2011-0240
- W. Yang, A. M. Marshall, D. Wanatowski, L. R. Stace, "An Experimental Evaluation of the Weathering Effects on Mine Shaft Lining Materials", *Advances in Materials Science and Engineering*, vol. 2017, Article ID 4219025, 12 pages, 2017. https://doi.org/10.1155/2017/4219025

2.2 Lady Loretta Mine

Lady Loretta Mine is an underground zinc, lead, silver mine with legacy workings. The deposit was discovered in 1969, and in 1987–1988 the first shaft was developed by Pancontinental Mining Ltd in the area near the current underground mine. Glencore Zinc Australia has owned the mine since 2012, when it merged with Xstrata Plc (previous owner). Underground operations at Lady Loretta commenced in 2013 and paused in 2015 in response to global zinc prices. Mining re-commenced in 2018 and is scheduled to reach end of LOM (life of Mine) in 2025. The modern Decline (initiated in 2013) is 500 m deep and is hosted within a Dolomite Unit of the Lady Loretta Formation. The main mineral resource is hosted in the ore sequence of the Lady Loretta Formation, which stratigraphically overlies this dolomite. Stoping is conducted into the ore bearing unit from the main Decline. On-site infrastructure includes several water storages (Catchment Dam A–CDA; Catchment Dam B–CDB; Paste Plant Dam (PPD); Leachate Management Dam–(LMD), legacy (potentially acid forming [PAF]) and modern waste rock dumps (WRD), a paste production plant, and a run of mine (ROM) area (Figure 1, AGE, 2020).

During active mining, the underground mine workings are backfilled in stages using paste produced from tailings in the paste production plant, and/or rockfill. Water for the paste production is held in the PPD (Figure 1, AGE, 2020). To ensure stability of the underground mine, the maximum allowable void volume (represented as a mass) at any one time is 150,000 tons. So that the void volume does not exceed the allowable limit, stoping and paste-filling occur concurrently, and they can overlap in different areas.

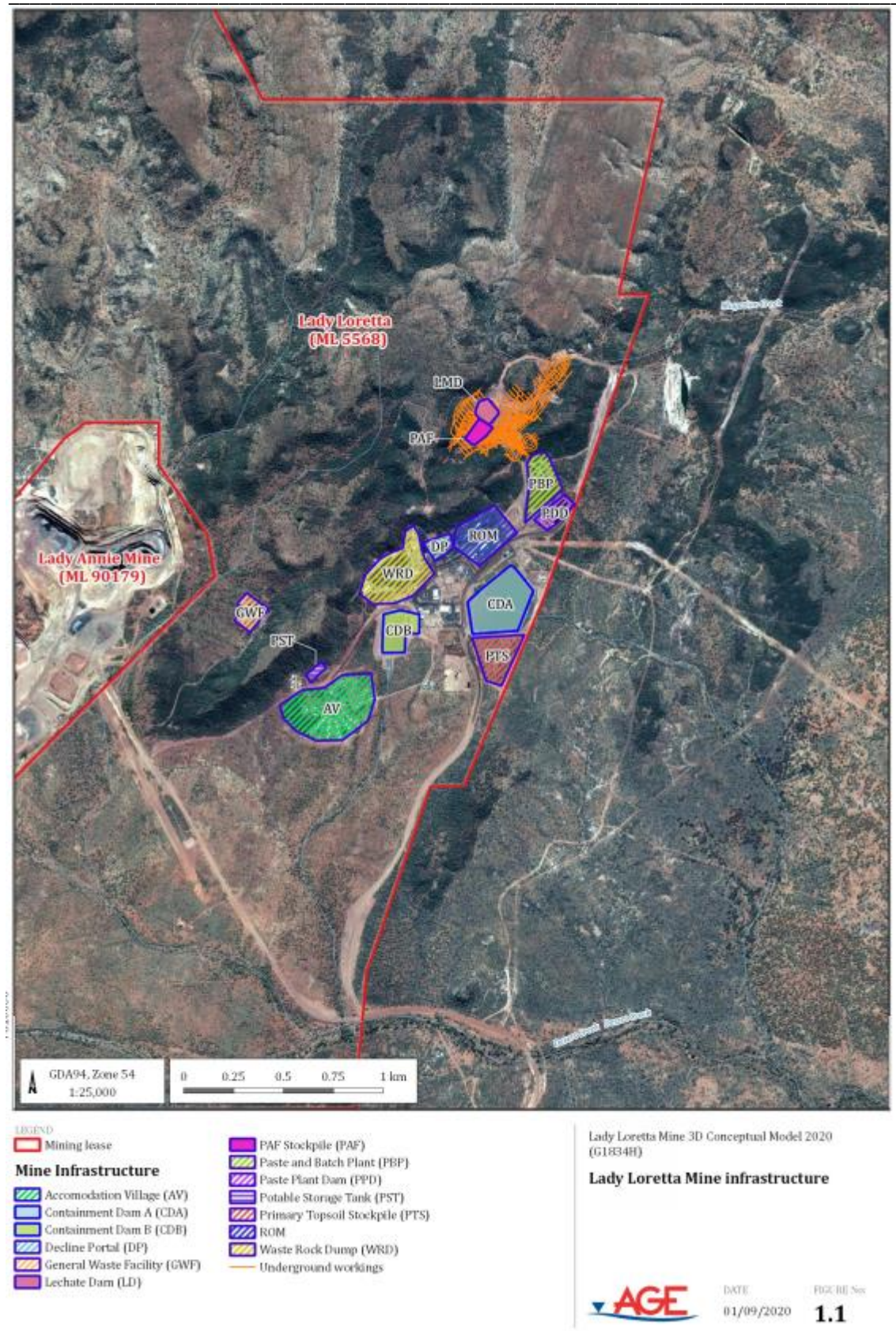


Figure 1 - Mine Surface Infrastructure.

2.3 Geological Setting

The geological settings summarised below were extracted from Noranda Pacific PTY LTD - Lady Loretta Feasibility Study in Brummer (2006) and Lady Loretta Feasibility Study Geotechnical Review (AMC, 2000).

The Lady Loretta deposit is in Northwest Queensland, 114 km NNW from Mount Isa. The deposit is considered a classic example of a sediment hosted Lead Zinc SEDEX deposit. It shares many features found in similar deposits within the Mount Isa inlier (i.e., Mount Isa, Hilton, and George Fisher). The deposit is unique for the inlier, having a single ore lens position, high base metal grades, and strong association with barite mineralisation. Age dating of tuff units within the host rocks indicates an age of 1,647 Ma. The deepest portion of the ore body reaches elevation 830 mRL in relation to AHD (510 m below the surface). Note, all levels in this report are provided in RL in relation to The Australian Height Datum 1971 (AHD71).

The deposit is hosted within the upper portion of the Lady Loretta Formation and is localised within a synformal structure locally referred to as the Small Syncline. The structure is characterised as a dominantly northeast plunging, tight syncline with an axial length of approximately 1.3km. To the southwest, a larger Big Syncline occurs which is separated from the Small Syncline by a tight anticlinal fold. Both synclines are complicated by several significant, cross cutting faults that display local offsets.

Sulphide mineralisation within the Small Syncline occurs on both steeply dipping limbs, which at depth join to form a keel structure. Northern and southern extents of the deposit are fault truncated by the Carlton and Max's Fault's, respectively.

The ore hosting sediments are dark grey massive siltstone and marks the base of an interbedded sequence and sandstones known as the Cyclic Unit. This unit overlies an interbedded pyritic siltstone unit (the Pyrite Unit). The ore sits in a stratigraphical position indicative of a major sedimentological change. This change is expressed by stratigraphy grading upwards indicating a period of quiescent deposition (the Pyrite Unit), then reverting to a higher energy environment reflected by the interbedded Cyclic Unit. The ore horizon is directly overlaid by the Cyclic Unit.

Fine grained pyrite with intergrown sphalerite and galena dominate the ore deposit. Mineralisation displays a well-defined zonation from finely banded massive sulphides in the keel (with lesser pyrite), to a coarser, baritic type mineralisation found higher on the deposit limbs. Overall, the deposit exhibits a pronounced metal zonation from high lead, zinc-rich mineralisation found in the Western Limb and keel, to a low lead, zinc-rich mineralisation found in the Eastern Limb.

Figure 2 from Brummer (2006) is a lithological cross section through 2300N (mine grid). This figure shows the major identified fault structures, which are locally known as the Carlton, Max's, and Koff's Faults.

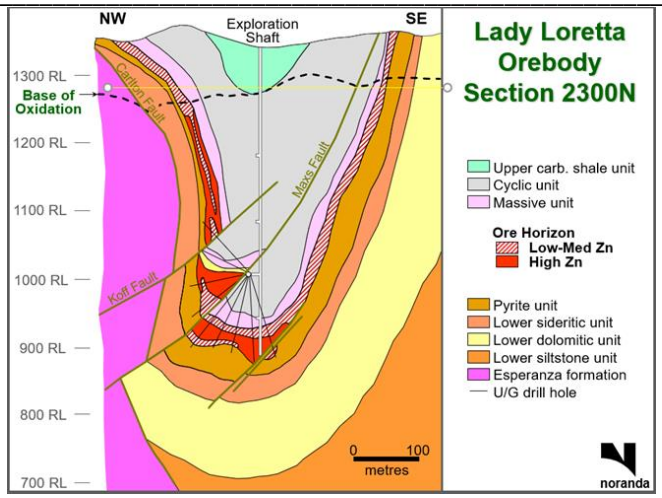


Figure 2- Lithological Section through 2300 N (Brummer, 2006)

2.4 Rock Mass Properties

Rock mass is a matrix consisting of rock material and rock discontinuities. Rock mass characterisation and classification is determined by assigning values to a set of characteristics parameters. Reliable estimates of the strength and deformation characteristics of rock masses are required for almost any form of geotechnical engineering investigation and are important for analysis and modelling of potential subsidence of an underground mine.

The intact mechanical properties for the diverse types of lithologies found at Lady Loretta have been assessed during previous feasibility studies. Shorthand abbreviations for their lithologies are summarised in Table 1 and results are respectively located in Table 2 and Table 3.

Table 1- Shorthand Abbreviations for the Different Lithologies

Lithological Unit	Abbreviation
Cyclic Unit	CU
Massive Unit	MU
Ore Horizon Banded	OH Banded
Ore Horizon Massive	OH Massive
Ore Horizon (Banded and Massive)	OH Combined
Pyritic Unit	PU
Lower Siderite/Dolomite Unit	LS/LD

Table 2- Intact Rock Properties from BFP 1997 Study

BFP, 1997	Mean UCS_{50} (MPa)	Std. Dev.	Samples	Mean Young's Modulus, E (GPa)
CU	158	58	4	55
MU	134	-	1	-
OH	80	34	7	64
PU	-	-	-	149

- Tested by James Cook University of North Queensland and Queensland Institute of Technology.
- Individual modulus results not provided, 'secant' or 'tangent' not specified.
- UCS results normalised for 50 mm diameter core.

Table 3- Intact Rock Properties from Noranda 2000 Study

Noranda, 2000	UCS_{50} (MPa)	Std. Dev. (MPa)	No. of Samples	E (GPa)	Std. Dev (GPa)	υ	Std. Dev	Samples
CU	122	70	4	-	-	-	-	-
MU	83	53	3	-	-	-	-	-
OH								
Banded	143	103	9	75	20	0.24	0.04	8
Massive	87	28	4	58	11	0.26	0.04	7
Combined	126	89	13	67	18	0.24	0.04	15
PU	101	33	3	36	25	0.27	0.11	11
LS/LD	95	29	2	-	-	-	-	-

- UCS results normalised for 50 mm diameter core, results from 'intact' failure only.
- E: Secant Young's Modulus at 50% UCS.
- υ: Poisson's Ratio.

2.5 Rock Mass Domaining

To assist in the geotechnical analysis, the rock mass is divided into a series of domains. Historically, the rock mass at Lady Loretta has been divided in the three ground types based on the Barton's Q system: hereafter labelled 'Type 1 Ground', 'Type 2 Ground' and 'Type 3 Ground'. MineGeoTech (2018) highlighted an insufficient database of Q parameters to provide the necessary resolution for determination of ground classification and therefore support selection on a local scale. The three ground type classification system was thereafter updated to use Rock Quality Designation (RQD) as the driving factor since significantly more data was available, and the results compared well with underground observations. As set out in the MineGeoTech (2018) report, the division between Type 2 Ground and Type 3 Ground was set at RQD of 15. Further mapping/logging conducted by MineGeoTech (2018) improved the resolution of the ground type model. The three ground types are shown in Table 4.

Table 4- Rock mass Domains

Group Type	RQD values	Group Description	Presence	Characteristics
Type 1	> 75	Fair to Good Ground	~40% of diamond drilling with RQD data	Can be jumbo scaled to solid with moderate effort, and hole blockage problems rarely occur.
Type 2	15 – 75	Very Poor to Fair	~52% of diamond drilling with RQD data	Not easily scaled to solid; Drive profile may over break up to 1.0m. Hole blockage may occur.
Type 3	< 15	Extremely Poor Ground	~8.7% of diamond drilling with RQD data	Over-scaling may destabilise ground and is hazardous; Common where major structures intersect. Partial blockage common in horizontal holes. High specification ground support required. Development support required as soon as possible to prevent deterioration.

2.6 Structural Domaining

The structural domaining at LLM reflects a global view of the discontinuity regime in the underground mine. MineGeoTech (2018) conducted a structural review using historical and newly collected data and compiled five structural domains. This data includes geotechnical logging from drilled cores, geology sirovision database and underground face and wall mapping to produce these structural domains (Figure 3). These five geotechnical domains identified at Lady Loretta are:

- Domain 1: Western Limb
- Domain 2: Western Limb between Max and Koff's faults
- Domain 3: Western Limb below Max's Faults
- Domain 4: Western Side of the Keel, and
- Domain 5: The Eastern Keel and Eastern Limb

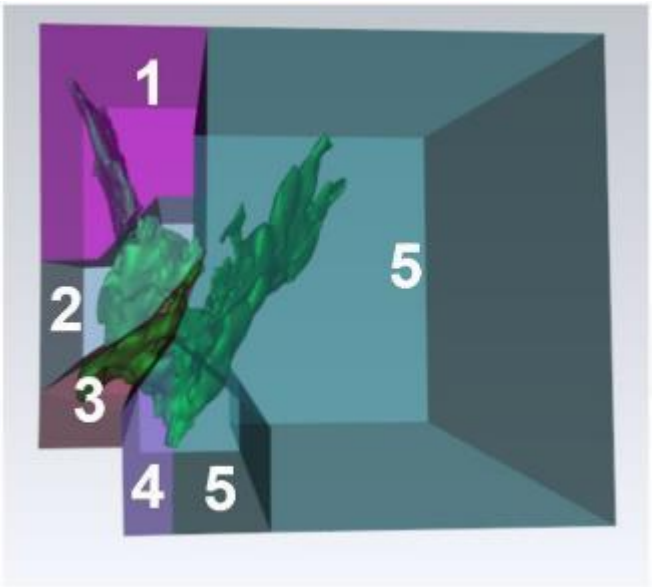


Figure 3- Lady Loretta Structural Domains

Table 5 contains a summary of the main discontinuity set data associated with each domain.

Table 5- Main Discontinuities Sets by Domain

Domain	Set Number	Dip/Dip Direction	Direction	Type
1: Western Limb	1	75/68	East Dipping	Bedding
	2	52/285	West Dipping	Joint
	3	63/202	South Dipping	Joint
2: Western Limb between Max and Koff's faults	1	73/152	South Dipping	Joint
	2	80/64	East Dipping	Bedding
	3	41/241	North Dipping	Fault
3: Western Limb below Max's Faults	1	60/66	East Dipping	Bedding
	2	44/178	South Dipping	Joint
	3	87/139	South Dipping	Joint
	4	70/257	West Dipping	Bedding
4: Western Side of the Keel	1	52/52	East Dipping	Bedding
	2	66/115	East Dipping	Bedding
	3	65/173	South Dipping	Joint
	4	60/247	West Dipping	Joint
5: The Eastern Keel and Eastern Limb	1	64/264	West Dipping	Bedding
	2	59/161	South Dipping	Joint

2.7 Faults

There are several major (regional) fault structures that have been identified within the Lady Loretta deposit, with some defining the structural domains. At LLM, rock mass within the fault zones is generally poor. Table 6 lists faults with descriptions by Sandy (2000). Regional faults and localised structures are used when undertaking stope stability assessments.

Table 6- Summary of Major Structures (Sandy, 2000)

Fault Name	Location	Strike Length	Dip Length	Dip/Direction	Comments
Max's	East Limb	+500m	+600m	50/280*	5 -10m thick, low RQD, contains gouge and open in all extents
Koff's	East Limb	+250m	+400m	40/280*	1-2m thick, gouge and interspersed broken rock, open in all extents
Carlton	West Limb	+500m	+600m	72/095*	2-20m thick, low RQD bands open in all extents
Thorpedo	East Limb	+500m	+600m	67/246	2-10m thick, gouge, highly weathered rock
Craig's	West Limb	+500m	+600m	88/297	1-2m thick, gouge and interspersed broken rock, open in all extents

2.8 Stress Magnitude and Orientation

The stress magnitude and orientation are important measurements to evaluate the level of rock mass stability. The Acoustic Emission (AE) method was used to estimate the in-situ stresses from two locations at LLM and to calculate the magnitude versus depth linear relationships (WASMAE-Lady Loretta – August 2015 – extracted from GCMP). Table 7 summarises the results.

Table 7- Magnitude and Orientation of Stress Component versus Depth

Vertical depth (m)	Sample location Borehole ID	Stress component	Magnitude (MPa)	Bearing (°)	Plunge (°)
363	Hole GT_1100_01	σ_1	23	314	02
		σ_2	16	044	02
		σ_3	10	176	87
393	Hole GT_1100_01	σ_1	26	314	06
		σ_2	17	044	04
		σ_3	11	171	83

2.9 Hydrogeological Model

LLM is being dewatered for mining activities and will naturally become flooded after cessation of the operations and dewatering. As such, hydrogeological aspects of LLM are important for the analysis and modelling. Typical of northwest Queensland, the Lady Loretta Mine experiences a tropical climate, with pronounced “dry” winter and ‘wet’ summer seasons.

Annual rainfall in the area is highly variable. The average total annual rainfall, evaporation, and potential evapotranspiration derived from Silo Data Drill records (1889–2017) are shown in Figure 4 (AGE, 2020).

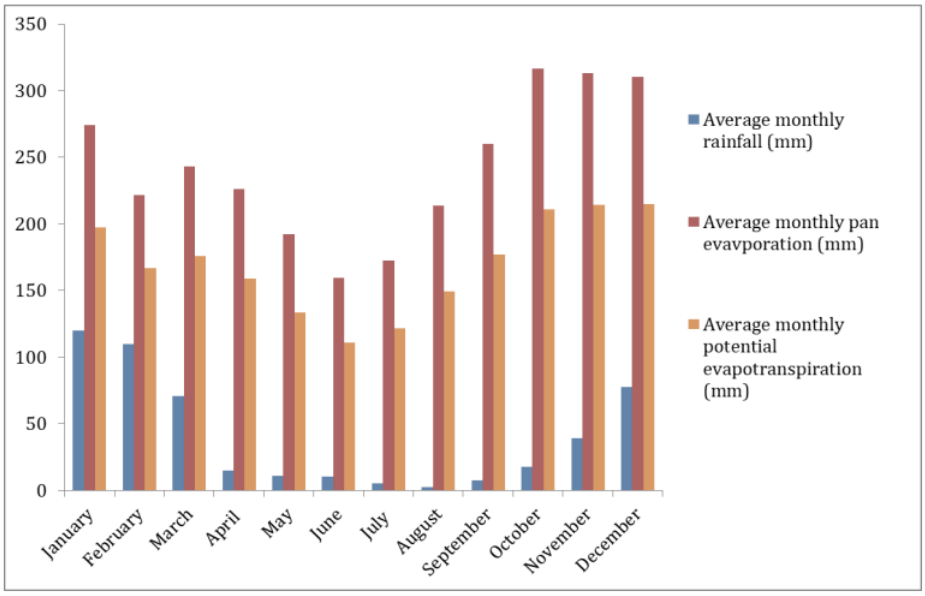


Figure 4 - Long term average climate data

The pre-mining groundwater level at Lady Loretta Mine was measured between 40 and 70 metres below ground level (m bgl) which is roughly at 1340 mRL, with deeper levels occurring in topographically elevated areas (C.M Jewel & Associates, 2006). The groundwater table in the vicinity of the exploration shaft at pre-construction was 58 m bgl. During shaft construction a low groundwater inflow rate was observed, typically around 2 litres per second (Douglas Partners, 2012).

Based on the groundwater monitoring station data, C.M Jewel & Associates (2006) concluded that the potentiometric surface would be a subdued reflection of topography, and regional groundwater flow directions would reflect surface water drainage channels with very low hydraulic gradients.

Lady Loretta Mine is a relatively "dry" mine. Underground observations indicate an increase of groundwater inflow after intense rain events, particularly from the water bearing Thorpedo Fault at upper levels of the mine. Groundwater recharge occurs mainly through direct rainfall infiltration, infiltration of slope run-off, and through stream channel seepage and overflow flooding events (C.M Jewel & Associates 2006). The typical groundwater ingress recorded to the underground workings during Care and Maintenance was approximately 21 ML per month, equivalent to 0.7 ML/day or 8.1 L/s (AGE, 2020).

The estimated hydraulic properties for the Lady Loretta Formation are presented in Table 8. These properties are derived from various methods including field testing, modelling, and analytical methods and assumes that the Lady Loretta Formation is behaving as a confined aquifer (AGE, 2020). The existing values are related to the bulk rock properties. However, observations on site indicate the aquifer is heterogeneous, due to the stratigraphic variability.

Table 8- Hydraulic Properties of the Lady Loretta Formation

Transmissivity	Storativity	Specific storage	Hydraulic conductivity	Source	Details
0.2 to 0.5 m^2/day	1 x 10^{-3} to 2 x 10^{-3}		5.0 x 10^{-4} to 1.3 x 10^{-3} m/day	Woodward-Clyde, 1994	Theim analysis on drawdown during shaft development
3 m^2/day	4.5 x 10^{-4}		2.0 x 10^{-2} m/day	Golder, 1986b	Packer tests on shafts and holes about 150 m to 250 m deep
	5 x 10^{-4} m^{-1}*	5 x 10^{-5} m^{-1}		AGE, 2015	Model calibration
	2 x 10^{-3} m^{-1}*	2 x 10^{-4} m^{-1}		AGE, 2018b	Groundwater storage calculation from water balance

Mine water is moderately acidic and brackish (Douglas Partners, 2012). From underground observations in LLM and other mines, localised corrosion in rock bolts and mesh are observed not only due to the presence of acidic groundwater, but also due to trapped SO_2 commonly present in open stopes that have a delay in backfilling, and in areas of poor ventilation.

As the mine approaches life of mine (LoM) in 2025, and the end of commercial proposition is called in 2032, plans to cease operations will include the withdrawal of groundwater pumps from the underground. Consequently natural flooding of the mine will commence. Seepage and groundwater modelling was not part of this study however it can be thought that over time, the groundwater flow directions may change, as the water levels recover and adjust to a new equilibrium. Therefore, the receptors that are currently protected from potential contamination by the flow directions under the cone of depression could become at risk under a future post-recovery groundwater regime.

The last numerical model (AGE, 2020) simulated water recovery after mine closure, and predicted a rapid, but not complete, recovery (i.e. a remnant cone of depression could persist after mine closure). Glencore is currently planning to update the groundwater modelling to predict the likely temporal and spatial patterns of the recovery, using the most up to date plans for the mine. This will inform strategies for mine rehabilitation (AGE,2020).

2.10 Mining Method and Backfilling

LLM uses an underground conventional long hole stoping and paste fill method of mining. Stopes currently follow a bottom-up longitudinal and transverse sequence with paste filling of voids. Loose Waste Rock Fill (RF) and PAF (Potential Acid Forming material) is also used where there are no exposures to subsequent stoping, and the fill material is not required to be self-supporting. The upper levels of the mine employed a top-down longitudinal and transverse sub-level open stoping method, with paste filling of the voids. The top-down sequence was minimised due to instances of caving from stope crowns exposing the paste filled stopes above. There are some remaining stopes in this sequence still to be mined, particularly at the sill pillar between 1025 and 1050 levels, with paste exposures in the crown.

2.10.1 Paste Filling

Backfilling is used as part of the mining process at Lady Loretta to maintain stable ground conditions and maximise ore extraction in a timely manner. The bottom up, primary/secondary/tertiary stoping mining method employed at Lady Loretta now leads to paste fill being the most appropriate backfill material for most of the stopes underground. When placed, this paste fill must:

- Provide a suitable bulking material that restrains rock mass unravelling.
- Remain self-supporting during nearby blasting activities.
- Maintain stability when exposed vertically or horizontally during adjacent mining activities.
- Has sufficient bond strength to avoid liquefaction during dynamic events.

Where there are no future exposures (vertical or horizontal) to the stope, loose waste Rock Fill (RF) can be used as the fill is not required to be self-supporting. This method is generally reserved for the final stopes in the stoping panel.

2.10.1.1 Paste Binder Content and Strength

Lady Loretta uses GP cement as the binder to their paste. The paste strength is sensitive to GP cement content and Figure 5 illustrates the relationship at 14 days hydration. The strength to GP cement content relationship is consistent also with 7 and 28 days hydration. The graph in Figure 5 indicates:

- The paste strength has a lineal relationship to binder content such that a 1% change in GP% corresponds to a strength increase of approximately 200-300 kPa.
- Paste batched with 2% binder generates no tangible strength.
- Due to variability in the imported tailings (and resulting solids%), 4% GP cement content generally produces paste with lower than the required design strength for vertical exposures. 4% GP cement content has historically caused large overbreak.

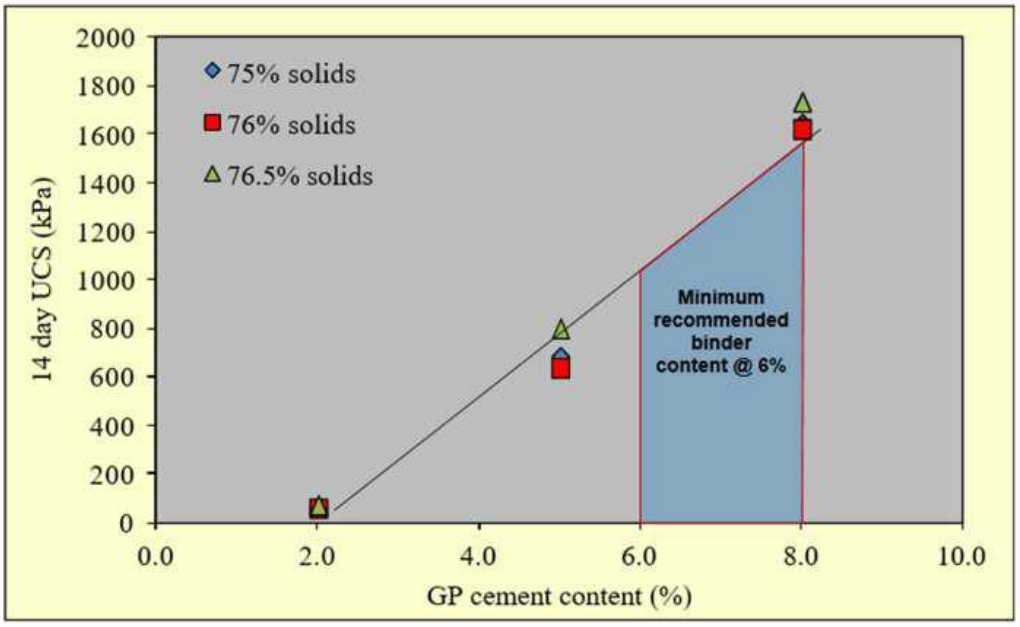


Figure 5- Curing time and GP cement content relation

Prior to the LLM temporary closure (from Q4 2015 to Q1 2018), most of the paste used low heat cement. Low heat cement produces higher strengths for the medium and longer curing times compared to GP cement. Historically, paste with 4% low heat cement content reached strengths of 1,000 – 1,200 kPa. This is compared to 400 – 500 kPa for paste with 4% GP cement. The top-down sequence stopes from 1175 level were backfilled with paste composed of low heat cement.

No time dependent deterioration study has been conducted of paste made at LLM. Deterioration is relevant for tailings containing sulphates which over time causes strength loss, and disintegration of the cement bonds within the paste. From the writer's professional experience at other copper mining operations, there can be a 3-5% decrease in strength per year from peak strength. The peak strength is generally in the vicinity of 28-112 days of curing.

2.11 Ground Support

All accessible areas by personnel at LLM are deemed supported ground, whereby an approved design of ground supporting elements have been installed. Various methods are used for designing ground support in LLM. The designs are based on a static loading environment. The mine is mostly within a medium stress state and does not experience seismicity. The methods used for ground support design include:

- Barton (1974) empirical Ground Support Design Chart.
- First principle calculations.
- Numerical Modelling (Map3D, Unwedge).
- Site experience and observation-based approach.

Figure 6 (extracted from the LLM GCMP) illustrates the use of Barton (1974) empirical Ground Support Graph. The graph plots each geotechnical domain boundary against the range of excavation profiles typically used at Lady Loretta.

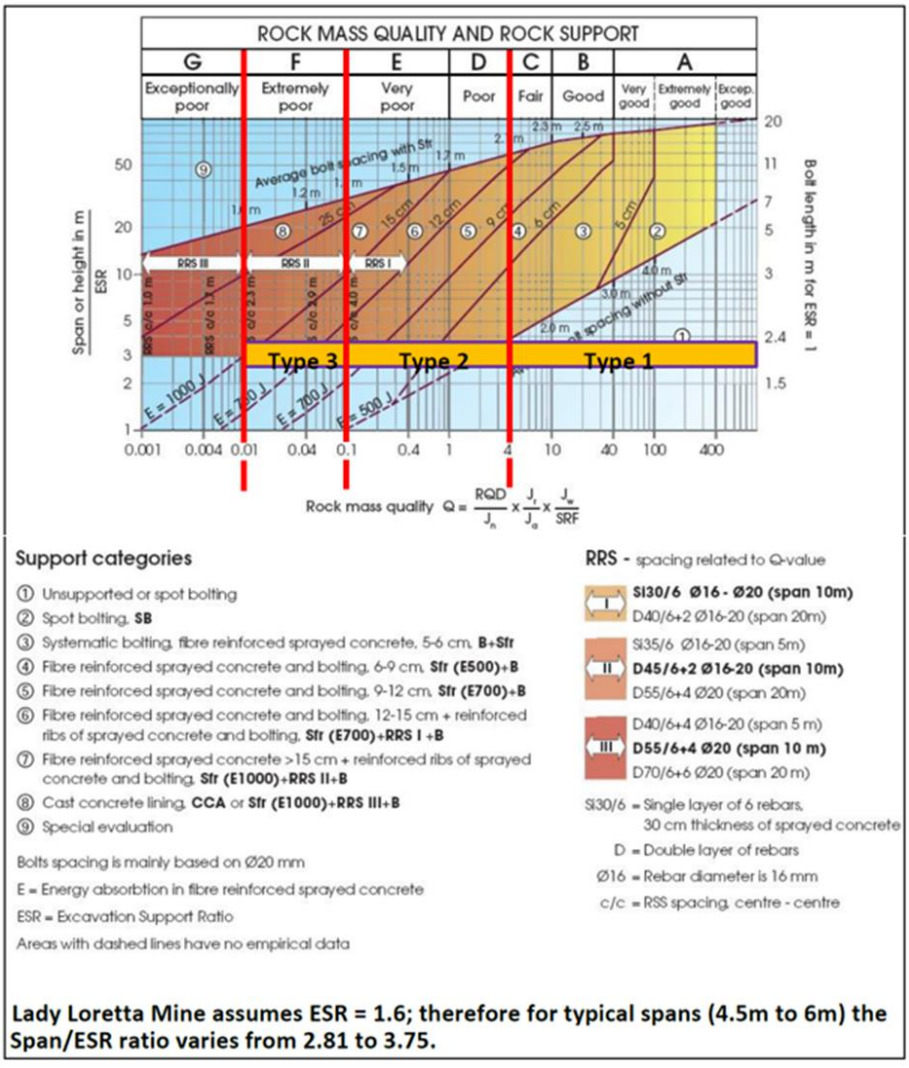


Figure 6- Lady Loretta Modified Barton Q-Method Handbook (2013) Ground Support Design Chart

2.12 Geotechnical Performance History

The ground condition excavated through LLM development drives is generally classified as 'Fair' to 'Good' (Bieniawski, 1989). However, there are four geological/geotechnical performance aspects to consider.

- Faults with exception of Thorpedo fault, exhibit poor ground. Fault exposures have additional ground support installed; 2 rings of 6 m long cable bolts spaced 2m x 2m, from 5m either side of the footwall and hanging wall fault contact. The Thorpedo Fault comprises fair ground, and it is water bearing which contributes to corrosion of support elements. Site observations indicate that faulting, on various occasions, prompted some falls of ground prior to installing the first pass of support (fibrecrete and bolting) and on one occasion, prior to second pass of support (cable bolting).
- The Massive Pyrite Layer localised stratigraphically at the top of the Pyrite Unit, prior reaching the Ore Horizon, is a highly fractured, very soft material. Its formation is likely due to shearing of this less competent layer in contact with the more competent Ore Horizon created during the formation of the syncline. This layer can be some 5m to 7m in thickness, and when intersected during ore drive development, falls of ground generally follow. To stabilize the poor ground, the support applied in most cases comprises an initial 50 mm of fibrecrete, mesh with stiff sets, and another layer of 50 mm of fibrecrete with 6 m long cable bolts spaced 2m x 2m in the backs. A fan of 4.5 m long cable bolts is occasionally installed if the overbreak is excessive. There have been no major stability issues since this heavy support has been applied.
- Gypsum ($CaSO_4.2H_2O$) formation within the rock mass, mostly observed in the Pyrite Unit, is the critical driver for ground support rehab at LLM. Gypsum formation is derived by the reaction with the acidic water percolating into the calcium rich mineralogy of the rock mass. The gypsum has a distinguishing crystal growing effect which can puncture and crack the fibrecrete, and snap resin bolts. Its prevalence is observed closer to the floor level where water ponds or at localised bearing water structures. Some fall of ground events occurred with the delamination of fibrecrete and slabbing in walls against bedding planes.
- The presence of SO_2 originating from high grade stopes left open for extended periods has increased corrosion rates in split sets, notably within the first 300 mm from the plate. SO_2 is lighter than air, so the gas concentrates at higher levels of drives and open stopes. Therefore, corroding ground support is prevalent in the backs and upper shoulders of the drives. Schedule constraints and paste availability are responsible for stopes being left open for extended periods. The level of corrosion varies according to the exposure time and concentration of the gas. Bolts have been replaced in cases of extreme corrosion.

Stope performance can be described generally as Good. Stopes typically experience overbreak in tension zones between the crown of the stope and the drives atop. There have been sporadic falls of ground associated with faults and structures that have been identified through back analysis and modelled. Insufficient paste strength has sometimes caused large overbreak on walls, particularly in stopes where cement content was 4%. Since the introduction of >6% cement in June 2020, overbreak in paste has generally not occurred. The Massive Pyrite Layer in the hanging wall of the western stopes and in the footwall of the eastern stopes has commonly caused large overbreak with slumping of material soon after firing and even during bogging.

3 SUBSIDENCE RISK MITIGATION CONTROLS

The service life of ground support is not indefinite and therefore will deteriorate and cease to function at some point in the future. Two main controls are in place to mitigate subsidence risk after mine closure, they being backfilling and flooding. Subsidence risk analysis should consider the time dependent factors involved in a mine closure with its underground openings, especially the continuous rock mass deterioration around voids not backfilled including the upper Decline.

3.1 Backfilling

Backfilling is the most important method of controlling subsidence at LLM during mining, and post closure since the creation of voids during mining are eliminated. All stopes will be backfilled at LLM. Most stopes will be tight filled (filled with no void remaining) except the top-down sequenced stopes at 1175 Level to 1050 Level. The uppermost operating levels of the mine are the 1175 Level and 1200 Level, with the surface at least 140 m above, at 1340 mRL. The subvertical orientation of the ore body, coupled with the relatively small span from footwall to hanging wall of the upper levels have been analysed for subsidence risk at the surface. These stopes have been paste filled to levels generally 5 m below floor of the supported drive. This void will be considered in the empirical and 2D model.

3.2 Flooding

After mine closure, the main dewatering pumps located at the bottom at 875 level will be decommissioned. Water inflow will fill the mine until the pre-mining water table level is reached at approximately 1290 mRL. The average surface level is around 1340 mRL. The highest level of the mine (the 1200 Level) and base of the crown pillar is located at 1215 mRL. Given the pre-mining water table, all mined stopes and developed levels are expected to eventually be under water. The water table at 1290 mRL after recharging will be located approximately in between stockpiles SP2 and SP3 in the Decline (Figure 7).

As the rising water level floods the mine, pore pressures will increase, and buoyancy forces will be generated. As a result, the overburden pressure and the potential for subsidence should be minimised. Although a buoyancy effect in mines is not commonly considered or acknowledged, Goetz et al, 1994 (in Wolkersdorfer C., 2008) observed positive buoyancy effects with lifting of the surface over an abandoned and flooded mine.

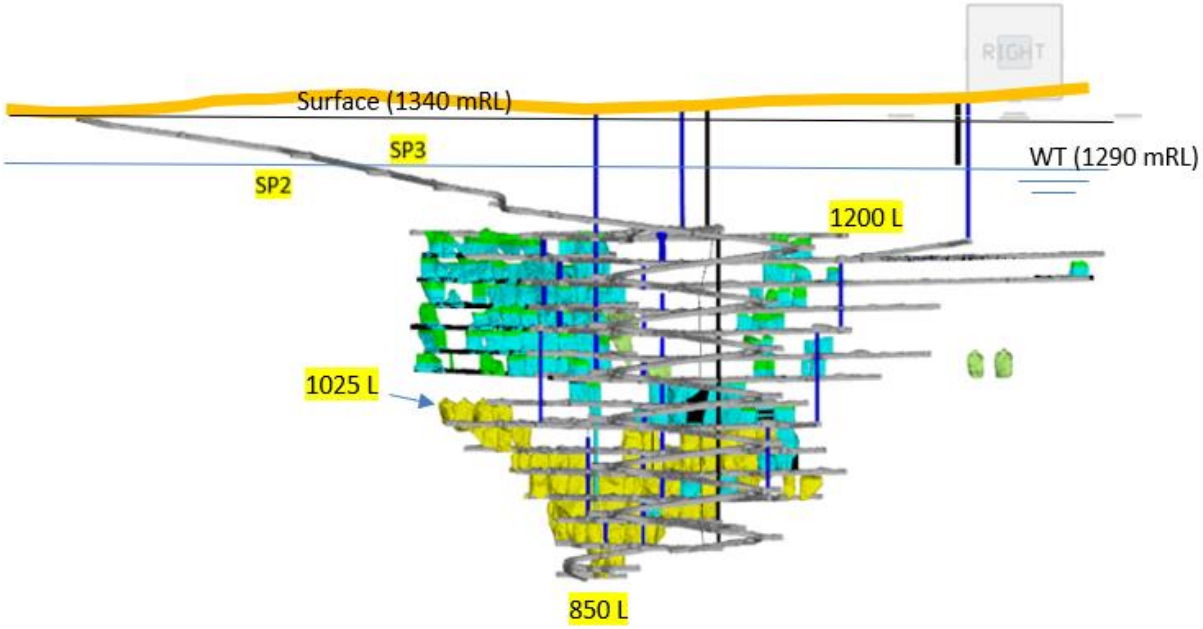


Figure 7- View from East showing location of SP2 and SP3 along the Decline. Pre-mining water table (WT), topographic surface and some levels shown for reference.

The recharged water will likely reach a pH and chemical composition close to pre-mining quality. Flooded areas of the mine will have no free oxygen radicals, which will delay further ground support deterioration. A benefit of flooding of the mine is also the prevention of disulphide oxidation.

4 GEOTECHNICAL MODELLING AND ASSESSMENT

Geotechnical modelling for the LLM closure subsidence risk was conducted using two methods. An empirical method analysed the failure probability of the three crown pillars (defined as the rock mass situated above an uppermost stope of the mine) – Eastern Limb, Western Limb, and North Ore Body, presenting the largest voids in the mine. Additionally, 2D modelling of these scenarios was conducted using Rocscience RS2®.

4.1 Representative Sections

The sections for the empirical and 2D analysis are illustrated as red lines in Figure 8. They are the three crown pillars for the underground mine. At the time of writing this report, the North Ore Body (NOB) crown pillar stopes had not been extracted.

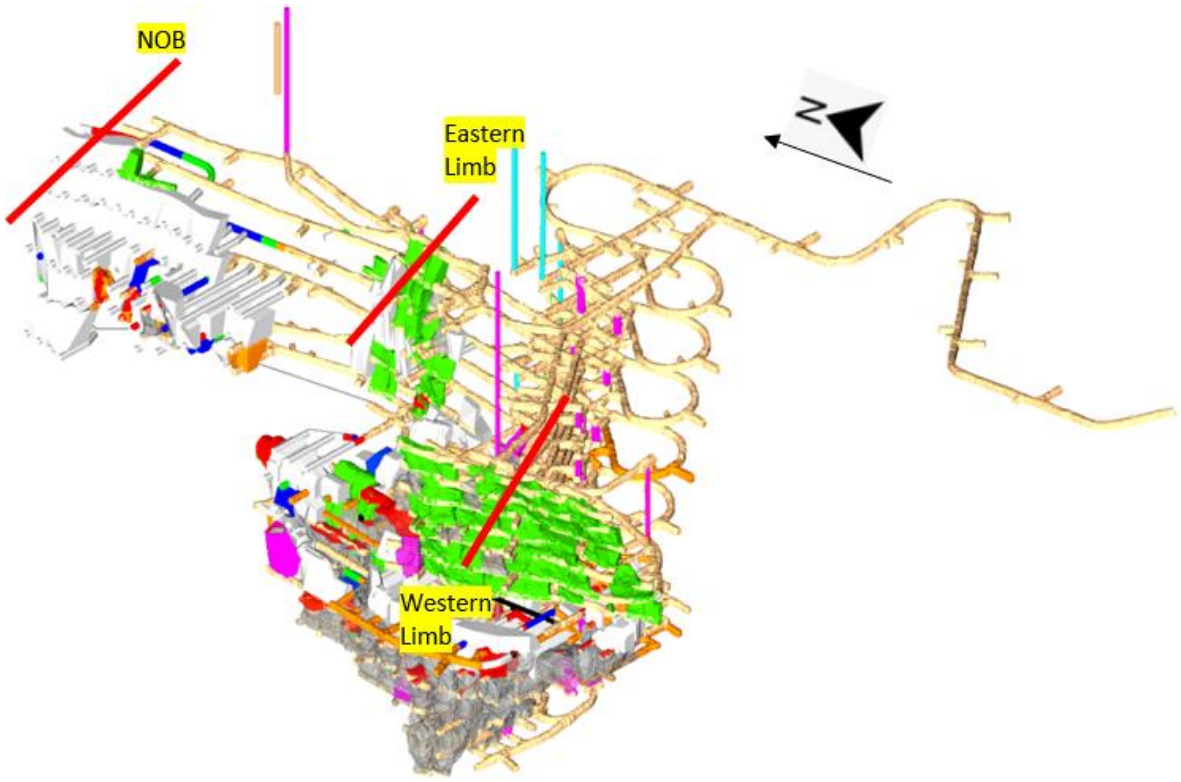


Figure 8- Underground location of the three crown pillars analysed. Red lines are representative sections.

4.2 Empirical Analysis - The Scaled Span Method

Carter (1992 and 2014) developed a method of designing stable crown pillars from a series of case studies measuring crown pillar stability. The 'Scaled Crown Span' concept characterises the geometry of a crown pillar in three dimensions and has been used widely in Australia and internationally. A summary of the method follows, and Appendix A provides further details.

4.2.1 Assessment methodology

Carter (2014) describes an empirical methodology for assessing crown stability using an empirical graph. To make the assessment from the graph two parameters are required:

- The rock mass quality, such as Q (including the groundwater factor, Jw) or RMR.
- The Scaled Span factor (CS) which is defined by:

$$C_S = S\left(\frac{\gamma}{T(1+S_R)(1-0.4\cos\theta)}\right)^{0.5}$$

where: S = crown pillar span (m);
γ = specific gravity (which is dimensionless but has the same numerical value as rock mass unit weight, tonnes/m^3);
T = thickness of crown pillar (m);
θ = orebody/foliation dip, and;
S_R = span ratio = S/L
(crown pillar span/crown pillar strike length)

4.2.2 General Assumptions

Variations in span and length of the crown have been accounted for in using the following dimensions:

- 13 m x 50 m for the Eastern Limb,
- 14 m x 125 m for the Western Limb, and
- 12 m x 70 m for the NOB.

Two cases are considered for the crown to account for the variability in the rock mass across the stope crown:

- Case 1. Fresh or slightly weathered rock carries all overlying domains (i.e. a worst-case scenario where the weathered rock is assumed to have no self-supporting capability).
- Case 2. Fresh, slightly weathered rock and the weathered domain supports the overlying cover (the weathered domain is self-supporting).

4.2.3 Rock Mass Characterisation

The Q values used in this assessment have been taken from the geotechnical report 'LLM Geotechnical Factual Report' (Mining One, 2011 and 2012). These values are summarised in Table 9. Underground observations taken by the geotechnical team at LLM post completion of this geotechnical report confirm 2nd quartile Q values are most appropriate. To consider post closure sensitivity the 1st quartile Q parameters will also be investigated.

Table 9- Q Values for different weathering grades

Weathering Grade	Q 1st Quartile	Q 2nd Quartile
Extremely Weathered	0.06	0.18
Highly Weathered	0.11	0.54
Moderately Weathered	0.16	1.11
Slightly Weathered	0.43	2.73
Fresh	1.1	4.21

The joint water value (Jw) in the Q classification can vary over time; both Jw =1 and Jw = 0.66 have been included in the assessment. At "wet" conditions (Jw = 0.66) larger water inflows into voids have potential to outwash joint filling and place outward pressure on the rockmass surrounding these voids. This wet scenario has been included in the analyses to represent the critical case; it is expected to be temporary only during the recharging stage when the ground water reaches the base of these crown pillars (125-128 m bgl). Once groundwater has recharged, pressures will equalise to a state equal or better to that of "dry" conditions, where Jw =1. Above the water table level (recharging and recharged) Jw can vary between that of wet and dry depending on presence of void and seasonal fluctuations.

4.2.4 Vertical distribution of domains

The vertical distribution of domains in the crown were inferred from available drillholes. The base of oxidation is highly variable at LLM. Two ranges of domain thicknesses were assessed, one is the average thickness across all drillholes, the other is based on the minimum thickness of fresh rock at the base of the crown. Table 10 presents the thickness of the materials assumed in the analysis.

Table 10- Material Domains Minimum Thickness (in metres)

Domain	Eastern Limb	Western Limb	North Ore Body
Cover (Soil)	3	3	3
Weathered (assumed)	37	37	37
Fresh or Slightly Weathered Rock	91	88	116

4.2.5 Geometry of the Stopes and Faults

Figure 9 and Figure 10 show the Eastern Limb and Western Limb, respectively. The Eastern Limb has two combined stopes as part of the crown pillar at this region. The Western Limb has five combined stopes.

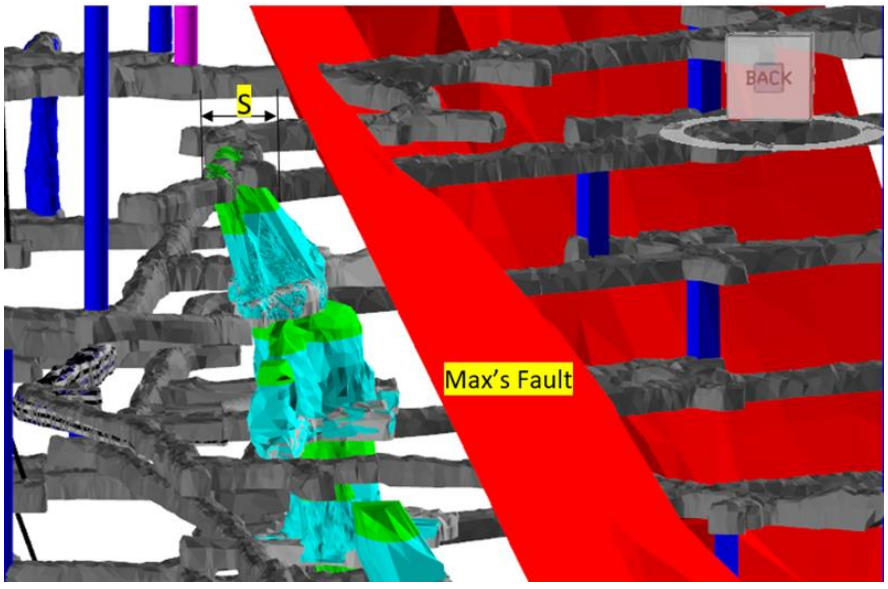


Figure 9- Eastern Limb with crown at 1200 level and Max's Fault. S = crown pillar span.

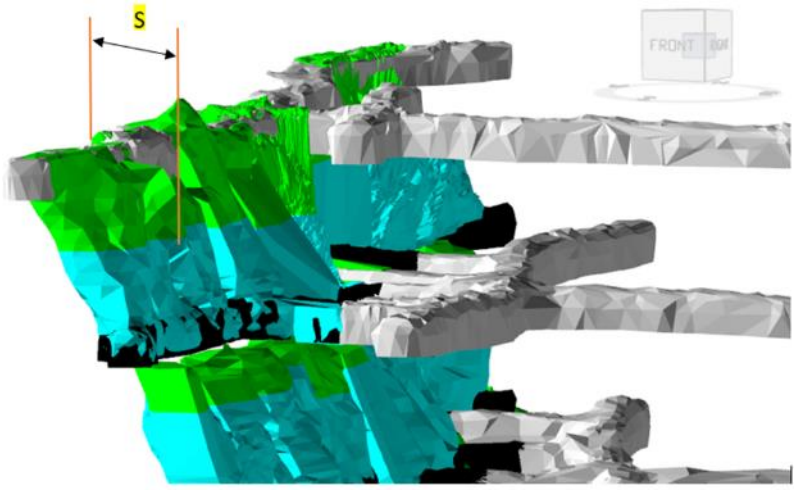


Figure 10- Western Limb and 5 longitudinal stopes mined (1175 to 1200 level). S = crown pillar span.

4.2.6 Results

Figure 11 and Figure 12 present the crown stability calculations for Case 1 and Case 2, respectively, for each region (Eastern and Western limbs and NOB). The figures are divided by the assumption of Q value for 1st and 2nd quartile data.

The results indicate the Western Limb has a lower Factor of Safety (FoS) due to its larger span (14m), longer length (125 m) and closer proximity to surface compared to the Eastern Limb and North Ore Body. The 'dry conditions' FOS (when Jw = 1) is applicable for the dry conditions during active mining, or upon completion. The wet FoS (Jw = 0.66 - medium inflow parameter) is a conservative application to wet areas or where water recharging is in progress. It can be assumed that when the mine is fully recharged to pre-mining water level that the FoS would replicate (or be better than) the dry condition FoS.

Crown Stability (Eastern Limb) - Q 2nd quartile - Weathered Rock Not Self-supporting						
Level - 1175 - 1200 (Eastern Limb)						
Cs	2.60	Scaled crown span (m)				
S	13.00	Stope span (m)				
γ	4.17	Ore Density (t/m3)	weighted for surcharge			
T	91.00	Thickness (m)			radians	cos
θ	77.00	Orebody Dip (degrees)			1.3439	0.225
Sr	0.26	Span Ratio (= Span / Strike Length)				
S	13.00	Span of crown (m)				
L	50.00	Length (m)				
Sc	6.16	Critical Span	5.1381			
Q	4.21	Dry conditions	2.7786	Wet conditions		
FOS	2.37	Factor of Safety	1.9771	FOS - wet (Jw = 0.66)		
Pf	0.04	Probability of Failure	3.79	%		

Crown Stability (Eastern Limb) - Q 1st quartile - Weathered Rock Not Self-supporting						
Level - 1175 - 1200 (Eastern Limb)						
Cs	2.60	Scaled crown span (m)				
S	13.00	Stope span (m)				
γ	4.17	Ore Density (t/m3)	weighted for surcharge			
T	91.00	Thickness (m)			radians	cos
θ	77.00	Orebody Dip (degrees)			1.3439	0.225
Sr	0.26	Span Ratio (= Span / Strike Length)				
S	13.00	Span of crown (m)				
L	50.00	Length (m)				
Sc	3.44	Critical Span	2.8744			
Q	1.10	Dry conditions	0.726	Wet conditions		
FOS	1.32	Factor of Safety	1.106	FOS - wet (Jw = 0.66)		
Pf	0.32	Probability of Failure	31.56	%		

Crown Stability (Western Limb) - Q 2nd quartile - Weathered Rock Not Self-supporting						
Level - 1175 - 1200 (Western Limb)						
Cs	3.12	Scaled crown span (m)				
S	14.00	Stope span (m)				
γ	4.20	Ore Density (t/m3)	weighted for surcharge			
T	88.00	Thickness (m)			radians	cos
θ	70.00	Orebody Dip (degrees)			1.2217	0.342
Sr	0.11	Span Ratio (= Span / Strike Length)				
S	14.0	Span of crown (m)				
L	125.0	Length (m)				
Sc	6.16	Critical Span	5.138			
Q	4.21	Dry conditions	2.779	Wet conditions		
FOS	1.97	Factor of Safety	1.646	FOS - wet (Jw = 0.66)		
Pf	0.10	Probability of Failure	9.52	%		

Crown Stability (Western Limb) - 1st quartile - Weathered Rock Not Self-supporting						
Level - 1175 - 1200 (Western Limb)						
Cs	3.12	Scaled crown span (m)				
S	14.00	Stope span (m)				
γ	4.20	Ore Density (t/m3)	weighted for surcharge			
T	88.00	Thickness (m)			radians	cos
θ	70.00	Orebody Dip (degrees)			1.2217	0.342
Sr	0.11	Span Ratio (= Span / Strike Length)				
S	14.0	Span of crown (m)				
L	125.0	Length (m)				
Sc	3.44	Critical Span	2.874			
Q	1.10	Dry conditions	0.726	Wet conditions		
FOS	1.10	Factor of Safety	0.921	FOS - wet (Jw = 0.66)		
Pf	0.44	Probability of Failure	43.77	%		

Crown Stability (NOB) - Q 2nd quartile - Weathered Rock Not Self-supporting						
Level - 1150 - 1175 (NOB)						
Cs	2.19	Scaled crown span (m)				
S	12.00	Stope span (m)				
γ	3.90	Ore Density (t/m3)	weighted for surcharge			
T	116.00	Thickness (m)			radians	cos
θ	70.00	Orebody Dip (degrees)			1.2217	0.342
Sr	0.17	Span Ratio (= Span / Strike Length)				
S	12.0	Span of crown (m)				
L	70.0	Length (m)				
Sc	6.16	Critical Span	5.138			
Q	4.21	Dry conditions	2.779	Wet conditions		
FOS	2.81	Factor of Safety	2.348	FOS - wet (Jw = 0.66)		
Pf	0.01	Probability of Failure	1.14	%		

Crown Stability (NOB) - 1st quartile - Weathered Rock Not Self-supporting						
Level - 1150 - 1175 (NOB)						
Cs	2.19	Scaled crown span (m)				
S	12.00	Stope span (m)				
γ	3.90	Ore Density (t/m3)	weighted for surcharge			
T	116.00	Thickness (m)			radians	cos
θ	70.00	Orebody Dip (degrees)			1.2217	0.342
Sr	0.17	Span Ratio (= Span / Strike Length)				
S	12.0	Span of crown (m)				
L	70.0	Length (m)				
Sc	3.44	Critical Span	2.874			
Q	1.10	Dry conditions	0.726	Wet conditions		
FOS	1.57	Factor of Safety	1.314	FOS - wet (Jw = 0.66)		
Pf	0.21	Probability of Failure	20.83	%		

Figure 11- Crown Stability Calculations Considering Weathered Rock Not Self-supporting (Case 1)

Crown Stability (Eastern Limb) - Q 2nd quartile - Weathered Rock Self-supporting						
Level - 1175 - 1200 (Eastern Limb)						
Cs	1.85	Scaled crown span (m)				
S	13.00	Stope span (m)				
γ	2.97	Ore Density (t/m3)	weighted for surcharge			
T	128.00	Thickness (m)			radians	cos
θ	77.00	Orebody Dip (degrees)			1.3439	0.225
Sr	0.26	Span Ratio (= Span / Strike Length)				
S	13.00	Span of crown (m)				
L	50.00	Length (m)				
Sc	6.16	Critical Span	5.1381			
Q	4.21	Dry conditions	2.7786	Wet conditions		
FOS	3.33	Factor of Safety	2.7784	FOS - wet (Jw = 0.66)		
Pf	0.00	Probability of Failure	0.22	%		

Crown Stability (Eastern Limb) - Q 1st quartile - Weathered Rock Self-supporting						
Level - 1175 - 1200 (Eastern Limb)						
Cs	1.85	Scaled crown span (m)				
S	13.00	Stope span (m)				
γ	2.97	Ore Density (t/m3)	weighted for surcharge			
T	128.00	Thickness (m)			radians	cos
θ	77.00	Orebody Dip (degrees)			1.3439	0.225
Sr	0.26	Span Ratio (= Span / Strike Length)				
S	13.00	Span of crown (m)				
L	50.00	Length (m)				
Sc	3.44	Critical Span	2.8744			
Q	1.10	Dry conditions	0.726	Wet conditions		
FOS	1.86	Factor of Safety	1.5543	FOS - wet (Jw = 0.66)		
Pf	0.12	Probability of Failure	12.03	%		

Crown Stability (Western Limb) - Q 2nd quartile - Weathered Rock Self-supporting						
Level - 1175 - 1200 (Western Limb)						
Cs	2.20	Scaled crown span (m)				
S	14.00	Stope span (m)				
γ	2.97	Ore Density (t/m3)	weighted for surcharge			
T	125.00	Thickness (m)			radians	cos
θ	70.00	Orebody Dip (degrees)			1.2217	0.342
Sr	0.11	Span Ratio (= Span / Strike Length)				
S	14.0	Span of crown (m)				
L	125.0	Length (m)				
Sc	6.16	Critical Span	5.138			
Q	4.21	Dry conditions	2.779	Wet conditions		
FOS	2.80	Factor of Safety	2.333	FOS - wet (Jw = 0.66)		
Pf	0.01	Probability of Failure	1.20	%		

Crown Stability (Western Limb) - 1st quartile - Weathered Rock Self-supporting						
Level - 1175 - 1200 (Western Limb)						
Cs	2.20	Scaled crown span (m)				
S	14.00	Stope span (m)				
γ	2.97	Ore Density (t/m3)	weighted for surcharge			
T	125.00	Thickness (m)			radians	cos
θ	70.00	Orebody Dip (degrees)			1.2217	0.342
Sr	0.11	Span Ratio (= Span / Strike Length)				
S	14.0	Span of crown (m)				
L	125.0	Length (m)				
Sc	3.44	Critical Span	2.874			
Q	1.10	Dry conditions	0.726	Wet conditions		
FOS	1.56	Factor of Safety	1.305	FOS - wet (Jw = 0.66)		
Pf	0.21	Probability of Failure	21.22	%		

Crown Stability (NOB) - Q 2nd quartile - Weathered Rock Self-supporting						
Level - 1150 - 1175 (NOB)						
Cs	1.66	Scaled crown span (m)				
S	12.00	Stope span (m)				
γ	2.96	Ore Density (t/m3)	weighted for surcharge			
T	153.00	Thickness (m)			radians	cos
θ	70.00	Orebody Dip (degrees)			1.2217	0.342
Sr	0.17	Span Ratio (= Span / Strike Length)				
S	12.0	Span of crown (m)				
L	70.0	Length (m)				
Sc	6.16	Critical Span	5.138			
Q	4.21	Dry conditions	2.779	Wet conditions		
FOS	3.71	Factor of Safety	3.096	FOS - wet (Jw = 0.66)		
Pf	0.00	Probability of Failure	0.06	%		

Crown Stability (NOB) - 1st quartile - Weathered Rock Self-supporting						
Level - 1150 - 1175 (NOB)						
Cs	1.66	Scaled crown span (m)				
S	12.00	Stope span (m)				
γ	2.96	Ore Density (t/m3)	weighted for surcharge			
T	153.00	Thickness (m)			radians	cos
θ	70.00	Orebody Dip (degrees)			1.2217	0.342
Sr	0.17	Span Ratio (= Span / Strike Length)				
S	12.0	Span of crown (m)				
L	70.0	Length (m)				
Sc	3.44	Critical Span	2.874			
Q	1.10	Dry conditions	0.726	Wet conditions		
FOS	2.07	Factor of Safety	1.732	FOS - wet (Jw = 0.66)		
Pf	0.08	Probability of Failure	7.65	%		

Figure 12- Crown Stability Calculations Considering Weathered Rock Self-supporting (Case 2)

Currently, the crown of the 1175 – 1200 level stopes are partially supported by the development drive ground support. In the writer's experience at LLM, this support was observed to have deteriorated since installation some 8-9 years ago. Observations of gypsum formation, dislodgement of fibrecrete, and rock bolts in advanced stage of corrosion were noted. For the closure stability assessment ground support within the mine will be disregarded.

Carter (2014) provides a classification for the suitable FoS requirements for design of crown pillars relevant to their service life (Table 11. For a closure assessment, Table 11 would indicate a FoS requirement of >>2 to safely consider the crown pillar 'Stable'.

Table 11- Acceptable Risk Exposure Guidelines - Comparative Significance of Crown Pillar Failure

Class	Probability of Failure %	Minimum Factor of Safety	Maximum Scaled Span, Cs (= Sc)	ESR (Barton et al. 1974)	Design Guidelines for Pillar Acceptability/Serviceable Life of Crown Pillar				
					Expectancy	Years	Public Access	Regulatory position on closure	Operating Surveillance Required
A	50 – 100	<1	$11.31Q^{0.44}$	>5	Effectively zero	< 0.5	Forbidden	Totally unacceptable	Ineffective
B	20 – 50	1.0	$3.58Q^{0.44}$	3	Very, very short-term (temporary mining purposes only ; unacceptable risk of failure for temporary civil tunnel portals	1.0	Forcibly Prevented	Not acceptable	Continuous sophisticated monitoring
C	10 – 20	1.2	$2.74Q^{0.44}$	1.6	Very short-term (quasi-temporary stope crowns ; undesirable risk of failure for temporary civil works)	2 – 5	Actively prevented	High level of concern	Continuous monitoring with instruments
D	5 – 10	1.5	$2.33Q^{0.44}$	1.4	Short-term (semi-temporary crowns, e.g.under non-sensitive mine infrastructure)	5 – 10	Prevented	Moderate level of concern	Continuous simple monitoring
E	1.5 – 5	1.8	$1.84Q^{0.44}$	1.3	Medium-term (semi-permanent crowns, possibly under structures)	15–20	Discouraged	Low to moderate level of concern	Conscious superficial monitoring
F	0.5 – 1.5	2	$1.12Q^{0.44}$	1	Long-term (quasi-permanent crowns, civil portals, near-surface sewer tunnels)	50–100	Allowed	Of limited concern	Incidental superficial monitoring
G	<0.5	>>2	$0.69\ Q^{0.44}$	0.8	Very long-term (permanent crowns over civil tunnels)	>100	Free	Of no concern	None required

4.2.7 Results Discussion

The results in Figure 11 and Figure 12 indicate that the crown pillar FoS against rock mass collapse varies with the different scenarios.

Table 12 below summarises the results including the probability of failure and the serviceability life (including those that are unacceptable, coloured red).

Discussed above, the most likely conditions are those of 2nd quartile Q parameters and Jw = 1. In all Cases (1 and 2) the FoS is acceptable above 2.0. Evidently, all scenarios utilising 1st quartile Q parameters, apart from Case 2 in NOB, are unacceptable with some very low FoS, and service life. Whilst 2nd quartile Q parameters are most likely, there will be occurrence of 1st quartile Q parameters in LLM, especially in association with fault zones. It is worth noting that "failure" does not imply total collapse, but the commencement of unravelling failures. The Western Limb achieved an unacceptable FoS when Jw =0.66 for Case 1 (weathered rock is not self-supporting) and all Jw conditions. This scenario cannot be discounted as it is assumed for early closure, during ground water recharge. The Western Limb crown pillar when "wet" and covered by Case 1 ground, found to have a FoS of 1.6, equating to a probability of failure of 5-10% and service life of 5-10 years.

For a closure assessment the results for the critical case must be addressed, that being Case 1, Jw = 0.66 and 1st quartile Q parameters. Results in Table 12 indicate that FoS can be as low as 0.9, but generally around 1.3. This corresponds to a service life of generally 2-5 years. In real terms, this assessment considers the void backs in the

1200 level are unsupported, so at such time when ground support has deteriorated beyond its usefulness, the backs will begin to unravel in (critical case) 2-5 years.

Table 12- Summary of FoS Results for the Scaled Span Method

Location	Case	JW	Q Quartile	FOS (Probability of failure%)	Serviceability Life (years)
Eastern Limb	1	0.66	1st	1.1 (20-50%)	1-2
			2nd	2.0 (0.5-1.5%)	50-100
		1	1st	1.3 (10-20%)	2-5
			2nd	2.4 (0.5-1.5%)	50-100
	2	0.66	1st	1.6 (5-10%)	5-10
			2nd	2.8 (<0.5%)	>100
		1	1st	1.9 (1.5-5%)	15-20
			2nd	3.3 (<0.5%)	>100
Western Limb	1	0.66	1st	0.9 (50-100%)	<0.5
			2nd	1.6 (5-10%)	5-10
		1	1st	1.1 (20-50%)	1-2
			2nd	2.0 (0.5-1.5%)	50-100
	2	0.66	1st	1.3 (10-20%)	2-5
			2nd	2.3 (0.5-1.5%)	50-100
		1	1st	1.6 (5-10%)	5-10
			2nd	2.8 (<0.5%)	>100
NOB	1	0.66	1st	1.3 (10-20%)	2-5
			2nd	2.3 (0.5-1.5%)	50-100
		1	1st	1.6 (5-10%)	5-10
			2nd	2.8 (<0.5%)	>100
	2	0.66	1st	1.7 (1.5-5%)	15-20
			2nd	3.1 (<0.5%)	>100
		1	1st	2.1 (0.5-1.5%)	50-100
			2nd	3.7 (<0.5%)	>100

RED FoS and Service Life are unacceptable for Closure

4.3 Empirical Analysis - Bulking of Failure

To explore the impact of the critical condition of crown pillar failure, a bulking failure analysis has been undertaken to assess the extent of the upward failure progression and subsidence at the surface. This method has also been applied to the upper Decline and is the basis for discussion for all capital / development openings.

4.3.1 Assessment methodology

The bulking failure analysis assumes failure progression only occurs in the vertical direction. The void decreases as the failure moves upwards until a point of choking, the depth of the void H is estimated as:

$$H = H_o - xB > 0 \qquad (1)$$

where H_o is the starting void height, x is the amount of failed ground (a length), and B is the bulking factor.

At void chocking, $H = 0$, the amount of failed ground equates to $x = H_o/B$. After failed ground, the depth from the surface to the top of a void is estimated as:

$$D = D_o - x > 0 \qquad (2)$$

where D_o is the starting depth. Given x = H_o/B at void chocking, Equation 2 becomes:

$$D = D_o - H_o/B > 0 \qquad (3)$$

which estimates the depth from the surface where void chocking occurs. Given void chocking occurs at the surface or lower ($D = 0$), the critical bulking factor is then:

$$B = H_o / D_o \qquad (4)$$

Conversely, the critical starting depth is:

$$D_o = H_o / B \qquad (5)$$

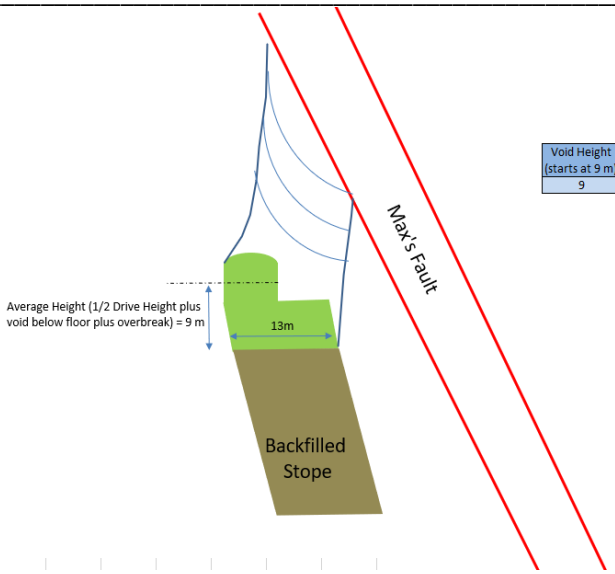
Bulking of soils and rocks classification descriptions from the British Geological Survey (BGS - Entwisle, D. et all, 2015) indicates that weak rocks that are likely to break into a wide variety of particle sizes, sand to cobble or even boulder, have a bulking factor of 0.40 (40%) to 0.55 (55%). For sandy material, the BGS indicates a bulking factor of 0.15 (15%).

For the assessment, a bulking factor of 0.1 (10%) was chosen for the weathered rock above the base of oxidation (around 40 m bgl). Rock below the base of oxidation has a bulking factor of 0.3 (30%) applied. These values are conservative compared to BGS (2015) but are frequently adopted in mining operations and considered appropriate.

4.3.2 Crown Pillar - Eastern and Western Limbs Bulking Results

As mentioned in Section 3.1, the upper level stopes of the mine in the Eastern and Western limbs are, and will not be, tight filled. Material that fails / unravels will occupy the void between the top of the backfill and the crown of the stopes. The drives atop the stopes are within the crowns of these stopes. As such, an overall void height of H_o = 9 metres between the top of paste backfill and backs of the drives can be assumed to remain for the life of mine. This void height is the average height along the wider section (13 m) of crown span.

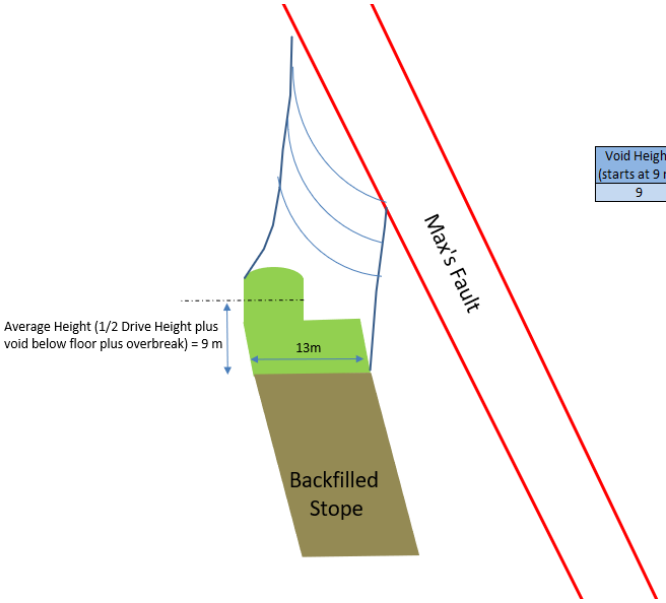
Due to Max's Fault proximity to the Eastern limb crown pillar, poor rock mass characteristics is expected. This fault, presenting a 5-10m thick zone mapped underground, will unravel, and occupy the void between the top of the back fill and the crown of the stopes. As shown in Figure 13, using Equation 3 and a bulking factor representative of poor ground of 10% (B = 0.1), the void chocking occurs D = 38 m below the 1340 mRL surface level.



Void Height (starts at 9 m)	Top of Void to Surface (m)	Remaining Void Height (m)	Bulking Factor
9	128	9	0.1
	119	8.1	
	110	7.2	
	101	6.3	
	92	5.4	
	83	4.5	
	74	3.6	
	65	2.7	
	56	1.8	
	47	0.9	
	38	0.0	

Figure 13- Schematic concept of void with filling by material from unravelling Max's Fault and chocking stage at 38 m below surface at the Eastern Limb. Starting point at 128 m below surface (base of crown pillar)

Using Equation 4, the critical bulking factor is around 7% such that the upward failure reaches the surface at the Eastern Limb (Figure 14). Such bulking factor is very unlikely. Based on the BGS (2015) soil classification, 7% is only achieved by very soft to soft clay or silt, this material is not recorded in LLM boreholes.

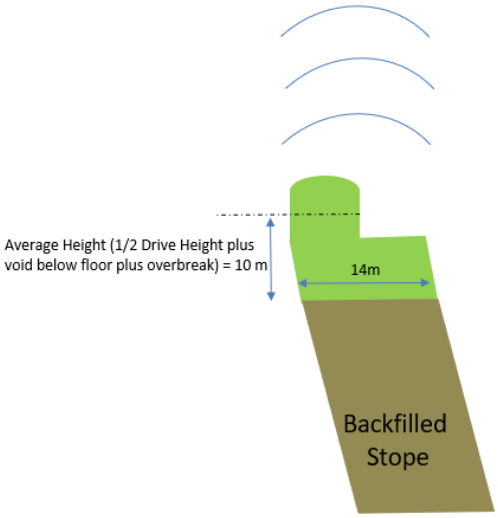


Void Height (starts at 9 m)	Top of Void to Surface (m)	Remaining Void Height (m)	Bulking Factor
9	128	9	0.07
	119	8.37	
	110	7.74	
	101	7.11	
	92	6.48	
	83	5.85	
	74	5.22	
	65	4.59	
	56	3.96	
	47	3.33	
	38	2.7	
	29	2.07	
	20	1.4	
	11	0.81	
	2	0.2	
	-7	-0.45	

Figure 14- Schematic concept of void with filling by material from unravelling Max's Fault and chocking stage at surface at the Eastern Limb. A bulking factor of 7% applied.

The Western Limb is not proximal to major structures. In contrast to the Eastern Limb, it can be assumed that the rock mass is better (not faulted), therefore a 30% bulking factor has been applied in Equation 3. The stopes are not tight filled; hence a span of 14 m and average void height of 10 m is used. Figure 15 shows void choking

occurs at 92 m from surface. Since this failure zone has chocked beneath the base of oxidation, the use of 30% bulking factor for the entire column is appropriate.



Void Height (starts at 10 m)	Top of Void to Surface (m)	Remaining Void Height	Bulking Factor
10	125	10	0.3
	115	7	
	105	4	
	95	1	
	85	-2	

Figure 15- Schematic concept of void with filling by material from unravelling rock mass and chocking stage at 92 m below surface at the Western Limb. Starting point at 125 m below surface (base of crown pillar)

Exploring the Scaled Span Method critical cases, all crown pillars were shown to fail. The bulking of failure analysis indicated that all upward ground collapse will be arrested prior to reaching the surface.

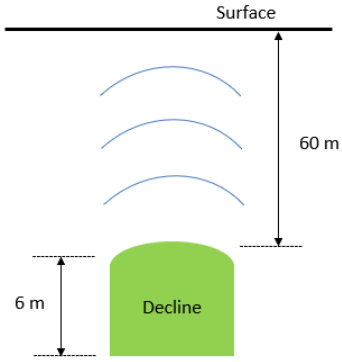
Failure propagation would reach 38 m bgl for the Eastern Limb. A sensitivity analysis found that the bulking factor must be lower than 7% for subsidence to reach the surface and this would not occur given the material types at LLM. For the Western Limb, the upward failure is expected to choke and terminate its progression at 92 m from surface. Since NOB has been tight filled, there is no void to allow propagation of failure.

The assessment confirms no subsidence should be seen at the surface.

4.3.3 Portal and Upper Decline

The portal and upper levels of the Decline will see inevitable deterioration of the ground support in the future; therefore, a bulking failure analysis is required. The dimension of the Decline (the void) is 6m high x 6 m wide.

Based on the report 'Lady Loretta Geotechnical Factual Report Proposed Decline and Shaft' (Mining One, 2012) the extremely weathered to highly weathered material is on average 40 m below surface. For this type of rock mass, it is plausible that a bulking factor of 10% (B = 0.1) is applied in the analyses. Using Equation 5, it was found that where the Decline is less than 60 m deep from surface, any upward failure will reach the surface before it bulks out and self supports (Figure 16). A plot has been produced in Figure 17, which graphs likely subsidence depth according to origin of failure. Figure 17 shows an upward failure that starts at 50 m from surface (Decline backs at 50 m bgl) will produce 1 metre of subsidence at surface level. For the backs at the portal entrance ('P' in Figure 17) located around 10 m bgl, a subsidence (S) of 5 m is expected.



Void Height (start at 6 m)	Top of Void to Surface (m)	Remaining Void	Bulking Factor
6	60	6	0.1
	54	5.4	
	48	4.8	
	42	4.2	
	36	3.6	
	30	3	
	24	2.4	
	18	1.8	
	12	1.2	
	6	0.6	
	0	0	

Figure 16-Schematic concept of void with filling by material from unravelling rock mass and chocking stage at surface for the Decline. Starting point at 60 m below surface.

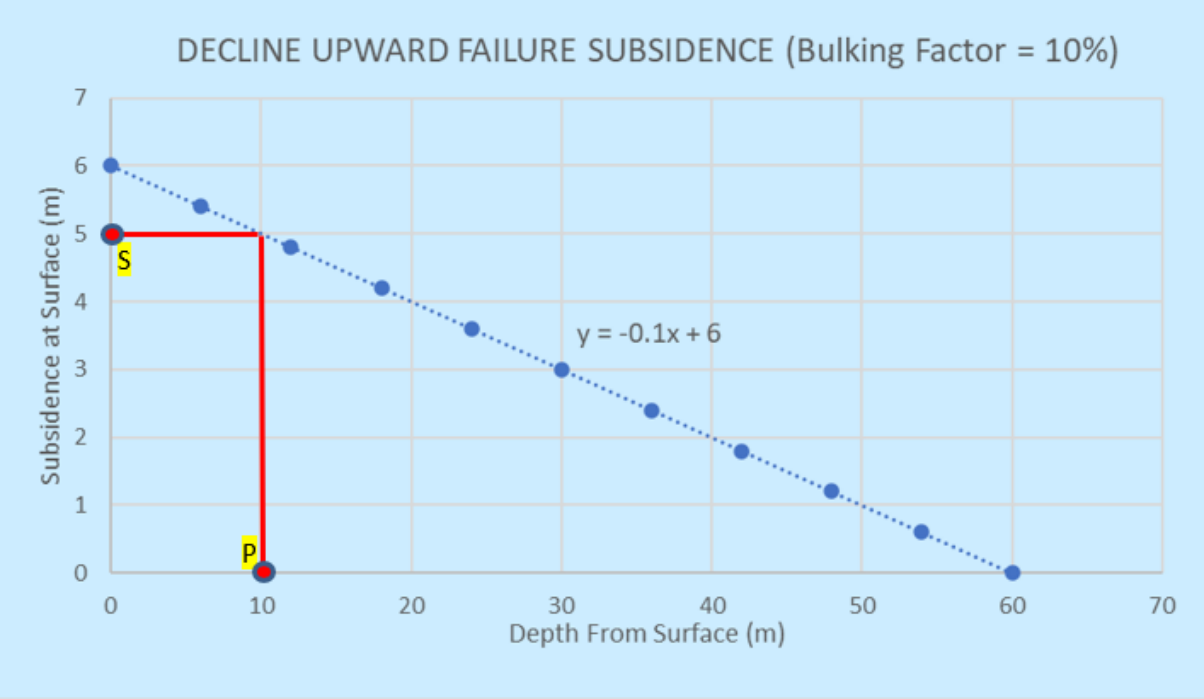


Figure 17- Subsidence metres at surface in relation to the depth from surface of the Decline. Portal backs (P) and expected subsidence (S) expected.

4.3.4 Subsidence from Voids Between Levels

As with the upper Decline, all development openings below are expected to show ground support deterioration. While the intersections along the Decline, the access drives and the footwall drives are spaced vertically every 25 m, they are positioned in a stepped layout. This stepped design will limit the available voids from one level to the other with any potential upward failure. Furthermore, based on Equation 5, in Section 4.3.1. a drive 6mH x 6mW will chock at 20 m high and subsidence on the level above will not occur. In this case a bulking factor of 30% can be applied since the uppermost level (1200 L) is approximately 100 m beneath the base of oxidation.

4.4 2D Modelling Analysis

The RS2® (formally Phase2®) 2D modelling software was chosen to examine potential subsidence on the surface. The modelling was staged from excavation and backfilling underground with "drained conditions" i.e. operational groundwater levels, to a final mine model with backfilled stopes and water recharge to the pre-mining level. Like the empirical analysis, three regions are considered: the Eastern Limb, Western Limb, and the North Ore Body (NOB). The cross sections reflect the wider crown span on the top level.

4.4.1 Rock Mass Characterisation

Material properties used in the numerical models were derived from laboratory test results presented in the GCMP, and from a review of the rock mass classification values (Q') presented in Sandy (2000). The material properties are presented in Table 13. Some values (in the GCMP) were assumed from a study conducted by AMC Consultants between 1997 and 2000, since laboratory or rock mass classification data were not available for some rock types, namely faults (AMC, 2020). Geological Strength Index (GSI) values, apart from the Fault, are based on underground observations by LLM site geotechnical engineers. A 40 m thick layer of soil was added to the model and assumed as a non-self-supporting load. Only elastic properties were considered in the model. AMC (2020) indicated that yielding with permanent change in shape occurs in stope walls following extraction, and for simplification on the method used here, the plastic properties will have little influence on surface.

Table 13- Material Properties

Unit	Friction angle (°)	Cohesion (kPa)	UCS (MPa)	E (GPa)	v	GSI	mi	mb	s	a	Er	Tensile strength (MPa)
CU			122#	*55*	*0.25*	60	*7*	1.678	0.012	0.503	28.6	-0.854
OH			80#	64	0.24	60	*7*	1.678	0.012	0.503	33.3	-0.560
PU			101#	36	0.27	60	*7*	1.678	0.012	0.503	18.7	-0.707
Fault	*30*	*20*	*30*			30		2.00	0.0023	1		-0.023
Soil	*35*	*50*		*100*	*0.25*							*-0.05*
Paste	*35*	*50*	*500*	*250*	*0.3*							*-0.05*

#Lowest value between 1997 and 2000 study from AMC 2020; *Assumed numbers are written in italics*

4.4.2 In-situ stress

The in-situ stress was determined using the Western Australia School of Mines AE method. The results were presented in the GCMP. The values used in the numerical modelling based on the overall excavation orientation for each of the 3 regions are shown in Table 14.

Table 14- Stress Applied

	Horizontal to Vertical Total Stress Ratio	
	Horizontal In-plane	**Horizontal Out-of-plane**
Western Limb	1.77	2.12
Eastern Limb	1.993	1.956
NOB	1.993	1.956

4.4.3 Mining sequence

The mining sequence for the Eastern and Western Limbs follows a top-down order from 1200 level to 1050 level and a bottom-up order from the lowest level in the chosen section to 1025 level. For the NOB, only bottom-up sequence was adopted in LLM. These sequences were modelled in distinct stages of excavation and backfilling in each of the three models, noting that the surface level was fixed at 1340 mRL. Further, voids (5 to 8 m high) at the top of backfilled stopes at upper levels of the Eastern and Western limbs were added to simulate the lack of localised tight filled areas.

4.4.4 Groundwater

The mining stages were modelled in a drained (dry) condition, apart from the final stage, where all stopes in each model have been backfilled. In the final stage, the water table level is modelled to reach a steady state pre-mining level of 1290 mRL after complete water recharge of the underground mine. All stages are in drained conditions with rock mass porosity assumed at 1% for the main lithologies and 9% for paste and 10% for soil based on the permeability from C.M Jewel & Associates (2006) and other literature sources. The base of the soil layer was assumed above the water table, at 1300 mRL, 40 m bgl.

4.4.5 Model results and limitations

The 2D analysis results from RS2® are presented in Figure 18 to Figure 23. Negative values indicate settlement and positive values indicate raising/swelling relative to the pre-mining levels. For a more comprehensive visualization of the results, refer to the electronic models provided in Interpret RS2® for each of the three sections.

For all three sections of each of the three regions, the recorded settlement on surface increases as the mining stages progress. Notably, in the final stage, where water is recharged into the system and pore pressure acts, there is a buoyancy effect with the raising/swelling of the rock mass lifting the surface level. This buoyancy effect will increase over time as the groundwater recharges, and the lifting of the ground surface will follow.

The vertical displacement at the final stage of mining (dry mine), that created by the buoyancy effect and groundwater recharge, and the long term closure resultant displacement are shown in Table 15 for each of the three representative sections.

Table 15- Surface displacement at various stages from 2D Analysis

	At Final Stage of Mining (Dry Mine)	Buoyancy Effect (Mine Recharged)	Net subsidence from pre-mining
Eastern Limb	20 cm ↓	18 cm ↑	2 cm ↓
Western Limb	20 cm ↓	32 cm ↑	12 cm ↑
North Ore Body	19 cm ↓	9 cm ↑	10 cm ↓

At the Eastern Limb, the vertical displacement changes over time, showing a settlement of 20 cm (at final stage of mining – dry mine) followed by an 18 cm uplift from flooding (the buoyance effect). This results in a final surface 2 cm lower (resultant settlement) than from a pre-mining surface. At the Western Limb, the resultant surface level shows a 12 cm uplift and the North Ore Body, a 10 cm settlement from pre-mining stage. These subsidence and uplift magnitudes would likely go unnoticed by visual observations.

Considering the low permeability of the rock mass and high water surface runoff, water table fluctuations will have minimum effect on the modelling.

A limitation of this model is that the result is based on an elastic model. Some degree of plasticity exists in the materials. Moreover, creep behaviour for the overburden materials (loose soil and vegetation) has not been considered, which may result in delayed subsidence. As such, the model is unable to predict when in time the events shown in the model output will occur.

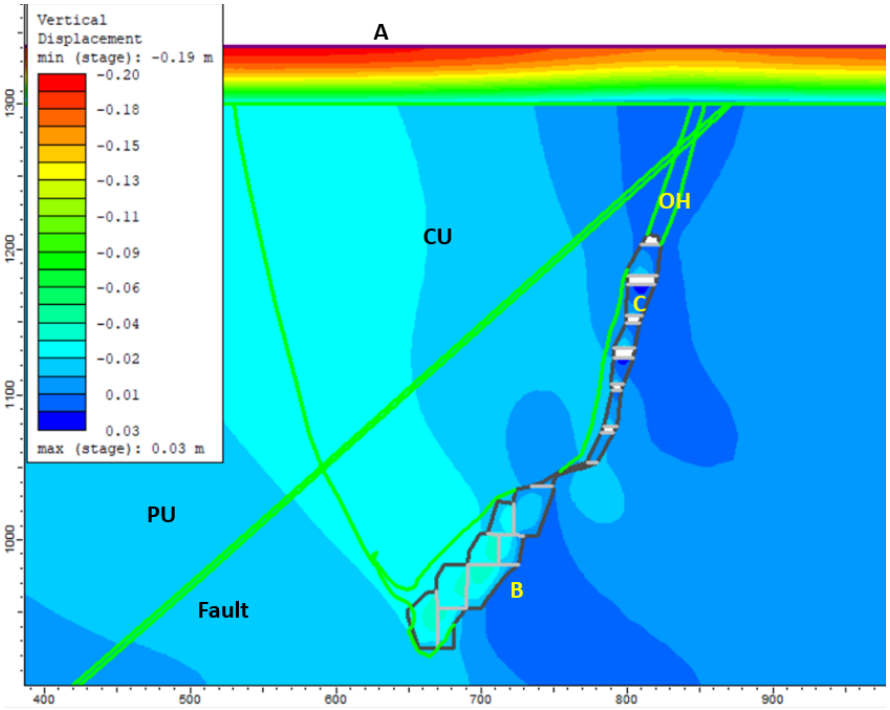


Figure 18- Eastern Limb – Final stage of mining with last stope backfilled (Dry conditions); 20 cm subsidence on surface (A), 2 cm raising at (B) and 3 cm of raising at the top of paste in (C)

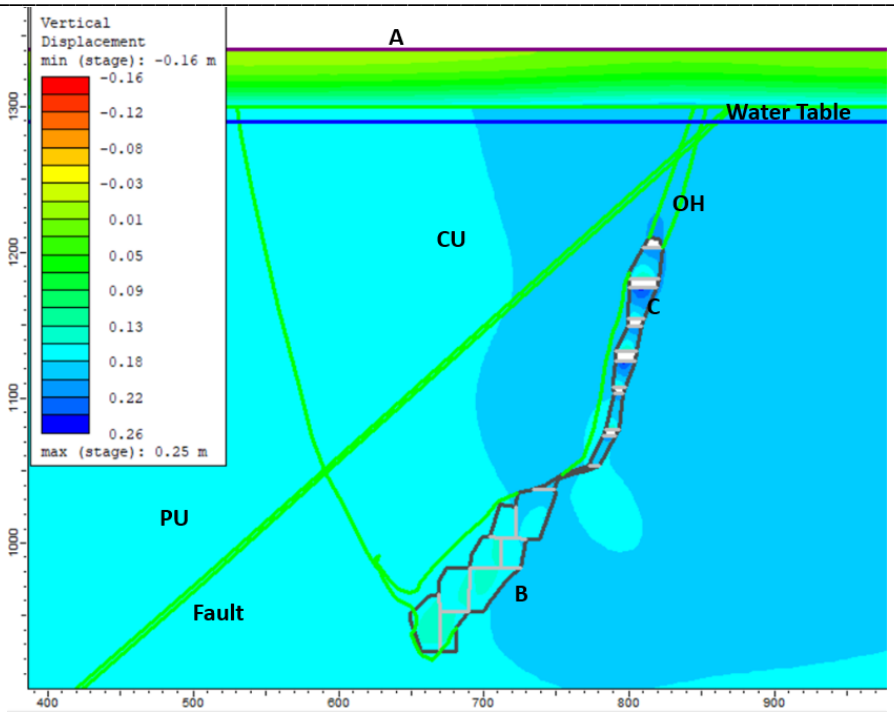


Figure 19- Eastern Limb – End of mining and water recharge completed (Flooded); 2 cm subsidence on surface (A), 18 cm raising at (B) and 24 cm raising on top of paste in 1150 L stope (C)

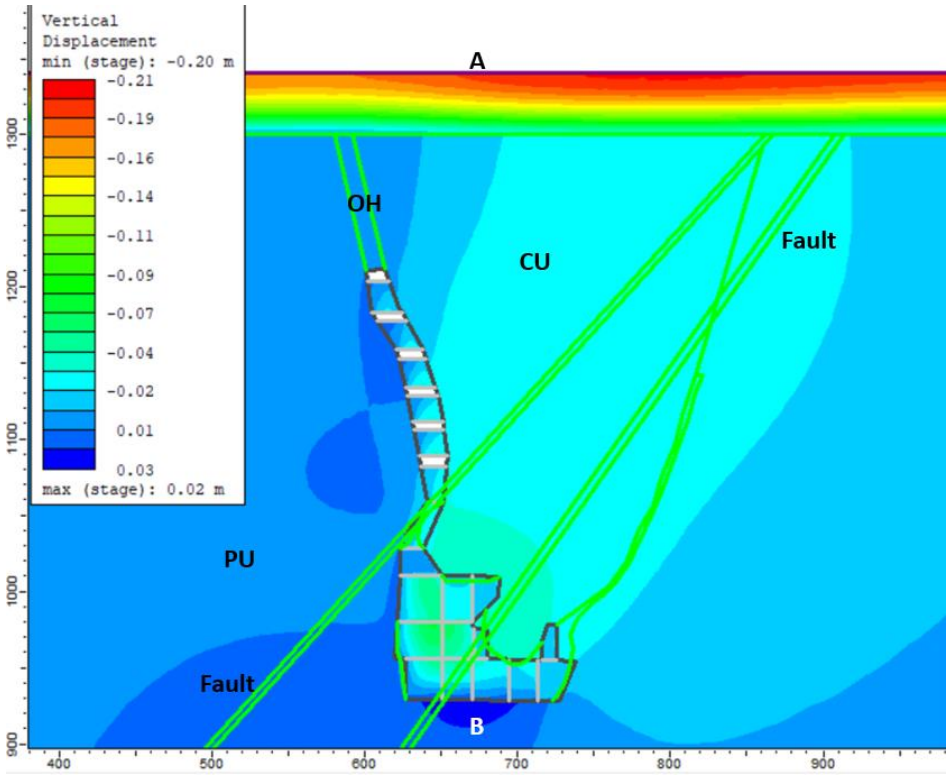


Figure 20 - Western Limb – Final stage of mining with last stope backfilled (Dry conditions);20 cm subsidence on surface (A) and 2.4 cm raising at the base of excavation (B)

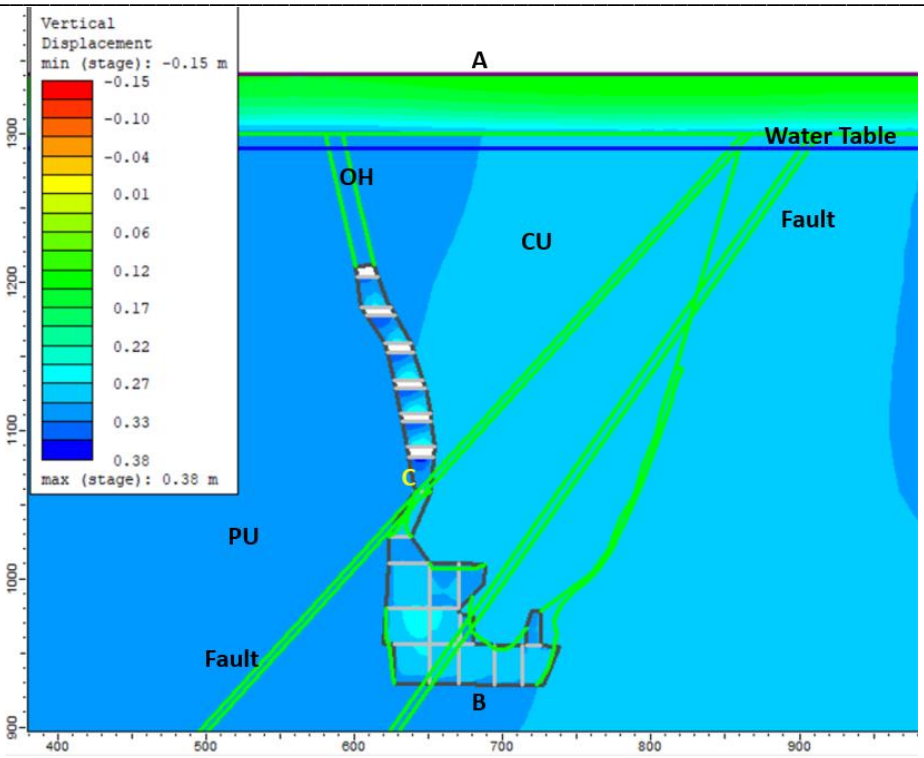


Figure 21- Western Limb – End of mining and water recharge completed (Flooded);12 cm raising on surface (A), 33 cm raising at the base of excavation (B) and 37 cm raising on top of paste in 1050 L stope (C).

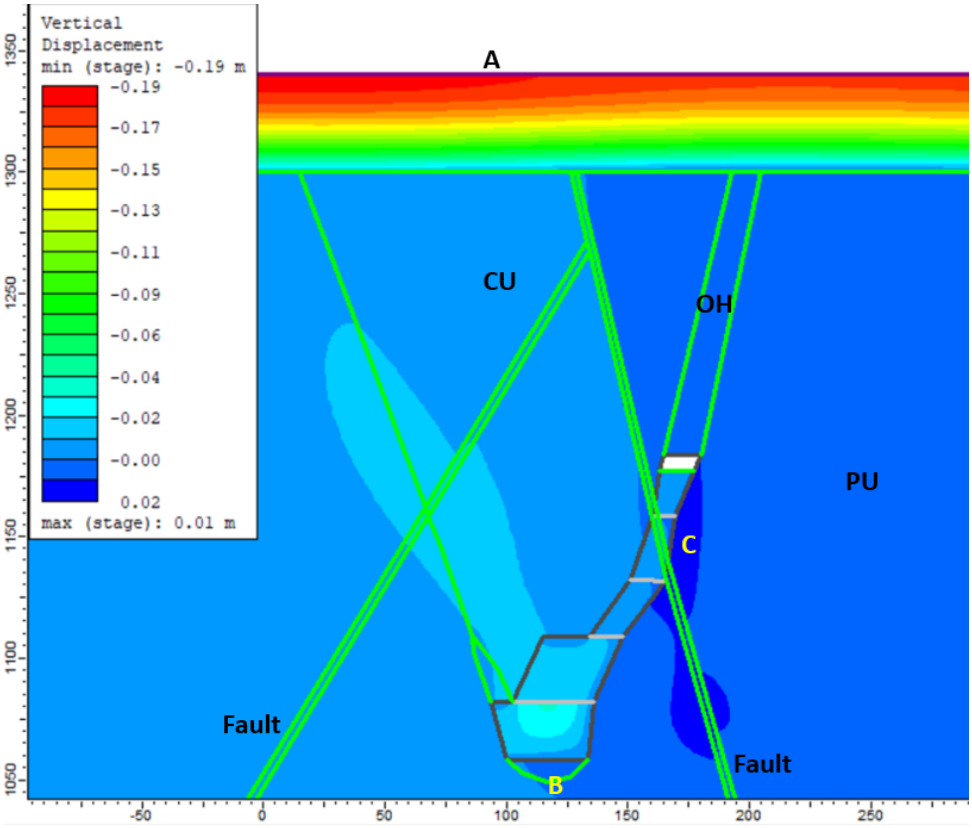


Figure 22 - NOB – Final stage of mining with last stope backfilled (Dry conditions); 19 cm subsidence on surface (A), < 1 cm subsidence at the base of excavation (B) and 1.4 cm raising (C).

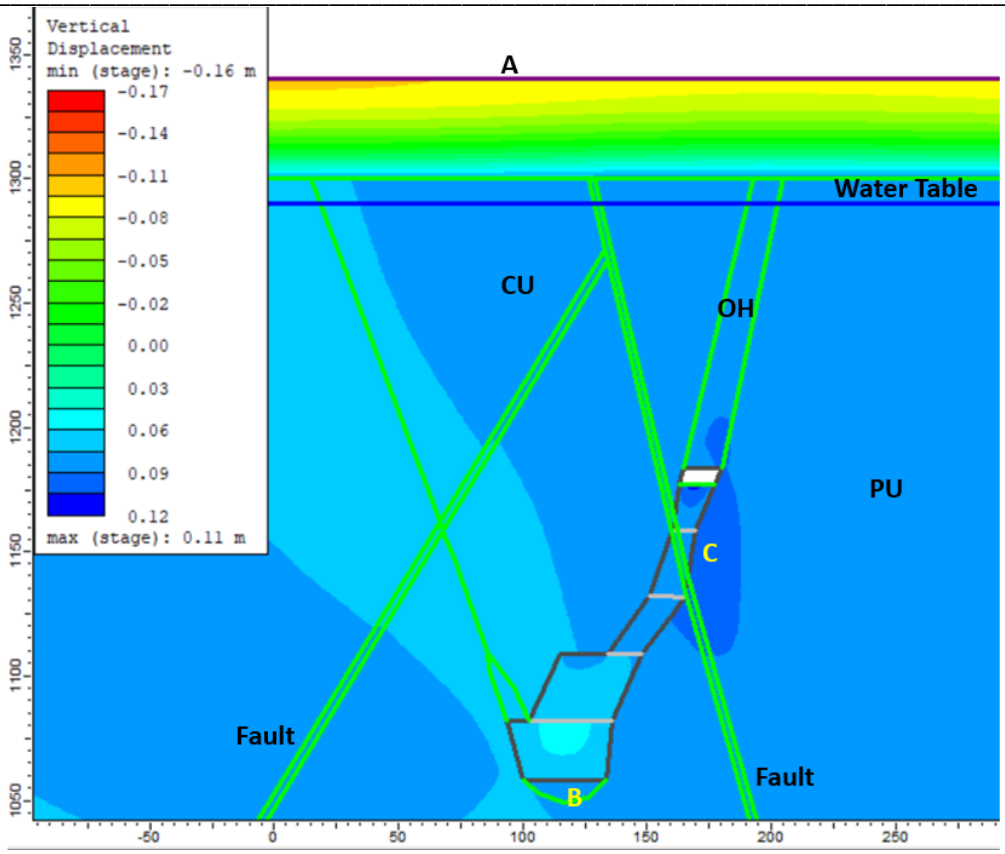


Figure 23 - NOB – End of mining and water recharge completed (Piezo line added); 10 cm subsidence on surface (A), 8 cm raising at the base of excavation (B) and 10 cm raising at (C).

4.5 Shaft Stability Assessment

There are four open shafts at LLM that require assessment, two fresh air rises (FAR) and two return air rises (RAR), one of which is also an exploration shaft. There is one additional historical (RAR) shaft, which during excavation collapsed at 30m deep. It was subsequently backfilled and another RAR location developed. Shaft locations are depicted in Figure 24.

The standard empirical method for assessing shaft stability is the McCracken-Stacey method (1989). This method modifies the standard rock mass quality Q rating by 3 additional factors to arrive at Q_R, the raise bore rock quality. LLGRD8, a 165.4m vertical diamond drill hole in the location of the fresh air rise (surface collar mine grid coordinates of 841mE, 2392mN), was logged as part of the Mining One 2012 report and considered representative of that existing ventilation shaft. The inferred location of LLGRB8 is depicted in Figure 24, in the location of 'Shaft 2 – Fresh Air'. The McCracken-Stacey methodology has been applied to this logging as an assessment of long-term shaft stability (logging is provided in Appendix B).

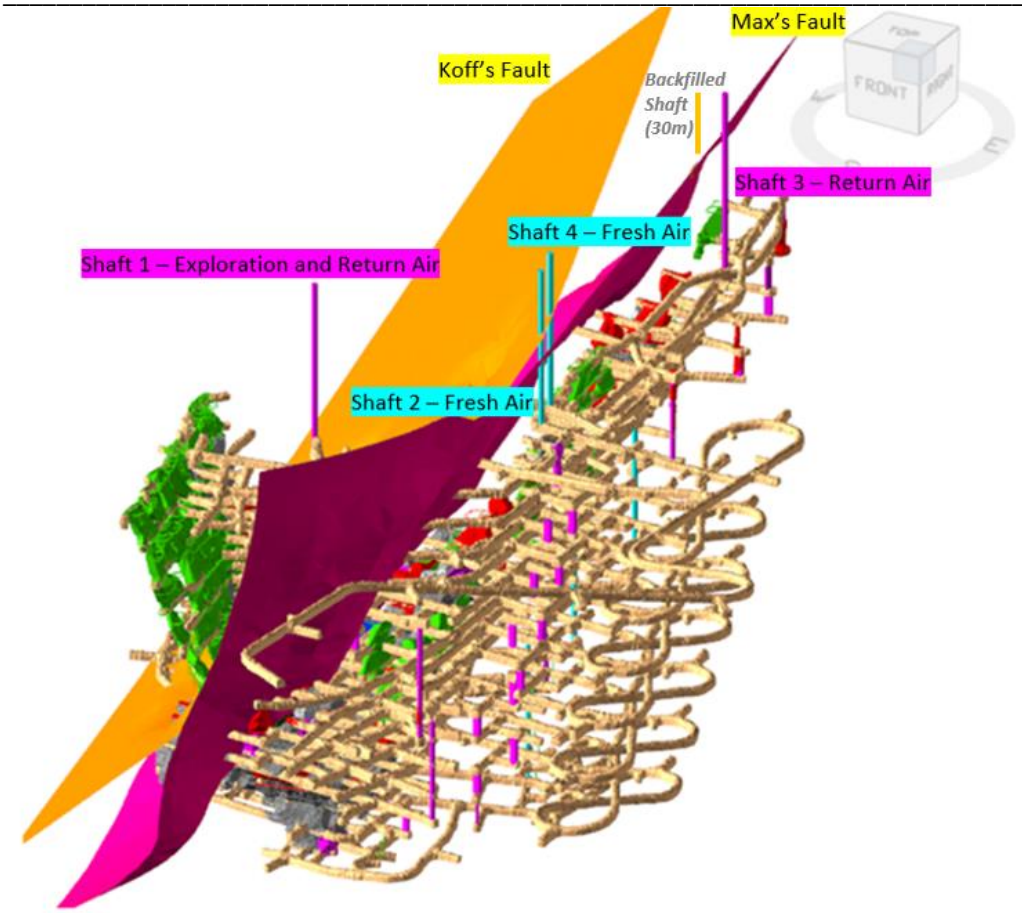


Figure 24- Location of shafts to development and faults. LLGRD8 cored hole at location of Shaft 2 – Fresh Air.

4.5.1 Assessment Assumptions

Information on discontinuity orientation was unavailable, however given most of the hole was logged as having 3 or more defect sets the Q_R orientation adjustment value of 0.85 was chosen which assumes 1 defect set with a dip 60-90° (true number of steeply dipping sets is likely to be >1 in some places which would further reduce Q_R). The poorest Q_R weathering adjustment value of 0.5 has been chosen given the long-term nature of the assessment and the fact that much of the length of the shaft will experience groundwater ingress and associated weathering over a considerable time. The Joint Water Reduction value, J_W, which was rated as 1 in the original 2012 assessment, has been reduced to 0.66 for depths below 60m which was the pre-mining depth of the water table (Douglas Partners 2012). Although hydrostatic pressure will equalise with flooding, there is not expected to be significant wash out of joint infill material, however it is expected that the presence of groundwater over the long term will reduce cohesion of joint surfaces so a reduction in stability is expected.

4.5.2 Shaft Assessment Results

Converting the calculated Q_R values to rock classes it is found that of the 165.4m hole:

- 0m to 43.9m: composed of "Extremely Poor" and completely oxidised ground.
- At 47m is the base of complete oxidation.

- 43.9 m to 113.6m: predominantly "Extremely Poor" to "Very Poor" ground, with some sections of "Poor."
- 113.6m to 132.8m: predominantly "Exceptionally Poor" to "Extremely Poor" due to fault intercepts.
- 114.5m to 117.5m Koff's Fault
- 131.5m to 132.8m Max's Fault
- 132.8 m to 165.4m: predominantly "Extremely Poor" to "Very Poor" ground, with some sections of "Poor."

To illustrate these classifications further, photos of selected core trays along with comments about classification have been included in Appendix C.

The expected stability of a shaft is relative to the shaft diameter. McCracken-Stacey's method includes a Probability of Failure (PoF) chart shown in Figure 25 with Q_R values calculated for LLGRD8 superimposed for a 5m shaft diameter, the standard for shafts at Lady Loretta. The meterage indicated in Figure 25 is the total accumulated length of core for those PoF categories, however discontinuous along the length of the hole. Based on this chart, assuming a 5m diameter:

- The completely oxidised upper section from 0 to 43.9m has a PoF >50%,
- The fault intercept section from 113.6 to 132.8m has a PoF >50%,
- Much of the rest of the hole also has a PoF >50%, with only an accumulated 43m having a PoF 25-50% and accumulated 17.6m with a PoF 10-25%.

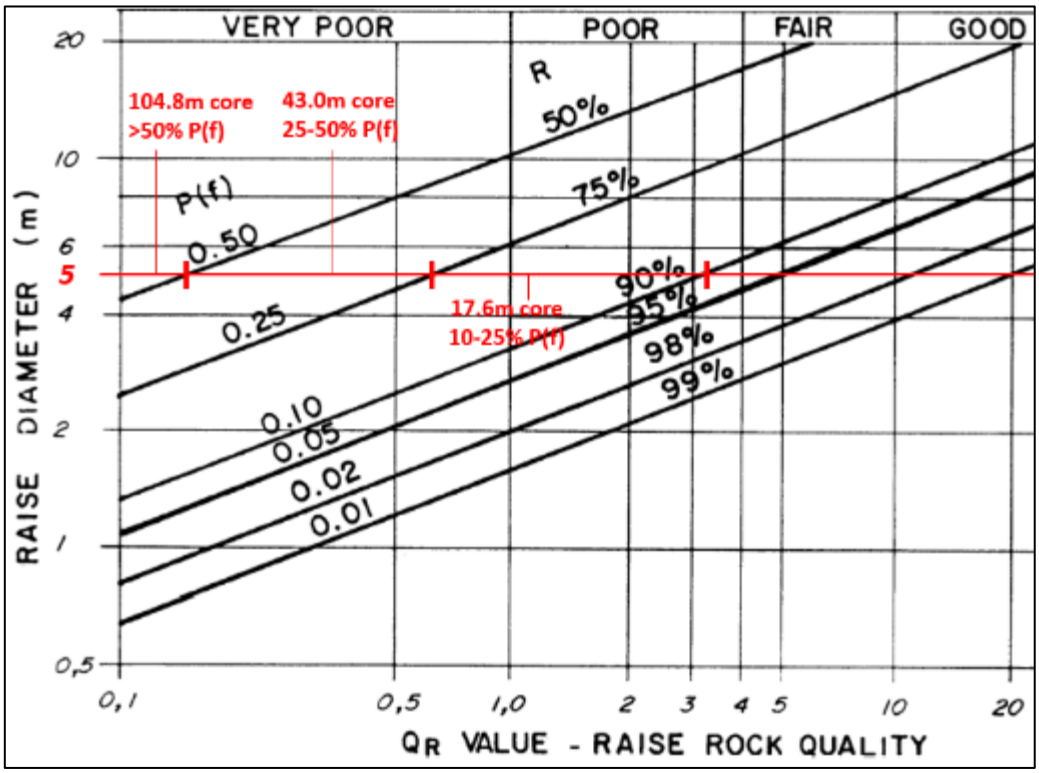


Figure 25- McCracken-Stacey (1989) Probability of Failure Chart with 5m Shaft diameter and QR results of LLGRD8 superimposed

Results indicate that pre-mining ground conditions for majority length of the 5m diameter shaft at LLM will be unstable without passive support. A concrete lining was applied during construction to address the likely failures that could occur. This support was designed to comply with the operational requirements of the mine life. The long-term functionality and necessary actions to avoid failure post mine closure will be discussed in Section 5.

4.5.3 Extrapolation to other Shafts

Similar shaft assessments have not been conducted for ground in the vicinity of the other three open shafts at Lady Loretta. Their conditions were assumed consistent to LLGRD8, as relatively poor and weathered ground persisted across the mine. LLM assumed that significant portions of the other shafts would also likely be unstable and hence all were concrete lined.

Conditions found in LLGRD8 can be confidently extrapolated to all other shafts. Section 6.3 of the LLM GCMP domains ground according to RQD values and classifies 52% of diamond drill core as 'Very Poor' to 'Fair' and 8.7% as 'Extremely Poor'. This proportion of poor ground is likely to be even higher closer to surface due to weathering. Additionally, two major faults, Max's and Koff's Fault intersect the Shaft with collars on surface (Figure 24). Both are filled with gouge and broken rock which will worsen stability.

4.6 Empirical and Modelling Results Discussion

Empirical assessment of the crown pillar stability indicates that in a most likely case there will be acceptable FoS but in critical cases, there will be unacceptable FoS. In these critical cases, FoS can be as low as 0.9 which indicates imminent failure. Generally, in critical cases FoS was around 1.3. When and if failure occurs, blocks will dislodge progressively and fall, filling the identified voids. Failure propagation (and bulking) assessment indicates that the voids left are small enough, that upwards progression will not reach the surface, and will not cause settlement. The Eastern limb at Max's Fault, was the critical scenario, where upward failure progression will reach only 38 m bgl before chocking.

2D modelling for each of the three regions show incremental surface settlement (negative values) as the mining stages progress. After mine closure as the groundwater recharges, a buoyancy effect will develop over time, causing lifting of the ground surface. Areas such as the Western Limb at this time will have a surface slightly above the pre-mining levels. The settlement and uplift of surface suggested by the modelling was minimal, and in the order of 20cm. The 2D modelling is supported by the empirical assessment.

Analysis of the upper Decline found that above 60 m bgl, a Decline failure will ravel and cause subsidence at the surface. In the area above the portal, subsidence could be seen in the order of 5 m for a failure that commences at 10 m from the surface. The shaft stability assessment revealed that ground conditions were 'Poor' to 'Extremely Poor' indicating that much of the length of the 5m diameter shafts at LLM will be unstable without passive support. This support must be functional post closure.

5 POST MINING STABILISATION OF UNDERGROUND WORKINGS

Stabilisation of underground workings that have been identified as a subsidence risk is best achieved by backfilling.

5.1 Backfilling Material Suitability

Mine waste rock material placed at the LLM waste rock dump (WRD) and used to construct the ROM pad are potential materials for use as Decline and shaft backfill with some provisions. Waste rock will be used to provide passive support to Decline and shaft walls and the Decline back. The backfilled material does not require to be self-supporting since it will not be exposed vertically or horizontally.

The advantages of using waste rock material are:

- Proximity to the mine portal and shafts,
- Relatively high strength,
- Reduction of WRD volume and assistance in surface and final site rehabilitation,
- Cost effective as opposed to imported or cemented fill.

Work commissioned by the *European Commission Directorate-General Research* (Mine Shafts: improving security and new tools for the evaluation of risks, 2013) recommended the following characteristics of the waste backfill for shafts in abandoned mines:

- Material of grain size between 20 and 120 mm (median of 100 mm), free of undersize particles,
- Compression strength of at least 30 MPa,
- Insoluble and non-flammable,
- Without toxic compounds,
- Zero risk of leaching harmful and hazardous elements,
- Meeting requirements of acceptable level of radioactivity.

The waste material stored in the LLM WRD, and ROM pad are composed of rocks sourced from the units described in Section 2.3. Notably, rocks within the Cyclic Unit (UCS = 122 MPa), Massive Unit (UCS = 83 MPa), Pyrite Unity (UCS = 101 MPa) and Lower Siderite/Dolomite Unity (UCS = 95 MPa). These units, being excavated during mine development, generally vary from slightly weathered to fresh rock. The more weathered material was excavated in the upper sections of the mine, particularly at the portal and box cut. These materials are stored in the ROM pad. Some weathered material and rocks with the friable gypsum compound were excavated in level footwall drives (PU Pyrite Unit) and are estimated at less than 5% of the WRD volume.

Additionally, as highlighted by ATC Williams report (2020), the WRD also includes paste from redevelopment and stope overbreak, which is dumped sporadically within the landform. The ATC Williams report also notes that the paste fill material stream is a process residue derived from the treatment of highly mineralised zinc and lead ores. Geochemical characterisation based on ABA (Acid Base Accounting) and single addition NAG (Net Acid Generation) testing indicates that the paste fill is unlikely to be PAF (Potentially Acid Forming) but could generate saline/neutral drainage if allowed to oxidise.

ATC Williams (2020) report undertook particle size distribution (PSD) testing of both the WRD and ROM, as reproduced in Table 16. In Table 16, sites TP2 to TP9 were from the WRD and TP11 and TP12 were from the ROM. The table indicates a large amount of silt and sand (higher percentage of smaller PSD fractions) on the WRD and more coarse material on the ROM pad. Paste has not been placed on the ROM. The PSD obtained from all sites do not meet the recommendations for backfilling the shafts, however the ROM material is preferred based on lower fines. It is therefore recommended for both the Decline and shaft sites that ROM material be utilised in the first instance.

Table 16- Waste Rock – Particle Size Distribution (TP2-TP9 = WRD and TP11-TP12 = ROM)

Sieve Size (mm)	TP2	TP3	TP5	TP6	TP8	TP9	TP11	TP12
0.075	32.2	22.5	54.8	15.6	21.2	43.6	5.7	6.6
0.15	34.1	26.1	64.0	18.8	24.0	46.0	7.1	8.3
0.3	36.3	29.4	69.1	22.3	26.0	47.9	9.0	10.6
0.425	37.6	31.1	70.3	24.2	27.2	48.9	10.2	12.0
0.6	39.3	33.2	71.5	26.7	28.9	50.1	11.8	13.7
1.18	43.5	38.2	73.8	32.7	33.2	53.3	15.8	18.2
2.36	50.4	45.9	76.6	41.1	38.9	58.3	22.2	25.3
4.75	58.0	53.5	79.8	50.7	46.7	64.6	29.8	35.0
6.7	65.0	60.0	82.0	58.7	52.6	69.6	36.9	42.1
9.5	71.5	66.7	85.0	67.8	59.9	74.5	43.8	49.8
13.2	80.4	75.7	88.3	78.0	69.5	79.7	51.4	58.7
19	84.4	84.5	91.0	87.0	75.6	86.6	62.3	65.0
26.5	92.1	91.6	93.9	93.1	83.9	92.8	72.0	74.5
37.5	98.3	97.7	96.4	99.5	94.1	98.3	80.7	84.3
63	100.0	100.0	100.0	100.0	100.0	100.0	97.8	100.0
75	-	-	-	-	-	-	100.0	-

5.2 Bulkhead Design

A Bulkhead will be applied for containing in place the waste backfill of the Decline. The bulkhead constructed will use the same specifications as the paste walls (bulkheads) currently utilised for production back filling, which are deemed suitable (Figure 26).

Bulkheads at Lady Loretta are based upon the Clune Wall Kit design. Bulkheads are constructed using two standard curved wall kits, depending upon the width of the drive. The walls kits consist of:

-Either curved wall kit: 5-6mW * 5-6mH, 5m Radius, or
-Curved wall kit: 7-8mW * 5-6mH, 7m Radius.
-2 x Vertical Columns,
-5 x Horizontal Cross Beams,
-Telescopic inserts for the columns and cross beams, and,
-Fixtures and fittings to secure.

The bulkhead must be constructed with a minimum fibrecrete thickness of 400mm. Fibrecrete must possess a UCS more than 15 MPA at the commencement of backfilling.

The Bulkhead needs to be free draining. This should be achieved by installing 100mm poly pipe through the bulkhead to drain potential water accumulation , reducing pressure against the structure. Poly drains should be installed at regular intervals across the entire bulkhead area, noting that lower drains will silt up quickly.

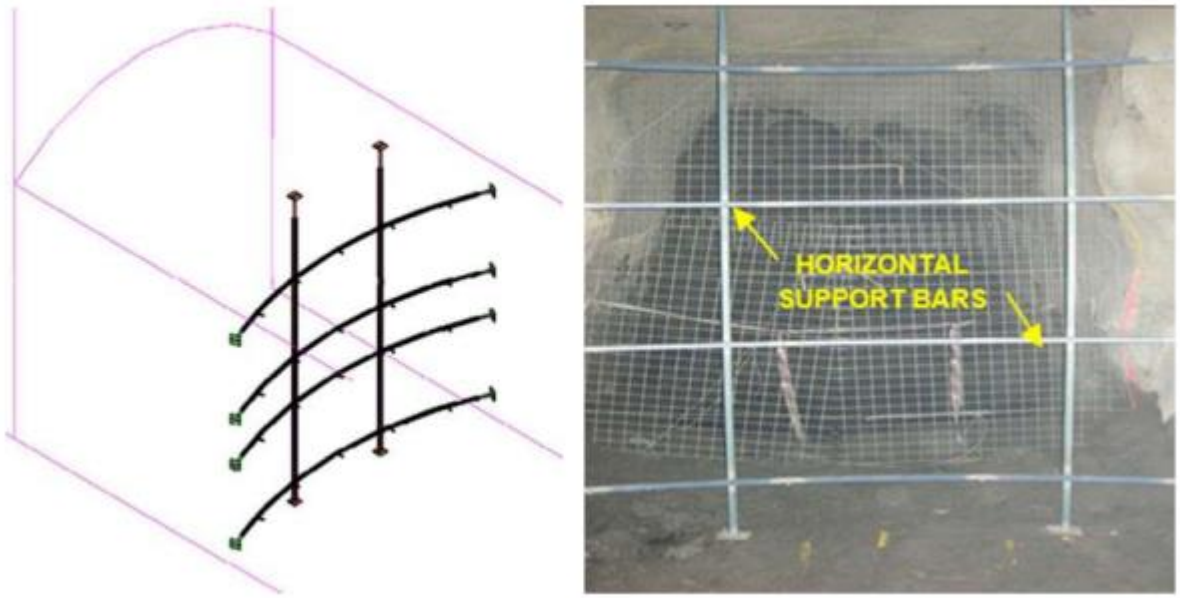


Figure 26- Clune Wall Kit Frame

5.3 Upper Decline Backfilling

As highlighted in Section 4.3.3., where the Decline is less than 60 m deep from surface, any upward failure will reach the surface before it bulks out and self supports. Considering a Decline gradient of 1: 7 and applying a 10% safety factor, the chainage to commence backfilling is 460 m from the portal as shown in Figure 27. The 10% safety factor covers eventual loss of durability in the bulkhead and collapse. Backfilling must also include stockpiles SP1 to SP4 and any crosscut in between. A “rolling bund” retreat method of placement is recommended, and this will provide the highest level of fill possible. Tight filing will be difficult to achieve, the best effort to reduce the void is required, but not essential.

A bulkhead must be installed at chainage 460 m to hold in place the waste at the start of the backfilling process. When the backfilling process is finished, a sealing bulkhead must be erected at the portal entrance. The box cut then requires backfilling to 3 m above portal backs. The material used to backfill the box cut must be geochemically benign and suitable for plant growth.

It is estimated that a total volume of around 20,500 m^3 of waste will be required to backfill the upper Decline and the boxcut. The most suitable material is that sourced from the ROM.

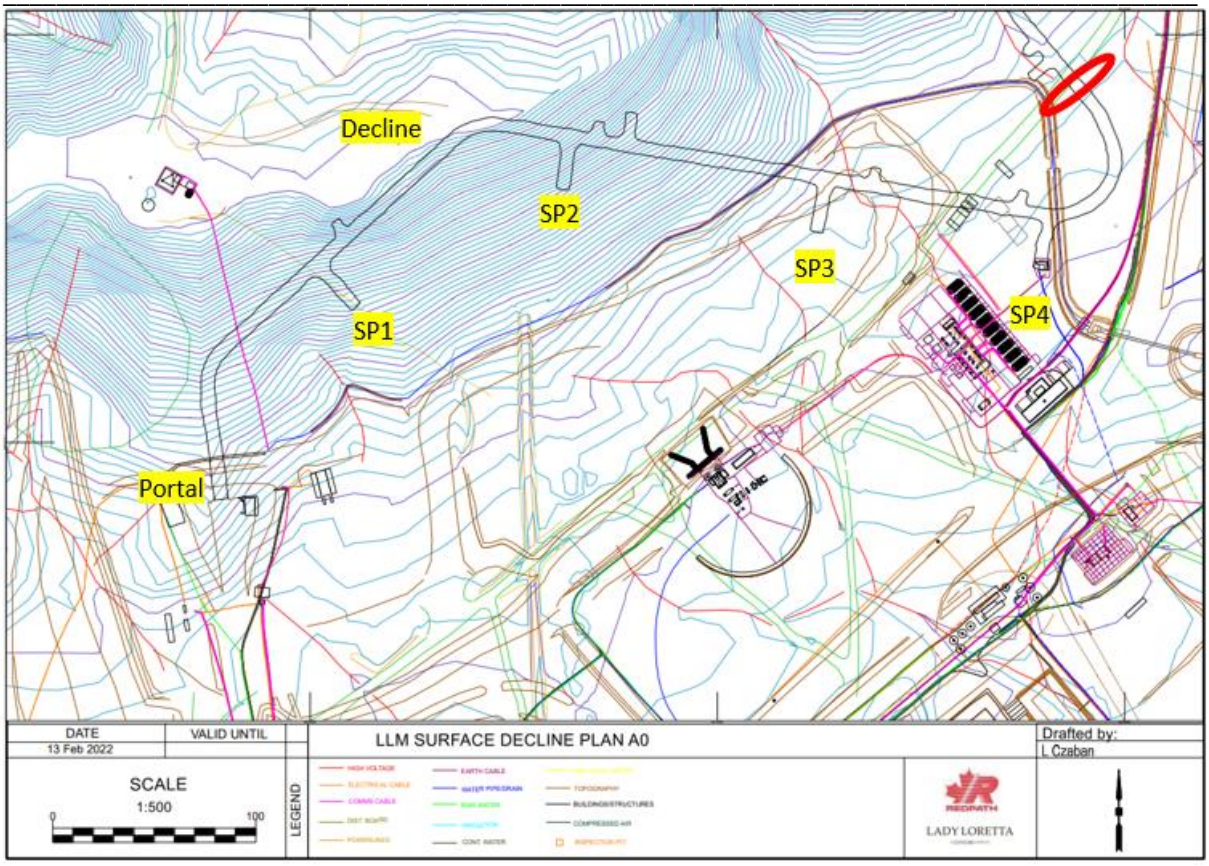


Figure 27 – Decline location on the topographic contour map showing where the backfilling towards the portal should start (Chainage 460 m in RED).

5.4 Shaft Backfilling

No bulkheads are required at the bottom of the shafts. To mitigate ongoing settlement and the lateral migration of smaller particles in the bottom of the shafts, it is recommended to use waste rock bunding. Waste rock should be placed in the underground drives, as high as possible to the backs, from the shaft brow to 10 m either side.

The most suitable material to backfill shafts are that sourced from the ROM. It is not recommended to use WRD material due to excess fines. The ROM material contains limited fines; however settlement will still occur in the shaft backfill. This will occur with progressive migration of the finer fractions to lower levels of the shaft as water percolates through voids between larger particles. To counteract this settlement, the following is required:

- Compact shaft material at the surface,
- Store additional fill material on top of the shaft, proud of the surface,
- Store additional fill material to the side of the shaft for future shaft top up,
- Monitor the settlement and top up shaft surface material as necessary, and
- Install perimeter fencing to restrict access.

It is estimated that a total of 12,000 m^3 of waste will be required to backfill the four shafts linked to surface. The historical shaft that has already been backfilled should have the same settlement controls in place.

5.5 Concrete Lining and Fibrecrete Durability

Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties, particularly its strength. Different concretes require different degrees of durability depending on the exposure environment and desired properties.

Concrete design has a wide range of different specifications and standards. Some recent durability evaluations conducted in Australia showed inconsistencies between the required values for design lives of 50 and 100 years (McDonnel et all., 2020). Durability of concrete is covered in Section 4 of AS 3600 Concrete Structures 3.1. The Standard applies to plain, reinforced, and prestressed concrete structures and members with a design life of 50 years ± 20% but notes that more stringent requirements would be appropriate for structures with a design life more than 50 years (e.g., monumental structures).

5.5.1 Types and Causes of Concrete Deterioration

Assessment of the potential causes, and factors that influence, concrete deterioration in the LLM concrete lined shafts and fibrecreted bulkheads are important to evaluate, including the suitability and potential long-term impacts on material strength.

Concrete can deteriorate for a variety of reasons, and concrete damage is often the result of a combination of factors. A comprehensive study presented by the Portland Cement Association of America is discussed here.

5.5.1.1 Corrosion Of Embedded Metals

Corrosion of reinforcing steel and other embedded metals is the leading cause of deterioration in concrete. When steel corrodes, the resulting rust occupies a greater volume than the steel. This expansion creates tensile stresses in the concrete, which can eventually cause cracking, delamination, and spalling. Steel, like most metals except gold and platinum, is thermodynamically unstable under normal atmospheric conditions and will release energy and revert to its natural state (iron oxide, or rust). This process is called corrosion.

The welded wire mesh of the bulkheads to be installed at the Decline, even though galvanised, can eventually corrode and weaken the fibrecreted wall. The lower bulkhead, at chainage 460 m, will be in a flooded zone of the abandoned underground mine (around 70 m below surface), and since the dry/wet cycle is not expected at this depth, the anticipated influence on the deterioration created by the acidic groundwater on the fibrecrete and consequently on the wired mesh will be slower. The concrete lining in the shafts is not reinforced.

5.5.1.2 Carbonation

Carbonation occurs when carbon dioxide from the air penetrates the concrete and reacts with hydroxides, such as calcium hydroxide, to form carbonates. In the reaction with calcium hydroxide, calcium carbonate is formed:

$$Ca(OH)2 + CO2 \rightarrow CaCO3 + H2O$$

This reaction reduces the pH of the pore solution to as low as 8.5, at which level the passive film on the steel is not stable. Carbonation is generally a slow process. In high-quality concrete, it has been estimated that carbonation will proceed at a rate up to 1.0 mm per year. The amount of carbonation is significantly increased in concrete with a high water-to-cement ratio, low cement content, short curing period, low strength, and when highly permeable or porous. Carbonation is highly dependent on the relative humidity of the concrete. The highest rate of carbonation occurs when the relative humidity is maintained between 50% and 75%. Below 25% relative humidity, the degree of carbonation that takes place is considered insignificant. Above 75% relative humidity, moisture in the pores restricts CO2 penetration. Lady Lorette regional humidity varies throughout the year, reaching an average of 27% in September and 53% in February (BOM, 2022 – Bureau of Meteorology). However, since the Decline and shafts will be naturally flooded, humidity will increase above the water table within these areas, exceeding 75%. Therefore, carbonation is expected to take place.

5.5.1.3 Sulphate Attack

Naturally occurring sulphates of sodium, potassium, calcium, or magnesium are sometimes found in soil or dissolved in groundwater. Sulphates can attack concrete by reacting with hydrated compounds in the hardened cement. These reactions can induce sufficient pressure to disrupt the cement paste, resulting in loss of cohesion and strength. Calcium sulphate attacks calcium aluminate hydrate and forms ettringite. Sodium sulphate reacts with calcium hydroxide and calcium aluminate hydrate forming ettringite and gypsum. Magnesium sulphate attacks in a manner like sodium sulphate and forms ettringite, gypsum, and brucite (Magnesium hydroxide). Brucite forms primarily on the concrete surface, consumes calcium hydroxide, lowers the pH of the pore solution, and then decomposes the calcium silicate hydrates.

Environmental conditions have a profound influence on sulphate attack. The attack is greater in concrete exposed to wetting-drying cycles which will occur within the LLM shafts with oscillations in the water table after the mine is flooded.

5.5.2 Expected Deterioration of Shaft Concrete Lining

At construction, all shafts except the exploration shaft were cast concrete lined for their entire length to ensure operational stability during life of mine. The concrete is without steel reinforcement. The exploration shaft, built in 1987-1988, was lined to 163 m bgl and bolt supported the remaining length to the current bottom at 318 m bgl.

It is well understood that long term exposure to mine water will have a negative effect on the strength and other material properties of concrete shaft linings. For example, Yang et al. (2017) in ‘An Experimental Evaluation of the Weathering Effects on Mine Shaft Lining Materials’, showed that concrete samples immersed in a simulated ‘mine water’ solution over a period of a year showed noticeable mass loss and decrease in uniaxial compressive strength results as well as deterioration in other strength parameters. The simulated ‘mine water’ solution in this study was mildly acidic and contained moderate amounts of dissolved salts (magnesium, sodium, chlorine, and sulphate). According to Douglas Partners (2012) the pre-mining groundwater in the LLM area is “acidic,

moderately saline and high in sulphate". In addition, the LLM GCMP notes (Sections 8.5 and 12.5) that 'reactive' ground conditions exist in several locations at LLM, particularly in the Pyrite unit; that exposure of this material by mining and contact with mine water produces a more aggressive solution; and this can further affect the level of deterioration that will be experienced by the shaft concrete walls.

With the flooding of the mine, it is expected that oxidation of reactive ground will continue and mixing due to entropy will occur. This will lead to residual flooded mine water with a lower pH and higher dissolved sulphates than the original groundwater.

Post closure, at and above the recharging water table level, sulphate attack will occur. The humidity created within the waste backfilled interparticle voids and capillary moisture will also prompt carbonation on the walls of the lined shafts.

The concrete lining shaft support has been effective at maintaining stability thus far, however it is expected to deteriorate. Durability is a complex topic; therefore, the concrete lining should be considered in the future to deteriorate to a point equal to total loss in functionality. Loss in functionality of the concrete lining applied in the shafts and risk of caving, will be counteracted by the passive support of the backfill.

5.5.3 Expected Deterioration of Fibrecrete Bulkhead

The recommended Decline bulkhead will be around 66 m bgl at chainage 460 m and therefore below the recharged groundwater level. The durability and inevitable deterioration will depend mostly on the groundwater composition when a steady state is reached. The speed of deterioration will be governed firstly by the corrosion of embedded metals, leading to cracking and disintegration and increased exposure and corrosion of embedded metals. Sulphate in water will also exacerbate the bulkhead deterioration by weaking the concrete and facilitating corrosion.

As previously stated, assurance of functionality is difficult. Therefore, the bulkhead in the Decline should be expected in the future to deteriorate to a point equal to total loss in functionality.

Loss in functionality of the fibrecrete bulkheads has been allowed for in the Decline backfill design. An additional 10 % of chainage metres were added down gradient to ensure that, after eventual collapse of the bulkhead, the waste backfill will immediately rill and thereafter slowly creep downhill. It is expected that only fines will continue to wash through the backfilled area and creep down gradient whilst larger blocks will remain in place. Backfilling with material from the ROM in the first instance will reduce this occurrence.

5.6 Expected Deterioration of Development Primary Support

Ore development drives are mined during stoping which are then backfilled with paste and/or waste rock. Drives below the upper Decline, which will not be backfilled, comprise the remaining of the capital development, mainly the Decline beyond chainage 460 m, the access drives and footwall drives. These drives will be naturally flooded since they will be below the post closure water table. The primary support installed during their

development comprises 75mm fibrecrete and resin bolts. As mentioned previously, the fibrecrete will deteriorate by sulphate attack and the bolts will experience corrosion. This progressive deterioration will weaken the ground support to a point of complete loss of function.

Intersection ground support, with the additional 6 m long cement grouted cable bolts, will likewise deteriorate by the combination of sulphate attack on the grout and corrosion in the embedded metal strands.

It is expected that there may be ground failure after ground support ceases to function. The occurrence of failures will be significantly minimised when drives become flooded, and passively supported by water. These drives are below the critical depth of 60 m bgl and therefore subsidence on the surface due to upward failure progression is highly unlikely.

6 MONITORING

Under section 126C(1)(j) of the *Environmental Protection Act 1994* (EP Act), the administering authority considers monitoring and maintenance necessary to decide if the progressive rehabilitation and closure plan is consistent with the requirements of the legislation. The rehabilitation planning part must contain a monitoring and maintenance program that identifies and describes the monitoring systems that will be conducted to demonstrate that set targets as per the EP Act have been achieved. As stated in the EP Act, the program must include, but is not limited to:

- Description of methodologies and standards, which could include field-based assessments and the application of new remote sensing, GIS, and other relevant emerging technologies.
- Monitoring that enables the repeatable collection of relevant statistically valid data.
- Monitoring using appropriate quality assurance and data management processes and systems.
- Regular analysis of site data including multi-year comparison trends and benchmarking against analogue/reference sites.
- Contingency strategies if monitoring data indicates milestone criteria are not being met.
- Post-closure monitoring to ensure milestone criteria has been demonstrated.
- Intent of monitoring reports, such as provision of results and key findings.

Although being in a remote area, LLM is still subject to personal, wildlife and cattle incursions. As such, it is important to monitor potential areas of subsidence in a remotely fashion. Satellite monitoring methods have evolved rapidly and can be used for long term monitoring. Other techniques of remote monitoring will likely appear in the future and be autonomous, facilitating and decreasing the costs involved. Remote monitoring not only will fulfil EP Act requirements but also create a safer environment for potential life incursions. As such, these technological advances are strongly recommended for subsidence monitoring of the surface above the upper Decline areas (from portal to chainage 460 m), around the shafts and crown pillars zones.

7 CONCLUSION

The likelihood of crown pillar collapse into remaining underground voids and consequential surface subsidence has been assessed post closure for LLM's Eastern limb, Western limb, North Ore Body, shafts, upper Decline, and the deeper development drives that will remain open post closure.

The Scaled Span Method indicates acceptable FoS for the crown pillars using the most likely scenario of ground and water condition. Most scenarios using the poorer ground conditions (1st quartile Q), which have a low likelihood of occurrence but cannot be completely discounted, had unacceptable FoS. The service life in these (and limited other) scenarios were generally of 2 to 5 years. In exploring critical cases, it was found that upwards ground collapse will arrest itself by choking, prior to reaching the surface at 38 m bgl for the Eastern Limb and 92 m bgl for the Western Limb. NOB has been tight filled and is not at risk of failure progression to these extents. The empirical assessment concluded that although crown pillar failure could occur, it would not cause settlement on the surface.

2D modelling suggests minor subsidence in the Eastern Limb and the North Ore Body and small uplift in the crown pillar above the Western Limb due to the buoyance effect, after closure and during groundwater recharge. These vertical movements would likely go unnoticed by visual observations. The flooding of the mine will have a positive outcome, creating a passive support in the voids underground. With negligible free oxygen in the underwater environment, deterioration of the rock mass will be slowed, and operational stability issues associated with the expanding gypsum crystals will not be of concern.

Ground support will ultimately deteriorate, allowing upward failures. Bulking failure method indicates that ground failure into voids at depths above 60 m bgl will not self-arrest and will reach the surface, showing subsidence. The method also indicates that failure progression from open drives of one level of the mine will not cause subsidence on the level above. The shafts are unstable if unsupported, and existing concrete lining is anticipated to deteriorate over time. As such, backfilling is important to reduce the underground voids and minimise hazards in the future.

The Decline is to be backfilled to a chainage 460 m from portal and the shafts are to be backfilled until the collar is covered. An estimated total volume of 20,500 m^3 of waste will be required to backfill the upper Decline and the boxcut. It is estimated that a total of 12,000 m^3 of waste will be required to backfill the four shafts linked to surface. One historical shaft has already been backfilled. The backfill material should be sourced primarily from the ROM pad due to its larger coarser fraction and limited fines. Only ROM pad material should be used to backfill the shafts. Material from the Waste Rock Dump can be used in the Decline after ROM material has been exhausted.

Areas above the portal, upper level of the Decline and around the five shafts must be barricaded and sign posted as future subsidence can occur atop these areas. Surface monitoring is recommended of these areas and proactively above the crown pillar.

8 APPENDIX A

The method of designing stable crown pillars (Carter 1992 and 2014) has been developed from a series of case studies measuring crown pillar stability. The method known as the Scaled Crown Span concept is a procedure for characterizing the geometry of a crown pillar in three dimensions and has been used to determine crown stabilities for mines in Australia and internationally. The following is verbatim from Carter, TG., 2014. "Guidelines for use of the Scaled Span Method for Surface Crown Pillar Stability Assessment; Golder and Associates."

Given the typical stope geometry and geological and rock mass conditions comprising a typical crown pillar situation, it was recognized that:

$$Crown\ Stability = f\left(\frac{T\sigma_h\theta}{SL\gamma u}\right)$$

where *increased stability* for any rock mass quality would be reflected by an increase in:
- T, the rock crown thickness
- σ_h, the horizontal insitu stress
- and/or…in θ, the dip of the foliation or of the underlying opening, and;

where *decreased stability* for any crown would result from increases in:
- S, the crown span
- L, the overall strike length of the opening
- γ, the mass (specific gravity) of the crown
- and/or…in u, the groundwater pressure.

Noting that this stability expression could be split into two, based on (a) mined opening geometry and (b) rock mass characteristics, led to the development of the basic deterministic assessment approach of comparing the dimensions of the crown pillar over the stope opening geometry, as characterized by the Scaled Crown Span (CS), against a critical rock mass competence, Qcrit (at which failure might be expected) as defined from the boundary between the failure cases and the stable cases.

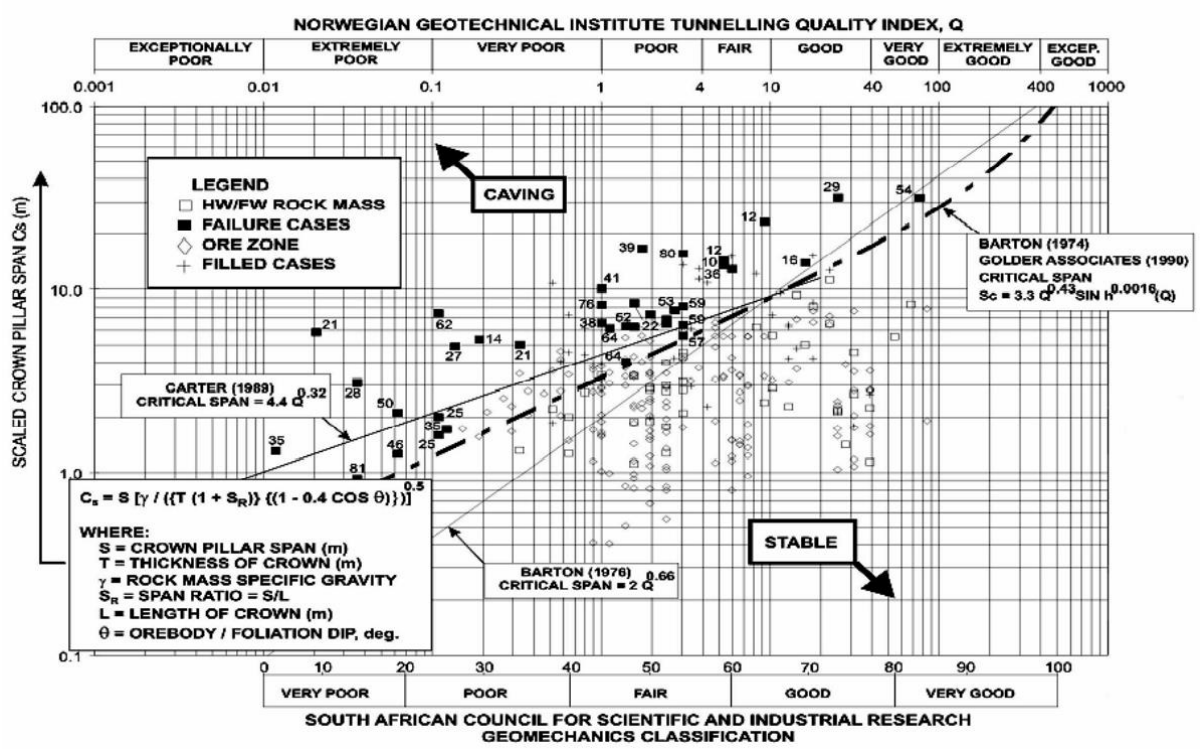
Geometry definition

In developing the three-dimensional geometry term for characterizing the overall crown pillar with respect to its actual span, S, four component terms were considered – a thickness to span ratio term, to maintain some connection with the original non-scaled "rules of thumb", – an inclination factor term, reflecting the fabric of the rock mass and typically the stope dip angle, – a term to account for the three dimensional geometry of the crown (incorporating a hydraulic radius – span ratio factor), and – a weight term to account for equivalent Terzaghi-style "rock loading" effects with respect to the size of the crown and due to any super incumbent loads – such as overburden. The final Scaled Span, CS relationship was thus defined as follows:

$$C_S = S\left(\frac{\gamma}{T(1+S_R)(1-0.4\cos\theta)}\right)^{0.5}$$

where: S = crown pillar span (m);
γ = specific gravity (which is dimensionless but has the same numerical value as rock mass unit weight, tonnes/m^3);
T = thickness of crown pillar (m);
θ = orebody/foliation dip, and;
S_R = span ratio = S/L
(crown pillar span/crown pillar strike length)

In the same manner as the Q-chart, this scaling expression, CS, is plotted on the y-axis against rock quality on the x-axis. The plot shows the original chart published in 1990, with each of the case records identified as to whether the case was an open stope, or backfilled, and whether stable or not.



The Original Scaled Span Chart, showing stable and failed case records plotted as Scaled Spans versus Rock Quality

Rock mass quality definition

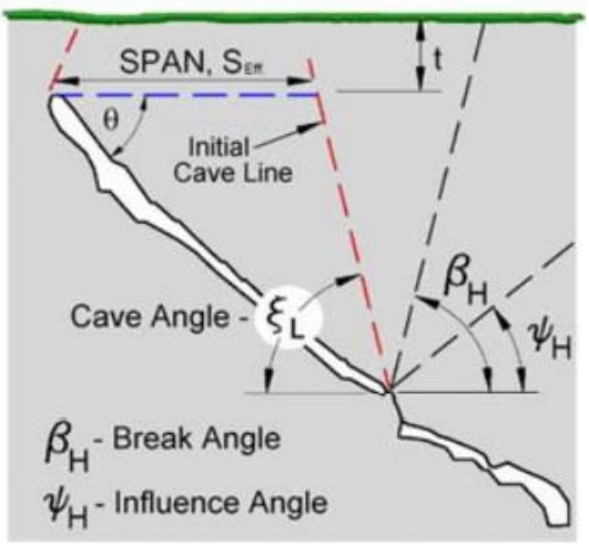
From the plot, the Scaled Spans for all the original case records have been plotted against rock quality, using both the RMR/Q classification axes, each positioned relative to each other on the basis of the well-known correlation expression; RMR76 = 9 · ln(Q) + 44, where RMR76 values were categorized according to the 1976 codings, thereby maintaining an equivalence with GSI. In the original work, rather than merely defining the critical rock mass quality Qcrit for each given case and using this for comparing with the Scaled Span, a limiting span at which failure might be expected was defined based on a regression fit to the data. As it was noted that the best fit line dividing the failed and stable case records was similar in shape and closely matched the empirical "unsupported span" curve originally proposed by Barton et al, 1974 for the tunnelling and natural cavern cases, a similar power curve regression fit was formulated to define the Critical Scaled Span (SC or Scrit), at which failure might be expected; viz:

$$S_C = 3.3 \text{x } Q^{0.43} \text{ x } \sinh^{0.0016}(Q)$$

where the hyperbolic sinh term was introduced into the expression to fit the marked trend of significant non-linearity to increased stability at high rock mass competence.

Revision

In the revision to the basic relationships published in 2002, the controlling "span" at crown level was therefore redefined to take into account the equivalent "effective" span, S_{EFF} of the hangingwall projection up to the elevation of the stope crown, as shown in the right diagram , with the extent determined from the cave line, ξL with the failure geometry, that might develop post-collapse of the crown and hangingwall estimated by drawing break lines up from the base of the stope.



Concept of effective span for shallow dipping stopes based on zone of influence and cave and break angles

The logic for this definition was, in concept, that the mode of failure associated with a shallow dipping stope in blocky rock, while intrinsically different from caving in coal, would still tend on a gross scale to encompass a similar extent of ground deformation, as crudely might still be postulated based on inferred cave and break angles. To apply this correction, an expression for the effective crown span (S_{EFF}) as defined as "the actual span at crown level, plus the horizontal projection of the hangingwall span-length (within the cave line extent)," was developed as follows:

$$S_{Eff.} = S + L_H\left(\cos\theta - \frac{\sin\theta}{\tan\xi_L}\right)$$

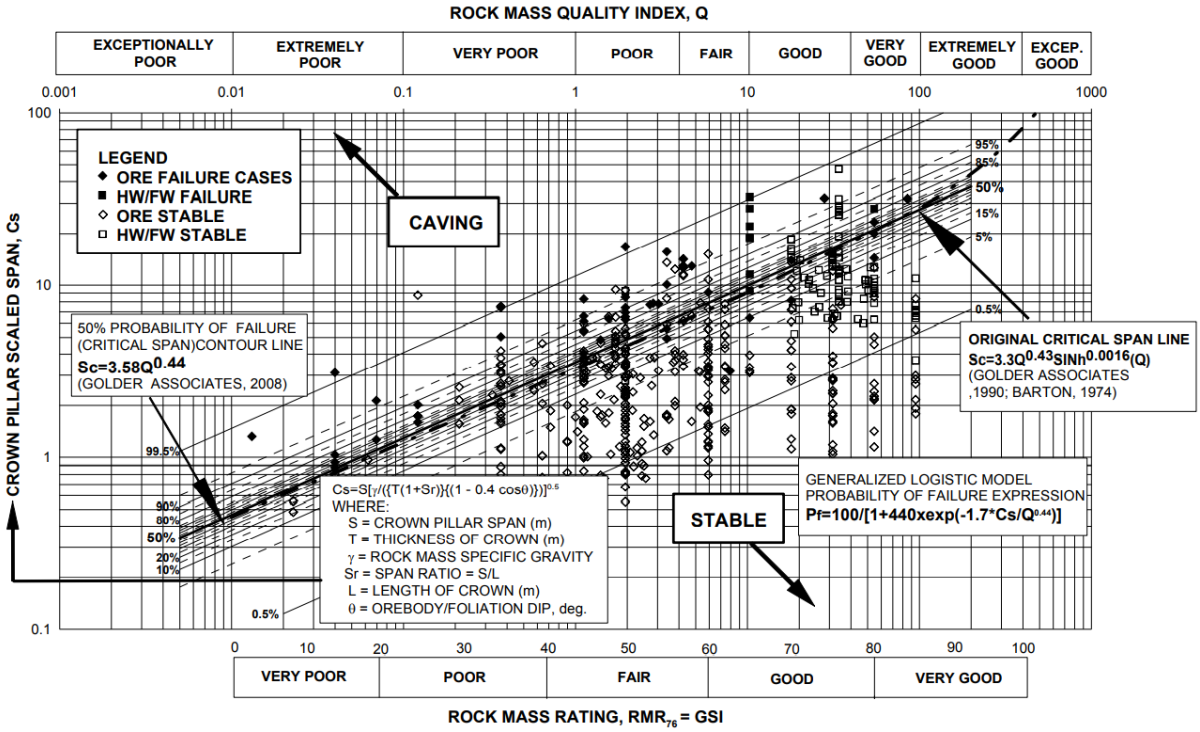
where: S = actual crown span of the stope (m);
L_H = (hangingwall length of the stope (m);
ξ_L = cave angle, and;
θ = stope/ore body dip

Logistic regression and the improved chart

The other significant improvement made to the Scaled Span methodology has been in improving the chart and rankings to make it easier to better address various levels of allowable risk from the perspective of different stakeholders.

Acceptable Risk Exposure Guidelines – Comparative Significance of Crown Pillar Failure

Class	Probability of Failure %	Minimum Factor of Safety	Maximum Scaled Span, Cs (= Sc)	ESR (Barton et al. 1974)	Design Guidelines for Pillar Acceptability/Serviceable Life of Crown Pillar				
					Expectancy	Years	Public Access	Regulatory position on closure	Operating Surveillance Required
A	50 – 100	<1	$11.31Q^{0.44}$	>5	Effectively zero	< 0.5	Forbidden	Totally unacceptable	Ineffective
B	20 – 50	1.0	$3.58Q^{0.44}$	3	Very, very short-term (temporary mining purposes only ; unacceptable risk of failure for temporary civil tunnel portals	1.0	Forcibly Prevented	Not acceptable	Continuous sophisticated monitoring
C	10 – 20	1.2	$2.74Q^{0.44}$	1.6	Very short-term (quasi-temporary stope crowns ; undesirable risk of failure for temporary civil works)	2 – 5	Actively prevented	High level of concern	Continuous monitoring with instruments
D	5 – 10	1.5	$2.33Q^{0.44}$	1.4	Short-term (semi-temporary crowns, e.g.under non-sensitive mine infrastructure)	5 – 10	Prevented	Moderate level of concern	Continuous simple monitoring
E	1.5 – 5	1.8	$1.84Q^{0.44}$	1.3	Medium-term (semi-permanent crowns, possibly under structures)	15–20	Discouraged	Low to moderate level of concern	Conscious superficial monitoring
F	0.5 – 1.5	2	$1.12Q^{0.44}$	1	Long-term (quasi-permanent crowns, civil portals, near-surface sewer tunnels)	50–100	Allowed	Of limited concern	Incidental superficial monitoring
G	<0.5	>>2	$0.69\ Q^{0.44}$	0.8	Very long-term (permanent crowns over civil tunnels)	>100	Free	Of no concern	None required



Updated scaled span chart with probability of failure contour intervals

In its most basic form, the Scaled Span method can be applied deterministically to assess failure risk by simply comparing the Scaled Span (CS) reflecting the mined geometry, to the Critical Span (SC), reflecting the rock mass quality and calculating an approximate Factor of Safety, Fc ≈ SC/CS. If this is done and the Scaled Span, CS exceeds the Critical Span, SC, as defined by the assumed rock quality, unless the stope had been sufficiently supported, or fill approaches had been used in mining; for any opening with Fc less than 1.0 the likelihood of failure would be predicted to be high.

While this simplistic approach is straightforward, with increasing use of the Scaled Span approach being made for checking whether abandoned mine workings might or might not need remediation, this deterministic Factor

of Safety approach wasn't found to provide sufficient discrimination for making expensive decisions, particularly at the high consequence end of the risk scale (where these needed to be made more based on estimates of the likelihood of failure). As both regulators and mine operators wished to prioritize solutions based on the severity of perceived problem excavations using risk ranking matrices, so that the likelihood of failure and potential consequences could be better assessed, attempts were made in the mid-1990's to develop a better, probabilistic assessment approach for use with the scaling expressions.

Multiple probabilistic spreadsheet analyses using @Risk with Latin Hypercube sampling were therefore conducted on case records from the database where sufficient rock quality information was available to characterize rock mass quality variability.

Plotting the SC/CS ratios as a cumulative frequency distribution from this assessment suggested that the variability was approximately normally distributed, which then allowed a crude error function fit to be formulated between the assessed probability of failure (Pf) and the SC/CS quotients, (Carter, 2000); as follows:

$$P_f = 1 - \mathrm{erf}\left[\frac{2.9F_c - 1}{4}\right]$$

where: P_f= Probability of failure;
$F_c \approx$ an approximate Factor of Safety
$= S_C/C_S$, and;
erf( ) is the standard error function

The updated chart now includes iso-probability lines that define seven classes of stability state, based on their likely longevity / design; life expectancy, based on extrapolated experience from stability assessments for geotechnically controlled risks as observed not just for crown pillars but also for other underground and surface excavations.

Assessing Change in Rock Quality and Failure Risk with Time

Assessing stability state under long-term conditions remains one of the key problems for characterizing crown pillars for mine closure. The historical database provides a time history of stable and unstable cases, some of which were known to have been stable, from a general perspective point of view for many years before they failed. From the figure, the two clearly different maxima in the failure cases occur within a decade or so of original mining and then after 60 to 70 years. The reason for these two maxima is likely completely different.

The initial peak is largely thought to originate because of design problems due to the crown thickness being underestimated or the rock quality less competent than expected. The second peak is however likely related to rock competence, and degradability behaviour. This difference is of importance in assessing longevity, as although the updated Scaled Span chart and evaluation methodology can be used to rapidly assess failure risk, cognizance must always be given to the fact that longevity of a given excavation will differ dramatically dependent on the rock type and initial quality, and whether support has been designed for permanence, or not.

All the case record data continues to support the 1996 observations that suggests that from the viewpoint of long-term stability, there appear to be two basic, quite different rock mass behavioural characteristics, i.e.,

– the essentially non-degradable, competent rock types (hard igneous and metamorphic types and well cemented sedimentary units) which exist, tend not to spall and hence seem to survive, and

– the degradable, weathering susceptible, weak, or highly fragmented rock types, that most commonly fail in due course of time, due to disaggregation and spalling.

These latter rock masses are of most concern when applying the Scaled Span methodology, as they are notoriously difficult to properly characterize. Of importance also is the fact that the exact timing of the second peak is not just a pure function of time (i.e. always problems happen after 60-70 years), but rather on original mined stope void space as well as crown pillar thickness, rock quality, propensity of the rock mass to degradation and also stress changes that may occur with ravelling. It is recommended, therefore, that when examining the potentially degradable rock masses using the updated probability chart that some parallel evaluation also be conducted of caving mechanics, specifically checking whether bulking will be a feasible restraint on cave ravelling or whether chimney caving might be problematic.

Optimizing definition of water and stress terms

As indicated previously, Q rather than Q' should be used with the Scaled Span method. However, this raises another issue of concern to ensure that "correct" definition of rock quality is achieved for crown pillar stability evaluation. This requires rational definition of what stress state and what water term should be considered when using the Q system for rock mass characterization
The Scaled Span design charts have been benchmarked to the complete Q, rather than to Q' specifically so that water and stress can be considered. Although Q and Q' both become identical numerically for many rock masses, under typical water and stress conditions, i.e. JW = 1, suggesting dry conditions, and SRF = 1, suggesting normal confinement. These may not be appropriate for many crowns where rivers and lakes exist above the crowns where Jw might have a lower value than unity, or for any thin crowns or crowns with any significant degree of weathering. In all these cases an SRF of 2.5 is suggested as per Barton's 1976 recommendations.

Accounting for overburden

In many situations, rock crown pillars exist beneath thick overburden cover. The question thus often arises, as to how one takes account of the impact that thick overburden, or high groundwater level imposes on crown stability. Utilizing the Scaled Span chart, two simple approximations have been found effective for considering these two situations. Instead of just using the natural specific gravity for the crown pillar rock mass in the geometry term for the y-axis on the Scaled Span chart, the influence of high overburden thickness or an overlying lake can be considered as a straightforward density increase in the geometry term.

9 APPENDIX B

McCracken-Stacey Method Q_R Results for LLGRD8

Interval From (m)	Interval To (m)	Core Loss (m)	Recovered (m)	Rock Type	Rock Weathering	Alteration	Strength of Core	RQD (%)	No. of Defects	No. of Defect Sets	Defect Type	Roughness	Infill	Infill Thickness (mm)	Density (T/m³)	Sigh/SigV	UCS (Mpa)	Jw	SRF	RQD	Jr	Ja Code	Ja	Jn	Q'	Q	Wall Adjustment	Orientation Adjustment	Weathering Adjustement	Qr	Rock Class
0	2.4	0.2	2.2	SH/SLSTN	EW	HAEM	R0	0	99	3.5	BP/JN	PS	SF	1	2.6	2	0.25	1	2.5	10	1	SF	4	12	0.21	0.08	1	0.85	0.5	0.035	EXT Poor
2.4	3.8	0	1.4	SH/SLSTN	EW	HAEM	R0	0	99	20	BP/JN	PS	SF	~	2.6	2	0.25	1	2.5	10	1	SF	4	20	0.13	0.05	1	0.85	0.5	0.021	EXT Poor
3.8	5.2	0	1.4	SH/SLSTN	EW	HAEM	R0	0	99	20	BP/JN	PS	SF	~	2.6	2	0.25	1	2.5	10	1	SF	4	20	0.13	0.05	1	0.85	0.5	0.021	EXT Poor
5.2	6.8	0	1.6	SH/SLSTN	EW	HAEM	R0	0	99	20	BP/JN	PS	SF	~	2.6	2	0.25	1	2.5	10	1	SF	4	20	0.13	0.05	1	0.85	0.5	0.021	EXT Poor
6.8	7.6	0.2	0.6	SH/SLSTN	EW	HAEM	R0	0	99	20	BP/JN	PS	SF	~	2.6	2	0.25	1	2.5	10	1	SF	4	20	0.13	0.05	1	0.85	0.5	0.021	EXT Poor
7.6	8.9	0	1.3	SH/SLSTN	EW	HAEM	R0	9	99	20	BP/JN	PS	SC	0.1	2.6	2	0.25	1	2.5	10	1	SC	2	20	0.25	0.1	1	0.85	0.5	0.043	EXT Poor
8.9	10.2	0	1.3	SH/SLSTN	EW	HAEM	R0	0	99	20	BP/JN	PS	NN	~	2.6	2	0.25	1	2.5	10	1	NN	1	20	0.5	0.2	1	0.85	0.5	0.085	EXT Poor
10.2	11.5	0.1	1.2	SH/SLSTN	EW	HAEM	R0	10	99	20	JN	PS	SF	0.1	2.6	2	0.25	1	2.5	10	1	SF	4	20	0.13	0.05	1	0.85	0.5	0.021	EXT Poor
11.5	13	0	1.5	SH/SLSTN	EW	HAEM	R0	17	99	20	BP/JN	SS	SF	0.1	2.6	2	0.25	1	2.5	17	3	SF	4	20	0.64	0.26	1	0.85	0.5	0.108	Very Poor
13	14.9	0	1.9	SH/SLSTN	HW	HAEM	R1	7	40	20	BP/JN	PS	SF	1	2.6	2	1	1	2.5	10	1	SF	4	20	0.13	0.05	1	0.85	0.5	0.021	EXT Poor
14.9	15.8	0	0.9	SH/SLSTN	HW	HAEM	R1	20	30	20	BP/JN	PS	SF	1	2.6	2	1	1	2.5	20	1	SF	4	20	0.25	0.1	1	0.85	0.5	0.043	EXT Poor
15.8	17.6	0.1	1.7	SH/SLSTN	HW	HAEM	R2	0	25	3	BP/JN	PS	SF	100	2.6	2	5	1	2.5	10	1	SF	4	9	0.28	0.11	1	0.85	0.5	0.047	EXT Poor
17.6	18.2	0	0.6	SH/SLSTN	EW	SERI/KAOL	R0	0	99	3	FLT	PK	SF	600	2.6	2	0.25	1	2.5	10	0.5	SF	4	9	0.14	0.06	1	0.85	0.5	0.024	EXT Poor
18.2	20.1	0.1	1.8	SH/SLSTN	EW	SERI/KAOL	R0	0	99	3	FLT	PK	SF	1900	2.6	2	0.25	1	2.5	10	0.5	SF	4	9	0.14	0.06	1	0.85	0.5	0.024	EXT Poor
20.1	21.8	0	1.7	SH/SLSTN	EW	HM/SER	R0	0	99	20	FLT	PK	SF	1700	2.6	2	0.25	1	2.5	10	0.5	SF	4	20	0.06	0.03	1	0.85	0.5	0.011	EXT Poor
21.8	24.2	0	2.4	SH/SLSTN	HW	HAEM	R0	10	40	20	BP/JN	PS	SC	0.1	2.6	2	0.25	1	2.5	10	1	SC	2	20	0.25	0.1	1	0.85	0.5	0.043	EXT Poor
24.2	27.3	0.2	2.9	SH/SLSTN	HW	HAEM	R1	0	50	20	BP/JN	PS	SC	0.1	2.6	2	1	1	2.5	10	1	SC	2	20	0.25	0.1	1	0.85	0.5	0.043	EXT Poor
27.3	29	0	1.7	SH/SLSTN	EW	HAEM	R0	0	40	20	BP/JN	PS	SF	<0.1	2.6	2	0.25	1	2.5	10	1	SF	4	20	0.13	0.05	1	0.85	0.5	0.021	EXT Poor
29	30.3	0.4	0.9	SH/SLSTN	EW	HAEM	R0	0	99	20	FLT	PS	SF	1300	2.6	2	0.25	1	2.5	10	1	SF	4	20	0.13	0.05	1	0.85	0.5	0.021	EXT Poor
30.3	32.1	0	1.8	SH/SLSTN	HW	HAEM	R2	15	35	3.5	BP/JN	PS	SF	0.2	2.6	2	5	1	2.5	15	1	SF	4	12	0.31	0.13	1	0.85	0.5	0.053	EXT Poor
32.1	34.1	0	2	SH/SLSTN	HW	HAEM	R3	50	35	3	BP/JN	PS	SF	0.2	2.6	2	25	1	2.5	50	1	SF	4	9	1.39	0.56	1	0.85	0.5	0.236	Very Poor
34.1	35.2	0	1.1	SH/SLSTN	EW	HAEM	R0	0	21	3.5	FLT	PK	SF	0.1	2.6	2	0.25	1	2.5	10	0.5	SF	4	12	0.1	0.04	1	0.85	0.5	0.018	EXT Poor
35.2	37.1	0.9	1	SH/SLSTN	EW	HAEM	R0	0	99	20	FLT	PK	GT	?	2.6	2	0.25	1	2.5	10	0.5	GT	12	20	0.02	0.01	1	0.85	0.5	0.003	EXC Poor
37.1	37.9	0.1	0.7	FAULT	EW	HAEM	R0	0	99	20	FLT	PK	GT	800	2.6	2	0.25	1	2.5	10	0.5	GT	12	20	0.02	0.01	1	0.85	0.5	0.003	EXC Poor
37.9	39	0	1.1	FAULT	EW	HAEM	R0	0	99	20	FLT	PK	GT	1100	2.6	2	0.25	1	2.5	10	0.5	GT	12	20	0.02	0.01	1	0.85	0.5	0.003	EXC Poor
39	41.7	0.2	2.5	SH/SLSTN	EW	HAEM	R0	41	40	20	BP/JN	PS	SF	0.2	2.6	2	0.25	1	2.5	41	1	SF	4	20	0.51	0.21	1	0.85	0.5	0.087	EXT Poor
41.7	43	0	1.3	SH/SLSTN	EW	FE	R0	0	99	3.5	BP/JN	PS	SF	0.1	2.6	2	0.25	1	2.5	10	1	SF	4	12	0.21	0.08	1	0.85	0.5	0.035	EXT Poor
43	43.9	0	0.9	SH/SLSTN	EW	FE	R0	0	99	3.5	FLT	PK	SF	900	2.6	2	0.25	1	2.5	10	0.5	SF	4	12	0.1	0.04	1	0.85	0.5	0.018	EXT Poor
43.9	45.3	0	1.4	SH/SLSTN	EW	FE	R1	43	50	3.5	BP/JN	PS	SF	2	2.6	2	1	1	2.5	43	1	SF	4	12	0.9	0.36	1	0.85	0.5	0.152	Very Poor
45.3	47	0	1.7	SH/SLSTN	EW	FE	R1	37	25	3.5	BP/JN	PS	SF	1	2.6	2	1	1	2.5	37	1	SF	4	12	0.77	0.31	1	0.85	0.5	0.131	Very Poor
47	48.4	0.1	1.3	SH/SLSTN	HW	FE	R1	18	35	3.5	BP/JN	PS	SF	0.5	2.6	2	1	1	2.5	18	1	SF	4	12	0.38	0.15	1	0.85	0.5	0.064	EXT Poor
48.4	51.5	0	3.1	SH/SLSTN	HW	FE	R1	40	45	3.5	BP/JN	PS	SF	0.1	2.6	2	1	1	2.5	40	1	SF	4	12	0.83	0.33	1	0.85	0.5	0.142	Very Poor
51.5	53.4	0.1	1.8	CARB.SH/SL	MW	SERI	R1	18	60	20	BP/JN	PS	SC	<0.1	2.6	2	1	1	2.5	18	1	SF	4	20	0.23	0.09	1	0.85	0.5	0.038	EXT Poor
53.4	54.8	0	1.4	CARB.SH/SL	MW	FE/SERI	R0	41	30	3.5	BP/JN	PS	SC	<0.1	2.6	2	0.25	1	2.5	41	1	SC	2	12	1.71	0.68	1	0.85	0.5	0.290	Very Poor
54.8	56	0	1.2	CARB.SH/SL	MW	FE/SERI	R0	22	30	3.5	BP/JN	PR	SF	<0.1	2.6	2	0.25	1	2.5	22	1.5	SF	4	12	0.69	0.28	1	0.85	0.5	0.117	Very Poor
56	58	0	2	CARB.SH/SL	MW	FE/SERI	R1	11	50	3.5	BP/JN	PS	SF	<0.1	2.6	2	1	1	2.5	11	1	SF	4	12	0.23	0.09	1	0.85	0.5	0.039	EXT Poor
58	59.1	0	1.1	SH/SLSTN	HW	HAEM	R0	0	99	20	~	PS	NN	0	2.6	2	0.25	0.66	2.5	10	1	NN	1	20	0.5	0.2	1	0.85	0.5	0.085	EXT Poor
59.1	60.5	0	1.4	SH/SLSTN	HW	QTZ+HAEM	R2	24	99	20	~	PS	NN	0	2.6	2	5	0.66	2.5	24	1	NN	1	20	1.2	0.48	1	0.85	0.5	0.204	Very Poor
60.5	61.6	0	1.1	SH/SLSTN	HW	QTZ+HAEM	R0	0	99	20	~	PS	NN	0	2.6	2	0.25	0.66	2.5	10	1	NN	1	20	0.5	0.2	1	0.85	0.5	0.085	EXT Poor
61.6	63	0	1.4	SH/SLSTN	HW	QTZ+HAEM	R0	28	40	20	BP/JN	PS	SC	0.1	2.6	2	0.25	0.66	2.5	28	1	SC	2	20	0.7	0.28	1	0.85	0.5	0.119	Very Poor
63	64.1	0	1.1	SH/SLSTN	HW	HAEM	R0	0	40	20	BP/JN	PS	SC	1.1	2.6	2	0.25	0.66	2.5	10	1	SC	2	20	0.25	0.1	1	0.85	0.5	0.043	EXT Poor
64.1	65.3	0	1.2	SH/SLSTN	HW	HAEM	R1	17	99	20	~	PS	SC	0	2.6	2	1	0.66	2.5	17	1	SC	2	20	0.43	0.17	1	0.85	0.5	0.072	EXT Poor
65.3	66.8	0	1.5	SH/SLSTN	HW	HAEM	R2	0	0	20	BP/JN	PS	SC	0	2.6	2	5	0.66	2.5	10	1	SC	2	20	0.25	0.1	1	0.85	0.5	0.043	EXT Poor
66.8	68.5	0	1.7	SH/SLSTN	MW	HAEM	R2	26	30	3.5	BP/JN	PS	SF	<0.1	2.6	2	5	0.66	2.5	26	1	SF	4	12	0.54	0.22	1	0.85	0.5	0.092	EXT Poor
68.5	70	0	1.5	CARB.SH/SL	SW	CARB	R3	20	30	2.5	JN	PS	NN	0	2.6	2	25	0.66	2.5	20	1	NN	1	6	3.33	1.33	2.5	0.85	0.5	1.416	Poor
70	72.2	0	2.2	SH/SLSTN	SW	SERI	R3	34	35	3	BP/JN	PS	SF	0	2.6	2	25	0.66	2.5	34	1	SF	4	9	0.94	0.38	1	0.85	0.5	0.161	Very Poor
72.2	73.5	0	1.3	SH/SLSTN	SW	SERI	R2	13	30	3	BP/JN	PS	NN	0	2.6	2	5	0.66	2.5	13	1	NN	1	9	1.44	0.58	1	0.85	0.5	0.246	Very Poor
73.5	75.3	0	1.8	SH/SLSTN	SW	SERI	R3	43	30	3	BP/JN	PS	NN	0	2.6	2	25	0.66	2.5	43	1	NN	1	9	4.78	1.91	2.5	0.85	0.5	2.030	Poor
75.3	75.8	0	0.5	SH/SLSTN	SW	SERI	R3	0	99	20	BP/JN	PS	NN	NN	2.6	2	25	0.66	2.5	10	1	NN	1	20	0.5	0.2	1	0.85	0.5	0.085	EXT Poor
75.8	76.8	0	1	SH/SLSTN	SW	SERI	R3	0	99	3.5	BP/JN	PS	NN	NN	2.6	2	25	0.66	2.5	10	1	NN	1	12	0.83	0.33	1	0.85	0.5	0.142	Very Poor
76.8	77.7	0	0.9	SH/SLSTN	SW	SERI	R3	33	18	3	BP/JN	PS	NN	NN	2.6	2	25	0.66	2.5	33	1	NN	1	9	3.67	1.47	2.5	0.85	0.5	1.559	Poor
77.7	80.8	0	3.1	SH/SLSTN	SW	SERI	R3	74	23	3	BP/JN	PS	NN	NN	2.6	2	25	0.66	2.5	74	1	NN	1	9	8.22	3.29	2.5	0.85	0.5	3.495	Poor
80.8	81.9	0	1.1	CARB.SH/SL	SW	SERI	R3	0	99	20	FLT	PK	GT	1100	2.6	2	25	0.66	2.5	10	0.5	GT	12	20	0.02	0.01	1	0.85	0.5	0.003	EXC Poor
81.9	83.9	0	2	CARB.SH/SL	SW	SERI	R3	0	99	20	FLT	PK	GT	2000	2.6	2	25	0.66	2.5	10	0.5	GT	12	20	0.02	0.01	1	0.85	0.5	0.003	EXC Poor
83.9	85.1	0	1.2	CARB.SH/SL	FR	SERI	R3	53	18	3.5	JN	PS	SF	1	2.6	2	25	0.66	2.5	53	1	SF	4	12	1.1	0.44	1	0.85	0.5	0.188	Very Poor
85.1	87	0	1.9	CARB.SH/SL	SW	SERI	R2	31	99	3.5	JN	PS	SF	0.1	2.6	2	5	0.66	2.5	31	1	SF	4	12	0.65	0.26	1	0.85	0.5	0.110	Very Poor
87	88.8	0	1.8	CARB.SH/SL	SW	SERI	R2	43	16	3.5	JN	PS	SF	<0.1	2.6	2	5	0.66	2.5	43	1	SF	4	12	0.9	0.36	1	0.85	0.5	0.152	Very Poor
88.8	91.1	0	2.3	CARB.SH/SL	SW	SERI	R4	51	30	3.5	JN	PS	NN	~	2.6	2	50	0.66	2.5	51	1	NN	1	12	4.25	1.7	2.5	0.85	0.5	1.806	Poor
91.1	94.1	0	3	CARB.SH/SL	FR	SERI	R4	80	30	3.5	JN	PS	SF	<0.1	2.6	2	50	0.66	2.5	80	1	SF	4	12	1.67	0.67	1	0.85	0.5	0.283	Very Poor
94.1	96.4	0	2.3	CARB.SH/SL	SW	SERI	R3	35	20	3.5	FLT	PK	GT	10	2.6	2	25	0.66	2.5	35	0.5	GT	12	12	0.12	0.05	1	0.85	0.5	0.021	EXT Poor
96.4	98.5	0	2.1	CARB.SH/SL	FR	SERI	R3	65	26	3.5	JN	PS	SF	~	2.6	2	25	0.66	2.5	65	1	SF	4	12	1.35	0.54	1	0.85	0.5	0.230	Very Poor
98.5	100	0	1.9	CARB.SH/SL	FR	SERI	R3	33	32	3.5	JN	PS	SF	<0.1	2.6	2	25	0.66	2.5	33	1	SF	4	12	0.69	0.28	1	0.85	0.5	0.117	Very Poor
100	103	0	2.3	CARB.SH/SL	FR	SERI	R4	49	22	3.5	JN	PS	SF	~	2.6	2	50	0.66	2.5	49	1	SF	4	12	1.02	0.41	1	0.85	0.5	0.173	Very Poor
103	104	0	1.7	CARB.SH/SL	FR	SERI	R4	48	25	3.5	JN	PK	GT	50	2.6	2	50	0.66	2.5	48	0.5	GT	12	12	0.17	0.07	1	0.85	0.5	0.028	EXT Poor
104	107	0	2.8	CARB.SH/SL	FR	SERI	R5	73	16	3	JN	PS	SF	~	2.6	2	95	0.66	2.5	73	1	SF	4	9	2.03	0.81	1	0.85	0.5	0.345	Very Poor
107	109	0	1.9	CARB.SH/SL	FR	CAL MAG	R5	74	16	3	BP/JN	PS	NN	~	2.6	2	95	0.66	2.5	74	1	NN	1	9	8.22	3.29	2.5	0.85	0.5	3.495	Poor
109	111	0	1.6	CARB.SH/SL	FR	CAL MAG	R5	23	18	3.5	BP/JN	PS	NN	~	2.6	2	95	0.66	2.5	23	1	NN	1	12	1.92	0.77	1	0.85	0.5	0.326	Very Poor
111	114	0	2.9	CARB.SH/SL	FR	CAMAG	R5	62	40	3.5	BZ/JN	PS	NN	~	2.6	2	95	0.66	2.5	62	1	NN	1	12	5.17	2.07	2.5	0.85	0.5	2.196	Poor
114	115	0	1.5	CARB.SH/SL	FR	CAMAG	R4	21	16	3.5	FLT	PK	GT	1500	2.6	2	50	0.66	2.5	21	0.5	GT	12	12	0.07	0.03	1	0.85	0.5	0.012	EXT Poor
115	116	0	1.3	CARB.SH/SL	MW	~	R0	0	1	20	FLT	PK	GT	1300	2.6	2	0.25	0.66	2.5	10	0.5	GT	12	20	0.02	0.01	1	0.85	0.5	0.003	EXC Poor
116	118	0	1.3	CARB.SH/SL	MW	~	R0	0	1	20	FLT	PK	GT	1300	2.6	2	0.25	0.66	2.5	10	0.5	GT	12	20	0.02	0.01	1	0.85	0.5	0.003	EXC Poor
118	120	0	2.4	CARB.SH/SL	SW	~	R3	27	50	3.5	FLT	PK	GT	~	2.6	2	25	0.66	2.5	27	0.5	GT	12	12	0.09	0.04	1	0.85	0.5	0.016	EXT Poor
120	122	0	2.1	CARB.SH/SL	SW	SERI	R3	49	30	3.5	BP/JN	PS	GT	10	2.6	2	25	0.66	2.5	49	1	GT	12	12	0.34	0.14	1	0.85	0.5	0.058	EXT Poor
122	125	0	2.6	CARB.SH/SL	MW	HAEM	R0	35	40	3.5	BP/JN	PK	GT	1.5	2.6	2	0.25	0.66	2.5	35	0.5	GT	12	12	0.12	0.05	1	0.85	0.5	0.021	EXT Poor
125	127	0	2.3	SH/SLSTN	MW	HAEM	R2	51	35	3.5	BP/JN	PS	SC	0.1	2.6	2	5	0.66	2.5	51	1	SC	2	12	2.13	0.85	1	0.85	0.5	0.361	Very Poor
127	130	0	3	SH/SLSTN	MW	HAEM	R2	45	40	3.5	BP/JN	PR	SC	0	2.6	2	5	0.66	2.5	45	1.5	SC	2	12	2.81	1.13	2.5	0.85	0.5	1.195	Poor
130	132	0	1.4	SH/SLSTN	HW	HAEM	R0	0	1	20	FLT	PK	GT	~	2.6	2	0.25	0.66	2.5	10	0.5	GT	12	20	0.02	0.01	1	0.85	0.5	0.003	EXC Poor
132	133	0.1	1.2	SH/SLSTN	HW	HAEM	R0	0	1	20	FLT	PK	GT	~	2.6	2	0.25	0.66	2.5	10	0.5	GT	12	20	0.02	0.01	1	0.85	0.5	0.003	EXC Poor
133	135	0	2.2	CARB.SH/SL	HW	HAEM	R3	36	99	20	BP	PS	NN	0	2.6	2	25	0.66	2.5	36	1	NN	1	20	1.8	0.72	1	0.85	0.5	0.306	Very Poor
135	138	0	3.1	SULF+C.SHL	FR	SERI	R2	63	24	3	JN	PS	SF	<0.1	2.6	2	5	0.66	2.5	63	1	SF	4	9	1.75	0.7	1	0.85	0.5	0.298	Very Poor
138	141	0	3.1	SULF+C.SHL	MW	SERI	R3	60	23	3	JN	PS	SF	<0.1	2.6	2	25	0.66	2.5	60	1	SF	4	9	1.67	0.67	1	0.85	0.5	0.283	Very Poor
141	144	0	3.1	SULF+C.SHL	FR	SERI	R2	40	40	3.5	JN	PS	SF	0.1	2.6	2	5	0.66	2.5	40	1	SF	4	12	0.83	0.33	1	0.85	0.5	0.142	Very Poor
144	145	0	1	SULF+C.SHL	FR	SERI	R2	44	15	3	JN	PS	SF	<0.1	2.6	2	5	0.66	2.5	44	1	SF	4	9	1.22	0.49	1	0.85	0.5	0.208	Very Poor
145	149	0.1	3.1	SULF+C.SHL	FR	SERI	R4	56	45	3.5	BP/JN	PS	SF	<0.1	2.6	2	50	0.66	2.5	56	1	SF	4	12	1.17	0.47	1	0.85	0.5	0.198	Very Poor
149	151	0	2.6	SH/SLSTN	FR	SERI	R4	87	11	2	BP/JN	PS	SF	<<0.1	2.6	2	50	0.66	2.5	87	1	SF	4	4	5.44	2.18	2.5	0.85	0.5	2.311	Poor
151	154	0	3	SULF+C.SHL	FR	~	R4	78	10	3	BP/JN	PS	NN	~	2.6	2	50	0.66	2.5	78	1	NN	1	9	8.67	3.47	2.5	0.85	0.5	3.684	Poor
154	157	0	3	SULF+C.SHL	MW	HAEM	R4	76	30	3.5		PS	SC	?	2.6	2	50	0.66	2.5	76	1	SC	2	12	3.17	1.27	2.5	0.85	0.5	1.346	Poor
157	159	0	2.1	SULPHIDE	MW	HAEM	R2	38	35	3.5	JN	PS	SC	0.1	2.6	2	5	0.66	2.5	38	1	SC	2	12	1.58	0.63	1	0.85	0.5	0.269	Very Poor
159	162	0	3.1	SULPHIDE	MW	HAEM	R3	33	40	3	BP	PS	SC	<0.1	2.6	2	25	0.66	2.5	33	1	SC	2	9	1.83	0.73	1	0.85	0.5	0.312	Very Poor
162	165	0	3.1	SULPHIDE	MW	HAEM	R3	49	30	3	BP/JN	PS	SF	~	2.6	2	25	0.66	2.5	49	1	SF	4	9	1.36	0.54	1	0.85	0.5	0.231	Very Poor
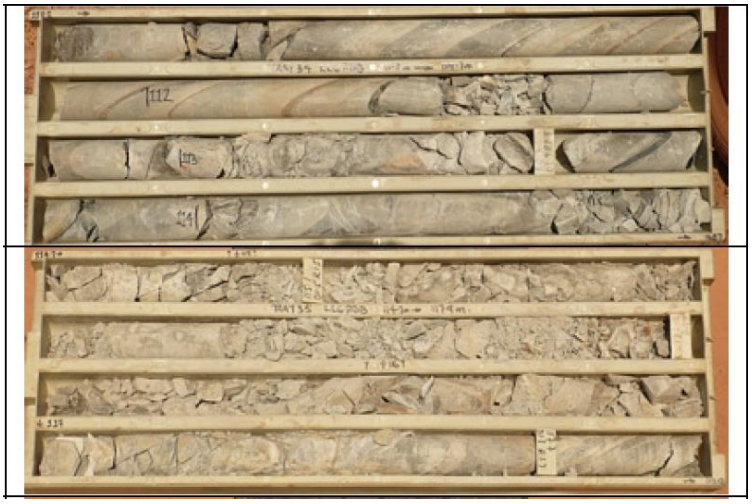
10 APPENDIX C

Selected core photos for LLGRD8 and associated Raise Bore Stability Rating Classifications

Trays 8 and 9 of LLGRD8: 23.6 – 30.3m.
Extremely Weathered material that has been classified as “Extremely Poor”.
Includes “Exceptionally Poor” classified ground Koff’s Fault intercept (114.5-117.5m)



Trays 34 and 35 of LLGRD8: 111.2 – 117.9m.
Includes “Exceptionally Poor” classified ground at the Koff’s Fault intercept (114.5-117.5m)



Trays 47 and 48 of LLGRD8: 156.7 – 163.3m.
Moderately Weathered Rock classified as “Very Poor”



DOCUMENT INFORMATION

DOCUMENT CHANGE CONTROL

Version	Description of Changes/amendments	Author (s)	Date
DRAFT 1.0	Geotechnical Assessment of critical areas of the mine /subsidence. Draft for Client comment	Mario Melhem	10/11/2021
DRAFT 2.0	Mitigation measures for the subsidence with backfilling and shafts assessment.	Mario Melhem/ Tom McGushin	18/03/2022
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APPENDIX I CLOSURE GROUNDWATER MODELLING REPORT

Glencore Australia

Lady Loretta Mine Groundwater Closure Report

30 May 2022

CDM Smith

listen. think. deliver.

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Section 1 Introduction

1.1 Background

The Lady Loretta Mine (LLM) is located approximately 140 kilometres north-west of Mount Isa in Queensland (Figure 1-1). LLM is an underground zinc-lead-silver (Zn-Pb-Ag) mine currently operating on mining lease ML5568 in accordance with Environmental Authority (EA) EPLM00982013. Redpath Australia Pty Ltd (Redpath) currently operate LLM on behalf of Glencore. The ML and EA for LLM are held by Noranda Pacific Pty Ltd (Noranda), which is a wholly owned subsidiary of Glencore. The mining lease covers around 2783 hectares with an approximate disturbance footprint of 140 hectares, and is adjacent to the Lady Annie Copper Mine located on mining lease ML90179, which is operated by Austral Resources.

A Detailed Closure Plan (DCP) has been developed and a Progressive Rehabilitation and Closure Plan (PRCP) is under development for the Lady Loretta Mine (LLM). The current campaign of mining operations is scheduled for completion in 2025. Above ground and selected below ground infrastructure is to be decommissioned and demolished. Decommissioning and demolition works are planned starting with the underground zone, shafts area and processing zone.

CDM Smith Australia Pty Ltd (CDM Smith) was engaged by Glencore Australia (Glencore) to undertake a desktop hydrogeological assessment of the Lady Loretta Mine (LLM) and surrounds to assist in closure planning and contaminant management. Specifically, Glencore requires development of a numerical groundwater flow model for prediction of groundwater system response to cessation of mining, and the potential fate of contaminants of concern (CoCs) during and after groundwater recovery. The objective of the numerical model is to assist in the development and implementation of an appropriate closure monitoring network and program.

1.2 Mine Operations

The operation produces approximately 1.6 million tonnes (MT) of high-grade Zn-Pb-Ag ore each year which is transported to Mount Isa and blended with ore from George Fisher Mine prior to processing. Zn-Pb-Ag mineralisation at LLM was indicated by a geochemical soil survey in 1968 and confirmed in 1969 by diamond drilling. Ore production from LLM commenced in September 2012 and in October 2015 production paused. The mine was placed under care and maintenance in 2015 in response to a low Zn price. Production recommenced in August 2018 and the underground mine has advanced to approximately 550 metres deep. The mine consists of four shafts and a decline whose portal is located between the Waste Rock Emplacement (WRE) and the Run of Mine (ROM) pad, which provides underground access to operational areas (Figure 1-1). The mining method at Lady Loretta is based on a mixture of transverse and longitudinal long hole open stoping with paste fill operations (Xstrata, 2012). Ore is trucked to the surface and the ROM pad where it is then crushed in a jaw crusher and stockpiled. Crushed ore is loaded and trucked to the Glencore Mount Isa processing plant for concentrating and smelting. During mining the underground workings are backfilled in stages using paste produced from tailings and cement in the paste production plant. Paste backfill is used to increase the structural integrity of mined out stopes and provide support to the underground mining operation. Following paste operations, fibrecrete is applied to the underground surfaces to assist in stabilising the rock wall material.

1.3 Mine Closure

A Detailed Closure Plan has been developed for the LLM with the aim to leave a safe, stable, non-polluting and sustainable final landform for the final land use that is consistent with the surrounding landscape (LLM, 2021a). Above ground and selected below ground infrastructure is to be decommissioned and demolished. Decommissioning and demolition works are planned to start with Underground Zone, Shafts Area, Processing Zone; with General Infrastructure Zone decommissioning, followed by Administration and Maintenance Zones.

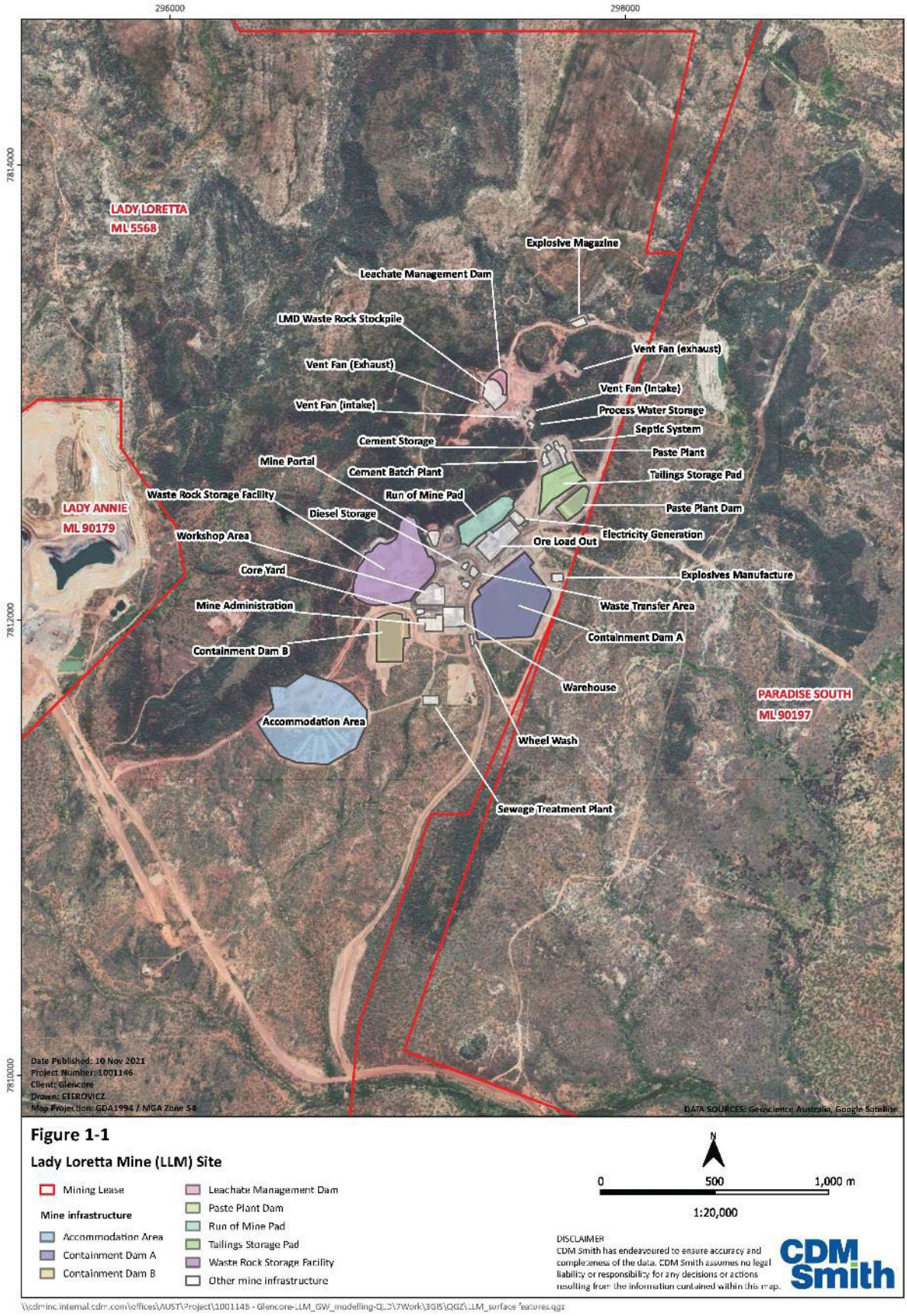


Figure 1-1 Lady Loretta Mine Site

1.4 Objectives and Scope of Work

The objective of the Lady Loretta Mine groundwater scope is to characterise the key hydrogeological features of the site, represent these in the model domain and consider Contaminants of Concern (COC) in relation to the groundwater at the site. To assist in assessing groundwater system response to mine closure it is necessary to update the hydrogeological conceptualisation and the existing numerical groundwater flow model to support CoC fate and transport predictions via solute transport modelling.

The scope of work (SOW) for this report includes the following components:

Stage 1 Hydrogeological conceptualisation and numerical groundwater flow model:

- Review of relevant reports and information describing the results of work that has previously been undertaken.
- Describe and characterise the key hydrogeological features. Identify and describe the processes that control or influence the movement and storage of groundwater and solutes in the hydrogeological system. The conceptualisation considers the physical processes and resulting heads and flows of groundwater.
- Identification of existing knowledge gaps and uncertainties relating to hydrogeological conceptualisation of LLM Study Area and its representation in a numerical groundwater flow model.
- Updating and revise the existing numerical groundwater flow model.

Stage 2 Potential fate of COC and solute transport modelling:

- Sources of identified CoCs from LLM facilities to groundwater.
- Pathways and mechanisms for CoC release from LLM facilities.
- Concentrations of potential CoCs being released from LLM facilities.
- Develop a solute transport model to assess the fate of potential CoCs in groundwater.
- Evaluation of potential impacts to groundwater resources based on conceptual and model outcomes.
- Summarise these findings to support mine closure planning.

This report summarises the studies completed to date in relation to the stages presented above.

1.5 Previous Model Studies

Previous hydrogeological conceptualisation studies were completed by Australian Groundwater and Environment (AGE) in 2015 (AGE,2015) and 2020 (AGE,2020). It has been observed that the AGE 2015 and 2020 renewed conceptual models demonstrated an evolution of conceptual thinking, with differences in terms of fault barrier conceptualisation and groundwater flow or movement between the two models identified.

AGE also updated the LLM numerical groundwater flow model in 2015 to align with the 2015 conceptualisation and to incorporate revisions to mine development and associated dewatering, and the model calibration was updated from a steady state solution to a transient calibration. It should be noted that the numerical groundwater model was not revised and updated since 2015. As such the current AGE 2020 conceptualisation does not align with the AGE 2015 numerical model construct and conceptualisation.

Due to this misalignment a revision and update to the conceptual model is required, and subsequent to this an update the numerical groundwater model to realign this model to the conceptual model is required. This realignment, developed as part of this report, will ensure that the conceptual model and numerical model have consistent hydrogeological processes represented. With both the conceptual and numerical models aligned works can progress on the development and implementation of an appropriate closure groundwater monitoring program.

This assessment details the works undertaken to revise and update the model studies and apply revised models to a solute transport model scope.

Section 2 Physical Setting

2.1 Lady Loretta Mine Key Features

2.1.1 Underground Mine

The underground mine is approximately 550 metres deep and consists of four shafts and a decline whose portal is located between the Waste Rock Emplacement (WRE) and the Run of Mine (ROM), which provides underground access to operational areas. The mining method at Lady Loretta is based on a mixture of transverse and longitudinal long hole open stoping with paste fill operations. Ore is trucked to the surface where it is then crushed in a jaw crusher and stockpiled. Crushed ore is loaded and trucked to the Glencore Mount Isa processing plant for concentrating and smelting. During mining the underground workings are backfilled in stages using paste produced from tailings and cement in the paste production plant. Paste backfill is used to increase the structural integrity of mined out stopes and provide support to the underground mining operation. Following paste operations, fibrecrete is applied to the underground surfaces to assist in stabilising the rock wall material.

2.1.2 Waste Rock Emplacement and Stockpiles

Waste rock produced by the mine is potentially acid forming (PAF) and is either used as loose fill underground or stored on the surface in the WRE.

Stockpiles at the LLM include growth medium stockpiles, the leachate management dam (LMD) stockpile and cover stockpiles. All waste rock characterised as non-acid forming (NAF) is moved to the ROM pad, which lies directly east of the decline portal and WRE. The ROM area consists of a crushing plant and is designed for surface storage of the ore extracted from the underground mine, awaiting transfer to Glencore's Mount Isa Mines (MIM) processing plant for further processing. In association with the paste plant and batch plant, the ROM is one of the key features of material transfer.

2.1.3 Water Management Infrastructure

Water management infrastructure includes four containment dams, called containment dam A (CDA), containment dam B (CDB), the paste plant dam (PPD) and the leachate management dam (LMD). CDA largely receives runoff from the ROM stockpile, crushing and loading area, decline portal, mine office and surrounding infrastructure. CDB largely receives runoff from the WRE. The PPD largely receives runoff from the paste and batch plants, and the LMD largely receives runoff from the LMD stockpile and surrounding infrastructure. Smaller unregulated sediment dams are located directly adjacent to CDA, CDB and the PPD.

2.1.4 Lady Annie East Borefield Operations

Raw water is sourced from the Lady Annie East (LAE) borefield for use in underground machinery, paste mix water, fire water, dust suppression and potable water system feed water. The annual average extraction rate of raw water from the LAE borefield is 766 mega litres per year (ML/year) (LLM, 2021a). Noranda holds a licence number 403766 to extract groundwater from the borefield at an extraction point on Lot 1 UN7 (LLM, 2021b). The borefield is located east of the Lady Loretta Mine and the current production bores are called GW15, GW17 and GW18.

2.1.5 Other infrastructure

Other mine related infrastructure includes an accommodation camp, offices and warehouses, fuel farm, explosive and chemical storage areas, emergency response buildings, water treatment plant and the communication tower. The paste plant and batch plant are located in the north-east portion of the operational area, which receives material post processing for reuse underground at LLM.

2.2 Climate

The climate at LLM is dominated by high temperatures, with a regional annual evaporation of 2954 mm/year and an annual rainfall of 414 mm/year. Rainfall is highly variable year on year with long term minimum and maximum rainfall varying between 116 and 1224 mm, respectively. Annual rainfall is concentrated in a distinct wet season from October through to March, with the highest average monthly total occurring in the months November to March (Figure 2-1). On average, monthly rainfall is always exceeded by evaporation.

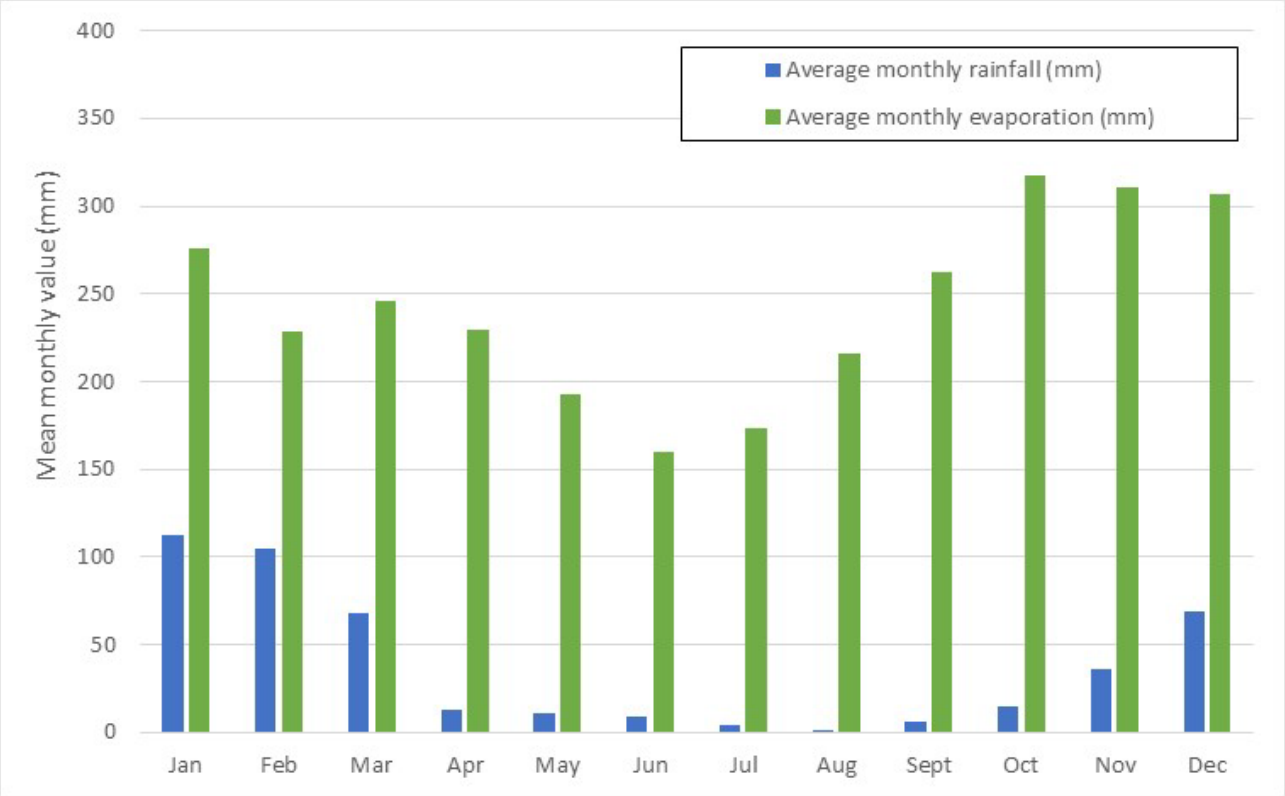


Figure 2-1 Average Monthly Rainfall and Evaporation

Long term rainfall monthly cumulative deviation from the mean (CDFM) is shown in Figure 2-2, based on the rainfall data obtained from the Australian climate SILO database. Periods of below average rainfall are represented as downward trending slopes, and above average rainfall as upward trending slopes. The data show decadal long periods of below average rainfall and, typically, shorter periods of above average rainfall.

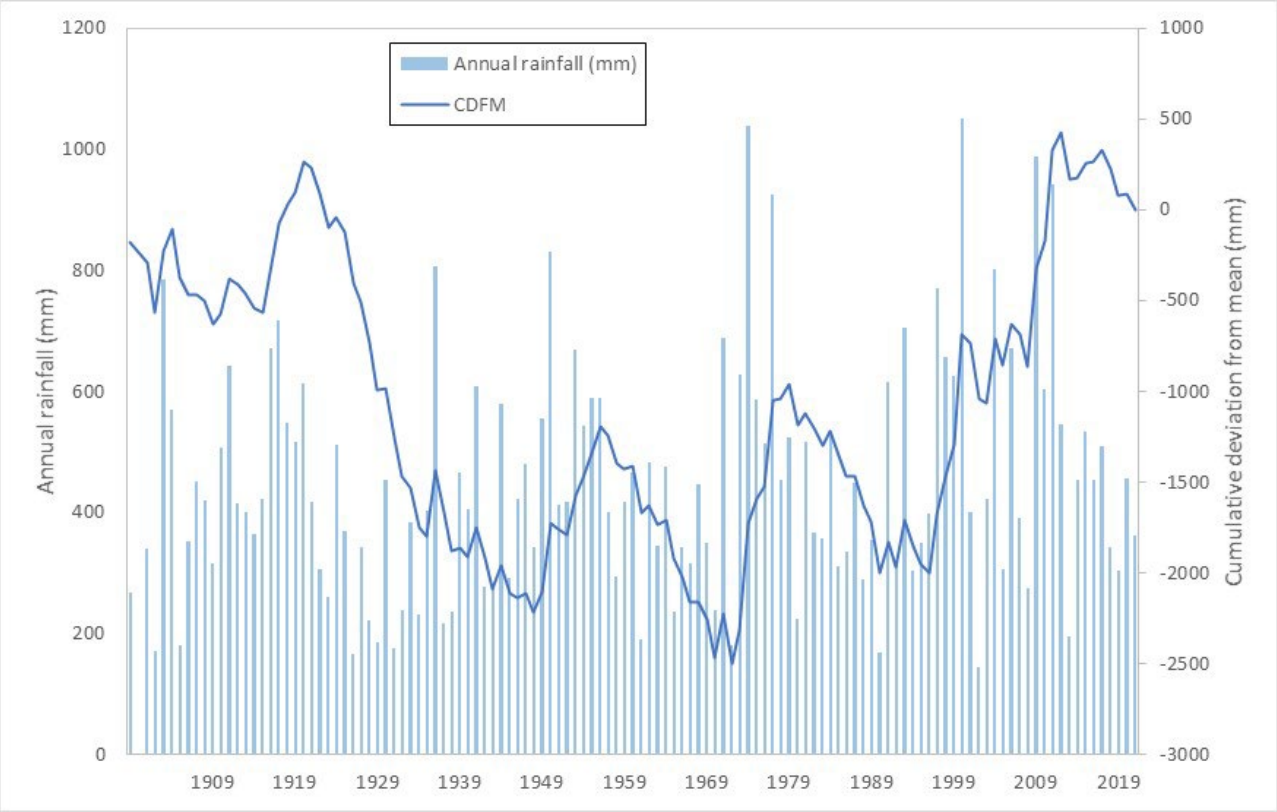


Figure 2-2 Long term Rainfall and CDFM

2.3 Topography and Hydrology

The topography in the study area ranges from approximately 300 to 390 m Australian Height Datum (AHD). The topography is characterised by higher elevation to the north of the LLM site and lower elevation to the south as shown in Figure 2-3. The major topographical feature associated with LLM is a north-east to south-west orientated ridgeline rising to 385 mAHD. The majority of LLM operations are located on the eastern flank of the ridgeline.

The LLM sits within ephemeral drainage lines that flow only in direct response to rainfall. LLM operations are located within the Leichhardt River catchment at the headwaters of Magazine and Desert Creeks. The creeks form the main ephemeral drainage lines within the immediate vicinity of the LLM. Natural surface water flow from LLM is channelled through Magazine Creek. Surface flows in the southern catchments are channelled through Desert Creek.

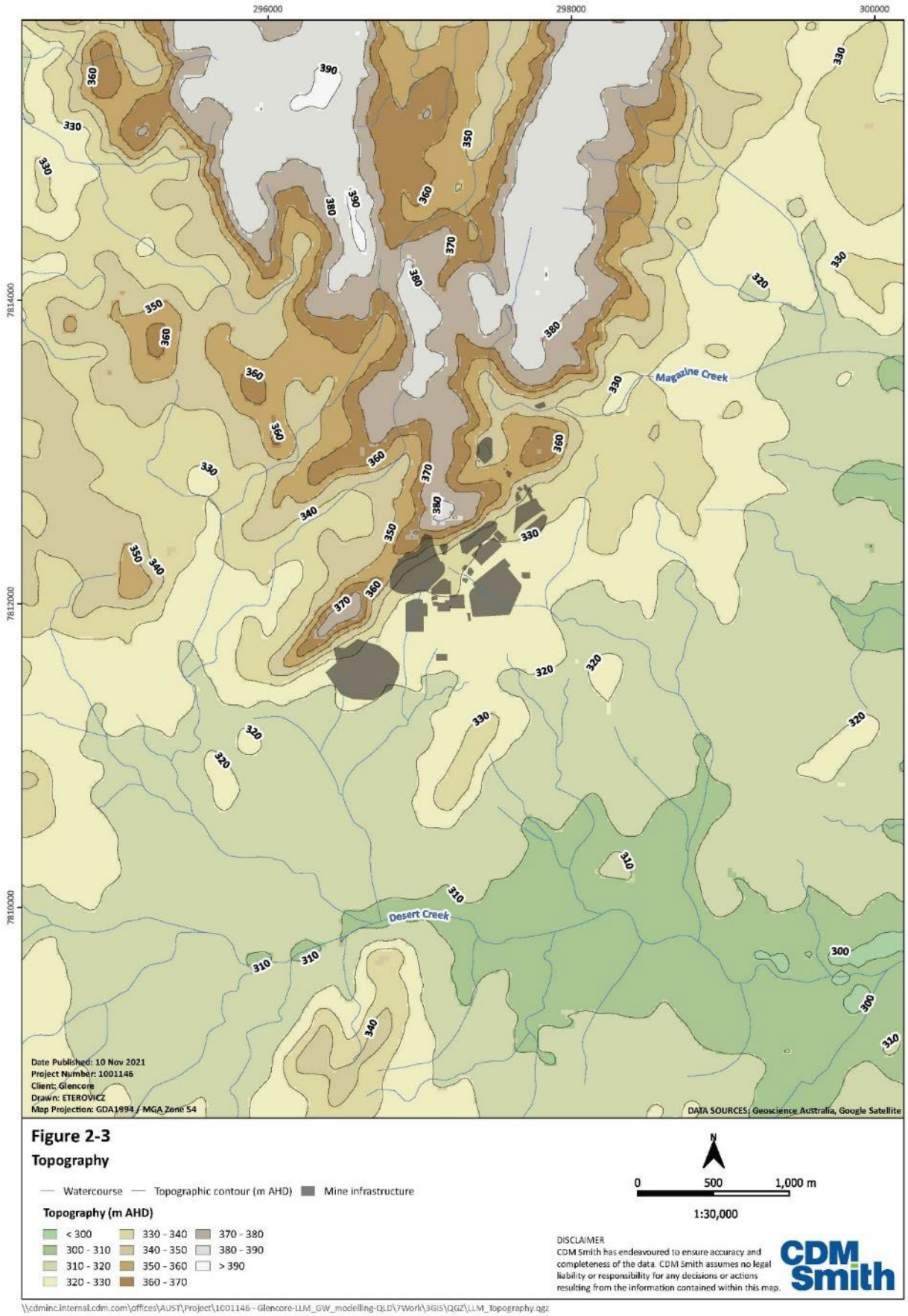


Figure 2-3 Site and Surrounds Topography

2.4 Geology

2.4.1 Lady Loretta Block

The LLM is located in the Western Fold Belt of the Mount Isa Inlier. The deposit is hosted within the Paleoproterozoic Lady Loretta Formation (Figure 2-4), which forms the uppermost outcropping unit of the McNamara Group (Valenta, 2018). The area is structurally complex and the Lady Loretta deposit is hosted in the keel of the Small Syncline, a tight north-east trending fold truncated by steep to moderately north-west dipping faults called the Koff and Max's Faults, as shown in Figure 2-5.

The LLM ore bearing zone is divided into two areas, the Big and Small Synclines. The Big Syncline contains uneconomical low base metal grades. A north-south trending fault separates the Big and Small synclines. The major Carlton Fault Zone truncates the syncline to the north-west. The Carlton Fault is associated with extensive zones, up to 200m wide, of shearing and brecciation (Hancock and Purvis, 1990). It is postulated as a feeder zone for metal rich fluids (Hancock and Purvis, 1990).

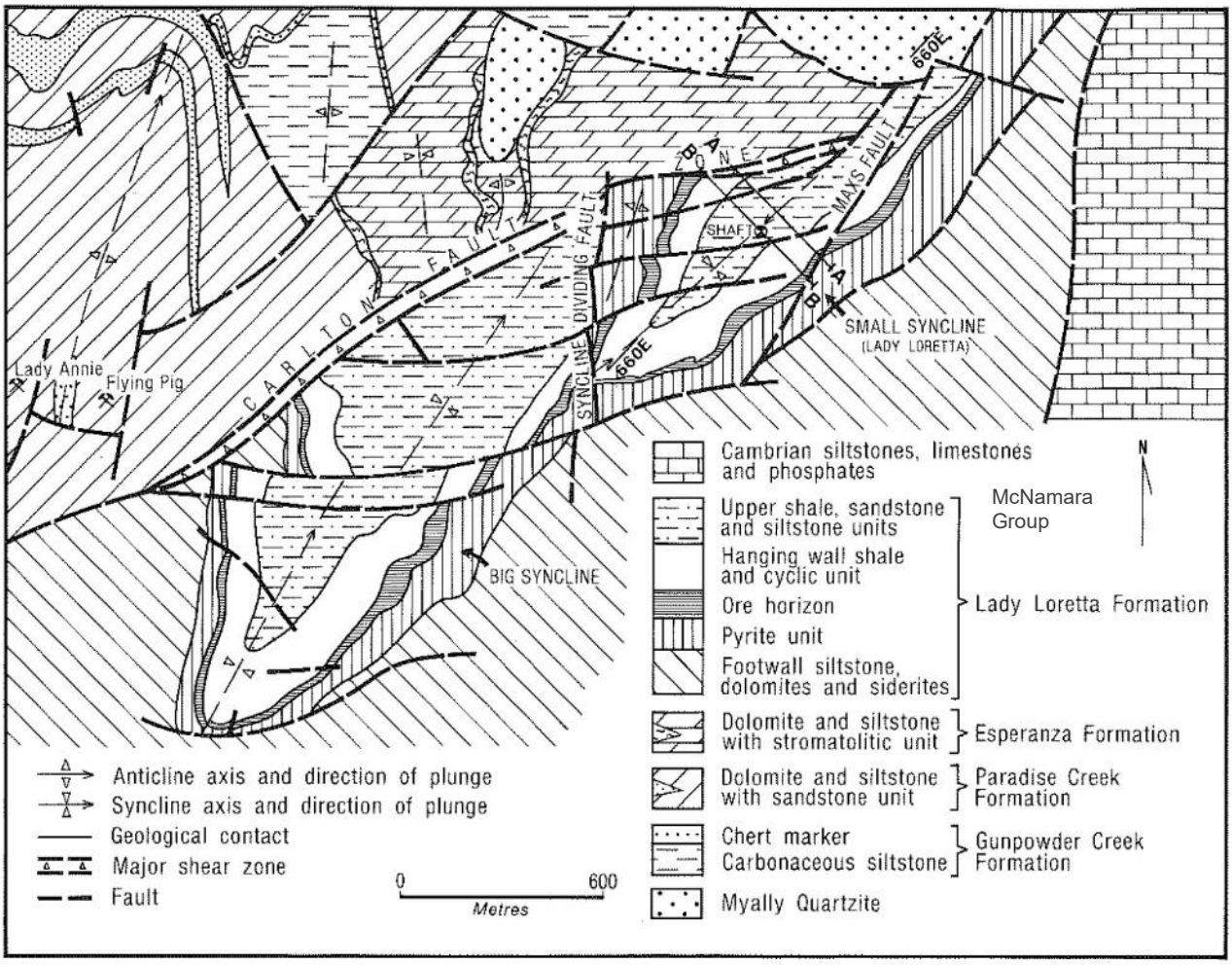


Figure 2-4 Plan View Geological Map of the Lady Loretta Deposit and Stratigraphic Column for the Lady Loretta Region (Hancock and Purvis, 1990).

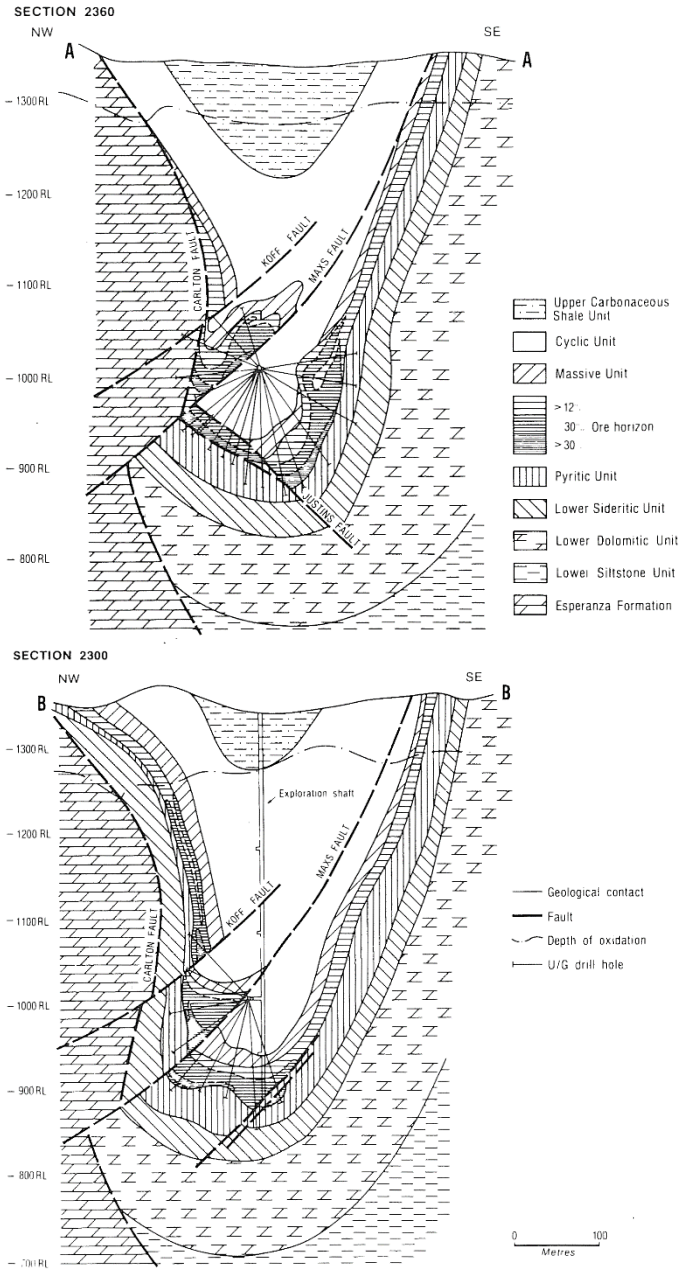


Figure 2-5 Lady Loretta Cross Sections A-A' and B-B' (Hancock and Purvis, 1990)

The surface geology is shown in Figure 2-6 and the lithology summary description is presented in Table 2-1. The ore sequence is truncated to the north-west by the north-east trending Carlton Fault zone, which juxtaposes older basin units to the north against the Lady Loretta Formation to the south (Mark, 1998). The Carlton Fault swings into convergence with the north to north-east trending Western Border Fault, which truncates Cambrian and Mesozoic cover rocks east of LLM. The Western Border Fault divides the LLM sulphide ore bearing zone from the less deformed Cambrian strata to the east, while the Carlton Fault separates the Lady Loretta Formation from the Paradise Creek Formation to the west.

The Lady Loretta Formation, one of seven that form the McNamara Group in the area, comprises dolomite, sandstone, siltstone, with chert and quartzite. The Proterozoic rocks are variably overlain by a thin layer of Mesozoic and Quaternary sediments. Although these recent sediments are not ubiquitous, they are widespread across the area (AGE, 2020).

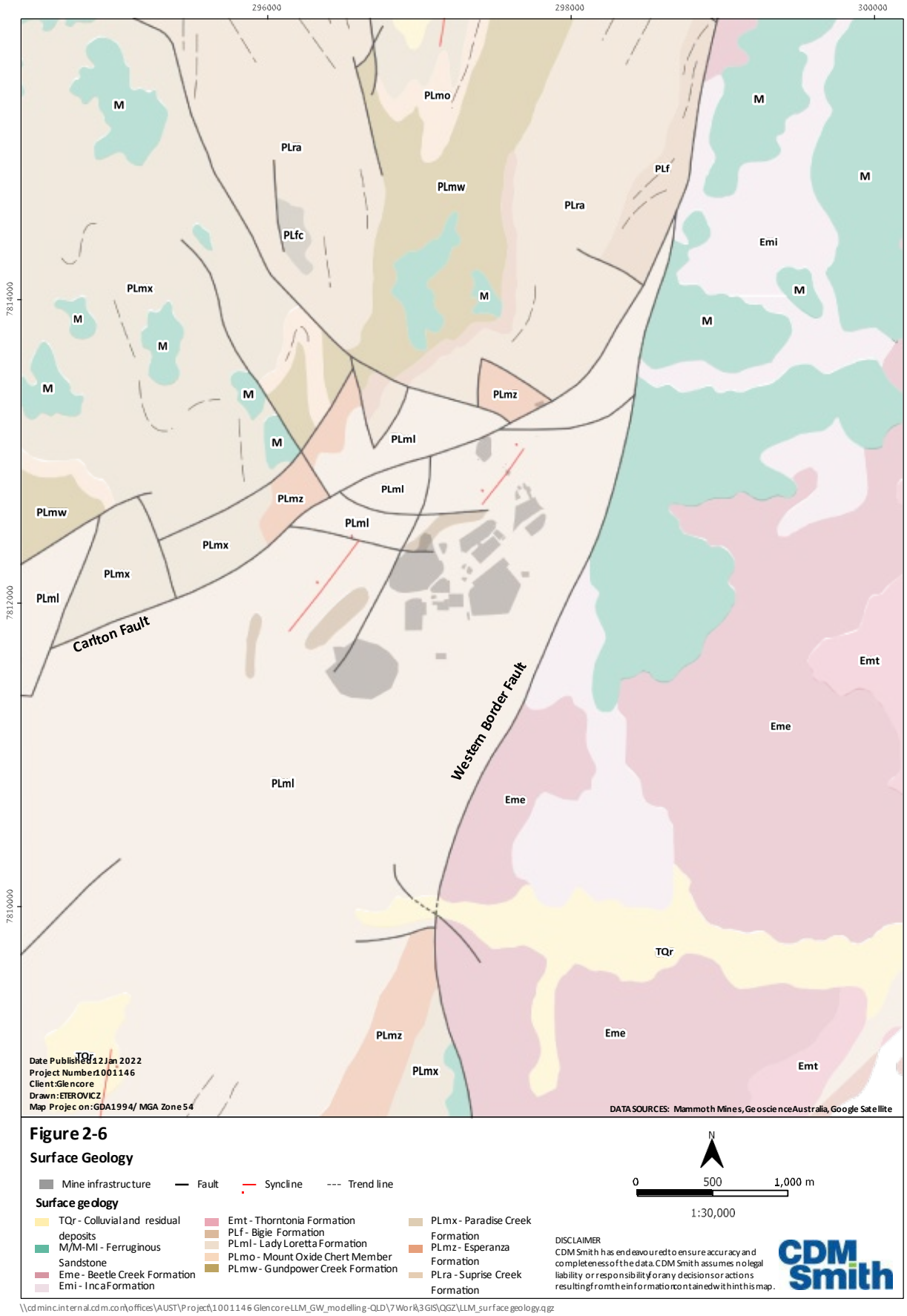


Figure 2-6 Site and Surrounds Surface Geology

Table 2-1 Site and Surrounds Stratigraphic Descriptions

Map Symbol	Age	Group	Formation	Lithology Summary
TQr	Late Tertiary - Quaternary		Alluvium and regolith	Clay, silt, sand, gravel and soil; colluvial and residual deposits (generally on older land surfaces)
M	Jurassic – Cretaceous			Ferruginous sandstone, conglomerate, siltstone and claystone
Emi	Cambrian – Early Ordovician	Narpa Group	Inca Formation	Siliceous shale and chert with limestone interbeds
Eme		Narpa Group	Beetle Creek Formation	Chert, siliceous shale with trilobite fossils, basal conglomerate
Emt		Narpa Group	Thorntonia Limestone	Thick-bedded, dolomitic limestone and dolomite with layers and nodules of chert
Emh	Neoproterozoic – Early Cambrian	Shadow Group	Mount Hendry Formation	Conglomerate, feldspathic sandstone, shale, mudstone and dolomite
PLms	Paleoproterozoic - Mesoproterozoic	McNamara Group	Shady Bore Quartzite	Flaggy to massive medium-grained orthoquartzite; interbeds of fine-grained sandstone, siltstone, and dolomite
PLml		McNamara Group	Lady Loretta Formation	Laminated stromatolitic and intraclastic dolomite, dolomitic siltstone, limestone, shale
PLmz		McNamara Group	Esperanza Formation	Stromatolitic chert and dolomite, siliceous and dolomitic sandstone
PLmx		McNamara Group	Paradise Creek Formation	Stromatolitic dolomite, dolomitic siltstone, some limestone interbeds, dolomite with chert nodules after anhydrite; minor pink to grey fine tuff
PLmo		McNamara Group	Mount Oxide Chert Member	Grey laminated chert
PLmw		McNamara Group	Gunpowder Creek Formation	Laminated siltstone, dolomitic and carbonaceous siltstone, fine-grained sandstone, feldspathic and pyritic quartzite, pebbly clayey sandstone
PLmp		McNamara Group	Torpedo Creek Quartzite	White to medium orthoquartzite, with gypsum pseudomorphs locally
PLra	Paleoproterozoic		Surprise Creek Formation	Buff, pink, white, and pale bluish grey thin-bedded fine to medium-grained labile and ferruginous feldspathic sandstone, pebbly sandstone, conglomerate, mudflake-shale pellet beds, micaceous siltstone and quartzite
PLfc			Fiery Creek Formation	Reddish brown, grey and black vesicular metabasalt and trachybasalt, locally porphyritic; purple to brown labile and micaceous sandstone, tuffaceous conglomerate; minor felsic flows and breccia
PLf			Bigie Formation	Purple-brown hematitic labile sandstone, pebbly sandstone, tuff, conglomerate and red-brown siltstone

2.4.2 Cambrian Block

To the east of the Paleoproterozoic rocks of the Mount Isa Inlier and the Western Border Fault are the Cambrian formations, which are overlain by surficial alluvium and Mesozoic sediments, varying in thickness up to 25 m. The Cambrian Block comprises four major formations as described below:

- Inca Formation underlies the surficial alluvium and Mesozoic sediments, consisting of siliceous shale and chert with limestone interbeds.
- Beetle Creek Formation consists of chert, siliceous shale with trilobite fossils, and basal conglomerate.
- Thorntonia Limestone consists of thick-bedded, dolomitic limestone and dolomite with layers and nodules of chert with variable thickness and predominantly outcrops in the south-east.
- Mount Hendry Formation consists of conglomerate, feldspathic sandstone, shale, mudstone and dolomite and outcrops in the south-east.

2.4.3 Paleoproterozoic Block

The Palaeoproterozoic formations to the west of the Carlton Fault are dominated by the Paradise Creek Formation, Gunpowder Creek Formation and Surprise Creek Formation. The following provides a lithology description of each formation:

- Esperanza Formation consists of stromatolitic chert and dolomite, siliceous and dolomitic sandstone.
- Paradise Creek Formation consists of stromatolitic dolomite, dolomitic siltstone, some limestone interbeds, dolomite with chert nodules.
- Gunpowder Creek Formation consists of laminated siltstone, dolomitic and carbonaceous siltstone, fine-grained sandstone, feldspathic and pyritic quartzite, pebbly clayey sandstone.
- Surprise Creek Formation consists of buff, pink, white, and pale bluish grey thin-bedded fine to medium-grained labile and ferruginous feldspathic sandstone, pebbly sandstone, conglomerate, mudflake-shale pellet beds, micaceous siltstone and quartzite.

Section 3 Hydrogeology

3.1 Hydrogeological Units

The water bearing units at the LLM site include the Lady Loretta Formation, the Cambrian Block and the Paleoproterozoic Block formations called the Esperanza and Paradise Creek units. The overlying Quaternary and Mesozoic units are rarely saturated (AGE, 2020), with the reported depth to the water table in the Cambrian Block typically more than 30 metres below ground level (mbgl). There is minimal hydrogeological information for the Esperanza and Paradise Creek Formations and only two monitoring bores in the area are screened in the Paradise Creek Formation.

The faults known as Koff and Max do not display noticeable seepage at points where they are intersected in the underground mine (AGE, 2020). Other faults not shown include Craigs Fault and Thorpedo Fault. Craigs Fault is oriented north to north-east and south to south-west and represents a narrow zone. Both Craigs Fault and Thorpedo Fault, when intersected in the underground mine, typically produce an inflow of groundwater (AGE, 2020). Koff Fault, Max Fault and Thorpedo Fault terminate at the surface, near the eastern limb of the small syncline. There is no available information or data to describe the fault structure and groundwater behaviour for the Carlton Fault or Western Border Fault. The significance of these fault structures with respect to groundwater flow is currently unknown (discussed further in Section 4).

3.2 Groundwater Monitoring Network

The LLM groundwater monitoring network includes three main types of monitoring points:

- EA-listed compliance bores.
- Internal monitoring points for background data accumulation.
- Leak detection bores which are shallow vertical groundwater bores designed to detect potential contamination from surface water infrastructure features.

The groundwater monitoring network is summarised in Table 3-1 and locations are shown in Figure 3-1. The network consists of 35 groundwater (GW) monitoring bores and 17 Leak detection (LD) sites. The LD sites are typically dry.

The LLM EA requires groundwater to be monitored on a quarterly basis at eight reference or compliance bores and six LD bores. In December 2018 Glencore received an EA amendment to remove GW07 compliance bore (as noted in Table 3-1). In 2019 monitoring bores GW02 and GW04 had collapsed and in February 2020 monitoring bore GW07 had also collapsed. In 2021 LLM augmented the groundwater monitoring network with the replacement and installation of additional bores to assist in understanding the extent of the mine depressurisation.

The monitoring network changes include the following:

- Decommissioning three failed groundwater monitoring bores as noted above.
- Installation of seven open standpipe groundwater monitoring bores at new sites GW02a, GW04a, GW07a, GW36, GW37, GW38 and GW39.

Table 3-1 LLM Groundwater monitoring network

LLM Bore ID	Description	Easting GDA94 Zone 54	Northing GDA94 Zone 54	Surveyed elevation top of casing (mAHD)	Surveyed elevation ground level (mAHD)	Total depth (m)
GW01	EA Reference	297258	7812784	346.9	345.9	70
GW02	Decommissioned	296375	7812249	331.7	331.7	30
GW02a	EA Reference	296372	7812250	331.76	330.91	126
GW03	EA Reference	298760	7813355	320.5	319.9	73
GW04	Decommissioned	298816	7810667	304.8	304.1	65.5
GW04a	EA Compliance	298815	7810670	304.09	303.15	42.8
GW05	Removed from EA	297472	7809978	-	315	38.5
GW06	Removed from EA	297518	7813285	-	344	89.5
GW07	Decommissioned	297943	7813358	331.8	331.6	61
GW07a	EA Compliance	298181	7813222	326.12	325.12	105
GW08	EA Compliance	297017	7811217	316.3	315.6	120
GW09	EA Reference	293773	7814701	311	310.3	90
GW10	Internal monitoring	298707	7814109	328.1	327.4	120
GW11	EA Reference	296393	7813439	342.5	341.9	120
GW12	Internal monitoring	296460	7809836	308.7	308.1	160
GW13	Internal monitoring	295706	7810452	311	310.3	120
GW14	Internal monitoring	296309	7812089	333.4	332.7	73
GW15	Drawdown only	298238	7812164	316.8	316.2	69.9
GW16	Drawdown only	298574	7812908	329.5	328.7	73
GW17	Drawdown only	297914	7810834	307.9	307.5	58.00
GW18	Removed from EA	299022	7814060	-	303	-
GW19	Drawdown only	297936	7811092	310.1	309.3	121.36
GW20	Drawdown only	297375	7809678	303.6	303.2	81.5
GW21	Internal monitoring	297916	7811931	315.9	315.3	-
GW34	Internal monitoring	297936	7812848	-	339	144
GW35	Internal monitoring	298083	7812352	329.3	328.6	74
GW36	Internal monitoring	296728	7811760	324.11	323.18	93
GW37	Internal monitoring	296292	7810890	310.73	309.68	76
GW38	Decommissioned	297724	7811869	-	-	-
GW39	Internal monitoring	298245	7812924	334.18	333.18	50.9
LD01	EA Reference	297824	7812634	332.3	331.6	52
LD02	EA Compliance	297715	7812383	325.6	325	30
LD03	EA Reference	297321	7812193	327.4	326.8	52
LD04	EA Compliance	297661	7811987	319.5	318.7	30
LD05	EA Reference	297050	7812086	328.6	327.9	52
LD06	EA Compliance	296915	7811738	321.7	321	30
LD07	Internal monitoring	297020	7811937	-	361	-

LLM Bore ID	Description	Easting GDA94 Zone 54	Northing GDA94 Zone 54	Surveyed elevation top of casing (mAHD)	Surveyed elevation ground level (mAHD)	Total depth (m)
LD08	Internal monitoring	297017	7811840	-	332	-
LD09	Internal monitoring	296908	7811841	-	304	-
LD10	Internal monitoring	296907	7811928	-	327	-
LD11	Internal monitoring	297591	7812209	-	335	-
LD12	Internal monitoring	297622	7812167	-	336	-
LD13	Internal monitoring	297659	7812095	-	335	-
LD14	Internal monitoring	297596	7811942	-	337	-
LD15	Internal monitoring	297470	7811914	-	351	-
LD16	Internal monitoring	297400	7811912	-	328	-
LD17	Internal monitoring	297759	7812452	-	344	-

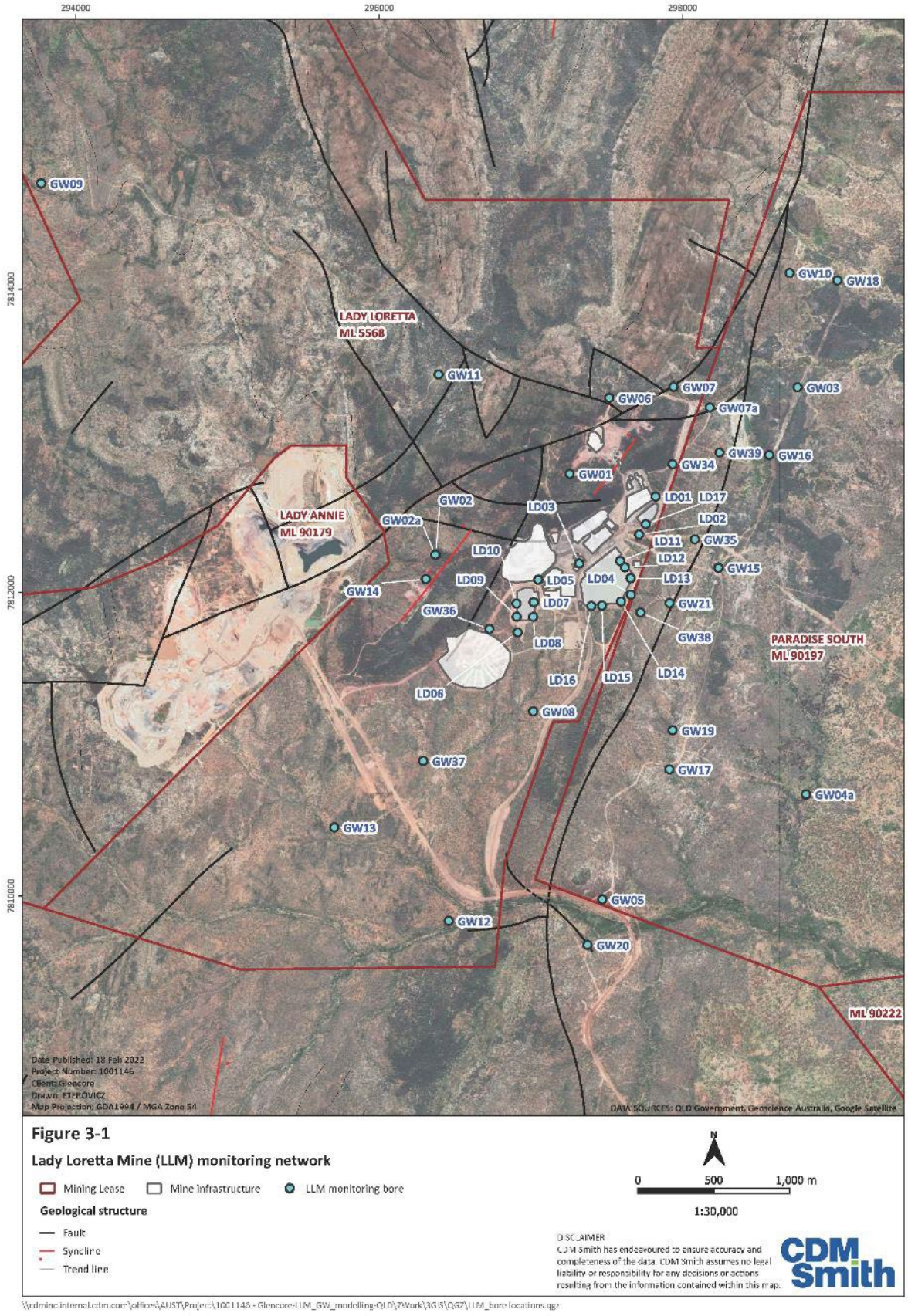


Figure 3-1 Lady Loretta Mine Monitoring Network

3.3 Hydraulic Properties

3.3.1 Paleoproterozoic - Lady Loretta Block

Douglas Partners in 2012 completed a review of the hydrogeological information and data for LLM based on previous investigations as shown in Table 3-2. A summary of the main hydrogeological information is provided below:

- Rock units of the Lady Loretta synclinal structure hosting the orebody are extensively fractured.
- Permeability of the surrounding rock mass outside fracture/fault zones is likely to be low.
- Bulk rock mass hydraulic parameters are estimated to be in the following ranges:
  - Transmissivity 0.2 to 3.0 m^2/day
  - Hydraulic Conductivity 5.0E-04 to 2.0E-02 m/day
  - Storativity 4.5E-04 to 2.0E-03

Table 3-2 Lady Loretta Previous Investigation Permeability Results

Description	Golder Associates (1985, 1986a & 1986b)	Hardcastle & Richards (1987)
Transmissivity (m^2/day)	3.0	0.2 to 0.5
Storativity	4.5E-04	1.0E-03 to 2.0E-03
Hydraulic Conductivity (m/day)	2.0E-02	5.0E-04 to 1.3E-03

AGE (2021) completed slug testing on recently completed monitoring bores, a summary of the results is provided in Table 3-3. The testing was undertaken using a standard technique, where a solid slug was inserted into the bore, resulting in a displaced raised water level. The slug testing program comprised conventional rising and falling head tests and the data was analysed using the Bouwer and Rice method (Bouwer & Rice, 1976) to provide estimates of hydraulic conductivity, which shows the permeability of Lady Loretta Block rocks is generally low ranging from around 9.0E-04 to 2.4E-01 m/day.

Table 3-3 2021 Permeability and Hydraulic Conductivity Results

Bore ID	Hydraulic Conductivity (m/day)	Transmissivity (m^2/day)
GW02a	9.0E-04	
GW07a	1.0E-03	
GW07a	9.0E-04	
GW36	5.0E-03	2.00E-03
GW37	2.4E-01	

3.3.2 Cambrian Block

A literature review completed by AGE in 2020 analysed the data from 25 bores with relevant hydraulic properties (AGE, 2020). Table 3-4 lists hydraulic properties derived from pumping tests for the bores screened in the Cambrian Block. In summary, the hydraulic conductivity values obtained from pumping tests range from 2.46 to 123 m/day.

Table 3-4 Cambrian Block Permeability and Hydraulic Conductivity Results (AGE, 2020)

Bore ID	Rate (L/sec)	Airlift yield (L/sec)	Aquifer thickness[a] (m)	Hydraulic Conductivity[a] (m/day)	Transmissivity [a] (m^2/day)	Storativity [a] (m-1)	Specific storage (m^{-1})
GW17	1.6	1.2 ; 1.0[b]; 0.8[c]	18	123	2,210		
GW18	1.4	1.25[c]					
GW03		1.1	12	2.46	29.5	1.39E-08	
GW10		0.2					
GW15		3	20	55.3	1,110		1.73E-06
GW20		5	18	10.8	194	2.60E-06	

Notes: a All data is from the most recent report by Rob Lait & Associates (2013), unless otherwise noted.
b Douglas Partners (2007).
c obtained from bore report for bore RN 146130.

3.3.3 Paleoproterozoic Block

There is minimal hydrostratigraphic information and permeability data for the Paleoproterozoic Block located west of the Carlton Fault. Yield data obtained from the Queensland groundwater database of registered bores indicates air lift yields range from 0.1 to 2.2 L/sec as shown in Table 3-5. The bore log lithology descriptions are similar to the Lady Loretta Formation and the fractured rock is likely to have variable permeability. Representative values of hydraulic conductivity and specific yield are 8.0E-04 m/day and 12%, respectively based on siltstone (Domenico and Schwartz, 1990 and Morris and Johnson, 1967).

Table 3-5 Queensland Groundwater Database - Reported Bore Yields

QLD RN Bore ID	LLM Monitoring Bore	Air Lift Yield	Bore Log Listed Formation
146844	GW11	0.10 L/sec at 47 m 0.10 L/sec at 54 m 0.20 L/sec at 73 m	Paradise Creek Formation
146847	GW09	0.10 L/sec at 36 m 0.20 L/sec at 68 m 2.20 L/sec at 76 m	Paradise Creek Formation

3.4 Groundwater Heads and Flow Direction

3.4.1 Lady Loretta Block

Groundwater head data is available for the Lady Loretta Block bores from August 2013 to July 2021. The groundwater head elevations typically show a declining trend (Figure 3-2). The groundwater monitoring data shows there are variable drawdown rates within the bores over the monitoring period. The highest decline rate is recorded at bore GW13 at 1.5 m/year and GW7, GW8 and GW12 at approximately 0.6 m/year. The lowest decline rate is recorded at bore GW14 at approximately 0.1 m/year and minimal change at GW34 at approximately 0.07 m/year.

Higher elevation areas in the north have higher hydraulic heads for example GW6 and GW7 while lower elevation areas typically have lower hydraulic heads; for example GW8, GW12 and GW13, indicating the natural (pre-mine) groundwater flow direction is inferred as south towards Desert Creek consistent with ephemeral drainage lines and topography. However, the pre-mine groundwater flow field has been altered due to mine dewatering, and flow direction is now generally towards the LLM underground workings. Considering the reported GW14 groundwater heads, which is located between the LLM and the Lady Annie mine pit, there does not appear to be significant dewatering interference between the two mines.

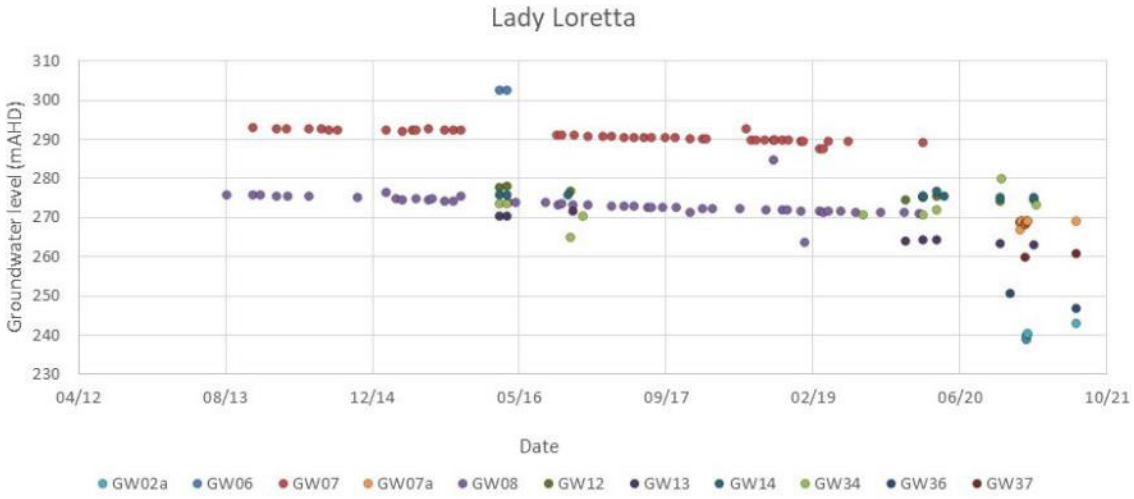


Figure 3-2 Lady Loretta Block Groundwater Heads

3.4.2 Cambrian Block

Groundwater head data is available for the Cambrian Block bores from July 2013 to March 2021 (Figure 3-3). All the groundwater monitoring bores show a declining groundwater level trend over the monitoring period. The groundwater heads are approximately 269 to 273 mAHD, with the lowest at GW15 at approximately 268.5 mAHD (possibly in response to pumping from GW15). There are no obvious seasonal recharge responses to annual rainfall evident in the groundwater heads and there is a visible rate of groundwater decline since 2018, despite an increasing slope in CDFM data for the same period.

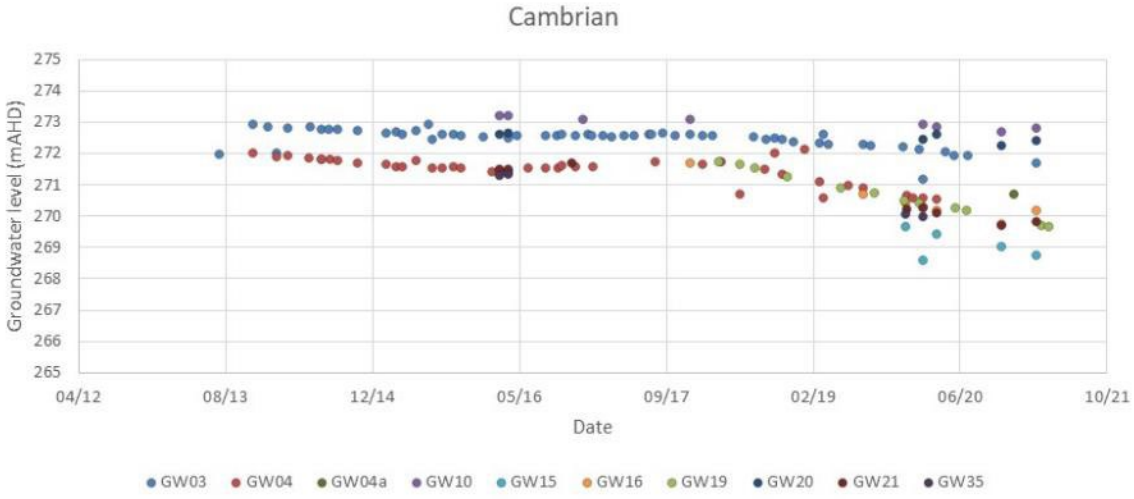


Figure 3-3 Cambrian Block Groundwater Heads

Table 3-6 shows groundwater head statistics and Figure 3-4 shows the average groundwater head over the monitoring period. Groundwater head decline is greatest at monitoring bore GW15. The groundwater heads show a drawdown and flow direction towards the monitoring bore GW15 from the north and south. The groundwater decline is likely to be attributed in part to the LAE borefield. Whilst there is little west to east spread of water head datapoints, the available initial/earliest data suggests the natural (pre-mine) groundwater flow direction inferred as east, consistent with ephemeral drainage lines and topography.

Table 3-6 Groundwater Head Statistics

Bore ID	Minimum Head mAHD	Mean Head mAHD	Maximum Head mAHD	Count
GW10	272.7	273.0	273.2	8.0
GW03	271.2	273.3	319.9	57.0
GW16	269.7	270.6	271.7	9.0
GW15	268.6	269.7	271.4	7.0
GW21	269.7	270.6	271.7	8.0
GW19	269.7	270.7	271.7	12.0
GW04	270.5	271.5	272.1	41.0
GW20	272.3	272.5	272.6	6.0

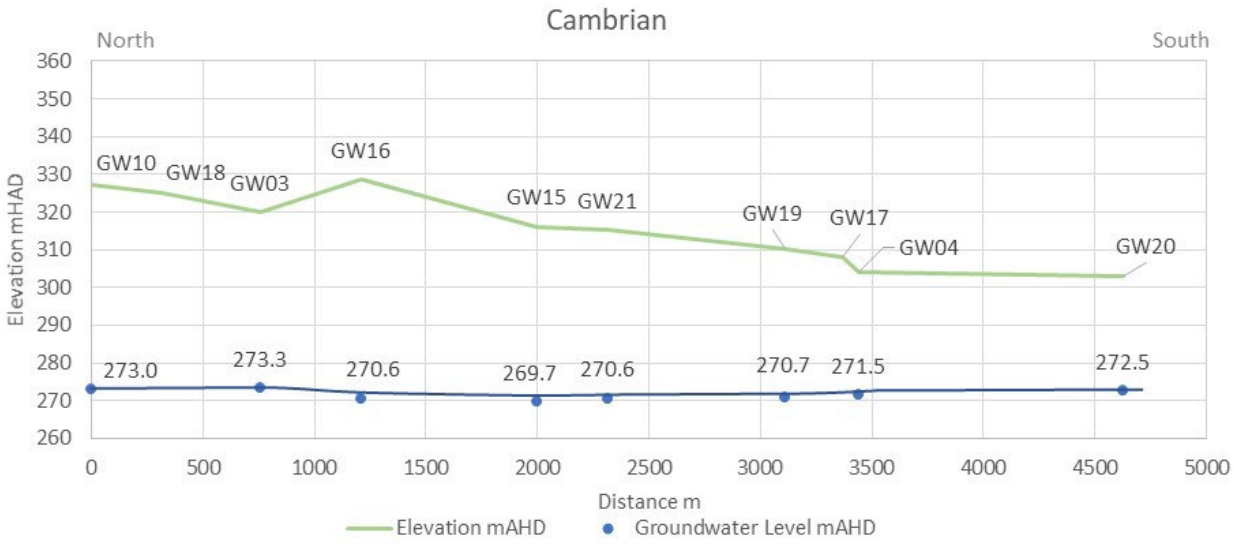


Figure 3-4 Cambrian Block Average Groundwater Heads

3.4.3 Paleoproterozoic Block

There are two groundwater monitoring bores located in the Paleoproterozoic Block west of LLM and the Carlton Fault (Figure 3-5). The groundwater level measurements over the monitoring period are relatively consistent and show minor change since 2013 despite a variable slope in CDFM data for the same period and no evident recharge response to rainfall. Bore GW11 is located greater than 1 kilometre from LLM and GW09 greater than 4 kilometres. The natural (pre-mine) groundwater flow direction is inferred as west based on the topography and groundwater head data for bores GW09 and GW11.

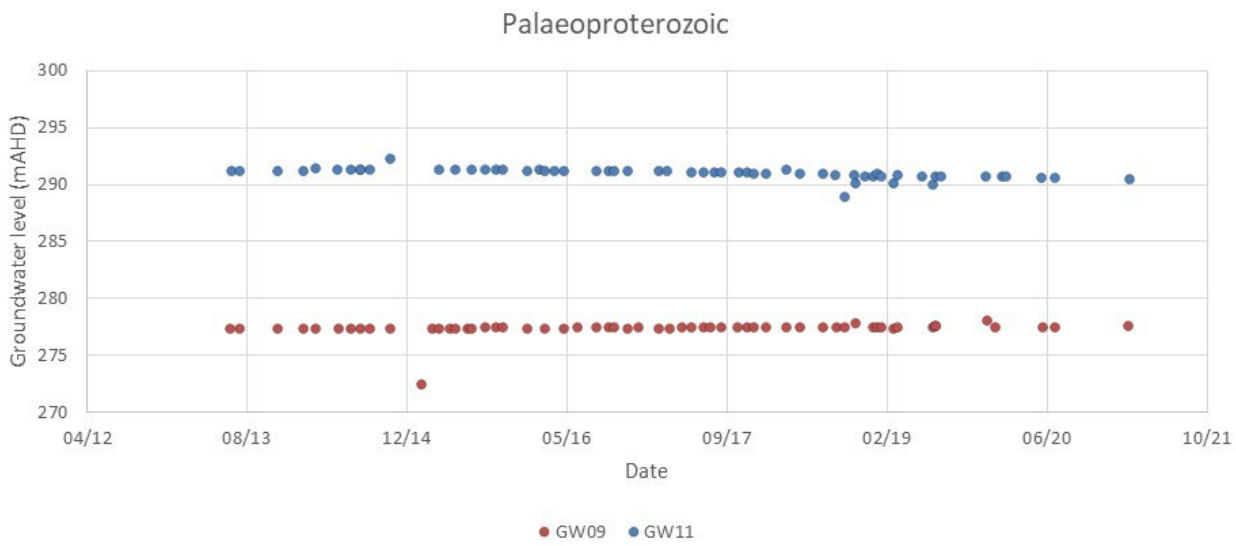


Figure 3-5 Paleoproterozoic Block Groundwater Heads

3.5 Groundwater Potentiometric Contours

Figure 3-6 shows the average observed groundwater heads and interpreted head contours based on monitoring bore data for the project area. Shown inferred contour lines are drawn by hand without sophisticated software and are not representative of calculated fault permeability or behaviour. The observed groundwater heads to the east of the Western Border fault show a minimum of 269.7 mAHD in GW15 and a maximum elevation of 273.3 mAHD in GW03. All the other monitoring bores located to the east of the fault show groundwater heads within this range.

Carlton and Western Border Faults are expected to exert a major control on groundwater flow fields, with groundwater contours also influenced by drawdowns that develop in response to mine dewatering and borefield production. Because of these influences it is not possible to clearly attribute groundwater contours to specific fault controls, so a quantification of the specific influence of faults cannot be made at this time. However, there is a hydraulic gradient towards the LAE borefield and to the LLM site. Overall, on the Lady Loretta Block there is evidence of localised groundwater flow towards LLM due to dewatering within the underground mine workings, a cone of depression has developed, drawing groundwater toward the central part of the site operations. The cone of depression extends south to south-west along the axis of the syncline, toward bore GW13 and there is minimal depressurisation evident in the west around GW14. This contour assessment is considered further as part of the reconceptualisation presented in Section 4.

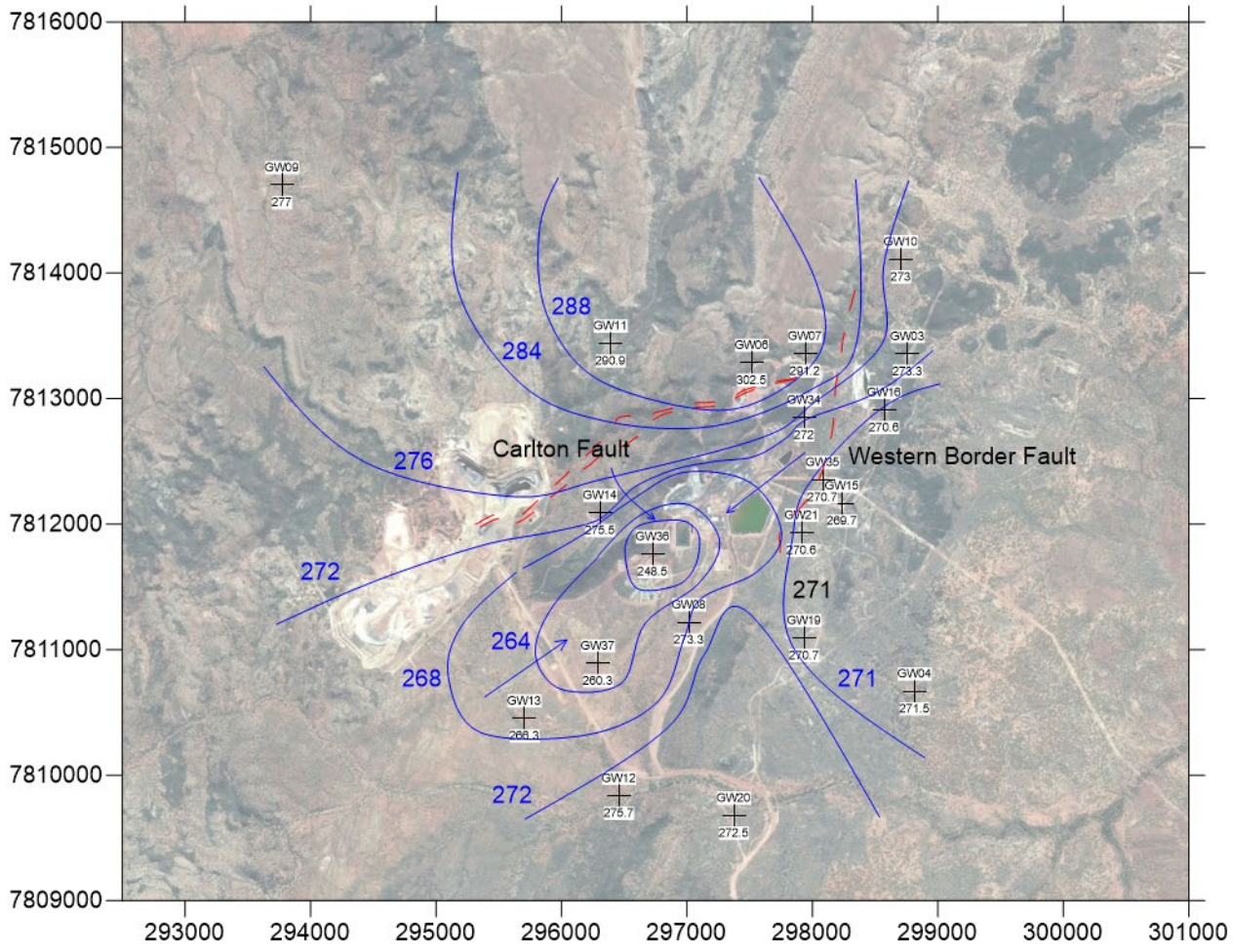


Figure 3-6 **Average Observed Groundwater Levels and Contours (mapped fault locations cannot assumed to be exact or precise)**

3.6 Groundwater Quality

Proportional abundances of major cations and anions are shown on the piper diagram Figure 3-7 for monitoring bores across the site. Piper Plots explain the classification type of water facies on the basis of its interaction with rock and soil minerals. The diamond plot at the centre is a blend of two trilinear plots on the two sides of the diamond. Different quadrants of the diamond show the different type of water on the basis of ion concentration dominance.

Based on the Piper Plot all formations have calcium-bicarbonate dominated groundwater except for the Paleoproterozoic Block, which has calcium-chloride dominated groundwater in some locations. The Paleoproterozoic Block bores located furthest from the LLM to the north-west indicates calcium as the dominant cation and chloride as the dominant anion. Groundwater with calcium as the dominant cation and bicarbonate the dominant anion is typically consistent across the site.

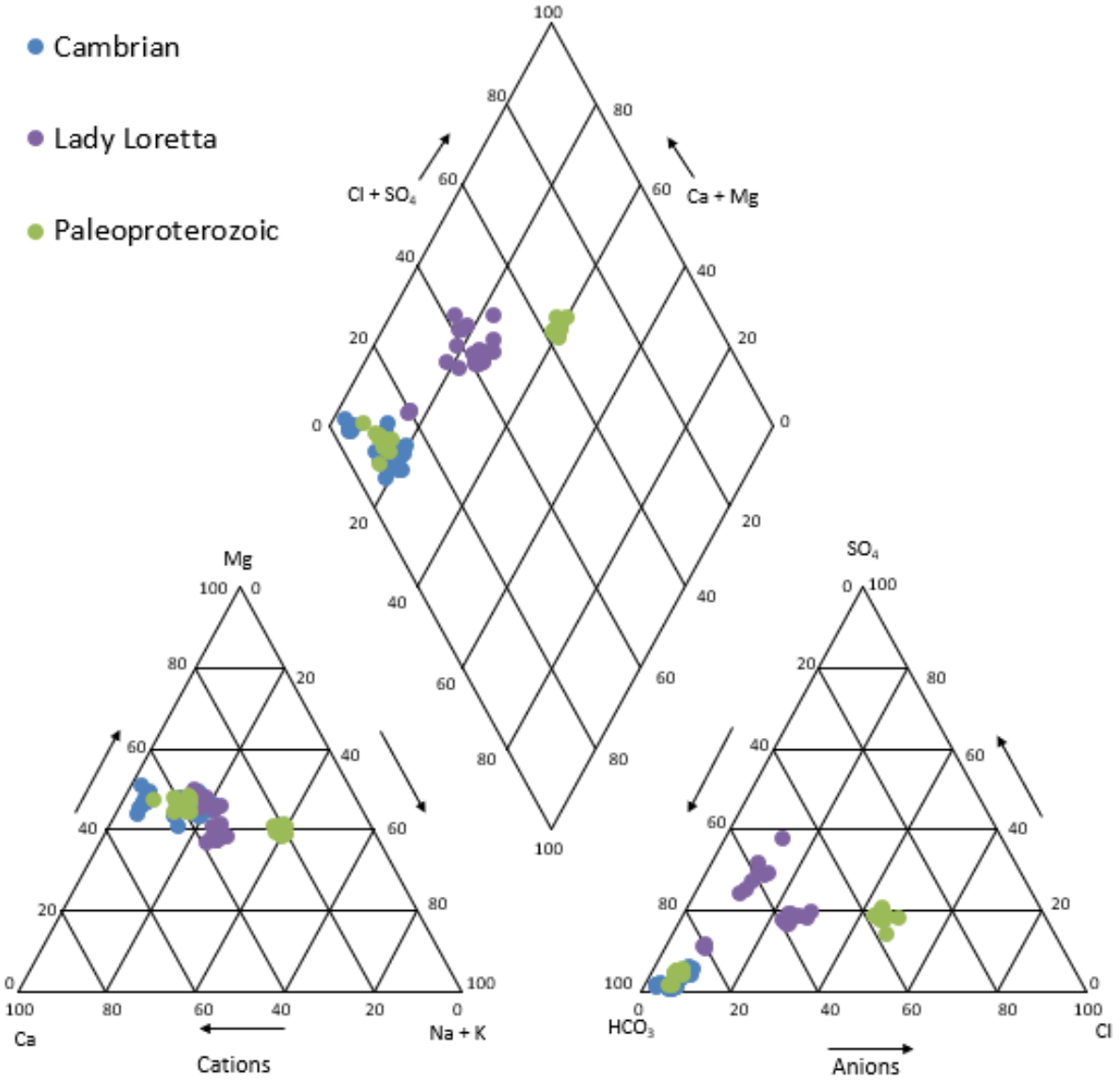


Figure 3-7 Piper Diagram for all Selected Groundwater Samples

The cations versus chloride proportional abundances are shown in Figure 3-8 for monitoring bores across the site. Based on Figure 3-8 the cations versus chloride plots indicate that groundwaters are similar. All formations have calcium -bicarbonate dominated groundwater except for monitoring bore GW09, which has calcium-chloride dominated groundwater. GW09 located furthest from the LLM to the north-west shows calcium as the dominant cation and chloride as the dominant anion.

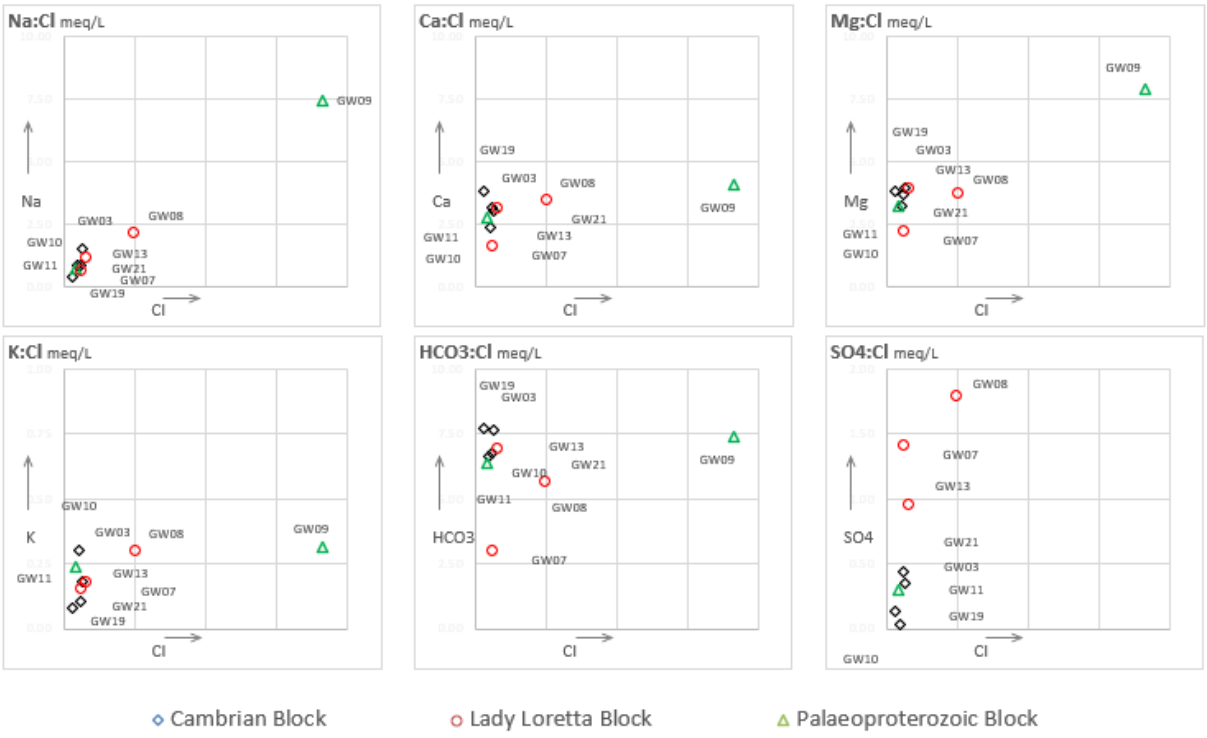


Figure 3-8 Major Ion and Chloride Ratio Plots for Selected Groundwater Samples

Figure 3-9 to Figure 3-11 show electric conductivity (EC) for monitoring bores across the site. The groundwater samples indicate EC values of less than 1000 µS/cm, with the exception of GW09 which reports an EC of almost 2000 µS/cm. Notably, the bores located on the eastern and western side of the Carlton Fault and Western Border Fault show comparable EC values.

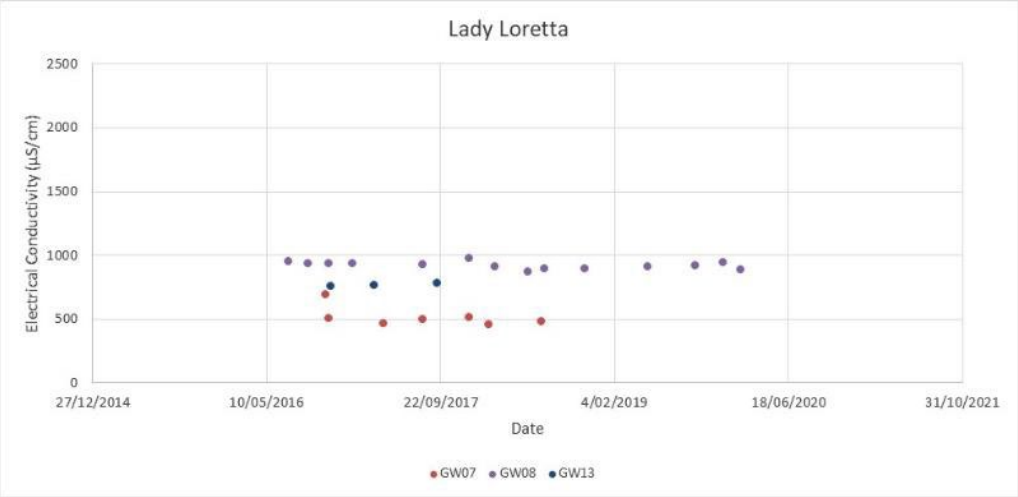


Figure 3-9 Lady Loretta Block EC

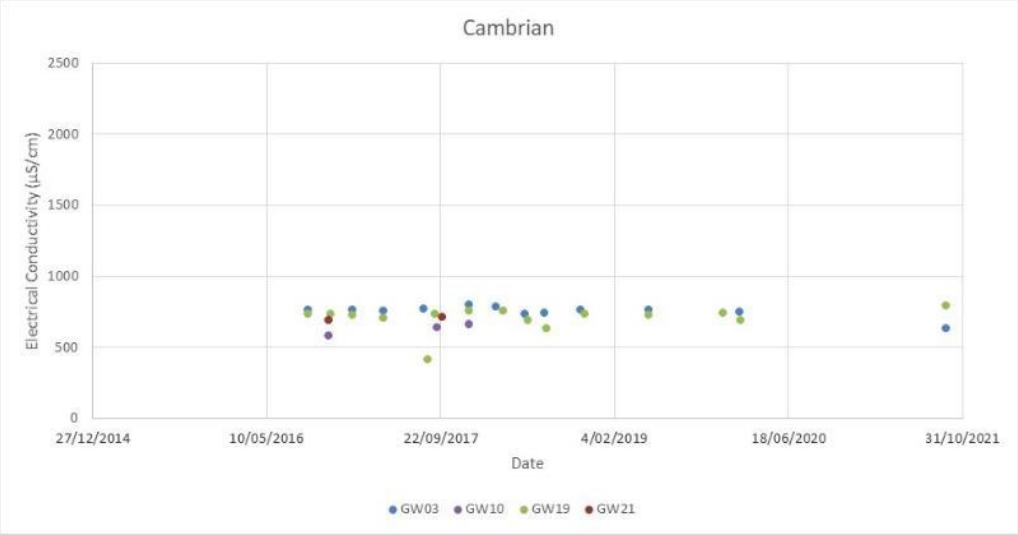


Figure 3-10 Cambrian Block EC

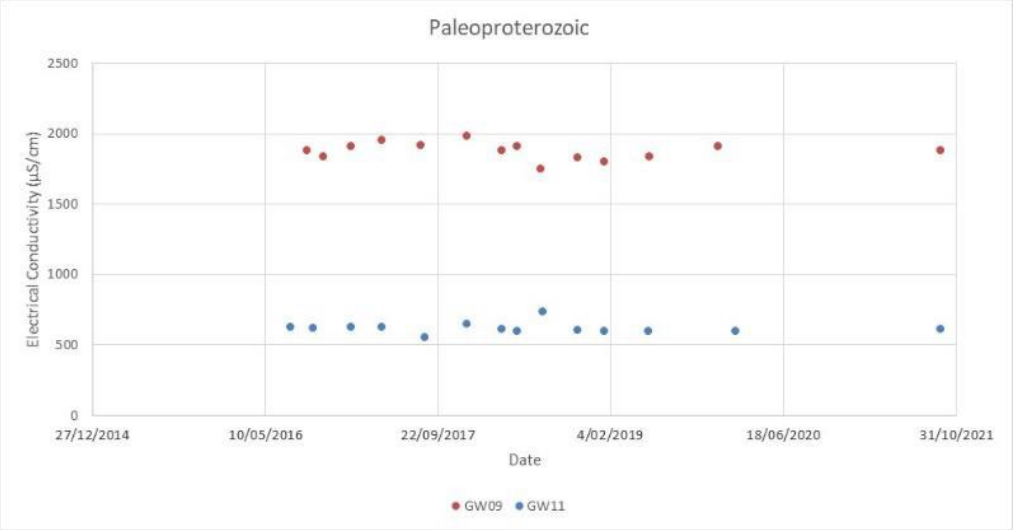


Figure 3-11 Paleoproterozoic Block EC

3.6.1 Hydrochemistry Assessment

Salient Solutions Pty Ltd completed an assessment of the hydrochemistry of the groundwater in and around LLM as an independent constraint on the site conceptualisation (Appendix A). The assessment used cations and anion chemistry together with water quality parameters to:

- Assess possible fault fracture groundwater connectivity between the Cambrian, Lady Loretta and Proterozoic blocks through application of hydrochemical analysis.
- Potentially evaluate the degree of connectivity/permeability between the blocks through the fault network that could be inferred by the hydrochemistry assessment findings.
- Evaluate the findings of the assessment relative to the other work scopes, and establish if the hydrochemistry of the site supports the understanding of groundwater flows at the site.

The following subsections summarises the findings (Appendix A: Evans, 2022).

3.6.1.1 LLM Blocks

Two primary potential sources of chemical constituents measured in the groundwater in the region of LLM are considered:

- The first is from salts depositing either via rainfall or via dryfall (dust) mechanisms.
- The second is associated with mineral dissolution, both under natural conditions and under conditions imposed due to mining activities.

Groundwater in the Lady Loretta Block is considered oxidised to mildly reducing. This suggests that the sulphidic mineralisation has the potential to be oxidised as groundwater flows through the strata. Dewatering associated with mining operations has induced hydraulic gradients towards the mine, and this has meant that there is a greater supply of oxidised groundwater available for oxidation processes. Conversely, samples from GW08 show that under near natural conditions, the groundwater can become mildly reduced.

The chloride concentration in groundwater across the site indicates locally differing recharge rates within the block, and these concentrations are preserved, indicating a degree of compartmentalisation within the Lady Loretta Block. This compartmentalisation via chloride concentrations can also be seen in the Proterozoic Block, indicating this compartmentalisation occurs at a regional scale within blocks, and is not unique to Lady Loretta. The sulphate findings at Lady Loretta also suggest compartmentalisation as well as informing the distribution of sulphidic mineralisation within the bedrock and indicate that sulphur is being contributed to the groundwater from mineral dissolution (or oxidation) processes (as discussed above) and this could be considered compartmentalised in the vicinity of the underground workings. This intra-block compartmentalisation, particularly in the vicinity of the underground workings is a key finding in relation to closure planning.

There are differences between the metal concentrations recorded in samples collected of the underground groundwater versus regional groundwater samples:

- Arsenic generally is at higher concentrations in the regional water and is mostly non-detectable in the underground seepage of groundwater.
- Lead concentrations are low, but there are detectable levels in all samples whereas lead is mostly below detection limits in the regional groundwater.
- Molybdenum and cadmium concentrations are essentially at the same levels between the two groundwaters (underground seepage versus regional groundwater).
- Cobalt, nickel and zinc are at much higher levels in the underground seepage of groundwater when compared to the more regional groundwater, with zinc being 20 to 50 times higher.

- Regional groundwaters (that is, groundwater outside of the influence of direct impacts of mining) show background levels of some metals that are well above detection limits, confirming that natural weathering processes in metalliferous terrains produce higher than usual background metal contents. The occurrence of a large number of outliers in the metals data for the Lady Loretta Block and the Proterozoic Block also supports the hypothesis that groundwater in these two Blocks can be compartmentalised, that is, they are not well-mixed.

3.6.1.2 Regional Conclusions

From a regional perspective there is little evidence from the water quality study to support broad scale mixing between groundwaters from different geological blocks in the vicinity of LLM, considering the results of the major ion chemistry assessment. The chemical types of the Cambrian Block groundwater are sufficiently different from those in the groundwater of the Lady Loretta Block to indicate that if flow across the Western Boundary Fault is possible, it is of a small magnitude. Alternatively, the hydrochemical advective "front" of Cambrian Block groundwater chemistry has not had sufficient time to reach the groundwater monitoring locations and analysed. Differing concentration of metals further emphasises the difference between groundwater in the Cambrian Block compared to groundwater from the other Blocks.

3.7 Groundwater Recharge and Discharge

3.7.1 Groundwater Recharge

Recharge to the groundwater system is likely to occur through rainfall infiltration. The recharge rate is expected to vary spatially across the project area and is highly likely to be related to lithology type (AGE, 2020) and the degree to which outcrop occurs. The rate of rainfall infiltration is likely to be low, due to the climate setting where evaporation rates are higher than rainfall rates across the seasons. Estimates of recharge between 1 to 5 % of rainfall are typical in this type of environment (AGE, 2020), consistent with the fresh-brackish levels of salinity. The Thorntonia Limestone is identified as the most likely pathway for groundwater recharge into the aquifers and formations targeted by the LAE Borefield (AGE, 2015). Douglas Partners (2007) also state that recharge is likely to be enhanced in proximity to the Western Border Fault due to increased fracturing along this structural feature.

3.7.2 Groundwater Discharge

The major discharge from LLM is inflow to the underground mine workings. Regional aquifer through-flow is also considered a discharge mechanism for the Cambrian Block groundwater system in the study area, with groundwater flow inferred to be toward the east.

3.7.2.1 Mine Discharge

Douglas Partners in 2012 completed a hydrogeological assessment to determine likely inflows to LLM underground workings. The analysis undertaken provided the data listed in Table 3-7.

Table 3-7 Mine Groundwater Inflows

Description	Inflow L/sec
Mine areas and crosscuts	5
Development drives	10 to 20
The decline	10
High volume, short term inflows from intersected faults and old boreholes	Unknown
Total inflows to the Lady Loretta mine	25 to 35

AGE in 2020 estimated that the typical recorded groundwater inflow to the underground workings during care and maintenance was approximately 8 L/sec. During operations, the volume of water pumped from the mine reaches approximately 15 L/sec (AGE, 2020), which includes around 7 L/sec of water introduced to the mine from the surface.

Total mine inflow estimates range from 8 to 35 L/sec, dependant on the mining activities and geology intersected.

3.7.2.2 LAE Production

There are three production bores called GW15, GW17 and GW18. The annual average extraction rate of raw water from the LAE borefield is 766 ML per year, which equates on average to approximately 24 L/sec (LLM, 2021b). There are no known landholders in the area that extract groundwater from groundwater bores.

Section 4 Hydrogeological Conceptualisation

4.1 AGE Conceptualisations 2015 and 2020

4.1.1 AGE Previous Conceptual Models and Fault Behaviour

Previous hydrogeological conceptualisation studies were completed by Australian Groundwater and Environment (AGE) in 2015 (AGE,2015) and 2020 (AGE,2020). It has been observed that the AGE 2015 and 2020 conceptual models demonstrated an evolution of conceptual thinking, with differences in terms of fault barrier conceptualisation and groundwater flow or movement between the two models identified.

AGE in 2015 updated the LLM numerical groundwater model to incorporate the mine development and associated dewatering, and the model calibration was updated from a steady state solution to a transient calibration. The following observations were noted in the AGE 2015 report in relation to the groundwater conceptualisation of the Western Border Fault (AGE, 2015).

- *The bores located on the eastern and western side of the fault show comparable EC values which confirms that the fault is unlikely act as a barrier to groundwater flow.*
- *The bores located immediately west of the fault record groundwater levels between 271 mAHD (GW35) and 280 mAHD (GW12). These bores show marginally higher groundwater levels in comparison to groundwater levels to the east of the fault. Therefore, while the fault appears to separate the groundwater system into two zones, the hydraulic disconnect between the two zones is not significant.*

The AGE 2015 numerical model defined the hydraulic parameter for the Carlton and Western Border Fault as a horizontal permeability or hydraulic conductivity value of 0.02 m/day illustrating that AGE considered this a barrier.

AGE in 2020 updated and renewed only the groundwater conceptual model, with no numerical model works completed. The following points are summarised from the AGE 2020 report.

- *The hydraulic gradients and temporal trends reinforced the conceptualisation that the Western Border Fault acts as a barrier to flow.*
- *The Palaeoproterozoic Block was separated from the Lady Loretta Block by the Carlton Fault, with lithological and hydraulic evidence indicating that the fault acts as a barrier to hydraulic connection between the two zones.*
- *The groundwater quality for the Cambrian block shows no indications of mixing with source waters from LLM. This observation fits with the understanding of the Western Border Fault acting as a barrier to flow.*
- *The Western Border Fault acts as a barrier to groundwater flow, and there is negligible interference between the Lady Loretta Block and the Cambrian Block.*

4.1.2 Review of AGE Conceptualisation

The AGE 2020 concept of barrier to flow is shown below where there is nearly no flow across faults (Figure 4-1).

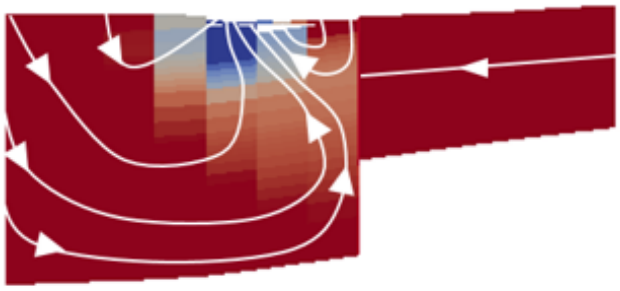


Figure 4-1 Cross Section of Barrier Fault Flow Lines (McCallum et al., 2018)

Faults can broadly exhibit three behaviours in a fluid flow context these behaviours are (Figure 4-2):

- A barrier to both along and across fault flow.
- A conduit to both along and across fault flow.
- A conduit to along fault flow and a barrier to across fault flow.

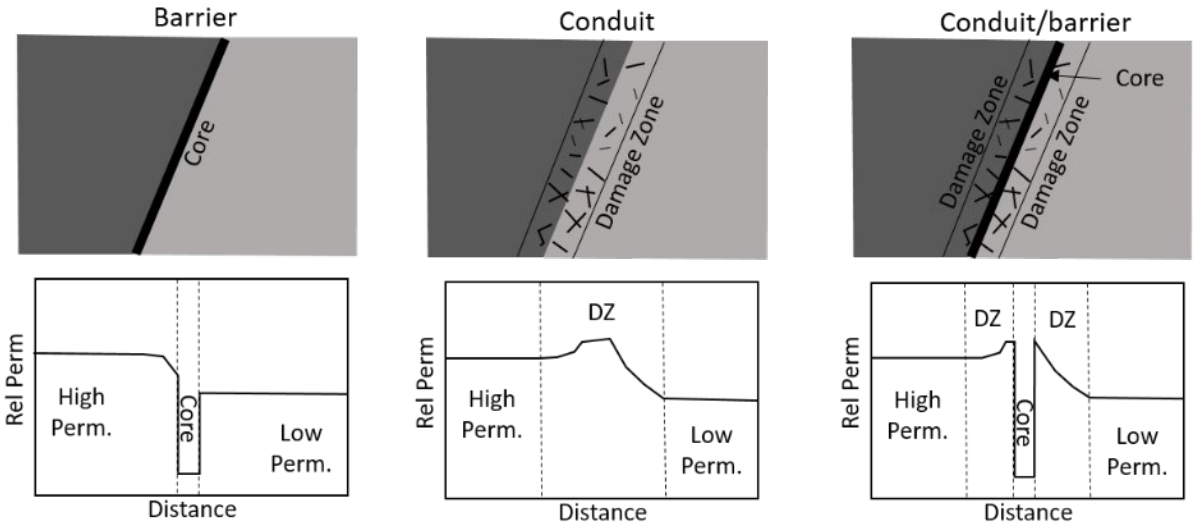


Figure 4-2 Three Conceptual Models of how Fault Zones Impact Fluid Flow Properties (McCallum et al., 2018)

Ideally, to represent the faults within the context of the conceptual conduit-barrier system, details of the physical characteristics of the fault zones need to be represented. This includes the widths and permeabilities of the fault core and the damage zone (McCallum et al., 2018). There are insufficient site data or information to inform fault permeabilities and determine the fault behaviour to groundwater flow. Ideally, a site field and data collection program (possibly including groundwater isotopic studies) would inform the fault behaviour and this information would inform the regional numerical model.

However, since this conceptualisation and parameterisation is not possible based on the available information and data, it is necessary to test each of the possibilities in a sensitivity analysis or calibration exercise. It is important that each of the three scenarios is tested in the numerical analysis to consider the likely fault behaviour. The use of the recently developed modelling technique PESTPP-IES (White, 2018) that can run numerical groundwater models stochastically in a highly efficient manner will be used to assess the knowledge gap for the hydraulic properties of the faults and fault behaviour.

4.1.3 Re-conceptualisation of Study Area Hydrogeological Interactions

A simplified revised conceptual cross section is shown in Figure 4-3 based on the available hydrogeological information and assessment works completed above.

Key features of the hydrogeological conceptualisation are as follows:

- The Western Border Fault divides the LLM sulphide ore bearing zone from the less deformed Cambrian Block to the east, while the Carlton Fault separates the Lady Loretta Block from the Paleoproterozoic Block to the west. There is no Cambrian block to the west of Western Fault.
- The major Carlton Fault Zone truncates the syncline to the north-west. The Carlton Fault is associated with extensive zones (up to 200m wide) of shearing and brecciation.
- The major faults (Carlton Fault and Western Border Fault) are considered to exert a major control on flow patterns in the topography driven and structurally controlled hydrogeological system. However, it is difficult to different fault control on flow given other influences on groundwater flow at this time (e.g mine dewatering).
- The natural groundwater flow direction is likely structurally controlled in an unstressed environment and is assumed to follow the ephemeral drainage lines and site topography.
- The groundwater head decline is likely to be attributed to both the LAE borefield (Cambrian Block) and mining activities (Lady Loretta Block). Constant groundwater inflow rate to underground workings is about 252 ML/year and the annual average extraction rate of raw water from the LAE Borefield is 766 ML per year.
- A hydraulic gradient towards the LAE borefield and to the LLM site has been identified. Overall, on the Lady Loretta Block there is evidence of localised groundwater flow towards LLM due to dewatering within the underground mine workings - a cone of depression has developed, drawing groundwater toward the central part of the site operations.
- Cambrian Block hydrostratigraphy hydraulic conductivity values range from 2.5 to 123 m/day, whilst Lady Loretta Block hydrostratigraphy permeability values are low ranging from around 0.001 to 0.25 m/day. There is minimal hydrostratigraphy information and permeability data for the Paleoproterozoic Block and representative values for the lithology are likely in the range 0.001 m/day. Regardless of the hydraulic properties of the Western Boundary Fault, the hydraulic conductivity contrast between the Cambrian and Lady Loretta Blocks will influence the distribution of hydraulic gradients across the fault.
- The chloride concentration in groundwater across the site indicates locally differing recharge rates within the block, and these concentrations are preserved, indicating a degree of flow compartmentalisation within the Lady Loretta Block at least. The intra-block compartmentalisation seen in the Lady Loretta Block is also exhibited in the Proterozoic Block, showing this intra-block compartmentalisation is not unique to Lady Loretta and is occurring at a regional scale (Appendix A: Evans, 2022).
- From a regional perspective there is little evidence to support broad scale mixing between groundwaters from different geological blocks in the vicinity of LLM considering the results of the major ion chemistry assessment completed. The chemical types of the Cambrian Block groundwater are sufficiently different from those in the groundwater of the Lady Loretta Block to indicate that if flow across the Western Boundary Fault is possible, it is of a small magnitude. Alternatively, the advective hydrochemical “front” of Cambrian Block groundwater has not had sufficient time to reach the observation points and be sampled.
- There does not appear to be substantial drawdown or water head differences across the Carlton Fault.
- There is insufficient data to definitively determine how the faults may influence fluid flow based on the desktop assessment works completed (considering active dewatering in the study area). However, numerical modelling approaches are to be used to further assess fault behaviour.

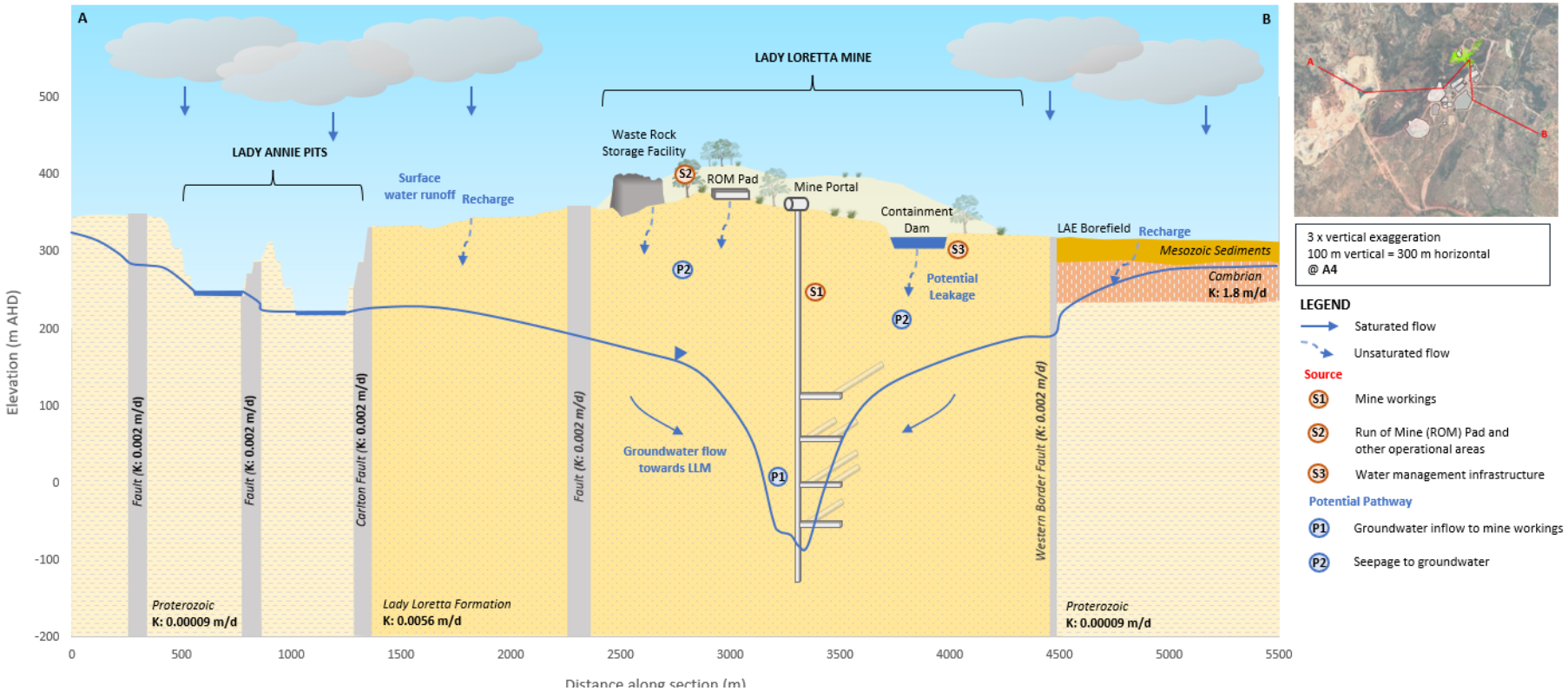


Figure 4-3 Conceptual Hydrogeological Model Schematic – Operating Mine

Section 5 Numerical Groundwater Modelling

Following the revision of the conceptual hydrogeological model this project involves the development of a numerical groundwater model for the prediction of groundwater system response to cessation of mining, and to assist in understanding the potential fate of CoCs during and after groundwater recovery. The overall objective of the numerical model is to assist in the development and implementation of an appropriate closure monitoring network and groundwater monitoring program.

This section focuses on groundwater flow modelling for assessing an after-closure scenario considering the updated conceptualisation for the site and surrounds. Section 7 describes the solute transport modelling that was undertaken to assess and map the potential fate of identified CoCs sourced from LLM operations.

The original LLM groundwater model (AGE, 2013; AGE, 2015) was used as a basis for representing the updated hydrogeological conceptualisation described in the earlier sections of this report. The updated LLM groundwater model is referred to as the LLM2021 model herein.

5.1 Model Objective

The objective of the LLM2021 groundwater flow model is to:

- Assess groundwater flow fields during mining operation, closure recovery and long-term new quasi-equilibrium.
- Estimate groundwater flux to the underground workings over time after the cessation of mining.

The potential transport and fate of CoCs during and after groundwater recovery is assessed using solute transport modelling (Section 7).

5.2 Model Construction

The LLM2021 groundwater model was upgraded from the original model (AGE, 2015) with the latest hydrogeological conceptualisations as reported in the earlier sections of this report. This section highlights the key changes that have been made to the model for this scope. In addition, a brief description of model settings that remain unchanged from the original model (AGE, 2015) is provided herein for completeness.

5.2.1 Numerical Code

The original groundwater model (AGE, 2015) was developed in MODFLOW-SURFACT (Panday and Huyakorn, 2008), a legacy numerical code that is gradually being phased out and replaced by MODFLOW-USG (Panday et al., 2013). MODFLOW-USG inherits most, if not all, capabilities from MODFLOW-SURFACT and is freely available and well maintained by the United States Geological Survey (USGS).

MODFLOW-USG was selected as the numerical code for the development of the LLM2021 groundwater flow model. Groundwater Vistas version 8 (ESI, 2020) and the Python module FloPy (Bakker et al., 2016) were used for the pre- and post-processing of model data.

5.2.2 Spatial Discretisation

The LLM2021 model domain (Figure 5-1) and grid (Figure 5-2) are consistent with the original model (AGE, 2015). The model domain was discretised into rectangular cells comprising 661 rows and 297 columns. There are 196,317 cells in each layer with the cell dimension varying from 10 x 10 m covering the LLM site and LAE borefield to 100 x 100 m outside the area of interest. The model grid was rotated from north 20 degrees to the east to align the cells parallel to the LAE borefield that is consistent with the principal groundwater flow direction.

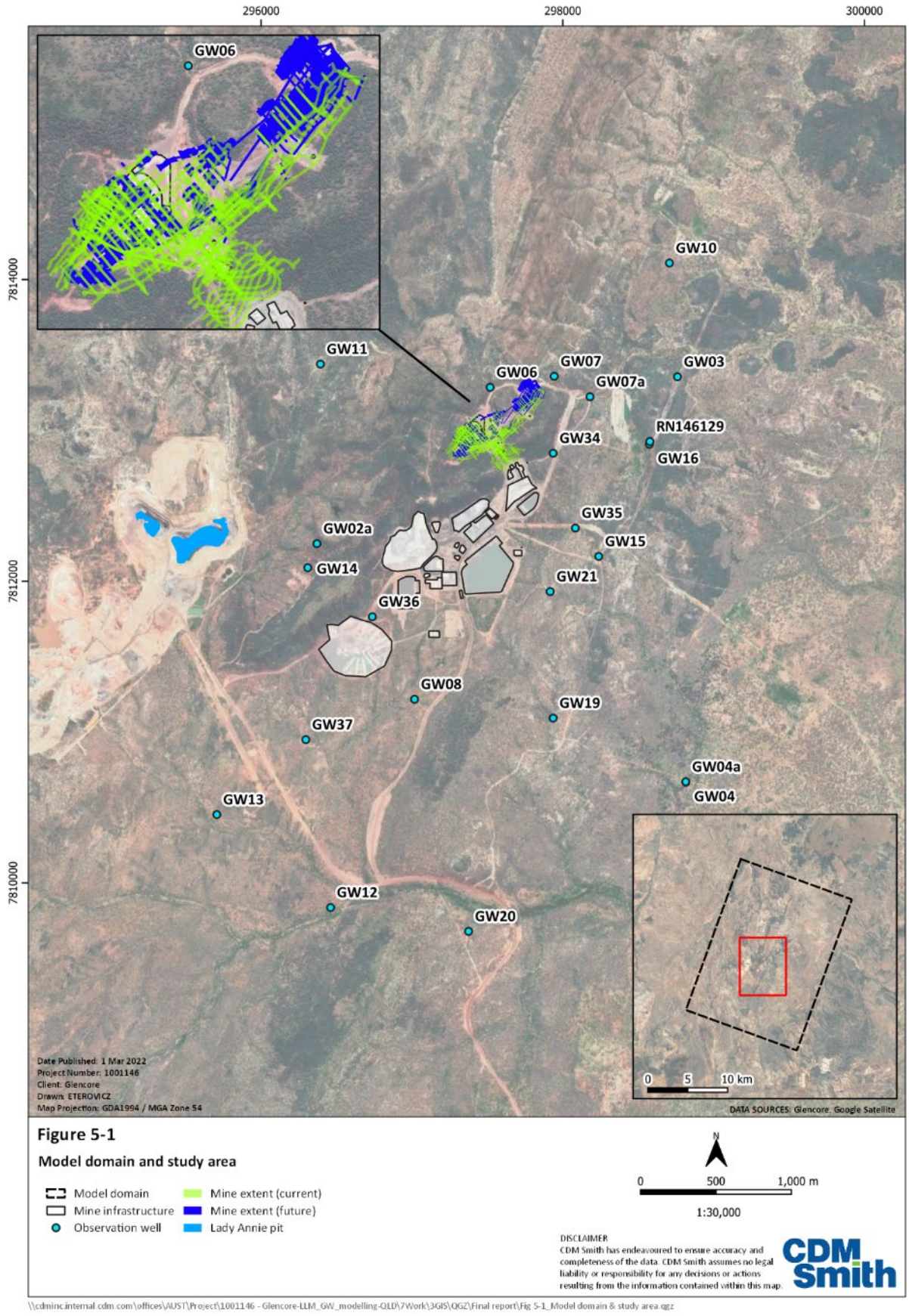


Figure 5-1 Model Domain and Study Area

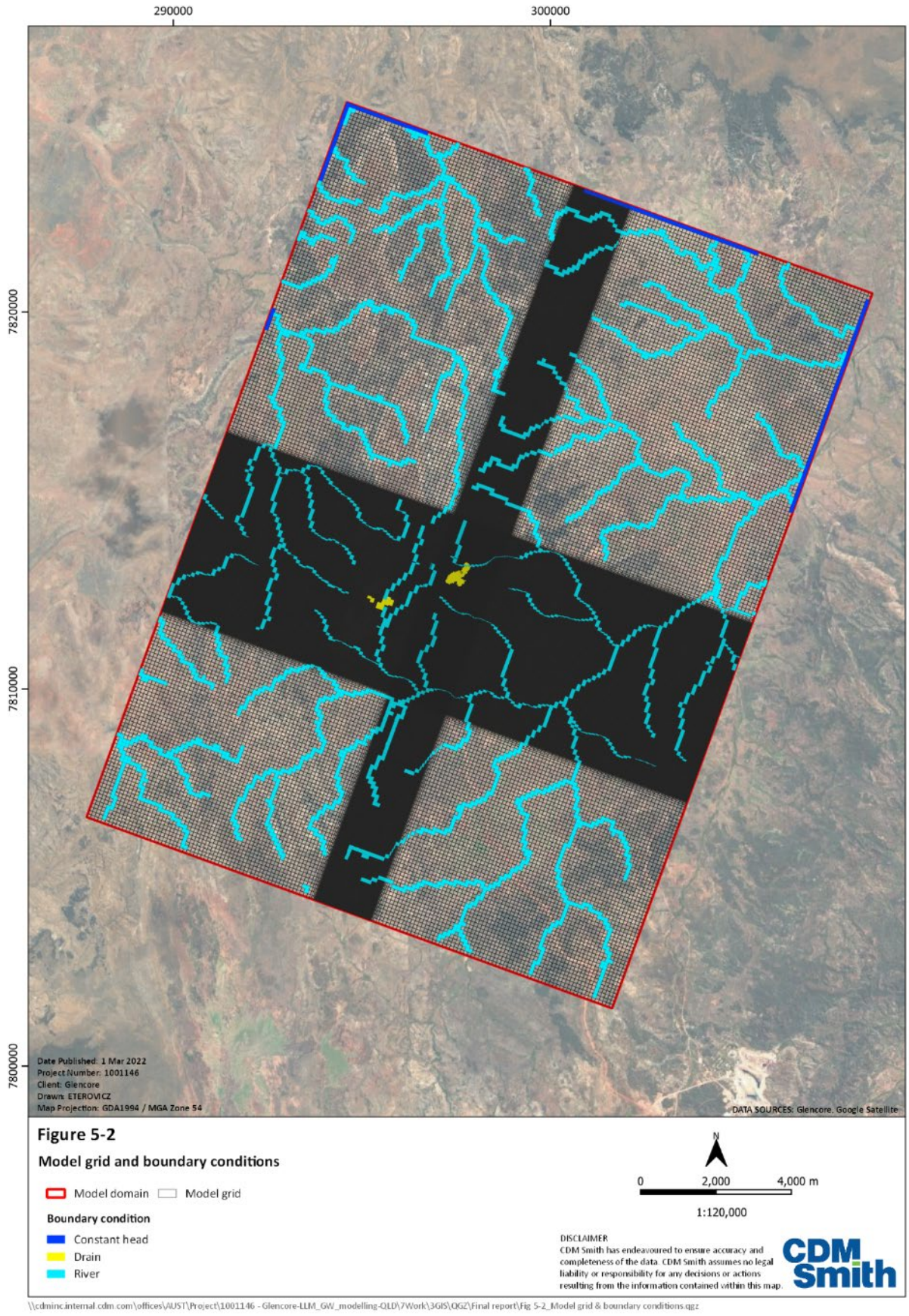


Figure 5-2 Model Grid and Boundary Conditions

The total model extent is approximately 20 km in the northeast and southwest direction and approximately 15 km wide in the northwest to southeast direction, covering an area of approximately 300 km².

5.2.3 Model Layers and Elevation Surfaces

The original groundwater model (AGE, 2015) has six layers with the bottom layer completely inactivated. As the numerical code does not compute groundwater level for inactive cells, this inactive layer was removed from the LLM2021 model to enhance the model agility (i.e. reduce model file size and hence processing time), resulting in a total of five model layers.

As part of this work, we attempted to use the existing geological Leapfrog model to set the elevation surfaces for the LLM2021 model. However, this was found to not be feasible due to missing data (i.e. the geological block to the northwest of Western Fault) and the very limited extent of the geological model. As such, the update of elevation surfaces was simplified as follows.

The top elevation surface (Figure 5-4) represents the land surface, and is consistent between the LLM2021 model and the original model (AGE, 2015). While not documented in AGE (2015), this elevation surface is believed to be sourced from the ELVIS database with a spatial resolution of 30 x 30 m. Following the original model (AGE, 2015), a constant thickness approach was adopted for the LLM2021 model due to the lack of data for finer parameterisation.

Figure 5-3 and Table 5-1 show the model layer setup with two key differences compared to the original model (AGE, 2015):

- The original model (AGE, 2015) contains a hydraulic parameter zone in the top layer to represent the Cambrian block to the west of Western Fault. However, our hydrogeological conceptualisation review shows that there is no Cambrian block to the west of Western Fault. Therefore, this zone was changed to represent the Lady Loretta Formation in the LLM2021 model and extended to all layers.
- Based on our hydrogeological conceptualisation review, the thickness of model layer 1 was increased from 50 m in the original model (AGE, 2015) to 80 m in the LLM2021 model. This is to account for the nominal thickness of 50 m for the Cambrian block and 30 m for the overlying surficial sediments. The thicknesses of other model layers were also adjusted as shown in Table 5-1.

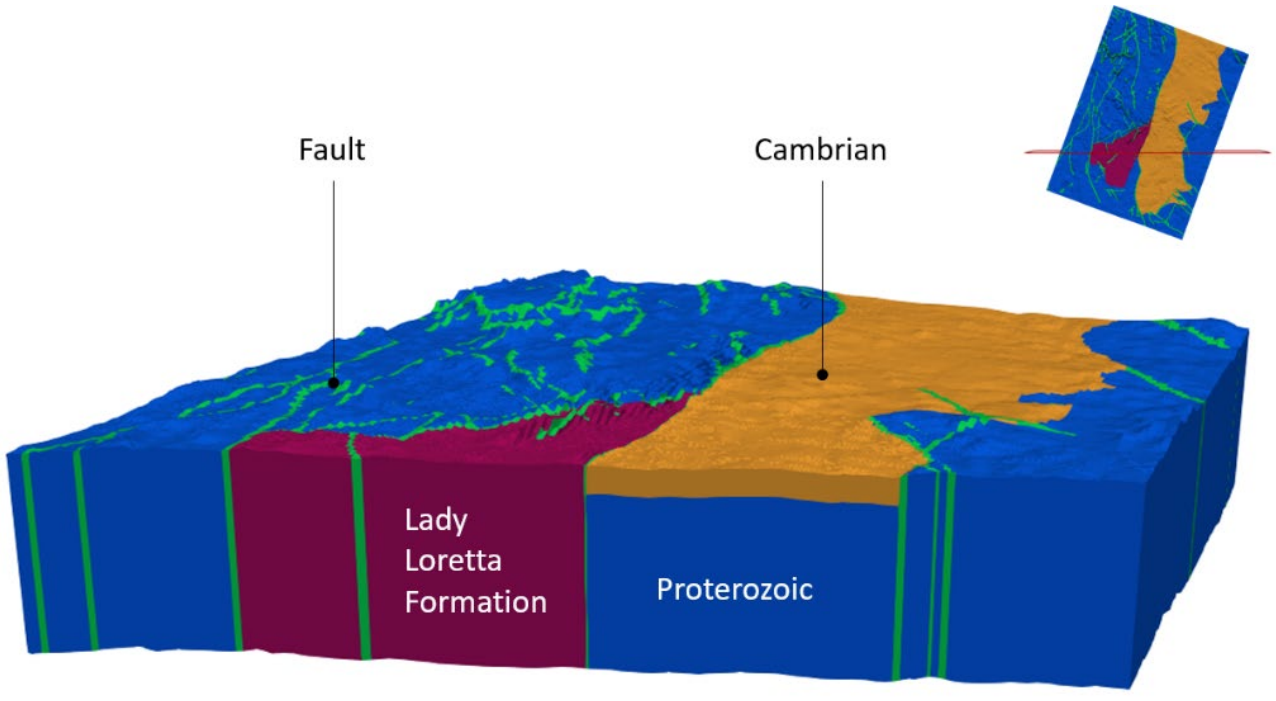


Figure 5-3 Model Cross-section

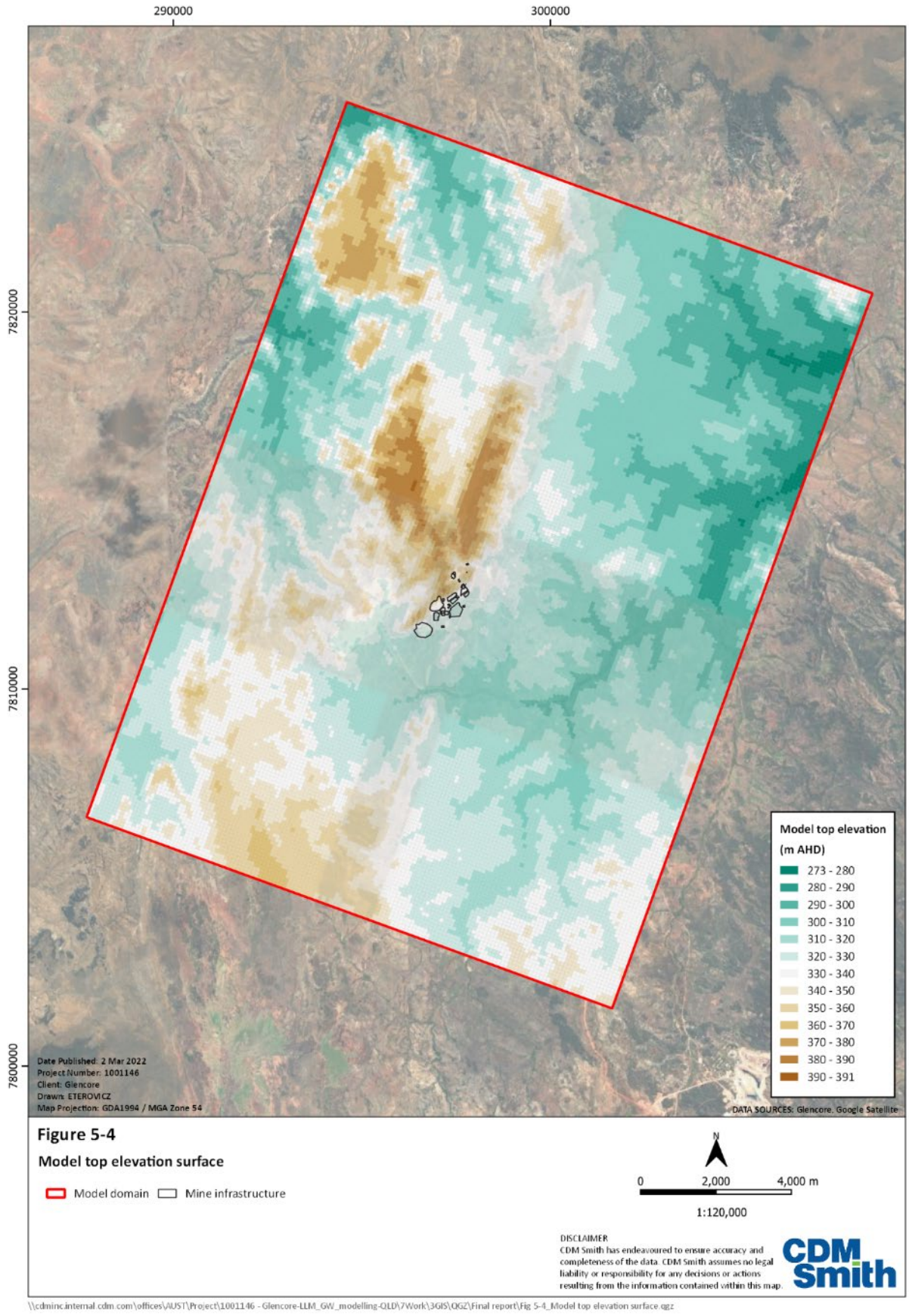


Figure 5-4 Model Top Elevation Surface

Table 5-1 Model Layer Setup

Model layer	Hydrostratigraphy	Thickness (m)
1	Lady Loretta Formation, Cambrian, Proterozoic and faults	80
2	Lady Loretta Formation, Proterozoic and faults	100
3		120
4		140
5		160

5.2.4 Boundary Conditions

Model boundary conditions represent the key physical processes of a given groundwater system. For the LLM2021 model, the key processes simulated include:

- Regional groundwater flows
- Surface drainage
- Rainfall recharge
- Groundwater evapotranspiration
- Mine dewatering
- Borefield production

5.2.4.1 Regional Groundwater Flows

Regional groundwater flows across the model domain edges are represented using the constant head boundary (Figure 5-2). The constant head value is spatially and temporally constant, and the value of 275 m AHD from the original model remains unchanged in the LLM2021 model (the selection of head value is not fully explained in AGE 2015). Assuming groundwater flow conforms to the topography (Figure 5-4), the constant head cells were assigned to the northeastern portion of the model domain in the top layer to represent regional groundwater outflows.

5.2.4.2 Surface Drainage

The ephemeral drainage features within the model domain mostly flow only in direct response to rainfall that produces runoff. This process is simulated in the LLM2021 model using the MODFLOW RIV Package (Figure 5-2). Consistent with the original model (AGE, 2015), the river stage and bottom elevation were both set to the DEM values, such that the river cells only act as a groundwater draining feature and do not produce any recharge to the groundwater system.

Riverbed conductance controls the magnitude of groundwater discharge through the river cells. Different from the original model, the riverbed conductance for the LLM2021 model was estimated through model calibration (but was found to be insensitive after the calibration). The riverbed conductance is spatially and temporally constant.

5.2.4.3 Rainfall Recharge

A portion of rainfall percolates through the soil and eventually reach the water table, becoming groundwater recharge. This process is simulated in the LLM2021 model using the MODFLOW RCH Package. There are two parts to the recharge setup, including rainfall rate and rainfall-to-recharge ratio.

The rainfall rate is based on the Camooweal Township weather station (37010; Figure 2-1 and Figure 2-2) and was set to be time-varying but spatially uniform in the LLM2021 model. The rainfall-to-recharge ratio represents the portion of rainfall that becomes recharge and was estimated through model calibration. The ratios were initially zoned based on surface geology (Figure 5-5), with further spatial heterogeneity added through the use of pilot point calibration.

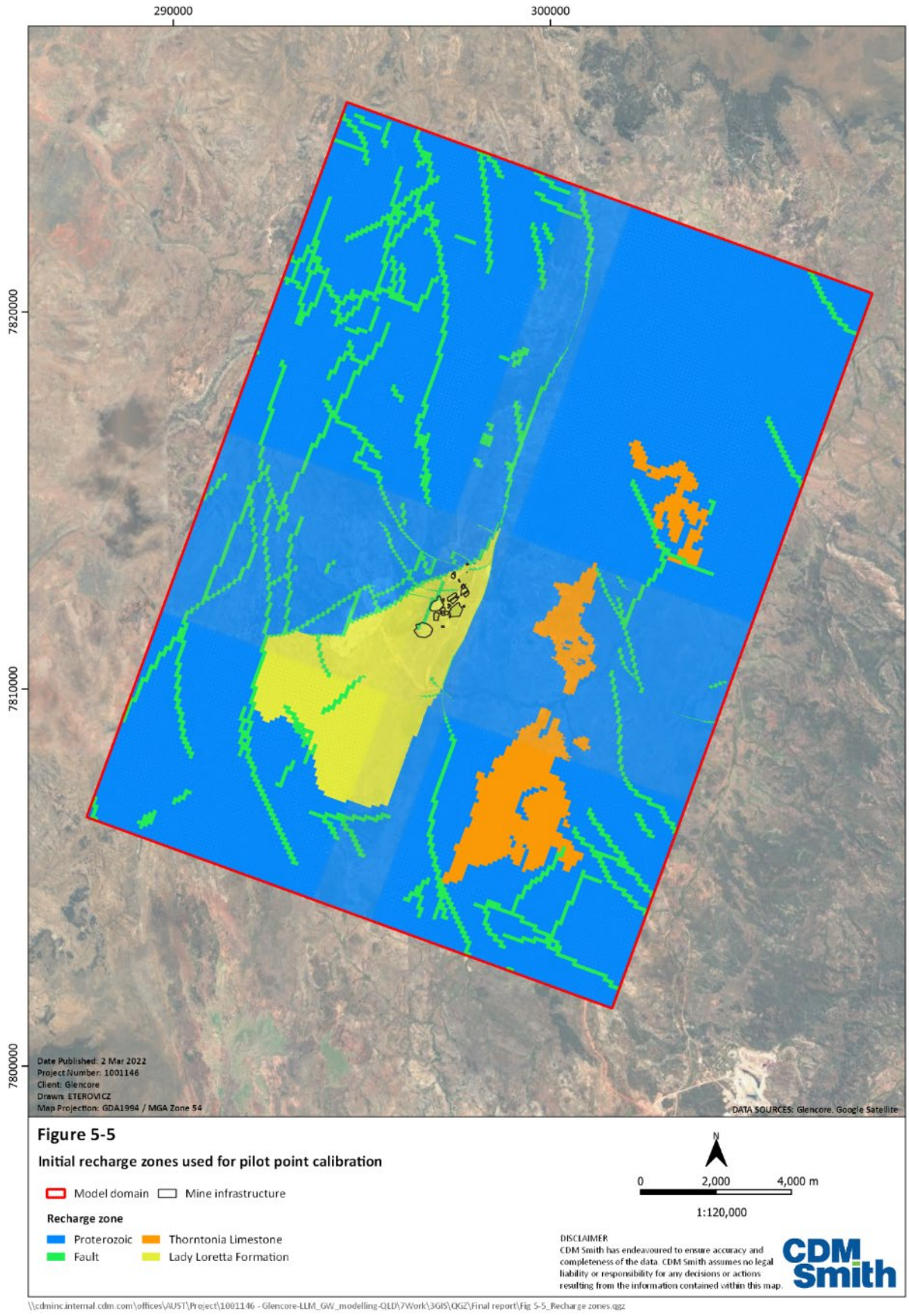


Figure 5-5 Initial Recharge Zones Used for Pilot Point Calibration

5.2.4.4 Groundwater Evapotranspiration

Shallow groundwater can be lost to the atmosphere through evapotranspiration (ET), either via plants whose roots access the capillary fringe or shallow water tables. This process is represented in the LLM2021 model using the MODFLOW EVT Package. This package takes two inputs, including potential ET rate and extinction depth.

The potential ET rate refers to the groundwater ET rate that would occur if the water table was at the land surface. In the LLM2021 model, the potential ET rate is based on the Camooweal Township weather station (37010; Figure 2-1) from the SILO database. Pan evaporation is considered too high to be used as the potential ET rate as it assumes unlimited water availability. Instead, the potential ET rate is based on the FAO56 estimates (Allen et al., 1998), which is the reference ET rate that takes temperature, relative humidity, wind speed and solar radiation into account. The potential ET rate for the LLM2021 model is time-varying but spatially uniform.

Extinction depth defines the depth threshold below which no groundwater ET occurs. The extinction depth for the LLM2021 model was set to the conventional value of 2 m and remains spatially and temporally constant. Within the model domain, most groundwater ET is expected to occur in low-lying areas (Figure 5-4) where the water table is generally shallower.

5.2.4.5 Mine Dewatering

Mining at the LLM commenced in 2012 and the current campaign of mining operations is scheduled for completion in 2025, with dewatering continued (in parallel with the Resource Development program to review potential to extend the Ore Reserve) until the end of 2032. Mine dewatering (i.e. abstractions of water from within the mine) is represented in the LLM2021 model using the MODFLOW DRN Package (Figure 5-2). The spatial extent and elevations of the historical and future mine plan (activated after Q1 2022) were provided by Glencore. However, due to the lack of timing information
(i.e. how the mine extent and elevations change over time), the historical and future mine extent and elevations are assumed to be constant throughout their corresponding simulation periods. This approach has the potential to introduce bias into the calibration but is considered a compromise that needs to be made given the data availability. This approach ensures the impact of mining is not underestimated and is therefore considered a conservative assumption.

The elevation data for mine levels are spatially variable and can be as low as -145 m AHD. These elevation values were used to set the drain stage and assign model layer for each drain cell. The magnitude of groundwater discharge to the mine is controlled by the drain conductance, which was set to be spatially and temporally constant, and estimated through model calibration.

Mine dewatering is scheduled to discontinue from 2033 onwards. The mine will be backfilled at the end of the Commercial Proposition period with material from surface. The backfilling activity as per the closure plan is defined as backfilling the upper section of the mine decline and upper section of the ventilation shafts only. Given the other sources of uncertainty (e.g. structural and parameter uncertainty), detailed simulation of backfilling is not considered to be warranted at this time, and is unlikely to add much value to the modelling outcomes. This process is represented in the LLM2021 model by deactivating the drain cells. It is acknowledged that backfilling is not an instantaneous process and its representation in the model is simplified.

The neighbouring Lady Annie pit is simulated in a similar manner using drain cells (Figure 5-2). The spatial extent and pit bottom elevations were provided by Glencore, with a nominal elevation of 241.4 m AHD for the western pit and 214 m AHD for the eastern pit. These elevations and the drain conductance were set to be spatially and temporally constant. The drain conductance for the Lady Annie pit was estimated through model calibration separately from the LLM drain conductance. Given its relatively early commencement in 2007, the Lady Annie pit is assumed to be active throughout the simulation period.

5.2.4.6 LAE Borefield Production

Groundwater discharge through LAE borefield production is represented in the LLM2021 model using the MODFLOW WEL Package. The spatial location (Figure 5-2) and time-series pumping rates of the three production wells GW15, GW17 and GW18 were provided by Glencore.

Using the capability of MODFLOW-USG, the LLM2021 model was instructed to automatically reduce pumping rates to prevent the hosting cells from becoming dry. For numerical modelling purposes the LAE borefield production is scheduled to cease operation by December 2025 in alignment with the proposed mine closure schedule.

5.2.5 Hydraulic Properties

Model parameters that control the hydraulic properties of the LLM2021 model include hydraulic conductivity, specific storage and specific yield. Hydraulic conductivity describes how easily water can pass through a given porous medium, while the specific storage and specific yield relate to the amount of water that can be released from or stored in the porous medium in response to changes in hydraulic head under confined and unconfined conditions, respectively.

Aquifer test and literature values reported in Section 3.3 were used as the basis to set the lower and upper bounds for the hydraulic properties of the LLM2021 model. The hydraulic properties were then refined through model calibration where the parameters were adjusted within their lower and upper bounds until a good fit to the field observations is achieved. The hydraulic parameters were initially zoned (Figure 5-6), with further spatial heterogeneity added through the use of pilot point calibration (see Section 5.3.1).

5.2.6 Temporal Discretisation

Time discretisation defines the simulation period and the temporal resolution of the model. A stress period is defined as a period of time where stresses (e.g. pumping) on a given groundwater system remain constant. The stress period setup for the LLM2021 model is provided in Table 5-2.

Table 5-2 Model Stress Period Setup

Stress period	Start date	Stop date	Period length	Description
1	-	31/12/2011	-	A steady-state period to represent the long-term average conditions without any mining activities. This period provides the initial conditions for the subsequent transient periods.
2 - 42	1/01/2012	31/03/2022	Quarterly (90 - 92 days)	These transient periods represent the historical calibration period. Mining activities commenced in Sep 2012.
43 - 78	1/04/2022	31/12/2250	Gradually increases from quarterly to 20-yearly	These transient periods represent the future prediction period. Future mine plan is assumed to commence in Apr 2022 and cease to operate by the end of Dec 2025. Mine dewatering is scheduled to cease operation from 2033 onwards and the mine will be backfilled, with backfilling defined as backfilling the upper section of the mine decline and upper section of the ventilation shafts only. This period is extended to approximately 230 years into the future to assess any long-term impact of mining.

The model starts with a steady-state period to represent the long-term average conditions without any LLM mining activities, with the aim to provide the initial conditions for the subsequent transient periods. The transient periods are quarterly for the historical calibration period and gradually increase to 20-yearly for the future prediction period. Historical mining commenced in September 2012 while the future mine plan is assumed to commence in April 2022 and cease to operate by the end of December 2025. Mine dewatering is scheduled to cease operation from 2033 onwards and the mine will be backfilled, with backfilling defined as backfilling the upper section of the mine decline and upper section of the ventilation shafts only. The future period is extended hundreds of years into the future to

assess any long-term impact associated with water level recovery within the backfilled mine voids and surrounding groundwater system.

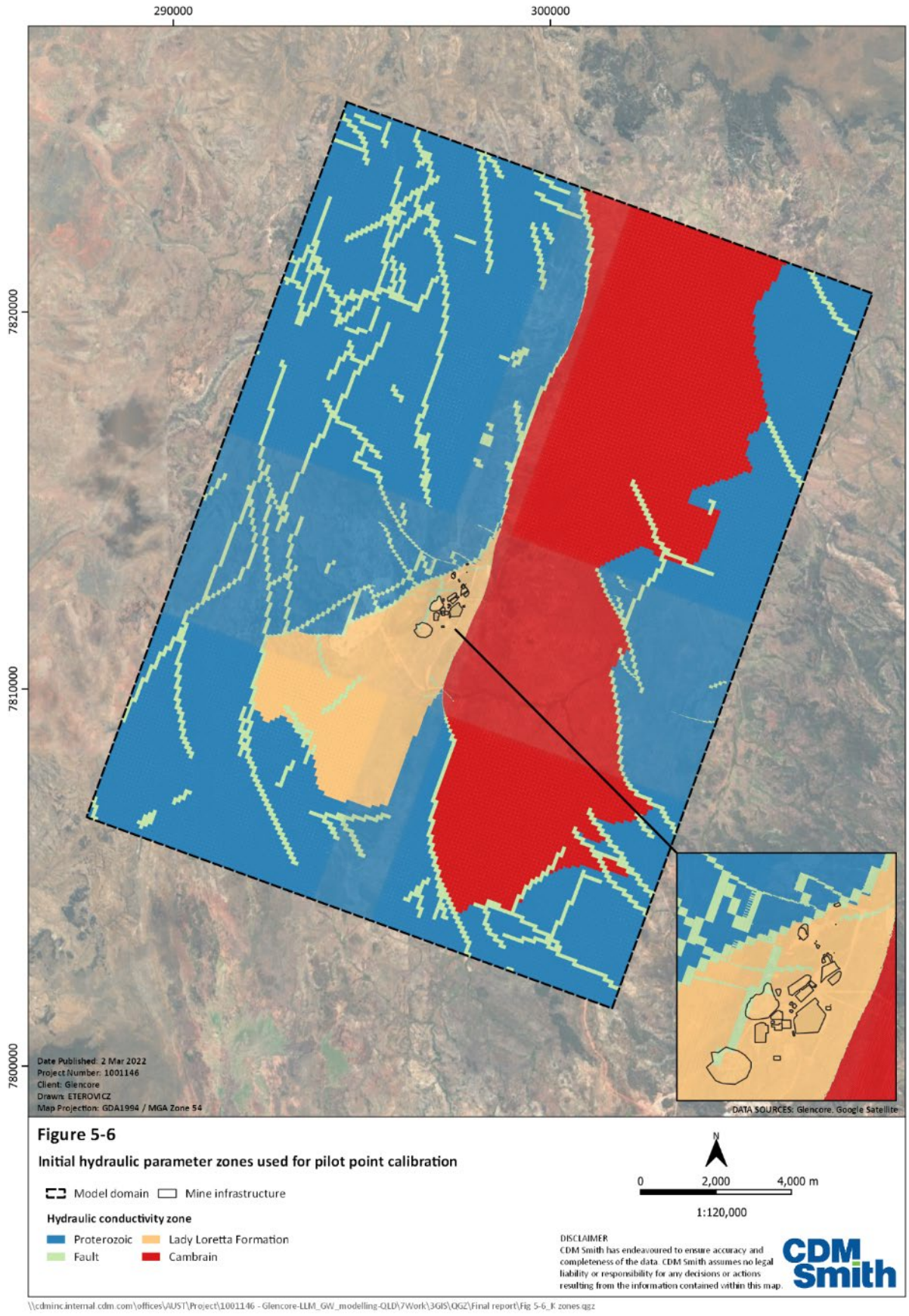


Figure 5-6 **Initial Hydraulic Property Zones Used for Pilot Point Calibration**

5.3 Model Calibration and Sensitivity Analysis

Model calibration is a process of tuning model parameters to fit field observations. This process, however, is non-unique in that there can be numerous combinations of parameters that fit the field observations similarly well. Traditional groundwater modelling generally employs a deterministic approach where a single calibrated model is developed to make predictions. However, due to non-uniqueness, a model that can fit the field observations does not necessarily mean the model represents the 'truth'. Instead, that model just represents one of numerous realisations that can fit the field observations (a realisation represents a possible combination of model parameters).

It is a better approach to capture as many model realisations as possible that can fit the field observations. However, this generally requires a stochastic approach where multiple models are developed, calibrated and used to make predictions, which can be extremely time consuming and hence not as commonly applied as the deterministic approach. This limitation has been overcome by the recently developed modelling technique PESTPP-IES (White, 2018) that can run numerical groundwater models stochastically in a highly efficient manner. In this study, 100 model realisations were developed and calibrated, enabling probabilistic predictions and a more robust uncertainty analysis.

5.3.1 Calibration Approach

The LLM2021 model was calibrated to 23 observation wells (Figure 5-1) with their water level measurements averaged to the quarterly stress periods, resulting in a total of 226 water level targets. In addition, as it is generally good modelling practice to include multiple types of calibration targets, a flux target was included for the recorded groundwater ingress to the underground workings of 8 L/sec (approximately 700 m^3/d) during the care and maintenance period (Section 3.7.2.1).

The model parameters that were calibrated include horizontal hydraulic conductivity, vertical anisotropy of hydraulic conductivity (i.e. K_h / K_v), specific storage, specific yield, rainfall-to-recharge ratio, drain conductance (separately for the LLM and Lady Annie pit) and riverbed conductance (see Table 5-3). The boundary conductance terms are assumed to be spatially and temporally constant, while the hydraulic parameters were calibrated using the pilot point technique (Doherty et al., 2010) where parameter values are estimated at the pilot point locations and then interpolated to all model cells. This study used a highly parameterised approach with a total of 9,140 pilot points set up and calibrated.

PESTPP-IES (White, 2018) excels at calibrating highly parameterised models as its computational time is independent of the number of parameters to calibrate. Instead, its run time depends on the number of calibrated model realisations to be generated, which was set to 100 model realisations in this study given the model complexity. These 100 model realisations were initially developed in a random manner within the bounds provided in Table 5-3, calibrated to the field observations simultaneously, and then used together for the prediction forecasts. This approach provides insights into the different possible parameter combinations that are supported by the field observations and the resulting predictions.

Table 5-3 summarises the settings of model parameters used for the calibration, where the initial values are based on either site knowledge or the geometric mean of the upper and lower bounds. For each parameter, the initial value was used to determine the centre of a log-normal distribution that was used to draw random values for the realisations. The spread of the distribution is controlled by standard deviation and it is assumed that ± 2 standard deviations cover 95% of values.

Table 5-3 Settings of Initial Hydraulic Parameters for Calibration

Parameter	Description	Initial value	Lower bound	Upper bound
Hydraulic conductivity (m/d)	Lady Loretta Formation	1×10^{-2}	1×10^{-4}	1×10^{0}
	Cambrian	5×10^{0}	1×10^{0}	5×10^{1}
	Proterozoic	1×10^{-4}	1×10^{-6}	1×10^{-2}
	Fault	1×10^{-3}	1×10^{-4}	1×10^{-1}
Vertical anisotropy (K_h / K_v)	Lady Loretta Formation	1×10^{0}	1×10^{0}	1×10^{2}
	Cambrian	1×10^{0}	1×10^{0}	1×10^{2}
	Proterozoic	1×10^{0}	1×10^{0}	1×10^{2}
	Fault	1×10^{0}	1×10^{0}	1×10^{2}
Specific storage (m^{-1})	Lady Loretta Formation	3×10^{-6}	1×10^{-6}	1×10^{-5}
	Cambrian	3×10^{-6}	1×10^{-6}	1×10^{-5}
	Proterozoic	3×10^{-6}	1×10^{-6}	1×10^{-5}
	Fault	1×10^{-5}	1×10^{-6}	1×10^{-4}
Specific yield (-)	Lady Loretta Formation	3×10^{-3}	1×10^{-3}	1×10^{-2}
	Cambrian	3×10^{-3}	1×10^{-3}	1×10^{-2}
	Proterozoic	3×10^{-3}	1×10^{-3}	1×10^{-2}
	Fault	3×10^{-3}	1×10^{-3}	1×10^{-2}
Rainfall-to-recharge ratio (%)	Lady Loretta Formation	1×10^{-2}	1×10^{-4}	5×10^{-2}
	Cambrian	1×10^{-2}	1×10^{-4}	5×10^{-2}
	Proterozoic	1×10^{-2}	1×10^{-4}	5×10^{-2}
	Fault	1×10^{-2}	1×10^{-4}	5×10^{-2}
Drain conductance (m^2/d)	LLM	1×10^{2}	1×10^{1}	1×10^{3}
	Lady Annie pit	1×10^{2}	1×10^{1}	1×10^{3}
Riverbed conductance (m^2/d)	Surface creeks	1×10^{0}	1×10^{-1}	1×10^{1}

5.3.2 Calibration Performance

5.3.2.1 Calibration Statistics

A scatter plot comparing the observed and simulated groundwater levels is shown in Figure 5-7. The black data points represent the mean while the blue error bars represent the range of simulated groundwater levels from the 100 calibrated model realisations. The blue error bars indicate the uncertainty associated with the simulated groundwater levels, which varies between observations. The diagonal 1:1 reference line represents the ideal situation where the simulated groundwater levels fit the observations perfectly. Data points that are closer to the 1:1 reference line indicate a better calibration performance, and vice versa.

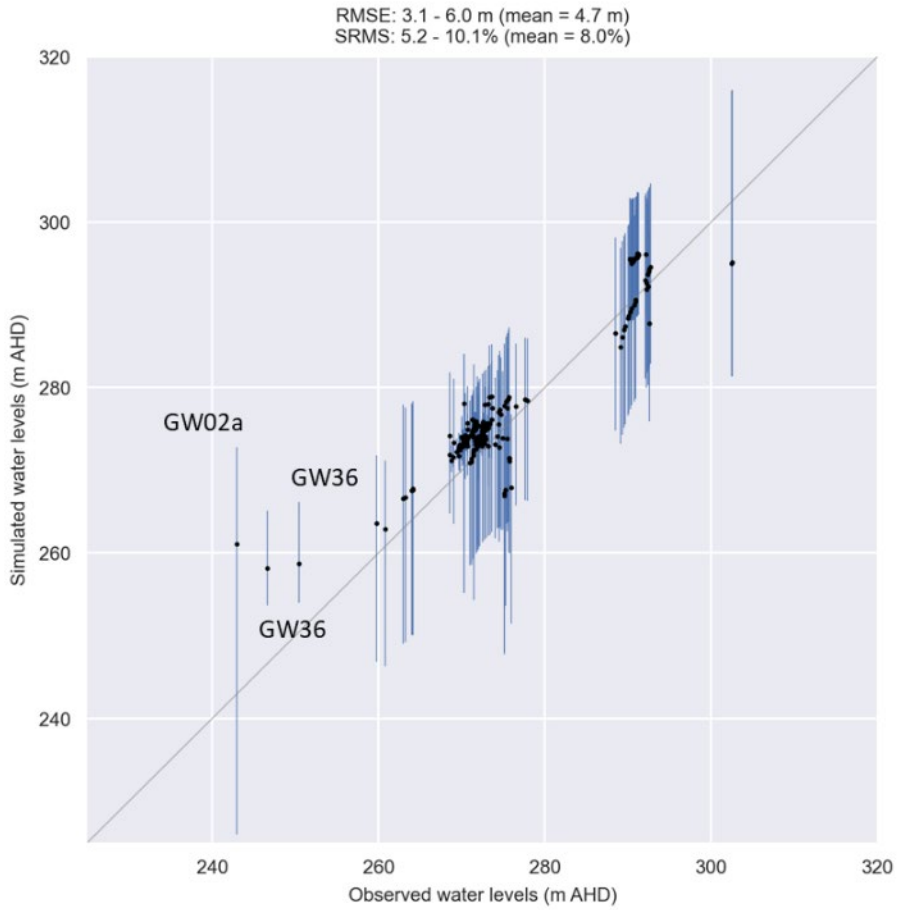


Figure 5-7 Comparison of Observed and Simulated Water Levels

Figure 5-7 shows an overall satisfactory calibration performance where the cloud of data points centre around the 1:1 reference line, indicating little systematic bias towards overestimation or underestimation. The 100 calibrated realisations show a root mean squared error (RMSE) of 3.1 – 6.0 m (mean: 4.7 m) and a scaled root mean squared (SRMS) error of 5.2% - 10.1% (mean: 8.0%), suggesting all the 100 calibrated realisations have achieved a reasonable fit to the observations.

The results show a considerable discrepancy for GW02a with a large uncertainty. This well was recently drilled in 2021 and its water level continued to increase from 208.5 to 242.9 m AHD between Jan and Jul 2021, suggesting a slow recovery that is not intended for the model to replicate. Two water level measurements from GW36 also show a notable discrepancy, where none of the 100 realisations can fit the observed values (i.e. the blue error bars do not intersect with the 1:1 reference line). Review of daily drilling reports and field notes reveals that there were development issues with this well, which have the potential to influence the water level measurements.

5.3.2.2 Calibrated Groundwater Flux to Mine

Figure 5-8 shows the probability distribution of simulated groundwater flux to the mine during the care and maintenance period from the 100 calibrated model realisations. The probability distribution resembles a normal distribution with the peak (i.e. the most likely value) at the flux target of 700 kL/d, suggesting an acceptable calibration performance. The probability distribution also provides insights into the uncertainty associated with the flux estimate, where more than 95% of the realisations lie between 600 and 800 kL/d. The RMSE is relatively small and ranges between 0.8 and 135.8 kL/d with a mean of 33.8 kL/d. It should be acknowledged that the mine is represented in a simplified manner in the model (Section 5.2.4.5), and therefore there is uncertainty associated with the mine flux calibration from a conceptual point of view.

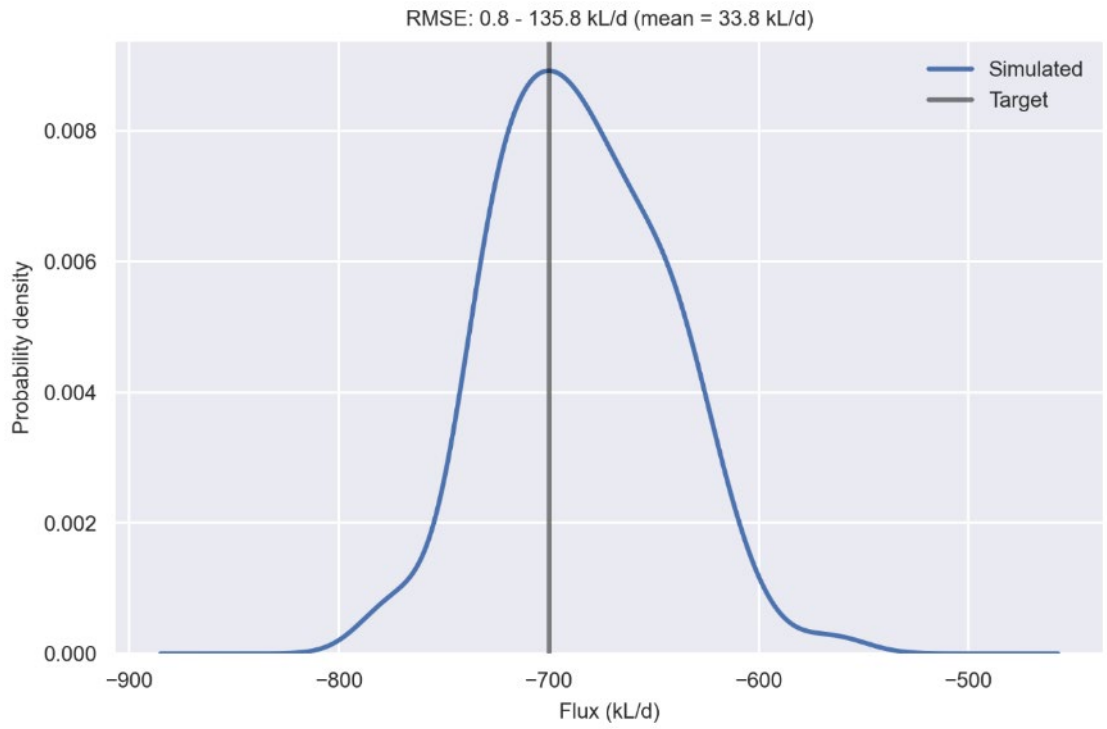


Figure 5-8 Probability Distribution of Simulated Flux to the Mine During the Care and Maintenance Period

5.3.2.3 Calibrated Hydrographs

A subset of observed hydrographs is compared with the modelled water levels in Figure 5-9 and Figure 5-10. These hydrographs were selected based on their length of historical records and spatial location. The full set of hydrographs are provided in Appendix B. In general, Figure 5-9 and Figure 5-10 show a reasonable match between the observed and simulated water levels. Some discrepancies can be attributed to the fact that the historical mine extent and elevations are assumed to be constant throughout the calibration period due to the lack of data for finer parameterisation.

Some observation wells such as GW03 shows a small variation in the modelled water levels across the 100 realisations (i.e. smaller uncertainty), while some observation wells such as GW07, GW12 and GW13 show a large variation in the modelled water levels (i.e. larger uncertainty). This information provides insights into how much confidence we can have on model results in different areas.

5.3.3 Calibrated Parameters

Table 5-4 shows a high-level view of the calibrated parameter statistics based on the geometric mean across the 100 model realisations. The spatial distributions of the calibrated parameters are shown in Figure 5-11 to Figure 5-15.

One key knowledge gap is the hydraulic properties of the faults. Following AGE (2015), the faults were implemented into the model as semi-vertical features, where the spatial distribution of faults is assumed to be the same across the model layers. The faults are represented in the model as a separate hydraulic parameter zone, the values of which were determined through model calibration in a stochastic manner. Through PESTPP-IES, the conceptualisation of faults was initially randomised. For a given fault, some realisations conceptualised the fault as a barrier to groundwater flow (i.e. low K) while some other realisations conceptualised the fault as a conduit (i.e. high K). After fitting to the field observations, these realisations converged to the conclusion that the faults are generally more permeable than the Proterozoic and less permeable than the Cambrian, and the fault permeability is generally in the same order of magnitude as the Lady Loretta Formation permeability. The faults do not act as impermeable barriers, and likely have low permeability.

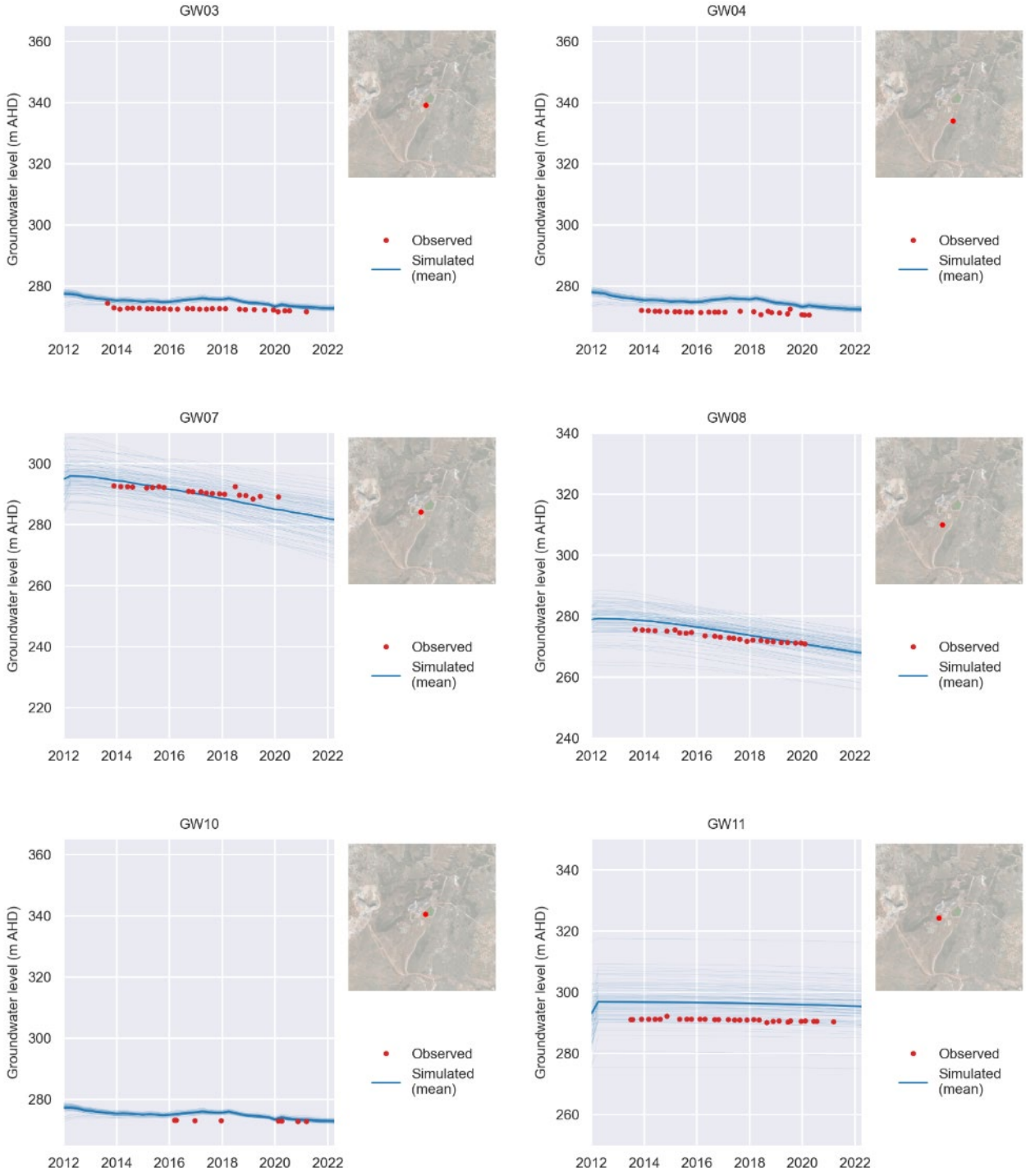


Figure 5-9 Hydrograph Comparisons (Set 1)

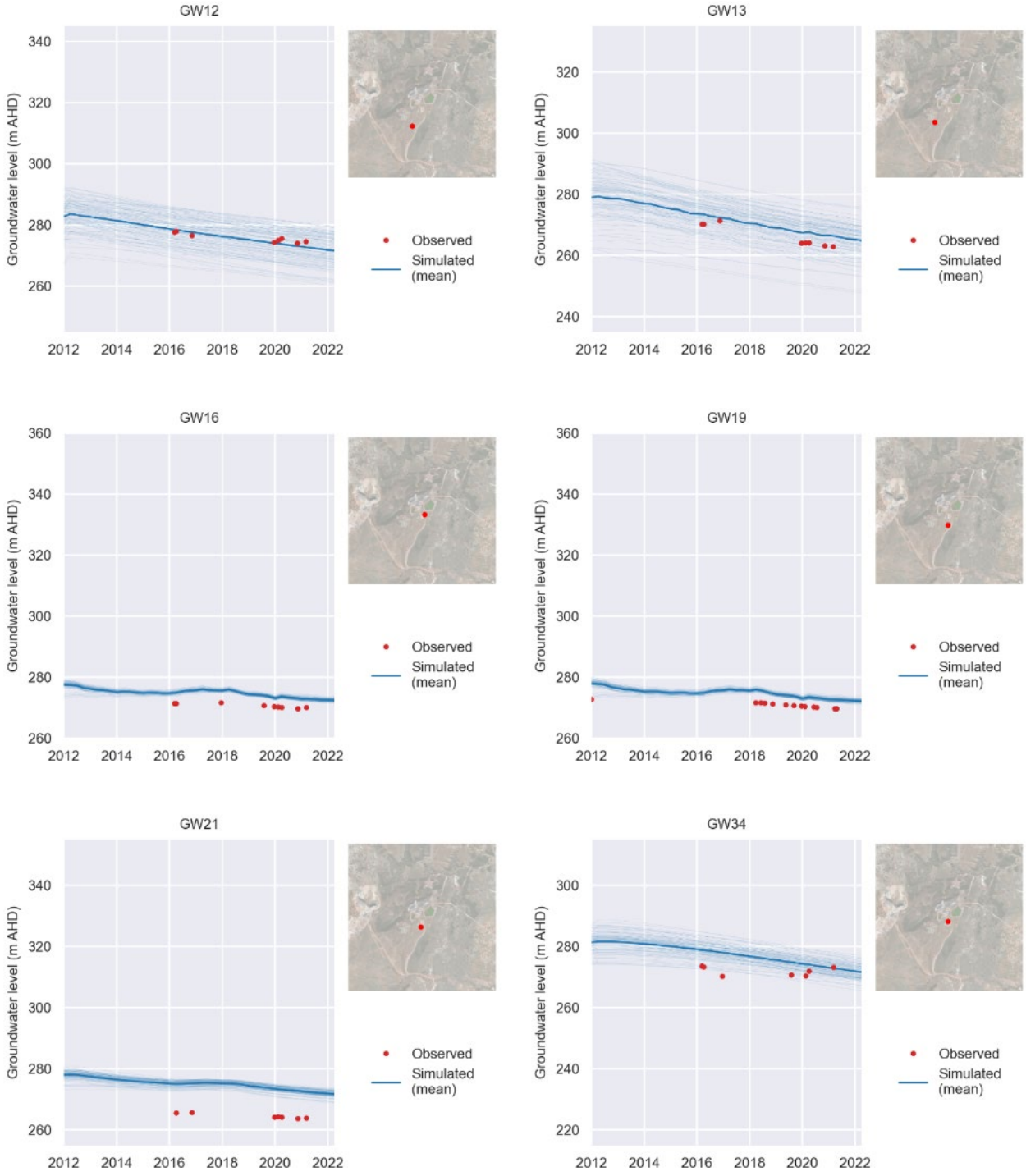


Figure 5-10 Hydrograph Comparisons (Set 2)

Table 5-4 Calibrated Parameter Statistics Based on the Geometric Mean of Each Realisation

Parameter	Description	Geometric mean	Minimum	Maximum	Uncertainty (expressed as std)
Hydraulic conductivity (m/d)	Lady Loretta Formation	5.6×10^{-3}	1.5×10^{-3}	1.4×10^{-2}	2.1×10^{-1}
	Cambrian	1.8×10^{1}	1.1×10^{1}	2.7×10^{1}	7.4×10^{-2}
	Proterozoic	8.7×10^{-5}	3.7×10^{-5}	1.7×10^{-4}	1.3×10^{-1}
	Fault	2.0×10^{-3}	8.6×10^{-4}	4.0×10^{-3}	1.4×10^{-1}
Vertical anisotropy (K_h / K_v)	Lady Loretta Formation	7.8×10^{0}	3.0×10^{0}	1.4×10^{1}	1.5×10^{-1}
	Cambrian	2.0×10^{0}	1.3×10^{0}	3.2×10^{0}	8.4×10^{-2}
	Proterozoic	2.1×10^{0}	1.3×10^{0}	3.1×10^{0}	6.9×10^{-2}
	Fault	2.6×10^{0}	1.5×10^{0}	5.4×10^{0}	1.0×10^{-1}
Specific storage (m^{-1})	Lady Loretta Formation	2.0×10^{-3}	3.8×10^{-4}	6.7×10^{-3}	2.3×10^{-1}
	Cambrian	3.2×10^{-3}	1.1×10^{-3}	7.1×10^{-3}	1.3×10^{-1}
	Proterozoic	5.9×10^{-3}	2.8×10^{-3}	1.1×10^{-2}	1.2×10^{-1}
	Fault	3.3×10^{-3}	1.1×10^{-3}	6.1×10^{-3}	1.7×10^{-1}
Specific yield (-)	Lady Loretta Formation	3.8×10^{-6}	2.1×10^{-6}	6.9×10^{-6}	1.3×10^{-1}
	Cambrian	3.3×10^{-6}	2.0×10^{-6}	4.9×10^{-6}	7.1×10^{-2}
	Proterozoic	3.3×10^{-6}	2.7×10^{-6}	4.1×10^{-6}	3.8×10^{-2}
	Fault	5.8×10^{-6}	3.2×10^{-6}	9.6×10^{-6}	1.2×10^{-1}
Rainfall-to-recharge ratio (%)	Lady Loretta Formation	2.6×10^{-1}	1.7×10^{-1}	3.4×10^{-1}	7.9×10^{-2}
	Cambrian	3.4×10^{-1}	2.3×10^{-1}	5.3×10^{-1}	8.2×10^{-2}
	Proterozoic	2.6×10^{-1}	1.9×10^{-1}	3.7×10^{-1}	5.5×10^{-2}
	Fault	4.0×10^{-1}	3.1×10^{-1}	5.3×10^{-1}	5.4×10^{-2}
Drain conductance (m^2/d)	LLM	2.2×10^{2}	5.3×10^{1}	8.6×10^{2}	3.1×10^{-1}
	Lady Annie pit	2.7×10^{2}	2.6×10^{1}	9.6×10^{2}	3.1×10^{-1}
River conductance (m^2/d)	Surface creeks	4.0×10^{-1}	1.0×10^{-1}	2.1×10^{0}	3.1×10^{-1}

Uncertainty is expressed as the standard deviation of the log-transformed parameters, where a larger value suggests a larger spatial heterogeneity and hence the geometric mean in Table 5-4 being less representative. For instance, assuming the log-transformed parameters are normally distributed, a standard deviation of 0.25 means 95% of values are within an order of magnitude of the geometric mean.

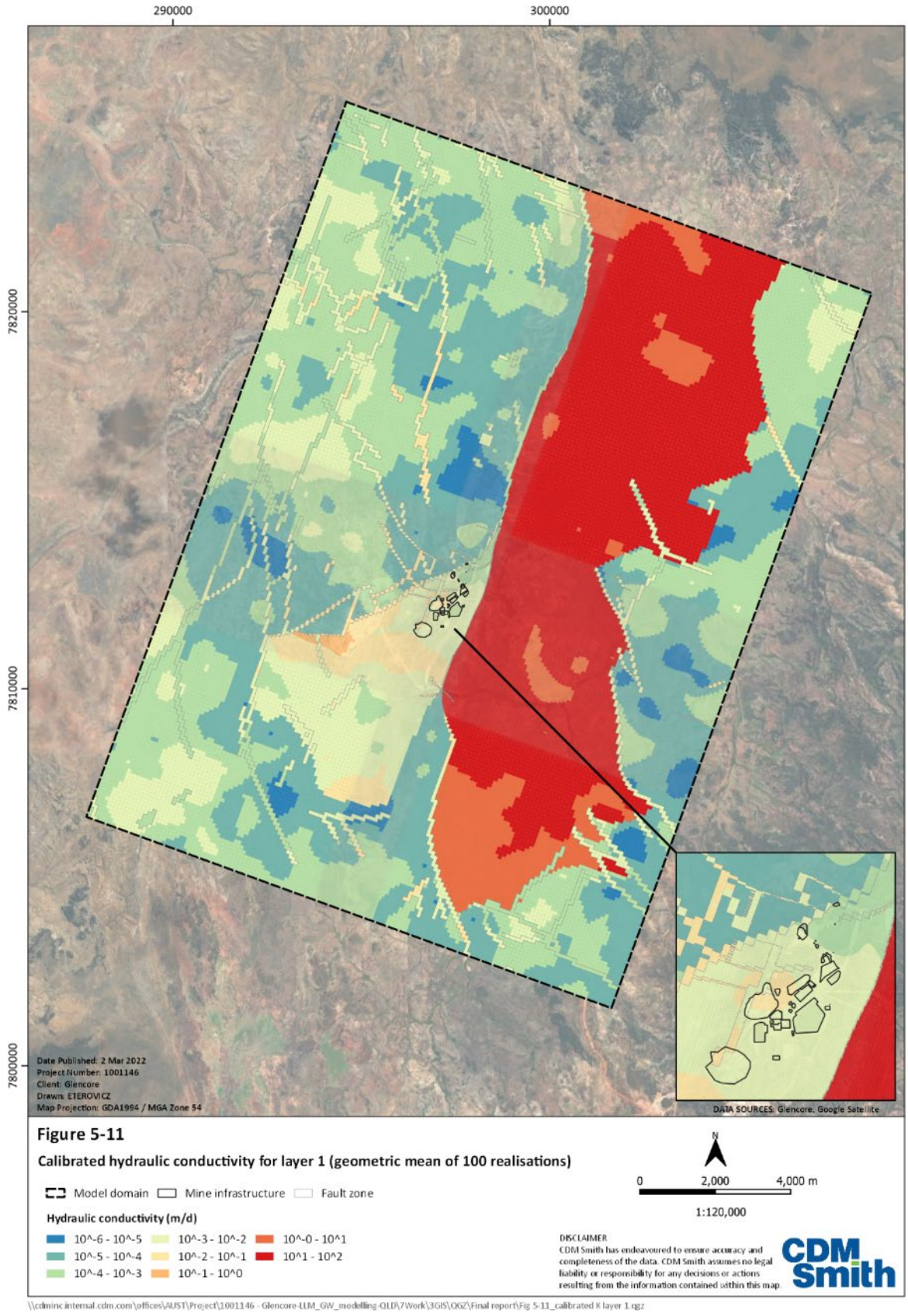


Figure 5-11 Calibrated Hydraulic Conductivity for Layer 1 (Geometric mean of 100 realisations)

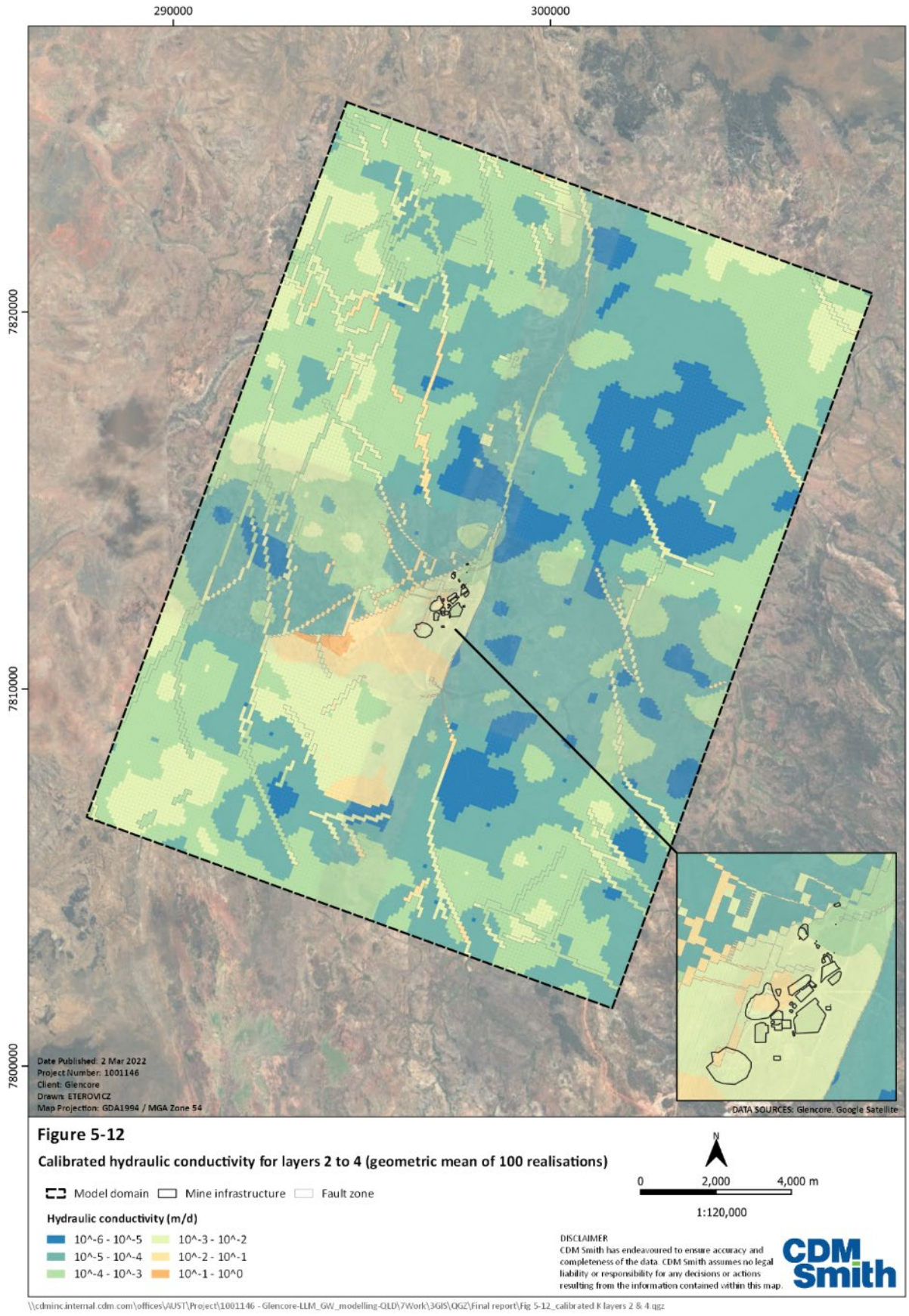


Figure 5-12 Calibrated Hydraulic Conductivity for Layers 2 to 4 (Geometric mean of 100 realisations)

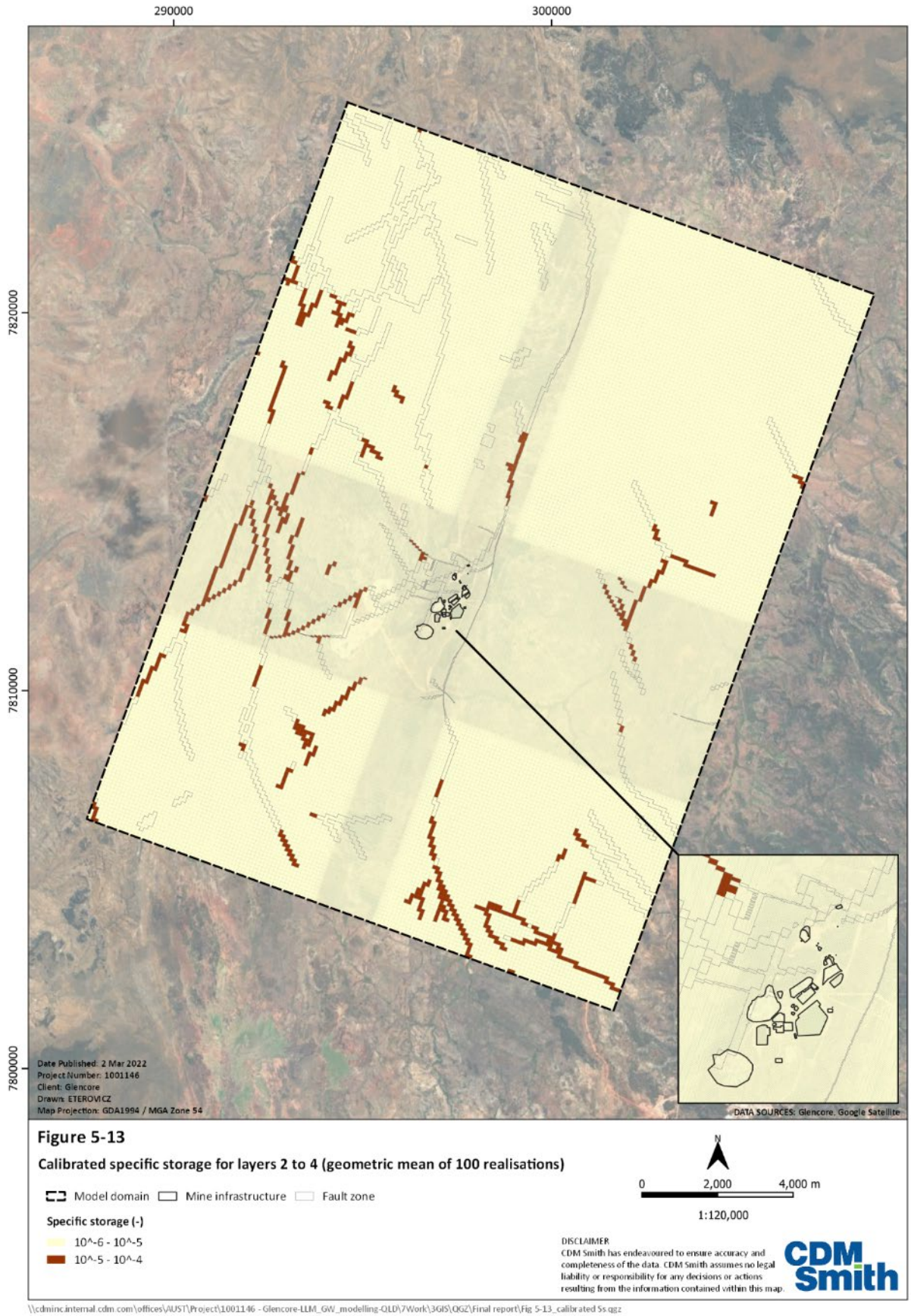


Figure 5-13 Calibrated Specific Storage for Layers 2 to 4 (Geometric mean of 100 realisations)

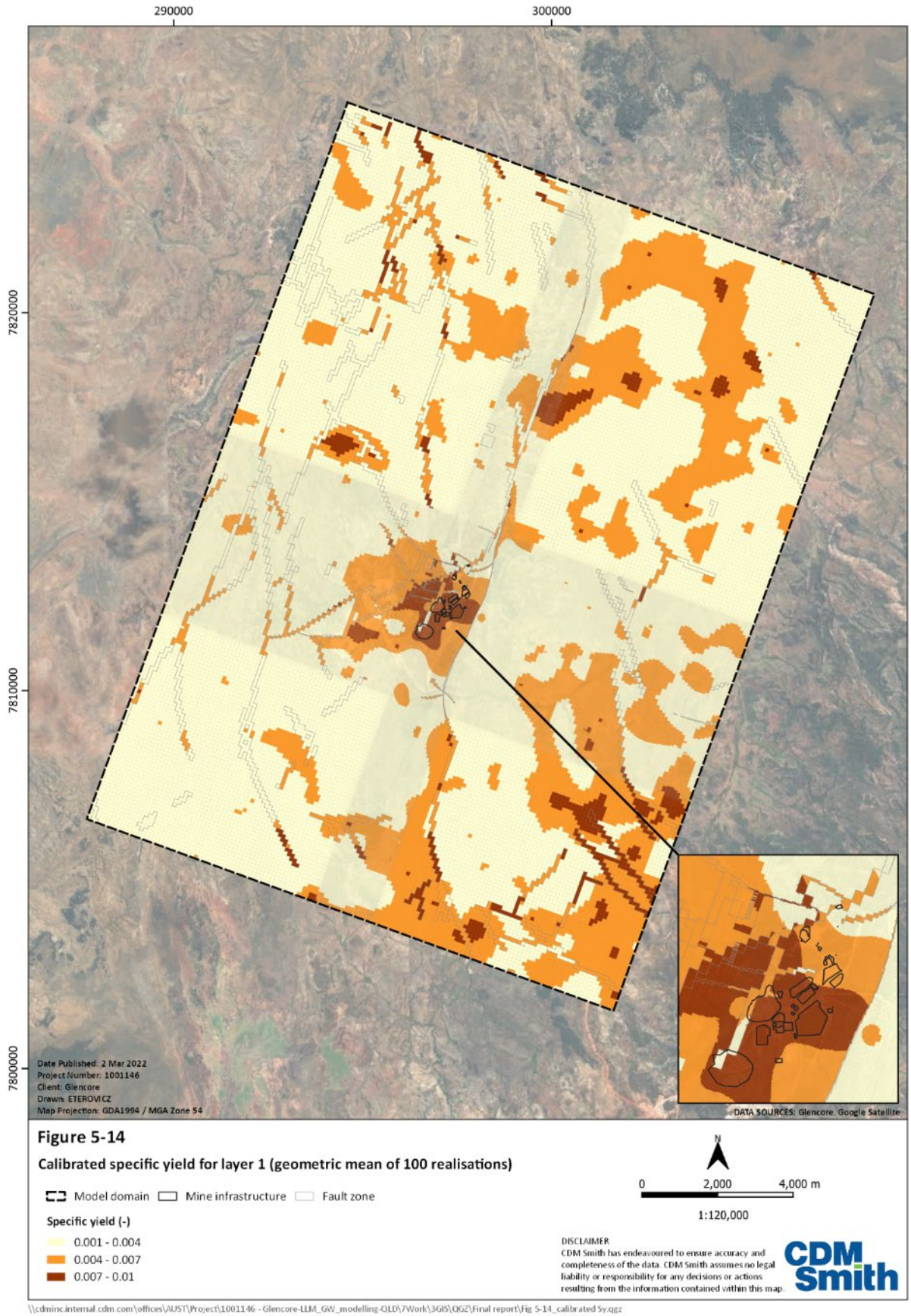


Figure 5-14 Calibrated Specific Yield for Layer 1 (Geometric mean of 100 realisations)

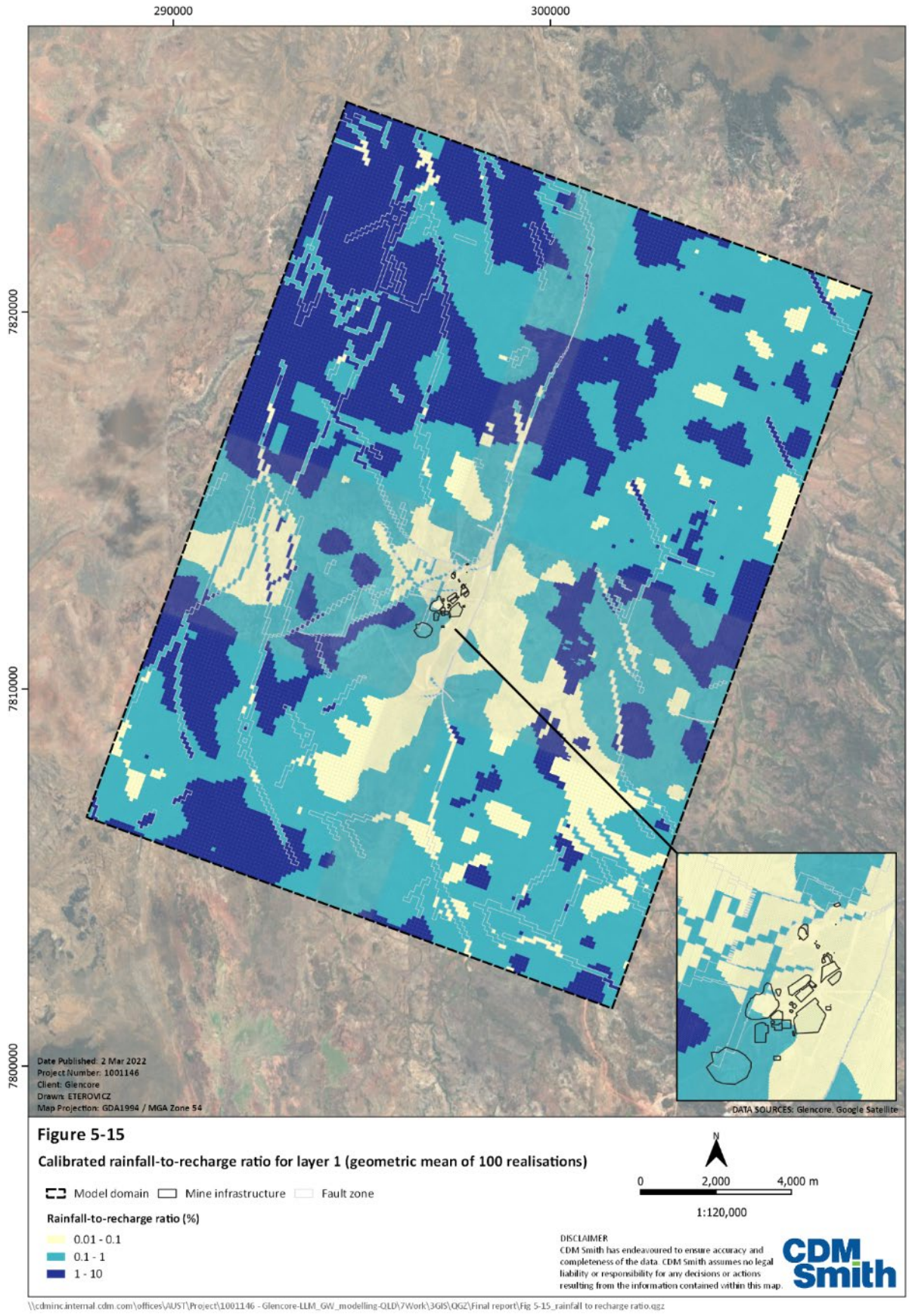


Figure 5-15 Calibrated Rainfall-to-Recharge Ratio for Layer 1 (Geometric mean of 100 realisations)

5.3.4 Calibrated Model Results

5.3.4.1 Calibrated Groundwater Level Contours

The calibrated groundwater levels (mean of 100 realisations) at the end of calibration period for layers 1 and 4 are shown in Figure 5-16 and Figure 5-17 respectively.

Both figures show that the relatively low fault permeability (Figure 5-11 and Table 5-3) has limited the majority of groundwater drawdown impact within the Lady Loretta Formation. The layer 1 contours show more influence from topography, while the layer 4 contours show a considerably lower water level as this layer hosts the majority of mining (i.e. larger drain cell extent and lower drain stages).

5.3.4.2 Calibrated Model Mass Water Balance

The calibrated model mass water balance (mean of 100 realisations) for the pre-mining period and at the end of calibration period is shown in Table 5-5. For the pre-mining period, inflows are dominated by rainfall recharge while outflows are dominated by groundwater ET and regional outflows (i.e. constant head fluxes). Most of the groundwater ET is expected to occur in low-lying areas where the water table is generally shallower. Groundwater discharge to the Lady Annie pit is relatively small, and river leakage is nil as groundwater levels are suppressed by ET.

At the end of calibration period, rainfall recharge is still the dominant inflow, albeit lower than the pre-mining period due to yearly fluctuations. There is also a notable increase in storage (note that storage inflow is a MODFLOW convention that actually represents reduction in groundwater storage) and regional groundwater inflows. The outflows are dominated by ET and groundwater extraction, with a notable increase in drain outflows due to the LLM underground workings and a decrease in regional groundwater outflows.

The model results show a mass balance percentage discrepancy of less than 1% for all times throughout the mining operation and post-mining period, which is acceptable based on requirements of the Australian Groundwater Modelling Guidelines (Barnett et al., 2012).

Table 5-5 Calibrated Mass Water Balance for the Pre-mining Period and at the End of Calibration (Mean of 100 realisations)

Inflow (kL/d)	Pre-mining period (31/03/2012)	End of calibration (31/03/2022)
Storage	500	822
Constant head	29	432
Recharge	5336	3594
Total	**5865**	**4849**
Outflow (kL/d)		
Storage	828	80
Constant head	1511	110
Wells	0	1582
Drains (LLM)	0	615
Drains (Lady Annie)	279	180
River leakage	0	0
ET	3249	2286
Total	**5867**	**4853**
Percent discrepancy	**-0.03%**	**-0.08%**

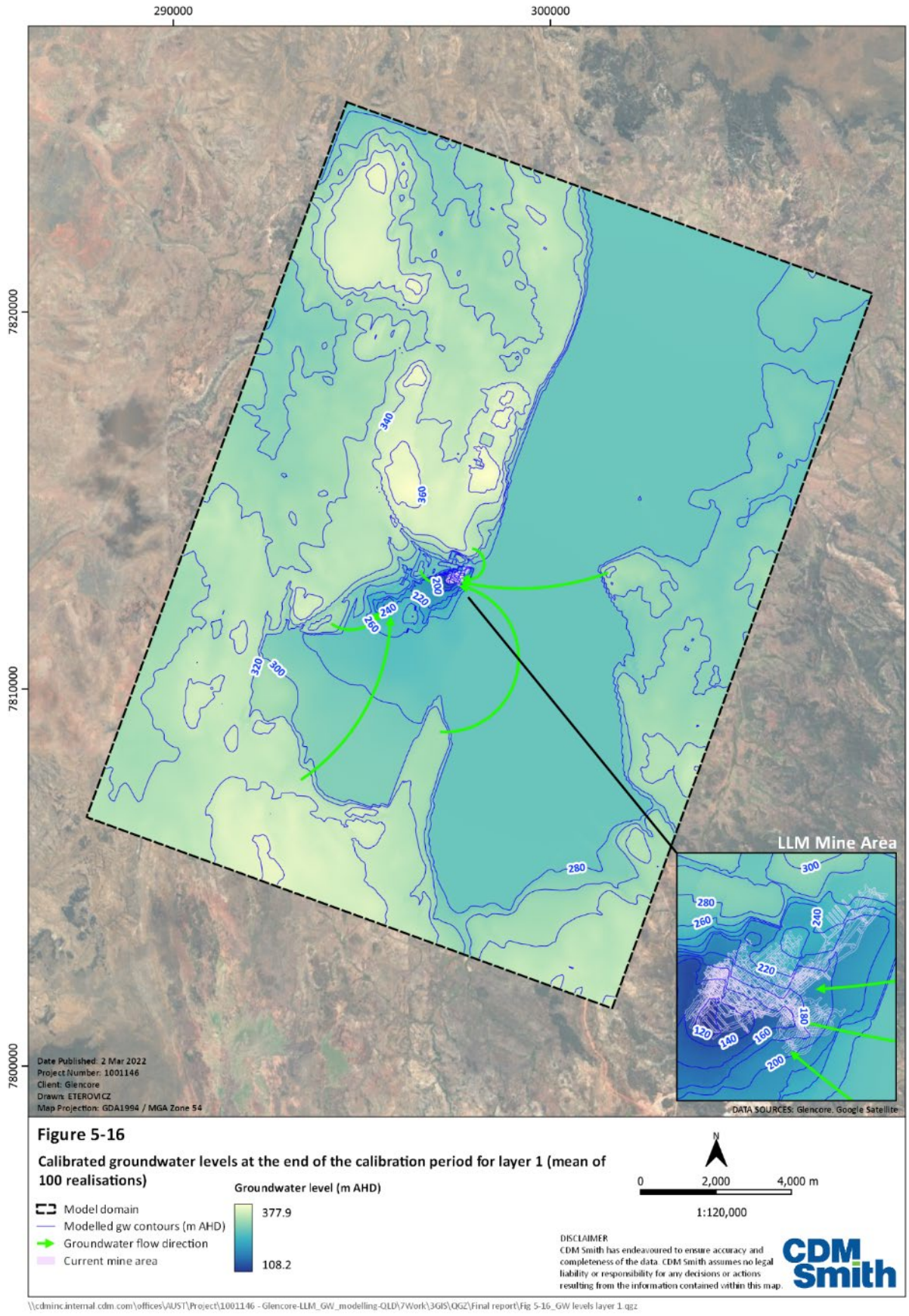


Figure 5-16 Calibrated Groundwater Levels at the end of Calibration Period for Layer 1 (Mean of 100 realisations)

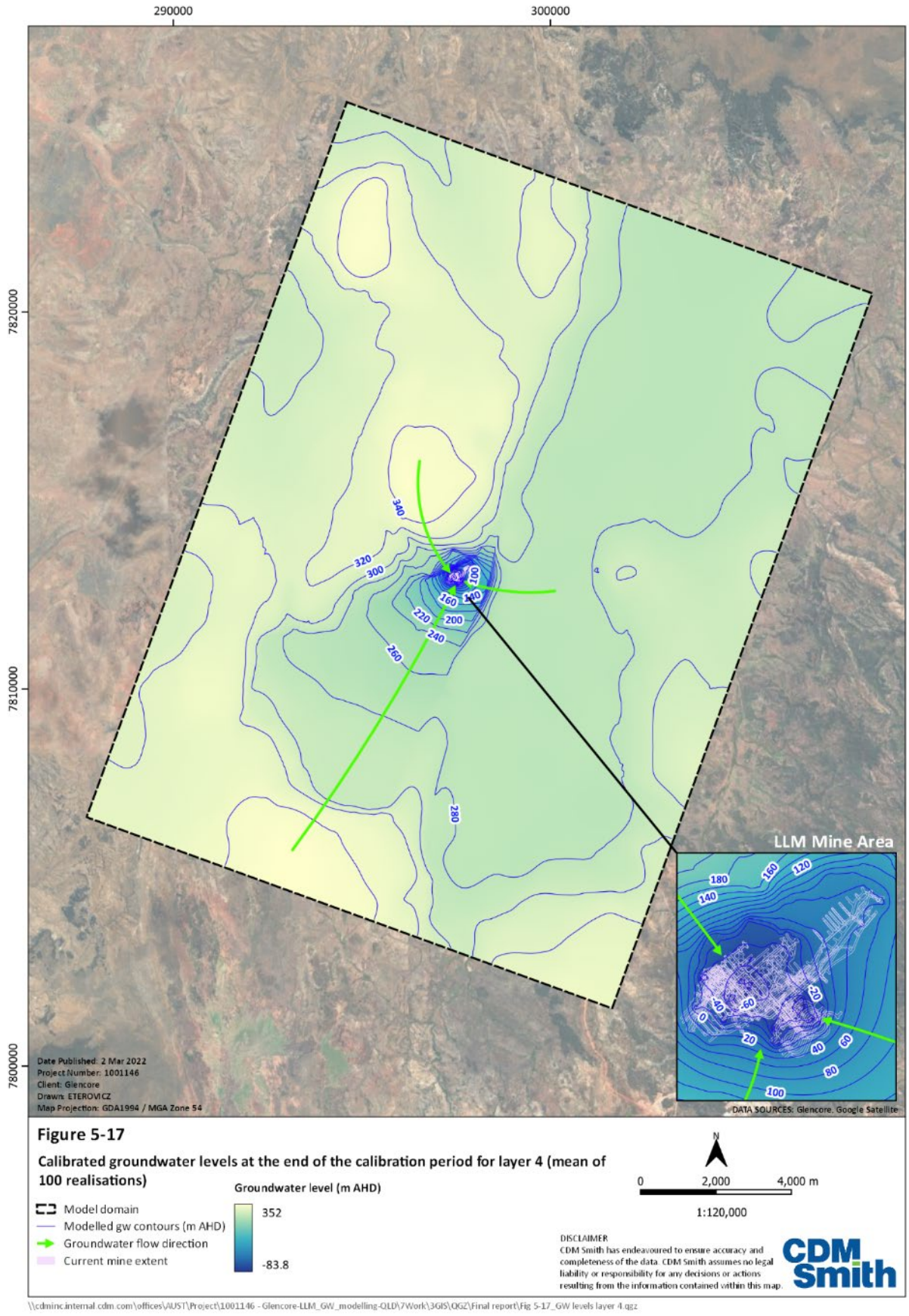


Figure 5-17 Calibrated Groundwater Levels at the end of Calibration Period for Layer 4 (Mean of 100 realisations)

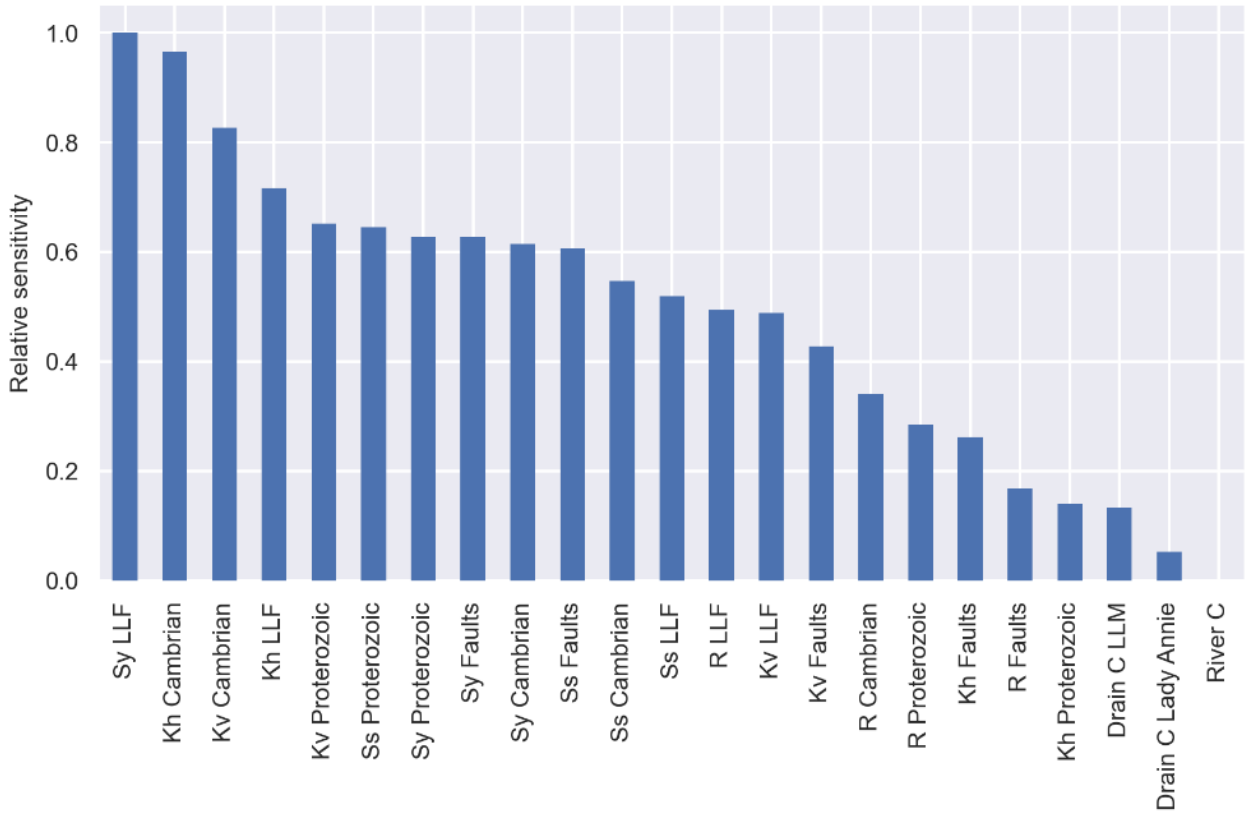
5.3.5 Sensitivity Analysis

Due to the stochastic approach adopted in this study, sensitivity analysis needs to be undertaken in a different manner using the concept of relative uncertainty reduction of parameter (Manewell and Doherty, 2021) that is defined as follows:

$$r_i = 1 - \frac{\sigma_i^{post}}{\sigma_i^{prior}}$$

where r_i is the relative uncertainty reduction of parameter i, σ_i^{prior} is the prior uncertainty of parameter i (i.e. the standard deviation of parameter i across the 100 realisations before calibration), and σ_i^{post} is the posterior uncertainty of parameter i (i.e. the standard deviation of parameter i across the 100 realisations after calibration). This approach is based on the rationale that the uncertainty (i.e. the standard deviation across the 100 realisations) of a more sensitive parameter would be reduced more by the calibration, and vice versa.

The min-max normalised parameter sensitivities are shown in Figure 5-18. The specific yield of Lady Loretta Formation (LLF) was found to be the most sensitive, possibly due to its control on the LLF response to the LLM underground workings and the inclusion of a flux calibration target. The hydraulic conductivity of Cambrian and LLF were also found to be sensitive, which is expected as these formations host the majority of groundwater level observation wells.



Kh = Horizontal hydraulic conductivity, Kv = Vertical anisotropy of hydraulic conductivity, Ss = specific storage, Sy = specific yield, R = rainfall-to-recharge ratio, C = Conductance, LLF = Lady Loretta Formation

Figure 5-18 Min-max Normalised Parameter Sensitivities

5.4 Model Predictions and Uncertainty Analysis

5.4.1 Prediction Approach

As discussed in Section 5.1, the Stage 1 objective of the LLM2021 groundwater flow model is to assess the groundwater flow fields during mining operation (already provided in Figure 5-16 and Figure 5-17), closure recovery and long-term new quasi-equilibrium. In addition, the LLM2021 model is to be used to estimate groundwater flux to the underground workings over time.

The scenario setup involves the following:

- Using the future mine plan between April 2022 and Dec 2025. Dewatering from the underground mine is scheduled to continue (to allow additional demolition waste from regulated dams to be disposed underground) until the end of 2032 and the mine is backfilled from 2033 onwards.
- Extending the latest pumping rates to December 2025, after which the pumping wells are deactivated for the post-mining period.
- Setting the future climate, including rainfall and ET rates, based on the average of last five years.
- A budget zone was set up for the LLM drain cells to estimate groundwater flux to the underground workings over time, especially for the post-dewatering period where the LLM drain cells are deactivated.

The stochastic modelling approach adopted in this study enables a more robust uncertainty analysis. Our approach is mathematically complex in that it involves sampling the posterior prediction space, which is a non-linear technique that is not subject to any linear assumptions between the model parameters and outputs. Despite the mathematical complexity, the uncertainty associated with the flux-to-mine estimates is presented in a straightforward manner where realisation results are shown individually to indicate the range of plausible possibilities that are supported by the field observations.

5.4.2 Prediction Groundwater Flow Fields

The predicted groundwater flow fields at the end of future dewatering (December 2032) and at the post-mining equilibrium (year 2250) are shown in Figure 5-19 and Figure 5-20 respectively.

Figure 5-19 shows that groundwater levels at LLM can be as low as -2 m AHD at the end of future dewatering, with the majority of drawdown impact limited to the Lady Loretta Formation.

Figure 5-20 shows that after more than 200 years into the future, the cone of depression caused by the LLM mining is predicted to be completely dissipated, with a groundwater level of approximately 280 m AHD in the vicinity of the former mine. In comparison, the Lady Annie pit is predicted to behave as a local groundwater sink where the groundwater level can be as low as 214 m AHD. The regional groundwater flow fields appear to follow the topography again.

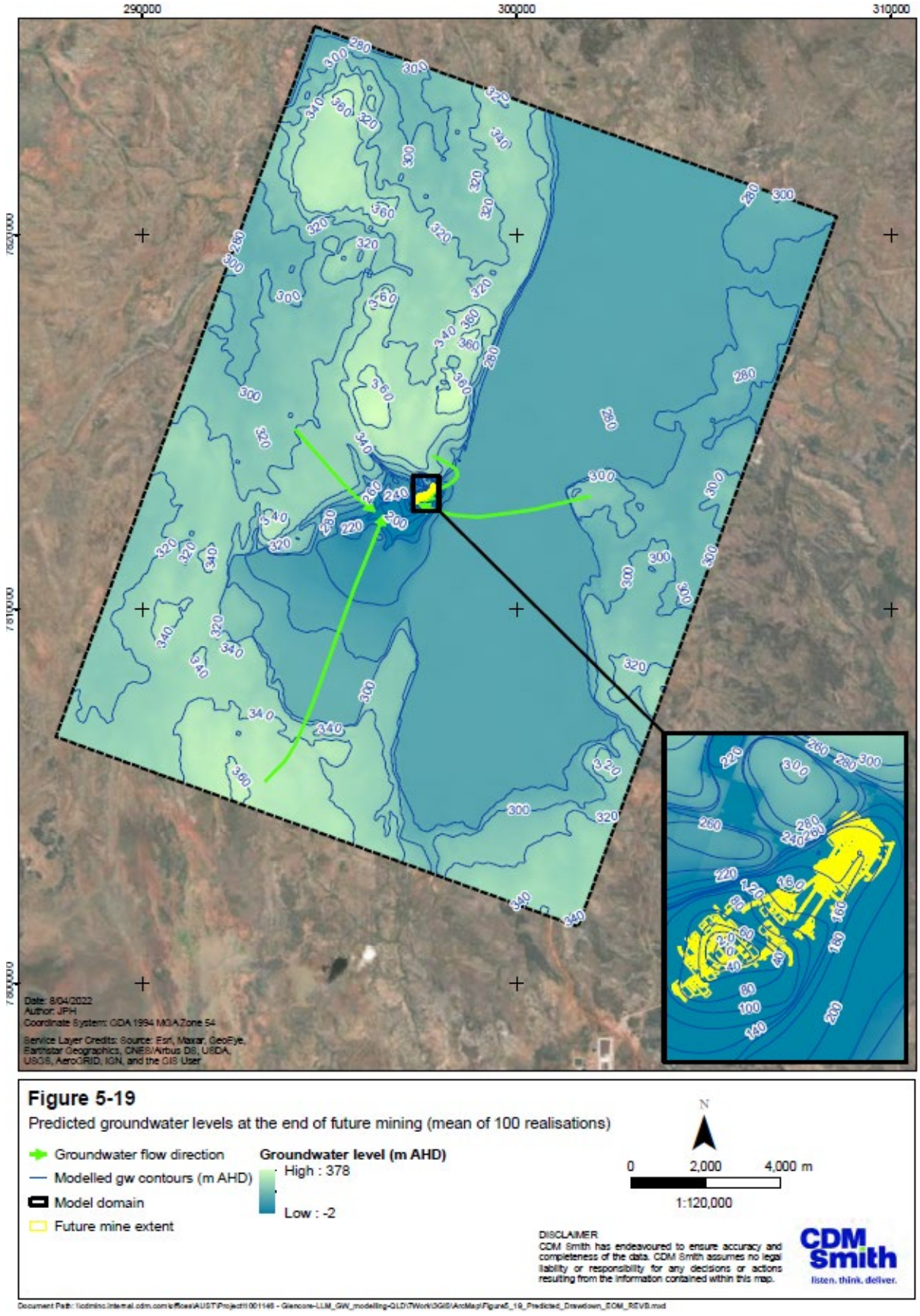


Figure 5-19 Predicted Groundwater Flow Fields at the end of Future Dewatering (Mean of 100 realisations)

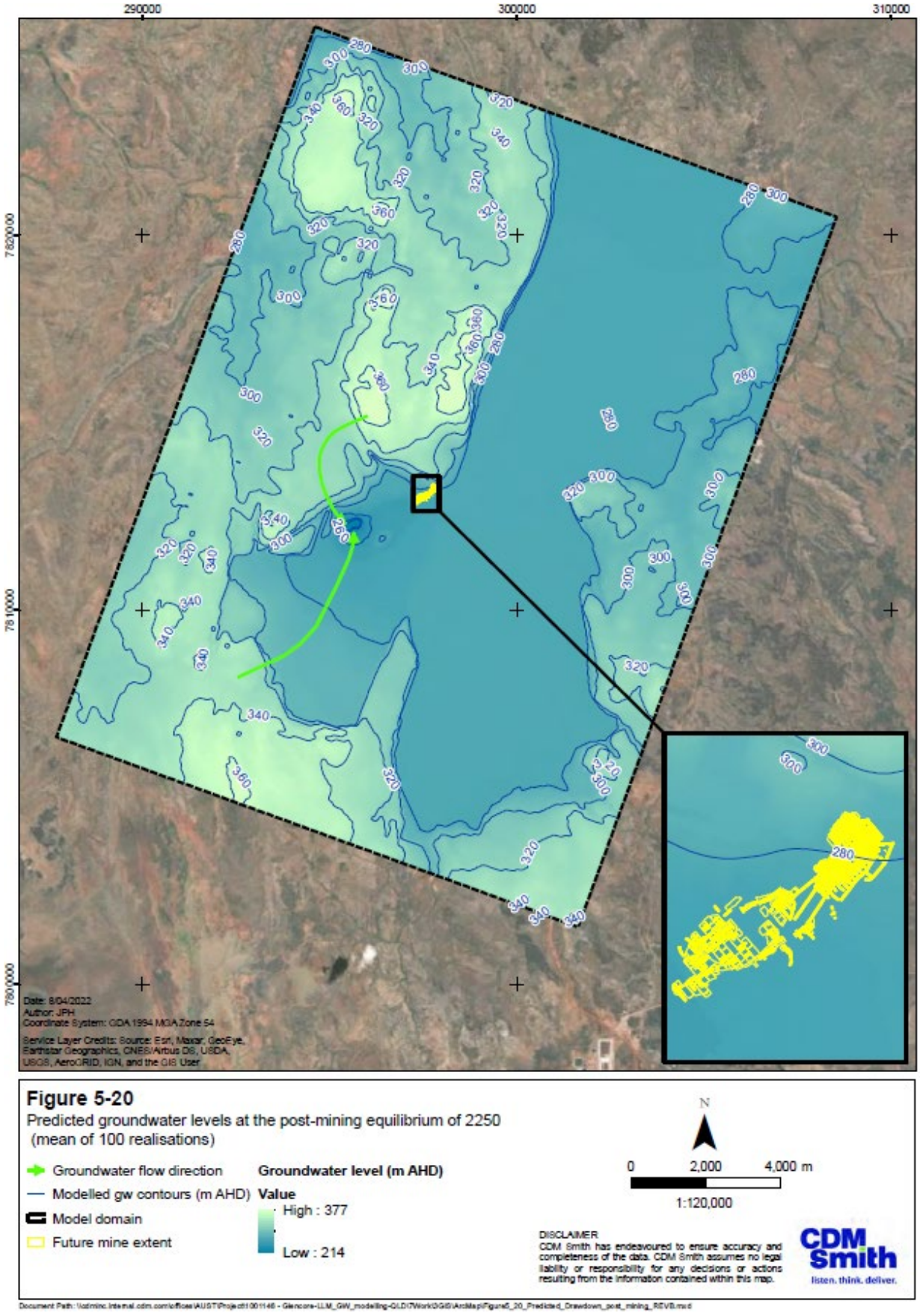


Figure 5-20 Predicted Groundwater Flow Fields at the Post-mining Equilibrium of 2250 (Mean of 100 realisations)

5.4.3 Predicted Groundwater Flux to Underground Workings

Groundwater fluxes to the underground mine workings over time predicted by the 100 calibrated realisations are shown in Figure 5-21. The semi-transparent lines represent the realisations individually and are an indicator of predictive uncertainty, while the solid line represents the mean of the realisations. The time axis is based on the number of years elapsed since the cessation of mining (Dec 2025).

The modelled flux is predicted to be approximately 630 kL/d at the cessation of mining, reducing over time as dewatering continues. As mine dewatering ceases to operate, groundwater inflow to the mine decreases rapidly as the heads in the backfilled mine voids rises. The modelled flux becomes stabilised at approximately 5 kL/d 50 to 60 years after the cessation of mining. A detail breakdown of modelled flux is shown in Table 5-6.

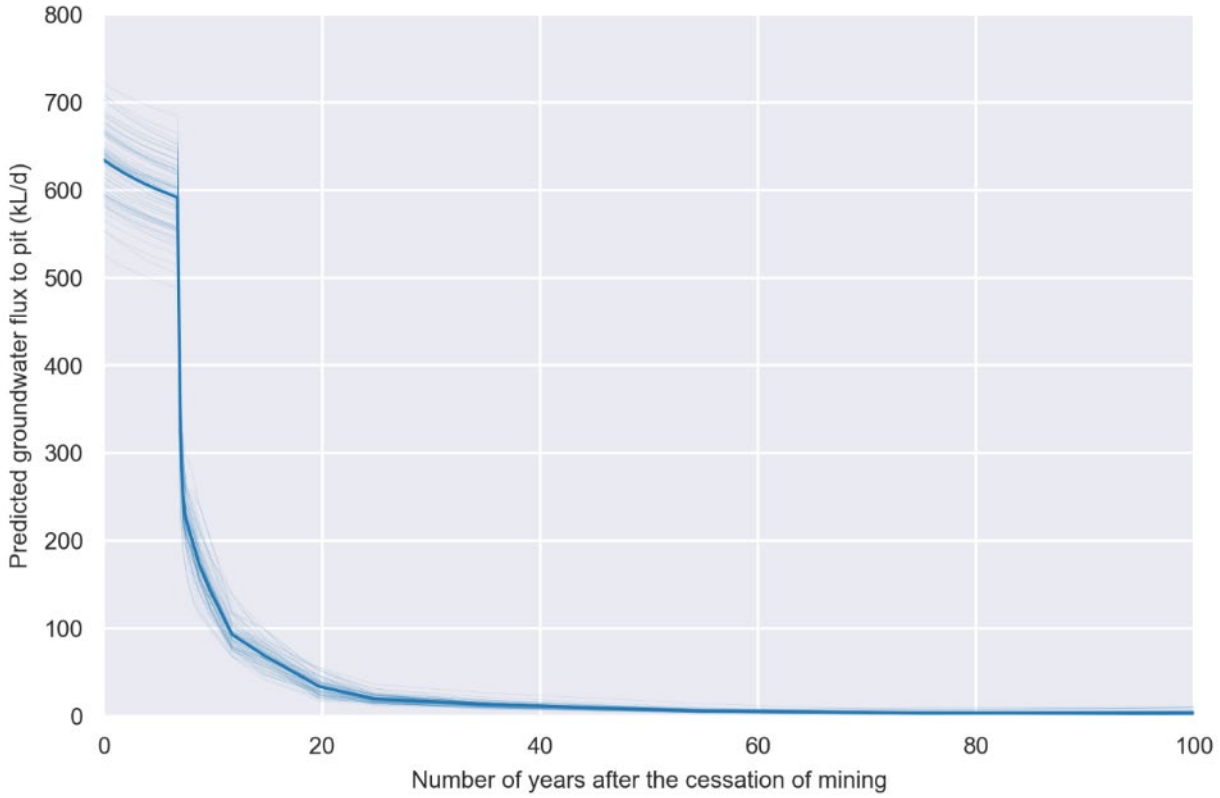


Figure 5-21 Predicted Groundwater Flux to the Underground Workings Over Time

A post closure conceptual model is shown in Figure 5-22 based on the available hydrogeological information and the numerical model results for post closure. Key features being:

- After more than 200 years into the future, the cone of depression caused by the LLM mining is predicted to be completely dissipated.
- Groundwater levels in the vicinity of the former LMM approximate 280 m AHD.
- The Lady Annie pit is predicted to behave as a local groundwater (evaporative) sink where the groundwater level can be as low as 214 m AHD.
- The regional groundwater flow fields appear to follow the topography (in a subdued manner).

Table 5-6 Predicted Groundwater Flux to the Underground Workings from the 100 Calibrated Realisations

Years elapsed since the cessation of mining	Mean flux (kL/d)	Minimum flux (kL/d)	Maximum flux (kL/d)
0	636.5	527.4	723.2
1	627.8	519.7	715.5
2	620.1	512.9	708.9
3	613.2	506.9	703.0
4	607.0	501.6	697.8
5	601.4	496.9	693.0
7	591.5	488.8	684.9
8	214.7	149.6	291.2
9	172.7	114.9	241.2
10	142.9	98.3	203.6
12	93.2	67.7	139.0
15	69.1	40.9	99.6
20	33.9	17.4	56.2
25	20.2	12.1	36.7
35	13.6	8.4	27.0
55	6.2	3.1	14.5
75	3.9	1.6	9.8
95	3.9	1.1	10.9

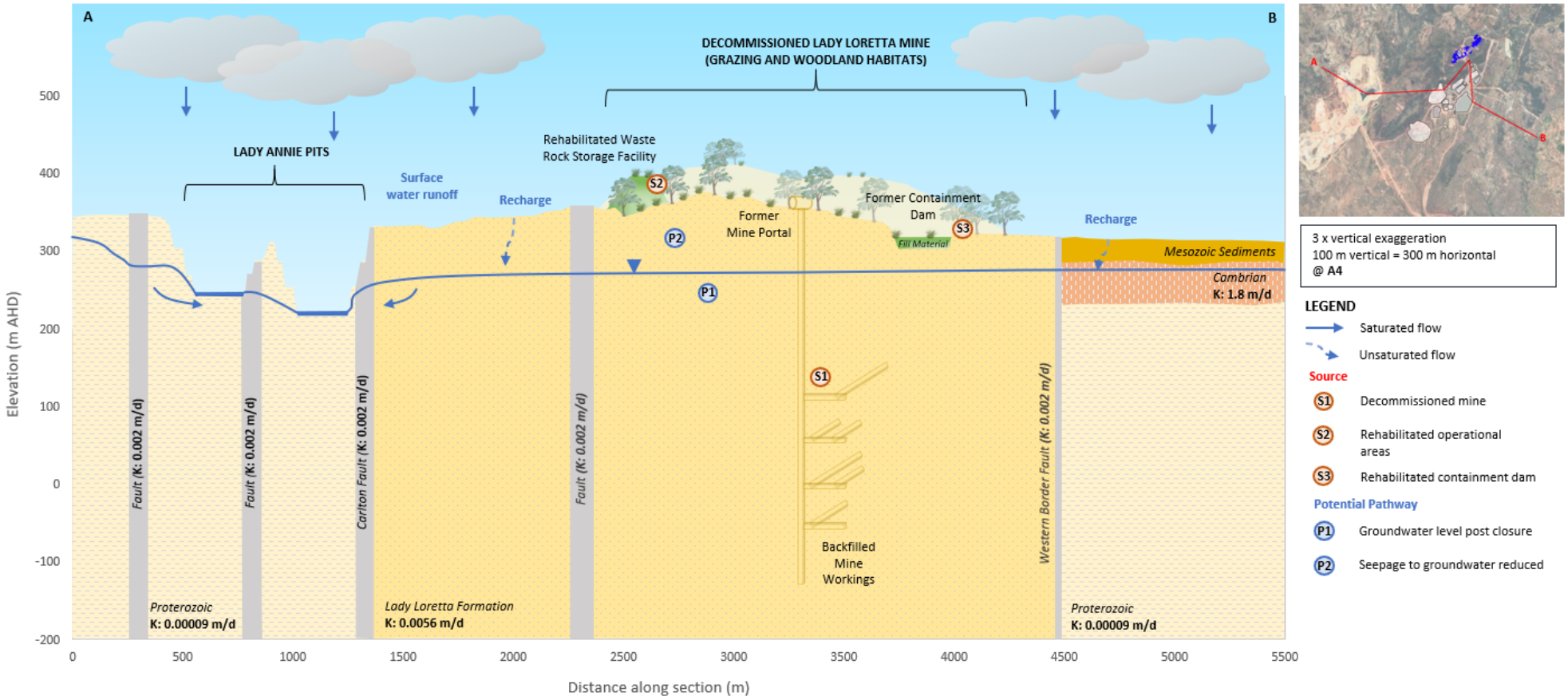


Figure 5-22 Conceptual Model – Post Closure

Section 6 Environmental Values and Contaminants of Concern

6.1 Environmental Values

The Environmental Values (EV) of waters and wetlands are protected under the Environmental Protection Water and Wetland Biodiversity Policy 2019. LLM is located within the Leichardt River water catchment plan, and the EVs for the project area are determined in accordance with Section 6 of the EPP Water and Wetland Biodiversity Policy. The identified EVs for the LLM receiving environment are:

- aquatic ecosystem protection.
- cultural and spiritual values.
- waters that may be used for agricultural purposes.
- waters that may be used for drinking water.
- industrial use of water.

The below subsections describe the assessed site EVs.

6.1.1 Aquatic Ecosystem Protection

A search of the Queensland Globe and Queensland Wetland Maps shows no listed Groundwater Dependent Ecosystems mapped in the area or within 10 kilometres of LLM. The Queensland GDE mapping and Wetland Maps are developed through consultation and the integration of expert knowledge with detailed spatial data.

Based on this review there are no mapped:

- Ecosystems dependent on the surface expression of groundwater (surface expression GDEs).
- Ecosystems dependent on the sub-surface presence of groundwater (terrestrial GDEs).
- Ecosystems dependent on the subterranean presence of groundwater (subterranean GDEs).

A search of the Bureau of Meteorology National Atlas Groundwater Dependent Ecosystems (GDE) shows two low to moderate potential aquatic GDE types, to the southeast of LLM (Figure 6-1). The GDE Atlas was released in 2012 and was produced by conducting a national scale assessment using remote sensing and GIS rules-based analysis, which mapped the potential for groundwater/ecosystem interaction.

The two potential GDE locations are located over four kilometres southeast of LLM. No data is available in the area to directly assess the groundwater table and GDEs. Based on the available information the Cambrian units are overlain by surficial alluvium and Mesozoic sediments, varying in thickness up to 25 m. The depth of the groundwater is assumed to be greater than 30 m below surface and the overlying Quaternary and Mesozoic units are likely rarely saturated.

6.1.2 Cultural and Spiritual Values

Cultural and spiritual values may include custodial, spiritual, cultural and traditional heritage, hunting, gathering and ritual responsibilities. No cultural and spiritual values have been identified for groundwater in the project area.

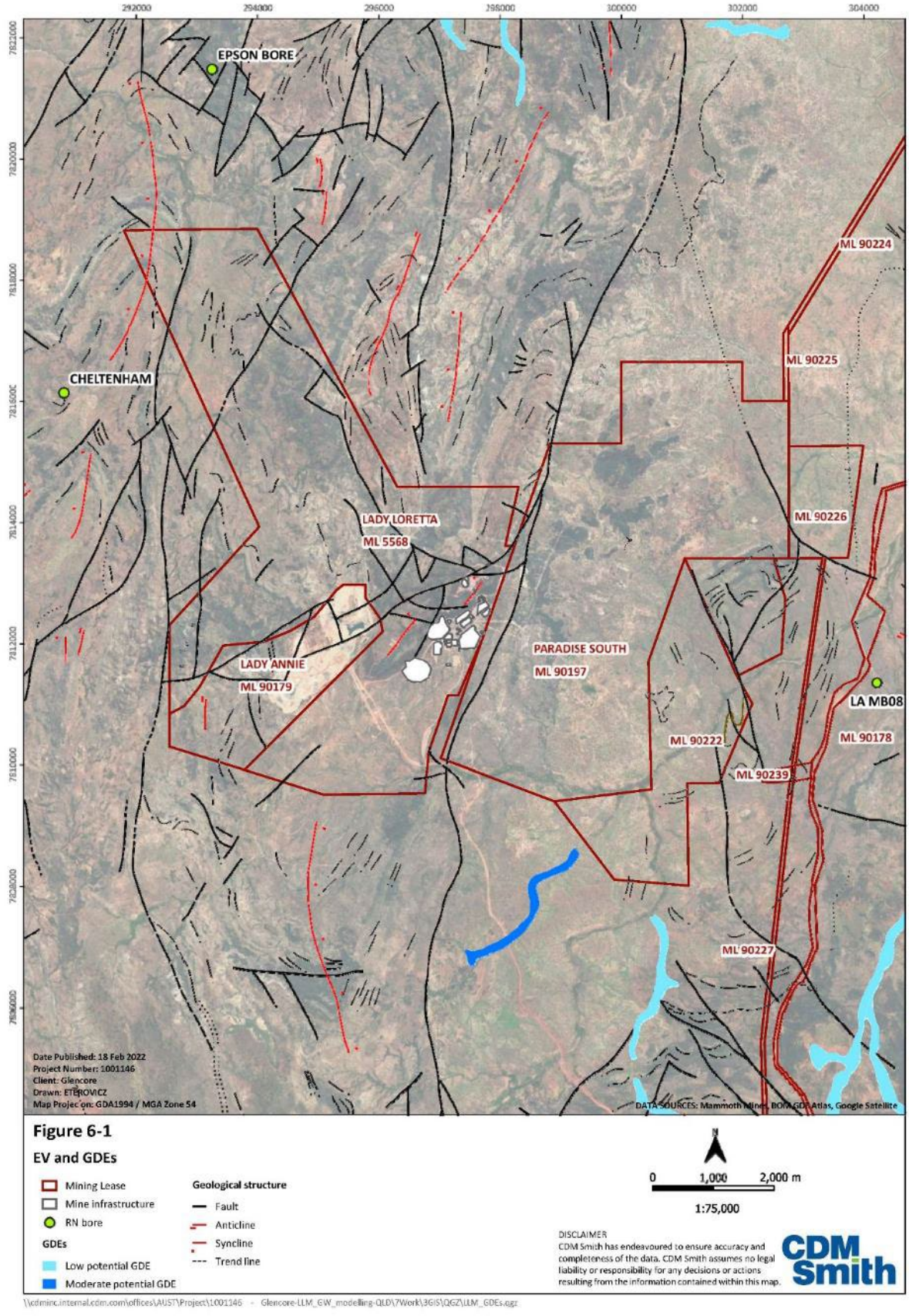


Figure 6-1 Environmental Values and Potential Groundwater Dependent Ecosystems

6.1.3 Agricultural / Industrial Use and Potable Water

A search of the Queensland Government groundwater database of registered bores within 10 kilometres of the LLM site was conducted:

- Within 5 km of LLM, there are 42 registered groundwater bores, with 39 bores listed or identified as related to mining activities and 3 abandoned. As such, there are no known or identified registered water supply stock or domestic bores within 5 kilometres of the LLM site.
- Between 5 and 10 kilometres of the LLM site there are three registered bores (RN32777 Epson bore and RN51356 Cheltenham bore to the northeast, and RN146610 LAMB08 to the west). The two registered bores RN32777 and RN51356 have no listed role shown in the registered bore report and RN146610 LAMB08 is listed as mine monitoring.

The two main users of groundwater for industrial use in the area are LMM and Lady Annie Mine. LLM sources raw water from the LAE bore field for use in the process, underground, paste mix water, fire water, dust suppression and potable water system feed water.

In addition, potable water for the site is produced at the LLM reverse osmosis water treatment plant for use across the mine and camp operation as drinking and sanitary purposes.

6.2 Environmental Values - Potential Risks

The potential environmental risks to EVs due to LLM's operations and closure have been considered and include the following:

- Operational and Closure Risk of seepage of contaminated water to underlying groundwater from water management infrastructure including Containment Dam A (CDA), Containment Dam B (CDB), the Paste Plant Dam (PPD) and the Leachate Management Dam (LMD).
- Operational Risk of seepage of contaminated water to underlying groundwater from Run of Mine (ROM) Pad and other operational areas.
- Operational and Closure Risk of acidic metalliferous drainage (AMD) developing in response to oxidation of sulphides in the underground mine workings, Waste Rock Emplacement (WRE), Leachate Management Dam (LMD) stockpile and legacy PAF mine waste.

6.3 Contaminants of Concern Sources and Water Quality

6.3.1 Surface Contaminants of Concern Sources

LLM containment structures have been assessed in accordance with the Manual for Assessing Consequence Categories and Hydraulic Performance of Structures resulting in a 'significant' consequence category on the basis that both, failure to contain overtopping and dam break failure scenarios result in general environmental harm of the downstream receiving environment (LLM, 2021b). All LLM containment structures therefore meet the criteria of a 'Regulated Structure' (dam) and must be designed, constructed and operated in accordance with the Manual and Schedule D of the LLM EA (LLM, 2021b). The Regulated Dams at LLM include:

- Containment Dam A (CDA)
- Containment Dam B (CDB)
- Paste Plant Dam (PPD)
- Leachate Management Dam (LMD)

The sources of potential contaminants of concern (COCs) for each containment structure are shown in Table 6-1.

Table 6-1 Potential COC Sources for each Containment Structure (LLM, 2021b)

Containment Structure	Potential Contaminants
Containment Dam A	Metal ore, AMD, hydrocarbons.
Containment Dam B	PAF waste rock, AMD, hydrocarbons.
Paste Plant Dam	Tailings, AMD, cement, batch plant reagents, hydrocarbons.
Leachate Management Dam	PAF waste rock, acid and metalliferous mine drainage.

According to Glencore's internal LLM Detailed Closure Plan, once the dams are no longer required during the rehabilitation process they will be decommissioned and rehabilitated subject to final landowner or third party user agreements (LLM, 2021a). As the containment dams are regulated structures under the environmental authority, each will require a decommissioning plan (LLM, 2021a). As part of the LLM closure strategy, the regulated dams will be decommissioned. LMD is planned for decommissioning in 2028 and the remaining regulated dams are planned for decommissioning in 2044. Decommissioning and rehabilitation of CDA, CDB and PPD can only occur after major works are completed in the catchments generating mine-affected waters and dewatering of the underground workings has been discontinued. Closure works have been completed within the LMD catchment, which has involved rehandling and removal of the LMD Stockpile to the Waste Rock Emplacement, as well as excavation and removal of additional mineralised material and placement of inert fill followed by revegetation works within the legacy mine area. Mine affected waters within the LMD catchment area have been reduced and once works have been effective in mitigating the risks presented in the receiving environment the dam cam be decommissioned.

The decommissioning process for the dams will include:

- Removal of any accumulated sediments and HDPE liners.
- Assessing the contaminated land risk and where necessary implementing remediation measures.
- Removal of leak detection system, piezometers, monitoring equipment (if present).
- Lowering the invert level of the emergency spillways.
- Pushing in sides and partial recontouring of the containment embankments to achieve the Final Landform profile.
- The above decommissioning process will ensure dams are no longer a source of COC.

6.3.2 Water Class and Water Quality

LLM has established water classes to define the different types and quality of water encountered at LLM (LLM, 2021b). The below subsections describe the established water classes.

6.3.2.1 Process Water

Process water describes water sourced from Containment Dam A for use as paste mix water and dust suppression within the LLM containment area. The water held in CDA is sourced from:

- Stormwater runoff within the CDA catchment.
- Brine from the CDA Water Treatment Plant (WTP) and potable water reverse osmosis plant.
- Water transfers from other site water storages - Containment Dam B and the Paste Plant Dam.
- Underground dewatering and water discharged from site oil water separators.

- Wheel wash wastewater and clean in clean out laundry wastewater.

The water quality contained in the CDA is characterised by elevated electrical conductivity and sulphate concentration and total metals including Aluminium, Cobalt, Lead, Nickel, Zinc and Iron (Table 6-2).

Table 6-2 CDA Water Quality Results (COCs)

Analyte	Units	Minimum	Mean	Maximum	Sample Count
pH	n/a	5.9	7.2	8.0	10
EC	µS/cm	3580.0	4468.0	5170.0	10
TSS	mg/L	10.0	37.9	73.0	10
Sulfate	mg/L	2420.0	3116.0	3580.0	10
Chloride	mg/L	58.0	66.0	74.0	10
Calcium	mg/L	576.0	647.4	741.0	10
Magnesium	mg/L	254.0	350.9	428.0	10
Sodium	mg/L	105.0	130.6	160.0	10
Potassium	mg/L	77.0	86.8	96.0	10
Aluminium	mg/L	0.02	0.44	1.07	10
Arsenic	mg/L	0.002	0.006	0.018	10
Cadmium	mg/L	0.010	0.040	0.080	10
Chromium	mg/L	<0.001	<0.001	<0.001	10
Cobalt	mg/L	0.103	0.221	0.310	10
Copper	mg/L	0.002	0.013	0.027	10
Lead	mg/L	0.076	0.359	1.530	10
Molybdenum	mg/L	0.004	0.010	0.031	10
Nickel	mg/L	0.038	0.074	0.107	10
Selenium	mg/L	<0.01	<0.01	<0.01	10
Zinc	mg/L	7.480	24.878	45.200	10
Boron	mg/L	0.120	0.154	0.200	10
Iron	mg/L	0.200	3.958	8.840	10
Mercury	mg/L	<0.0001	<0.0001	<0.0001	10

6.3.2.2 Waste Rock Leachate

PAF waste rock produced by mining operations that cannot be placed in underground voids is transferred to the surface and placed in the WRE. The WRE has been engineered to safely store PAF waste rock, limit seepage and direct runoff and leachate to Containment Dam B. PAF waste placed on the WRE is treated with hydrated lime and compacted in 1 metre lifts to limit oxidation processes and neutralise acid production. Water held in CDB is periodically transferred to CDA in accordance with the transfer rules stipulated in the Regulated Dam Operational Plan.

The water quality contained in the CDB is characterised by elevated electrical conductivity and sulphate concentration and total metals including Aluminium, Arsenic, Cadmium, Chromium, Cobalt, Copper, Lead, Nickel, Zinc and Iron (Table 6-3).

Table 6-3 CDB Water Quality Results (COCs)

Analyte	Units	Minimum	Mean	Maximum	Sample Count
pH	n/a	1.8	3.6	8.6	47
EC	µS/cm	3040.0	9081.5	33300.0	47
TSS	mg/L	5.0	46.9	813.0	46
Sulfate	mg/L	1380.0	8272.8	40600.0	47
Chloride	mg/L	24.0	133.6	400.0	47
Calcium	mg/L	286.0	522.7	793.0	47
Magnesium	mg/L	81.0	973.9	5050.0	47
Sodium	mg/L	23.0	121.6	349.0	47
Potassium	mg/L	1.000	76.021	251.000	47
Aluminium	mg/L	0.02	190.3	1240.0	47
Arsenic	mg/L	0.001	0.084	0.798	47
Cadmium	mg/L	0.001	1.032	6.770	47
Chromium	mg/L	0.001	0.042	0.327	47
Cobalt	mg/L	0.003	2.617	16.700	47
Copper	mg/L	0.003	2.586	19.400	47
Lead	mg/L	0.015	0.924	3.900	47
Molybdenum	mg/L	0.001	0.006	0.052	45
Nickel	mg/L	0.007	1.339	8.890	47
Selenium	mg/L	0.010	0.034	0.520	44
Zinc	mg/L	0.222	722.865	4610.000	47
Boron	mg/L	0.050	0.279	0.630	46
Iron	mg/L	0.050	943.212	5610.000	47
Mercury	mg/L	0.0001	0.0001	0.0002	44

6.3.2.3 Mine Dewatering

LLM mine dewatering activities results in approximately 1 ML/d of water pumped to the surface for storage in either CDA or PPD. Due to the high suspended solids loads produced, all mine dewatering is directed to either the CDA or PPD sediment dams to remove solids prior to entering either water storage. Water held in PPD is periodically transferred to CDA in accordance with the transfer rules stipulated in Regulated Dam Operational Plan.

The water quality contained in the PPD is characterised by elevated electrical conductivity and sulphate concentration and total metals including Aluminium, Arsenic, Cadmium, Chromium, Cobalt, Copper, Lead, Nickel, Zinc and Iron (Table 6-4).

Table 6-4 PPD Water Quality Results (COCs)

Analyte	Units	Minimum	Mean	Maximum	Sample Count
pH	n/a	4.5	6.8	7.9	23
EC	µS/cm	2330.0	4006.1	8560.0	23
TSS	mg/L	5.0	6764.6	135000.0	20
Sulfate	mg/L	1510.0	2798.7	6350.0	23
Chloride	mg/L	25.0	54.6	164.0	23
Calcium	mg/L	314.0	512.6	717.0	23
Magnesium	mg/L	150.0	347.3	1320.0	23
Sodium	mg/L	34.0	79.8	234.0	23
Potassium	mg/L	20.0	72.0	181.0	23
Aluminium	mg/L	0.01	45.6	1000.0	22
Arsenic	mg/L	0.001	3.029	69.6	23
Cadmium	mg/L	0.005	0.338	7.100	23
Chromium	mg/L	0.001	0.086	1.700	20
Cobalt	mg/L	0.049	0.801	15.000	23
Copper	mg/L	0.001	2.341	53.700	23
Lead	mg/L	0.002	47.163	1080.000	23
Molybdenum	mg/L	0.001	0.083	1.730	23
Nickel	mg/L	0.018	0.235	4.020	23
Selenium	mg/L	0.010	0.015	0.100	20
Zinc	mg/L	2.280	186.589	3870.000	23
Boron	mg/L	0.050	0.162	0.450	23
Iron	mg/L	0.050	770.859	16700.000	22
Mercury	mg/L	0.0001	0.0001	0.0010	20

6.3.3 Subsurface Contaminant Sources

The subsurface contaminant sources are the mine workings (backfilled with paste produced from tailings), the base of the modern WRE, and the base of the legacy PAF storage.

The water quality contained in the LMD is characterised by elevated electrical conductivity and sulphate concentration and total metals including Aluminium, Arsenic, Cadmium, Chromium, Cobalt, Copper, Lead, Nickel, Zinc and Iron (Table 6-5).

Table 6-5 LMD Water Quality Results (COCs)

Analyte	Units	Minimum	Mean	Maximum	Sample Count
pH	n/a	2.3	2.6	3.0	6
EC	µS/cm	1750.0	11358.3	39500.0	6
TSS	mg/L	9.0	179.6	1460.0	14
Sulfate	mg/L	935.0	14521.7	86900.0	14
Chloride	mg/L	5.0	49.0	170.0	14
Calcium	mg/L	93.0	318.3	720.0	14
Magnesium	mg/L	48.0	947.2	5400.0	14
Sodium	mg/L	2.0	31.2	112.0	14
Potassium	mg/L	1.0	6.4	24.0	14
Aluminium	mg/L	35.0	711.6	4400.0	14
Arsenic	mg/L	0.010	0.547	5.650	14
Cadmium	mg/L	0.199	3.602	18.100	14
Chromium	mg/L	0.004	0.077	0.539	14
Cobalt	mg/L	0.231	4.328	23.900	14
Copper	mg/L	0.581	8.917	55.500	14
Lead	mg/L	0.009	0.184	0.412	14
Molybdenum	mg/L	0.001	0.018	0.105	14
Nickel	mg/L	0.154	2.869	16.500	14
Selenium	mg/L	0.010	0.179	1.050	14
Zinc	mg/L	108.000	2494.643	12500.000	14
Boron	mg/L	0.050	0.541	5.000	14
Iron	mg/L	38.200	847.800	4430.000	14
Mercury	mg/L	0.0001	0.0003	0.002	14

According to the LLM supplied information, selected below ground infrastructure is to be decommissioned in accordance with the demolition study. Backfilling of the underground working will begin from 2033 onwards, with backfilling defined as backfilling the upper section of the mine decline and upper section of the ventilation shafts only.

6.4 Potential Exposure Pathways from COC Sources to Receptors

A potential exposure pathway is the route along which a COC might move through the environment from its source to a receptor. Potential pathways considered for the site are presented in Table 6-6. In summary, four pathways are considered relevant with respect to connection of the source (exposed containment structures, waste rock, underground workings) to EVs.

Table 6-6 Identified Pathways

Pathways (P)	Description
P1	Groundwater inflow to the underground workings and contact of water with exposed oxidised rock / materials.
P2	Vertical or lateral migration of solutes from the underground workings to the external groundwater.
P3	Abstraction and use (environmental values) of groundwater external to the mine infrastructure.
P4	Seepage of contaminated water from waste landforms and containment dams to underlying groundwater.

Post closure, the regulated dams will be decommissioned. LMD is planned for decommissioning in 2028 and the remaining regulated dams are planned for decommissioning in 2044. The primary aquifer recharge mechanisms will consist of direct infiltration via rainfall and infiltration associated with any surface water flow paths. Discharge mechanisms will remain unchanged, with any changes associated with groundwater flow related to any changes in mining activities occurring such as the Lady Annie site. The changes relating to future mining activities cannot be quantified at this time.

The development of the source-pathway-receptor model included assessment of the following:

- Sources of contamination or site activities that can cause contamination.
- Pathways by which contaminants can or may infiltrate to the local water table and then migrate via groundwater flow pathways.
- Receptor of the pollution who or what could be affected due to LLMs operations and closure.

The summary shown in Table 6-7 has been colour coded with:

- Orange indicating an open path based on the site setting and activities there is the potential for this pathway to be open.
- Green indicating the pathway is closed with either of the source, pathway and receptor elements closed. However long term monitoring of the groundwater monitoring and seepage detection bores will be required to confirm the success of the rehabilitation and removal of all source contaminants.

Table 6-7 Source, Pathway and Groundwater Receptor Summary

Current Operations			Post Closure[1]		
Source	**Pathway**	**Groundwater Receptor**	**Source**	**Pathway**	**Groundwater Receptor**
Mine workings, the base of the modern WRE, Leachate Management Dam stockpile and the base of the legacy PAF storage.	Groundwater inflow to the underground workings and contact of water with exposed oxidised rock / materials. Vertical or lateral migration of solutes from the underground workings to the external groundwater Abstraction of groundwater external to the mine infrastructure.	Industrial Use and Drinking Water Stock Water Aquatic Ecosystem Protection	Below and above ground infrastructure is to be decommissioned and the shafts and portal will be backfilled with suitable material, and demolition waste and sealed with a concrete plug.	Groundwater inflow to the underground mine workings reduced due to decommissioning and no longer possible through the modern WRE and PAF storage as the site has been successfully rehabilitated and all COC sources removed.	Industrial Use and Drinking Water Stock Water Aquatic Ecosystem Protection
Run of Mine (ROM) Pad and other operational areas.	Seepage of contaminated water to underlying groundwater. Abstraction of groundwater external to the mine infrastructure.	Industrial Use and Drinking Water Stock Water Aquatic Ecosystem Protection	Stockpiles, ROM and pads, roads etc removed and land rehabilitated so site activities benign.	Seepage of potential contaminants into groundwater no longer possible as site has been successfully rehabilitated and all COC sources removed.	Industrial Use and Drinking Water Stock Water Aquatic Ecosystem Protection
Seepage of contaminated water to underlying groundwater from water management infrastructure including CDA, CDB, PPD and LMD.	Seepage of contaminated water to underlying groundwater. Abstraction of groundwater external to the mine infrastructure.	Industrial Use and Drinking Water Stock Water Aquatic Ecosystem Protection	According to the LLM Detailed Closure Plan once the dams are no longer required during the rehabilitation process they will be decommissioned and rehabilitated.	Seepage of potential contaminants into groundwater no longer possible as site has been successfully rehabilitated and all COC sources removed.	Industrial Use and Drinking Water Stock Water Aquatic Ecosystem Protection

[1] Closure evaluation assumes all materials will be removed from site and there is no contaminant leachate at depth

Section 7 Solute Transport Modelling

7.1 Model Selection and Assumptions

The solute transport modelling objective is to predict the potential fate and transport of COCs in groundwater underlying the storage and backfilled underground areas, that have been identified as potential source of contamination, including:

- Containment Dam A (CDA)
- Containment Dam B (CDB)
- Paste Plant Dam (PPD)
- Leachate Management Dam (LMD)
- Backfilled underground galleries

The transport modelling is conducted with MODFLOW USG Transport (Panday, 2019). The transport component is added onto the predictive model scenario comprising mining operation and post-mining operations (cf. section 5.4). The aquifers parameters are from the best calibrated groundwater flow model (section 5.3) which estimated plausible aquifer hydraulic properties as well as recharge and discharge processes.

The transport approach is normalised. In a normalised approach, the individual concentrations are not provided in an absolute value (i.e. concentration in mg/L), but they are expressed as a percentage of the source concentration. The benefit of the normalised approach is that it is not COC species specific and can be applied to any non-reactive inorganic CoC. The normalised approach is suitable for the adopted conservative approach as some retardation or decay processes that could be specific to some chemical species are neglected. For the simplification of the normalised approach the background concentration (i.e. the natural pre-mining concentration of contaminant in groundwater) is set to zero. For a potentially present COC as background concentration, the normalised approach provides results that are an offset to the background concentration (i.e. the 0% contour reflects the background concentration and the 100% represents the source concentration which can be interpreted as being the background concentration plus an “added contamination concentration”. All the percentile contours are representing the residual of the “added contamination concentration”).

The physical and chemical processes that affect the fate and transport of dissolved groundwater contaminants include advection, hydrodynamic dispersion, molecular diffusion, adsorption, dilution and degradation. The combined effect of those processes controls how long a contaminant plume will grow, remain stable, or shrink. The processes can be described briefly as:

- Advection is the component of solute movement attributed to transport by the flowing groundwater. Advection is typically the dominant factor in transporting dissolved COCs.
- Hydrodynamic dispersion is a physical process whereby dissolved constituents spread at the pore-scale level, leading to larger-scale macroscopic spreading, both horizontally and vertically away from the centre of the plume mass. Dispersion is controlled by aquifer heterogeneity, temporal variations in the hydraulic gradient and the size and location of the initial plume. Dispersion is stronger in the direction of flow (the longitudinal dispersion) than in direction normal to the flow line (transverse dispersion). Though dispersion in the transverse direction is a much weaker process than dispersion in the longitudinal direction, at low velocities where molecular diffusion is the dominant dispersive mechanism, the coefficients of longitudinal and transverse dispersion can approach each other, i.e. become nearly equal.
- Molecular diffusion is a physical process whereby molecules move from an area of higher concentration to an area of lower concentration, and the rate of diffusion is typically overshadowed by advective and dispersive forces. However, molecular diffusion is often a significant factor in the pore-scale transfer of COC mass, and in

certain low permeability geologic formations with very slow advective movement, and correspondingly slow dispersive forces.

- Adsorption is a chemical process whereby dissolved COCs interact with and are 'captured' on the surface of solids. Adsorption of dissolved constituents onto subsurface materials is a phenomenon known to retard plume movement relative to groundwater. Adsorption is often described by the retardation factor which quantifies how many times slower a dissolved constituent moves relative to the average linear groundwater velocity.
- Dilution is the mixing of contaminated water with water of lower concentration leading to a reduction of concentration.
- Degradation processes are biological and chemical processes that decrease the mass of some dissolved constituents. These processes include the effects of biodegradation, photolysis, oxidation-reduction, and hydrolysis. They are generally grouped into either biologic or abiotic (chemical) degradation processes.

The modelling approach adopted in this assessment is considered conservative as it does not take into account all the aforementioned attenuation processes that reduce the concentration of COCs along the groundwater flow path. A conservative approach does not aim at making exact predictions, but aims at overestimating the potential impact related to the predictions. Conservative approaches are often adopted within impact assessments as it keeps the predictive uncertainty on the side of overestimation. Therefore, whenever the overestimated impacts remain within acceptable bounds, as in, no valued assets (i.e. environmental) are likely not to be affected by the project, the results can be considered reliable and do not require more detailed analyses

As part of the conservative approach the model is predicting advective and dispersive transport, with these processes tending to slow or reduce the contamination. Diffusion is not considered further as it is a small component of the overall fate and transport (Panday, 2019). Any adsorption and degradation processes have also not been considered further due to the conservative model approach.

Other conservative assumptions associated with this model comprise:

- The dam construction are not captured in the model development. The dam construction consists of CDA, CDB and PPD being HDPE lined and LMD is GCL lined. The dams therefore do have engineering containment features which the modelling excludes based on the conservative approach adopted. There is no evidence to show there is any contamination coming from the surface water dams, storage facilities or stockpile area so the contribution from this source is extremely conservative.
- For the source of contamination located at ground surface (CDA, CDB, PPD, LMD) the source of contamination was set directly at the water table, with the transport processes within the unsaturated zone not considered further. This is a conservative assessment as it assumes that the contamination crosses the unsaturated zone without delay nor decay.
- The sources of contamination are assumed constant for the whole simulation (running 220 years post-mining). For the surface water dams, the persistence of contamination release post-mining is conservative as site rehabilitation post-mining will reduce (if not completely remove) the potential release of contamination. For the underground workings, the source of contamination is also assumed constant in time for the duration of the whole simulation. This is a conservative assessment as it assumes no exhaustion of the contamination potency of materials post closure. It is understood that due to the planned decommissioning of the site infrastructure and rehabilitation of the site, the source of contamination to the water table will progressively decline, and consequently that the predicted long-term plume is predominantly an overestimation of the likely outcome.
- As this is a conservative transport model assessment the entirety of the underground workings is assumed to be a potential source of contamination (from the deepest point to the highest point). The water chemistry of the underground working is oxidised to mildly reducing. This suggests that sulphidic mineralisation has the potential to be oxidised as groundwater flows through the strata. The groundwater recovery post closure in the backfilled underground workings is likely to result in the reactive material being under water cover, which has proven to be a highly effective method for AMD control. Water cover is an effective barrier to the gaseous diffusion of oxygen.

The role of redox processes in limiting metals transport once the new groundwater flux equilibrium is reached is important, the redox processes would work to limit the future movement of contaminants that respond to changes in redox conditions.

7.2 Model Parameters and Boundary Conditions

The relevant transport parameters for the reference scenario are summarised in Table 7-1. Conservative assumptions were assumed to choose the parameters as describes in the following sub-sections.

Table 7-1 Assumed Transport Parameters

Parameter	unit	value
Longitudinal dispersivity	m	100
Transversal dispersivity	m	10
Vertical dispersivity	m	10
Porosity	-	Sy (heterogeneous)

7.2.1 Effective Porosity

In addition to the specific yield (Sy) for flow, MODFLOW requires the assignment of a separate porosity parameter, Ø, used for the mass transport solution. The value of Ø (porosity) is larger than Sy, as porosity measures the amount of water stored within the pores or fissures of the aquifer, while Sy is a measure of gravity drainage (a portion of the porosity). The difference between the porosity and the specific yield is the specific retention. To be conservative in this modelling, the porosity for mass transport is assumed to be equal to the specific yield, so therefore the analysis will be conservative (travel times are faster) In fractured rock aquifers effective porosity might approximate Sy due to the nature of flow in fractured rock systems.

The effect of variation of effective porosity on the transport predictions is considered in the sensitivity analysis.

7.2.2 Dispersivity

The dispersivity parameters have units of length. Field-scale dispersion in aquifers is understood to be scale dependent, where the magnitude of the dispersion coefficient is observed to be larger at larger scales of mass transport. This phenomenon is a result of larger plumes capturing progressively larger scales of heterogeneity (not represented in the flow modelling) which may lead to progressively larger spreading of the plume. Relationships between reported estimates of dispersivity and the field scales of investigations were reviewed critically by Gelhar et al. (1992). Results from the Gelhar et al. review (Figure 7-1) can be used to provide guidance on reasonable choices of values for these transport parameters. Thus, for a plume of scale 1 to 10 km existing estimates of longitudinal dispersivity are typically 10 to 100 m and estimates of horizontal transverse dispersivity are typically 1 to 10 m.

As a rule-of-thumb, the value of longitudinal dispersivity should not be much less than the typical length dimension of the model cells. Smaller values of dispersivity may cause numerical instabilities and failure of the simulation.

Larger values of dispersivity can also be regarded as conservative as they tend to enhance the size of the contamination plume. For the simulation a longitudinal dispersivity of 100 m and transverse and vertical dispersivity of 10 m was chosen. The effect of variation of dispersivity on the transport predictions is considered in the sensitivity analysis.

a. **Longitudinal dispersivity** **b.** **Horizontal transverse dispersivity**

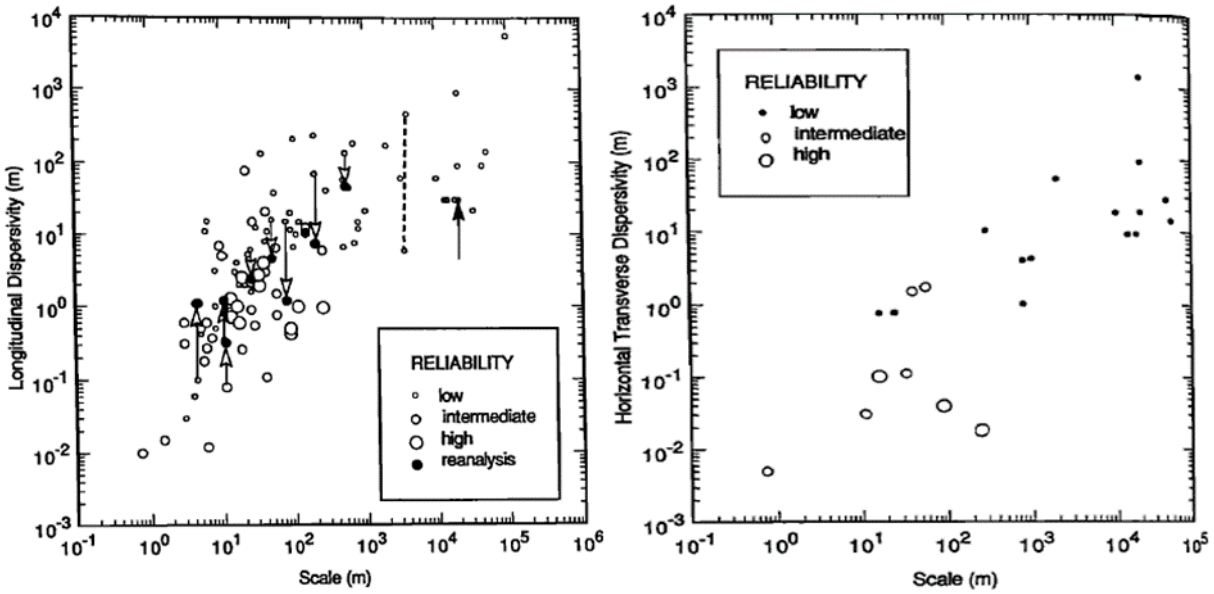


Figure 7-1 **Field-scale Dispersivity Values (after: Gelhar et al. 1992)**

7.2.3 Boundary Conditions

The release of contamination is controlled by a constant concentration boundary condition (BC). The constant concentration boundary condition acts as a contaminant source providing solute mass to the model domain in the form of a known concentration. The constant concentration BC is defined on layer 1 across the model nodes representing the CDA, CDB, PPD and LMD (Figure 7-2). The constant concentration is defined directly at the water table (in layer 1).

This is a conservative assumption, as the delay and attenuation represented by the transfer through the unsaturated zone is assumed to be instantaneous It should be noted that the model does not account for potential water table mounding associated with seepage beneath the respective dams. Dams are HDPE lined, and through this approach it is expected that this will minimise leakage, with the dams to be decommissioned at the end of operations.

For a conservative approach, the sources of contamination from the dams are assumed to persist post-mining operation and for the whole simulation (running for the 12 years of mining operation and 220 years post-mining). As previously stated, it is understood that the source of contamination to the water table will progressively falter following the site rehabilitation and consequently that the predicted long-term plume is suitable for the impact assessment as it provides a clear overestimation of the potential contamination.

The constant concentration BC representing the source of contamination associated with the underground workings is defined at all the nodes that are representing the underground mine across layer 2 to 5. For the backfilling of the mine workings, the source of contamination is also assumed constant in time for the duration of the whole simulation. It is conservative as it assumes no exhaustion of the contamination potency of the backfill materials or exposed rock.

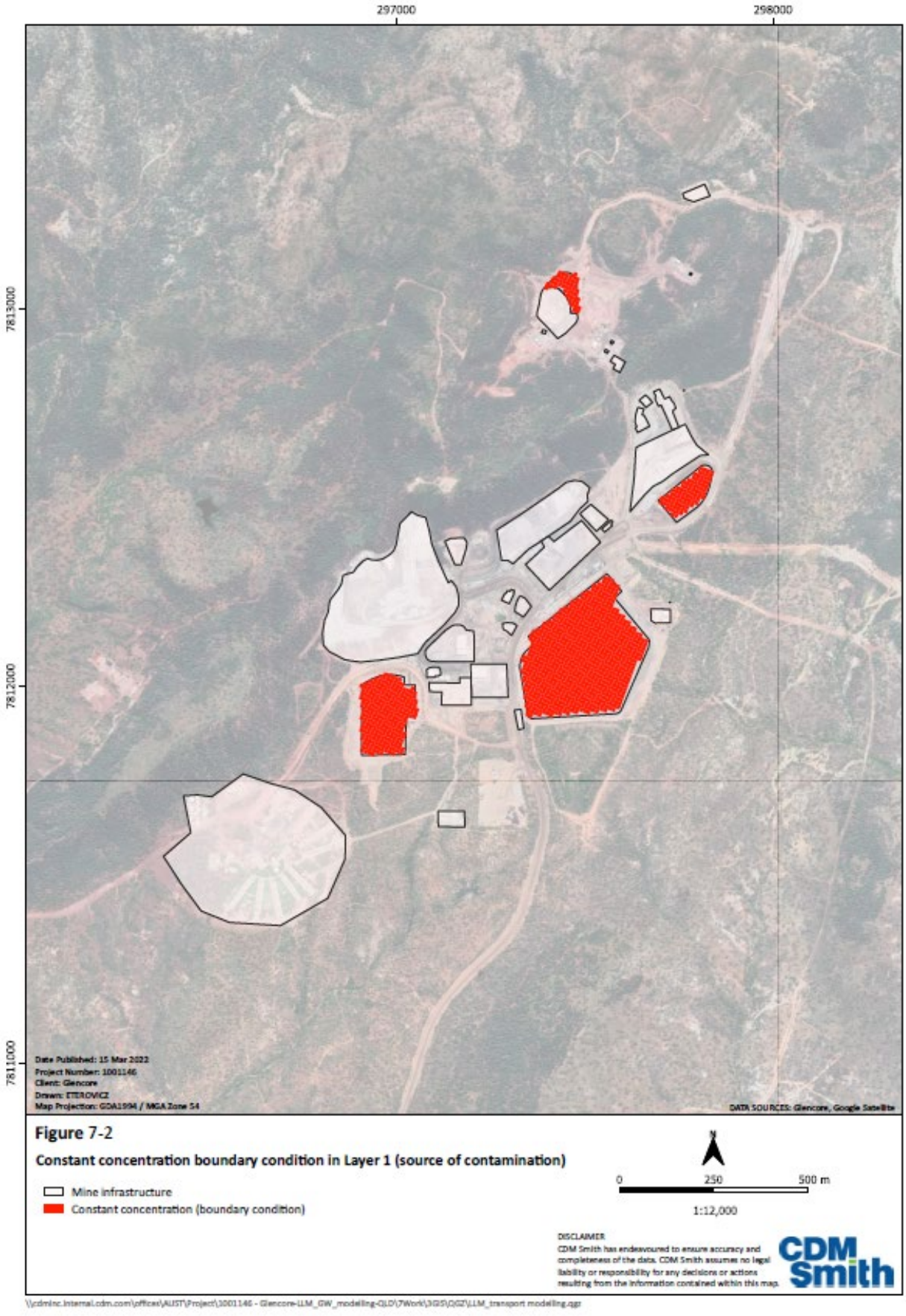


Figure 7-2 Constant Concentration BC in Layer 1 (source of contamination)

7.3 Model Results

The predictive simulation of mass transport uses the flow field from the calibrated groundwater flow model. The initial condition for the transient calibration, is provided by the first steady state stress period representing the aquifer in pre-mining condition (no contaminant is released during the pre-mining condition as background concentrations are assumed to be nil). As a normalised contamination transport was assumed, the modelling results represent the concentration as a percentage of the source concentration.

At 220 years post-mining, the concentration of any contaminant 300 m away from the sources is predicted to be less than 10% of the source concentration (Figure 7-3). For the mine workings, after 220 years, no contamination higher than 10% of the source concentration is predicted beyond 500 m of the mine.

At approximately 1,000 years post-mining, the 10% of source concentration limit is predicted to move around 20 m further from the source (Figure 7-4 to Figure 7-6) reflecting of the limited displacement within the aquifer once pre-mining condition have been re-established, which occurs approximately 200 years post-mining.

According to Glencore's internal LLM Detailed Closure Plan once the dams are no longer required during the rehabilitation process they will be decommissioned and rehabilitated subject to final landowner or third party user agreements (LLM, 2021a). As the containment dams are regulated structures under the environmental authority, each will require a decommissioning plan (LLM, 2021a). The regulated dams will be decommissioned with LMD planned for decommissioning in 2028 and the remaining regulated dams are planned for decommissioning in 2044.

As noted earlier the transport model method and approach is considered conservative. The sources of contamination from the dams are assumed to persist post-mining operation and for the whole simulation (running for the 12 years of mining operation and 220 years post-mining). However, this is highly unlikely to be realistic and the decommissioning will result in the structures not being present for the time period 220 years post mining.

Under these conservative modelling assumptions, at 220 years post-mining, the concentration of any contaminant will be less than 300 m away from the sources is predicted to be less than 10% of the source concentration and less than 350 m away from the sources is predicted to be less than 5%

7.4 Model Results Interpretation

The transport modelling does not discuss COCs individually and it is assumed that all COCs will behave similarly as a constituent in the model. The table below shows the normalised transport approach calculation for four common COCs: sulphate, cobalt, lead and zinc for each containment dam at 5% of initial concentration.

Table 7-2 CDA Water Quality Results (COCs)

Analyte	Units	Mean initial concentration	5% of mean initial concentration
Sulfate	mg/L	3116.0	155.8
Cobalt	mg/L	0.22	0.01
Lead	mg/L	0.36	0.02
Zinc	mg/L	24.9	1.2

Table 7-3 CDB Water Quality Results (COCs)

Analyte	Units	Mean initial concentration	5% of mean initial concentration
Sulfate	mg/L	8272.8	413.6
Cobalt	mg/L	2.6	0.13
Lead	mg/L	0.9	0.05
Zinc	mg/L	722.9	36.1

Table 7-4 PPD Water Quality Results (COCs)

Analyte	Units	Mean initial concentration	5% of mean initial concentration
Sulfate	mg/L	2798.7	139.9
Cobalt	mg/L	0.8	0.04
Lead	mg/L	47.2	2.36
Zinc	mg/L	186.6	9.3

Table 7-5 LMD Water Quality Results (COCs)

Analyte	Units	Mean initial concentration	5% of mean initial concentration
Sulfate	mg/L	14521.7	726.1
Cobalt	mg/L	4.33	0.22
Lead	mg/L	0.18	0.01
Zinc	mg/L	2494.6	124.7

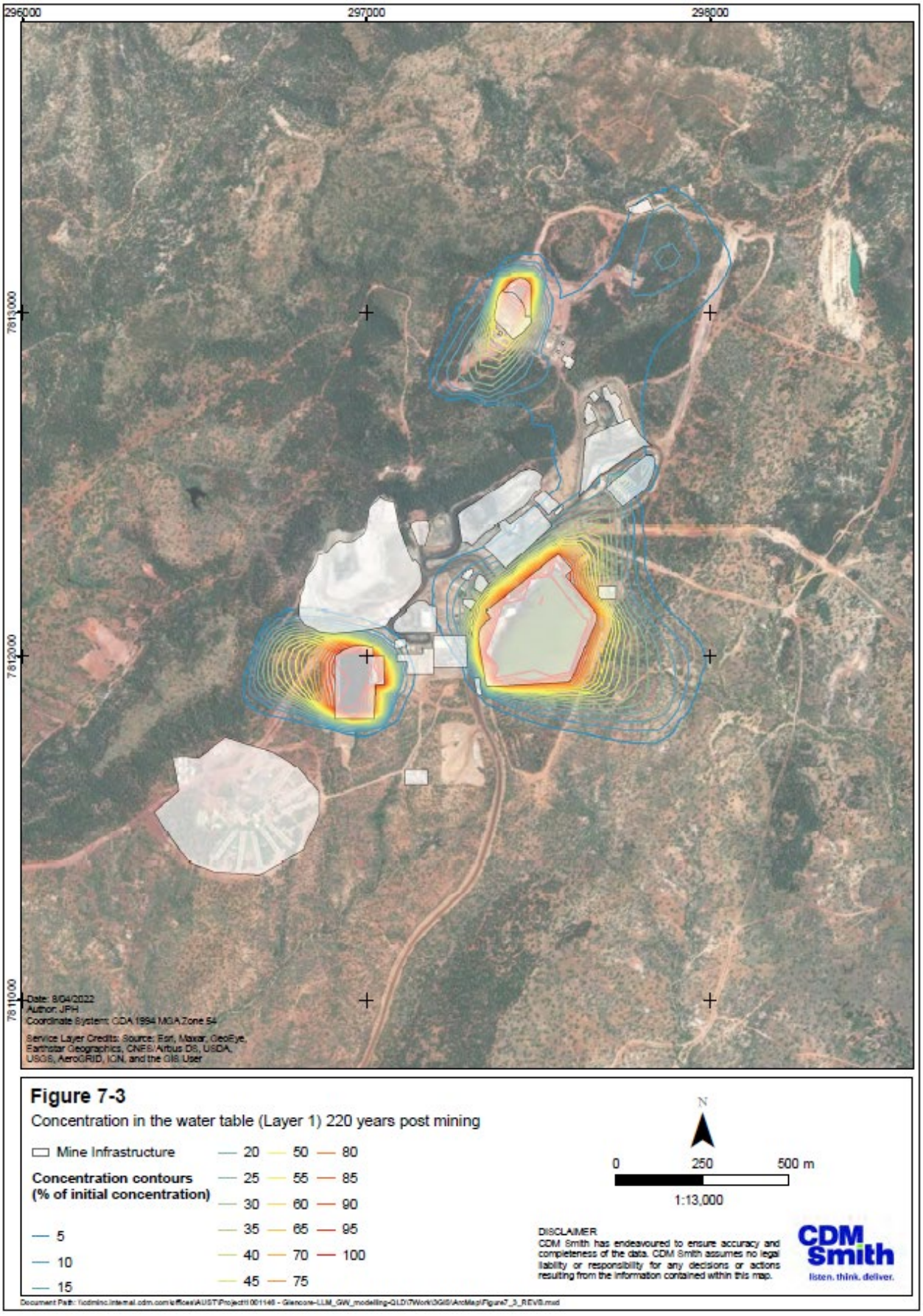


Figure 7-3 Predicted Concentration in the Water Table (Layer 1) - 220 years post-mining

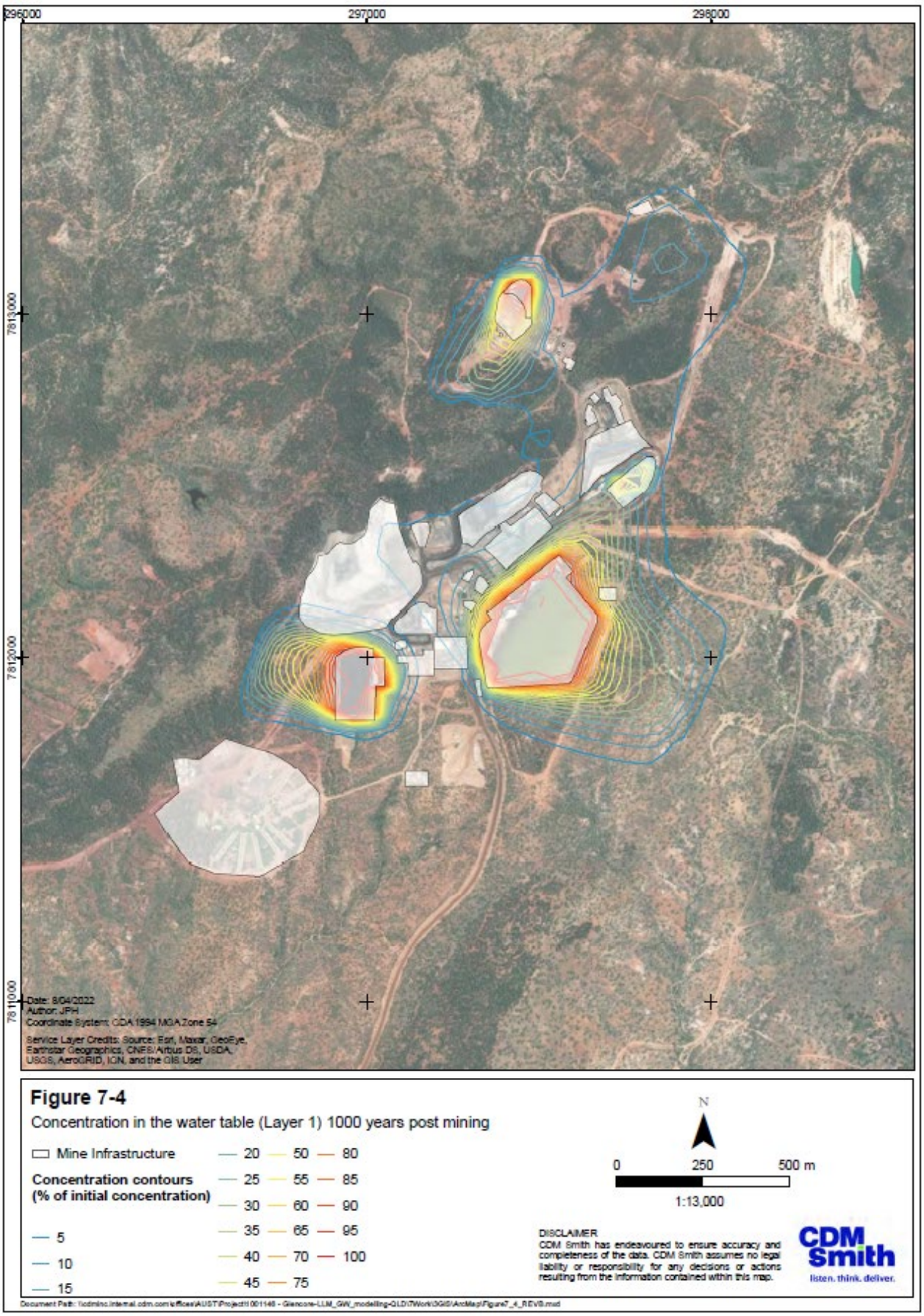


Figure 7-4 Predicted Concentration in the Water Table (Layer 1) - 1000 years post-mining

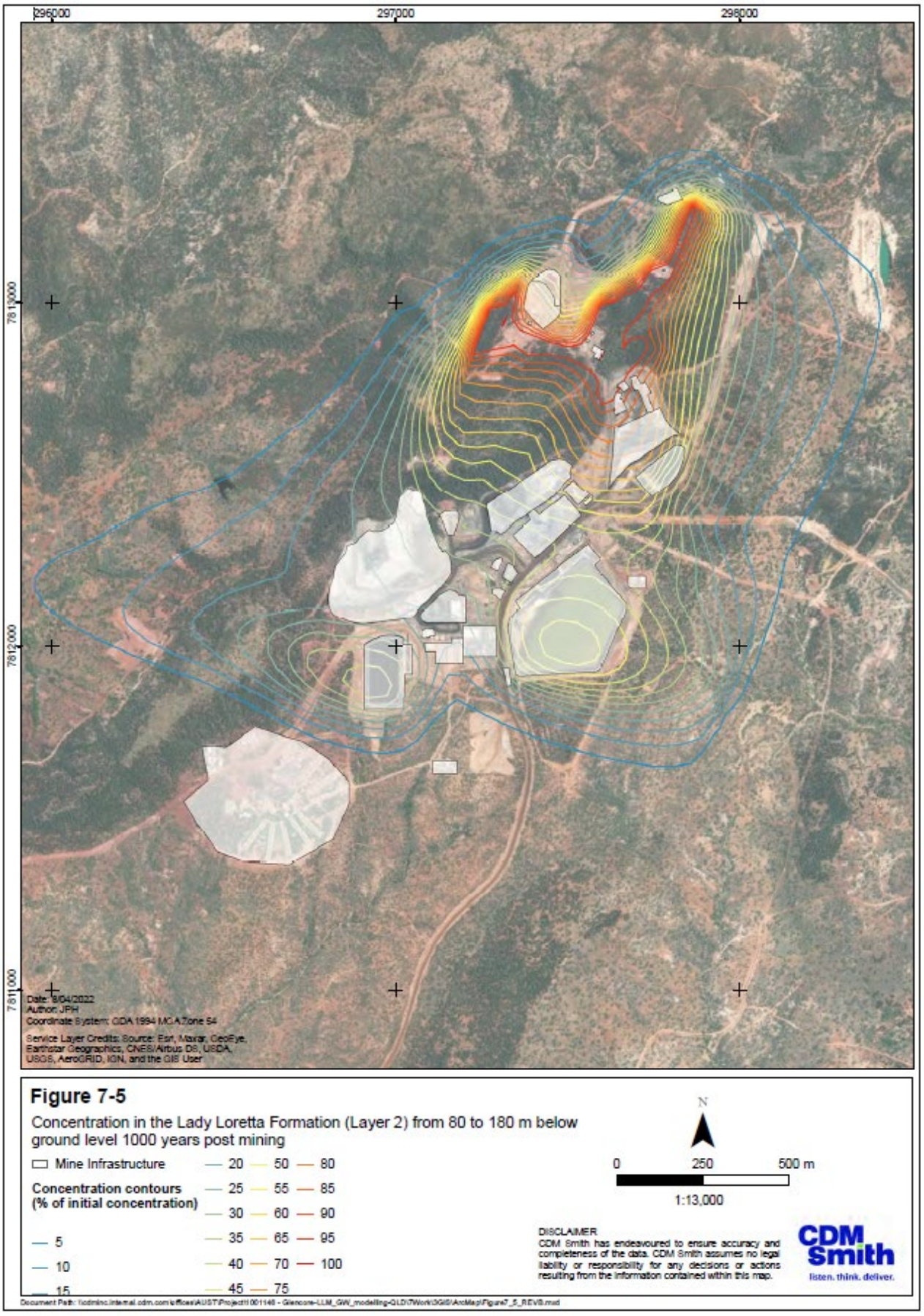


Figure 7-5 Concentration in the Lady Loretta Formation Between 80 to 180m Beneath Ground Level (layer 2)

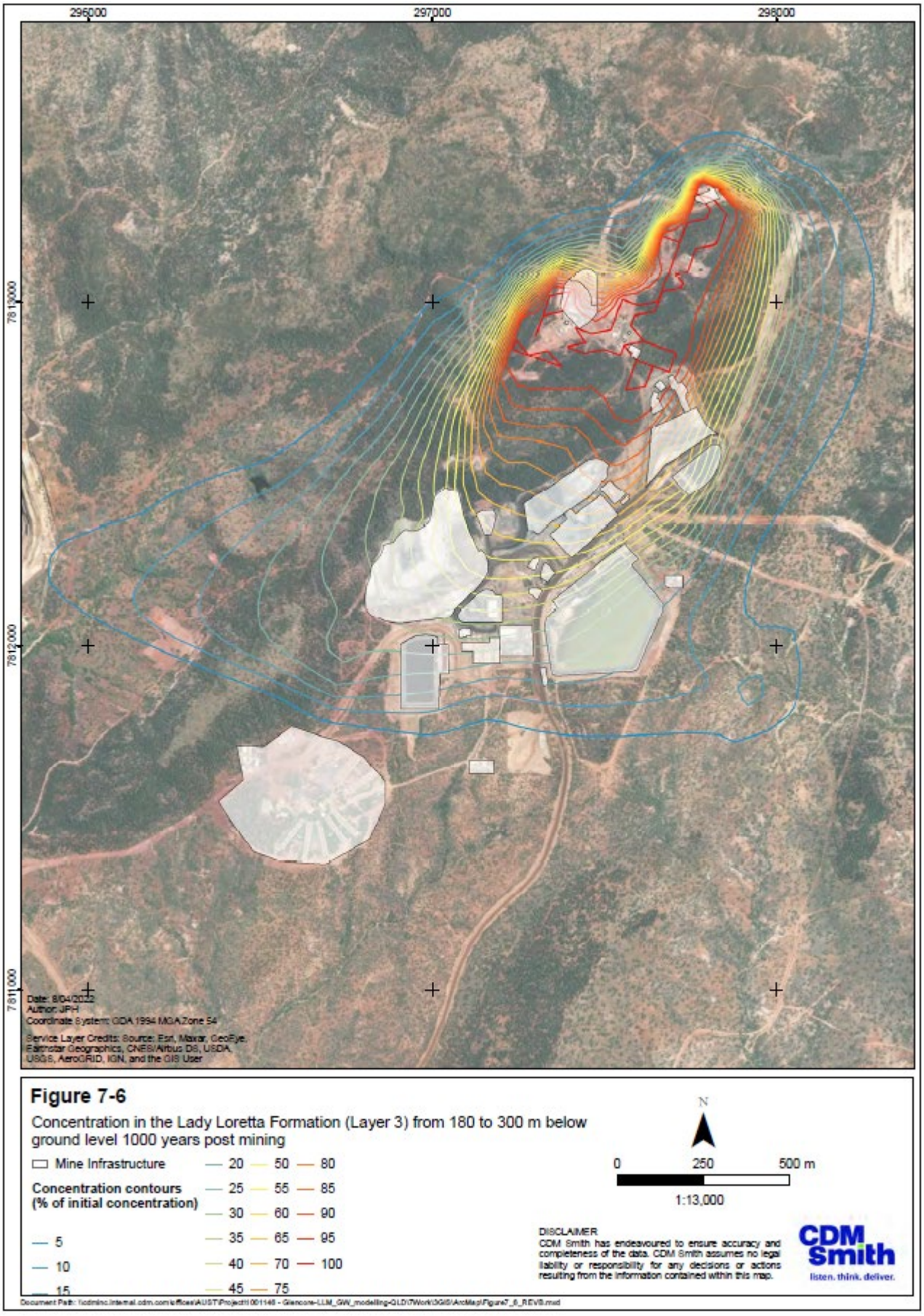


Figure 7-6 Concentration in the Lady Loretta Formation Between 180 to 300m Beneath Ground Level (layer 3)

7.5 Sensitivity Analysis

The sensitivity analysis explores the level of constraint of the model prediction and involves changing a model parameter (one at the time) to establish how the contamination propagation is affected by that change. Sensitive parameters generate a significant change while insensitive parameters generate little predictive change. The sensitivity analysis allows identification of which parameters are most controlling the propagation of the plume, and which would therefore require the most scrutiny to reduce predictive uncertainty. Insensitive parameters indicate that parameter error is of limited consequence.

Three sensitivity scenarios were designed and the method of varying parameters for the sensitivity analysis is summarised in Table 7-6. As the adopted dispersivity parameters in are conservative, the sensitivity run explores the influence of lower dispersivity parameters (Sensitivity scenario 1) and no dispersivity (sensitivity scenario 2). The reference scenario assumed that the transport of contaminant uses the same pore spaces than flow, and the sensitivity scenario 3 explores the influence of lesser pore space for contaminant movement than for water flow. Results of the sensitivity analysis are Illustrated in Figure 7-7. The analysis shows that a reduced dispersivity parameter considerably reduces plume propagation. No sensitivity scenario with a higher value of dispersivity was selected because the reference model scenario adopted a conservative value of dispersivity (overestimated). Sensitivity 3 scenario also shows a reduced plume propagation than the reference scenario.

Table 7-6 Sensitivity Run Parameters

Parameter	unit	Reference run	Sensitivity 1	Sensitivity 2	Sensitivity 3
Longitudinal dispersivity	m	100	10	No dispersivity	100
Transversal dispersivity	m	10	1	No dispersivity	10
Vertical dispersivity	m	10	1	No dispersivity	10
Porosity	-	Sy (Calibrated array[1])	Sy (Calibrated array[1])	Sy	0.8 x Sy

Note: 1. Sy is heterogeneous

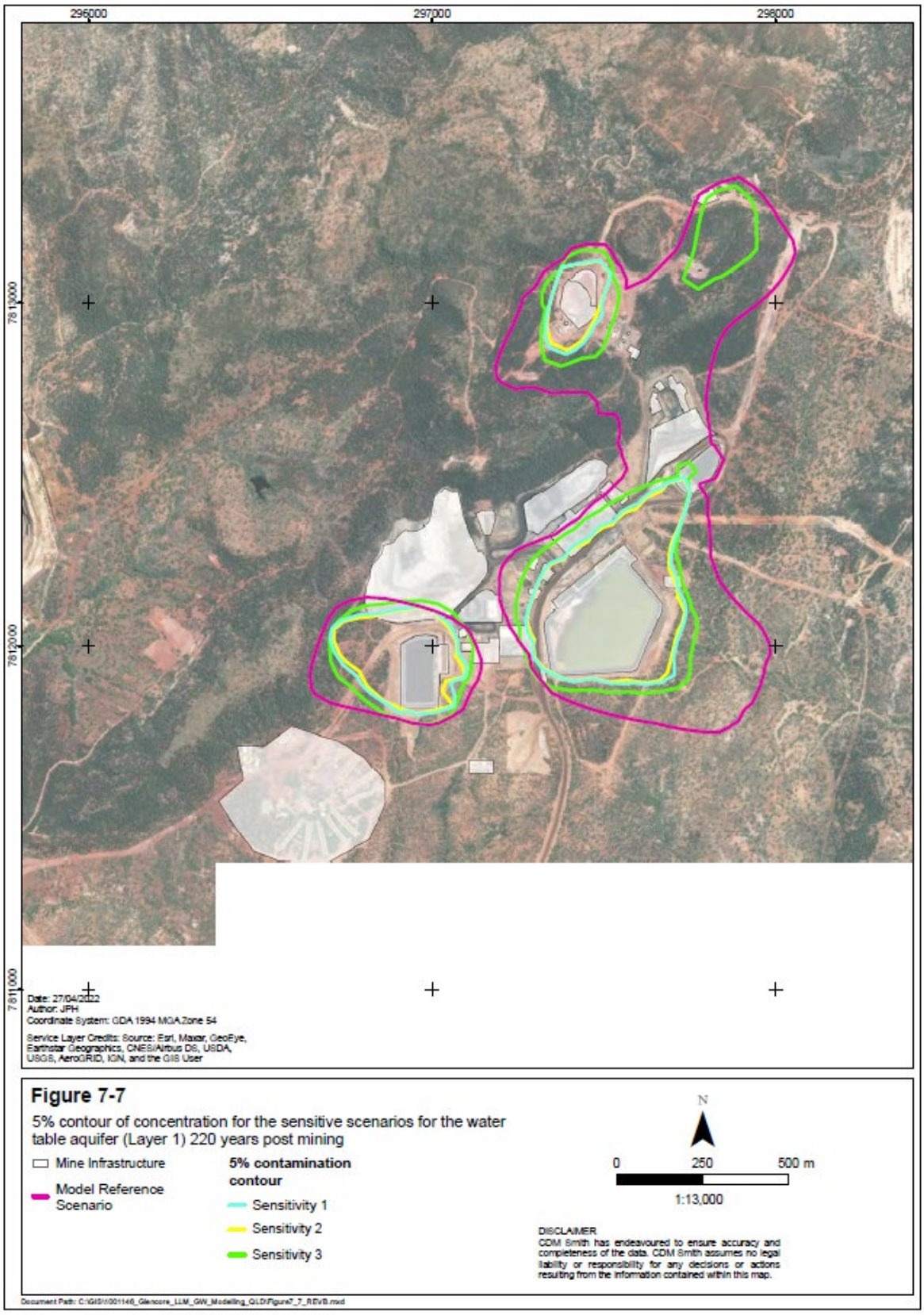


Figure 7-7 **5% contour of contamination for the sensitive scenarios for the water table aquifer (Layer 1) (under conservative modelling assumptions)**

Section 8 Evaluation of Potential Impacts to GW Resources

The likelihood of adverse impact on receptors is considered low given the current understanding of potential pathways identified and modelling results, namely:

- The major faults (Carlton Fault and Western Border Fault) are considered to exert a major control on flow patterns in the topography driven hydrogeological system. The water quality suggests a level of compartmentalisation in the Lady Loretta block and in the vicinity of the underground workings. This intra-block compartmentalisation, particularly in the vicinity of the underground workings is a key finding in relation to closure planning. The transport contamination plume is fully contained within the compartmentalisation in the Lady Loretta block.
- The regional groundwater flow fields appear to follow the topography in a subdued manner and the model contaminant plume propagation shows a dispersion in all directions from the various sources of contamination with a preferential extension toward the west in the regional flow gradient toward the Lady Annie pit. After 220 years post-mining, the concentration of any contaminant 300 m away from any of the sources is predicted to be less than 10% of the source concentration. At 1,000 years post-mining, the predicted plume extent remains little changed from that predicted 220 years post-mining.
- The transport model is highly conservative. The decommissioning will result in the dams not being present for the time period 220 years post mining. Under these conservative modelling assumptions, at 220 years post-mining, the concentration of any contaminant will be less than 300 m away from the sources is predicted to be less than 10% of the source concentration.
- The dams construction are not captured in the model development. There is no evidence to show there is any contamination coming from the surface water dams, storage facilities or stockpile area so the contribution from this source is extremely conservative. The dam construction consists of CDA, CDB and PPD being HDPE lined and LMD is GCL lined.
- EVs (stockwatering or ecological) have not been identified within the predicted transport model plume extent considering the current groundwater use.
- It should be noted that for future groundwater use:
  - Current water quality indicates that untreated groundwater is unsuited to the following uses – drinking water, stock water and industrial applications.
  - In order for future users to access groundwater, approval will need to be sought from the appropriate regulatory authority prior to accessing groundwater.
  - The absence of current groundwater users in the area (no bores within 5km, with the exception of the current LAE borefield) would indicate that accessing groundwater for use is not preferred by local stakeholders, with other water supply options (rainfall dams, surface water etc) in use for local supply.
- No groundwater receptors have been identified to date in the course of this study, with no known or identified registered water supply stock or domestic bores within 5 kilometres of the LLM site (outside of the to be decommissioned LAE borefield). Given the sites location and considering the points above future use of groundwater at the site is considered unlikely at this time.

Considering the above, while within the pre closure setting, pathways to receptors exist, the hydrogeological controls of COC from the sources is such that the likelihood of that pathway being realised is low. Therefore, the potential likelihood of impact to groundwater receptors is considered to be low. From a closure perspective, and considering the rehabilitation plan for the site, it is expected that EV exposure to potential COCs will also be low.

Given the fact that the dam construction consists of CDA, CDB and PPD being HDPE lined and LMD is GCL lined and there is no evidence to show there is any contamination coming from the surface water dams, storage facilities or stockpile area the closure strategy risk is expected to be even lower, and could be considered as a no risk situation.

In summary, given the current understanding of groundwater flow, containment dam management, EVs (potential GDEs) and absence of nearby groundwater users, there is a low risk of potential impact. A conceptual cross section summarising these findings is shown in Figure 8-1 based on the available hydrogeological information, numerical model results and solute transport model results to illustrate the groundwater situation as it is currently understood.

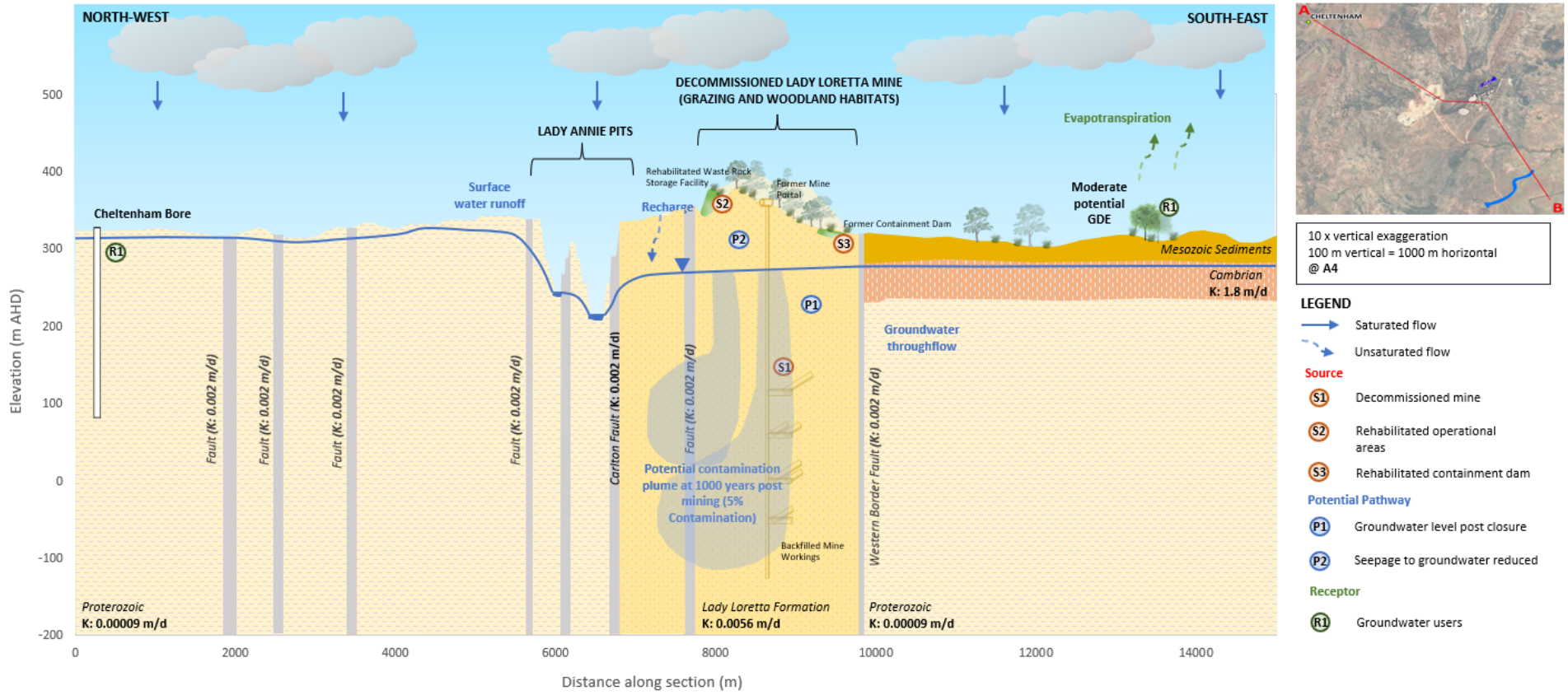


Figure 8-1 Conceptual Model – Post Closure showing Solute Transport Model Results and Receptors

Section 9 Conclusions

9.1 Conceptual Model

The conclusions for the Conceptual Model are listed below:

- The major faults (Carlton Fault and Western Border Fault) are assumed to exert a major control on flow patterns in the topography driven hydrogeological system. The Western Border Fault divides the LLM sulfide ore bearing zone from the less deformed Cambrian Block to the east, while the Carlton Fault separates the Lady Loretta Block from the Paleoproterozoic Block to the west. The major Carlton Fault Zone truncates the syncline to the north-west. The Carlton Fault is associated with extensive zones (up to 200m wide) of shearing and brecciation.
- Cambrian Block hydrostratigraphy hydraulic conductivity values range from 2.5 to 123 m/day, whilst Lady Loretta Block hydrostratigraphy permeability values are low ranging from around 0.001 to 0.25 m/day. There is minimal hydrostratigraphy information and permeability data for the Paleoproterozoic Block and representative values for the lithology are likely in the range 0.001 m/day. Regardless of the hydraulic properties of the Western Boundary Fault, the hydraulic conductivity contrast between the Cambrian and Lady Loretta Blocks will influence the distribution of hydraulic gradients across the fault.
- There has been identified a hydraulic gradient towards the LAE borefield and to the LLM site. Overall, on the Lady Loretta Block there is evidence of localised groundwater flow towards LLM due to dewatering within the underground mine workings. A cone of depression has developed, drawing groundwater toward the central part of the site operations.
- The chloride concentration in groundwater across the site indicates locally differing recharge rates within the block, and these concentrations are preserved, indicating a degree of flow compartmentalisation within the Lady Loretta Block at least. The compartmentalisation seen in the Lady Loretta block is also exhibited in the Proterozoic Block, showing this intra-block compartmentalisation is not unique to Lady Lorretta and is occurring at a regional scale (Appendix A: Evans, 2022).
- The sulphate findings at Lady Loretta also suggest compartmentalisation as well as informing the distribution of sulphidic mineralisation within the bedrock and this could be considered compartmentalised in the vicinity of the underground workings. This intra-block compartmentalisation, particularly in the vicinity of the underground workings is a key finding in relation to closure planning.
- From a regional perspective there is little evidence from the water quality study to support broad scale mixing between groundwaters from different geological Blocks in the vicinity of the Lady Loretta mine, considering the results of the major ion chemistry assessment completed. Differing concentration of metals further emphasises the difference between groundwater in the Cambrian Block compared to groundwater from the other Blocks.
- There is insufficient data to definitively determine how the faults may influence fluid flow based on the desktop assessment works completed (considering active dewatering in the study area). However, numerical modelling approaches were used to further assess fault behaviour, and are summarised below.

9.2 Groundwater Numerical Model

The original groundwater model (AGE, 2015) was upgraded to the LLM2021 model with the following key highlights:

- The modelling platform was upgrade from the legacy code MODFLOW-SURFACT to MODFLOW-USG that is technically more robust and accessible.
- The model hydrostratigraphy was updated based on insights from the Leapfrog geological model. In particular, the Lady Loretta Formation is represented in the LLM2021 model as a separate hydraulic property zone that is extended to all model layers.

- The Lady Annie pit was implemented in the LLM2021 model using the MODFLOW Drain Package.
- This study used a stochastic approach to develop 100 different possible combinations of hydraulic parameters that are fitted to the field observations. This approach better addresses the issue of non-uniqueness and enables probabilistic predictions and a more robust uncertainty analysis.

The key findings from this modelling work include:

- One key knowledge gap is the hydraulic properties of the faults. Through PESTPP-IES, the conceptualisation of faults was initially randomised. For a given fault, some realisations conceptualised the fault as a barrier to groundwater flow (i.e. low K) while some other realisations conceptualised the fault as a conduit (i.e. high K). After fitting to the field observations, these realisations converged to the conclusion that the faults are generally more permeable than the Proterozoic and less permeable than the Cambrian, and the fault permeability is generally in the same order of magnitude as the Lady Loretta Formation permeability. The faults do not act as impermeable barrier and likely have low permeability.
- Groundwater level at the LLM is predicted to be as low as -2 m AHD at the end of future dewatering, with the majority of drawdown impact limited to the Lady Loretta Formation. After more than 200 years into the future, the cone of depression caused by the LLM mining is predicted to be completely dissipated, with a groundwater level of approximately 280 m AHD in the vicinity of the former mine. In comparison, the Lady Annie pit is predicted to behave as a local groundwater sink where the groundwater level can be as low as 214 m AHD. The regional groundwater flow fields appear to follow the topography again.

9.3 Solute Transport Model

The transport modelling conducted in this assessment was designed conservatively, and it provides an overestimation of the contamination movement or propagation. The model conservative assumptions include:

- Neglecting the adsorption and degradation processes that would reduce the contamination propagation.
- A constant release of contamination within the aquifer during the whole modelling period.
- Neglecting transport through the unsaturated zone and assuming a contamination release directly in the groundwater aquifer.
- Extensive zone of contamination release within the underground galleries.
- Conservative dispersive and porosity parameters.
- A coarse grid discretisation tending to numerically overestimate dispersion.
- There is no evidence to show there is any contamination coming from the surface water dams, storage facilities or stockpile area so the contribution from this source is extremely conservative.
- One non-conservative assumption concerns the water table mounding that would be generated by seepage from the respective dams. Though, this assumption is not likely to outweigh the other conservative assumptions and the results are therefore still conservative.

The resulting contamination propagation shows a dispersion in all direction around the various source of contamination with a preferential extension toward the west in the regional flow gradient toward the Lady Annie pit. Under these conservative modelling assumptions, at 220 years post-mining, the concentration of any contaminant 300 m away from the sources is predicted to be less than 10% of the source concentration. For the mine workings, after 220 years, no contamination higher than 10% of the source concentration is predicted beyond 500 m of the mine. At approximately 1000 years post-mining, the 10% of source concentration limit is predicted to move around 20 m further from the source reflecting of the limited displacement within the aquifer once pre-mining condition have been re-established.

According to Glencore's internal LLM Detailed Closure Plan once the dams are no longer required during the rehabilitation process, they will be decommissioned and rehabilitated subject to final landowner or third-party user agreements (LLM, 2021a). As part of the LLM closure strategy, the regulated dams will be decommissioned. LMD is planned for decommissioning in 2028 and the remaining regulated dams are planned for decommissioning in 2044.

The transport model method and approach is conservative. The sources of contamination from the dams are assumed to persist post-mining operation and for the whole simulation (running for the 12 years of mining operation and 220 years post-mining). However, this is highly unlikely to be realistic and the decommissioning will result in the dams not being present. Under these conservative modelling assumptions, at 220 years post-mining, the concentration of any contaminant will be less than 300 m away from the sources is predicted to be less than 10% of the source concentration.

9.4 Groundwater Summary

- The major faults (Carlton Fault and Western Border Fault) are considered to exert a major control on flow patterns in the topography driven hydrogeological system, with flow across the faults considered limited.
- The nature of these fault controls at the regional scale has been confirmed via water quality/chemistry analysis results, and are also confirmed via numerical model findings that the faults do not act as impermeable barrier and likely have low permeability. In support of this interpretation there is little evidence from the water quality study to support broad scale mixing between groundwaters from different geological blocks further demonstrating the low permeability of the faults.
- Overall, on the Lady Loretta Block there is evidence of localised groundwater flow towards LLM due to dewatering within the underground mine workings. This dewatering together with other aquifer stresses creates difficulties in further assessing fault control on groundwater flow, hence the reliance on hydrochemistry and numerical modelling outcomes to characterise the fault flow regime and conclude the faults likely have a low permeability.
- The hydrochemistry assessment works also indicates locally differing recharge rates within the LL block, and these concentrations are preserved, indicating a degree of flow compartmentalisation within the Lady Loretta Block. This intra-block compartmentalisation, particularly in the vicinity of the underground workings is a key finding in relation to closure planning.
- Numerical modelling outputs also support this intra-block compartmentalisation, and help constrain drawdowns and also recovery. After more than 200 years into the future, the cone of depression caused by the LLM mining is predicted to be completely dissipated.

9.5 Potential Impacts Summary

- Environmental Values and a source pathway receptor assessment indicate that:
  - There are no listed Groundwater Dependent Ecosystems mapped in the area or within 10 kilometres of LLM. There are no known or identified registered water supply, stock or domestic bores within 5 kilometres of the LLM site (outside of the LAE borefield).
  - The LAE borefield provides groundwater for industrial use / potable supply (following processing) for the LLM and Lady Annie Mine. This borefield is planned for decommissioning as part of the mine closure.
  - For future groundwater use the current water quality indicates that untreated groundwater is unsuitable as a water supply and approval will need to be sought from appropriate stakeholders prior to any future access to groundwater. In addition, the absence of current groundwater users in the area would indicate that accessing groundwater for use is not preferred by local stakeholders, with other water supply options (rainfall dams, surface water etc) in use for local supply.

  - Routine groundwater monitoring will continue to be conducted for a period of time to build a dataset that provides statistically valid trends. This will allow measurement of groundwater level recovery and water quality for comparison against the groundwater model predictions.

- Environmental risk at the site is governed by potential seepage of contaminated mine waters to underlying groundwater from mine water management infrastructure including dams, ROM pad and AMD from waste rock emplacements, legacy PAF dumps and management dams. Closure planning approaches intend for mine water management infrastructure to be decommissioned and sites rehabilitated, leaving no ongoing risks from these structures. Legacy seepage at depth beneath these structures may still be present following closure. However, the nature of dam construction and the use of liners, as well as operational controls such as leak detection monitoring limit the potential for undetected seepage to occur during operations Primary COCs typically are elevated sulphate concentrations and total metals concentrations including aluminium, arsenic, cadmium, chromium, cobalt, copper, lead, nickel, zinc and iron.
- Primary pathways connecting COCs to groundwater are through water inflows into the underground workings or surrounds from surface (seepage) and vertical or lateral migration of solutes from the underground workings to external groundwater.
- Post closure the risk profile in regards to groundwater and groundwater receptors is considered low as:
  - Mine infrastructure will be decommissioned and removed, with the site rehabilitated as needs, thereby removing the majority of contaminant sources.
  - Potentially contaminated groundwater flows into the mine workings/surrounding area/from the mine workings into the local aquifer will be reduced with COC sources removed.
  - There are no recognised receptors in relation to groundwater in the vicinity of the site.
- Considering the above, the consequence of potential impact to groundwater receptors is considered to be low. From a closure perspective, and considering the rehabilitation plan for the site, it is expected that EV exposure to potential COCs will also be low.
- Given the fact that the dam construction consists of CDA, CDB and PPD being HDPE lined and LMD is GCL lined and there is no evidence to show there is any contamination coming from the surface water dams, storage facilities or stockpile area the closure strategy risk is expected to be even lower.

In summary, given the current understanding of groundwater flow, the conceptual and numerical modelling works completed, current and potential future EVs and absence of nearby groundwater users, proposed containment dam management, and the outcomes of solute transport modelling it can be concluded that there is a low risk of potential environmental impact at this time in relation to LLM following post closure decommissioning and rehabilitation activities.

Section 10 Limitations

The limitations of the study are outlined below:

- The exact location of the Carlton and Western Border fault is uncertain, and there is some uncertainty on the location, depth, direction and thickness of the faults.
- There is insufficient fault testing data or information to inform the Carlton and Western Border fault behaviour and permeability.
- Carlton and Western Border fault behaviour has been inferred based on groundwater head assessment and chemistry analysis completed as part of this scope.
- Assumptions were made on the formation locations and thicknesses for the Lady Loretta Block, Cambrian Block, and the Paleoproterozoic Block due to limitations in the available geological data provided.
- There are only two groundwater monitoring bores located in the Paleoproterozoic Block west of LLM and the Carlton Fault.
- The authors did not have access to accurate monitoring data or information available for the Lady Annie Mine. The assessment does not consider or include data or information on groundwater quality from the Lady Annie Mine.
- The Lady Annie Mine Closure Plan or Current Operations Plan is unknown to the authors. The numerical groundwater model and solute transport model includes the Lady Annie open cut pit and the location is predicted to behave as a local groundwater depression.
- The major limitation is the constant mining extent and elevations that were used for the calibration due to the lack of timing information.
- The 100 model realisations are unlikely to capture all the possibilities. The stochastic approach of using 100 model realisations is superior to the traditional deterministic approach where only one model is used, and these 100 model realisations provide useful insights into the predictive uncertainty and hydraulic properties of the faults.
- The water quality dataset is considered to be of a limited quality for this type of assessment, with inconsistent data collection periods, as well as periods within the time period though which no data was collected. Also of note is that water quality data was limited along the Carlton Fault, and this impacted hydrochemistry informing the conceptualisation in this area.
- The location of monitoring bores also influences the water quality assessment, as bores located in more distal locations from faults are less likely to present with clear geochemical signatures demonstrating connection between the relevant blocks through the faults.
- The numerical groundwater model and solute transport models are built on provided and specified dates for the mine operations, dewatering actives and backfill operations. Changes in the closure planning including dates, dewatering periods may result in changes to the model results.
- The transport model is highly conservative. The transport model does not include dates of the dam rehabilitation or decommissioning. The rehabilitation and decommissioning will result in the dams not being present. In addition, the dam construction details such as the HDPE and GCL liner are not included in the transport model development and results.

Section 11 Disclaimer

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If further information becomes available, or additional assumptions need to be made, CDM Smith reserves its right to amend this report.

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Appendix A Lady Loretta Mine Hydrochemical Assessment

Salient Solutions Pty Ltd

Lady Loretta Mine

Hydrochemical Assessment

FINAL

4 March 2022

Ray Evans

Salient Solutions Australia Pty Ltd

For CDM Smith

Lady Loretta Mine Hydrochemistry

The following sets out an assessment of the hydrochemistry of the groundwater in and around the Lady Loretta Mine as an independent constraint on the site conceptualisation.

The objectives of this hydrochemical review and assessment include:

- Assessment of possible fault fracture groundwater connectivity between the Cambrian, Lady Loretta and Proterozoic blocks through application of hydrochemical analysis;
- Possible evaluation of the degree of connectivity/permeability between the blocks through the fault network that could be inferred by the hydrochemistry assessment findings;
- To evaluate the findings of the assessment relative to the hydrogeological conceptualisation and the numerical groundwater model findings, and establish if the hydrochemistry of the site supports the understanding of groundwater flows at the site.

This assessment considers rainfall recharge to the aquifers but excludes surface water/shallow groundwater interaction linked to mining activities or any assessment of surface activities or processes post closure from a hydrochemical perspective that may impact groundwater across the site.

Site Contaminants of Concern and Site Environmental Values

While the primary focus of this assessment is to evaluate the hydrochemistry of the groundwater at the site in relation to the site conceptualisation and possible groundwater flow regimes there are key contaminants of concern and environmental values in relation to groundwater that are of particular interest from an environmental and mine closure planning perspective.

The following contaminants of concern have been identified for the Lady Lorretta mine that need to be considered as part of this scope:

Subsurface Contaminants of Concern (COC) / Sources

The subsurface contaminant sources are the mine workings (backfilled with paste produced from tailings). PAF waste rock produced by mining operations that cannot be placed in underground voids is hauled to the surface and placed in the LLM waste rock storage facility (WRSF). The mine dewatering is characterised by pH, high electrical conductivity, suspended solids, sulphate and total metal concentrations such as zinc, cadmium, iron and lead, with these constituents forming the COC.

According to the LLM Detailed Closure Plan all infrastructure (both above and below ground) is to be decommissioned and demolished in general accordance with the demolition study. From a subsurface perspective there are four shafts, a decline portal and numerous bores located across the mine lease. The shafts and mine portal will be backfilled with suitable material, including demolition waste (subject to an EA amendment which is in progress), and sealed with a concrete plug. Select monitoring bores may be kept for closure monitoring purposes.

The Environmental Values (EV) of waters and wetlands are protected under the Environmental Protection Water and Wetland Biodiversity Policy 2019. LLM is located within the Leichardt River water plan catchment and the EVs are determined in accordance with section 6 of the EPP Water and Wetland Biodiversity Policy. The identified EVs for the LLM receiving environment are:

- aquatic ecosystem protection
- cultural and spiritual values

- waters that may be used for agricultural purposes
- waters that may be used for drinking water
- industrial use of water

Data

A number of Excel files were supplied from the client, and these were combined into one master dataset. Chemical analyses were selected according to the following:

1. Duplicates were removed;
2. Analyses that did not contain at least a full set of major ions (Ca, Mg, Na, K, Cl, Total Alkalinity and SO_4) were removed. This included a large number of data points that reported field observations only;
3. Analyses that met the criteria of being within a 10% charge balance were retained, all others removed. The charge balance was calculated as the difference between the total anions and total cations divided by the sum of the total anions and cations, expressed as a percentage. Totals were derived as milli-equivalents per Litre. The seven major ions were used in this calculation;
4. Some underground metal analyses were not used as the sampling location and circumstances of sampling were not adequately documented.

The data cleaning resulted in a data set of 166 analyses spread across 14 bores (up to 172 samples for some metals data). The data spans the period from January 2012 to September 2021, with bore GW03 having 29 different analyses and a number of bores only one.

It should be noted that the dataset is considered to be of a poor quality for this type of assessment, with inconsistent data collection periods, as well as periods within the time period though which no data was collected. Also of note is that water quality data was limited along the Carlton Fault, and this impacted hydrochemistry informing the conceptualisation in this area. The location of monitoring bores also influences the assessment, as bores located in more distal locations from faults are less likely to present with clear geochemical signatures demonstrating connection between the relevant blocks through the faults.

Total Alkalinity (as $CaCO_3$ mg/L) was used as the measure of the CO_2-H_2O system activity in each sample (as opposed to carbonate and bicarbonate). Further data limitations (where applicable) are detailed further in the relevant sections below.

Laboratory TDS

No analyses have recorded laboratory TDS measurements. For future reference this should be rectified and TDS by evaporation at 180^o added as a standard measurement as part of future analysis suites.

Electrical Conductivity

A number of samples have both field and laboratory measurements of electrical conductivity. These are plotted in Figure 1. The data shows a good correlation, but it does not have a slope of 1, indicating that field EC is higher than the laboratory measurement at higher EC values. This discrepancy may reflect field meter calibration issues which may need to be followed up with field staff prior to any future sampling.

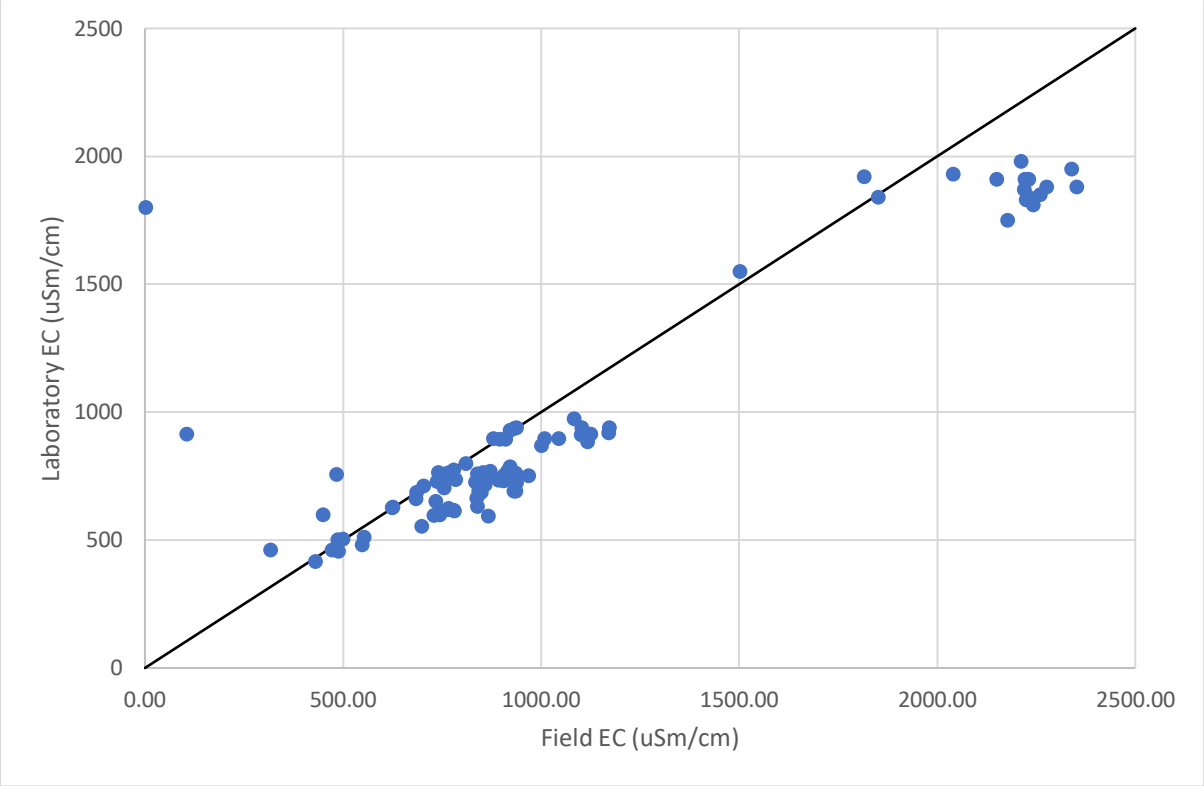
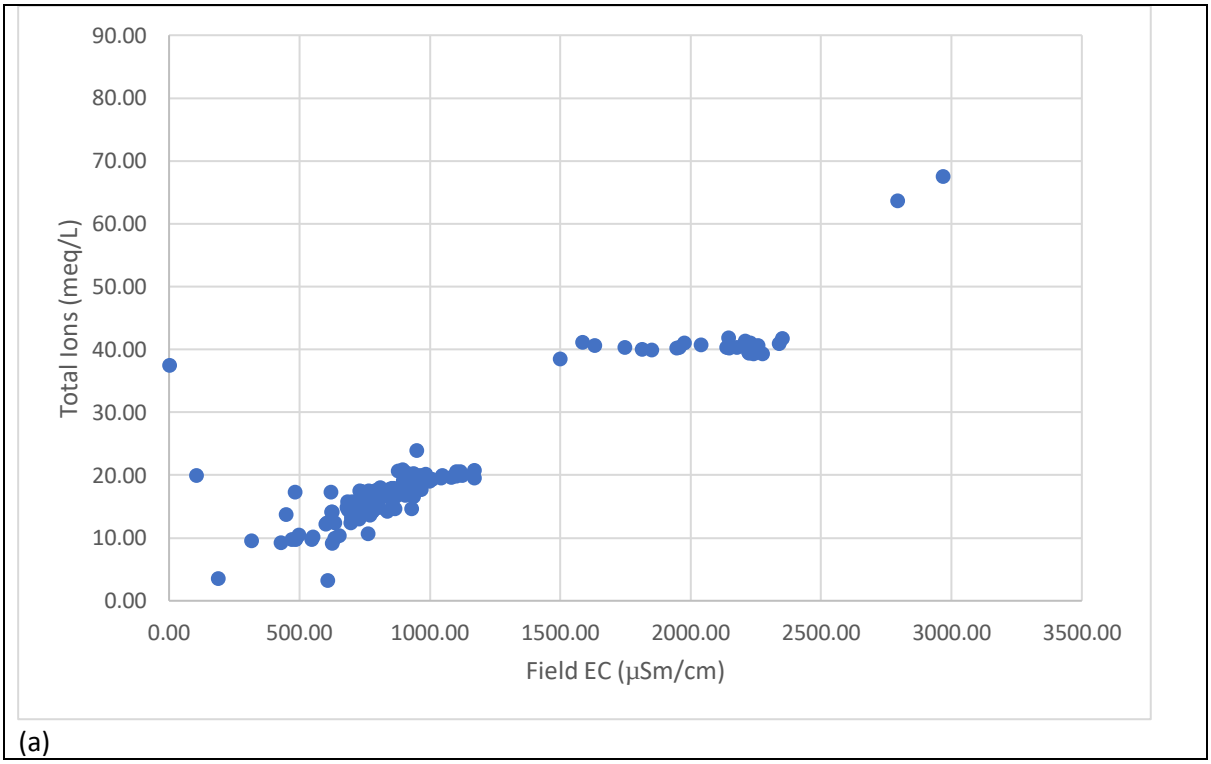


Figure 1: Field Electrical Conductivity versus Laboratory Electrical Conductivity (in µSm/cm)



(a)

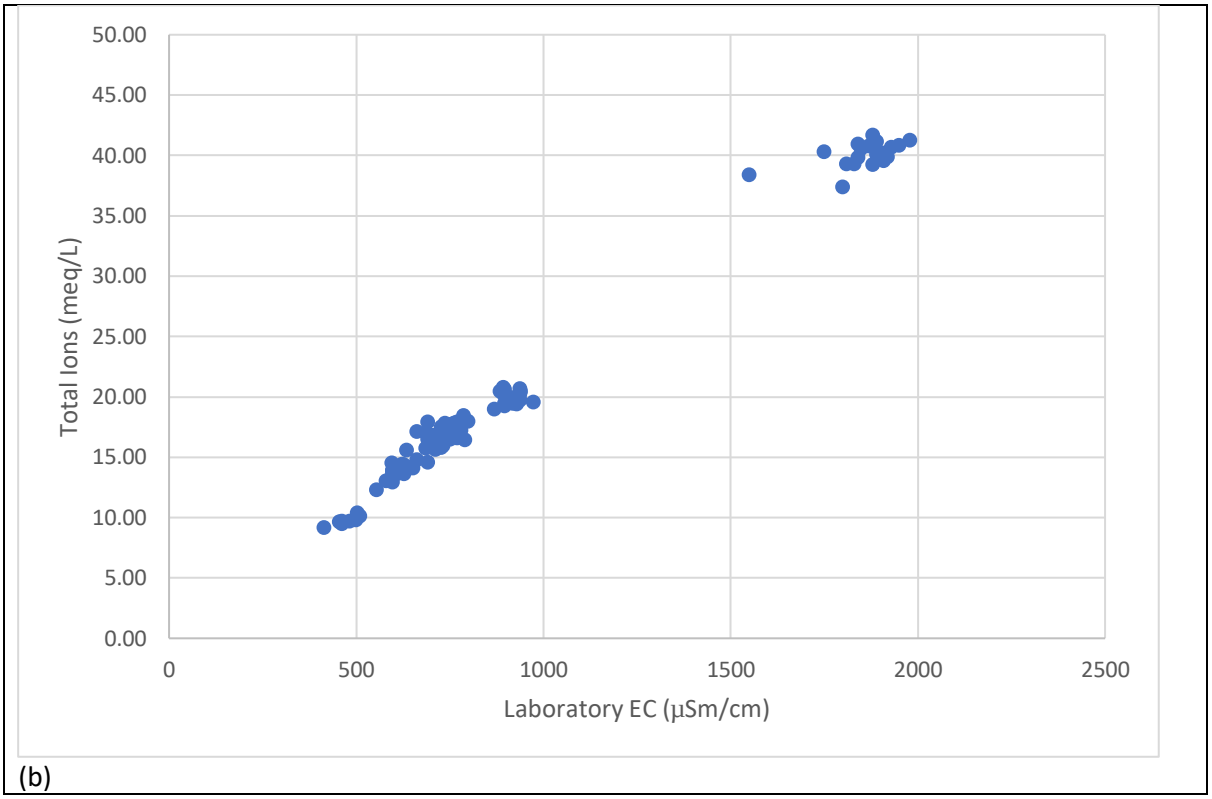


Figure 2: Electrical Conductivity versus Total Ions (a) Field EC vs Total Ions, and (b) Laboratory EC vs Total Ions

Total Ions, calculated as the sum of the major ions as milliequivalents per Litre (meq/L), were plotted against both laboratory and field EC measurements (Figure 2a and b). The plot of laboratory EC vs Total Ions (b) shows a good correlation, but the Field EC plot (a) shows a number of areas of poor correlation. This suggests that the field EC measurement may not be correct, and this could be a function of instrument error (calibration, etc). The almost linear correlation in Figure 2 (b) provides confidence that Total Ions can be used as a surrogate for TDS (or total salinity).

pH

Field pH and laboratory pH are only sporadically measured, with 96 samples collected where both parameters were measured. Moving forward these should be measured and reported on all occasions. A plot of pH field versus laboratory is presented in Figure 3. This shows a poor relationship between the two measurements with laboratory measurements consistently higher than their respective field reading. Usually, this relationship indicates that CO_2 has degassed in the sample bottle after sampling but prior to measurement, indicating that the holding period prior to analysis has been exceeded. In cases where the pH readings are more than one pH unit different between the two measurements, poor calibration of field equipment may be the issue impacting results. Disagreement between field and laboratory pH measurements places a question mark over the reported concentrations of ions that are biologically involved, such as HCO_3, SO_4, and Ca (Yesertener, 2010[1]).

Ordinarily, such poor correlation between the two measurements would invalidate further assessment. However, this would result in few samples being available for further study. One

[1] Yesertener, C. 2010 – Hydrogeochemical assessment of the Surficial Aquifer, Perth Metropolitan Area. WA Dept of Water, Report No. HG37

outcome from this lack of correlation is that the results of any assessment of pH driven chemical reactions would be uncertain, and as such, are not undertaken.

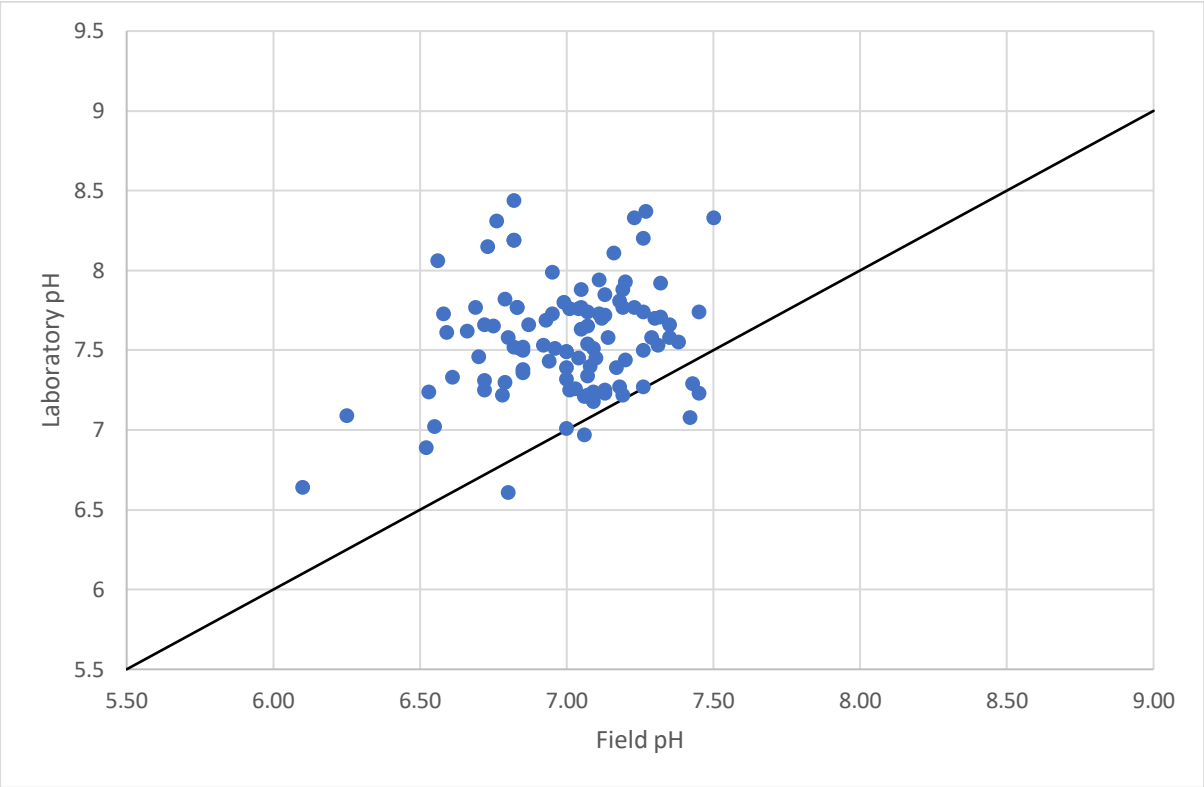


Figure 3: Field pH versus laboratory pH (1:1 line shown)

Field pH versus Field Redox

Redox and pH measured in the field were plotted to describe the likely Eh/pH relationships. The plot (Figure 4) shows that the measured values lie in a generally tight grouping showing neutral to slightly acid pH and oxidised to slightly reduced redox potential.

The lowest redox potential values are all from bore GW08. These values might indicate that the waters in GW08 are reduced and that dissolved sulfur might be speciated into H_2S or HS^-. Field observations recorded at the time the sample was taken note a strong sulfur smell. Thus, depending on the laboratory analytical methods used to measure sulfur, and the chemical evolution of the sample in the bottle during transit, the reported sulphate concentrations may be a minimum only.

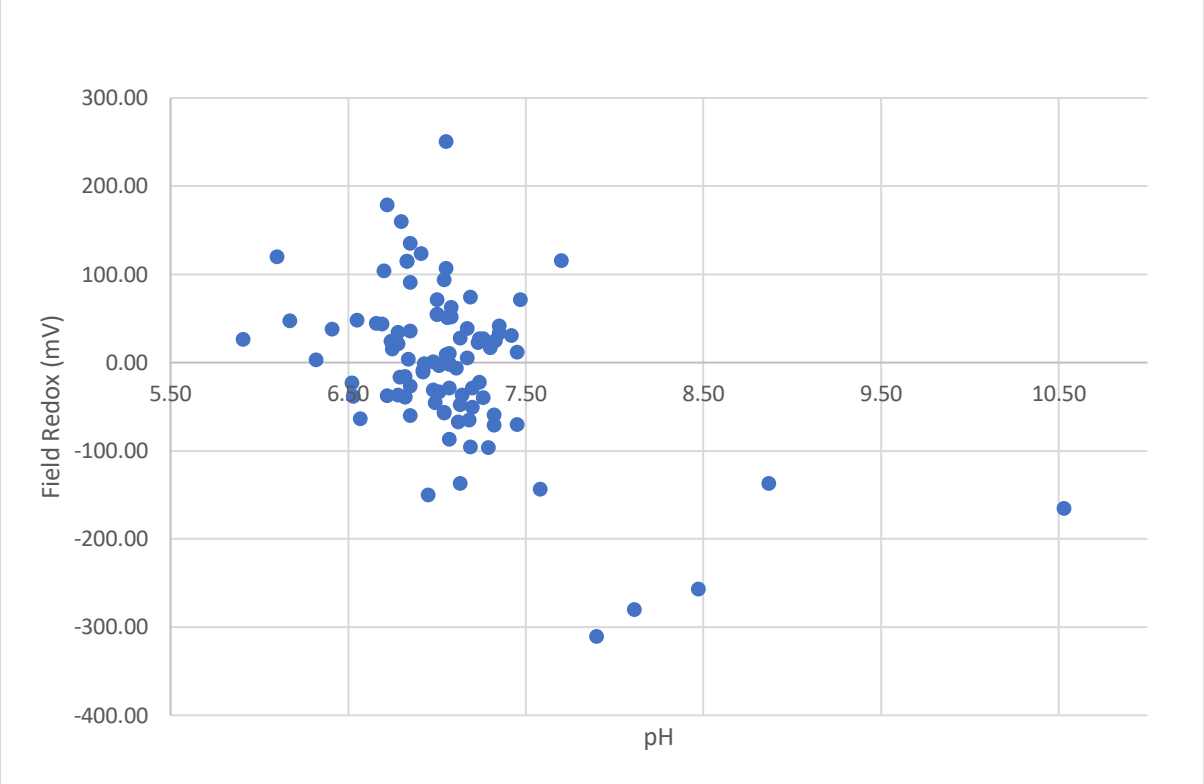


Figure 4: Field pH versus Field Redox

Data Analysis

As mentioned above, there were no measurements of TDS in the laboratory reported in the data. Total Ions (as milli-equivalents/L) were used as a surrogate of total salinity.

Sources of Ionic species

There are two primary potential sources of chemical constituents measured in the groundwater in the region of the Lady Loretta Mine. The first is from salts depositing either via rainfall or via dryfall (dust) mechanisms.

The first group could comprise salts from a continental origin or salts from an oceanic origin. Given that recharge is from monsoonal rainfall during the wet season, it is assumed here that the majority of salt from diffuse recharge sources has an oceanic origin.

The second is from mineral dissolution. In this latter group, there are three main mineral systems to be considered – all are present in the LLM area:

- primary alumino-silicate minerals;
- carbonates (limestone/calcite and dolomite); and
- sulfidic minerals (such as pyrite and those associated with mineralisation).

Other mechanisms/processes may influence the chemical make-up of the groundwater, but these are seen as minor. These include, ion exchange (both in the soil zone and in the weathered parts of the aquifer), sorption and desorption, and degradation of organic or carbonaceous materials.

Chloride is considered the most conservative of all of the major ions found in groundwater, especially at low ionic strength (low TDS). It is assumed here that chloride concentration is driven by the cycling of oceanic aerosols/salts through the aquifer. This may be a complex process due to local storage of salts in the unsaturated zone and/or local flow within compartmentalised blocks of

bedrock. Elevated levels of chloride might indicate halite dissolution as a potential source of salt, but the overall character of the groundwaters in the LLM area are dilute, and no halite has been recorded in the local bedrock sequences.

The distribution of Chloride in groundwater in the LLM area is generally simple at the broad scale, but can be complex at the local scale (Figure 5). Generally, groundwater in the Cambrian and Lady Loretta Blocks have low overall Chloride concentrations, whereas the limited data for groundwater in the Paleoproterozoic Block indicate higher levels of Chloride (except for groundwater sampled at bore GW07 – which is discussed in detail below). This distribution tends to suggest that infiltrating water undergoes little concentration due to evapotranspiration in the LL and Cambrian Blocks, when compared to the Paleoproterozoic Block.

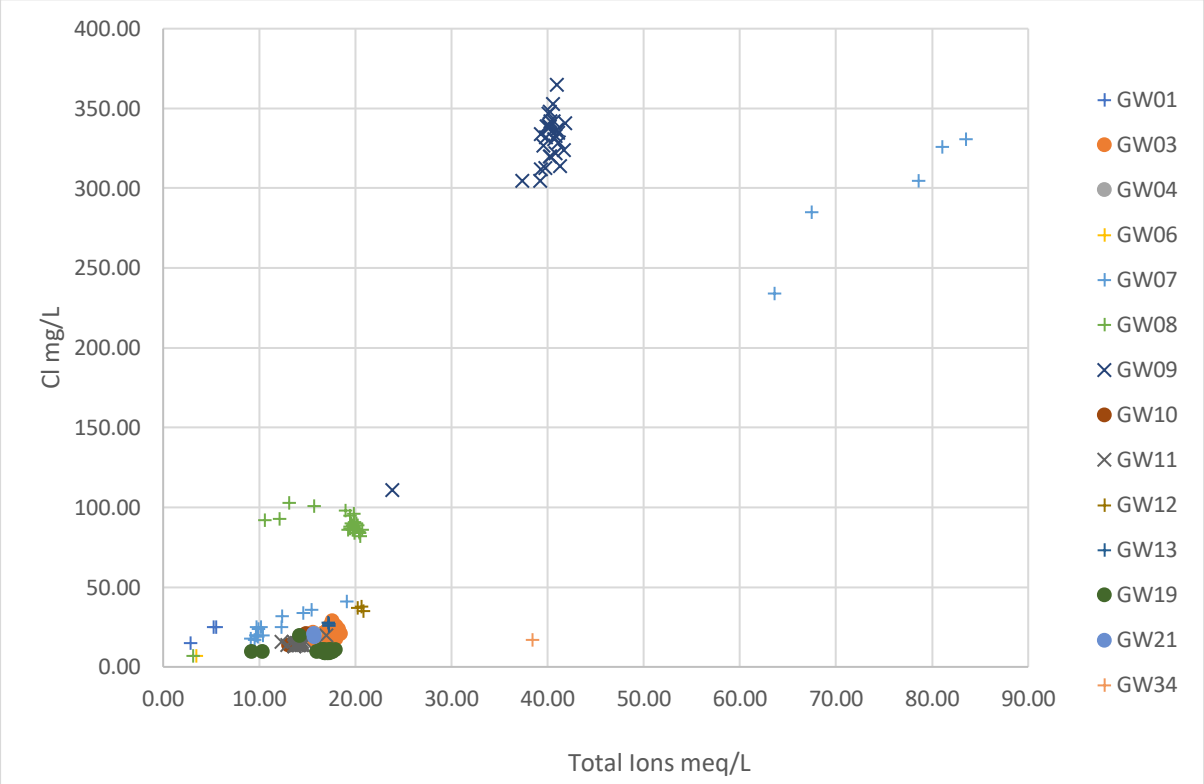


Figure 5: Chloride versus Total Ions. (+ - Lady Loretta Block, o – Cambrian Block, x – Paleoproterozoic Block)

At the detailed scale Chloride concentration for groundwater sampled at GW08 is about twice the Chloride concentration for groundwater from the LL and Cambrian Blocks. This may indicate that this groundwater is more highly concentrated during recharge at this particular location. It can also be concluded, if this is the case, that there is no major mixing of groundwaters within the LL Block following recharge, and therefore groundwater flow can be seen as compartmentalised within this section of the block.

If all the Chloride concentration in groundwater is from oceanic aerosols from rainfall, then one might expect that the Na/Cl weight ratio may reflect seawater values, assuming that Sodium behaves conservatively. Figure 6 shows the Na/Cl ratio for groundwaters plotted against Total Ions. The seawater ratio is also shown. Note that groundwater from bore GW09 falls on the seawater ratio line and indicates that at least the sodium and chloride conform with a simple diffuse recharge from oceanic salt sources. Some of the samples of groundwater from GW07 lie on the same ratio. However, most sampled groundwater shows a trend of increasing Na/Cl ratio for a given Total Ion value. This may indicate that sodium is preferentially added to the groundwater during recharge,

probably due to ion exchange process in the shallow soil/regolith. Note that there is no trend with increasing Total Ion value. The flow system, as it can be deduced, does not support increasing Cl values down the flow path. Thus, the data in Figure 6 show that this ratio is inherited probably shortly after recharge, and is then maintained within that part of the aquifer compartment. This further supports a conceptualisation of the aquifer within the blocks being compartmentalised in specific areas, with little interchange between compartments.

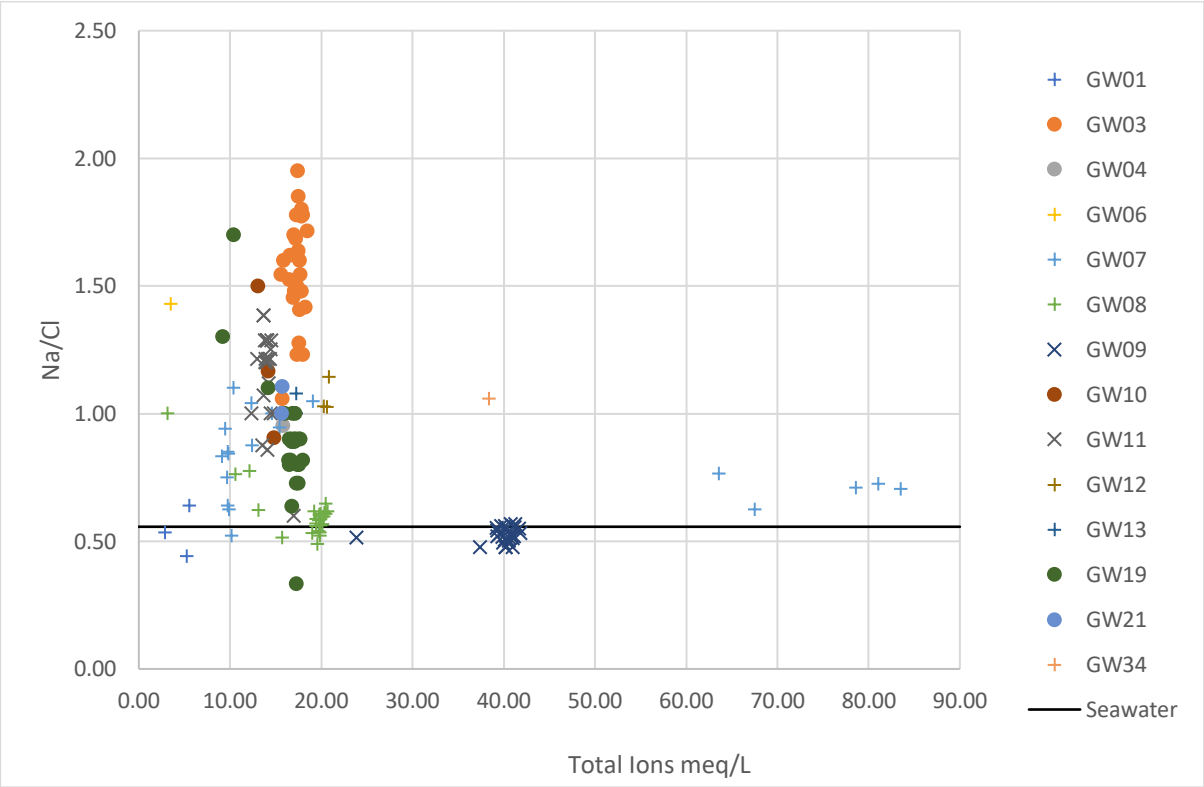


Figure 6: Na/Cl weight ratio vs Total Ions (+ - Lady Loretta Block, o – Cambrian Block, x – Paleoproterozoic Block)

Sulphate

Sulphate plotted against Total Ions (Figure 7) shows that:

- Sulphate concentration in the Cambrian Block groundwater is always low;
- Groundwater in the Lady Loretta Block has variable sulphate levels, including extremely high levels at times in bore GW07; and
- There is both low and high sulphate concentrations in groundwaters of the Paleoproterozoic Block.

These findings are consistent with the understanding of the distribution of sulphidic mineralisation within the bedrock, and indicate that sulfur is being contributed to the groundwater from mineral dissolution (or oxidation) processes. These oxidation processes are consistent with the measured redox potential (as discussed above).

The low sulphate content of groundwater within the Cambrian Block also indicates that the rocks are dominated by carbonates/dolomites, and not by gypsum.

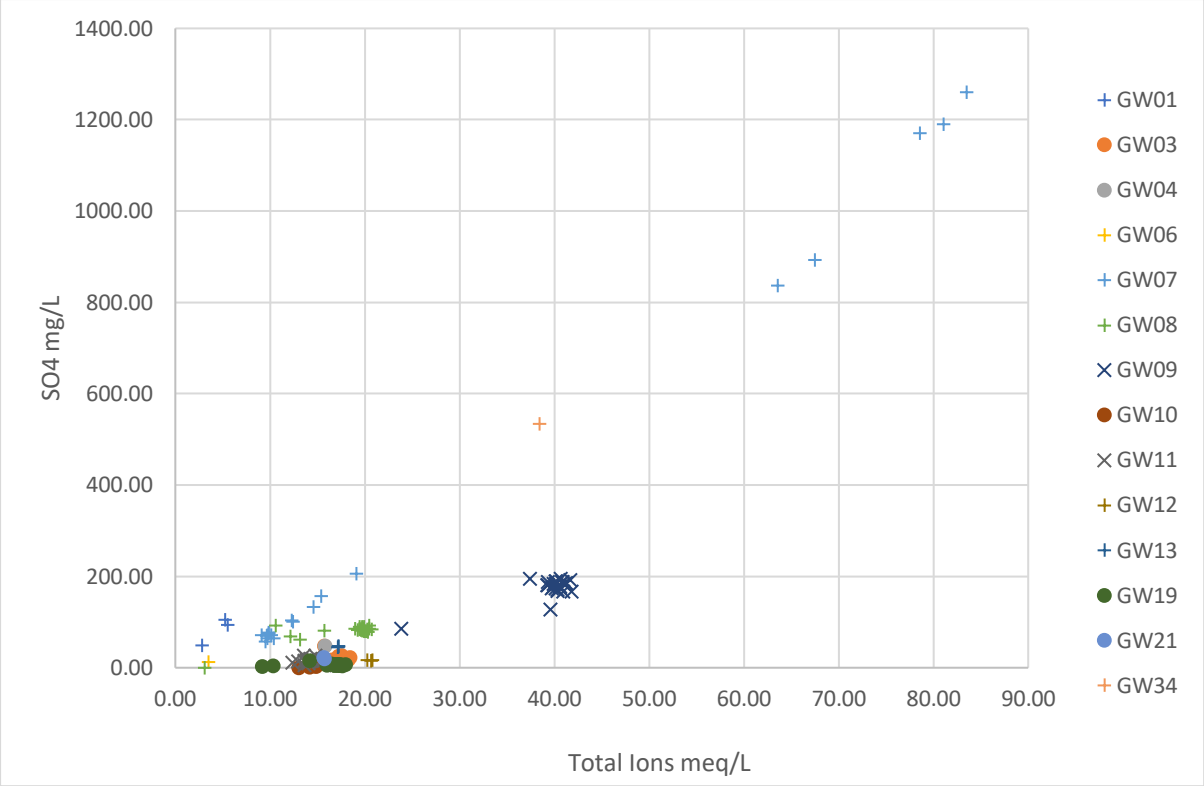


Figure 7: Sulphate versus Total Ions (+ - Lady Loretta Block, o – Cambrian Block, x – Paleoproterozoic Block)

Total Alkalinity

Total Alkalinity is reasonably constant across the different Block groundwaters, with values generally between 300 and 450 mg/L (Figure 8), though the proportion of Total Ions varies, with the Cambrian Block groundwaters having a larger proportion of Total Alkalinity when compared to groundwater sampled from bore GW07 in particular.

Total Alkalinity is most likely derived from two sources in the Lady Loretta area. Firstly, it is produced via the dissolution of carbonates (and dolomites), and secondly, it is produced via the dissolution of alumino-silicates.

Groundwater from bore GW11 (located in the Proterozoic block), GW12 and GW13 (located in the Lady Loretta block) have the same Total Alkalinity and Total Ion values as groundwater from the Cambrian Block. The piezometry of the site precludes any movement of groundwater from the Cambrian Block to the site of GW11, but there may be some limestone layers present at that site. Movement of groundwater may be occurring from the Cambrian Block to the site of GW12 and GW13, but more detailed piezometry would be required to confirm this. It is also possible that there are carbonate layers present in these bores.

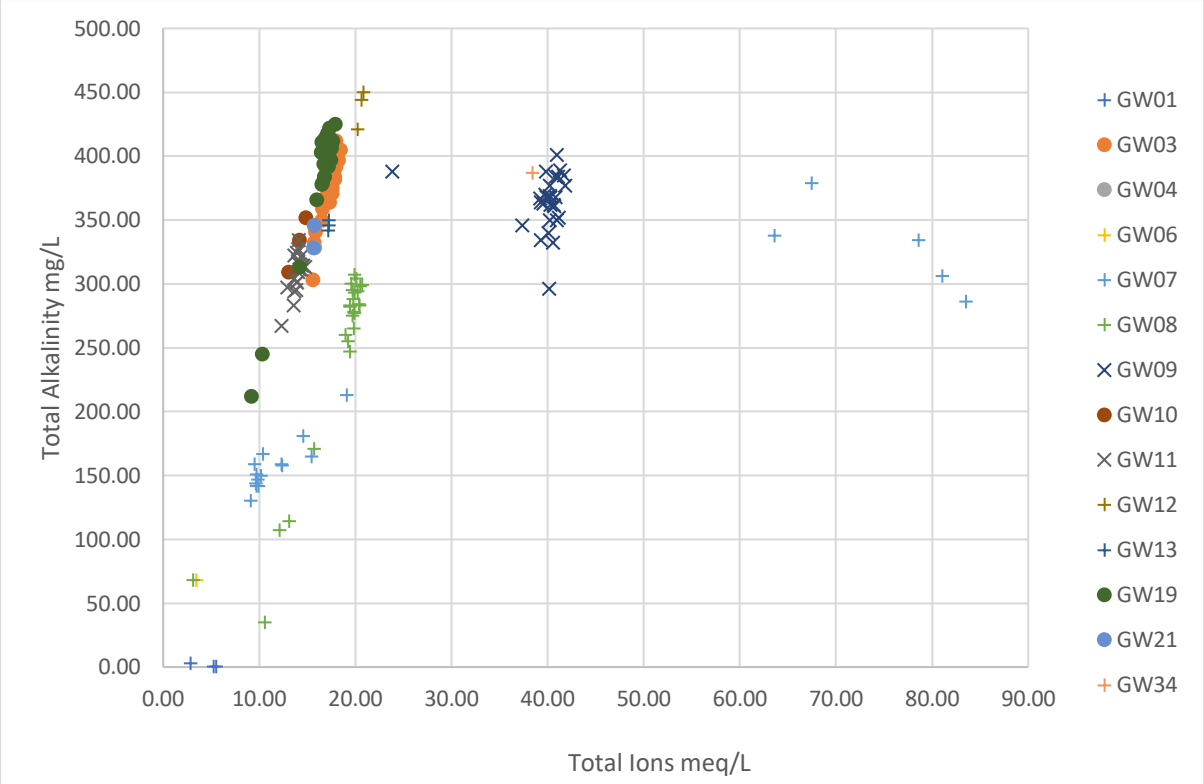


Figure 8: Total Alkalinity versus Total Ions (+ - Lady Loretta Block, o – Cambrian Block, x – Paleoproterozoic Block)

To further understand the geochemistry of the Cambrian Block groundwater, the molar ratio of Total Alkalinity to Calcium plus Magnesium was plotted against Total Ions (Figure 9).

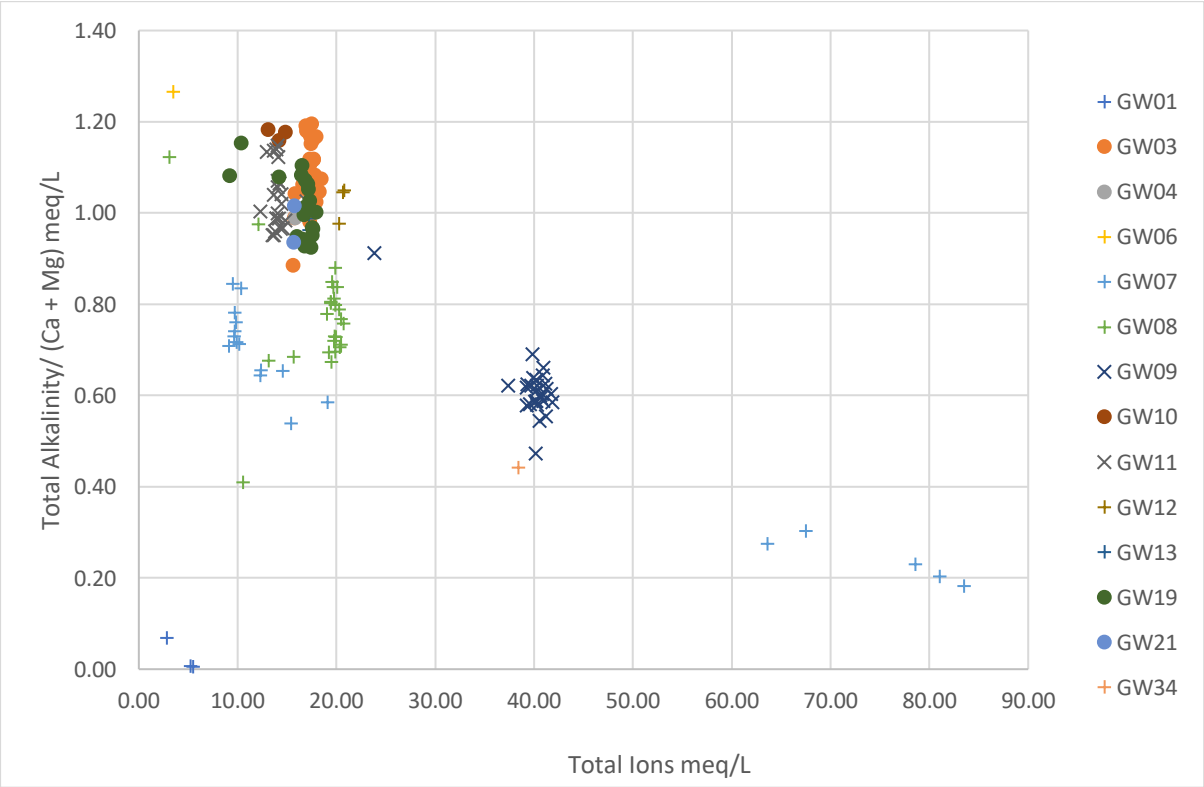


Figure 9: Molar ratio of Total Alkalinity/Ca plus Mg versus Total Ions (meq/L) (+ - Lady Loretta Block, o – Cambrian Block, x – Paleoproterozoic Block)

If dolomitic dissolution were the primary driver on the Total Alkalinity and, Calcium and Magnesium system, then one might expect that the ratio of those constituents would be unity. Figure 9 shows that the ratio for the Cambrian Block groundwater is close to one in all cases.

Interestingly, some of the non-Cambrian Block groundwater plots in the same space; namely, GW11, GW12 and GW13, as well as some early samples from GW08.

Temporal Variability of Water Chemistry

Changes in water chemistry for groundwaters sampled at bores GW03, GW07 and GW08 is discussed below within the context of understanding how dewatering of the aquifer affects chemical constituents, either through mine leakage or through borefield extraction. The focus of discussion is confined to changes in sulfate concentration and to changes in the molar ratio of Total Alkalinity to Calcium plus Magnesium.

Bore GW03

Bore GW03 samples groundwater from the Cambrian Block.

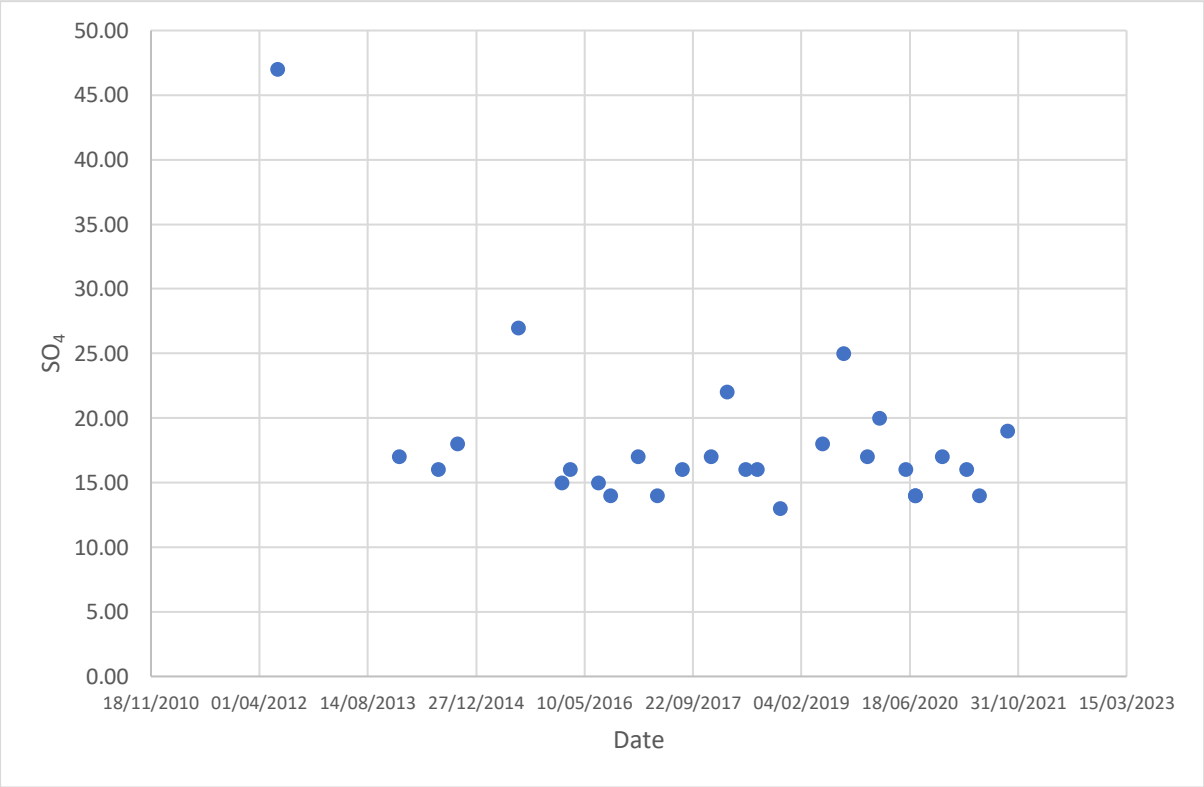


Figure 10: Sulfate concentration over time for GW03

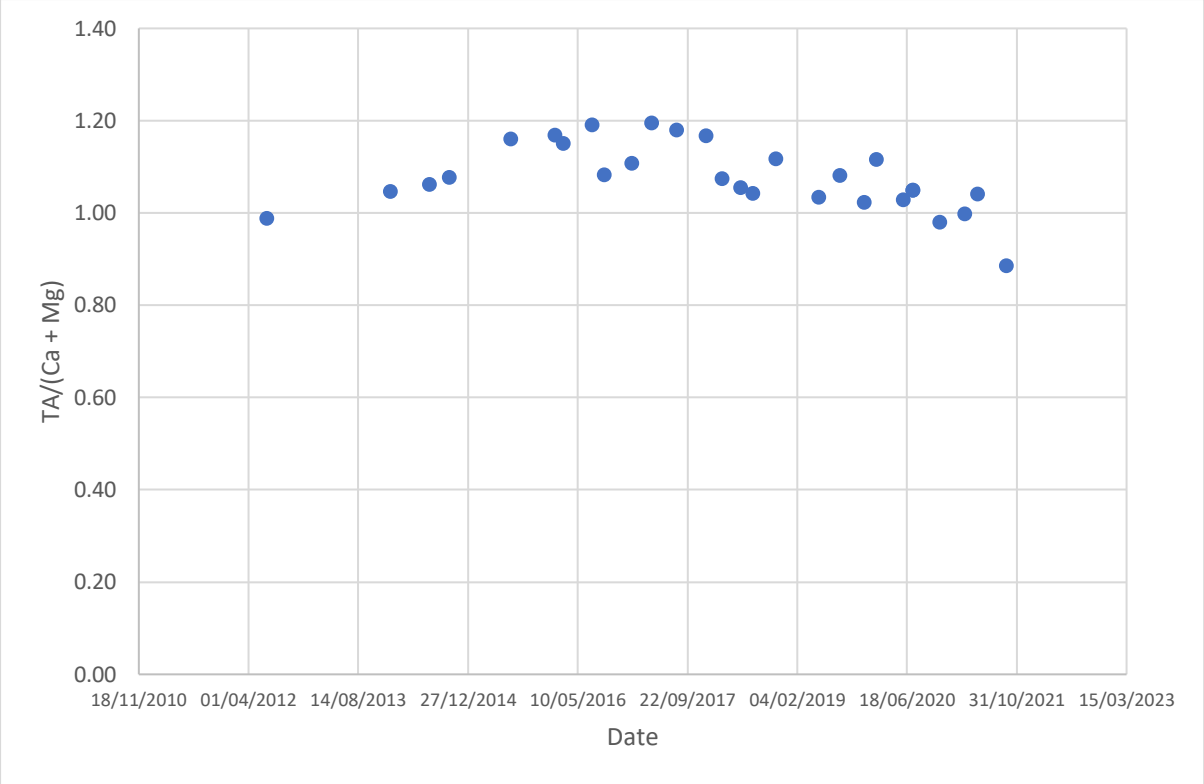


Figure 11: Molar ratio of Total Alkalinity/(Ca plus Mg) versus time for bore GW03

Figure 10 and Figure 11 show temporal changes in SO4 and the ratio TA/(CA + Mg) respectively. The trends with time are reasonably stable and indicate that as groundwater extraction from the borefield locally increases hydraulic gradients, the water chemistry is uniform. There appear to be no major water chemical reactions taking place at the temporal scale of the data.

Bore GW07

Bore GW07 samples groundwater from the Paleoproterozoic Block to the north of the Lady Loretta mine, and lies up gradient. The bore is situated very close to the Carlton Fault.

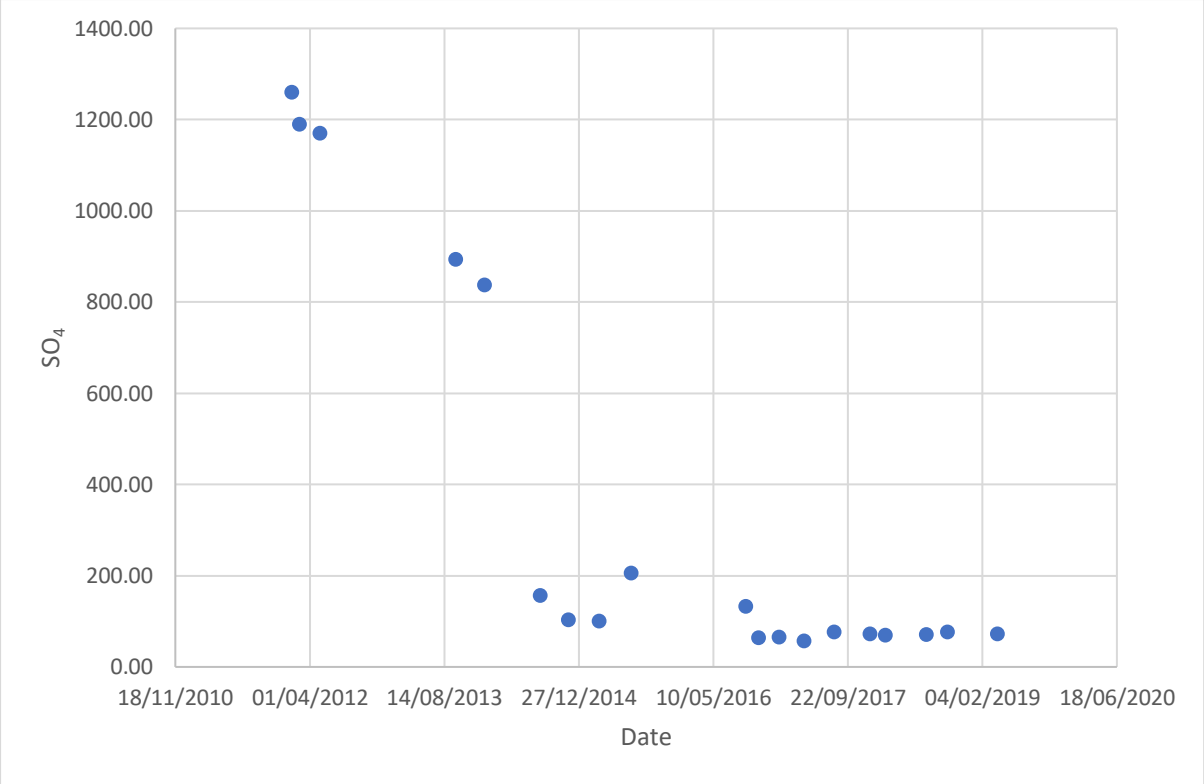


Figure 12: Sulfate concentration over time for GW07

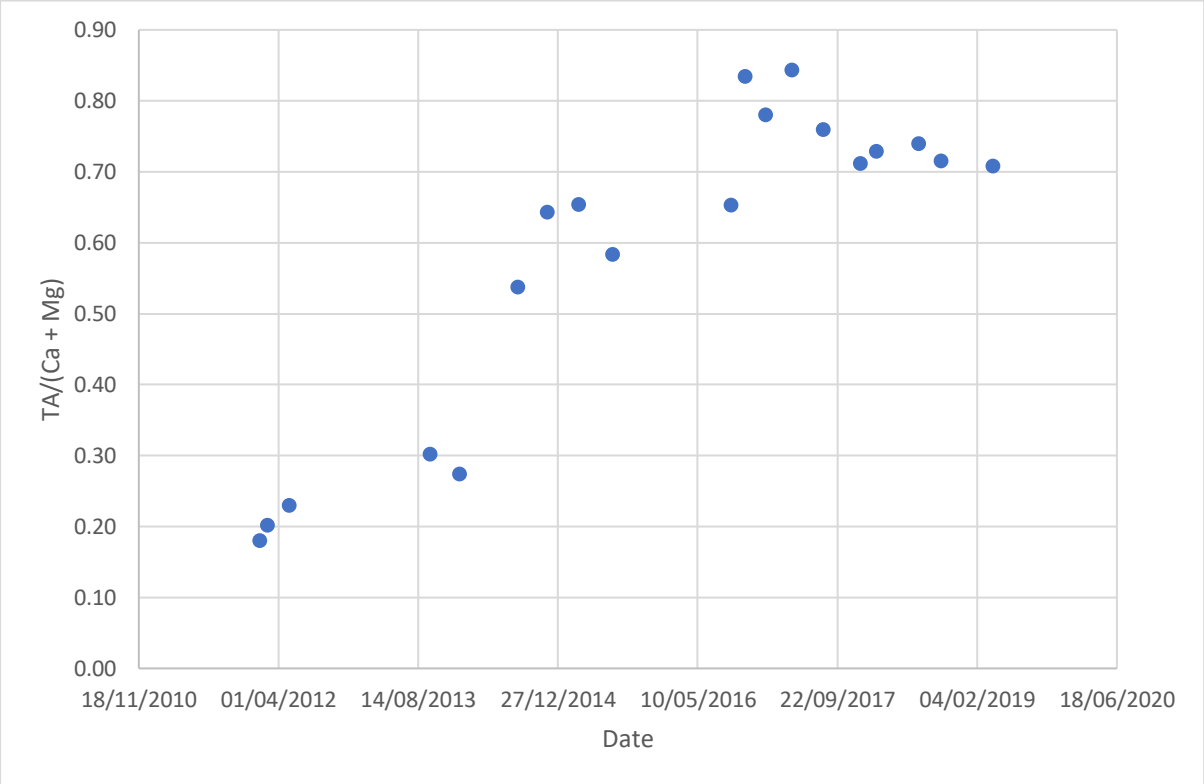


Figure 13: Molar ratio of Total Alkalinity/(Ca plus Mg) versus time for bore GW07

Changes in water chemistry for GW07 show that as the mine dewatering proceeds, there is a rapid decrease in SO4 concentrations, and a correlated increase in the ratio of TA/(Ca + Mg) (Figure 12 and Figure 13). In mid-2016 the two plots reach a dynamic equilibrium. The sulfate decrease is probably

indicative of the rate of oxidation of sulphidic minerals locally to the sampling point. As the hydraulic gradients increase and flow increases towards the mine, the newly arriving groundwater is unable to oxidise sufficient sulphides to maintain the original concentration. This potentially indicates very low storage in the aquifer, and high local groundwater velocity. The Total Alkalinity to Calcium plus Magnesium ratio increases substantially, but never reaches greater than about 0.8. This increase may be due to silicate dissolution processes, or the dissolution of carbonates, or a combination of both.

Bore GW08

Bore GW08 samples groundwater from the Lady Loretta Block and lies to the south east of the Lady Loretta mine.

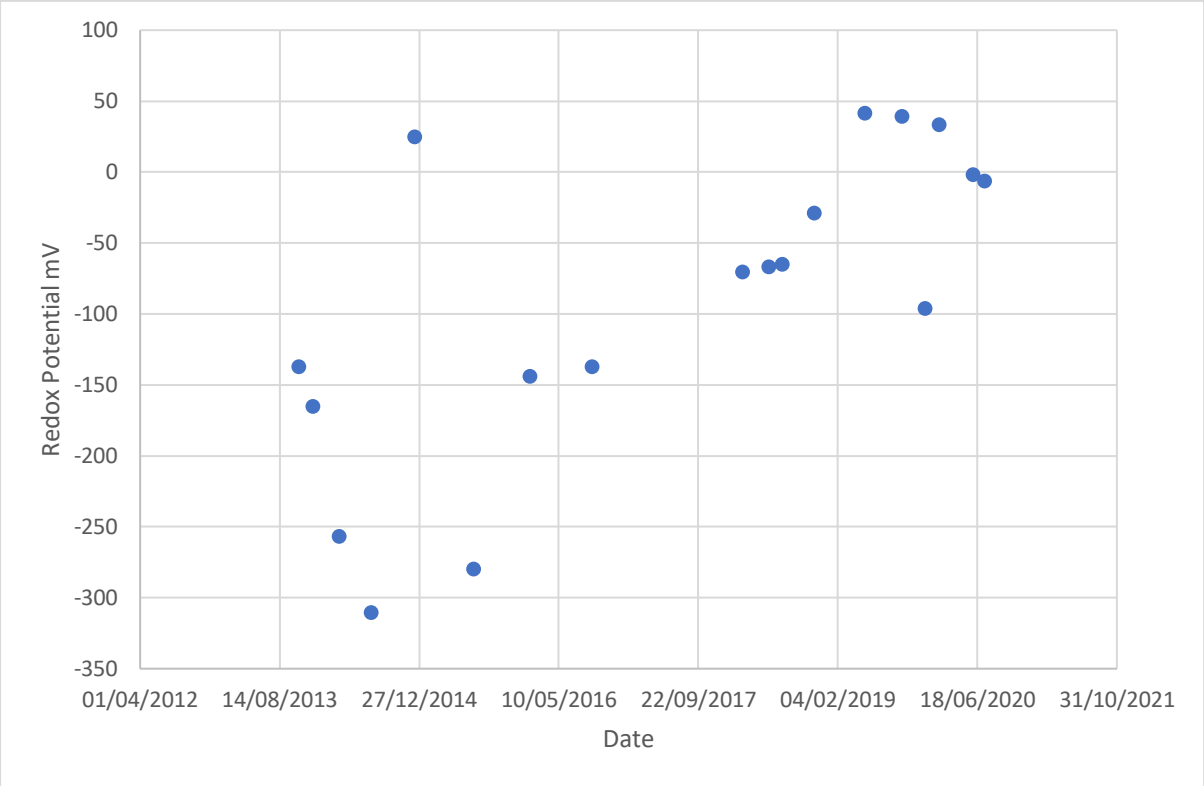


Figure 14: Redox potential variability over time for GW08

The redox potential for bore GW08 increases to mildly oxidised levels by early 2019 (Figure 14). This is a typical response of a system that is of low storage (buffer volume) and the introduction of oxygenated groundwaters. Figure 15, however, shows that sulfate concentration didn't change in response to this increase in oxidation, potentially indicating that either the kinetics of the oxidising process are stable under the flow conditions, or this is a larger store of dissolved sulfate within the vicinity of the bore.

The molar ratio of TA/(Ca + Mg) decreases over time (Figure 16), also indicating that silicate dissolution processes are most likely dominant, but the early data may indicate that there are carbonate rocks within the vicinity of the bore.

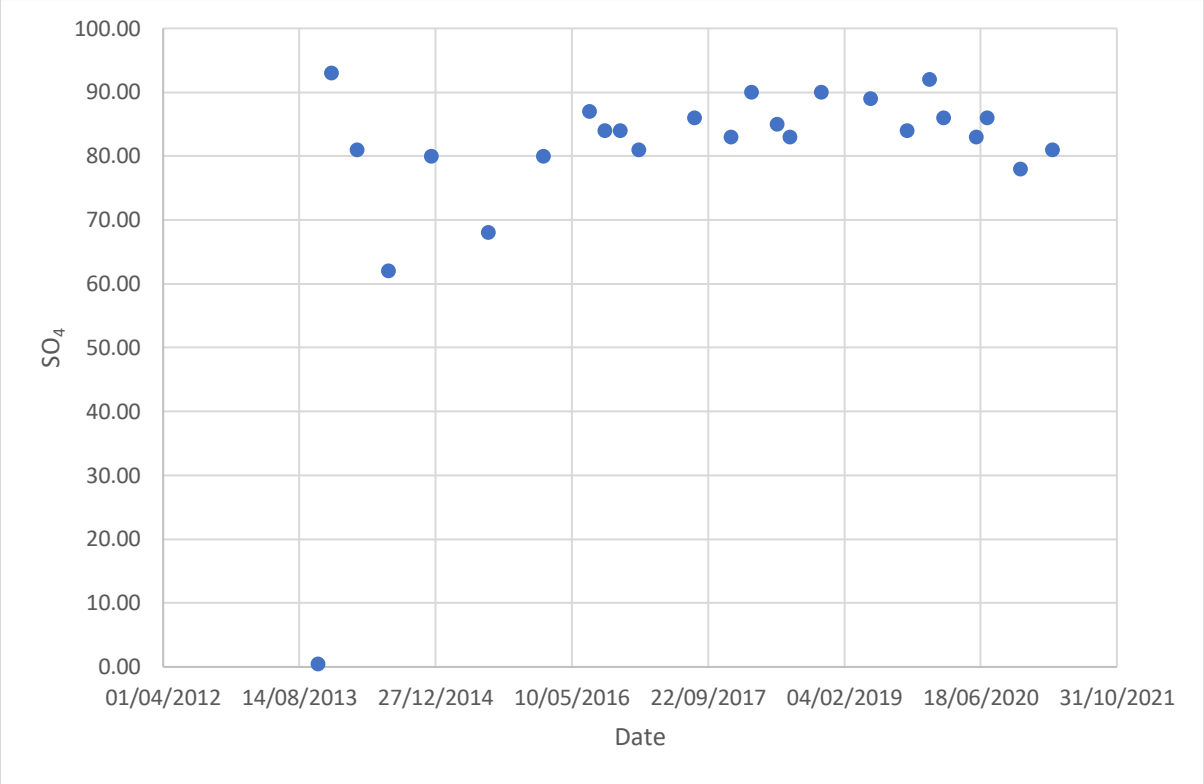


Figure 15: Sulfate concentration over time for GW08

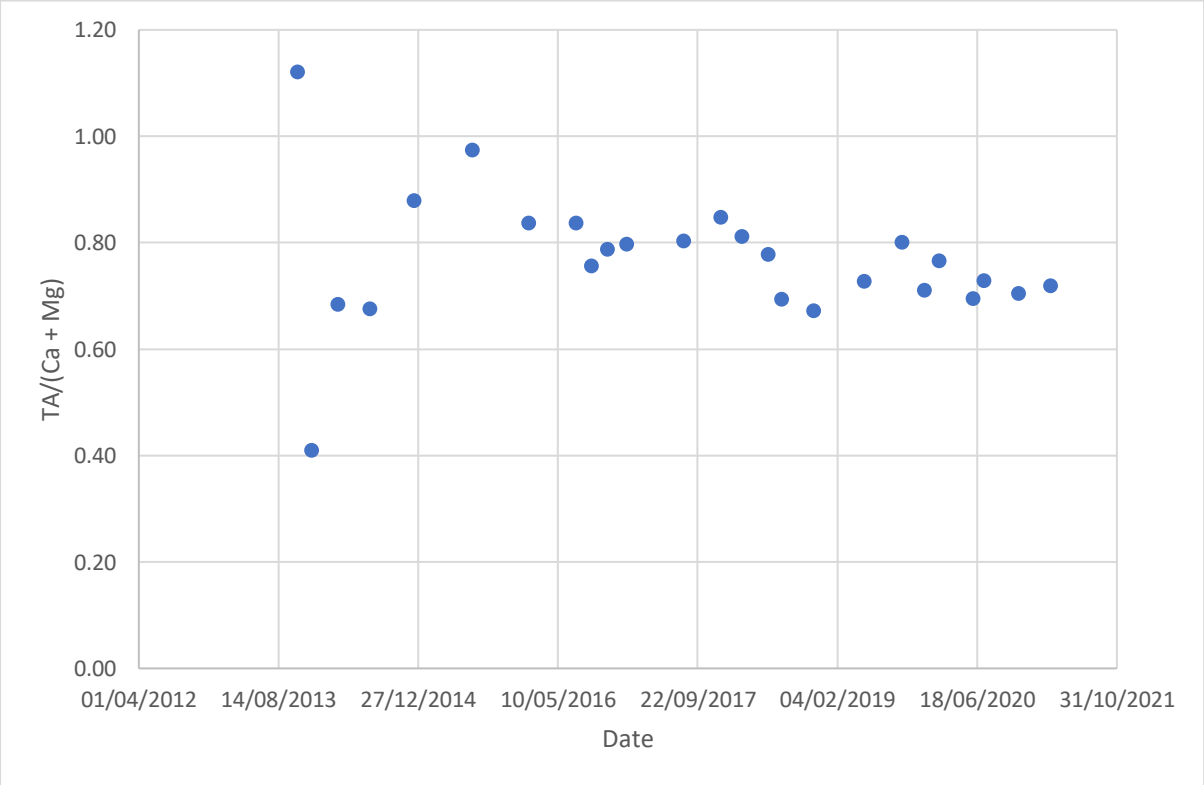


Figure 16: Molar ratio of Total Alkalinity/(Ca plus Mg) versus time for bore GW08

Water Chemistry of Underground Working Leakage

A number of water samples were taken from seepages in the mine over the period August 2019 to March 2020.

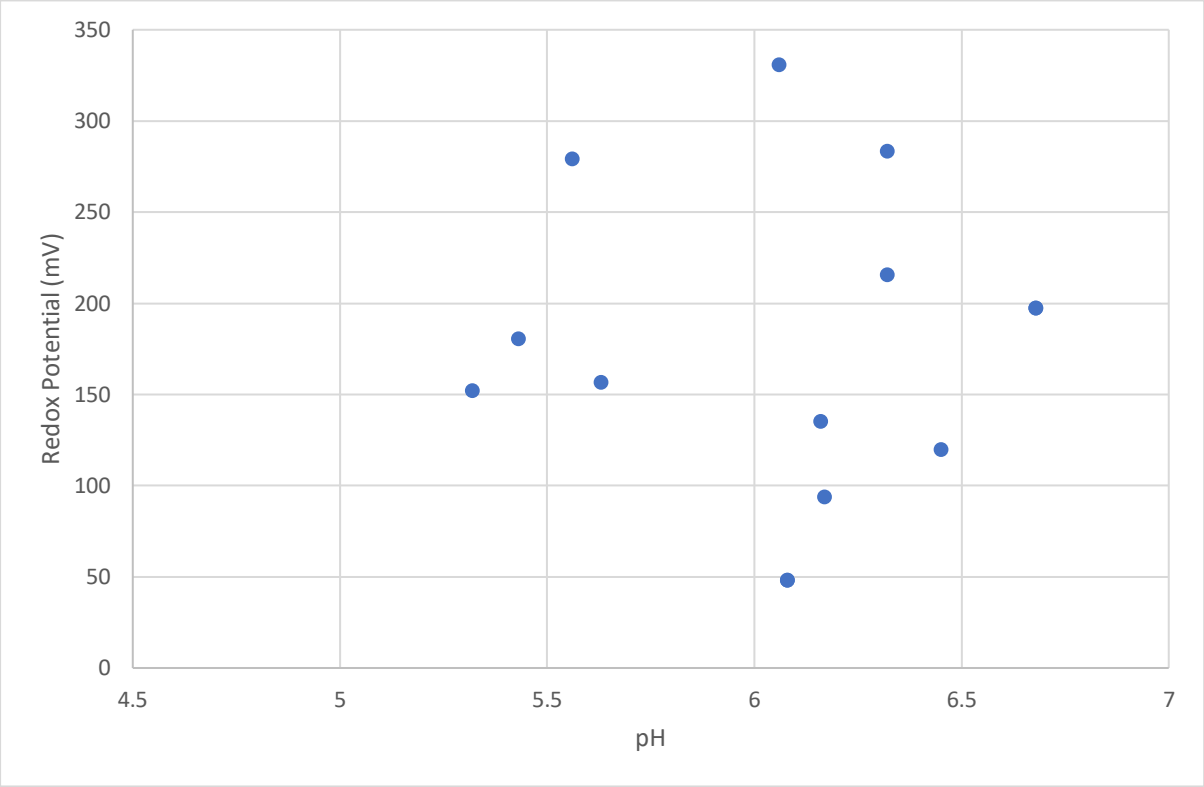


Figure 17: pH versus Redox Potential of Underground Leakage samples

The pH – Redox potential field (Figure 17) shows that the leakage water is slightly acid and oxidised. The oxidation state is similar to the regional samples (Figure 4), however, the pH is lower by about one pH unit. This is consistent with the level of sulphidic content of the mine sequence of rocks, and indicates its acid forming potential.

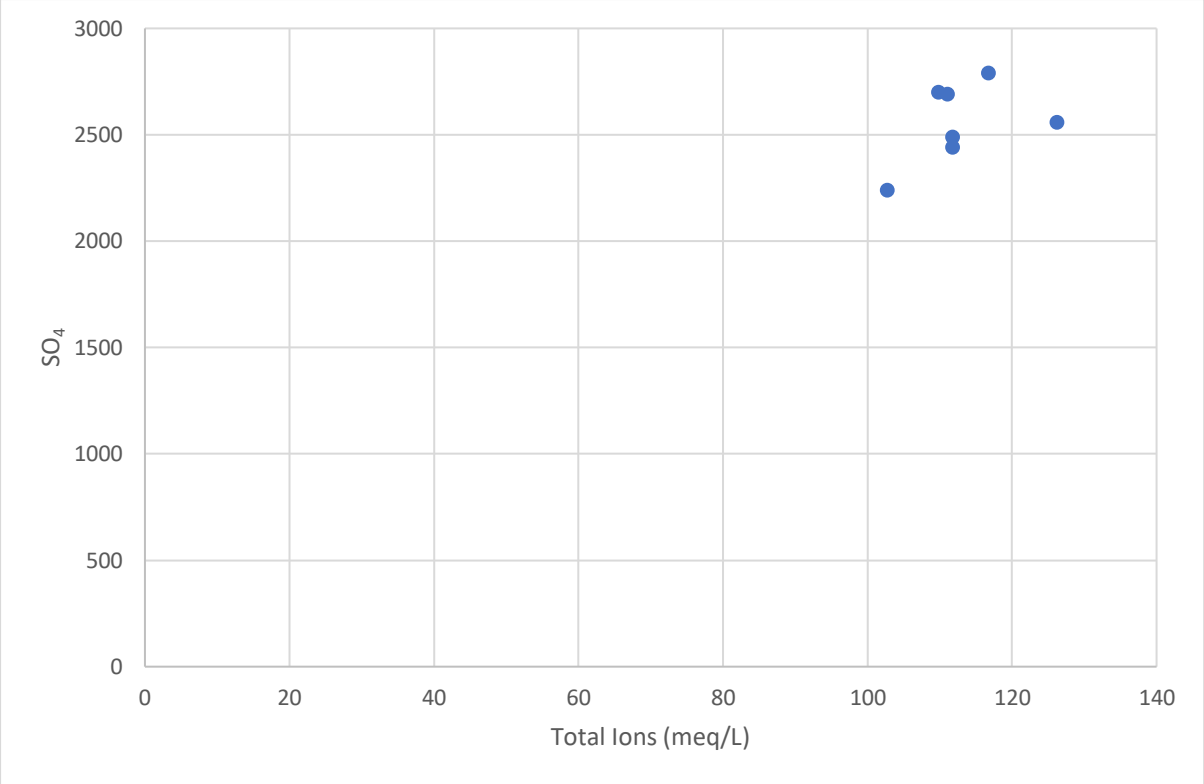


Figure 18: Sulfate versus Total Ions, Underground Leakage samples

Leakage samples are more saline (higher Total Ion values) and have higher Sulfate concentrations than the surrounding groundwater (Figure 18).

The molar ratios of Total Alkalinity to Calcium plus Magnesium () for underground leakage samples are small compared with all other samples and indicates that carbonate dissolution is not a controlling dissolution process close to the mine workings. Concentration of both divalent cations (Calcium and Magnesium) is high when compared to Total Alkalinity. It is unknown at this time what process is responsible for these values.

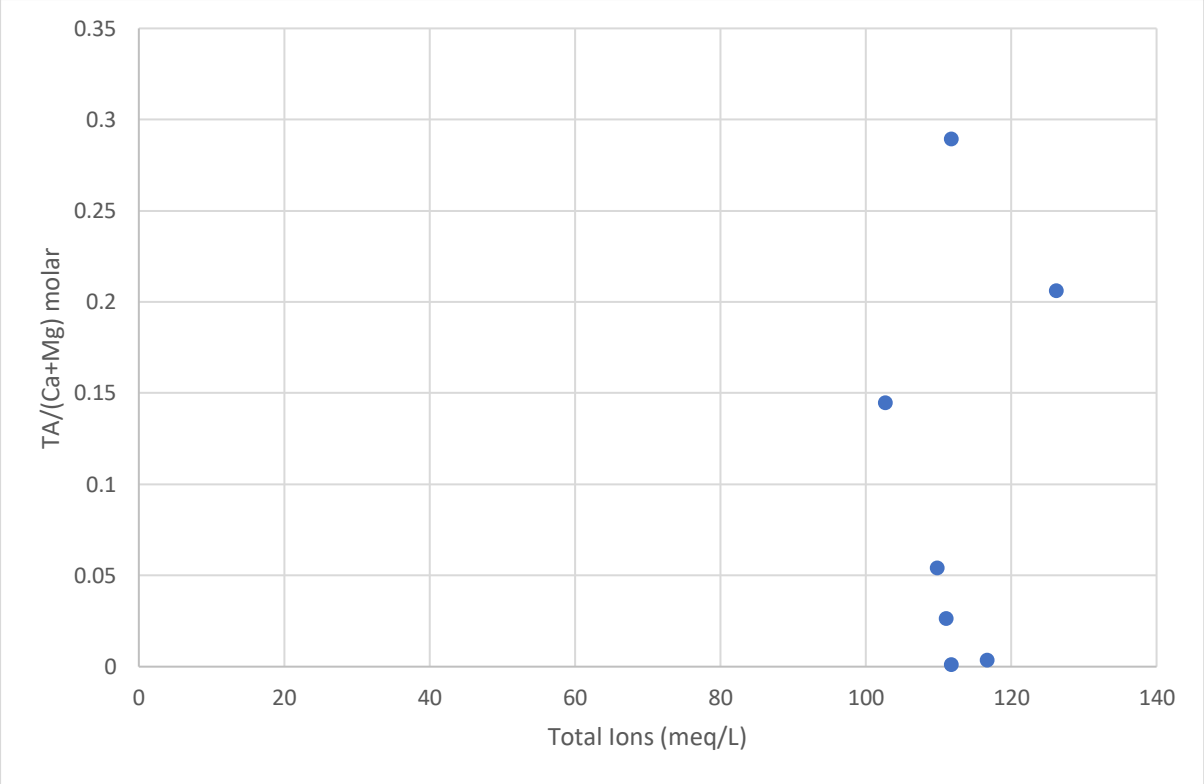


Figure 19: Molar ratio of Total Alkalinity/(Ca plus Mg) versus Total Ions (meq/L) for Underground Leakage samples

Major Ion Discussion

In an effort to further differentiate the groundwaters between Blocks, the molar ratio of Total Alkalinity to Calcium plus Magnesium was plotted against Sulphate (mg/L) (see Figure 20). The plot shows that groundwater from the Cambrian Block has a TA/(Ca+Mg) ratio of around 1, and low Sulphate, whereas groundwater from the Lady Loretta Block has a TA/(Ca+Mg) ratio approaching but never reaching 1, and increasing concentration of Sulphate. Groundwater from GW09 is consistent with the Lady Loretta character, but groundwater from GW11 is consistent with groundwater from the Cambrian Block. Groundwater from bores GW12 and GW13 show a transitional character between the two Blocks.

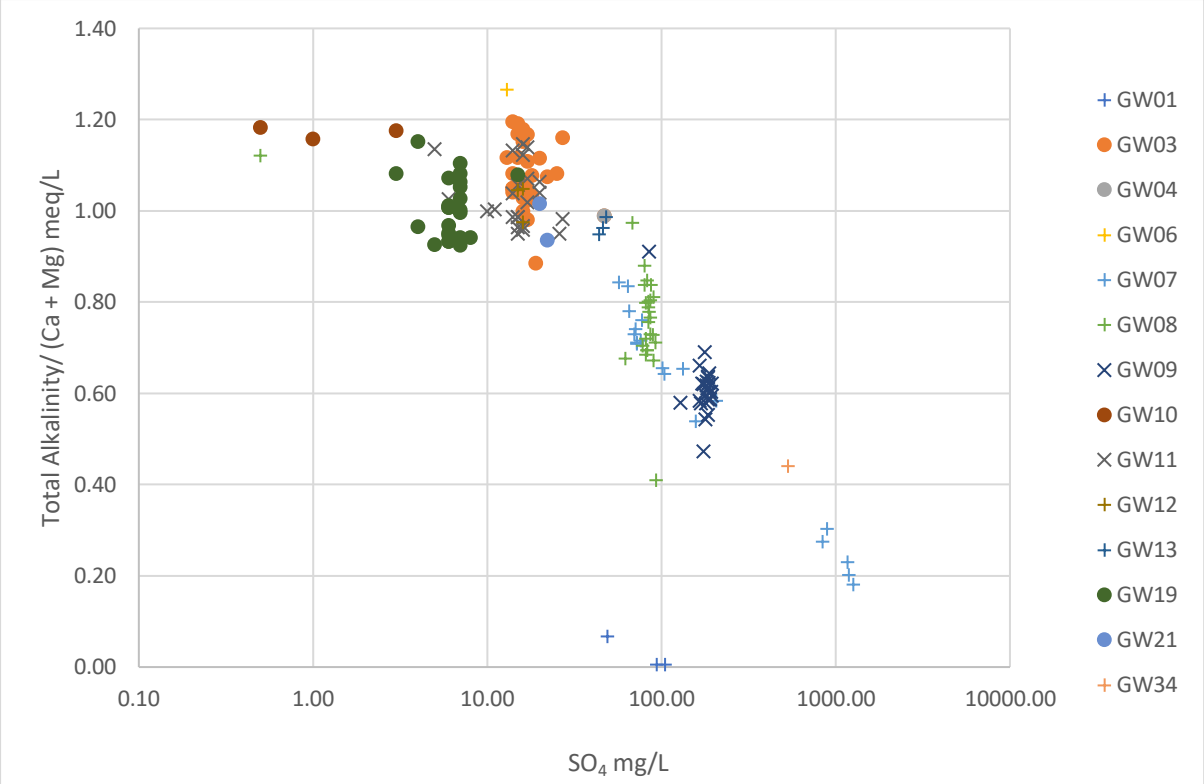


Figure 20: Molar ratio of Total Alkalinity/Ca plus Mg versus Sulphate (mg/L) (+ - Lady Loretta Block, o – Cambrian Block, x – Paleoproterozoic Block) Note the logarithmic scale on the X-axis.

One conceptual model of the Lady Loretta area is that the two main faults (the Western and Carlton Faults) are not barriers to lateral flow and that groundwater from the Cambrian Block is able to flow towards the Lady Loretta mine void consistent with the current understanding of hydraulic gradients in the area. From a hydrochemical point of view, this lateral flow can be tested by examining groundwater samples from bores completed in the Lady Loretta Block to see if they show signs of attaining a chemical signature similar to that from groundwater in the Cambrian Block. This is predicated, though, by where the "breakthrough" front of Cambrian groundwater has progressed. That is, once drawdown conditions were established at the mine void, actual particle flow across the fault will take time to reach the void. It is probable that, according to the conceptual model of fault character, the advective front is still somewhere between the Western Fault and the mine void. For the groundwater sampled at the intervening bores to show a Cambrian Block signature, the advective front will have to have reached the bores sampled.

Bores GW08, GW12, GW13 and GW34, located in the Lady Loretta Block, lie in these transitional areas. Piezometry appears to preclude flow from the Cambrian Block towards GW08, GW12 and GW13. However, there are hydrochemical signatures in these bores consistent with the typical chemical makeup of groundwater in the Cambrian Block. It is unclear if this indicates the advective front has reached these bores, or whether similar hydrochemical reactions are producing similar water chemistry.

Groundwater from GW34 is categorically not related to the Cambrian Block groundwater chemistry character.

Interestingly, groundwater sampled in GW06, GW07 located in the Lady Loretta Block and GW11 located in the Proterozoic Block all show similar character to Cambrian Block groundwater, but it is almost impossible for Cambrian Block groundwater to be found at these sites due to the large

groundwater gradient in the opposite direction. This indicates that some local geo-chemical features related to detailed bore lithology can produce similar results across the site.

Another consideration within which to assess the groundwater chemistry is whether there is hydrochemical evidence of the groundwater flow field prior to mining. That is, the site would have been in dynamic equilibrium prior to mining, and the groundwater would have been flowing according to the prevailing hydraulic gradients. These are unknown, but early groundwater level data suggests that the flow was from north-west to southeast. There is no chemical evidence to suggest or not suggest that groundwater was flowing from the Lady Loretta Block into the Cambrian Block. Bore GW21 is located very close to the mapped Western Border Fault, and is completed in the Cambrian strata. Groundwater at this site has the second highest level of Sulphate, indicating a potential influence or signature from the Lady Loretta Block. Bore GW04 has the highest sulphate content of the Cambrian Block and it is the furthest bore from the Western Border Fault.

There is expected to be a three to four order of magnitude change in hydraulic conductivity between the Lady Loretta Block (lower hydraulic conductivity) and the Cambrian Block (higher). This indicates a potential mass flux across the Western Fault that would be very small. Based on this consideration, it may be impossible to observe a change in water chemistry due to flow across the Western Fault in an easterly direction (that is, from the Lady Loretta to the Cambrian Block) within the accuracy of the chemical analyses undertaken.

The lateral flow of water between the Paleoproterozoic Block to the Lady Loretta block through the Carlton Fault has not been able to be assessed at this time from a hydrochemical perspective as there is insufficient data to complete the detailed assessment, and the Paleoproterozoic Block is inferred to be up hydraulic gradient from the Lady Lorretta block, so no groundwater is expected to flow from the Lady Loretta mine site to this Block.

Compartmentalisation within the Blocks

Chloride results as shown in Figure 5 shows that there is local compartmentalisation within the blocks, with results from select bores in the Lady Loretta and the Proterozoic blocks demonstrating this. In addition, sulphate findings also suggest compartmentalisation (Figure 10) as well as informing the distribution of sulphidic mineralisation within the bedrock, and indicate that sulfur is being contributed to the groundwater from mineral dissolution (or oxidation) processes and this could be considered compartmentalised in the vicinity of the underground workings.

Distribution of Metals in groundwater in the LLM region

The distribution of selected metals in groundwater across the Lady Loretta area was assessed as an aid to understanding what information can be inferred from their distribution and concentration and how this may constrain the existing conceptual model. The assessment also provides useful background information for consideration of Constituents of Concern during Stage 2 of the study.

The metals analysed in groundwater samples at the LLM, and assessed as part of this part of the project included Aluminium, Arsenic, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Molybdenum, Nickel, Selenium and Zinc. In addition, Boron and Iron were also analysed; these are not considered here.

Constituents were analysed for both dissolved and total concentrations. It is assumed that the field sampling procedures were appropriate for both types of laboratory analysis. Table 1 provides the percentage of samples for each constituent that were below the detection limit for both dissolved and total constituents.

Table 1: Percentage of Samples that had Detectable Levels of selected Metals

Metal	Total number of analyses	Detection limit (mg/L)	% of samples below detection limit for dissolved metals	% of samples below detection limit for total metals
Aluminium	167	0.01	80.2	44.9
Arsenic	168	0.001	37.5	33.1
Cadmium	164	0.0001	81.7	76.6
Chromium	167	0.001	91.0	71.1
Cobalt	169	0.001	33.1	27.5
Copper	170	0.001	72.9	52.1
Lead	165	0.001	93.3	75.4
Molybdenum	165	0.001	32.7	27.6
Nickel	170	0.001	38.8	39.5
Selenium	162	0.01	99.4	98.8
Zinc	171	<0.005	2.9	6.6
Mercury	162	0.0001	99.4	99.4

The difference between dissolved and total concentrations for specific constituents is due to the presence of particulate matter with associated metal content. The presence of particulates can be caused by inefficient filtering during the sampling operation, or particulates of a size smaller than the filter paper used at the time of sampling. Particulates may represent a phase that is mobile within the groundwater flow system and thus represent part of the transport process, or they may represent gels or films that have been dislodged from the bore casing or immediate surrounds of the bore during the disruptions from purging and sampling. In this latter case, the additional metals bound to these particles are not available for transport and do not constitute a component of the metal flux. There is not enough information to conclude what role the particulate portion of the total concentration has within this context, and as a result only dissolved concentrations will be considered further.

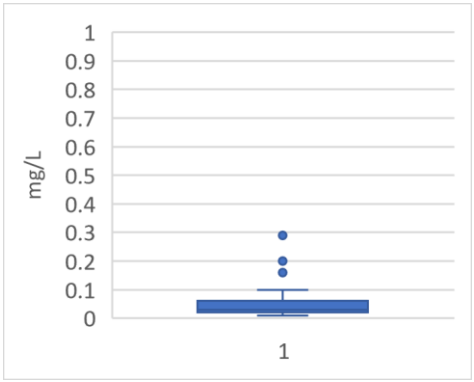
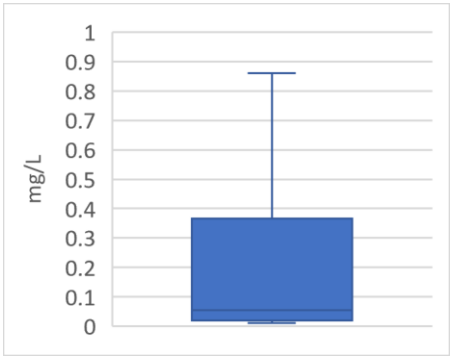
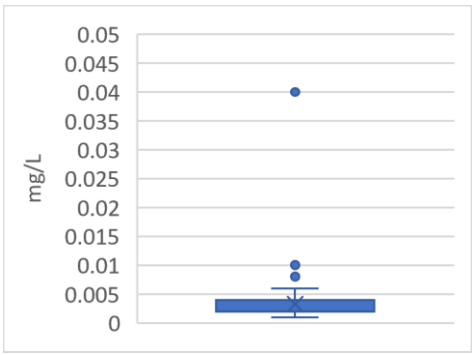
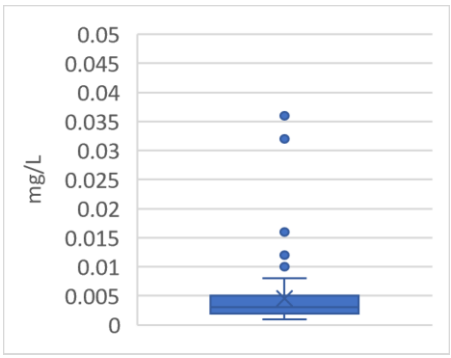
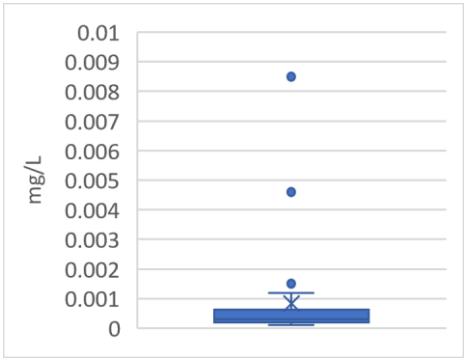
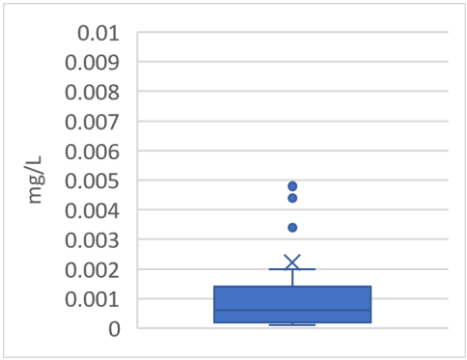
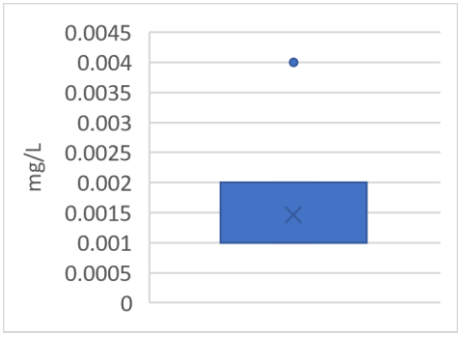
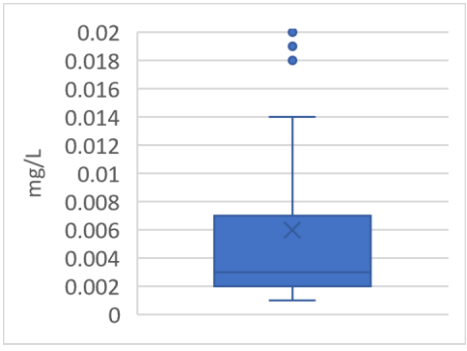
Table 1 shows that a large proportion of elements have concentrations below the detection limit. The exception is Zinc, where nearly all samples have a detectable concentration. Mercury, Selenium, Lead and Chromium are below detection limit in more than 90% of samples for dissolved species. Arsenic, Cobalt, Molybdenum and Nickel (in addition to Zinc) are below the detection limit for less than 40% of samples for dissolved species. This establishes a default background constituent presence as the groundwater samples represented in the Table are for observation bores some distance from the mine. That is, the rock mass at the bore sites have not been mechanically altered by mining, and have only undergone some dewatering due to mining operations.

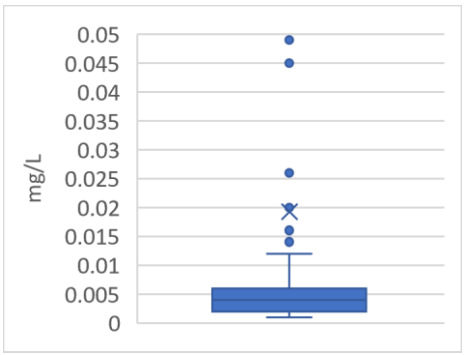
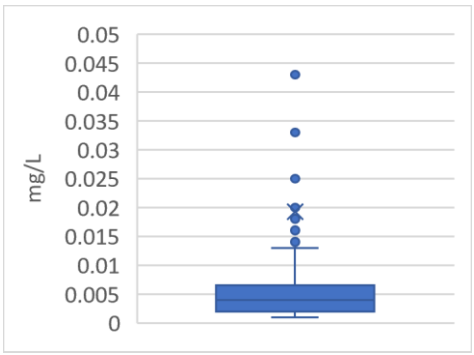
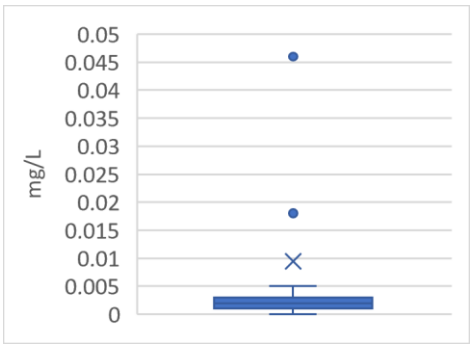
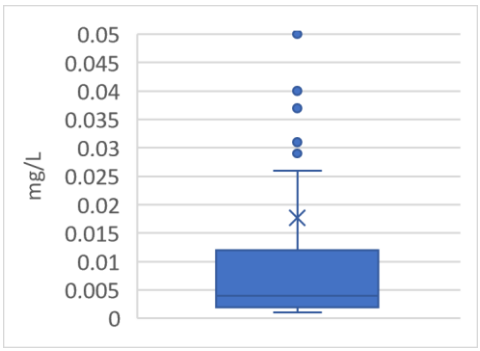
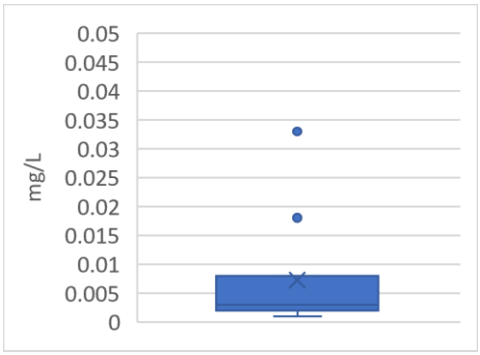
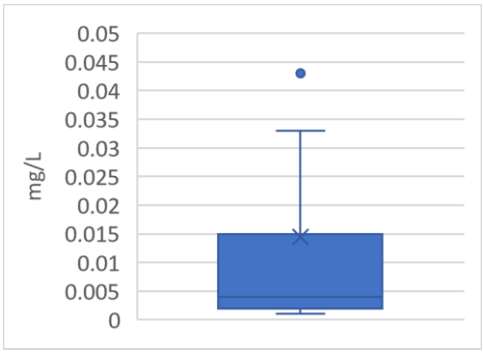
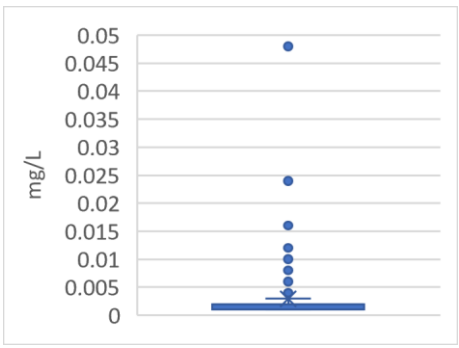
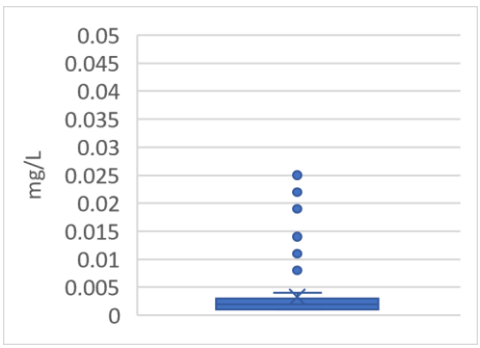
Table 2 provides information for the levels of constituents above the detection limit. That is, the concentration values that fall below the detection limit have been removed, and summary statistics for detected only concentrations are provided. The data is displayed in the form of box and whisker plots. The inner box represents the 25^{th} percentile value (the base of the box) and the 75^{th} percentile value (the top of the box). The whiskers (the lines above and below the box) identify the smallest (below) and largest (above) values that are not considered outliers. The dots represent outlier values

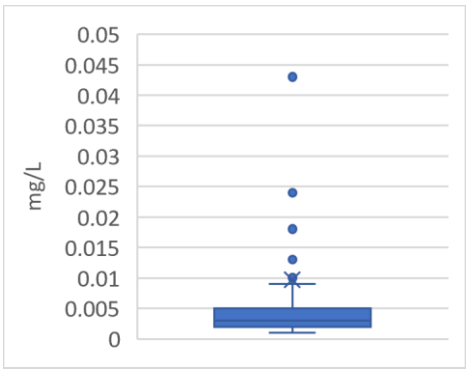
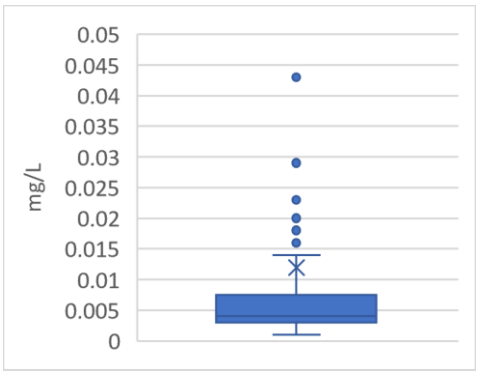
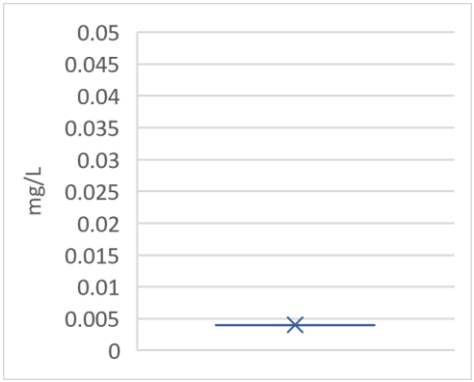
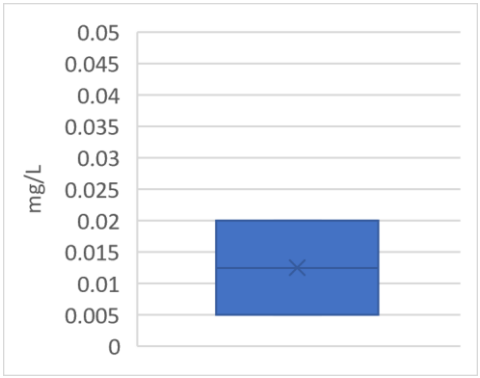
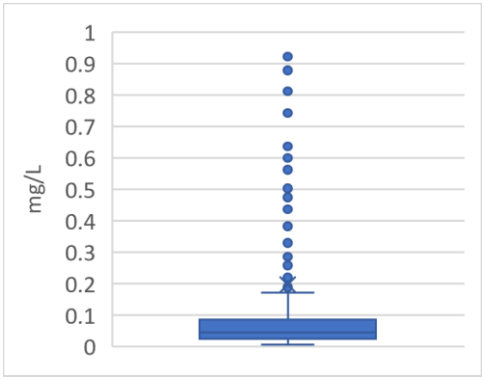
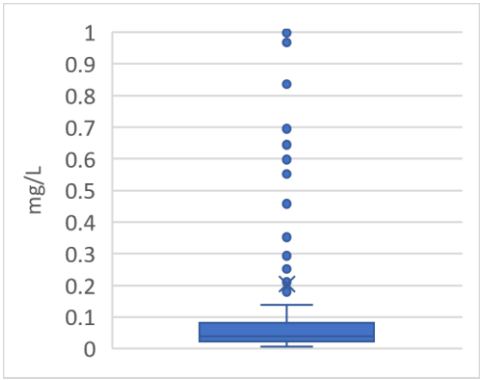
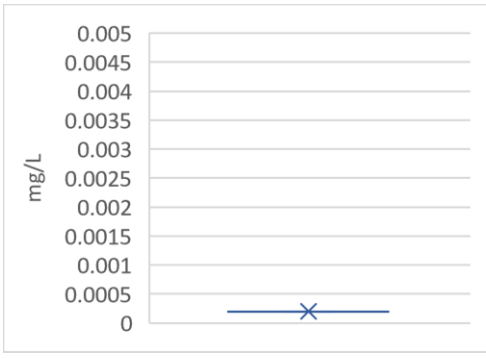
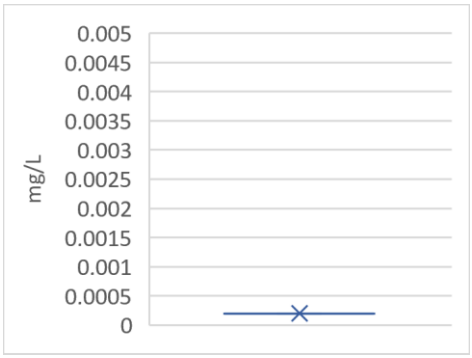
determined by being outside what is termed the inter-quartile distance. The line in the box is the 50th percentile value (the median) and the X is the mean value.

The data represents the background levels of metals in the groundwater and is not unexpected for a metalliferous terraine. Note also that the data is for all of the three geological blocks.

Table 2: Box and Whisker Plots of Selected Detected Metal Concentrations

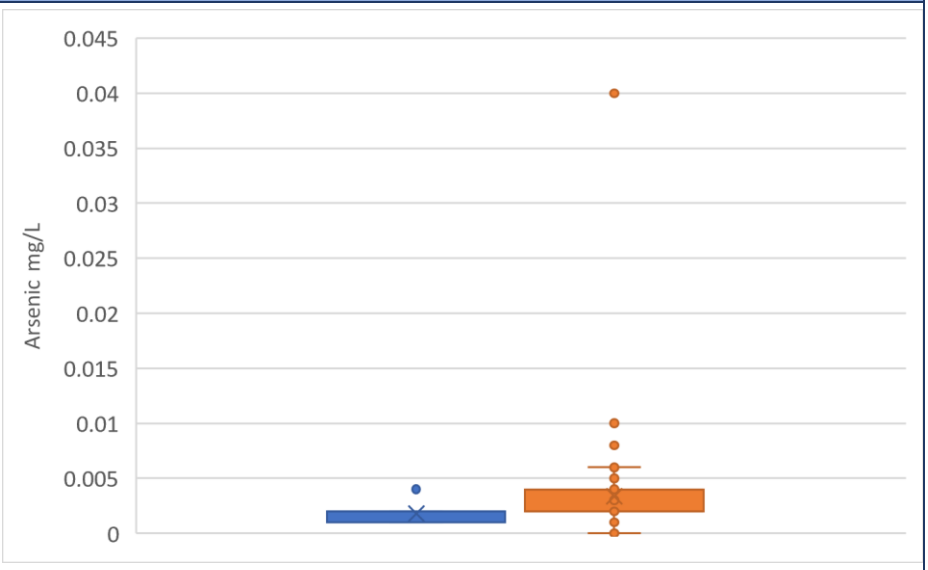
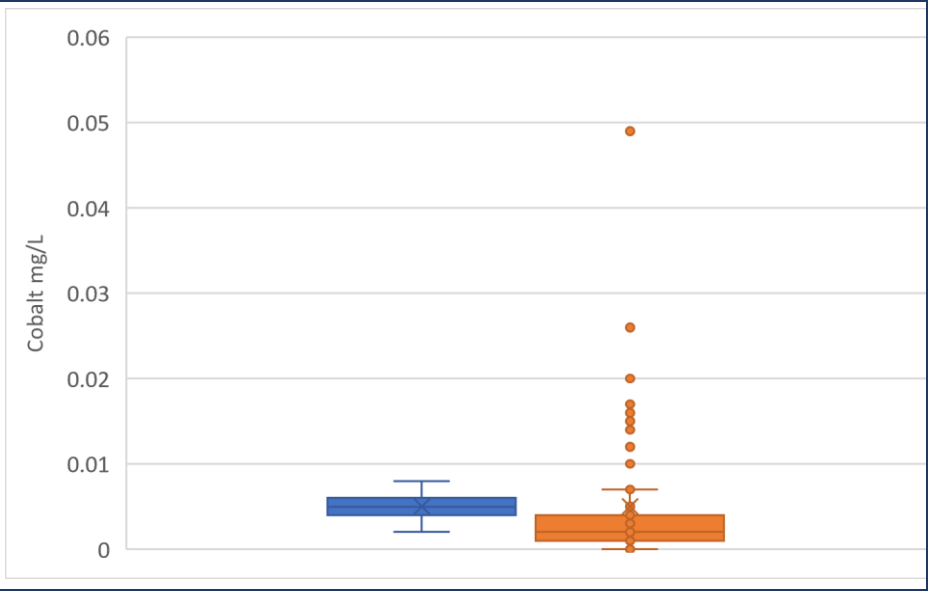
Metal	Dissolved	Total
Aluminium		
Arsenic		
Cadmium		
Chromium		

Metal	Dissolved	Total
Cobalt		
Copper		
Lead		
Molybde-num		

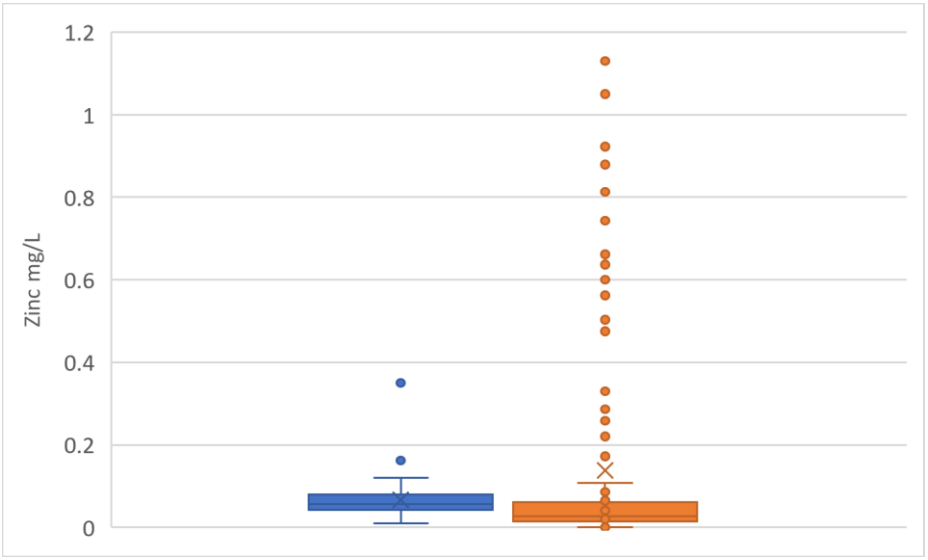
Metal	Dissolved	Total
Nickel		
Selenium		
Zinc		
Mercury		

The difference between groundwater sampled from the Cambrian Block and the other two Blocks (Paleoproterozoic and Lady Loretta) is further explored by considering box and whisker plots of dissolved Arsenic, Cobalt, Lead, Molybdenum, Nickel and Zinc (the main elements that have substantial detectable concentrations; Lead has been included as it is a potential CoC; see Table 3).

Table 3: Box and Whisker plots for selected dissolved metals for Cambrian Block (blue) and Lady Loretta plus Paleoproterozoic Blocks (orange)

Metal	
Arsenic	
Cobalt	

Metal	
Lead	
Molybdenum	
Nickel	

Metal	
Zinc	

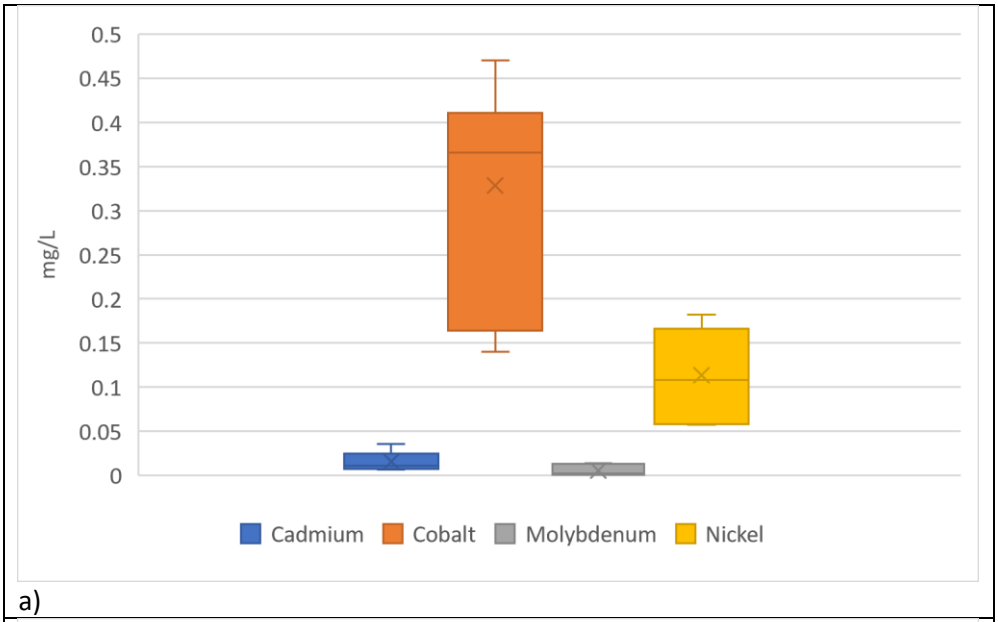
The plots show that the inter-quartile range (the width of the Box) is similar between the Cambrian and other Blocks. The median values are generally the same, but the means are different. The main difference though is that groundwater samples from the Lady Loretta and Paleoproterozoic Blocks have metal concentrations more likely to be outliers than for the Cambrian Block. That is, the concentration distribution is more likely to be uniform for the Cambrian Block, whereas, a number of samples provide concentrations that are more than the interquartile distance above the mean. This is particularly pronounced for Zinc.

Lead shows very low concentrations for all sampled groundwater.

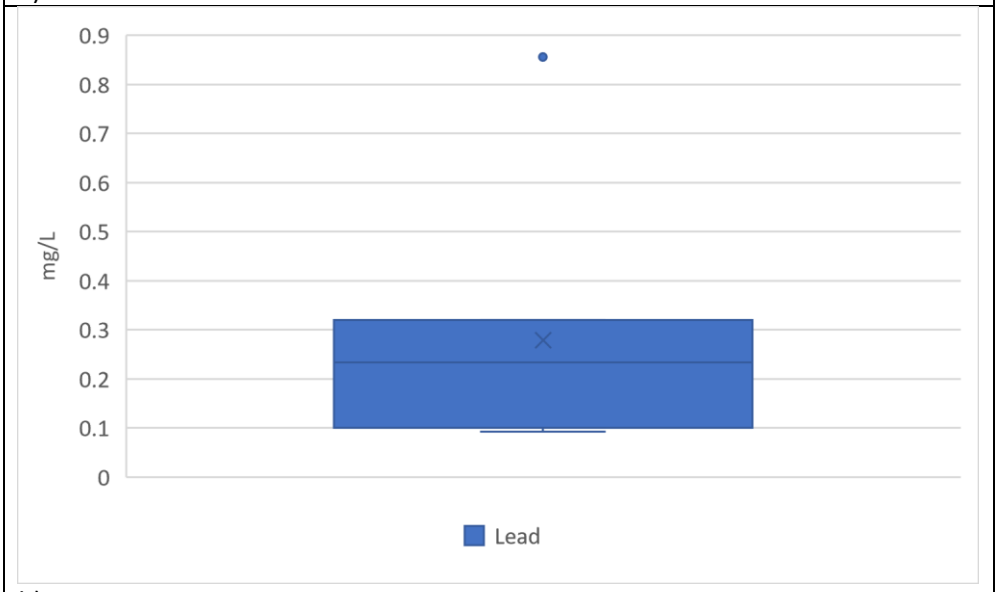
One interpretation of this data distribution is that the Cambrian Block groundwaters are comparatively more well mixed than the other groundwaters in the area, and that the Cambrian Block strata contains lower overall levels of these metals. Conversely, the plots show that the Lady Loretta and Paleoproterozoic Block strata have areas of high metal content, and that groundwaters within these areas are not mixing with adjoining areas to produce more uniform concentrations of the dissolved metals.

Concentration of Metals in underground mine seepage

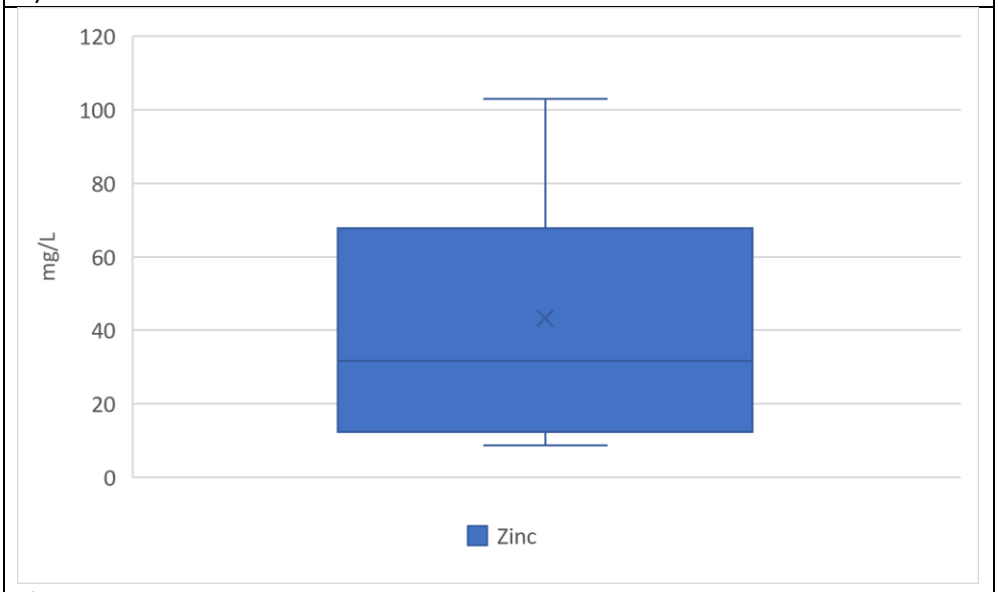
Some data (seven samples) is available for groundwater that has egressed into the mine over a seven-month period in late 2019 to early 2020. The metals content of the groundwater is slightly different to that of groundwater from the broader study area. Arsenic, Chromium, Copper and Mercury levels are either very close to or below detection for all samples. Cadmium, Cobalt, Lead, Molybdenum, Nickel and Zinc are above detection limits (Figure 21a, b and c).


0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
mg/L
Cadmium
Cobalt
Molybdenum
Nickel

a)


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
mg/L
Lead

b)


120
100
80
60
40
20
0
mg/L
Zinc

c)

Figure 21: Box and Whisker Plots for dissolved Metals analysed in Underground Mine Seepage

There are some distinct differences between the Metal concentrations in the Underground Seepage groundwater and the more regional groundwater. These include:

- Arsenic generally is at higher concentrations in the regional water and is mostly non-detectable in the underground seepage groundwater;
- Lead concentrations are low, but there are detectable levels in all samples (though only 7 in total) whereas Lead is mostly below detection limits in the regional groundwater;
- Molybdenum and Cadmium concentrations are essentially at the same levels between the two groundwaters (underground seepage versus regional groundwater);
- Cobalt, Nickel and Zinc are at much higher levels in the underground seepage groundwater when compared to the more regional groundwater, with Zinc being 20 to 50 times higher.

Conclusions

- Hydrochemical data quality is an issue with the current dataset, with potential issues attached to analysis suites and field measurement approaches identified.
- In addition, the regular scheduling of a standardised groundwater sampling suite should be considered to enable consistent detailed hydrochemical assessments to be undertaken that also include seasonal variability (recharge) influences.
- Two primary potential sources of chemical constituents measured in the groundwater in the region of the Lady Loretta Mine are considered:
  - The first is from salts depositing either via rainfall or via dryfall (dust) mechanisms;
  - The second is associated with mineral dissolution, both under natural conditions and under conditions imposed due to mining activities.

Lady Loretta Block Conclusions

Groundwater in the Lady Loretta Block is oxidised to mildly reducing. This suggests that sulphidic mineralisation has the potential to be oxidised as groundwater flows through the strata. The mine void has increased hydraulic gradients towards the mine and this has meant that there is a greater supply of oxidised groundwater available for oxidation processes. Conversely, samples from GW08 show that under near natural conditions, the groundwater can become mildly reduced. This is an important consideration for post-mining planning.

The Chloride concentration in groundwater across the site indicates locally differing recharge rates within the block, and these concentrations are preserved, indicating a degree of flow compartmentalisation within the Lady Loretta Block at least.

Regional groundwaters (that is, groundwater outside of the influence of direct impacts of mining) show background levels of some metals that are well above detection limits, confirming that natural weathering processes in metalliferous terrains produce higher than usual background metal contents.

The occurrence of a large number of outliers in the metals data for the Lady Loretta Block and the Proterozoic Block also supports the hypothesis that groundwater in these two Blocks can be compartmentalised, that is, they are not well-mixed.

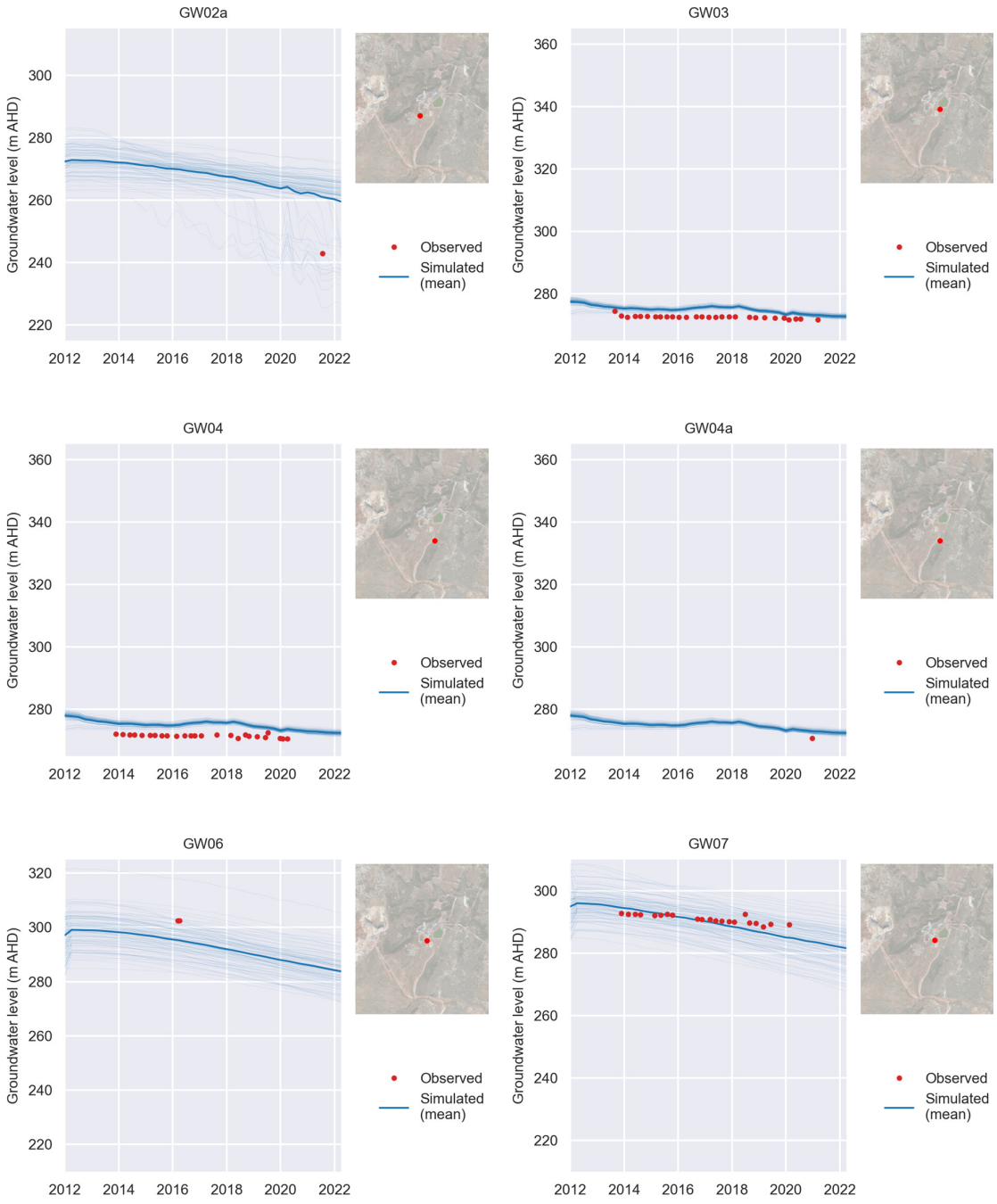
Regional Conclusions

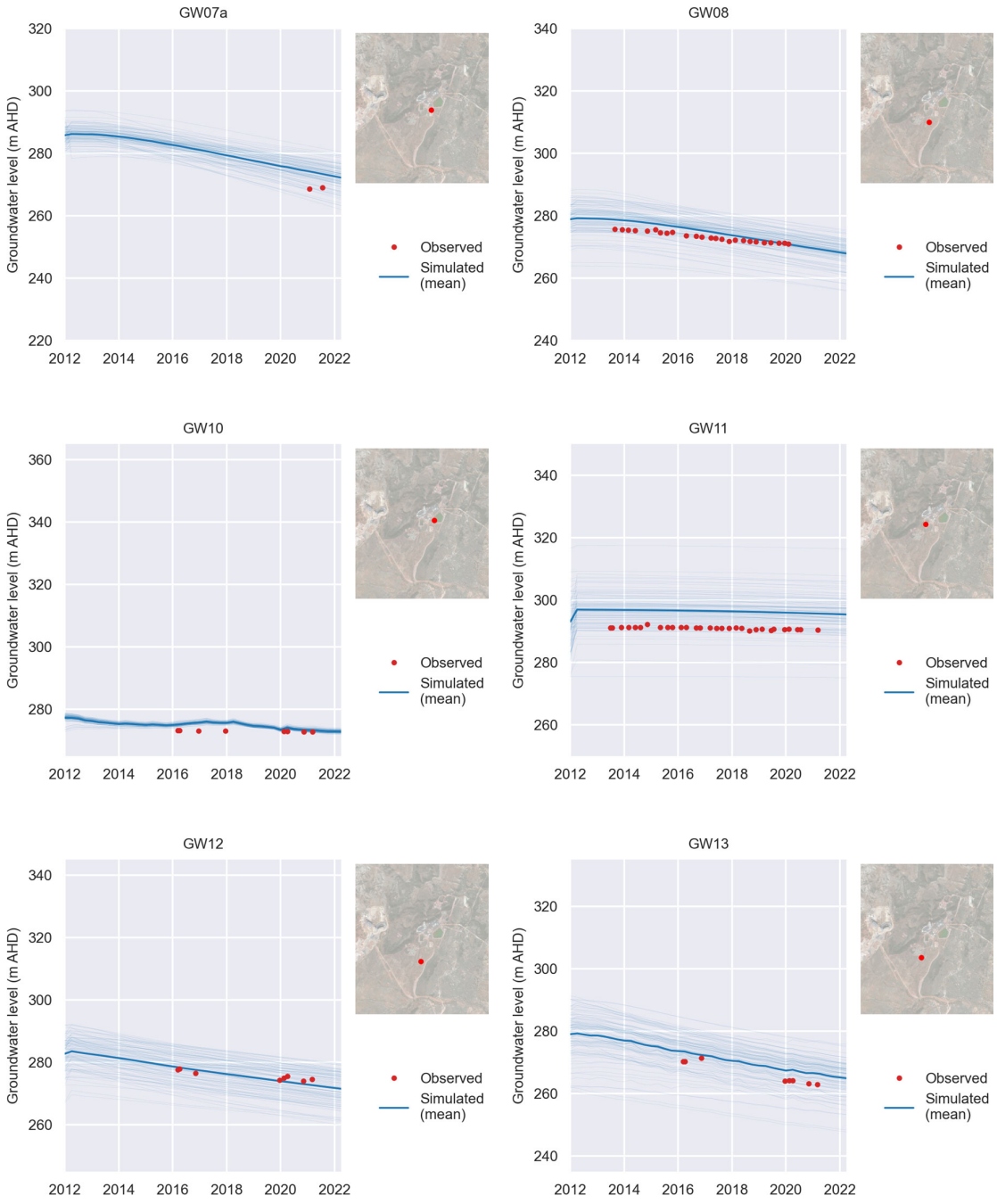
From a regional perspective there is little evidence to support broad scale mixing between groundwaters from different geological Blocks in the vicinity of the Lady Loretta mine considering the results of the major ion chemistry assessment completed. The chemical types of the Cambrian

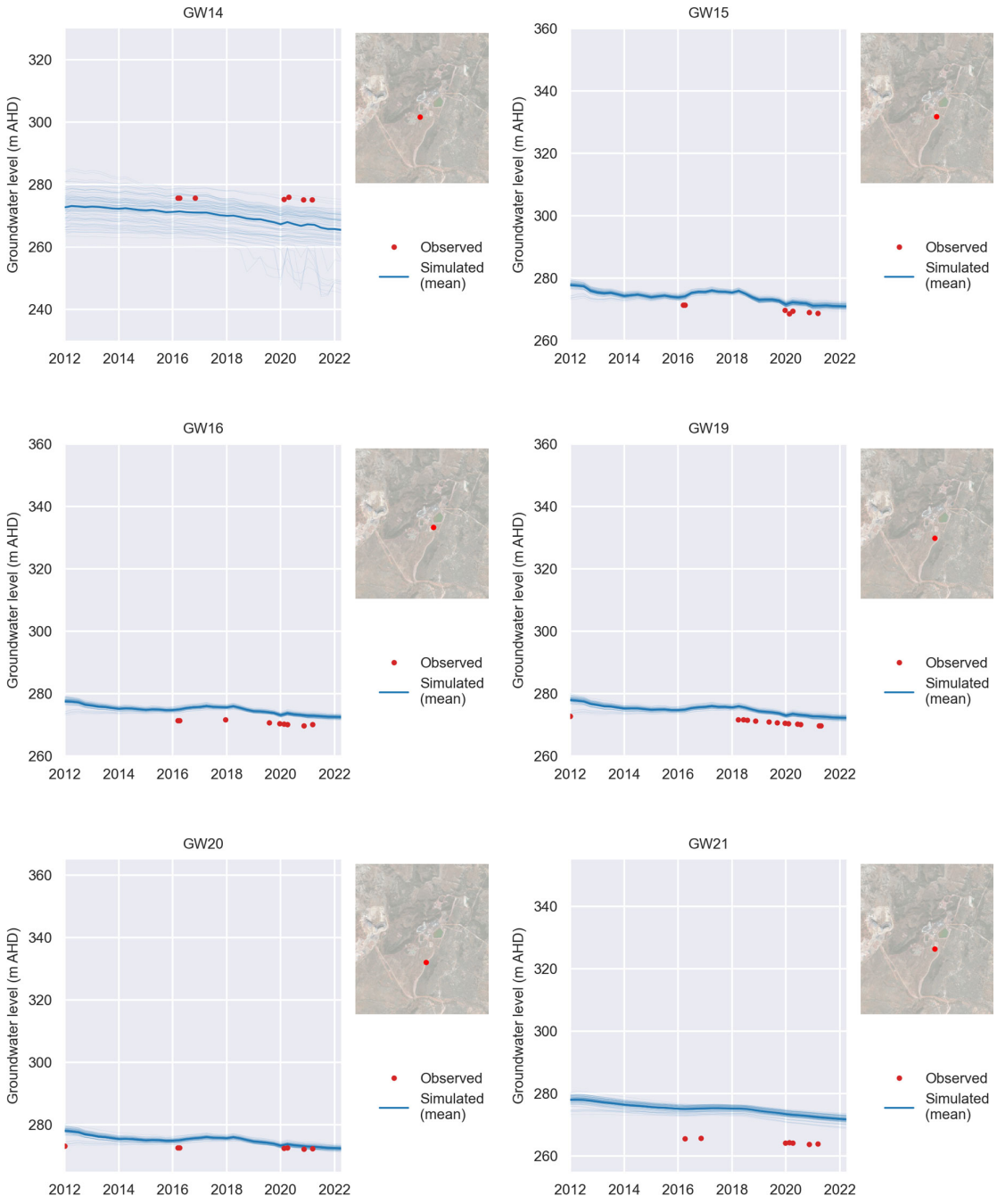
Block groundwater are sufficiently different from those in the groundwater of the Lady Loretta Block to indicate that if flow across the Western Boundary Fault is possible, it is of a small magnitude. Alternatively, the advective “front” of Cambrian Block groundwater has not had sufficient time to reach the observation points and be sampled.

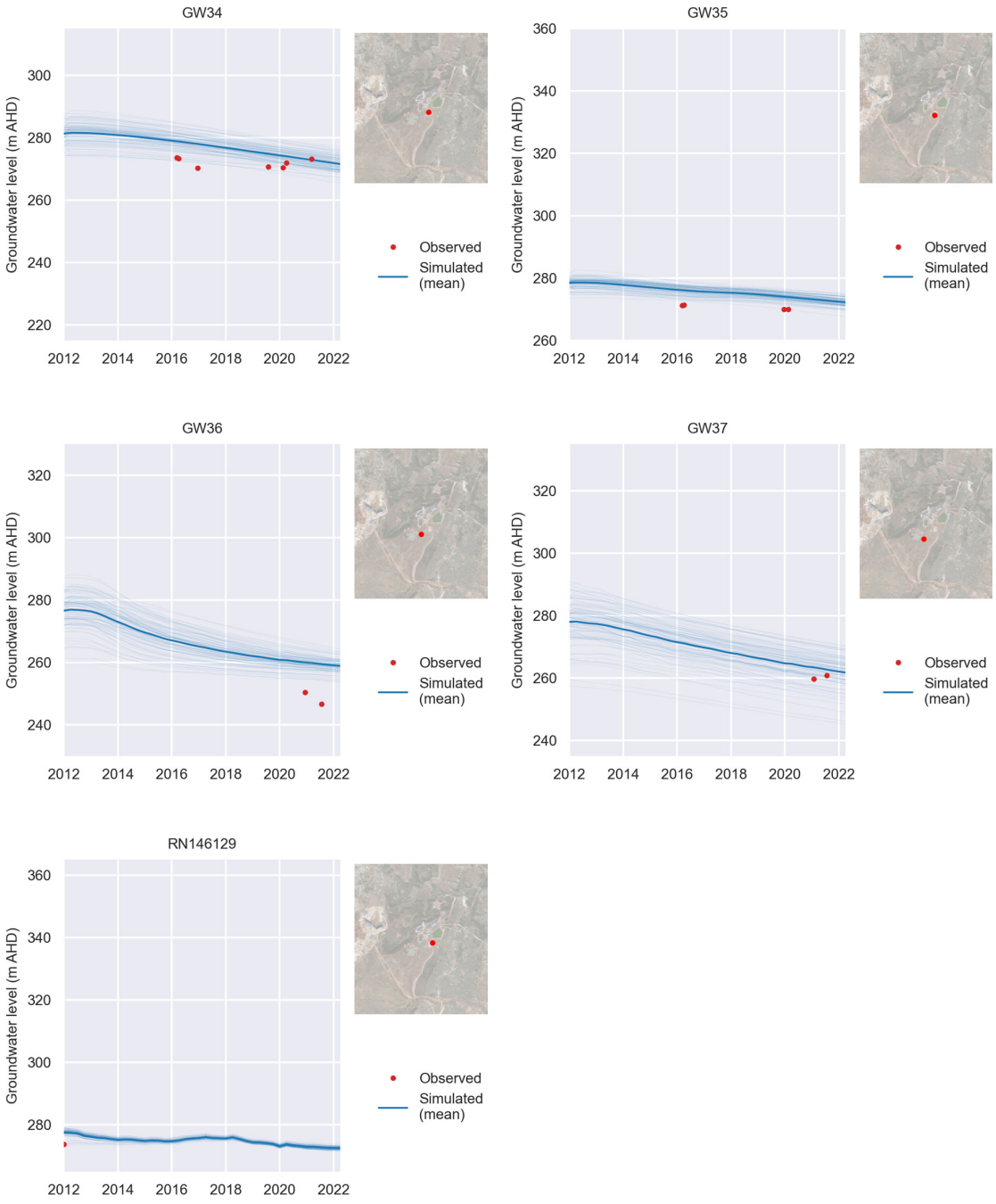
Differing concentration of metals further emphasises the difference between groundwater in the Cambrian Block compared to groundwater from the other Blocks, and supports the notion of a lack of mixing between the Cambrian and Lady Loretta Blocks.

Appendix B Bore Hydrographs


GW02a
GW03
GW04
GW04a
GW06
GW07
Groundwater level (m AHD)
Observed
Simulated (mean)


GW07a
GW08
GW10
GW11
GW12
GW13
Groundwater level (m AHD)
Observed
Simulated (mean)


GW14
GW15
GW16
GW19
GW20
GW21
Groundwater level (m AHD)
Observed
Simulated (mean)
2012
2014
2016
2018
2020
2022


GW34
Groundwater level (m AHD)
300
280
260
240
220
2012
2014
2016
2018
2020
2022
Observed
Simulated (mean)
GW35
Groundwater level (m AHD)
360
340
320
300
280
260
2012
2014
2016
2018
2020
2022
Observed
Simulated (mean)
GW36
Groundwater level (m AHD)
320
300
280
260
240
2012
2014
2016
2018
2020
2022
Observed
Simulated (mean)
GW37
Groundwater level (m AHD)
320
300
280
260
240
2012
2014
2016
2018
2020
2022
Observed
Simulated (mean)
RN146129
Groundwater level (m AHD)
360
340
320
300
280
2012
2014
2016
2018
2020
2022
Observed
Simulated (mean)

APPENDIX J PRCP PLAN SCHEDULE

Post-mining land uses (PMLU)										
Rehabilitation area	RA1									
Relevant activities	Waste Rock Emplacement									
Total rehabilitation area size (ha)	10.7									
Commencement of first milestone: RM2	10/12/2033									
PMLU	Native Habitat									
Date area is available	10/12/33	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx
Cumulative area available (ha)	10.7									
Milestone completed by	10/12/37	10/12/50	10/12/60	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx
Milestone Reference	**Cumulative area achieved (ha)**									
RM2	10.7									
RM7	1.7									
RM9	1.7									
RM10		1.7								
RM12		10.7								
RM13			10.7							

1) Insert new columns to the yellow table to include further rehabilitation milestone dates.
2) Insert new columns to the blue table to match rehabilitation milestone dates.
3) Insert new rows to the blue table to include additional rehabilitation milestone references.
4) Insert the relevant number in the "Milestone reference" column (i.e. RM1).

Post-mining land uses (PMLU)										
Rehabilitation area	RA2									
Relevant activities	Topsoil Stockpiles									
Total rehabilitation area size (ha)	5.7									
Commencement of first milestone: RM4	10/12/2035									
PMLU	Low Intensity Cattle Grazing									
Date area is available	10/12/35	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx
Cumulative area available (ha)	5.7									
Milestone completed by	10/12/38	10/12/50	10/12/60	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx
Milestone Reference	**Cumulative area achieved (ha)**									
RM5	5.7									
RM8	5.7									
RM11		5.7								
RM14			5.7							

1) Insert new columns to the yellow table to include further rehabilitation milestone dates.
2) Insert new columns to the blue table to match rehabilitation milestone dates.
3) Insert new rows to the blue table to include additional rehabilitation milestone references.
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Post-mining land uses (PMLU)										
Rehabilitation area	RA3									
Relevant activities	Leachate Management Dam (LMD) and Erosion and Sediment Control Facility									
Total rehabilitation area size (ha)	0.9									
Commencement of first milestone: RM5	10/12/2025									
PMLU	Native Habitat									
Date area is available	10/12/25	10/12/43	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx
Cumulative area available (ha)	0.5	0.9								
Milestone completed by	10/12/28	10/12/45	10/12/55	10/12/60	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx
Milestone Reference	**Cumulative area achieved (ha)**									
RM3	0.5	0.9								
RM6	0.5	0.9								
RM7	0.5	0.9								
RM8	0.5	0.9								
RM10			0.5							
RM13				0.9						

1) Insert new columns to the yellow table to include further rehabilitation milestone dates.
2) Insert new columns to the blue table to match rehabilitation milestone dates.
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Post-mining land uses (PMLU)										
Rehabilitation area	RA4									
Relevant activities	CDA, CDB, PPD, Sediment Dams and Erosion and Sediment Control Facilities									
Total rehabilitation area size (ha)	13									
Commencement of first milestone: RM5	10/12/2039									
PMLU	Low Intensity Cattle Grazing									
Date area is available	10/12/39	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx
Cumulative area available (ha)	13									
Milestone completed by	10/12/52	10/12/60	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx
Milestone Reference	**Cumulative area achieved (ha)**									
RM3	13									
RM6	13									
RM7	13									
RM8	13									
RM14		13								

1) Insert new columns to the yellow table to include further rehabilitation milestone dates.
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3) Insert new rows to the blue table to include additional rehabilitation milestone references.
4) Insert the relevant number in the "Milestone reference" column (i.e. RM1).

Post-mining land uses (PMLU)										
Rehabilitation area	RA5									
Relevant activities	Infrastructure - waste disposal trench, LMD area, explosive magazine									
Total rehabilitation area size (ha)	11.8									
Commencement of first milestone: RM6	10/12/2025									
PMLU	Native Habitat									
Date area is available	10/12/25	10/12/32	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx
Cumulative area available (ha)	0.7	8	11.8							
Milestone completed by	10/12/28	10/12/35	10/12/50	10/12/60	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx
Milestone Reference	**Cumulative area achieved (ha)**									
RM1		0.8								
RM3	0.7	8								
RM5		8								
RM7	0.7	8								
RM8	0.7	8								
RM10			11.8							
RM13				11.8						

1) Insert new columns to the yellow table to include further rehabilitation milestone dates.
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3) Insert new rows to the blue table to include additional rehabilitation milestone references.
4) Insert the relevant number in the "Milestone reference" column (i.e. RM1).

Post-mining land uses (PMLU)										
Rehabilitation area	RA6									
Relevant activities	Infrastructure									
Total rehabilitation area size (ha)	35.4									
Commencement of first milestone: RM1	10/12/2032									
PMLU	Low Intensity Cattle Grazing									
Date area is available	10/12/32	10/12/39	10/12/44	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx
Cumulative area available (ha)	15.7	29.3	35.4							
Milestone completed by	10/12/35	10/12/41	10/12/2046	10/12/50	10/12/60	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx
Milestone Reference	**Cumulative area achieved (ha)**									
RM1	6.5	20.1	35.4							
RM3	15.7	29.3	35.4							
RM5	15.7	29.3	35.4							
RM7	15.7	29.3	35.4							
RM8	15.7	29.3	35.4							
RM11				29.3						
RM14					35.4					

1) Insert new columns to the yellow table to include further rehabilitation milestone dates.
2) Insert new columns to the blue table to match rehabilitation milestone dates.
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4) Insert the relevant number in the "Milestone reference" column (i.e. RM1).

Post-mining land uses (PMLU)										
Rehabilitation area	RA7									
Relevant activities	Run of Mine (ROM) Pad, Paste Plant and Batch Plant									
Total rehabilitation area size (ha)	10.1									
Commencement of first milestone: RM1	10/12/2032									
PMLU	Low Intensity Cattle Grazing									
Date area is available	10/12/32		10/12/52	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx
Cumulative area available (ha)	10.1									
Milestone completed by	10/12/35	10/12/50	10/12/53	10/12/60	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx
Milestone Reference	**Cumulative area achieved (ha)**									
RM1	10.1									
RM3	10.1									
RM5	5.3		4.8							
RM7	5.3		4.8							
RM8	5.3		4.8							
RM11		5.3								
RM14				10.1						

1) Insert new columns to the yellow table to include further rehabilitation milestone dates.
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4) Insert the relevant number in the "Milestone reference" column (i.e. RM1).

Post-mining land uses (PMLU)										
Rehabilitation area	RA8									
Relevant activities	Exploration, Roads, Tracks and Borrow Sites									
Total rehabilitation area size (ha)	20.7									
Commencement of first milestone: RM6	10/12/2032									
PMLU	Native Habitat									
Date area is available	10/12/32	10/12/52	10/12/59	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx
Cumulative area available (ha)	1.5	6.5	20.2	20.7						
Milestone completed by	10/12/35	10/12/53	10/12/60	10/12/60	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx
Milestone Reference	**Cumulative area achieved (ha)**									
RM1	0.5									
RM3	1		14.7							
RM5		5								
RM7	1	6	19.7							
RM8	1		13.8							
RM13				20.7						

1) Insert new columns to the yellow table to include further rehabilitation milestone dates.
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4) Insert the relevant number in the "Milestone reference" column (i.e. RM1).

Post-mining land uses (PMLU)										
Rehabilitation area	RA9									
Relevant activities	Exploration, Roads, Tracks and Borrow sites									
Total rehabilitation area size (ha)	38.5									
Commencement of first milestone: RM6	10/12/2032									
PMLU	Low Intensity Cattle Grazing									
Date area is available	10/12/32	10/12/35	10/12/39	10/12/44	10/12/52	10/12/59	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx
Cumulative area available (ha)	2.4	3.1	3.5	4.2	17.6	38.5				
Milestone completed by	10/12/35	10/12/38	10/12/42	10/12/45	10/12/53	10/12/60	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx
Milestone Reference	**Cumulative area achieved (ha)**									
RM1	0.3									
RM3	2.1	3.1	3.5	4.2						
RM5					13.4					
RM7	2.1	3.1	3.5	4.2	17.6					
RM8	2.1	3.1	3.5	4.2	17.6					
RM14						38.5				

1) Insert new columns to the yellow table to include further rehabilitation milestone dates.
2) Insert new columns to the blue table to match rehabilitation milestone dates.
3) Insert new rows to the blue table to include additional rehabilitation milestone references.
4) Insert the relevant number in the "Milestone reference" column (i.e. RM1).

Post-mining land uses (PMLU)										
Rehabilitation area	RA10									
Relevant activities	Underground Openings - Shafts, decline, portal									
Total rehabilitation area size (ha)	0.6									
Commencement of first milestone: RM3	10/12/2032									
PMLU	Native Habitat									
Date area is available	10/12/35	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx	10/12/xxxx
Cumulative area available (ha)	0.6									
Milestone completed by	10/12/45	10/12/60		xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx	xx/xx/xxxx
Milestone Reference	**Cumulative area achieved (ha)**									
RM3	0.6									
RM4	0.6									
RM7	0.6									
RM8	0.6									
RM13		0.6								

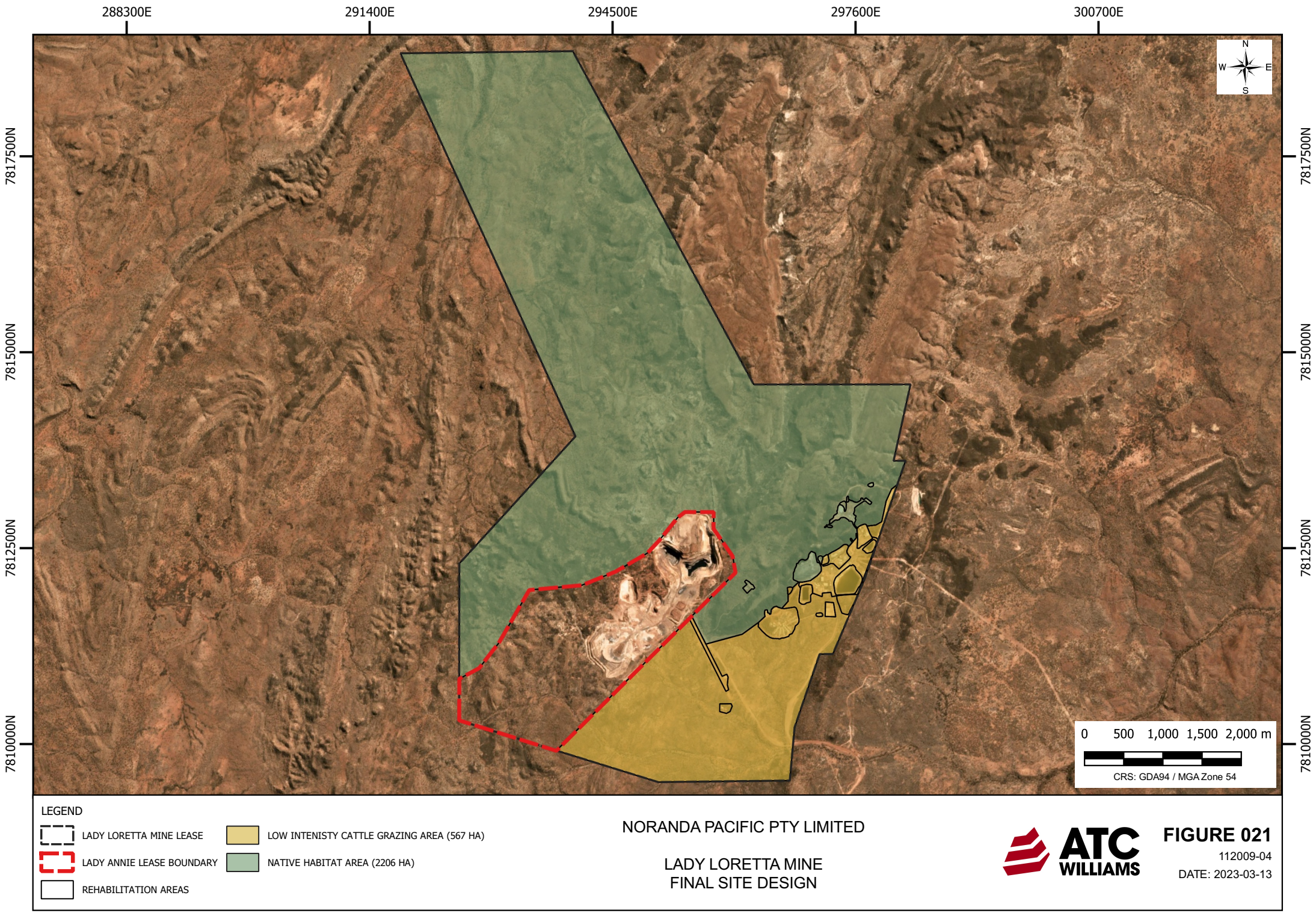
1) Insert new columns to the yellow table to include further rehabilitation milestone dates.
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3) Insert new rows to the blue table to include additional rehabilitation milestone references.
4) Insert the relevant number in the "Milestone reference" column (i.e. RM1).

Milestone reference	Rehabilitation milestone	Milestone criteria
RM1	Infrastructure decommissioning and removal (Fixed Plant)	a) Services disconnected (excluding services agreed with stakeholders for retention) b) Surface fixed plant and infrastructure including foundations (excluding that required for drainage or otherwise agreed with stakeholders for retention) has been removed ## c) Drillholes are capped / plugged and decommissioned in accordance with ESR/2016/1985 ## NOTE: Criteria transitioned from Land Outcome Document (Post Mine Land Use Plan, dated August 2018).
RM2	Infrastructure decommissioning and removal (Fixed Plant)	a)Crest treatments have been applied, and monitoring stations installed consistent with the WRE engineering design with Quality Assurance/Quality Control measures specified by an RPEQ to achieve the following performance objectives: i.Maximum hydraulic conductivity of the cover system is < 1.0 x 10-9m/s for bituminous geomembrane cover ii. Oxygen ingress to the underlying material is restricted iii. Effective overlap/joining of materials b) Batter treatments have been applied consistent with the WRE engineering design with Quality Assurance/Quality Control measures specified by an RPEQ c)A suitably qualified and experienced person has prepared an As-Constructed Report that details the works undertaken, and certified by an RPEQ that construction and encapsulation works were completed in accordance with design specifications, including: i.sub grade preparation ii.chemical and physical properties iii. geometry and spatial characteristics iv. drainage and flow conveyance
RM3	Remediation of contaminated land	a)Contaminated land investigation completed by suitably qualified person b)Soils and sediments contaminated by site activities have been assessed and managed (e.g. removed/remediated), as recommended by suitably qualified person c) A contaminated land survey carried out by an suitably qualified person including whether contamination unsuitable for the post-mining land use is occurring
RM4	Landform development and reshaping / re-profiling (Underground Openings)	a)Upper sections of ventilation shafts have been backfilled with ROM borrow material to preclude access to underground workings b)Surface subsidence generated depression as determined by subsidence monitoring is no greater than > 500 mm c)Upper section of mine decline has been backfilled with ROM borrow material to preclude access to underground workings d)Portal sealed and box-cut backfilled with inert material to form a free draining final surface e)A suitably qualified and experienced person has prepared an As-Constructed Report that details the works undertaken, and certified that construction and backfilling of underground openings met the design intent
RM5	Landform development and reshaping / re-profiling (ROM Pad, Paste Plant and Batch Plant, Infrastructure Area, Topsoil Stockpiles and Borrow Sites)	a)Terrain has been reprofiled with disturbed slopes not steeper than 4 H : 1 V and appropriately verified, with the exception of Borrow Area C b) A suitably qualified and experienced person has prepared a geotechnical stability report and safety assessment for slopes > 30 degrees and > 5m in height## c) Erosion and sediment control systems have been installed
RM6	Landform development and reshaping / re-profiling (Regulated Dams and Erosion and Sediment Control Facilities)	a) Recommendation by suitably qualified and experienced engineer that Regulated Dam status can be rescinded b) Erosion and sediment control systems have been installed c)Terrain has been reprofiled with disturbed slopes not steeper than 4 H : 1 V and verified by an appropriately qualified person d)Erosion and sediment control facilities (excluding facilities agreed with stakeholders for retention) decommissioned and left free draining e) Mine affected water will be either remediated, removed or disposed in accordance with relevant regulations. f) Contaminated sediment, along with synthetic liners, is remediated, removed or disposed in accordance with relevant regulations.

RM7	Surface Preparation	a)A suitably qualified person has assessed the characteristics of the soil and growth media and defined requirements for ameliorants and other treatments necessary to achieve the PMLU b)Ameliorants and other treatments (including application of stockpiled growth media) have been applied, as recommended by suitably qualified person. c)Final surface has been deep ripped on surfaces, with the exception of WRE (RA1) and Borrow Area C (RA8) d)Placement of minimum thickness of 150mm of growth media at ROM, Paste Plant and Batch Plant Area (RA7) and borrow site within (RA9), subject to recommendations by suitably qualified person.
RM8	Revegetation (all disturbed areas excluding WRE and Borrow Area C)	a) Complete seeding using seed mix and sowing rates described in Table 19 of the PRC Plan, or based on more recent seed mix and sowing rates as recommendations by suitably qualified person
RM9	Revegetation (WRE)	a) Complete seeding to the WRE crest area using seed mix and sowing rates described in Table 19 of the PRC Plan, or based on more recent seed mix and sowing rates as recommendations by suitably qualified person
RM10	Achievement of surface requirements - Vegetation on Developmental Trajectory (Native Habitat areas)	a)Corrective actions that are recommended by a suitably qualified persons identified through the rehabilitation monitoring methodology has been implemented. b)Corrective action arising from the routine inspections program have been undertaken to include weed control, erosion repair, livestock management. c)Ecosytem Function Analysis index scores compared to equivalent reference sites are: -Stability > 50 % of reference -Infiltration > 40 % of reference -Nutrient Cycling > 20 % of reference -Species Richness > 40 % of reference -Vegetation Dynamics > 20 % of reference -Habitat Complexity > 40 % of reference
RM11	Achievement of surface requirements - Vegetation on Developmental Trajectory (Low Intensity Cattle Grazing areas)	a)Corrective actions that are recommended by a suitably qualitied persons identified through the rehabilitation monitoring methodology has been implemented. b)Corrective action arising from the routine inspections program have been undertaken to include weed control, erosion repair, livestock management. c)Ecosystem Function Analysis index scores compared to equivalent reference sites are: -Stability > 50 % of reference -Infiltration > 40 % of reference -Nutrient Cycling > 20 % of reference -Vegetation Dynamics > 20 % of reference d)The basal area of grasses is > 30 % of reference
RM12	Achievement of surface requirements - WRE	a) A suitably qualified person has assessed the performance monitoring data for the WRE and verified that: -No active rill/gully erosion > 500 mm -Water flux into contained PAF waste is < 10 % of rainfall at the installed flux monitoring sites within the cover -Contaminant mass flux out of the WRE exhibits stable or decreasing trends when measured at an appropriate and representative location; if no trend can be determined then no persistent adverse environmental impacts when measured over a minimum 2-year monitoring period.

RM13	Achievement of post-mining land use to stable condition (Native Habitat areas)	a)Ecosystem Function Analysis index scores compared to Native Habitat reference sites are: -Stability Index > 80 % of reference -Infiltration > 60 % of reference -Nutrient Cycling > 60 % of reference -Species Richness > 60 % of reference -Vegetation Dynamics > 40 % of reference -Habitat Complexity > 60 % of reference b)Proportion of Category 3 restricted invasive plant species is not >10% of total vegetation groundcover** c)Weed densities will be similar to surrounding reference sites## d)No unrepaired active gullies (i.e. showing active sediment deposition and sides/floor devoid of cover) > 1 m deep## e)Surface water quality at downstream compliance points to meet contaminant limits defined in the current EA## f)Assessment and validation by suitably qualified person that the groundwater quality is safe, does not cause environmental harm (benchmarked to appropriate reference site(s)) and is able to sustain the nominated PMLU g)Evidence in rehabilitation report that appropriate risk assessment for geotechnical stability at the WRE, Underground Openings and Borrow Area C has been undertaken and control measures are in place## h)Contaminated Land Site Investigation verifies residual contamination presents no unacceptable risk to achieving the PMLU i) Backfill of ventilation shaft complete to pose no unacceptable safety risks to humans or wildlife j)Underground opening certified as safe by a suitably qualified geotechnical engineer (this only applies to RA10) **Defined by Biosecurity Act 2014
RM14	Achievement of post-mining land use to stable condition (Low Industry Cattle Grazing areas)	a) Assessment of carrying capacity by an appropriatley qualified person demonstrates a sustainable grazing outcome has been achieved b)Ecoystem Function Analysis index scores compared to equivalent reference sites are: -Stability > 80 % of reference -Infiltration > 60 % of reference -Nutrient Cycling > 60 % of reference -Vegetation Dynamics > 40 % of reference c)The basal area of grasses is > 60 % of reference d)Proportion of Category 3 restricted invasive plant species is not >10% of total vegetation groundcover** e)Weed densities will be similar to surrounding reference sites## f)No unrepaired active gullies (i.e. showing active sediment deposition and sides/floor devoid of cover) > 1 m deep## g)Evidence in rehabilitation report that appropriate risk assessment for geotechnical stability at the ROM, Paste Plant and Batch Plant, Infrastructure and Water Dam areas has been undertaken and control measures are in place## h)Surface water quality at downstream compliance points to meet contaminant limits defined in the current EA## i)Assessment and validation by suitably qualified person that the groundwater quality is safe, does not cause environmental harm (benchmarked to appropriate reference site(s)) and is able to sustain the nominated PMLU j)Assessment and validation by suitably qualified person that the long-term risks presented by groundwater contamination do not preclude the PMLU being sustained k)Contaminated Land Site Investigation verifies residual contamination presents no unacceptable risk to achieving the PMLU **Defined by Biosecurity Act 2014

1) Insert new rows below the table to record more Rehabilitation Area Milestones for the project
2) Ensure all Rehabilitation Milestones recorded in this table align with those included in the RA sheets in this form.
3) See the PRCP guideline before developing site-specific Rehabilitation Area Milestones



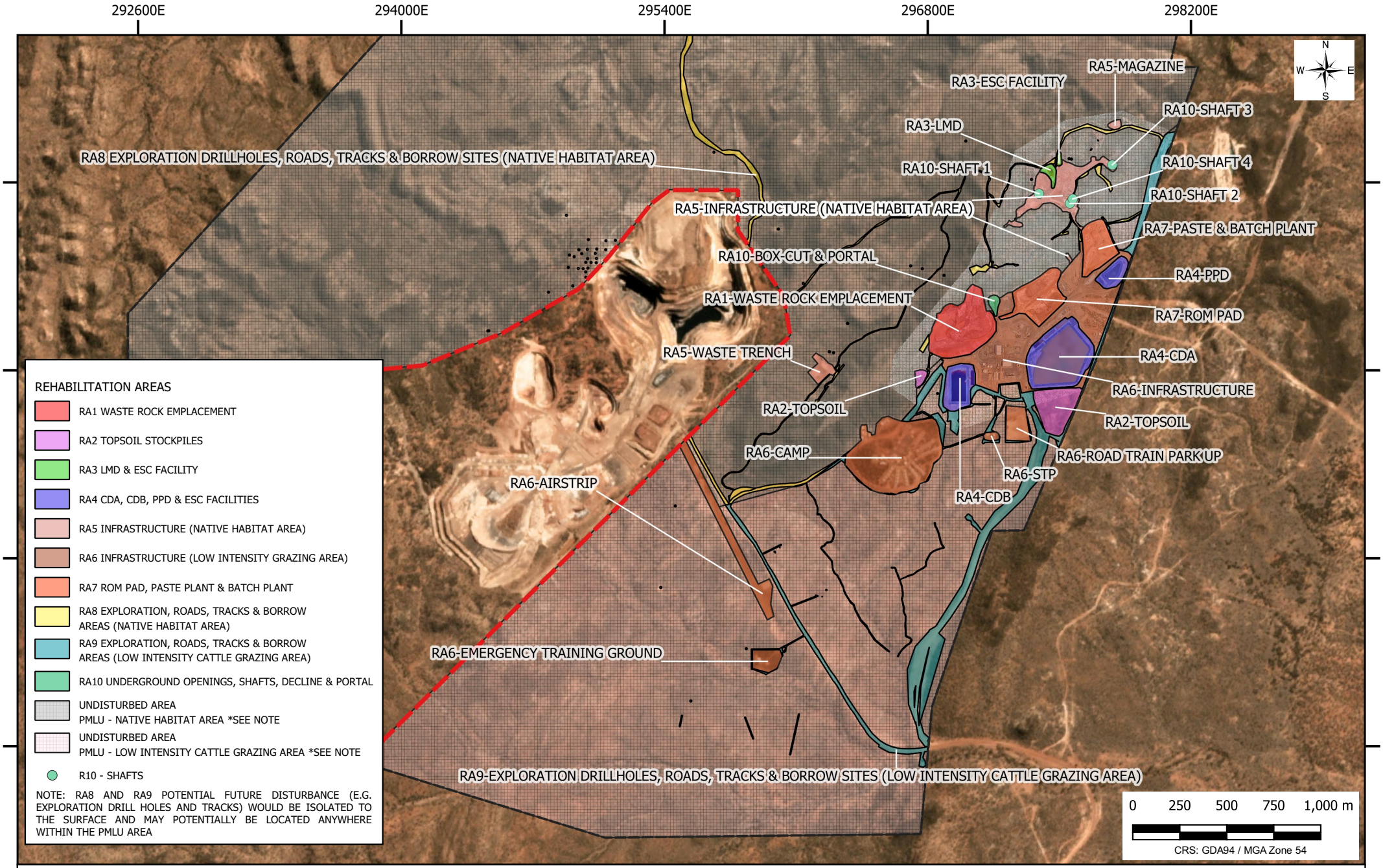
NORANDA PACIFIC PTY LIMITED

LADY LORETTA MINE
FINAL SITE DESIGN

ATC WILLIAMS

FIGURE 021
112009-04
DATE: 2023-03-13

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NORANDA PACIFIC PTY LIMITED

LADY LORETTA MINE
REFERENCE MAP

ATC WILLIAMS

FIGURE 022

112009-04

DATE: 2023-03-13

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