South32 Worsley Alumina

Hydrogeological Assessment - Extended Mining Areas - Quindanning

6 July 2023

CDM Smith

listen. think. deliver.

Table of Contents

Section 1 Introduction 5

1.1 Background 5

1.2 Objective and Scope of Work 5

1.3 Mining Operation 8

Section 2 Physical Setting 10

2.1 Climate 10

2.2 Topography and Land Use 11

2.3 Geology 14

Section 3 Hydrogeology 16

3.1 Hydrogeological Units 16

3.2 Groundwater Bores 16

3.3 Groundwater Levels and Flow Direction 20

3.4 Groundwater Recharge and Discharge 20

3.5 Hydraulic Properties 20

3.6 Water Quality 21

Section 4 Environmental Values and Contaminants of Concern 23

4.1 Environmental Values 23

4.1.1 Overview 23

4.1.2 Groundwater Dependant Ecosystems 23

4.1.3 Beneficial Use 23

Section 5 Preliminary Hydrogeological Conceptualisation 25

Section 6 Recommendations and Limitations 27

6.1 Gap Analysis and Recommendations 27

6.2 Limitations 28

Section 7 Monitoring Bore Locations and Target Formations 29

7.1 Proposed Drilling Locations and Estimated Depths 29

Section 8 Installation Methodology and Construction Requirements 34

8.1 Monitoring Bore Installation Methodology 34

8.2 Monitoring Bore Materials 35

8.3 Testing and Groundwater Sampling 35

8.3.1 Slug Testing 35

8.3.2 Groundwater Sampling Methodologies 35

8.3.3 Quality Management Processes 35

8.3.4 Laboratory Analysis 36

Section 9 Disclaimer 37

Disclaimer and Limitations 37

Section 10 References 38

Figures

Figure 1-1 Location of the extended mining areas – Quindanning 7
Figure 1-2 Laterite section (South32, 2021) 8
Figure 1-3 Project proposed roads and mining shapes 9
Figure 2-1 Mean monthly rainfall and temperature 10
Figure 2-2 Long term rainfall monthly cumulative deviation from the mean 11
Figure 2-3 Land use 12
Figure 2-4 Topographic elevation and watercourses 13
Figure 2-5 Surface geology 15
Figure 3-1 Registered groundwater bores 18
Figure 3-2 Groundwater bores associated with the existing Worsley Mining Development Envelope 19
Figure 3-3 Groundwater salinity 22
Figure 4-1 Potential Groundwater Dependent Ecosystems 24
Figure 5-1 Preliminary Hydrogeological Conceptual Model 26
Figure 7-1 Proposed drilling locations with mapped terrestrial GDE area 32
Figure 7-2 Proposed drilling locations with topography with topography / mapped terrestrial GDE area 33

Tables

Table 2-1 Land use categories found in the Project 11
Table 2-2 Stratigraphic Description 14
Table 3-1 Registered Bores within the Project 17
Table 3-2 Bores with hydraulic test data within 10 km of the Project 20
Table 7-1 Proposed Drilling Locations 29
Table 8-1 Livestock Drinking Water Guideline Values 36

Appendices

Appendix A Bore Schematic 41

Document history & status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
A	12/05/2023	Jon Fawcett	Jon Fawcett	12/05/2023	Draft
B	23/06/2023	CN	AM	23/06/2023	Draft
0	06/07/2023	JC	JC	06/07/2023	Final

Distribution of copies

Version	Date issued	Quantity	Electronic	Issued to
A	12/05/2023	1	PDF	Adam Stevens
B	27/06/2023	1	PDF	Adam Stevens
0	06/07/2023	1	PDF	Stuart Simmonds

Last Saved:	1 September 2026
File Name:	STH32 GW Assessment Quindanning RPT REV B
Author:	Andrew Macdonald
Project Manager:	Andrew Macdonald
Client:	South32 Worsley Alumina
Document Title:	**Hydrogeological Assessment - Extended Mining Areas - Quindanning**
Document Version:	Draft
Project Number:	1001487

Section 1 Introduction

1.1 Background

CDM Smith Australia Pty Ltd (CDM Smith) was engaged by South32 Worsley Alumina Pty Ltd Joint Venture (South32) to undertake a hydrogeological assessment supporting the Extended Mining Area called Quindanning (the Project). The Project is located approximately 140 km southeast of Perth within southwest Western Australia (Figure 1-1).

South32 Worsley Alumina operation currently includes bauxite mining near Boddington. Bauxite is transport via overland conveyor to an alumina refinery near Collie and port operations in the Bunbury Port. In 2005 Worsley Alumina was granted approval to expand the mining and processing operations and subsequently Ministerial Statement 719 (MS719) was granted. Under this approval Worsley Alumina obtained conditional approval to mine in areas known as the Extended Mining Areas. These areas are comprised of Brookton, Mid Central, Hotham North, Quindanning and Morgan.

South32 are completing environmental studies within the Extended Mining Areas as required by condition 8 of the Ministerial Statement 719. These studies are required to enable South32 to meet its commitments prior to undertaking any operations in these areas. This hydrogeological assessment report is undertaken for the Quindanning Extended Mining Area.

1.2 Objective and Scope of Work

The objective of this study is to complete a groundwater assessment for the Quindanning Extended Mining Area as required by condition 8 of the Ministerial Statement 719. A phased approach for the Project scope of work consists of the following:

- Phase 1 Desktop groundwater assessment, preliminary conceptual model and gap analysis.
- Phase 2 Drilling, bore construction, testing and monitoring.
- Phase 3 Final conceptual model, numerical modelling, impact assessment and final reporting.

This report details the Phase 1 desktop groundwater assessment and serves as a component of the front sections of the final groundwater assessment report (Phase 3), with outcomes informing the drilling program and associated field studies. The objective of Phase 1 is to characterise the key hydrogeological features of the site and provide recommendations for collecting site specific data to enable development of a numerical groundwater model.

The Phase 1 scope of work includes a desktop groundwater assessment for the site, including:

- Context setting and description of the Project. The context setting is based on a search of publicly available information and data for existing water bores and hydrogeological data in the vicinity of the site.
- Review and assessment of site setting, topography, surface water, climate, land use, geology and hydrogeology.
- Review and assessment of groundwater level, flow direction and quality data for the area, as well as assessing surface water occurrence to determine degree of surface water - groundwater interaction.
- Potential groundwater recharge and discharge pathways.
- Preliminary conceptual model development.

The desktop groundwater assessment informs the understanding of potential impacts, including a search of the Bureau of Meteorology (BoM) groundwater dependent ecosystems (GDEs) database. Using the information generated the key features and beneficial uses of groundwater were identified including:

- Groundwater Dependant Ecosystems (GDEs), which may include riparian vegetation, baseflow to waterways and springs.

- Assessment of groundwater Environmental Values including groundwater users, downstream users, sensitive receptors and receiving environment.

The Phase 1 assessment includes recommendations for prioritisation of any monitoring networks required based on environmental risks and impacts including:

- Gap analysis and recommendations for further studies for the area and option/s for collecting site specific data.
- Priority for a groundwater monitoring network based on the hydrogeology and environmental risks / impacts.
- Recommendations detailing proposed drilling locations, target depths, methodologies for the installation of bores and to conduct tests to inform site-specific hydraulic properties. The studies allow for refinement of the preliminary conceptual model and support ongoing environmental monitoring for the site.
- Preliminary groundwater monitoring plan for the site and a groundwater sampling / water level monitoring program with the objective of collecting sufficient data to assess conditions, seasonal variations and groundwater flow directions. The monitoring program considers groundwater interaction with surface waters and provide a proposed analytical suite and frequency of sampling.

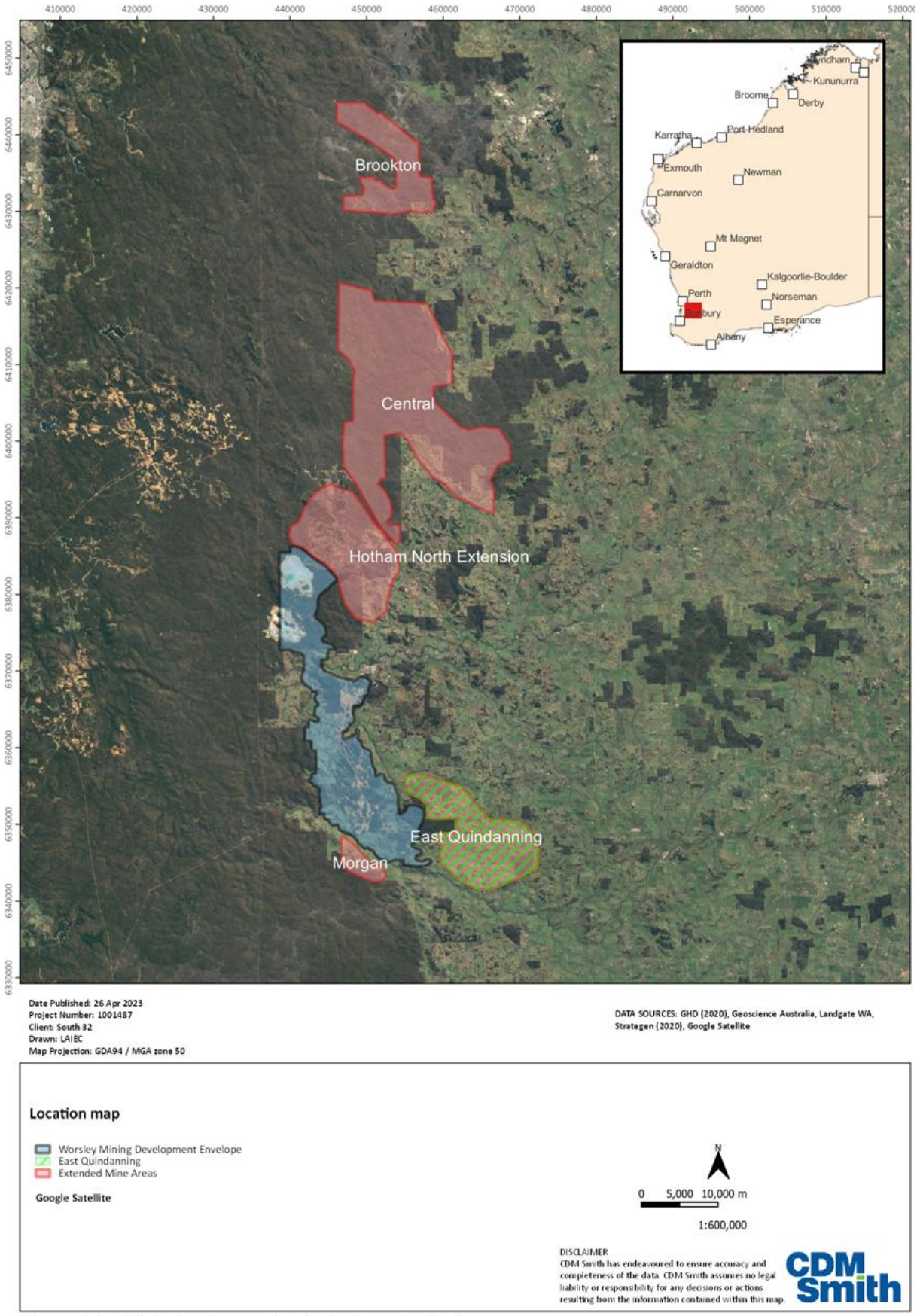

Figure 1-1 Location of the extended mining areas – Quindanning

1.3 Mining Operation

Worsley Alumina is currently operated by South32, extracting bauxite to produce aluminium. The mining area comprises of two sites called Saddleback and Marradong, located south of Boddington. Bauxite mining involves clearing vegetation, removal and stockpiling of topsoil and overburden, recovery of the ore and then backfilling with stockpiled overburden and re-contouring the landscape prior to rehabilitation (South32, 2021). The final rehabilitated bauxite pits are shallow and undulating.

A typical lateritic bauxite profile is shown in Figure 1-2. It is comprised of two distinct layers, the top layer is a cemented 'hardcap' and the bottom layer is a friable 'B-zone'. The laterite is generally overlain by a pisolitic gravel, below the laterite is deeply weathered to kaolinite and montmorillonite clays of variable thickness. Bedrock outcrops vary infrequently within the greenstone belt. Greenstone-derived bauxite is characteristically low silica bauxite whereas the granite-derived bauxite displays both a high free silica (quartz) and high RxSiO2 (South32, 2021). The proposed mining areas and roads for the Project are shown in Figure 1-3.

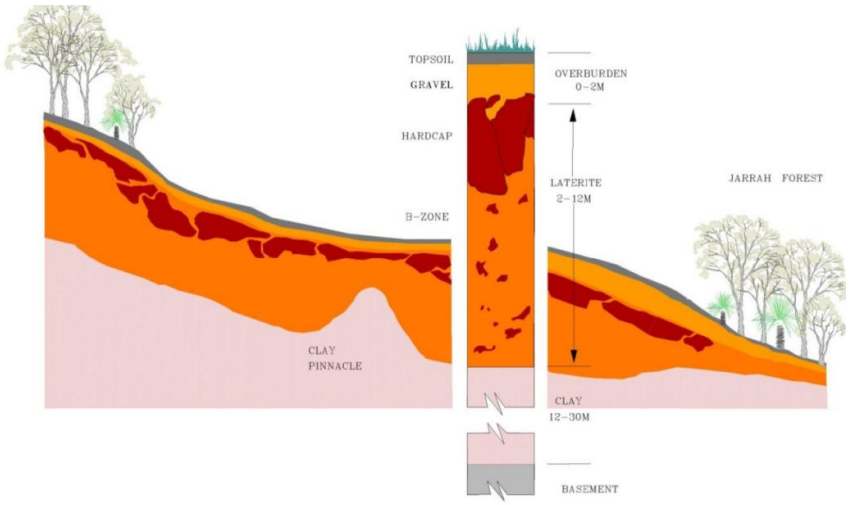

Figure 1-2 Laterite section (South32, 2021)



Figure 1-3 Project proposed roads and mining shapes

Section 2 Physical Setting

2.1 Climate

The climate of the area is hot, dry summers and cool, wet winters. There are two distinct seasons a hot and dry summer between December to February and a mild wet winter between June to August (Figure 2-1). The average annual pan evaporation measured at Boddington between 1970 and 2020 is 1626 mm (SILO, 2020). The average monthly pan evaporation is consistently highest between October and April, peaking in January (246 mm). Lower temperatures between May and September are associated with lower pan evaporation rates.

The Bureau of Meteorology has one rainfall station in proximity to the Project called Marradong (station number 9575). Marradong station has rainfall for the period 1898 to 2023. The mean annual recorded rainfall from 1898 to 2023 is 717.5 mm. The majority of rainfall typically occurs between May and September with January and February being the hottest month of the year and July the coldest month of the year.

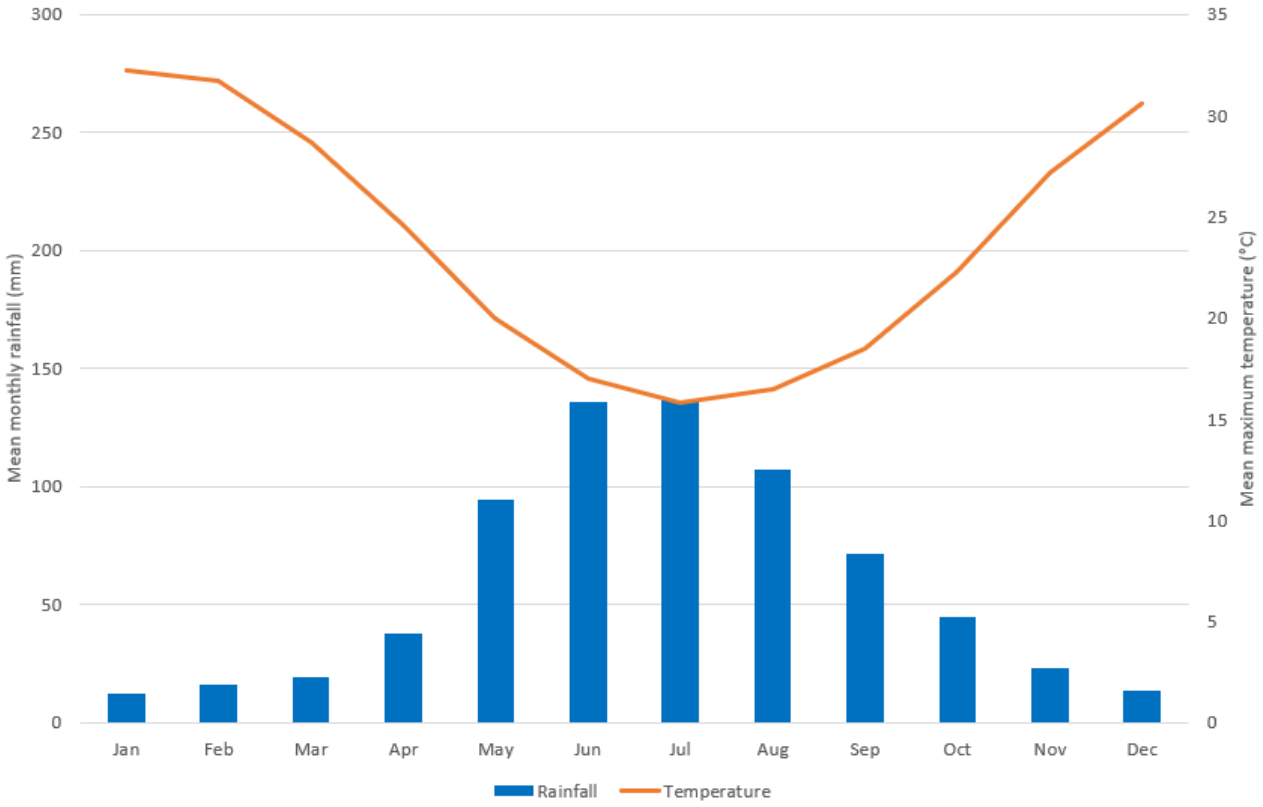

Figure 2-1 Mean monthly rainfall and temperature

Long term rainfall monthly cumulative deviation from the mean (CDFM) is shown in Figure 2-2, based on the rainfall data obtained from Marradong. 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. The region has experienced a notable rainfall reduction since the 1970s, with increased frequency of drought years.

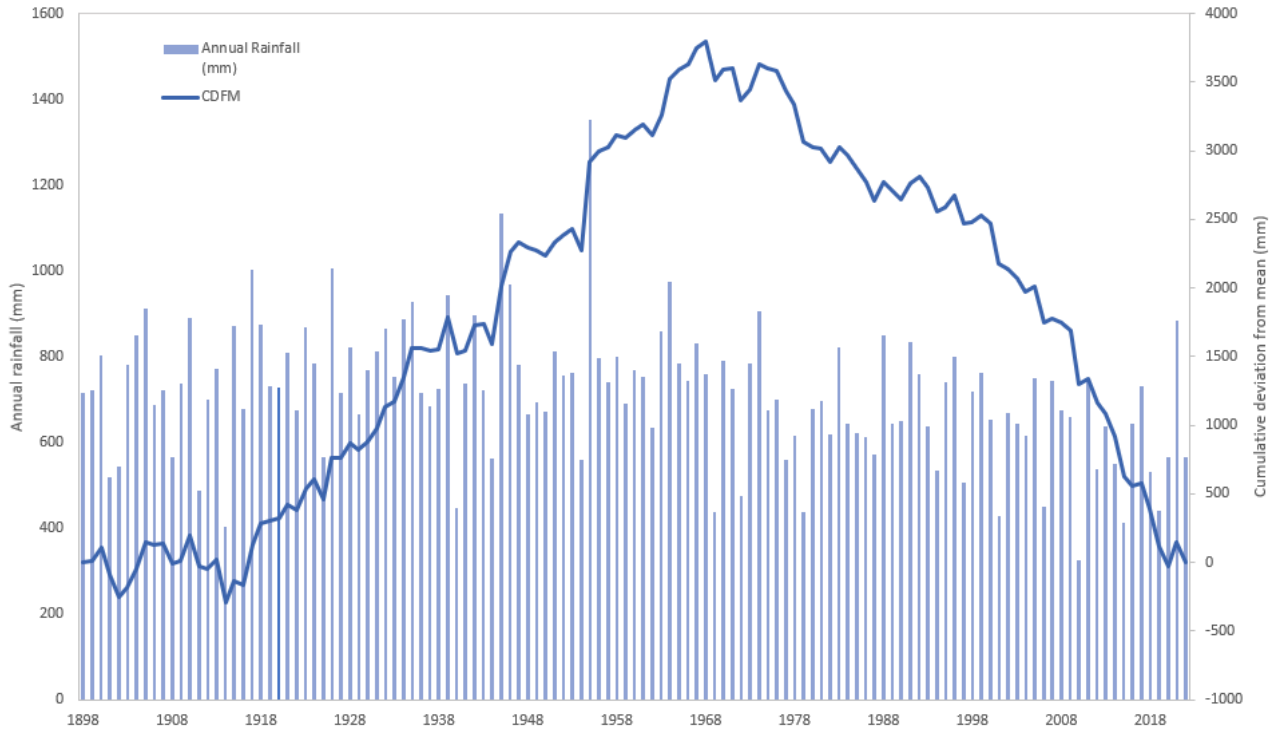

Figure 2-2 Long term rainfall monthly cumulative deviation from the mean

2.2 Topography and Land Use

According to the catchment scale land use data for Australia (ABARES, 2020), the major land uses in the area are for dryland cropping, grazing, forestry and land with minimal use (Figure 2-3 and Table 2-1).

The Project is situated where topography is moderate to gently undulating and is drained via water courses that generally flow south towards the Williams River via the Warrening Gully and northwest towards the Marradong Brook. The Project is situated in an area with elevations sloping from around 400 m Australian Height Datum (mAHD), flattening out to around 200 mAHD (Figure 2-4).

Table 2-1 Land use categories found in the Project

Land Use Classification	General Description	% of Project Area
Cropping	Dryland cropping	49.69
Residual native cover	Other minimal use	19.84
Grazing modified pastures	Grazing modified pastures	13.48
Production native forests	Production native forests	8.61
Plantation forests	Plantation forests	8.17
Reservoir - intensive use	Water	0.12
Roads	Urban intensive uses	0.08
Degraded land	Land in transition	0.01

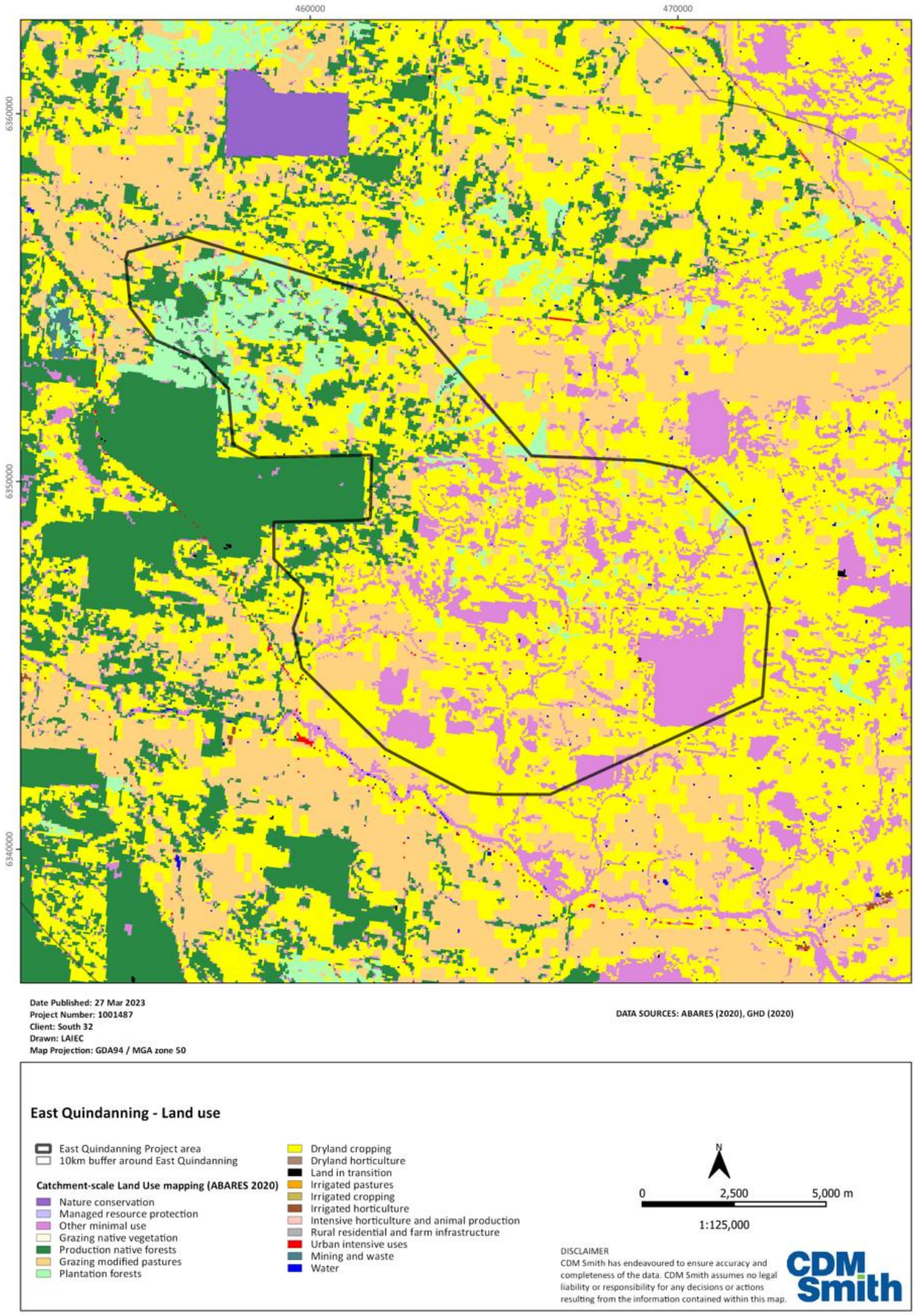

Figure 2-3 Land use

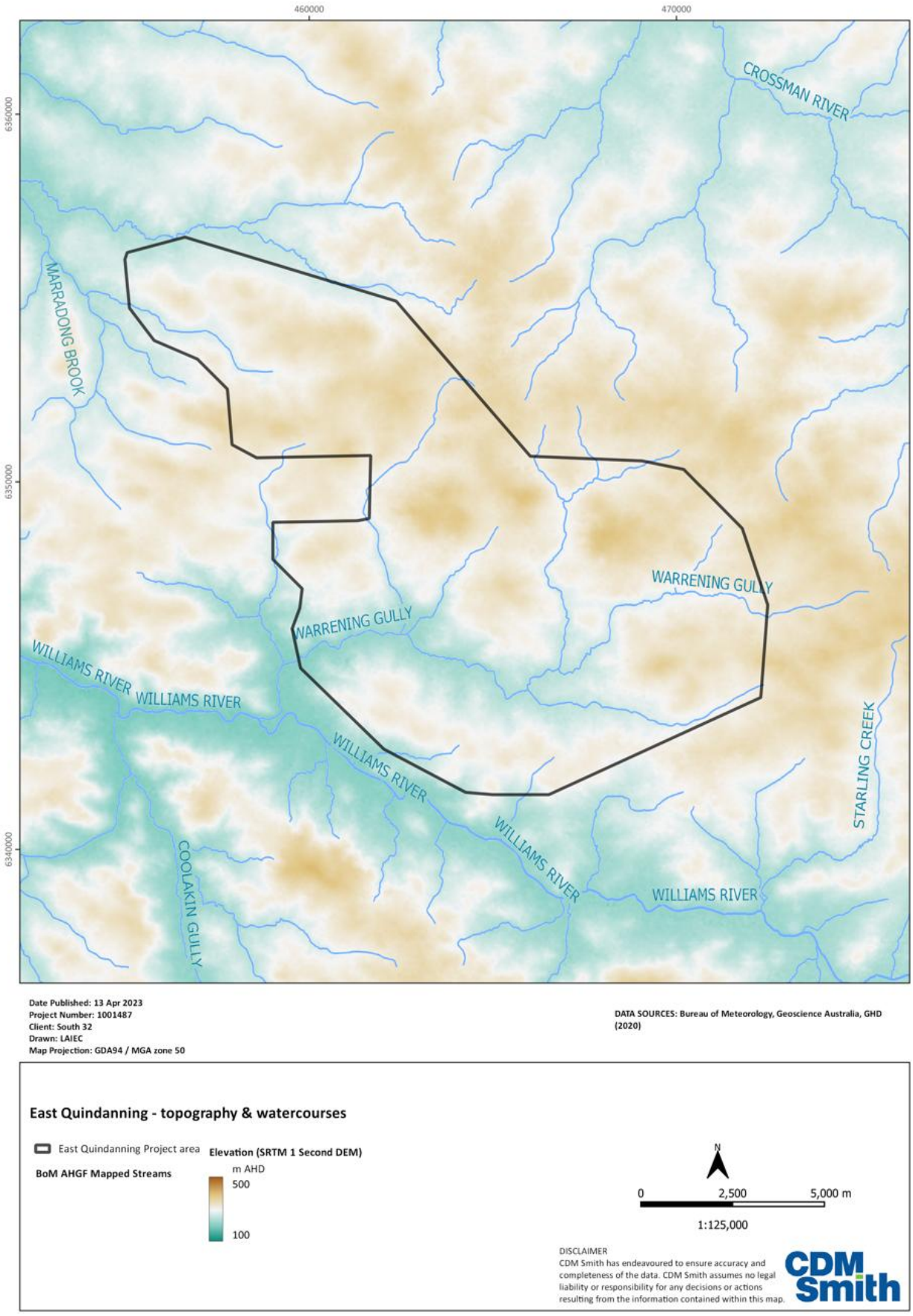

Figure 2-4 Topographic elevation and watercourses

2.3 Geology

The area is underlain by bedrock of the Archean age Yilgarn Craton, which consists of mainly felsic intrusive rocks and high-grade metamorphic rocks such as gneisses (Cassidy et al. 2006). This bedrock outcrops within the region, but commonly with an extensive layer of Cainozoic laterite developed. The fresh bedrock is overlain by a 10 to 20 m weathering profile, commonly comprising a thin gritty basal layer overlain by white to pink and yellow mottled clay (Kern, 1987). The clay may contain thin lenses of gritty sand. The surface has been heavily lateritized, and a massive laterite 2 to 4 m thick generally caps areas of more gentle relief. The thin top soil consists of laterite, colluvial sand and pisolitic gravel. The stratigraphic descriptions are presented in Table 2-2 and the surface geology is shown in Figure 2-5 (Geoscience Australia, 2012).

In the Project, much of the land has an inferred high degree of weathering as per the radiometrically-derived Weathering Intensity Index (Wilford and Roberts, 2019). The only areas of lower weathering intensity are found in the lower catchment of Warrening Gully, where there is likely greater incision to expose more fresh surfaces.

Table 2-2 Stratigraphic Description

Age	Symbol	Province	Description
Cenozoic	Qa	n/a	Alluvium. Channel and flood plain alluvium; gravel, sand, silt, clay; may be locally calcreted. Map unit is not present within the Project, but is found within 2 km of the Project.
Cenozoic	Qrc	n/a	Colluvium and/or residual deposits, sheetwash, talus, scree; boulder, gravel, sand; may include minor alluvial or sand plain deposits, local calcrete and reworked laterite.
Cenozoic	Czl	n/a	Ferruginous duricrust, laterite; pisolitic, nodular, vuggy; may include massive to pisolitic ferruginous subsoil, mottled clays, magnesite, reworked products of ferruginous and siliceous duricrusts, calcrete, gossan; residual ferruginous saprolite.
Archean	Ag	Yilgarn Craton	Undifferentiated felsic intrusive rocks, including monzogranite, granodiorite, granite, tonalite, quartz monzonite, syenogranite, diorite, monzodiorite, pegmatite. Locally metamorphosed, foliated, gneissic. Local abundant mafic and ultramafic inclusions.
Archean	An	Yilgarn Craton	Banded granitic gneiss (monzogranitic to granodioritic), quartzofeldspathic gneiss with mafic bands, migmatite, granofels, mafic and felsic granulites, hypersthene-plagioclase-quartz granulite; schist, pelitic or mafic granofels.



Figure 2-5 Surface geology

Section 3 Hydrogeology

3.1 Hydrogeological Units

Groundwater occurrence is likely to be limited to minor local aquifers and hosted in the weathered and fresh fractured zones of the Archaean basement rocks. The generalised hydrogeology of the Project comprises of three main aquifer units as described below.

- Shallow Weathered Profile:
  - Comprising lateritic cap rock and shallow gravely to sandy sediments which represents a seasonal aquifer with significant storage, infiltration and flow capability (GHD, 2020a).
  - Small supplies (5 to 10 m^3/d) may occur locally in gritty layers within the weathered profile (Kern, 1987).
  - This unit includes the Cenozoic strata such as colluvial and laterite mapped units as shown in Figure 2-5.
  - Groundwater flow and storage is likely controlled by secondary porosity formed from post depositional processes.
- Deep Weathered Profile:
  - Comprises of decomposed granite weathering profile and gravel at the base of the shallow weathered profile.
  - Moderate supplies (10 to 20 m^3 /d) may be obtainable from the gritty decomposed granite weathering profile, an aquifer of high storage potential, but limited bulk permeability (Kern, 1987).
  - Groundwater flow and storage is likely controlled by secondary porosity formed from post depositional processes.
- Fractured bedrock aquifer:
  - Groundwater may be present in the fresh bedrock fractures or joints, these fractures are generally restricted to the upper 5 to 10 m of fresh bedrock (Kern, 1987).
  - Permeability and yield are dependent on fracture development and connectivity of the fractures.
  - Very minor to minor local aquifer is likely to exist with fresh to brackish water quality.
  - Groundwater flow and storage is likely controlled by secondary fracture derived porosity.

3.2 Groundwater Bores

A search of the Bureau of Meteorology groundwater database within the Project shows 6 registered bores (Table 3-1). Within 10 km of the Project there are a total of 184 registered bores that are listed with different purposes of water supply (4), stock and domestic (4), monitoring (89), other (9) and unknown (78). The groundwater monitoring is undertaken in the neighbouring region, with 55 monitoring bores around the existing mining of the Worsley Mining Development Envelope, and a cluster of 34 monitoring bores close to Albany Highway east of the Project. Currently there is no dedicated groundwater monitoring bore network in the Project. The registered bores and groundwater monitoring locations are shown in Figure 3-1. Existing groundwater bores are located within the Worsley Mining Development Area. This development envelope is found to the northeast of the Project, within the existing Worsley Alumina development (GHD, 2020a). South32 mine site existing bore locations are shown in Figure 3-2.

Table 3-1 Registered Bores within the Project

Bore Identification	Easting GDA94/MGA Zone 50	Northing GDA94/MGA Zone 50	Drilled Date	Drilled Depth (mbgl)	Yield (L/Sec)	Standing Water Level (mbgl)	Bore Purpose
61406091	459767	6346589	no data	1	no data	no data	Unknown
61406093	461618	6346591	no data	3	no data	no data	Unknown
61406095	463970	6345036	no data	3	no data	no data	Unknown
61406096	464143	6345845	no data	4	no data	no data	Unknown
61406905	470602	6343816	30/06/1970	7.62	no data	no data	Unknown
61406906	466818	6346179	no data	4.9	no data	no data	Unknown

Standing water level (SWL): Measurements from the reference point on the bore to the groundwater level. Positive values are below the reference point and negative values are above the reference point.

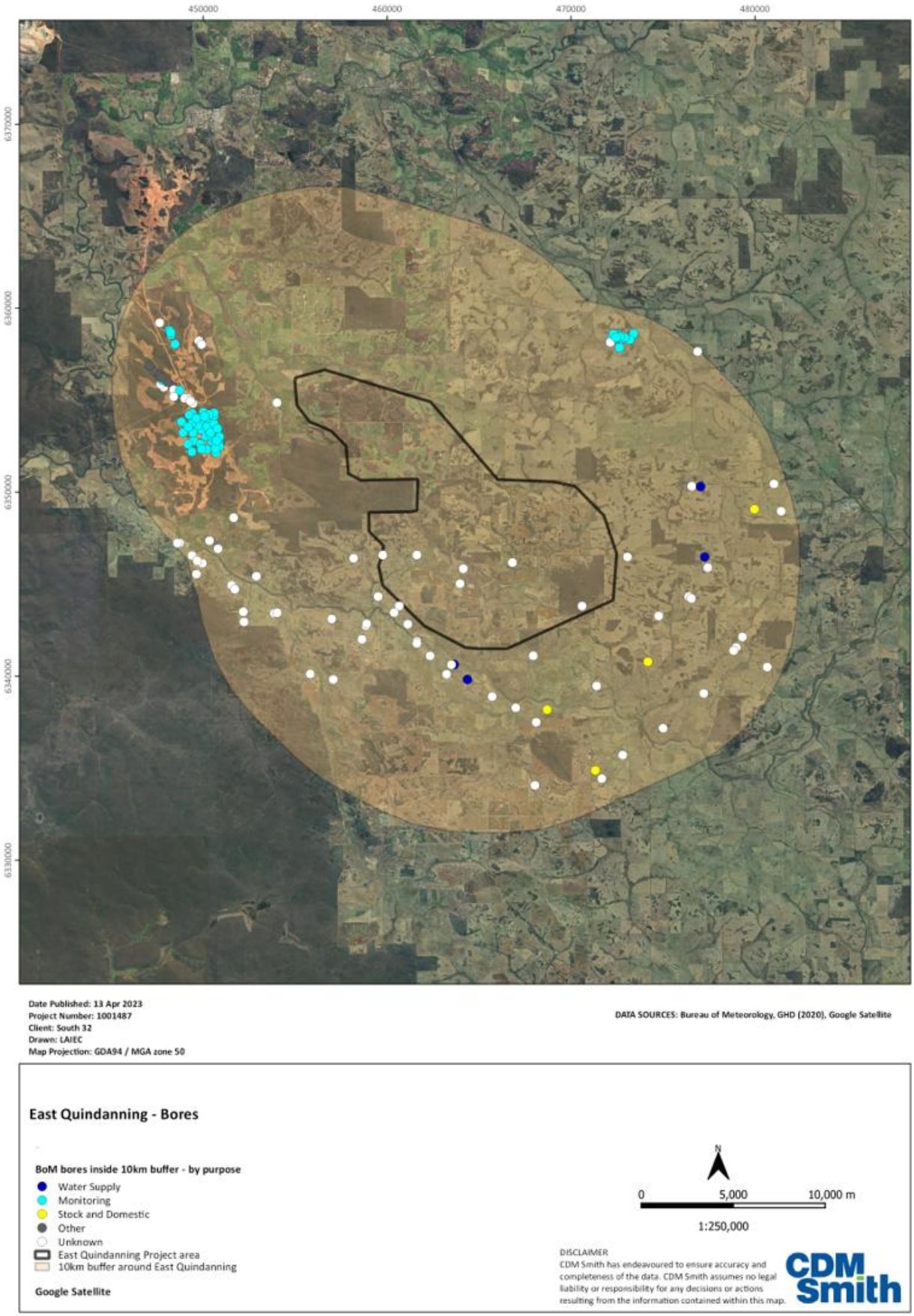

Figure 3-1 Registered groundwater bores

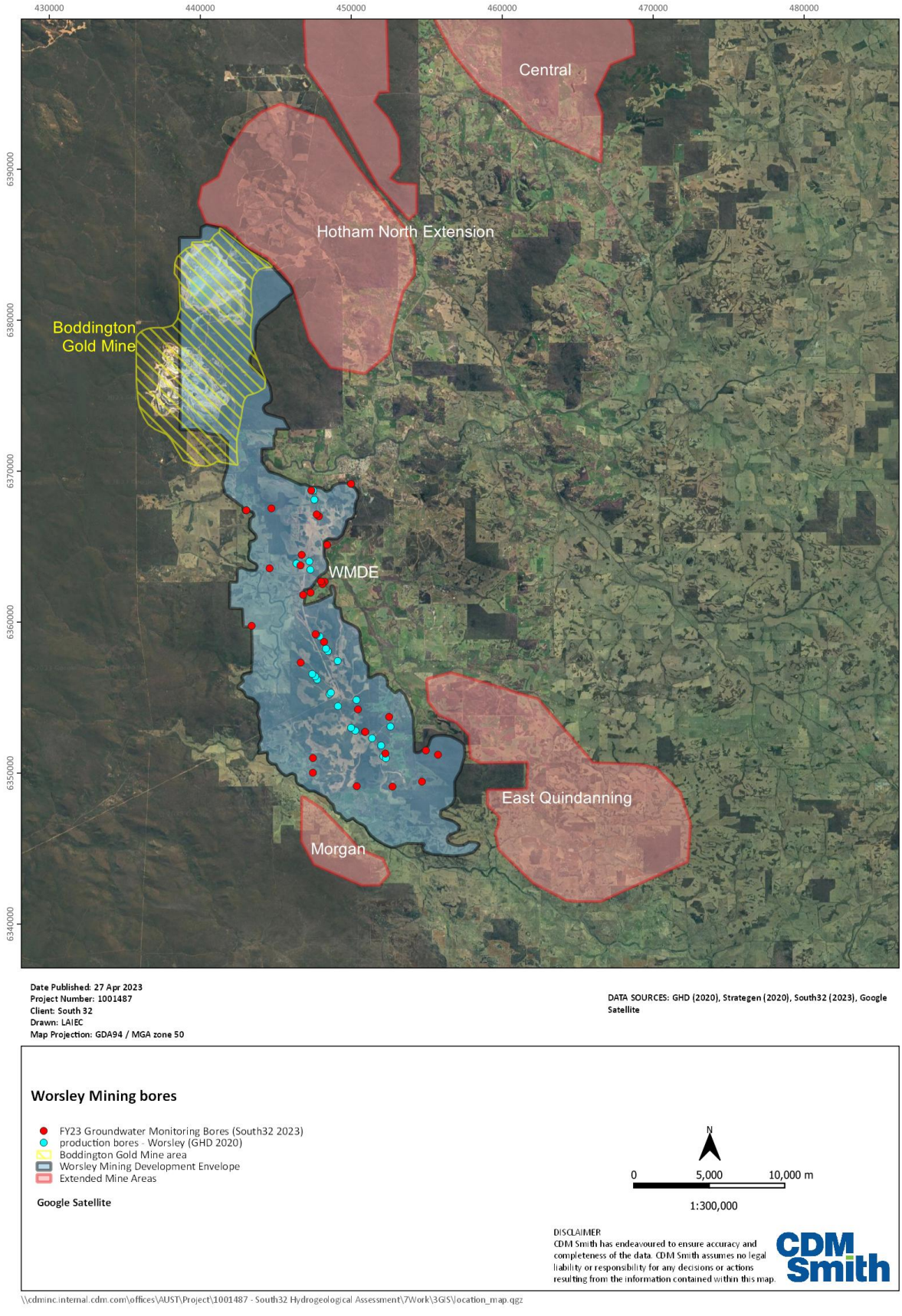

Figure 3-2 Groundwater bores associated with the existing Worsley Mining Development Envelope

3.3 Groundwater Levels and Flow Direction

The regional groundwater flow in the Project is likely to follow a subdued form of the topography, such that groundwater level is highest in areas of highest topography and lowest in areas of lowest topography. Groundwater is considered likely to be providing baseflow, following rainfall and aquifer recharge, to the major rivers and creeks of the area. Groundwater is expected to operate in local flow systems (Commander, 1989). There is insufficient data within the Project area to determine groundwater flow direction or groundwater level contours.

3.4 Groundwater Recharge and Discharge

Rainfall can percolate through the soil and eventually reach the water table as groundwater recharge. Only a small proportion of the rain will likely infiltrate the soils and percolate downwards until it reaches the water table and recharges the groundwater system. Groundwater flows down gradient towards depressions where it may discharge to stream courses, hillslope seeps, or by evaporation and usage by vegetation in swampy areas (Kern, 1987; GHD, 2020a; Nulsen, 1998). As the water flows down gradient, groundwater gradually increases in salinity, particularly if the flow is through clay strata and subsequently groundwater is of better quality higher in the topography than in lower areas (Kern, 1987). Based on the inferred groundwater flow direction discharge may occur to some extent south towards the Williams River via the Warrening Gully and northwest towards the Marradong Brook.

3.5 Hydraulic Properties

There are no published hydraulic properties for bores in the Project. To the west, in the Worsley Mining Development Envelope, several production bores have had aquifer tests (GHD, 2020a). Of the 19 production bores located with 10 km of the Project, 15 of these have a reported hydraulic conductivity values (Table 3-2). The data shows that permeability is heterogenous, and between production bores values range from 1 and 75 m/day. Pumping tests were conducted on two bores SE01/03 and SE02/03 in 2003. SE01/03 had a transmissivity calculated at 4 m^2/day with the average hydraulic conductivity over the fracture interval of about 0.2 m thickness intersected at approximately 20 m/day (ABC, 2023). SE02/03 had a transmissivity calculated at 3 m^2/day (ABC, 2023).

Hydraulic conductivity in the crystalline rocks can range over 10 orders of magnitude, with fractured and weathered media more permeable. Textbook values indicate hydraulic conductivities between 8.64 x 10^{-10} to 1.3 x10^{1} m/day, depending on how fractured or unfractured the crystalline rocks are, and that porosity for the same material is typically less than 0.10 (Hiscock, 2005; Freeze & Cherry, 1979). Saprolites typically have hydraulic conductivities between 8.64 x10^{-3} to 4.32x 10^{-1} m/day, and porosities of 5 to 30 % depending on the nature of the weathering products (Lachassagne et al., 2021).

Table 3-2 Bores with hydraulic test data within 10 km of the Project

Bore Identification	Drill Depth (m BGL)	Screened Interval Top (m BGL)	Screened Interval Bottom (m BGL)	Geology	Hydraulic Conductivity (m/day)	Distance to edge of Project area (km)
SE02/06	86	22	86	Saprock/Fractured rock	2	4.25
SE03/01	101.5	23.5	101.5	Fractured rock	11	4.45
SE02/03	100	45	100	Saprock/Fractured rock	33	4.51
SE01/03	100	45	100	Saprolite/Fractured rock	4	4.57
SE01/01	99.4	33.7	99.4	Saprock/Fractured rock	19	5.20
SE02/01	85	31	85	Fractured rock	5	5.40
K09	70	28.6	100	Saprolite/Saprock/Fractured rock	5	6.04

Bore Identification	Drill Depth (m BGL)	Screened Interval Top (m BGL)	Screened Interval Bottom (m BGL)	Geology	Hydraulic Conductivity (m/day)	Distance to edge of Project area (km)
T13	58	37.2	58	Saprolite/saprock/Fractured rock	75	6.37
T12	76.12	34.63	76.63	Saprolite/saprock/Fractured rock	22	6.47
K01	51.75	19.7	51.75	Saprolite/Saprock	2	6.83
K06	73.8	unknown	unknown	Fractured Rock	1	7.01
T07A	54.65	3	57	Saprolite/saprock	4	7.24
T10	35.3	11.3	35.3	Saprolite/saprock	20	7.58
K07	37.23	unknown	unknown	Saprolite/Saprock	3	7.67
K08	97	28.5	97	Saprolite/Saprock/Fractured rock	6	7.92

3.6 Water Quality

The publicly available hydrogeochemical data is limited for the Project. According to statewide mapping of groundwater salinity (DWER, 2018), there is a general east to west trend of increasing salinity (Figure 3-3). Much of the Project is mapped as having a Total Dissolved Solids (TDS) of 3,000 to 7,000 mg/L, with areas to the east hosting fresher groundwater at 1,000 to 3,000 mg/L TDS, and elevated salinity in the southwest of 7,000 to 14,000 mg/L outside the Project to the southwest, hypersaline groundwater is found approaching the Beaufort Palaeovalley near Dardadine.

In the surrounding regions, groundwater salinity range from under 100 to over 8,000 mg/L, with many fresher samples found in elevated terrain. In the Project, such local variation may also be found. It is likely salinity will vary locally, with higher salinity found down gradient along groundwater flowpaths, such as towards the Williams River. Southwestern Western Australia has been affected by dryland salinity due to land-clearing practices leading to rising water tables and elevated groundwater salinity (Raper et al., 2013). The modified land uses have likely affected parts of the Project, as shown in Figure 2-3.

No other hydrochemical parameters were obtained from the available data.

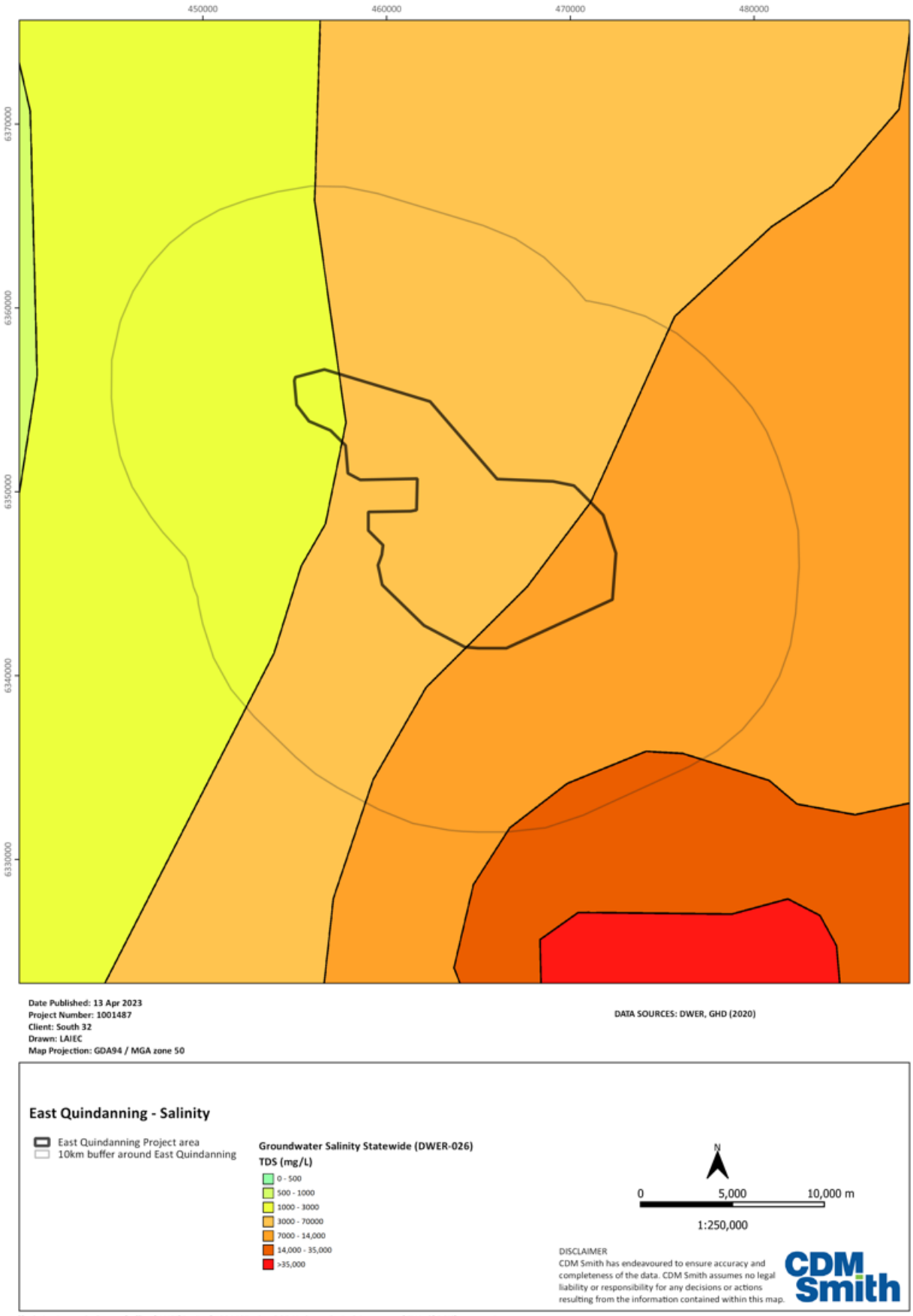

Figure 3-3 Groundwater salinity

Section 4 Environmental Values and Contaminants of Concern

4.1 Environmental Values

4.1.1 Overview

The Department of Mines, Industry Regulation and Safety guideline defines Environmental Value as "a beneficial use and/or an ecosystem health condition" (DMIRS, 2020a). A description of the environmental values such as groundwater dependent ecosystems and beneficial uses of groundwater in the Project are provided below.

4.1.2 Groundwater Dependant Ecosystems

The Bureau of Meteorology Groundwater Dependent Ecosystems (GDE) Atlas was produced by conducting a national-scale assessment using remote sensing and GIS rules based analysis, which mapped the potential for groundwater/ecosystem interaction. Figure 4-1 presents a locality plan of the identified GDEs using the GDE Atlas (BoM, 2019).

This shows that potential aquatic GDEs are mapped outside of the Project to the south of the Project near Williams River. Potential terrestrial GDEs are mapped in the central to northeast parts of the Project. The mapped high potential terrestrial GDEs are located near the drainage lines of the upper catchment tributaries.

No areas were mapped as being known GDEs, nor were any areas mapped from regional assessments. There are no listed internationally significant (Ramsar Wetlands) or nationally significant (Directory of Important Wetlands in Australia) wetlands located in the Project or the surrounding region (DAWE 2021; DCCEEW 2022).

4.1.3 Beneficial Use

There are only six registered groundwater bores found inside the Project, however no bore use is listed. The majority of registered groundwater bores within 10 km of the Project boundary have an unknown purpose. There are four stock and domestic bores and four water supply bores found to the south and east of the Project. No quantified volumes of extraction were found with any of the registered bores in the search area.

It is likely that the low average yields and nature of the local aquifer has resulted in the landholders reliant on surface water storage dams. It is likely elevated groundwater salinity limits the use of groundwater for human consumption. It is possible that groundwater is sourced in low quantities for domestic purposes and stock water use from bores that are not registered or known to be drilled. Adjacent to the Project, groundwater production bores are associated with the Worsley Alumina mine (GHD, 2020a).

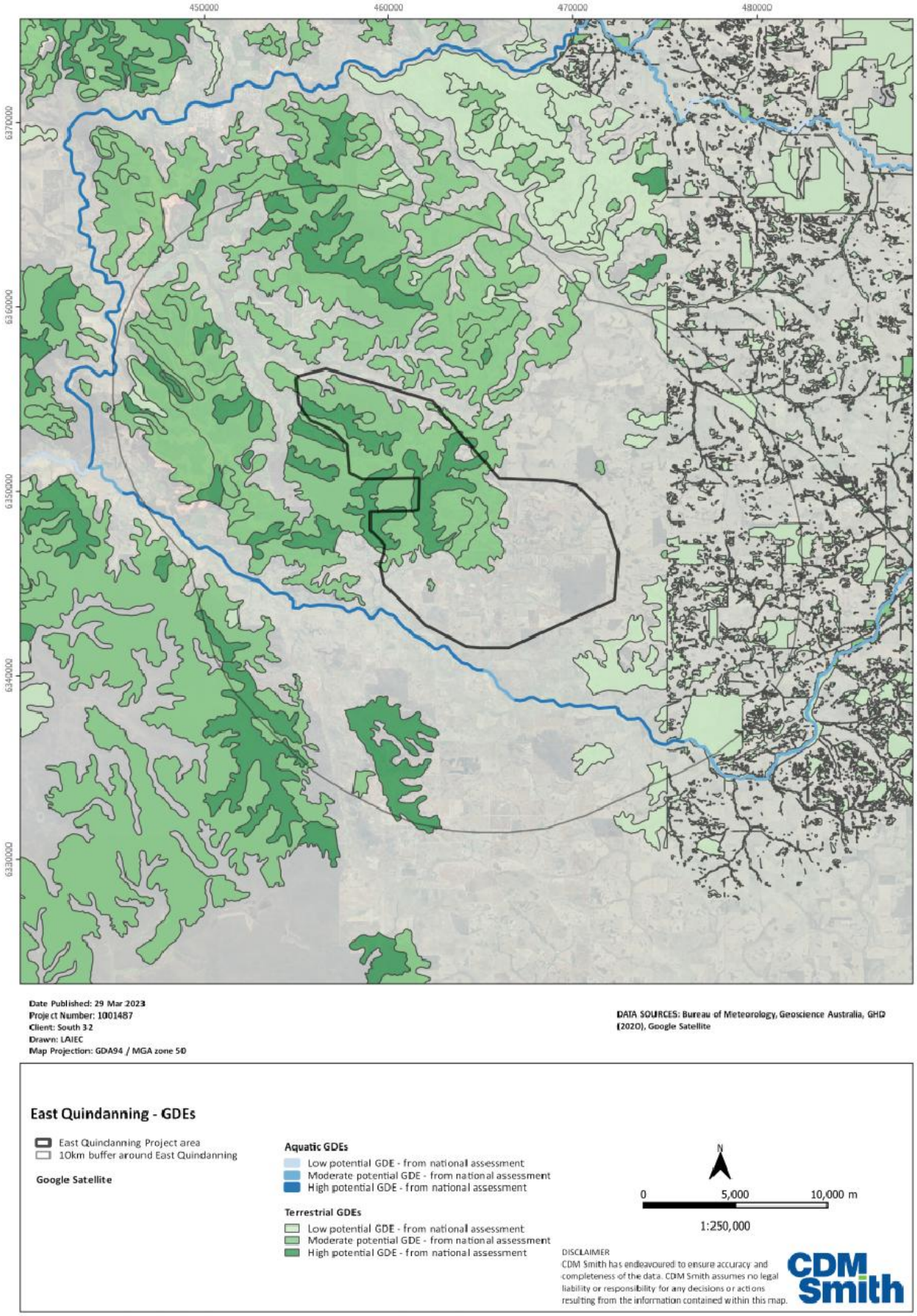

Figure 4-1 Potential Groundwater Dependent Ecosystems

Section 5 Preliminary Hydrogeological Conceptualisation

A simplified preliminary conceptual cross section is shown in Figure 5-1 based on the available hydrogeological information and assessment works completed above. Key features of the preliminary hydrogeological conceptualisation are as follows:

- The available hydrogeological data is limited for the Project. Groundwater occurrence is likely to be limited to minor local aquifers and hosted in the weathered and fresh fractured zones of the Archaean basement rocks. Groundwater may be found in three main components:
  - the shallow weathered profile, laterite and colluvium with small supplies likely obtained, especially from gritty layers.
  - deeper weathered profile, where decomposed granite can provide moderate supplies.
  - the upper part (approximately 5-10m) of the fresh granite, where open fractures exist to provide a minor aquifer.
- The spatial and depth extents of the hydrogeological units are uncertain. There is insufficient data to accurately depict water tables or groundwater flow directions.
- Groundwater flow is likely to operate in local flow systems, with the water table likely following a subdued form of the topography. In addition to the topographic drive, groundwater flow is likely somewhat structurally controlled due to the nature of the fractured rock aquifer.
- It is inferred that groundwater flow is generally in topographic directions. This is likely south towards the Williams River via the Warrening Gully and northwest towards the Marradong Brook.
- Groundwater is considered likely to be discharging to some extent, following rainfall and aquifer recharge, to the major rivers and creeks of the area.
- Groundwater flows down gradient towards depressions where it may discharge to stream courses, hillslope seeps, or by evaporation and usage by vegetation.
- Only a small proportion of the rain will likely infiltrate the soils and percolate downwards until it reaches the water table and recharges the groundwater system. Recharge is likely to be greater on the upper slopes where more permeable soils are typically found.
- The available hydrogeochemical data is limited for the Project. Much of the Project is mapped as having a Total Dissolved Solids (TDS) of 3,000 to 7,000 mg/L, with areas to the east hosting fresher groundwater at 1,000 to 3,000 mg/L TDS, and elevated salinity in the southwest of 7,000 to 14,000 mg/L. It is likely salinity will vary locally, with higher salinity found down gradient along groundwater flowpaths.
- Potential aquatic GDEs may be found to the south of the Project near Williams River. Potential terrestrial GDEs are mapped in the central to northeast parts of the Project. The mapped high potential terrestrial GDEs are located near the drainage lines of the upper catchment tributaries. No areas were mapped as being known GDEs, nor were any areas mapped from regional assessments.

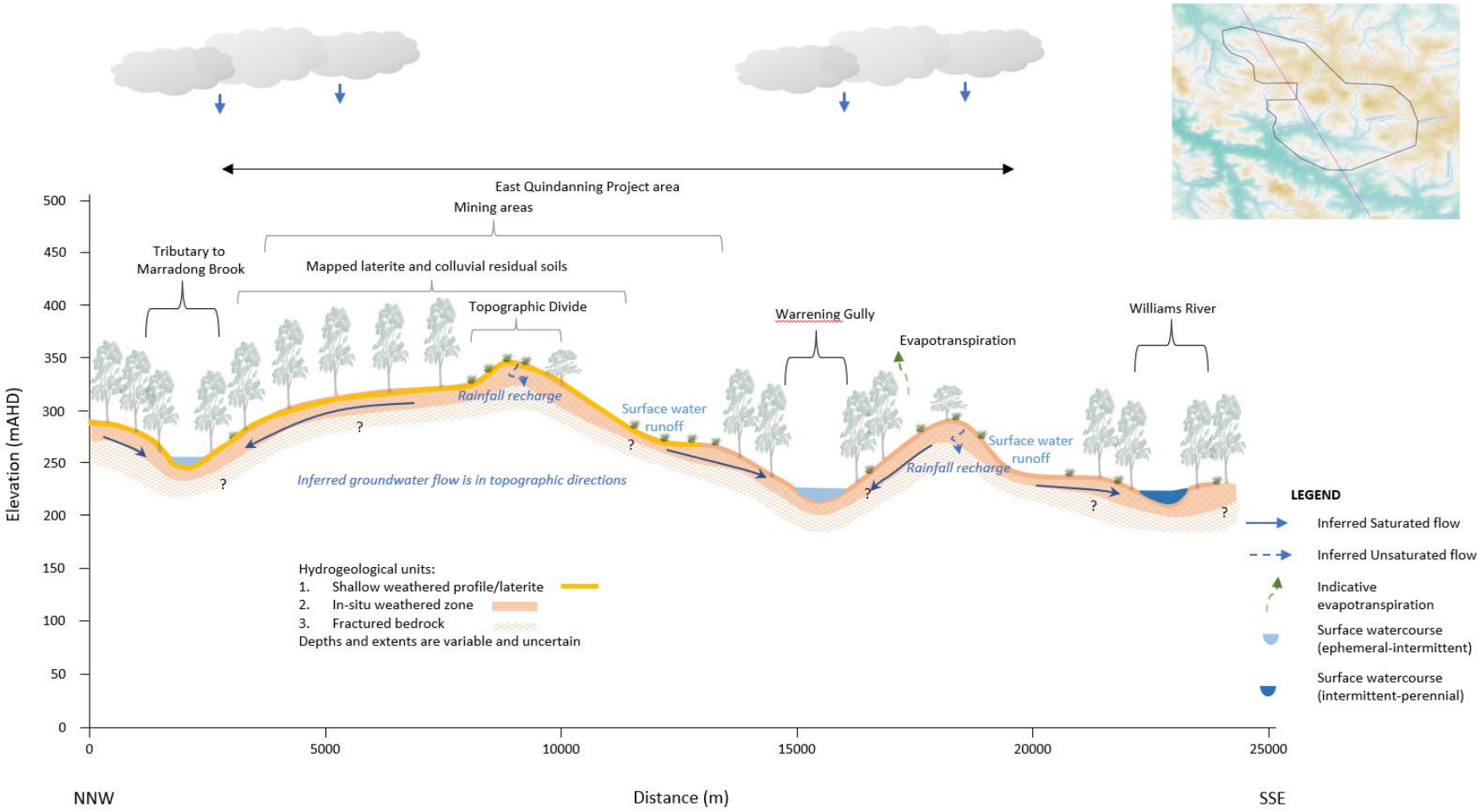

Figure 5-1 Preliminary Hydrogeological Conceptual Model

Section 6 Recommendations and Limitations

6.1 Gap Analysis and Recommendations

The following details the gap analysis and recommendations for further studies for the Project and options for collecting site specific data:

- There are no dedicated groundwater monitoring bores located within the Project.
- There is no available groundwater water level or water quality data available within the Project, and limited data in the surrounding region.
- Because there is limited data available, there is currently no available time series data for groundwater levels for seasonal analysis or trend analysis to be conducted.
- The is insufficient data on lithological variation vertically as to ascertain the hydrogeological units and their depth extents.
- There is no site specific aquifer parameters available such as hydraulic conductivity, transmissivity or storativity.
- There is insufficient data on groundwater use and extraction rates from existing bores in the surrounding region.
- There is insufficient local-scale data on the watercourses to determine the groundwater baseflow component.
- Unknown dewatering plans and operational summaries that define how water is planned to be moved around site. Unknown final mine schedule, construction, dewatering and mining plans.

The recommendations for further studies for the Project and options for collecting site specific data are outlined below:

- Drilling of site specific groundwater monitoring bores to confirm the formation thicknesses for the lateritic/colluvial, weathered zones and fractured zones, and to confirm the nature of the Archaean strata.
- The drilled bores need to be accurately surveyed including recording elevation of groundwater level at the bore and top of casing for each bore.
- Slug tests should be conducted on all monitoring bores to collect site specific aquifer parameters such as hydraulic conductivity.
- It is recommended water quality sampling of all monitoring bores be undertaken quarterly to capture seasonal variations.
- Continuous water level transducers and barometer should be installed in all newly constructed monitoring bores. The logging interval should be at least twice daily and downloaded quarterly.
- Collect time-series groundwater levels at most (if not all) existing monitoring bores over at least one wet season and dry season cycle. Minimum monitoring period is twelve months however extending this to twenty-four months is desirable for numerical model development.
- Bore census to confirm the status of registered or unregistered bores in the surrounding region and their purposes such as stock water or domestic purposes.
- Field groundwater monitoring events is recommended near the end of the wet season when groundwater levels are likely to be at their highest and near the end of the dry season when groundwater levels are likely to be at their lowest.
- Further information on cultural heritage, GDE / vegetation surveys completed for the study area to better understand and describe the environmental values that may be supported by groundwater.

- The preliminary conceptualisation will need to be updated by identifying the groundwater levels within proximity of the surface water features which host GDEs.
- Complete an environmental risk assessment that identifies all the environmental risk pathways and evaluate the risk pathway to derive a residual risk rating.

6.2 Limitations

The limitations of the study are outlined below:

- Assumptions were made on the formation locations and thicknesses due to limitations in the available geological data available.
- Assumptions were made on the likely groundwater flow directions water table due to limitations in the available data available.
- There are no groundwater monitoring bores located at the Project site and the available groundwater data is at this stage limited.
- The authors did not have access to accurate geological and groundwater monitoring data or information.
- The preliminary conceptual model shown in Figure 5-1 is based on minimal data sets and should not be considered accurate.

Section 7 Monitoring Bore Locations and Target Formations

7.1 Proposed Drilling Locations and Estimated Depths

In order to determine local groundwater conditions at the Project, standard hydrogeological assessment practices are to be used. This involves the drilling and installation of groundwater monitoring bores at each site to be completed. The number and location of these newly drilled bores needs to be confirmed with regard to providing sufficient data to build a data-driven water table map, inferred groundwater flow directions and surface / groundwater interactions. Where suitable, the selected locations have been positioned close to roads or proposed roads for easy access. However, to provide enough spatial coverage not all selected locations have identifiable road access.

It is also considered, based on previous studies, that groundwater bores which are considered to reflect the background hydrogeological setting unaffected by mining activities. These would be situated outside the area of mining influence (e.g. over 300 metres away and upgradient of such influences) and which are located within areas which are naturally vegetated (e.g. bush/jarrah forests) or in areas that have been cleared for agriculture (GHD, 2020a).

The bores are to be sighted in a groundwater upgradient and downgradient arrangement, with installation as follows:

- It is proposed 16 groundwater bores locations are drilled (Table 7-1). These locations have been mapped over visible imagery (Figure 7-1) and a digital elevation model (Figure 7-2). The purpose of the bores is to monitor groundwater quality and level and determine potential direction of groundwater flow.
- It is unknown the depth of the groundwater table depth or lithology thickness in the area. This will be determined by the drilling of the monitoring bores.
- It is proposed to drill, depending on hydrogeological conditions encountered shallow, and deep monitoring bores at various sites to understand vertical changes in groundwater processes. These sites are especially useful close to the planned mine pit locations and in upper catchment areas.
- Four bores are found in the Marradong Brook catchment while ten are found in the Warrening Gully catchment. These are required to identify the patterns in groundwater flow directions as a result of the intervening topographic divide.
- Four bores, MB_Q04, MB_Q03 and MB_Q15 (for Warrening Gully catchment) and MB_Q11 (for Marradong Brook catchment), are placed upstream of the likely areas affected by mining as to monitor baseline or background groundwater conditions.

Table 7-1 Proposed Drilling Locations

Bore ID	Easting GDA94/ MGA Zone 50	Northing GDA94/ MGA Zone 50	Location Description	Estimated Depth (mBGL)	Target Lithology	Category and Purpose
MB_Q01	460022	6345442	lower catchment near watercourse (Warrening Gully)	10 to 30	Weathered Profile	Monitoring and numerical model development
MB_Q02	462443	6345926	lower catchment near watercourse (Warrening Gully)	10 to 30	Weathered Profile	Monitoring and numerical model development
MB_Q03	465840	6344478	middle catchment near watercourse (Warrening Gully)	10 to 30	Weathered Profile	Monitoring and numerical model development

Bore ID	Easting GDA94/ MGA Zone 50	Northing GDA94/ MGA Zone 50	Location Description	Estimated Depth (mBGL)	Target Lithology	Category and Purpose
MB_Q04	470120	6346879	upper catchment near watercourse (Warrening Gully)	10 to 30	Weathered Profile	Monitoring and numerical model development
MB_Q05	461828	6348219	lower catchment near drainage line; within terrestrial GDE area, close to mapped mining areas	10 to 30	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_Q06	459145	6347980	lower catchment near drainage line; within terrestrial GDE area, close to mapped mining areas	10 to 30	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_Q07	462725	6350697	upper catchment near drainage line; within terrestrial GDE area	10 to 30	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_Q08	459171	6350683	upper catchment near drainage line; within terrestrial GDE area	10 to 30	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_Q09	457435	6353991	upper catchment near drainage line; within terrestrial GDE area	10 to 30	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_Q10	455146	6354865	lower catchment near drainage line; close to terrestrial GDE area	10 to 30	Weathered Profile	Monitoring and numerical model development
MB_Q11	460767	6355226	middle catchment near drainage line	10 to 30	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_Q12	459065	6352585	upper catchment near catchment divide, away from mapped drainage line; within terrestrial GDE area, close to mapped mining areas	10 to 30	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_Q13	461190	6352176	upper catchment, near catchment divide; within terrestrial GDE area	10 to 30	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_Q14	460567	6347232	lower catchment; within terrestrial GDE area, close to mapped mining areas	10 to 30	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development

Bore ID	Easting GDA94/ MGA Zone 50	Northing GDA94/ MGA Zone 50	Location Description	Estimated Depth (mBGL)	Target Lithology	Category and Purpose
MB_Q15	466053	6347824	middle catchment away from mapped drainage line	10 to 30	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_Q16	458055	6351455	upper catchment, near catchment divide; close to or within mapped mining areas	10 to 30	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development

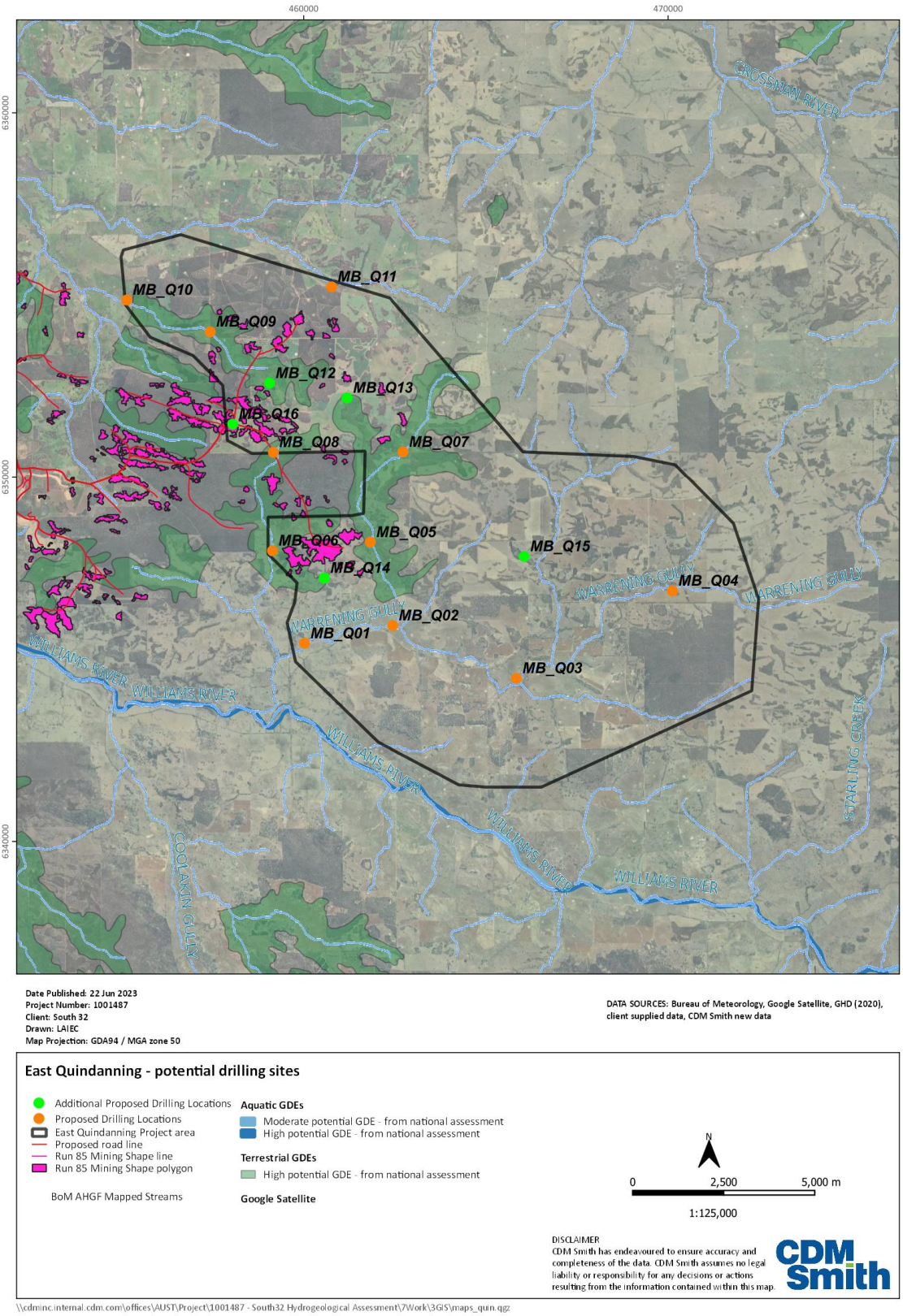

Figure 7-1 Proposed drilling locations with mapped terrestrial GDE area

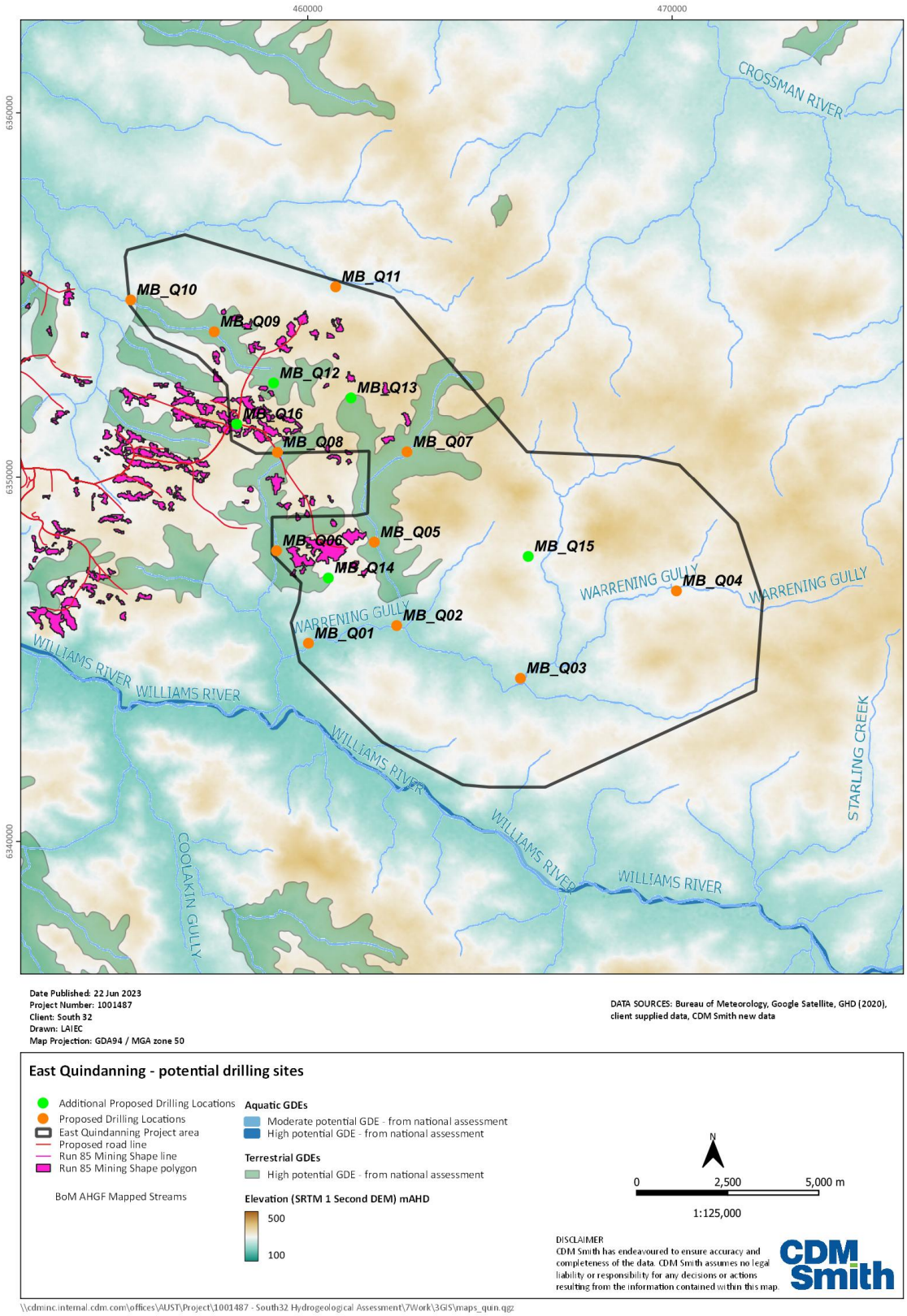

Figure 7-2 Proposed drilling locations with topography with topography / mapped terrestrial GDE area

Section 8 Installation Methodology and Construction Requirements

8.1 Monitoring Bore Installation Methodology

All groundwater bores will be installed as per the "Minimum Construction Requirements for Water Bores in Australia". Although largely dependent on site specific ground conditions, a general method of borehole construction and piezometer installation is summarised as follows:

- A Class 2 qualified driller will be required for the installation of the monitoring bores.
- A diameter hole of 155 mm would be sufficient for the holes as it is recommended that only one 50 mm diameter piezometer is to be installed in each hole.
- The groundwater monitoring bore will be constructed by carefully lowering 50 mm uPVC screen/end cap and casing into the open hole. The drilling rig should have suitable slips/elevators set up to hold the weight of the piezometer while it is being installed.
- Once the casing is installed within the bore, the gravel filter pack (2-5mm quartz gravel) shall be tremmied into place within the well screen section and to a minimum of 1 m above the screen. A bentonite seal is then emplaced, and the bore is then completed by backfilling and sealing with concrete grout at the surface. It is important that the placement of all backfilling material, gravel packs and seals must be carefully undertaken at a controlled rate with appropriate settlement times to ensure placement at the correct depth and avoid bridging at higher levels within the hole.
- Each groundwater monitoring bore shall be developed after installation has been completed to clear residual drill fluid and cuttings from the piezometer. This can be done by using compressed air to lift the water column to surface. Airlifted water should be run through a V-notch weir to determine yields.
- Once constructed the bore should have an end cap and lockable bore monument installed. It is recommended that the monument be grouted in place and well-marked.

A proposed preliminary schematic for each borehole has been provided in Appendix A. Geological logging is necessary prior to confirming the installation specification of each monitoring bore to ensure the bore screen is located in the correct lithology/aquifer. Final bore design will be confirmed by the hydrogeologist in the field during installation based on field conditions.

The hydrogeologist's duties include geological logging of drill cuttings, recording v-notch yields and water quality parameters during drilling, advising on bore construction parameters to meet the Project requirements and confirmation that bores are airlift developed after drilling until produced water was clear, free of fines and water quality parameters had stabilised.

8.2 Monitoring Bore Materials

The following materials are proposed for the drilling and piezometer installation:

- Drilled at 155 mm for a 50 mm uPVC CL 12 or 18 casing thread jointed PVC specific to environmental assessments
- Sufficient casing centralisers
- 50mm uPVC CL 12 or 18 slotted screen (<1mm slot width)
- Piezometer end caps to prevent ingress of particulate matter to the piezometers
- Filter pack comprising uniformly graded, clean gravel pack with diameter between 2 – 5 mm
- Borehole sealant (bentonite pellets) and cement based grout
- Bore cap, monuments and locks to cover and protect the bore and any installed equipment

8.3 Testing and Groundwater Sampling

8.3.1 Slug Testing

Following the installation of the monitoring bores, it will be necessary to perform a slug or rapid displacement test on each monitoring bore to determine aquifer hydraulic conductivity. The results of the slug tests should be analysed using software packages to calculate hydraulic conductivity.

8.3.2 Groundwater Sampling Methodologies

Groundwater sampling will be required following the installation of the monitoring bores and bore development. Representative groundwater samples are to be collected following stabilisation of field water quality parameters. Low flow method of sampling should be adopted as part of the groundwater sampling methodology. Low flow methods minimise the impact of the sampling method on the aquifer and are more likely to obtain a representative sample, while some high flow pumps can sometimes induce water chemistry changes.

Prior to groundwater sampling a standing water level should be measured for each bore.

Field water quality analysis should include at a minimum electrical conductivity, pH, and temperature.

Collected groundwater samples will need be stored in laboratory supplied bottles and, where required, field filtered (i.e. dissolved metals). Samples will be sent to a NATA accredited laboratory after each sampling event in accordance with industry standard chain of custody (COC) protocols.

It is recommended sampling of the bores should be undertaken quarterly to capture seasonal variations. Groundwater monitoring is recommended near the end of the wet season when groundwater levels are likely to be at their highest and near the end of the dry season when groundwater levels are likely to be at their lowest.

8.3.3 Quality Management Processes

Groundwater sampling is to be conducted in accordance with:

- Geoscience Australia (2009) “Groundwater Sampling and Analysis – A Field Guide” (record 2009/27)
- The Australian/New Zealand Standard Water quality – “Sampling, Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples” (AS/NZS 5667.1:1998)
- The Australian/New Zealand Standard Water quality – “Sampling, Part 11: Guidance on sampling of groundwaters” (AS/NZS 5667.11)

For QA/QC purposes, blind duplicate samples are to be collected at each site monitoring network location and at a minimum 1:10 ratio basis. All monitoring field equipment should be calibrated in accordance with the manufacturer's specifications.

8.3.4 Laboratory Analysis

The following analysis is based on the South32 Water Management Plan (South32, 2020) which details the monitoring to be undertaken. The representative samples taken from the bores shall be analysed for the following parameters:

- Standing water level measurement.
- pH, electrical conductivity, total dissolved solids, hardness and alkalinity.
- Fluoride, nitrate and nitrite, Silicon as SiO2.
- Major cations and anions. Na, K, Ca, Mg, Fe, SO4, Cl.
- Filtered and unfiltered metals (Al, As, B, Bo, Be, Cd, Cr, Co, Cu, Fe, Hg, Pb, Mn, Mo, Ni, Se, U, Zn).
- Cyanide.
- TRH and BTEXN.

Stock watering has been identified as a potential beneficial use of groundwater and Table 8-1 lists the livestock water guidelines values.

Table 8-1 Livestock Drinking Water Guideline Values

Parameter	ANZECC, 2000 Guideline – Stock Drinking Water
TDS (mg/L)	4,000 – 5,000 (Beef Cattle)
Calcium (mg/L)	1,000
Fluoride (mg/L)	2
Sulfate (mg/L)	1,000
Nitrate (mg/L)	1,500
Nitrite (mg/L)	30
Aluminium (mg/L)	5
Arsenic (mg/L)	0.5
Boron (mg/L)	5
Cadmium (mg/L)	0.01
Chromium (mg/L)	1
Cobalt (mg/L)	1
Copper (mg/L)	1 (Beef Cattle)
Lead (mg/L)	0.1
Mercury (mg/L)	0.002
Molybdenum (mg/L)	0.15
Nickel (mg/L)	1
Selenium (mg/L)	0.02
Uranium (mg/L)	0.2
Zinc (mg/L)	20

Notes: - Where guidelines stipulate, the value for beef cattle has been adopted.
- The stock water guidelines (ANZECC, 2000) stipulate for metals and metalloids that trigger values relate to total or unfiltered concentrations of the constituent.

Section 9 Disclaimer

Disclaimer and Limitations

This report has been prepared by CDM Smith Australia Pty Ltd (CDM Smith) for the sole benefit of South32 Worsley Alumina for the sole purpose of a hydrogeological assessment supporting the Extended Mining Area called Quindanning.

This report should not be used or relied upon for any other purpose without CDM Smith's prior written consent. Neither CDM Smith, nor any officer or employee of CDM Smith, accepts responsibility or liability in any way whatsoever for the use of or reliance on this report for any purpose other than that for which it has been prepared.

Except with CDM Smith's prior written consent, this report may not be:

a. released to any other party, whether in whole or in part (other than to officers, employees and advisers of South32 Worsley Alumina);

b. used or relied upon by any other party; or

c. filed with any Governmental agency or other person or quoted or referred to in any public document.

Neither CDM Smith, nor any officer or employee of CDM Smith, accepts responsibility or liability for or in respect of any use or reliance upon this report by any third party.

The information on which this report is based has been provided by South32 Worsley Alumina and third parties. CDM Smith (including its officers and employees):

a. has relied upon and presumed the accuracy of this information;

b. has not verified the accuracy or reliability of this information (other than as expressly stated in this report);

c. has not made any independent investigations or enquiries in respect of those matters of which it has no actual knowledge at the time of giving this report to South32 Worsley Alumina; and

d. makes no warranty or guarantee, expressed or implied, as to the accuracy or reliability of this information.

In recognition of the limited use to be made by South32 Worsley Alumina of this report, South32 Worsley Alumina agrees that, to the maximum extent permitted by law, CDM Smith (including its officers and employees) shall not be liable for any losses, claims, costs, expenses, damages (whether in statute, in contract or tort for negligence or otherwise) suffered or incurred by South32 Worsley Alumina or any third party as a result of or in connection with the information, findings, opinions, estimates, recommendations and conclusions provided in the course of this report.

If further information becomes available, or additional assumptions need to be made, CDM Smith reserves its right to amend this report.

Section 10 References

Australian groundwater modelling guidelines, June 2012. Authors: Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A and Boronkay A.

Australian Bore Consultants, 2003. Boddington Bauxite Mine 2003 Groundwater Program Bore Completion Report. February, 2003.

ANZECC and ARMCANZ, 2000. Australian and New Zealand guidelines for fresh and marine water quality. Volume 1, The guidelines / Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand. October 2000.

ANZG, 2018. Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Government and Australian state and territory governments, Canberra, ACT.

ABARES (2020) Catchment scale land use of Australia – Update December 2020. https://www.agriculture.gov.au/abares/aclump/catchment-scale-land-use-of-australia-update-december-2020. Raster geospatial data (TIFF format), downloaded 23 March 2023.

Allen, A. D. (1996) Hydrogeology of the Northeastern Goldfields, Western Australia. Geological Survey of Western Australia, Record 1996/4. Department of Minerals and Energy, Western Australia.

Brodie, R.S., Lawrie, K.C. & Commander, D.P. (2012). Groundwater—lifeblood of the continent. In: Shaping a Nation: A Geology of Australia, Blewett, R.S. (ed.), Geoscience Australia and ANU E Press, Canberra, pp. 332–379.

Bureau of Meteorology (2015) Australian Hydrological Geospatial Fabric (Geofabric). Web map service, http://geofabric.bom.gov.au/simplefeatures/wms?request=getCapabilities, date accessed 27 March 2023.

Bureau of Meteorology (2019). Groundwater Dependent Ecosystem Atlas. Data download for polygon areas in the Murray River region of Western Australia, shapefile format, downloaded 19 January 2023.

Bureau of Meteorology (2021), National Groundwater Information System. Groundwater Information. Data download for bores in the Murray River region of Western Australia, shapefile format, downloaded 21 January 2023.

Bureau of Meteorology (2023). Climate Data Online. http://www.bom.gov.au/climate/data/index.shtml. Data downloads for selected climate stations, downloaded 9 March 2023.

Cassidy, K.F., Champion, D.C., Krapež, B., Barley, M.E., Brown, S.J.A., Blewett, R.S., Groenewald, P.B., and Tyler, I.M. (2006). A revised geological framework for the Yilgarn Craton, Western Australia: Western Australia Geological Survey, Record 2006/8.

Commander, D.P. (1989). Hydrogeological Map of Western Australia, 1:2,500,000 scale. Geological Survey of Western Australia. Perth, 1 map sheet.

DAWE (2021) Directory of Important Wetlands in Australia, https://www.dcceew.gov.au/water/wetlands/australian-wetlands-database/directory-important-wetlands, accessed 30 March 2023

DCCEEW (2022) Australian Ramsar Wetlands, https://www.dcceew.gov.au/water/wetlands/australian-wetlands-database/australian-ramsar-wetlands, accessed 30 March 2023

DMIRS (2020a). Statutory Guidelines for Mining Proposals. Version 4.0, 24pp. Government of Western Australia Department of Mines, Industry Regulation and Safety. https://www.dmp.wa.gov.au/Documents/Environment/REC-EC-114D.pdf

DMIRS (2020b). Mining Proposal Guidance – How to prepare in accordance with Part 1 of the Statutory Guidelines for Mining Proposals. Version 4.0, 68pp. . Government of Western Australia Department of Mines, Industry Regulation and Safety. https://www.dmp.wa.gov.au/Documents/Environment/REC-EC-115D.pdf

DWER (2018). Groundwater Salinity Statewide (DWER-026). Department of Water and Environmental Regulation, Western Australia. Web map service, https://services.slip.wa.gov.au/public/services/SLIP_Public_Services/Water/MapServer/WMSServer, date accessed 29 March 2023.

DWER (2021) Water Allocation Plans and Statements (DWER-086), web mapping service, https://services.slip.wa.gov.au/public/services/SLIP_Public_Services/Water/MapServer/WMSServer, accessed 30 March 2023

Freeze, R.A. and Cherry, J.A. (1979). Ground Water. Prentice Hall, Upper Saddle River USA, 604 pp. ISBN 0-13-365312-9.

Geoscience Australia (2012). Surface Geology of Australia 1:1 million scale dataset 2012 edition. http://pid.geoscience.gov.au/dataset/ga/74619. Web map service, https://services.ga.gov.au/gis/services/GA_Surface_Geology/MapServer/WMSServer?REQUEST=GetCapabilities&SERVICE=WMS&VERSION=1.3.0, date accessed 27 March 2023.

Geoscience Australia (2011). SRTM-derived 1 Second Digital Elevation Model. http://pid.geoscience.gov.au/dataset/ga/72759. Web Coverage Service, http://services.ga.gov.au/gis/services/DEM_SRTM_1Second/MapServer/WCSServer?, date accessed 27 March 2023.

GHD (2020a). Worsley Mine Expansion - Revised Proposal. South32 Worsley Alumina Pty Ltd EPA Assessment No. 2216. EPBC Reference No. 2019/8437. Groundwater and surface water studies. August 2020. Report submitted to the WA Environmental Protection Authority, https://www.epa.wa.gov.au/sites/default/files/PER_documentation2/Appendix%20I1%20-%20Groundwater%20and%20Surface%20Water%20Studies%20%28GHD%2C%202020a%29.pdf, downloaded 9 March 2023.

GHD (2020b). Worsley Mine Expansion - Revised Proposal. South32 Worsley Alumina Pty Ltd EPA Assessment No. 2216. EPBC Reference No. 2019/8437. Soil Characterisation Study. May 2020. Report submitted to the WA Environmental Protection Authority, https://www.epa.wa.gov.au/sites/default/files/PER_documentation2/Appendix%20H1%20-%20Worsley%20Mine%20Expansion%20Soil%20Characterisation%20Study.pdf, downloaded 29 March 2023.

Gray, D.J., Noble, R.R.P., Reid, N., Sutton G.J. and Pirlo, M.C. (2016). Regional scale hydrogeochemical mapping of the northern Yilgarn Craton, Western Australia: a new technology for exploration in arid Australia. Geochemistry: Exploration, Environment, Analysis. Vol. 16 | 2016 | pp. 100–115. https://doi.org/10.1144/geochem2014-333

GSWA (1983) Collie, Sheet SI 50-6. Geological map, Australia 1:250,000 geological series. First Edition, 1983. Low, G.H., Lowry, D.C., Lake, R.W., Wilde S.A., and Hirschberg K-J.B.

GSWA (1980). Pinjarra, Sheet SI 50-2 and part of Sheet SI 50-1. Geological map, Australia 1:250,000 geological series. First Edition, 1980. Lowry D.C., Wilde S.A., and Walker I.W.

Hiscock, K.M. (2005). Hydrogeology: Principles and Practice. Blackwell Publishing, Oxford, 389pp.

Johnson, S.L. and Commander, D.P., 2006, Mid West Regional Minerals Study – Groundwater Resource Appraisal, Department of Water, Hydrogeological Record Series HG 17, August 2006.

Kern, A.M. (1987). Report on Groundwater Prospects, Warrening Gully – Quindanning. Hydrogeology Report 2780. Geological Survey of Western Australia, Perth, 1987. GSWA File No. 103/87.

Lachassagne, P., Dewandel, B. and Wyns, R. (2021). Review: Hydrogeology of weathered crystalline/hard-rock aquifers—guidelines for the operational survey and management of their groundwater resources. Hydrogeology Journal (2021) 29:2561–2594. https://doi.org/10.1007/s10040-021-02339-7

Magee, J.W., 2009. Palaeovalley Groundwater Resources in Arid and Semi-Arid Australia – A Literature Review. Geoscience Australia Record 2009/03. 224 pp.

Nulsen, R.A. (1998). Groundwater trends in the agricultural area of Western Australia. Department of Primary Industries and Regional Development, Western Australia, Perth. Report 173.

Raper, P., Simons, J., George, R., Speed, R., Smith, R., Ryder, A., Stainer, G., Kendle, A. and Bennett, D. (2013). Will climate variability reduce dryland salinity risk in the south-west agricultural region of Western Australia. Extended Abstract. IAH Congress 2013 - Solving the groundwater challenges of the 21st century. September 2013, Perth, Western Australia.

SILO (2023). SILO - Australian climate data from 1889 to yesterday. Data download for point data, https://www.longpaddock.qld.gov.au/silo/point-data/, downloaded 9 March 2023.

South32, 2020. Water Management Plan, Business Blueprint Boddington Bauxite Mine.

Turner, J.V., Barr, A.D., Challen, R.P., Johnson, S.L., Townley, L.R., Wright, K.D., Woodbury, R.J., Watson, G.R., Bartle, G.A. and Gailitis, V. (1996). Groundwater Supply to the Mining Industry in the WA Goldfields. Minerals and Energy Research Institute of Western Australia (MERIWA), Report no. 154. AMIRA Project No. P321A and MERIWA Project No. M217. CSIRO Division of Water Resources, Perth. March 1996.

Wilford, J., Roberts, D. 2019. Weathering Intensity Model of Australia. Geoscience Australia, Canberra. http://dx.doi.org/10.26186/5c6387a429914

Appendix A Bore Schematic

Groundwater Development Plan Generic Bore Design 1001487

