South32 Worsley Alumina

Hydrogeological Assessment - Extended Mining Areas – Hotham North

5 July 2023

CDM Smith

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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 Hotham North (the Project). The Project is located approximately 120 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 Hotham North Extended Mining Area.

1.2 Objectives and Scope of Work

The objective of this study is to complete a groundwater assessment for the Hotham North 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.

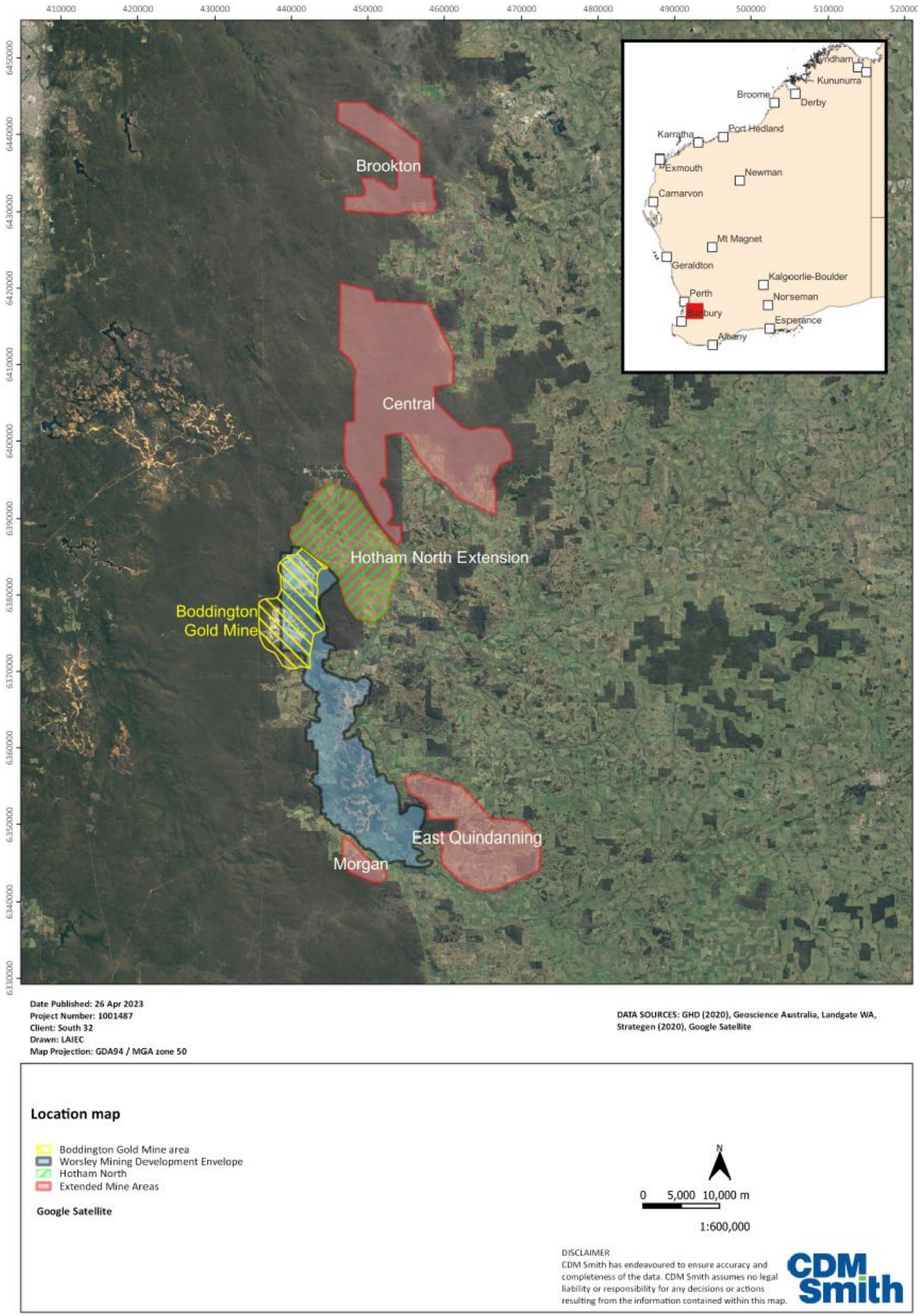

Figure 1-1 Location of the extended mining areas – Hotham North

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.

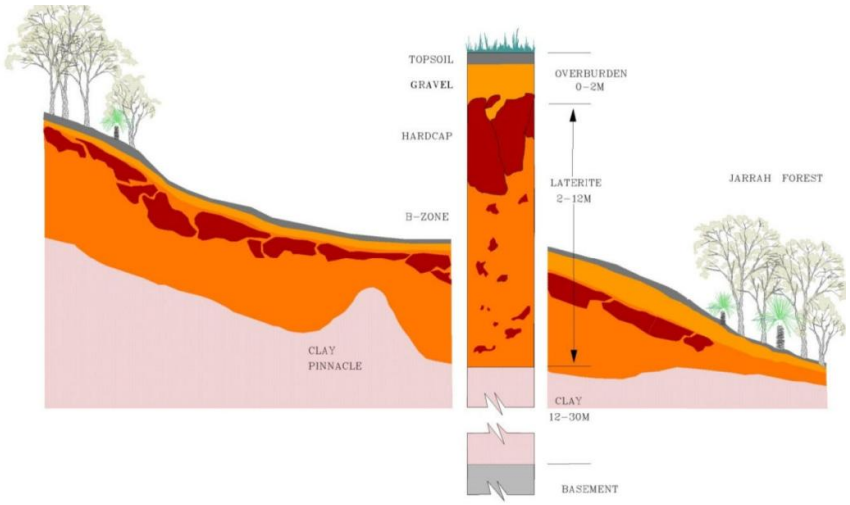

Figure 1-2 Laterite section (South32, 2021)

Boddington Gold Mine is located adjacent to the Project and north of the current Worsley Alumina bauxite mining operation (Figure 1-1). The gold mine is currently operated by Newmont, producing gold and copper. The mine open pit and tailings storage facility are shown in the aerial imagery.

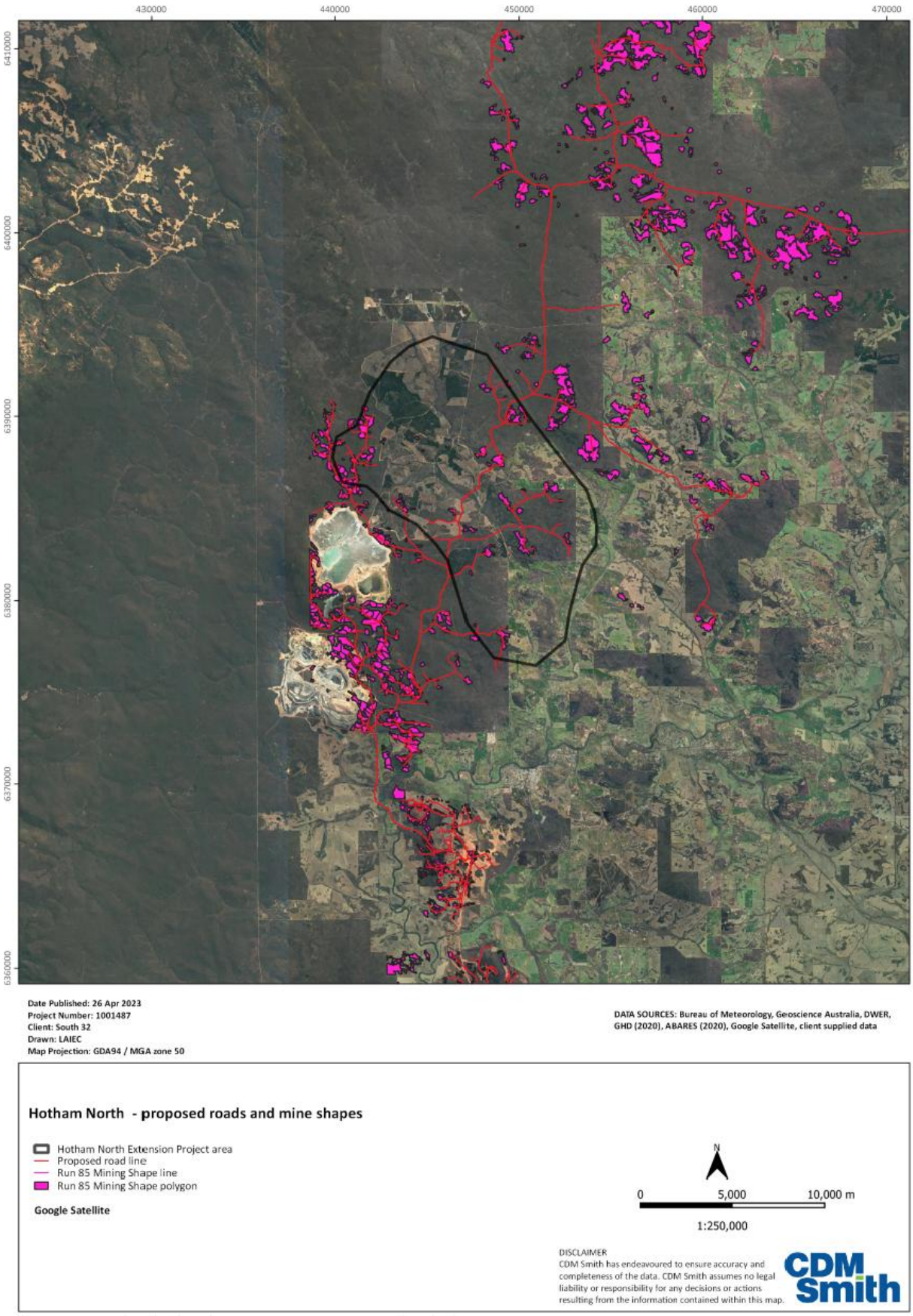

Figure 1-3 Project proposed roads and mining shapes

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 Bannister between 2010 and 2022 is 1638 mm (SILO, 2023). The average monthly pan evaporation is consistently highest between October and April, peaking in January (266 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 Bannister (station number 9507). Bannister station has rainfall for the period 1886 to 2023. The mean annual recorded rainfall from 1886 to 2022 is 644.4 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. Temperature data for Bannister was not available, and temperature data was obtained from Wandering (station number 10917).

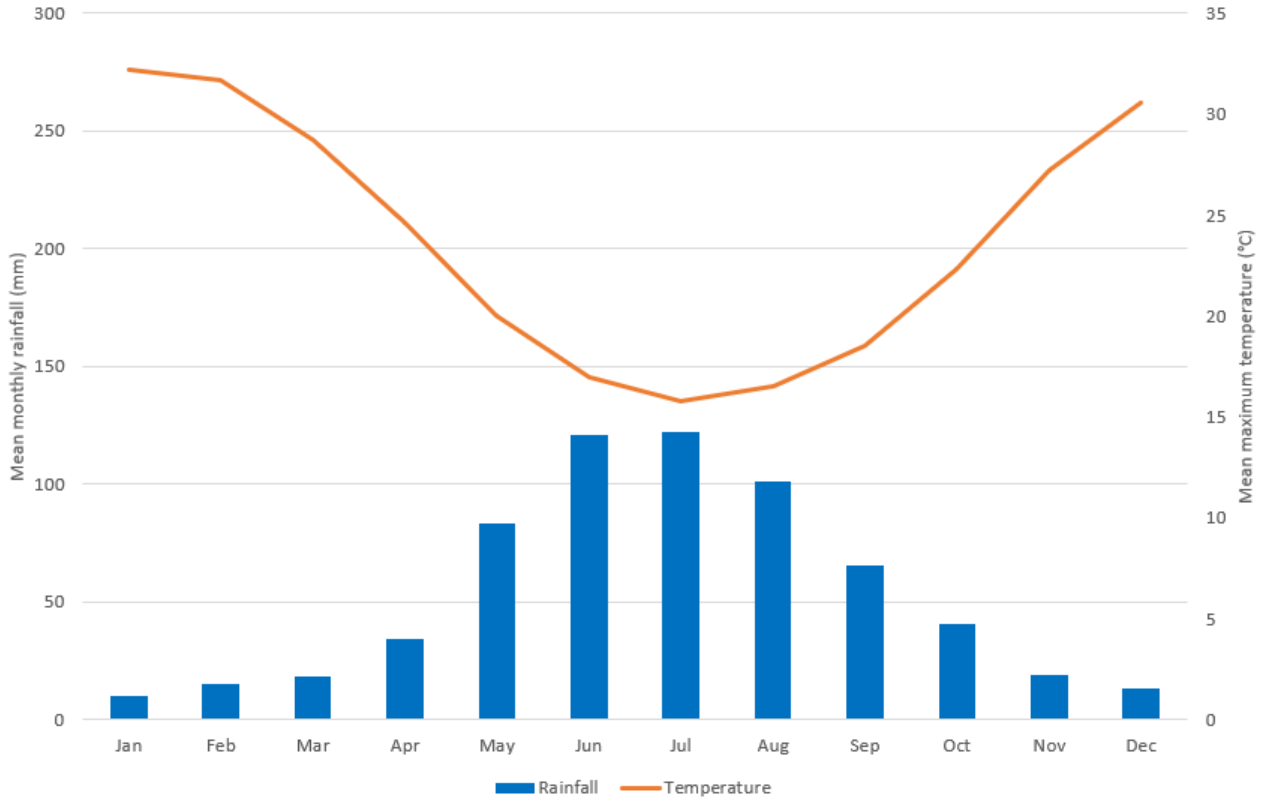

Figure 2-1 Mean monthly Rainfall and Temperature

Long term rainfall monthly cumulative deviation from the mean (CDFM) is shown in Figure 2-2, based on the rainfall data obtained from Bannister. 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.

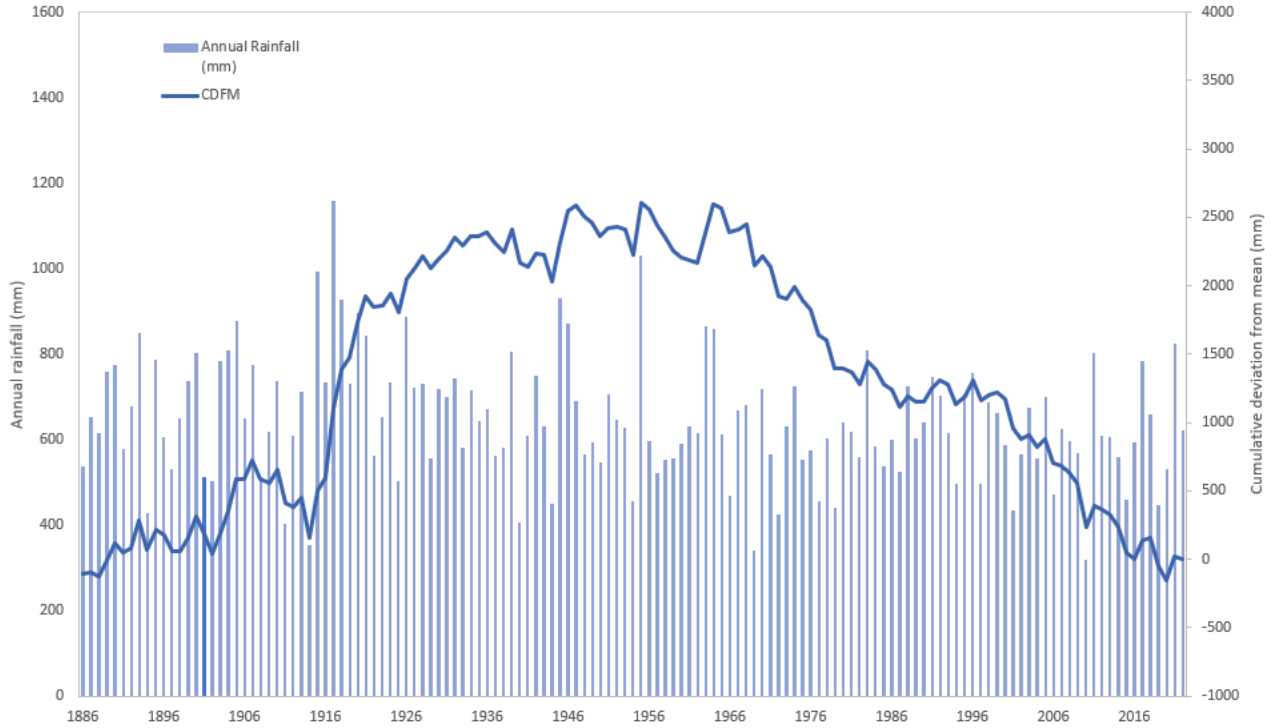

Figure 2-2 Long term rainfall monthly cumulative deviation from the mean

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 southeast towards the Bannister River via a main northwest-to-southeast unnamed tributary. The Project is situated in an area with elevations sloping from around 545 m Australian Height Datum (mAHD), flattening out to around 180 mAHD (Figure 2-4).

Table 2-1 Land use categories found in the Project

Land Use Classification	General Description	% of Project Area
Production native forests	Production native forests	54.35
Plantation forests	Plantation forests	26.81
Grazing native vegetation	Grazing native vegetation	6.75
Cropping	Dryland cropping	5.86
Residual native cover	Other minimal use	4.08
Grazing modified pastures	Grazing modified pastures	2.04
Reservoir - intensive use	Water	0.05
Marsh/wetland	Water	0.03
Roads	Urban intensive uses	0.01
Airports/aerodromes	Urban intensive uses	0.01
Degraded land	Land in transition	0.01

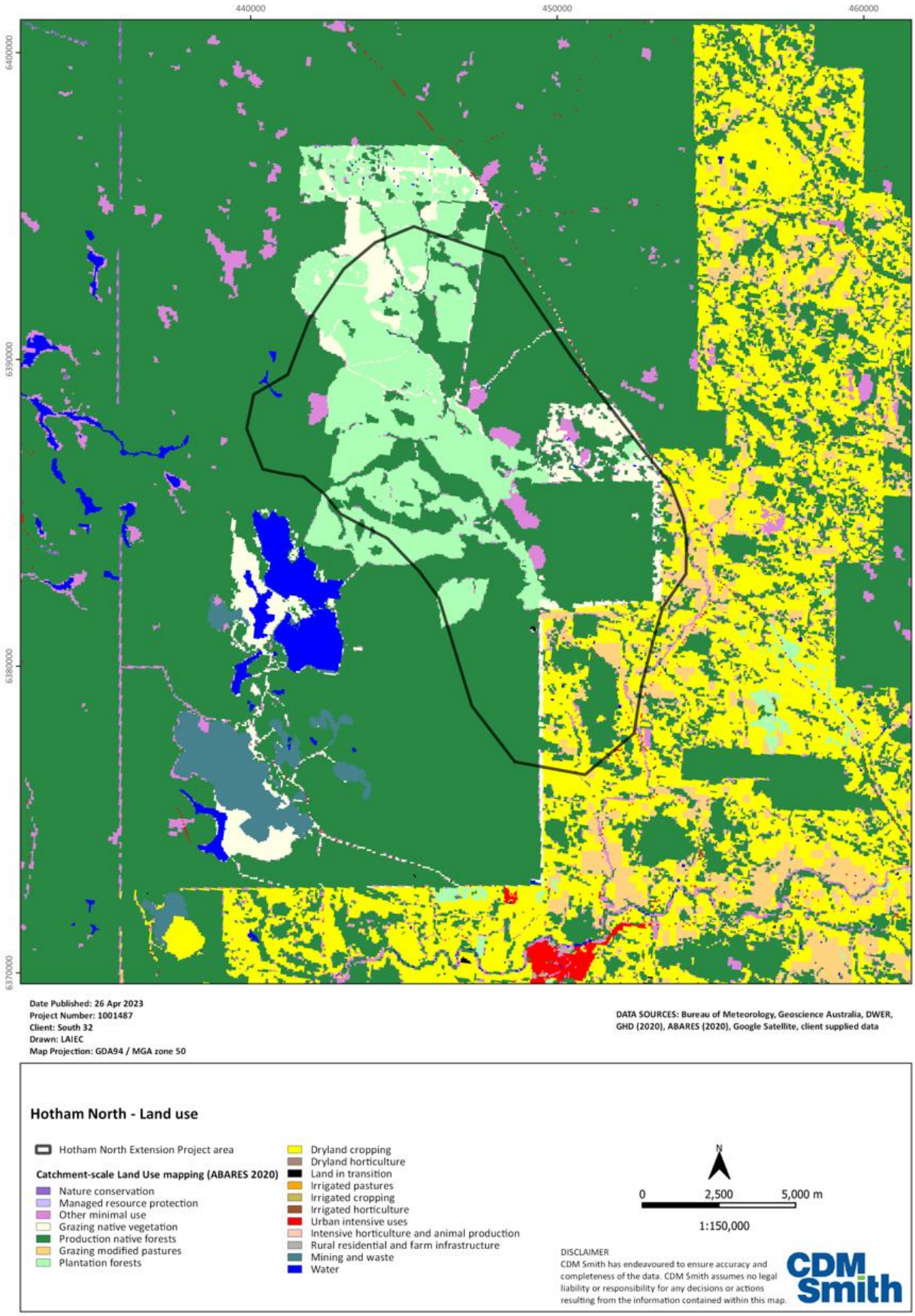

Figure 2-3 Land use

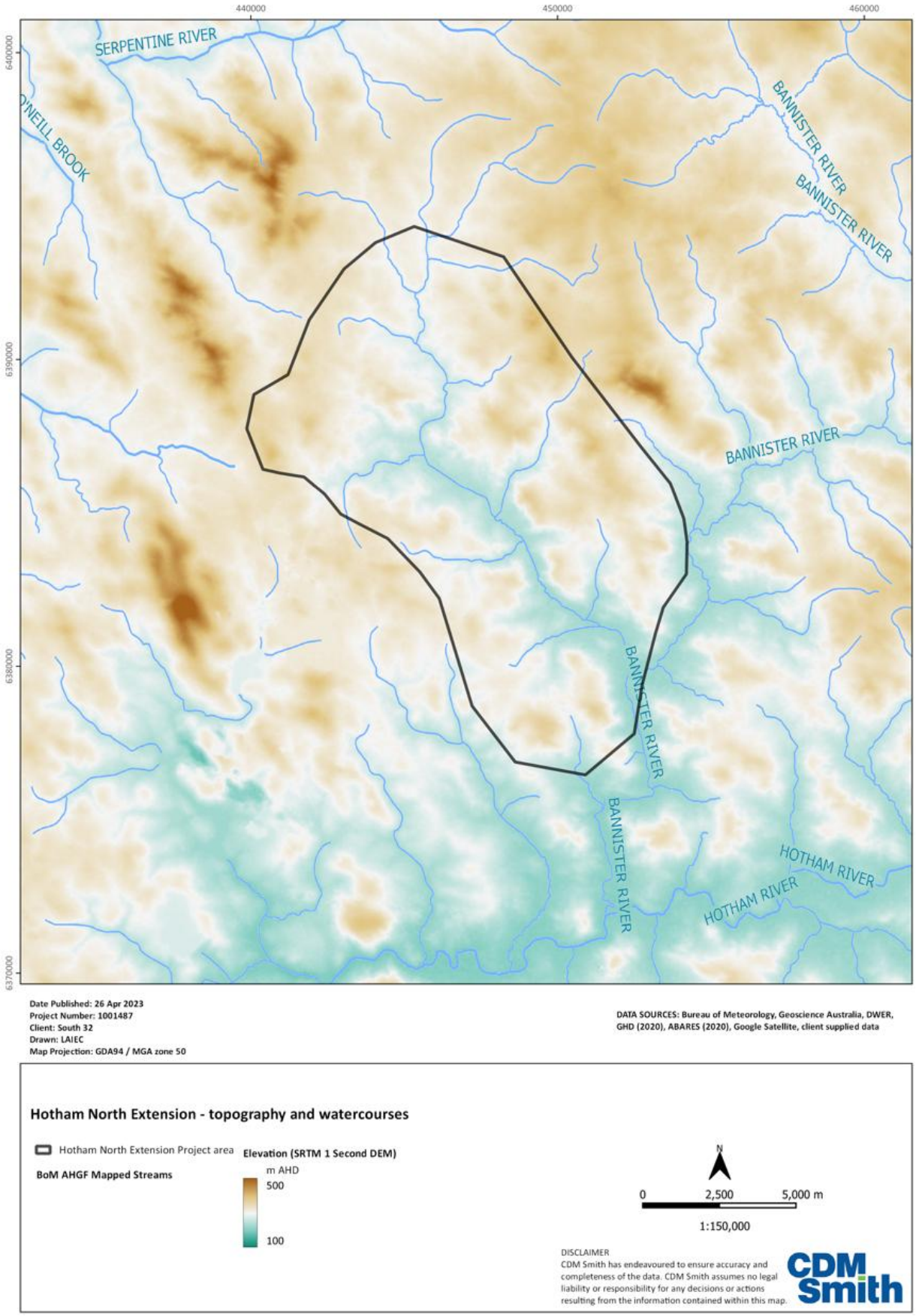

Figure 2-4 Topographic elevation and watercourses

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 Saddleback Group is a volcanogenic greenstone sequence developed in the Western Gneiss Terrain of the Archaean Yilgarn Block. The Saddleback Group consists of greenschist to amphibolite facies metamorphic rocks in a greenstone belt. This greenstone belt is enclosed by Neoarchaean granites that dominate the Project (Global Groundwater, 2020). The stratigraphic descriptions are presented in Table 2-2 and the surface geology is shown in Figure 2-5 (Geoscience Australia, 2012).

The fresh bedrock is overlain by a weathering profile up to 40 m thick, dominated by a quartz-rich granitic saprolite, commonly comprising a thin gritty basal layer overlain by a mottled and pallid zone clay-dominated horizon (Turner et al., 1997; Raper, 2005; Clarke et al., 2002; Strategen, 2013). The clay may contain thin lenses of gritty sand. The surface has been heavily lateritised, and a massive laterite 2 to 4 m thick generally caps areas of more gentle relief. The surficial lateritic cap comprises of nodular or pisolitic ferruginised material (Turner et al., 1997). The thin top soil consists of laterite, colluvial sand and pisolitic gravel.

There are Proterozoic dolerite to gabbro dykes that transect the granite greenstone belt, including a dominant east to southeast trending set, south to southeast trending set and potentially a third east to northeast trending set (Global Groundwater, 2020). 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 valley to the southeast of the Project approaching Bannister River.

Table 2-2 Stratigraphic Description

Age	Symbol	Province	Description
Quaternary	Qa	n/a	Alluvium: Channel and flood plain alluvium; gravel, sand, silt, clay; may be locally calcreted.
Quaternary	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	Czs	n/a	Sand or gravel plains; may include some residual alluvium; quartz sand sheets commonly with ferruginous pisoliths or pebbles; local clay, calcrete, laterite, silcrete, silt, colluvium.
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.
Archaean	Af	Yilgarn Craton	Felsic volcanic rocks and porphyry: Plagiophyric dacite, felsic lavas and pyroclastics.
Archaean	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.
Archaean	At	Yilgarn Craton	Amphibolite, mafic schist, mafic rock intercalated with granite, para-amphibolite; metabasalt, metagabbro, metapyroxenite and metadolerite.
Archaean	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.

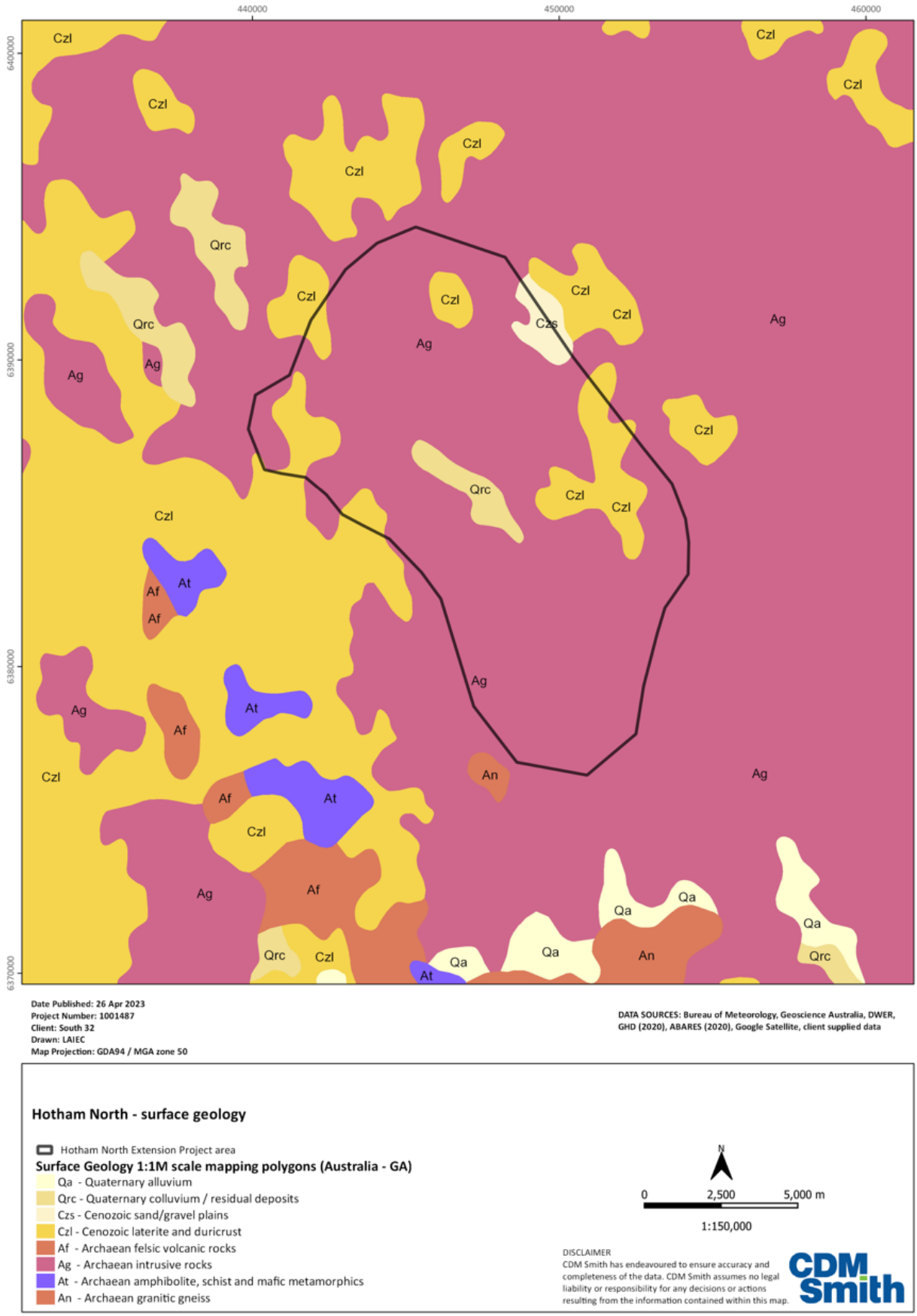

Figure 2-5 Surface geology

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. No palaeovalleys are mapped within the Project, with the Hotham palaeovalley located to the south (Bell et al., 2012). Groundwater supplies are associated with Cenozoic palaeovalley networks, where these are present. The generalised hydrogeology of the Project comprises of three main aquifer units as described below.

- Shallow Weathered Profile:
  - The topsoil is typically 0.1 m thick and contains gravel, sand and organic matter. This is underlain by a gravelly soil layer of 0.5 to 8 m thick and a high hydraulic conductivity (Strategen, 2013).
  - The weathered profile comprises of a lateritic cap rock and shallow gravely to sandy sediments which represents a seasonal aquifer with significant storage, infiltration and flow capability (GHD, 2020a). This unit includes the Cenozoic strata such as colluvial and laterite mapped units as shown in Figure 2-5. The thickness of the lateritic cap is variable. It is commonly around 1 to 5 m thick, but is reduced or absent in places such as eroded hill slopes, and may be substantially thicker in areas of extensive erosion (Strategen, 2013; Global Groundwater, 2020).
  - As a shallow aquifer, it is highly responsive to rainfall patterns (Strategen, 2013). 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. At the base of the weathering profile, the partly weathered/saprolitic basal zone is more permeable than the overlying pallid and mottle zone (Clarke et al., 2002). The pallid zone is oxidised and clay-dominated, and can be up to 70 m thick with the lower aquifer semi-confined (Strategen, 2013).
  - This is the main aquifer (Turner et al., 1997; Strategen, 2013) found at the interface between the saprolite and upper bedrock surface (Global Groundwater, 2020). The permeable section is a thin layer at the base of the weathering profile, often in the saprock (Turner et al., 1997). The base of the weathering profile is around 8 times more permeable than the rest of the saprolite and forms a key aquifer (Clarke et al. 2002). The base of the weathered zone is more granular than the mottled and pallid zone clays. The highly permeable section is typically 7 and to 15 m thick (Global Groundwater, 2020; Strategen, 2013).
  - Geologic structures in the basement, such as dykes, fault zones and quartzite beds, may control groundwater flow in the overlying saprolitic aquifers (Clarke et al., 2002). 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. However, these fractures generally remain open in the upper 10 to 15 m of fresh bedrock (Strategen, 2013) and may persist for 30 to 40 m into fresh granite around faults (Turner et al., 1997). The aquifer permeability and yield are dependent on fracture development and connectivity of the fractures. The fracture system drains relatively young groundwater, sourced from the surficial weathered zone aquifer (Turner et al., 1997).
  - Where fractures are well-connected and open, these may be fast draining and locally have high transmissivity, thus leading to low residence times (Turner et al., 1997; Global Groundwater,2020). The fractured rock aquifer is hydraulically connected to the saprolitic aquifers in the deep weathered profile (Turner et al., 1997). Typically, this is a minor local aquifer however where connected fractures permit, high yielding bores of up to 22 L/Sec have been reported (Global Groundwater, 2020).

- There are south east trending dolerite dykes and hydraulic conductivity along these dykes is higher parallel to the dykes (Strategen, 2013). Groundwater flow and storage is controlled by secondary fracture derived porosity, specifically by the intensity and openness of fracture zones (Global Groundwater, 2020).

3.2 Groundwater Bores

A search of the Bureau of Meteorology groundwater database within the Project shows no registered bores. Within 10 km of the Project there are a total of 112 registered bores that are listed with different purposes monitoring (34) and unknown (78). The majority of the monitoring bores are found to the south of the Project close to the town of Boddington. To the southwest and south of the Project, is the Worsley Mining Development Envelope where numerous production bores and other bores exist. The registered bores and groundwater monitoring locations are shown in Figure 3-1.

Within 10 km of the Project there are 3 production bores close to the Boddington town called M01/11, M02/08 and M02/18. 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). As part of Newmont's operations at Boddington Gold Mine, there are 102 monitoring bores, at least 4 dewatering bores and 11 groundwater supply bores (Global Groundwater, 2020). South32 mine site existing bore locations are shown in Figure 3-2**Error! Reference source not found.**.

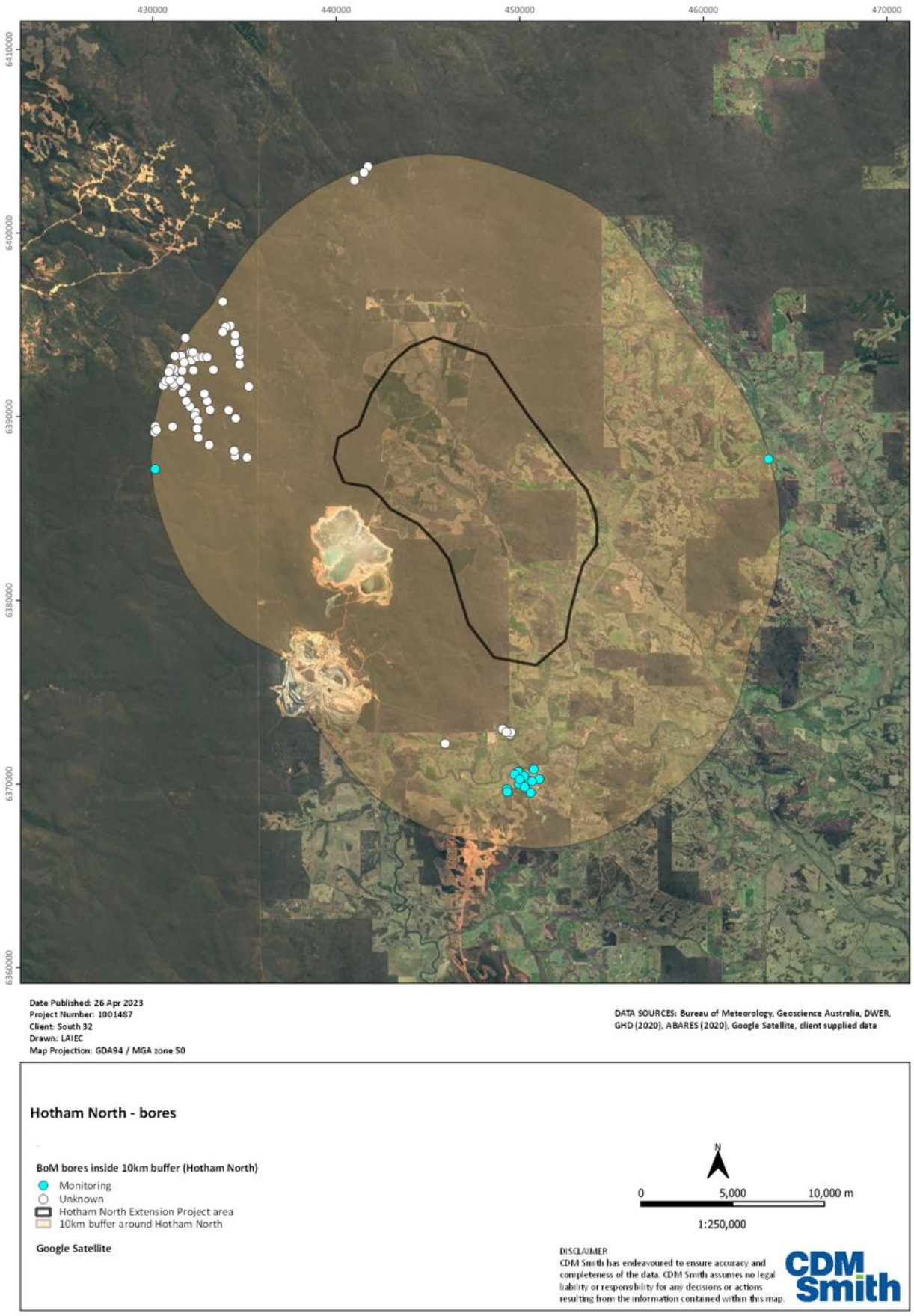

Figure 3-1 Registered groundwater bores

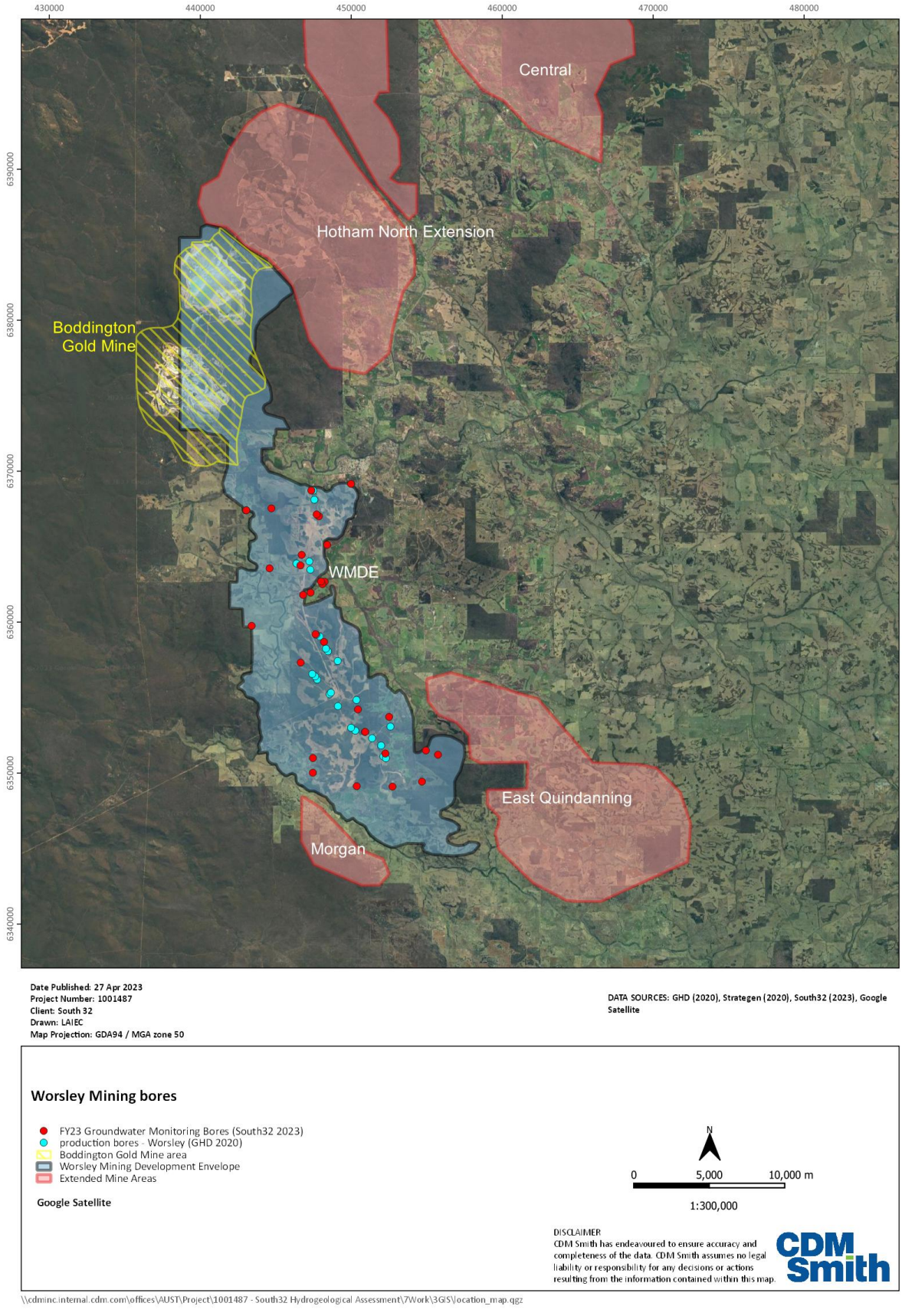

Figure 3-2 Groundwater bores associated with the existing Worsley Mining Development Envelope

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). The water table is expected to be topographically controlled and may vary from ground surface to 20 metres below ground (Turner et al., 1997; Raper, 2005). There is insufficient data within the Project area to determine groundwater flow direction or groundwater level contours.

The adjacent Boddington Gold Mine conducts mine dewatering, rainfall interception and abstraction from Hotham River (Strategen, 2013). The mine dewatering has likely resulted in a groundwater sink, with the groundwater flow direction towards the gold mine. The Project and Boddington Gold Mine area are separated by a topographic and surface water divide located between the Bannister River and Thirty Four Mile Brook subcatchments. Naturally, the groundwater flow systems are likely topographically controlled and will influence the groundwater interaction between the two areas. The reported drawdown at the Boddington Gold Mine is up to 200 m with the drawdown primarily extending to the northwest and southeast of the mine, and not beyond the Thirty Four Mile Brook sub catchment (Strategen, 2013).

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. Recharge is likely to be greater on the upper slopes where more permeable soils are typically found (Clarke et al., 2002).

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 southeast towards the Bannister River via a main northwest to southeast unnamed tributary.

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). Within 10 km of the Project there are 3 production bores close to the Boddington town called M01/11, M02/08 and M02/18 and only one of these bores M02/18 had hydraulic conductivity calculated at 0.04 to 0.1 m/day.

Although the weathered and fractured aquifer is extensive and likely acts as a continuous and connected hydraulic system, the hydraulic properties are highly variable on a local scale (Global Groundwater 2020). Airlift development for bores at Boddington Gold Mine suggests that hydraulic conductivities for the weathered and fractured upper bedrock are relatively low, ranging from 0.0003 to 0.04 m/day, with an average of 0.003 m/day (Global Groundwater, 2020).

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 8.64×10^{-10} to 1.3×10^{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 8.64×10^{-3} to 4.32×10^{-1} m/day, and porosities of 5 to 30 % depending on the nature of the weathering products (Lachassagne et al., 2021).

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). The Project is found within the area mapped as having a Total Dissolved Solids (TDS) of 500 to 1,000 mg/L, with areas to the east hosting fresher groundwater at 1,000 to 3,000 mg/L TDS, and more saline groundwater in the west at 3,000 to 7,000 mg/L TDS.

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.

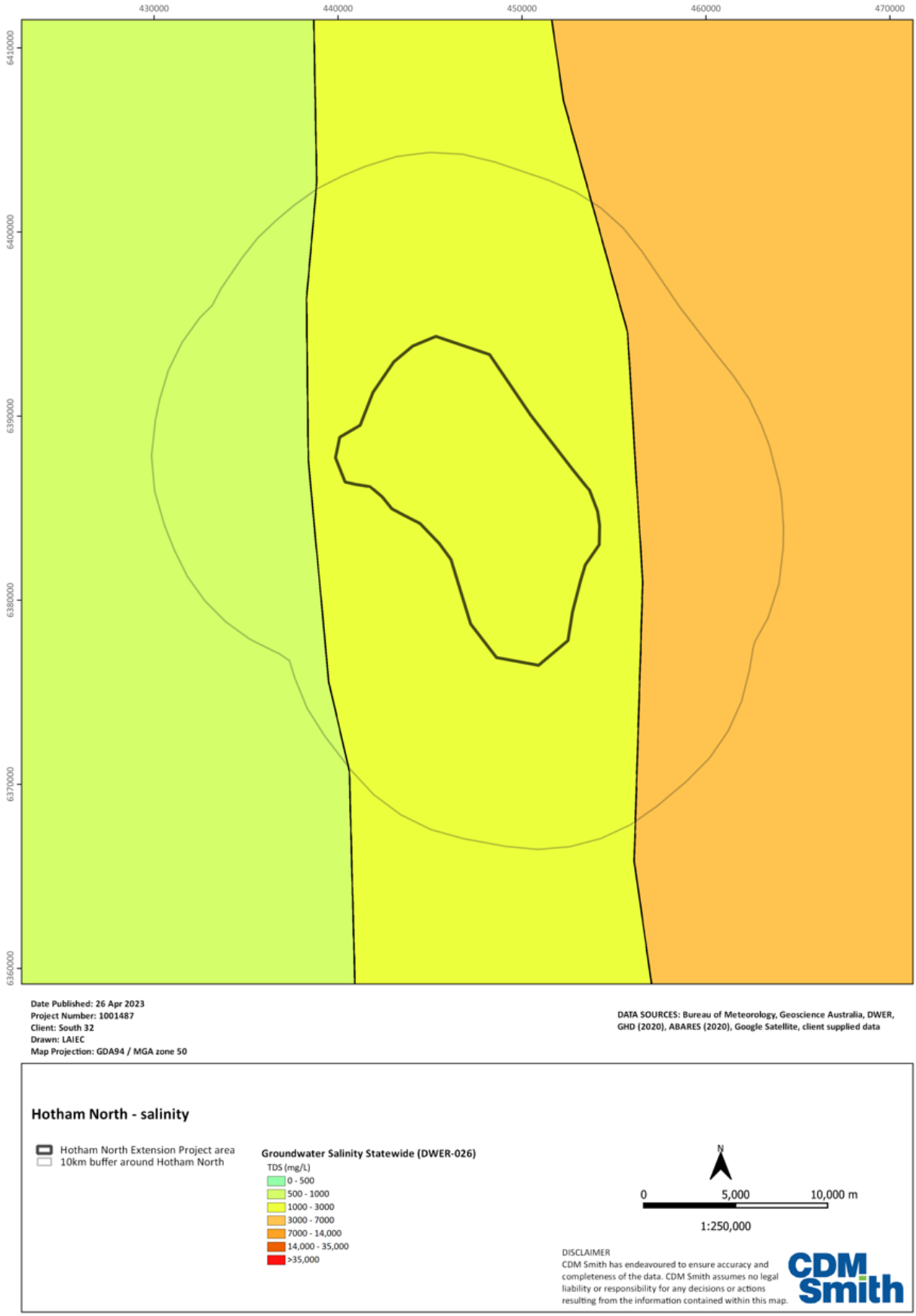

Figure 3-3 Groundwater salinity

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 southeast near Hotham River and to the west and northwest of the Project associated with Serpentine River, O'Neill Brook and South Dandalup River. Potential terrestrial GDEs are mapped in 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 no groundwater bores found inside the Project and the majority of registered groundwater bores within 10 km of the Project boundary have an unknown purpose. 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.

To the south of the Project, production bores are associated with mining at Worsley Alumina (GHD, 2020a). The Boddington Gold Mine is a user of groundwater with water requirements up to 29 GL/yr used for ore processing, dust suppression and domestic purposes (Strategen, 2013). Water is sourced from mine dewatering and groundwater inflow into the pits (4 to 10 GL/yr), rainfall/runoff harvesting (5 to 15 GL/yr) and abstraction from Hotham River (2 to 10 GL/yr) (Strategen, 2013).

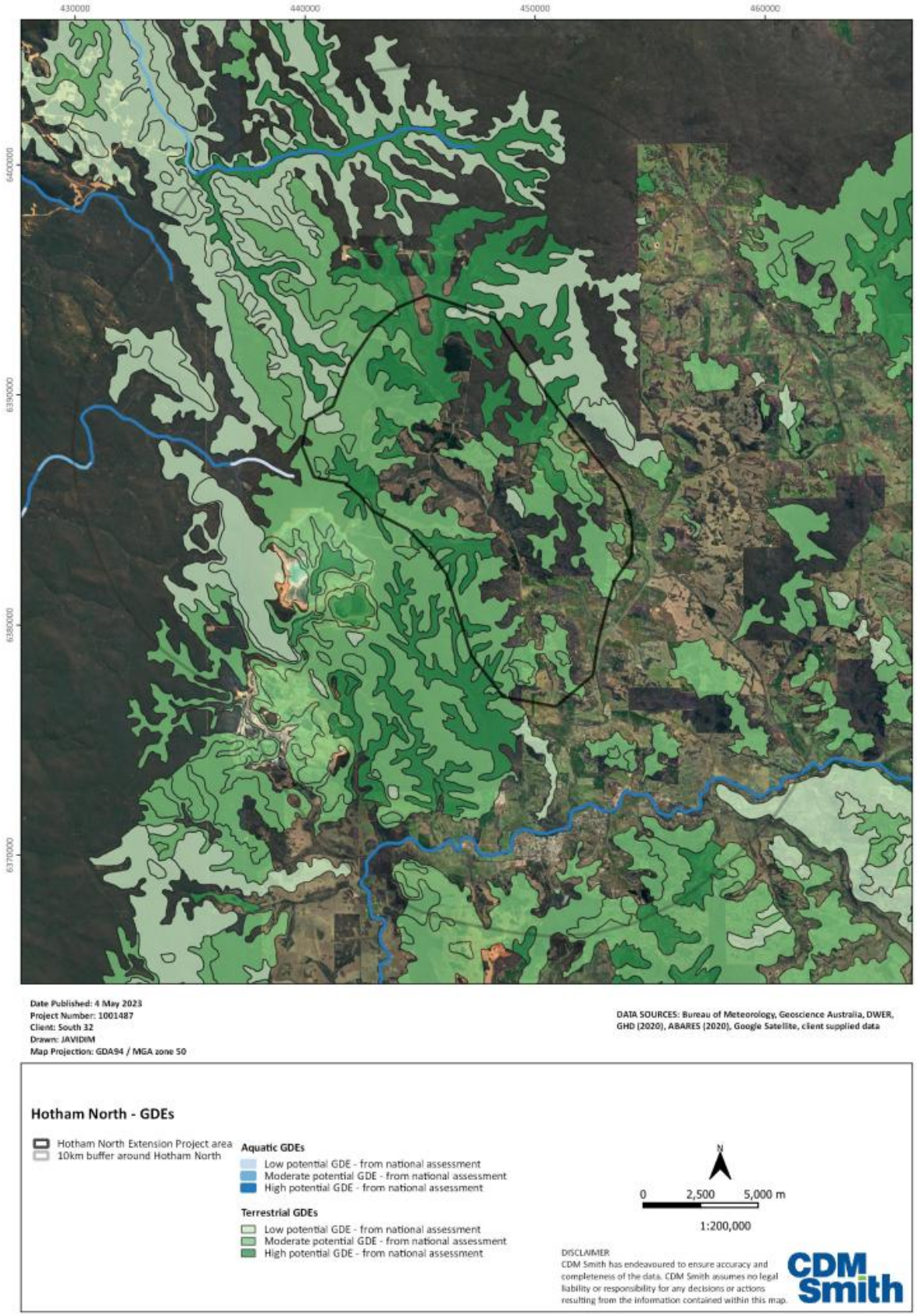

Figure 4-1 Potential Groundwater Dependent Ecosystems

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 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 southeast towards the Bannister River via a main northwest-to-southeast unnamed tributary.
- 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. The area mapped as having a Total Dissolved Solids (TDS) of 500 to 1,000 mg/L, with areas to the east hosting fresher groundwater at 1,000 to 3,000 mg/L TDS, and more saline groundwater in the west at 3,000 to 7,000 mg/L TDS. It is likely salinity will vary locally, with higher salinity found down gradient along groundwater flowpaths.
- No aquatic GDEs are mapped in the Project area although potential terrestrial GDEs are mapped in the Project. No areas were mapped as being known GDEs, nor were any areas mapped from regional assessments.
- The adjacent Boddington Gold Mine conducts mine dewatering, rainfall interception and abstraction from Hotham River. The mine dewatering has likely resulted in a groundwater sink, with the groundwater flow direction towards the gold mine.
- The Project and Boddington Gold Mine area are separated by a topographic divide. Naturally, the groundwater flow systems are likely topographically controlled and will influence the groundwater interaction between the two areas.

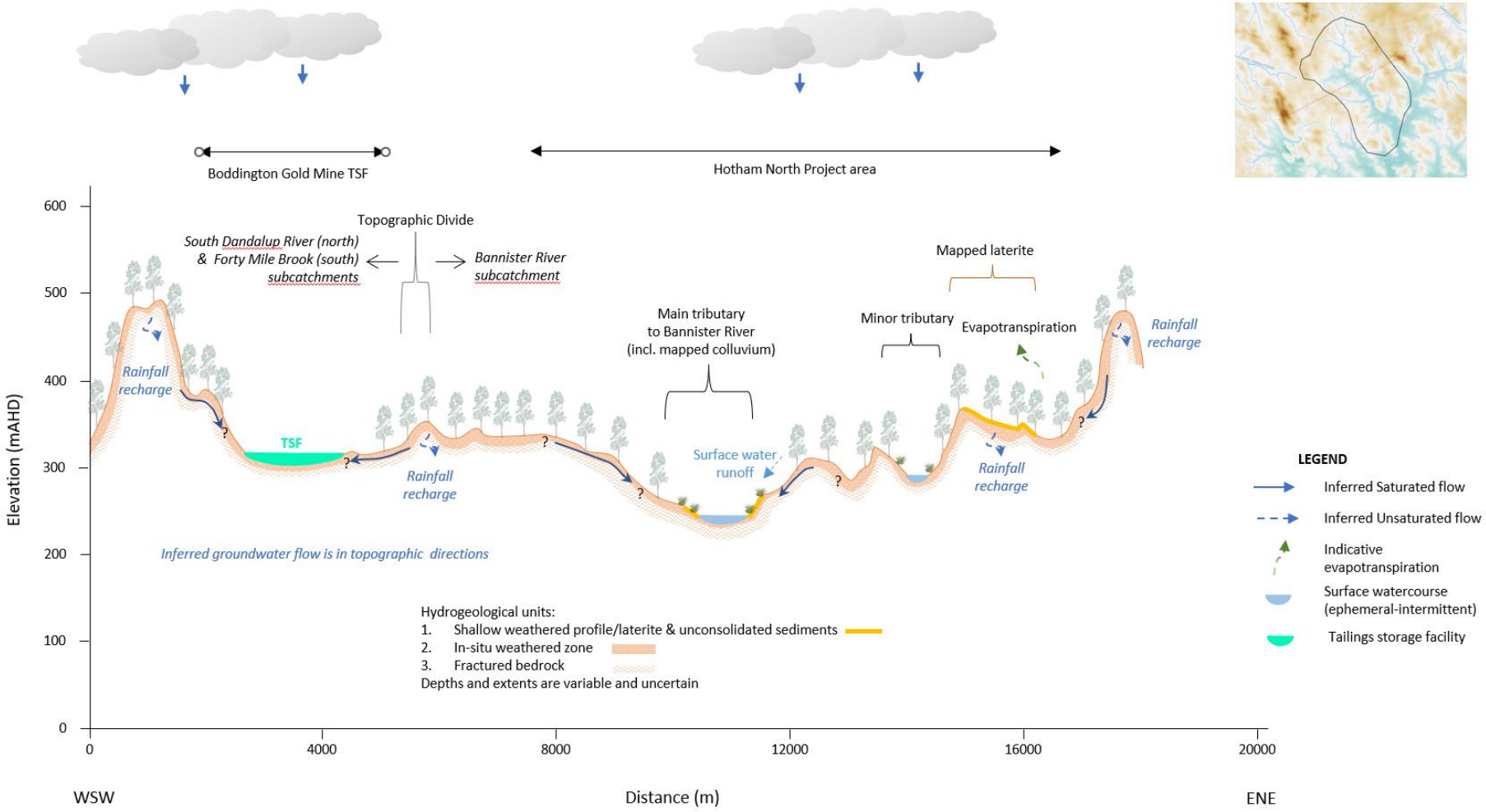

Figure 5-1 Preliminary Hydrogeological Conceptual Model

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 completion 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 13 groundwater bore 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.
- Three of these proposed bores (MB_H13, MB_H01 and MB_H12) are located upgradient of the proposed mining areas. The purpose of the upgradient bores is to monitor water quality and water level and determine 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_H01	445352	6390756	upper catchment near drainage line (trunk); within terrestrial GDE area	10 to 40	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_H02	450760	6389470	upper catchment near drainage line; within terrestrial GDE area	10 to 40	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_H03	444115	6386495	upper catchment near drainage line	10 to 40	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_H04	449245	6386530	middle catchment near drainage line	10 to 40	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_H05	447242	6383374	middle catchment; within terrestrial GDE area, close to mapped mining areas	10 to 40	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_H06	452186	6380408	lower catchment near drainage line (trunk)	10 to 40	Weathered Profile	Monitoring and numerical model development
MB_H07	450646	6377175	lower catchment near drainage line	10 to 40	Weathered Profile	Monitoring and numerical model development
MB_H08	449945	6382176	middle catchment near drainage line (trunk)	10 to 40	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_H09	441537	6387105	upper catchment; within terrestrial GDE area, close to mapped mining areas	10 to 40	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_H10	447936	6378070	lower catchment away from mapped drainage line; within terrestrial GDE area, close to mapped mining areas	10 to 40	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_H11	451305	6386120	middle catchment; within terrestrial GDE area, close to mapped mining areas	10 to 40	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_H12	448632	6390104	upper catchment away from mapped drainage line; within terrestrial GDE area	10 to 40	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development
MB_H13	445773	6394131	upper catchment near drainage line; within terrestrial GDE area	10 to 40	Shallow / Deep Weathered Profile (and/or fresh fractured rock)	Monitoring and numerical model development

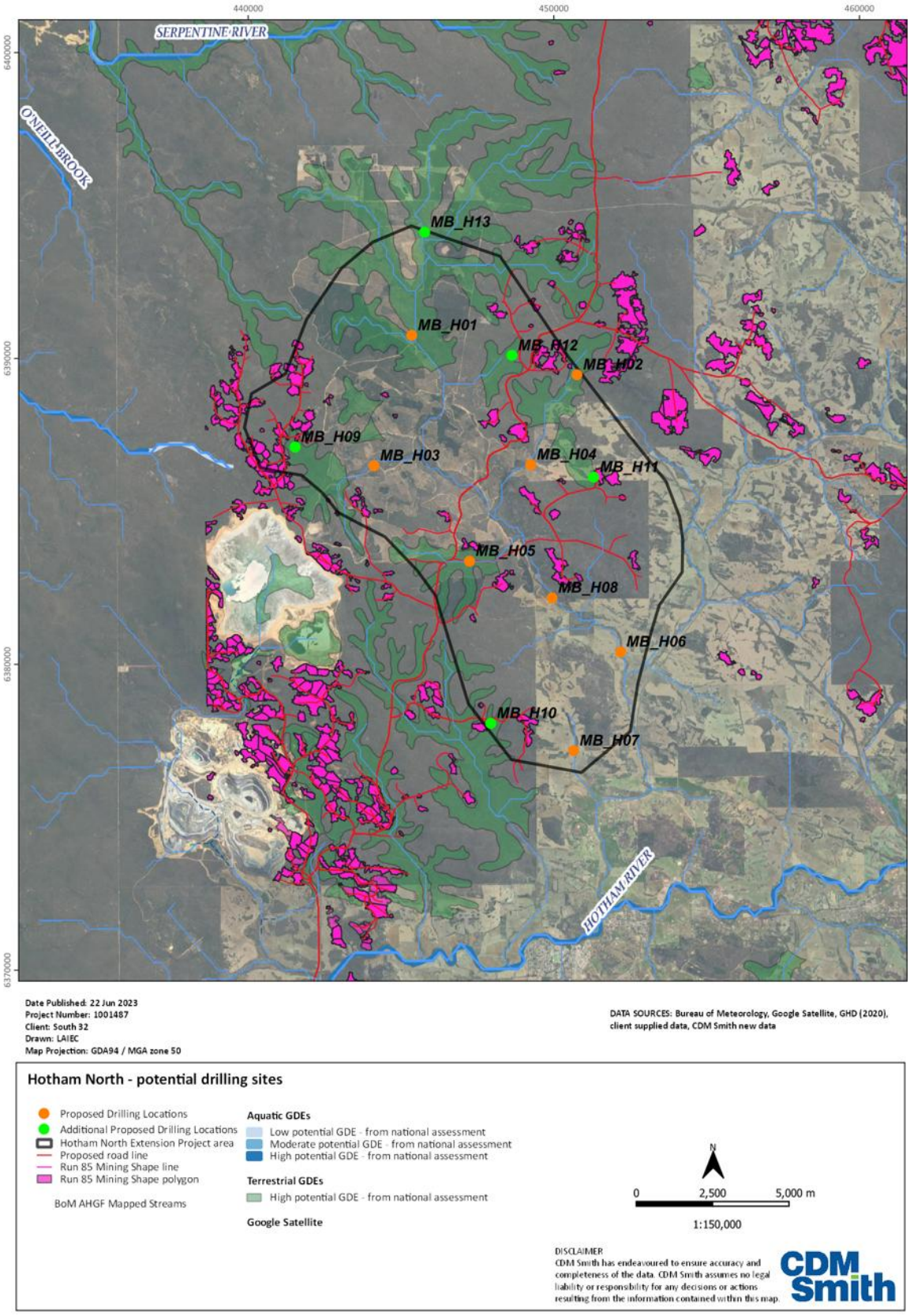

Figure 7-1 Proposed drilling locations with mapped terrestrial GDE area

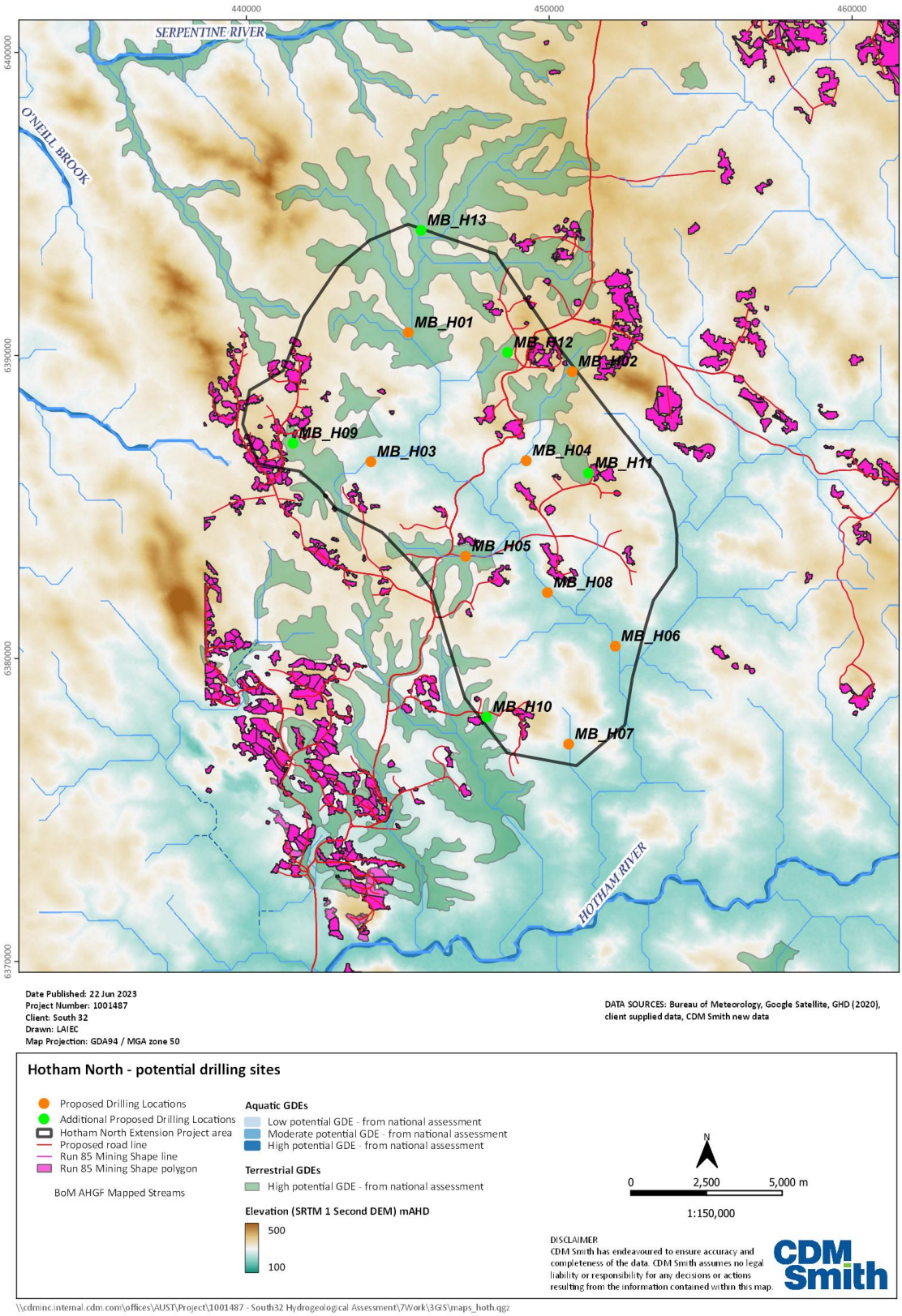

Figure 7-2 Proposed drilling locations with topography / mapped terrestrial GDE area

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

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 Hotham North.

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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 Bore Schematic

Groundwater Development Plan Generic Bore Design 1001487

