Cleary Bros (Bombo) Pty Ltd

ABN: 28 000 157 808

Albion Park Quarry Extraction Area Stage 7 Extension

Groundwater Assessment

Prepared by

Jacobs Australia Pty Limited

August 2021

Specialist Consultant Studies Compendium

Part 8

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Albion Park Quarry Extraction Area Stage 7 Extension

Groundwater Assessment

Prepared for:	R.W. Corkery & Co. Pty Limited Level 1, 12 Dangar Road PO Box 239 BROOKLYN NSW 2083 Tel: (02) 9985 8511 Email: brooklyn@rwcorkery.com
On behalf of:	Cleary Bros (Bombo) Pty Ltd PO Box 210 PORT KEMBLA NSW 2505 Tel: (02) 4275 1000 Email: info@clearybros.com.au
Prepared by:	Jacobs Australia Pty Limited Level 7, 177 Pacific Highway NORTH SYDNEY NSW 2060 Tel: (02) 9928 2100 Email: ben.rose@jacobs.com Ref No: IA222501

August 2021

Contents

Executive Summary

Cleary Bros (Bombo) Pty Ltd (Cleary Bros) (the Applicant) owns and operates the Albion Park Hard Rock Quarry ('the Quarry'), located at Croom, NSW. Cleary Bros is proposing to extend the current extraction area (the Project).

A groundwater impact assessment was undertaken to assess potential impacts to groundwater due to the Project and support the environmental impact statement for the Project.

The groundwater impact assessment included:

- Review of relevant legislation, policy guidelines and licences
- Review of the Project's environmental setting, including development of a conceptual hydrogeological model
- Calculation of groundwater inflows to the extraction area, groundwater level drawdown and baseflow reduction using an industry standard numerical groundwater flow model, MODFLOW
- Assessment of potential impacts to groundwater due to the Project
- Development of groundwater related mitigation and management measures.

The groundwater flow model calculated low groundwater inflow rates, a limited drawdown extent and small reductions to baseflow volume. The base case model predicts:

- a maximum groundwater inflow rate of up to 187 kL/d
- a 2 m drawdown contour that extends about 50 m to 250 m from the proposed extended extraction area
- a baseflow reduction ranging from less than 1 kL/d in early years of the Project to a peak of less than 5 kL/d in later years of the Project.

Uncertainty analysis was undertaken to assess the effect of individually varying model input parameter values on model predictions. The results from uncertainty analysis model runs do not vary considerably from the base case results.

The model's predictions align with observations from the existing extraction area, where drawdown extent is limited and groundwater inflows are very low (except for the sump, groundwater is generally not observed on the existing pit floor or side walls).

Potential groundwater impacts due to the Project were assessed against the NSW Aquifer Interference Policy's Minimal Impact Considerations. The 2 m groundwater level drawdown contour does not encroach on any existing registered bore used for water supply, nor are high priority GDEs subjected to drawdown. Also, the Project is unlikely to lower groundwater quality and reduce the beneficial use category of the groundwater source beyond 40 m of the Project Area. Potential impacts to groundwater due to the Project are assessed to be less than the NSW Aquifer Interference Policy's Minimal Impact Considerations.

For water licensing, without partition of groundwater and surface water take, based on the maximum groundwater inflow rate of up to 187 kL/d, an annual groundwater entitlement for a volume of 68 ML will be required from the Sydney Basin South Groundwater Source of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011.

Due to some small baseflow reductions (maximum less than 5 kL/d), if the groundwater and surface water take is partitioned, annual entitlement of 2 ML would be required from the Minnamurra River Management Zone of the Illawarra Rivers Water Source of the Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011 to cover the baseflow reduction. With partitioning, the annual groundwater entitlement would be 2 ML less and 66 ML. The takes associated with groundwater inflow and baseflow reduction would occur in perpetuity.

Entitlements for the Minnamurra River Management Zone will be secured through the purchase of existing entitlements on the market, while entitlements for the Sydney Basin South Groundwater Source will be secured through the upcoming Controlled Allocation Order.Management and mitigation measures are outlined in the report, including recommendations for ongoing groundwater monitoring.

The Project is considered to constitute a low risk to groundwater systems.

Important note about your report

The sole purpose of this report is to present the findings of a groundwater impact assessment, in connection with the proposed Albion Park Quarry extension Project, to enable key information to be drawn into the Project's EIS. The report was commissioned by Cleary Bros (Bombo) Pty Ltd and was produced in accordance with, and is limited to the scope of services set out in, the proposal/contract between Jacobs and the Client. That scope of services, as described in this report, was developed with the Client.

All reports and conclusions that deal with sub-surface conditions are based on interpretation and judgement and as a result have uncertainty attached to them. This report contains interpretations and conclusions which are uncertain, due to the nature of the investigations. No study can investigate every risk, and even a rigorous assessment and/or sampling programme may not detect all problem areas within a site.

This report is based on assumptions that the site conditions as revealed through sampling are indicative of conditions throughout the site. The findings are the result of standard assessment techniques used in accordance with normal practices and standards, and (to the best of Jacobs knowledge) they represent a reasonable interpretation of the current conditions on the site. Sampling techniques, by definition, cannot determine the conditions between the sample points and so this report cannot be taken to be a full representation of the sub-surface conditions. This report only provides an indication of the likely sub surface conditions.

Conditions encountered during quarrying may be different from those inferred in this report, for the reasons explained in this limitation statement. If site conditions encountered during quarrying are different from those encountered during the Jacobs and others' site investigations, Jacobs reserves the right to revise any of the findings, observations and conclusions expressed in this report.

The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the Project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete, then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

Except as specifically stated in this report, Jacobs makes no statement or representation of any kind concerning the suitability of the site for any purpose or the permissibility of any use.

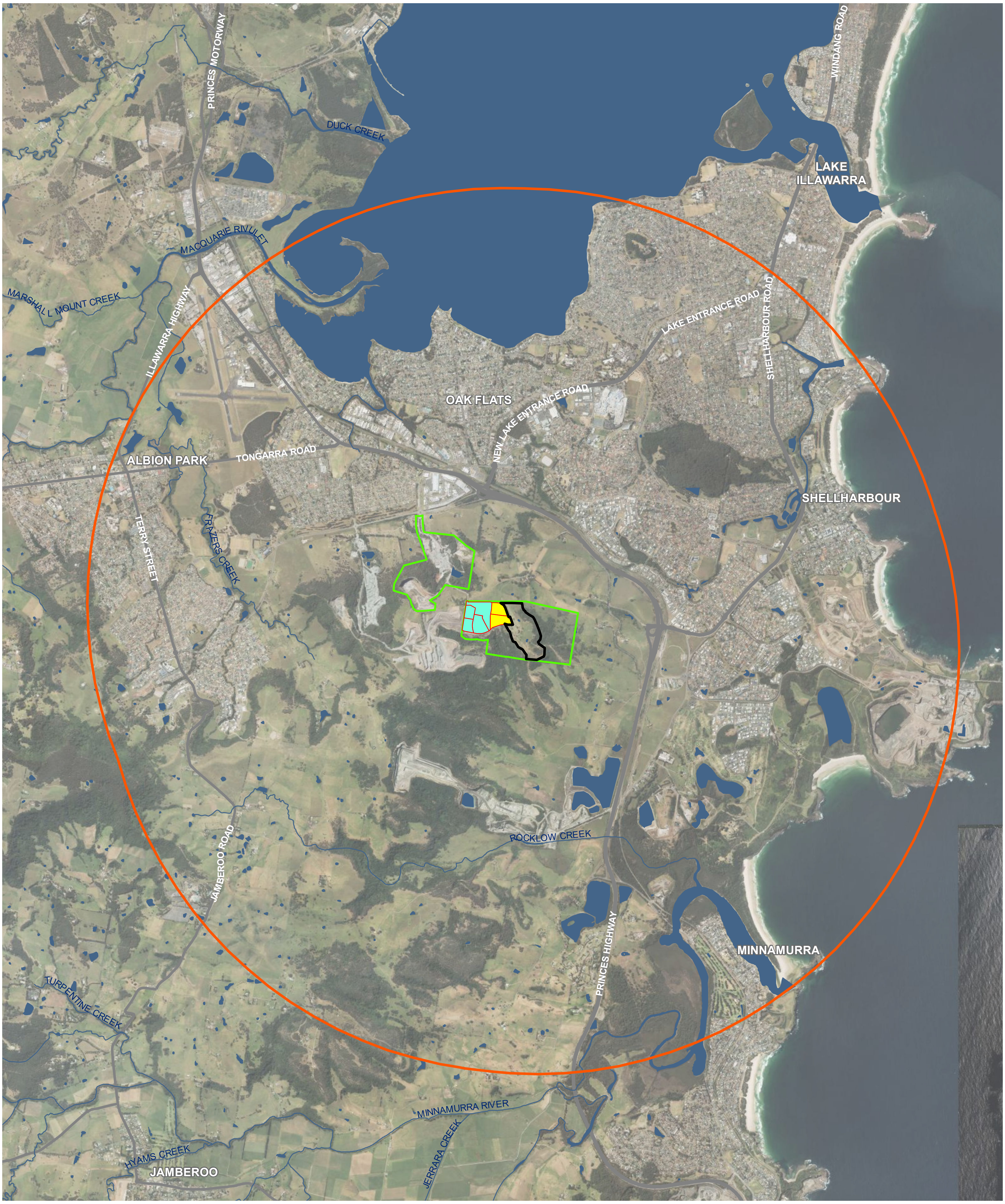
1. Introduction

1.1 Background

Cleary Bros (Bombo) Pty Ltd (Cleary Bros) owns the Albion Park Hard Rock Quarry ('the Quarry'), located at Croom, NSW (**Figure 1.1**). Cleary Bros is proposing to extend the current extraction area (the Project).

The Project has been classified as a "State Significant Development" under Schedule 1 (7) of the State Environmental Planning Policy (State and Regional Development) 2011.

This report documents a groundwater impact assessment undertaken to support the environmental impact statement (EIS) for the Project.



- 🟧 Study area
- ⬛ Proposed extraction area extension
- 🟨 Current extraction area
- 🟦 Previous extraction stages
- — Watercourse
- ▬ Waterbody
- 🟩 Quarry boundary

0 1 2 km

1:45,000 at A3

N

Data sources

NSW Spatial Services 2019

GDA94 MGA56

Figure 1.1 Project location

Date: 9/12/2020 Path: \\Jacobs.com\ANZ\IE\Projects\04_Eastern\IA222500\STG1 Files\Data\GIS\22_Spatial\GIS\Directory\Templates\Figures\IA222501_GIS_F003_ProjectLocation _r1v1.mxd
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1.2 Study area

A groundwater study area (**Figure 1.1**) consisting of an approximate 5 km radius from the Project Area was adopted for this report.

1.3 Project description

1.3.1 Overview

The Project would principally comprise extraction and in-pit crushing and screening to produce hard rock aggregates, armour rock and pavement products to meet the increasing supply demands of these markets over the next 30 to 40 years. In addition, ancillary Project elements would include elements such as, but not be limited to, the construction of internal haul roads, overburden stripping and emplacement, receipt of Virgin Excavated Natural Material (VENM) and excavated natural material (ENM), and rehabilitation.

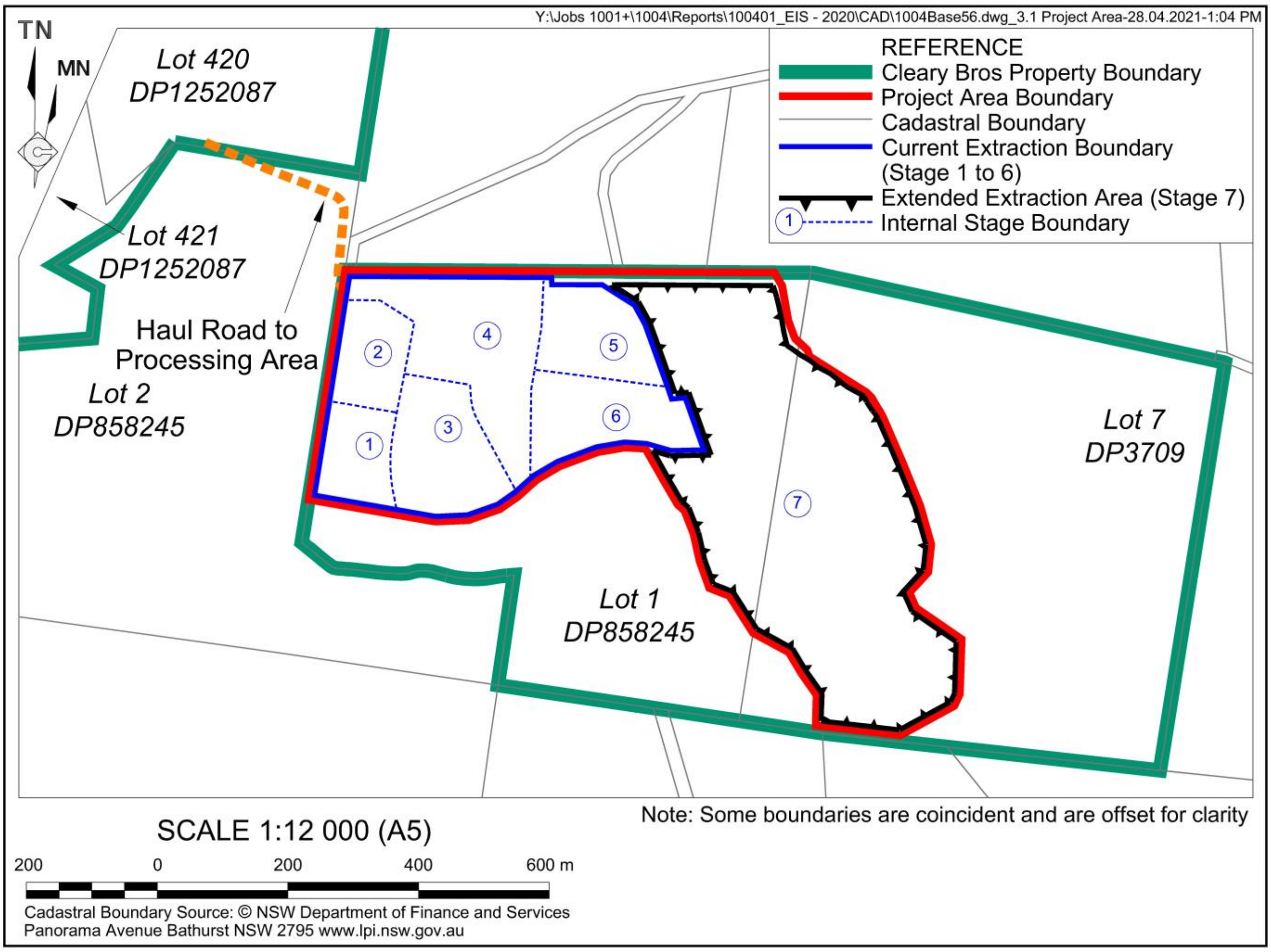
The Project Area (**Figure 1.2**) covers Stages 1 to 6 of the Quarry, which are currently approved extraction areas, and the proposed Stage 7 extension area. Stages 1 to 6 are included in the Project Area as a quantity of rock remains to be extracted in these stages and greater efficiencies would be achieved by extracting the remaining rock concurrently in Stages 5, 6 and 7. Furthermore, some of the overburden and soil from Stage 7 would be used for the rehabilitation of sections of Stages 1 to 4.

Figure 1.3 displays the area referred to as the Eastern Rim which forms the eastern half of Stages 7c and 7d and would be the final area to be extracted within Stage 7. This approach would enable the extraction activities in the western half of Stages 7c and 7d to be shielded visually from the east.

The Project activity would extract:

- Overburden comprising clay and variably weathered Bumbo Latite collectively, which is between 2 m and 8 m thick in the Stage 7 area.
- Bumbo Latite, which comprises two flows referred to as the Upper Latite and the Lower Latite respectively, and an interburden layer of agglomerate or volcanic breccia which separates the Upper Latite and the Lower Latite.

The base of the Lower Latite occurs at approximately 52 metres Australian Height Datum (mAHD) and 17 mAHD within the northern and southern ends of Stage 7, respectively. The Lower Latite is underlain by the finely bedded grey-green Kiama Sandstone.



Note: Some boundaries are coincident and are offset for clarity

Cadastral Boundary Source: © NSW Department of Finance and Services
Panorama Avenue Bathurst NSW 2795 www.lpi.nsw.gov.au

Figure 1.2: Project Area stages (source: RW Corkery & Co.)

1.3.2 Extraction area design and timing

Figure 1.3 displays the design of the Project's ultimate extraction area. The Stage 7 extension area has been designed with parameters comparable to those already adopted in Stages 1 to 6, namely:

- bench heights = up to 14 m
- operational bench widths = approximately 25 m
- terminal bench widths = approximately 5 m
- typical extraction face = 75° from the horizontal on the eastern extraction faces and up to 90° from the horizontal on all other faces.

The Stage 7 extraction sequence is summarised in **Table 1.1**

Table 1.1: Stage 7 extraction sequence

Stage	Area (ha)	Extraction Duration (years)
7a	10.5	12
7b	2.0	5
7c	5.0	10
4/5/6/7d	9.1	15

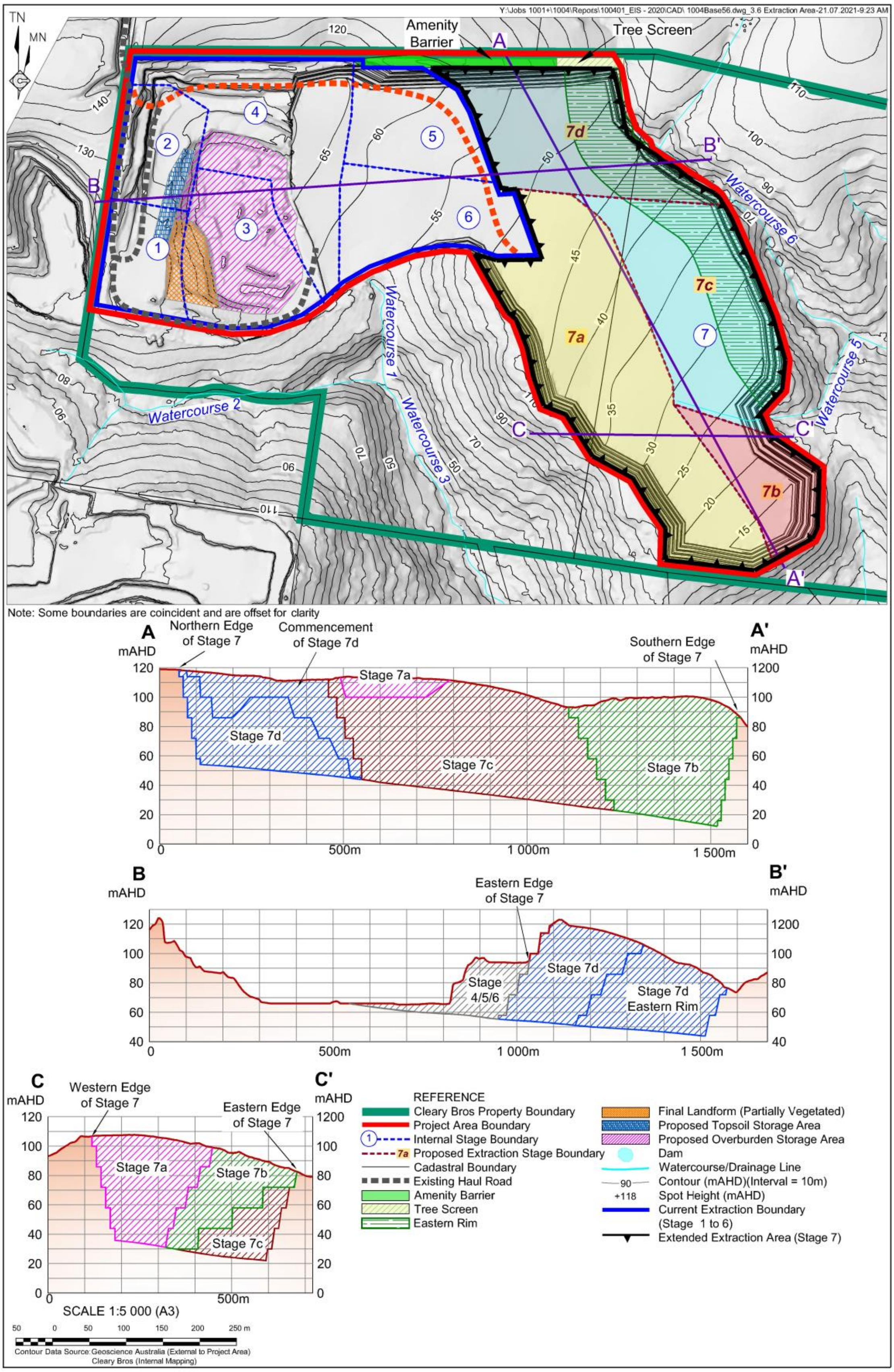


Figure 1.3: Extraction area design (source: RW Corkery & Co.)

1.3.3 Water management and usage

Surface water will be managed through the construction of diversion banks to re-direct clean runoff away from the active extraction area where required and a series of sediment basins and a sump within the active extraction area to control sediment-laden runoff. Mitigation measures would be used to ensure no pollution occurs at surface water resources beyond the Project Area.

Expected maximum annual water usage would be 108 ML, principally for dust suppression. This water would be sourced principally from the on-site water storage, with additional water sourced from the sump. Further detail on water management is provided in the Project's Soil and Water Assessment (SEEC, 2021).

1.3.4 Final landform

Cleary Bros has defined five rehabilitation domains for the Project’s final landform:

- Terrace Domain – steeper terminal faces of the extraction area with 14 m benches, 5 m berms and face angles of between 75° and 90°. Overburden and other suitable materials would be placed on the berms to provide a growth medium with water holding capacity for trees and shrubs. Heights of some upper terminal faces would be reduced to soften visual impacts as described in Section 3 of the EIS.
- Slope Domain – the intermediate slope between the Terrace and Plain Domains with variable slopes of between 5° and 18° formed from overburden or other suitable back fill materials. Final slopes would be planted with trees and shrubs. Pasture species would be established on the lower gentler slopes grading to the Plains domain.
- Plains Domain – overburden or other suitable back fill would be placed on the floor of the extraction area to a variable depth with a gentle slope. The final profiled Plains Domain would incorporate a series of retained dams which would provide ongoing use for sediment control and stock watering.
- Open Water Domain – due to the generally southerly dip of latite resource and the surrounding topography within the Project Area, extraction would create a low point at the southern end of Stage 7 which would form a permanent or semi-permanent water feature collecting surface water running from much of the extraction area.
- Foreshore Domain – the area between the Plains Domain and the Open Water Domain would be a low-gradient transitional area comprising wetland and water-loving vegetation.

Figure 1.4 displays a profile of each of the domains whilst **Figure 1.5** displays a plan of the areas covered by each domain.

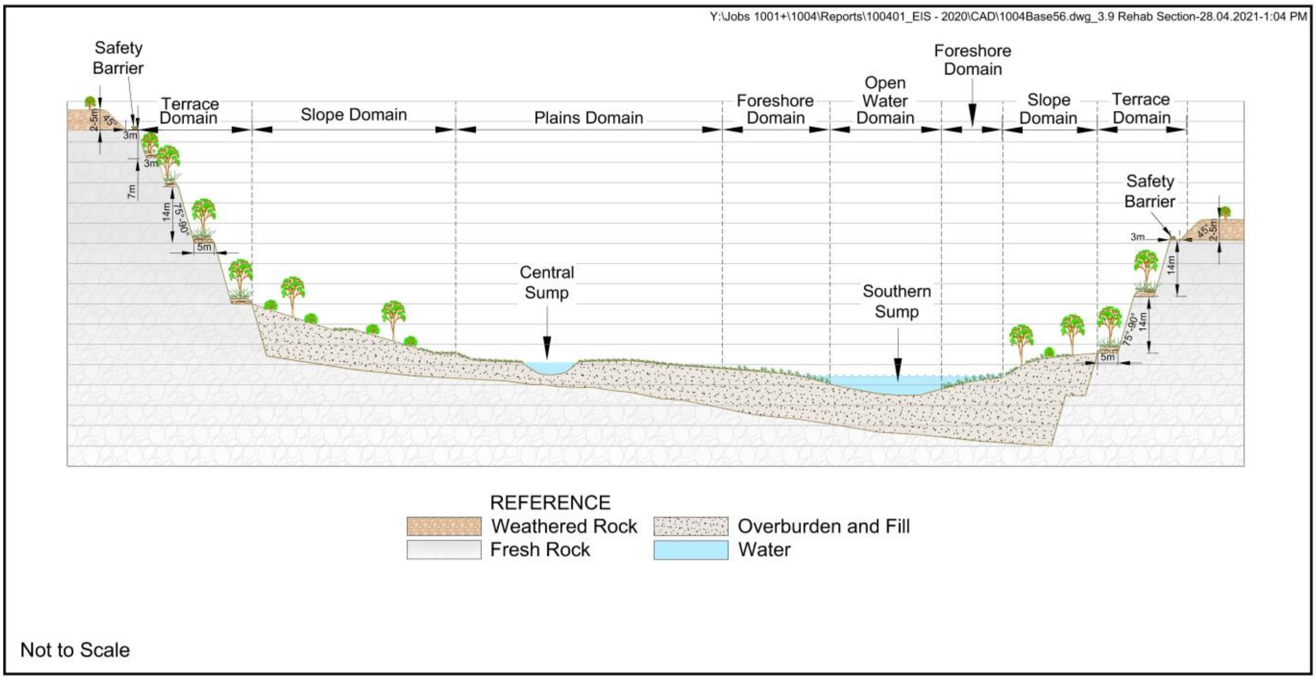


Figure 1.4: Profile of Project rehabilitation domains (source: RW Corkery & Co.)

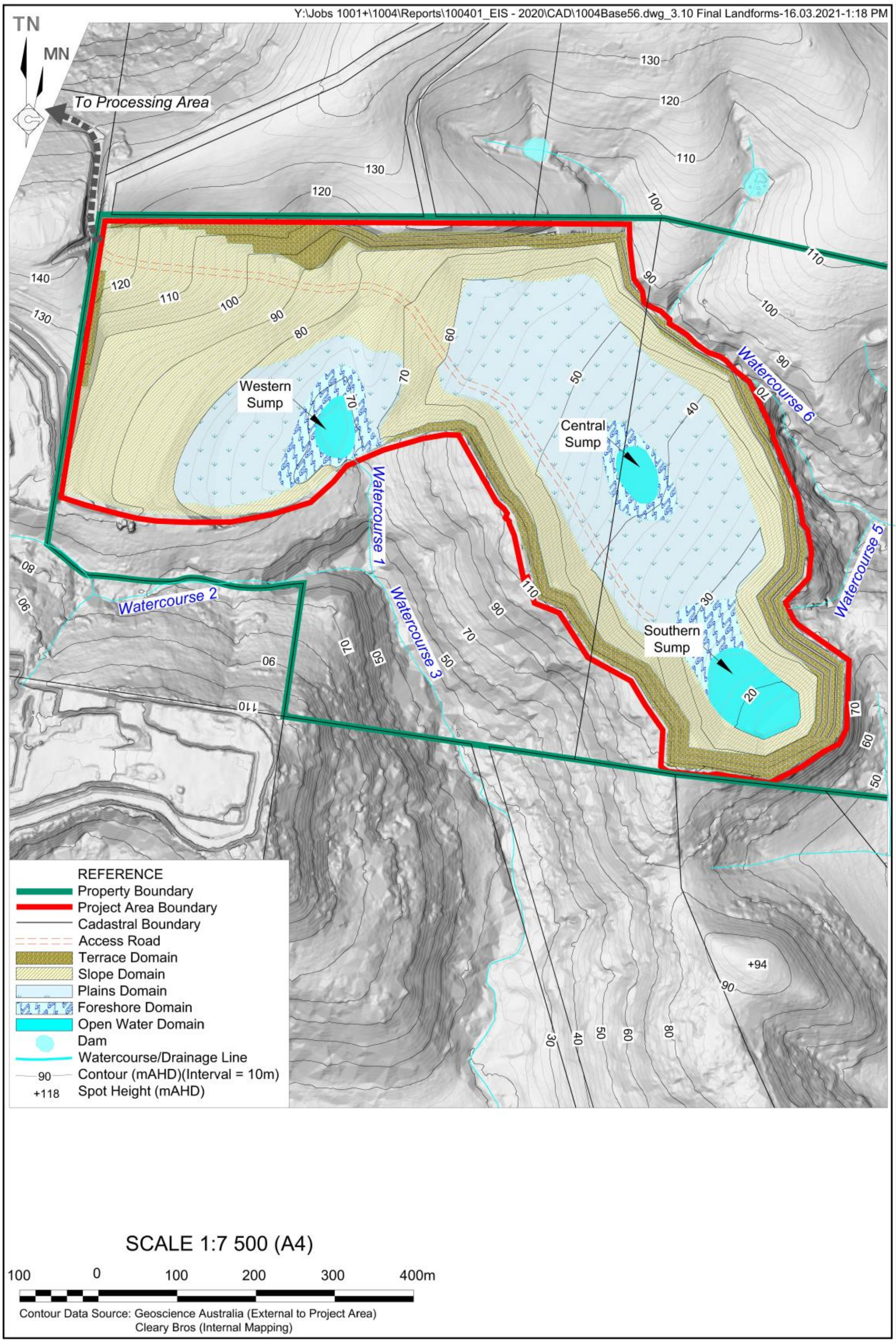


Figure 1.5: Plan of Project rehabilitation domains (source: RW Corkery & Co.)

1.4 Report objective and layout

The purpose of this report is to document an assessment of potential impacts to groundwater due to the Project, to support the environmental impact statement (EIS) for the Project.

The report is divided into the following sections:

- Section 1 – Introduction, introduces and describes the Project and outlines the objective of the report.
- Section 2 – Legislative and policy context.
- Section 3 – Existing environment, describes elements of the existing environment relevant to groundwater. The section content is based on review of site-specific data and data/mapping available in the public domain.
- Section 4 – Conceptualisation, conceptualises hydrogeology relevant to the Project.
- Section 5 – Groundwater impact assessment, summarises the results of the groundwater impact assessment completed for the Project.
- Section 6 – Management and mitigation measures, outlines management and mitigation measures for the Project.
- Section § – Conclusion, provides a summary of assessment findings.

1.5 Secretary’s Environmental Assessment Requirements

An EIS must be prepared in response to requirements set out by the Secretary of the NSW Department of Planning, Industry and Environment (DPIE). These requirements are known as the Secretary’s Environmental Assessment Requirements (SEARs).

Key issues relating to groundwater, as identified in the SEARs (NSW DPIE, 2019), are provided in **Table 1.2**. **Table 1.2** also includes direction to the relevant section(s) within this report where each issue has been addressed.

Table 1.2: Coverage of SEARs relating to groundwater

SEAR	Coverage in report
Water	
'a detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume and frequency of any water discharges), water supply infrastructure and water storage structures'	Covered in Project's surface water assessment SEEC, 2021)
'identification of any licensing requirements or other approvals under the Water Act 1912 and/or Water Management Act 2000'	Sections 2.1, 2.2, 5.4
'demonstration that water for the construction and operation of the development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP)'	Covered in Project's surface water assessment (SEEC, 2021)
'a description of the measures proposed to ensure the development can operate in accordance with the requirements of any relevant WSP or water source embargo'	Sections 2.1, 2.2, 5.4
'an assessment of the likely impacts on the quality and quantity of existing surface and ground water resources, including a detailed assessment of proposed water discharge quantities and quality against receiving water quality and flow objectives'	Covered in Project's surface water assessment (SEEC, 2021) and Section 5
'an assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users'	Covered in Project's surface water assessment SEEC, 2021), Project's biodiversity assessment (SEEC, 2021) and Section 5
'a detailed description of the proposed water management system (including sewage), water monitoring program and other measures to mitigate surface and groundwater impacts'	Covered in Project's surface water assessment (SEEC, 2021) and Section 6
Biodiversity	
'a detailed assessment of the likely biodiversity impacts of the development, paying particular attention to threatened species, populations and ecological communities and groundwater dependent ecosystems, undertaken in accordance with the Biodiversity Assessment Method and documented in a Biodiversity Development Assessment Report'	Covered in Project's biodiversity assessment (Niche, 2021) and Section 5.2.2 and 5.2.4

2. Legislative and policy context

The legislative and policy context relevant to groundwater are summarised in the following sections.

2.1 Water Act 1912 and Water Management Act 2000

Water resources in NSW are administered under the Water Act 1912 and the Water Management Act 2000 (WM Act) by the DPIE-Water. In general, the WM Act governs the issue of water access licences (WALs) and approvals for those water sources (rivers, lakes, estuaries and groundwater) in NSW where Water Sharing Plans (WSPs) have commenced. The WSPs for the Project have commenced and water management for the Project is therefore generally governed under the WM Act. The WSPs relevant to the Project are outlined in Section 2.2.

Ordinarily, if an activity leads to a take from a groundwater or surface water source covered by a WSP, then an approval and / or licence is required. In general, the WM Act requires:

- a WAL to take water;
- a water supply works approval to construct a work; and
- a water use approval to use the water.

Where an activity leads to a take from a groundwater or surface water source not covered by a WSP or consists of an activity not specifically addressed by the WM Act, then the activity is managed through the Water Act 1912. In such cases, the Water Act 1912 requires:

- a licence to extract groundwater or surface water using any type of work; and
- a water supply work approval to construct a work.

It is noted that, as the Project is considered to be a State Significant Development, under section 4.41 (1g) of the EP&A Act 1979, the authorisation provided by a water use approval under Section 89 of the WM Act, a water management work approval under Section 90 of the WM Act or an activity approval under Section 91 WM Act are not required. Rather, this authorisation is provided by a development consent.

Thus, if the Project's groundwater / surface water extraction is assessed and approved as part of the State Significant Development proposal, only a WAL would be required. A WAL is required for dewatering and other taking of water from any water source which is covered by a WSP under the WM Act, subject to exemptions provided under the Water Management Regulation. A WAL authorises the taking of a share of water from a specified water source in accordance with the volumetric entitlement in the WAL. That entitlement is measured by the number of units assigned to the WAL and the annual volumetric value of a unit for that water source as determined by the Minister administering the WM Act. Units can be transferred from one WAL to another. A WAL is held personally and may be transferred and otherwise dealt with in accordance with the WM Act.

2.2 Water Sharing Plans

2.2.1 Relevant Water Sharing Plans

The Project resides in the Sydney Basin South Groundwater Source of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 (NSW Government, 2011a). As at December 2020, the NSW Water Register (Water NSW, 2020a) indicates this groundwater source has 104 WALs and a total share component of 4,434 units, with 3,655 ML of water made available. NSW Government (2011a) indicates the long-term average annual extraction limit (LTAEL) for this water source is 69,892 ML/year. Thus, about 94% of the groundwater in this water source is currently unassigned.

Surface water WSPs are potentially relevant to the groundwater assessment if the Project causes baseflow reductions to nearby watercourses due to groundwater level drawdown.

With regards to surface water, the Project resides in the Minnamurra River Management Zone of the Illawarra Rivers Water Source of the Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011 (NSW Government, 2011b). For the Illawarra Rivers Water Source, the NSW Water Register (Water NSW, 2020a) indicates there is a total of 92 ML allocated for variants of domestic and stock licences and 3,033 ML for the unregulated river license category. The WSP (NSW Government, 2011b) indicates that trading into the management zone is not permitted, but that trading within the management zone is permitted, subject to assessment.

2.2.2 Existing Water Access License entitlements

Cleary Bros holds one WAL for groundwater relating to the Albion Park Quarry the details of which are provided in **Table 2.1**.

Table 2.1: Site WALs

Water type	WAL	Volume
Groundwater	WAL41971	15 share components (units or ML)

2.3 NSW Aquifer Interference Policy (2012)

The NSW Aquifer Interference Policy (AIP) (DPI, 2012) outlines ‘Minimal Impact Considerations’ for water table and groundwater pressure drawdown for high priority groundwater dependent ecosystems (GDEs) (as identified in the WSP), high priority culturally significant sites (as identified in the WSP) and existing groundwater supply bores. Water quality impact considerations are also outlined.

Different ‘Minimal Impact Considerations’ from DPI (2012) are applicable to different groundwater system types. In the context of the AIP, the Project is characterised to reside in the ‘porous and fractured rock water sources’ sub-category of the ‘less productive groundwater sources’ category. This characterisation is made on the basis that groundwater systems in the vicinity of the Project Area do not simultaneously have existing bores that can yield greater than 5 L/s and a total dissolved solids concentration of <1,500 mg/L, which is the NSW DPI (2012) criteria used distinguish a ‘highly productive’ groundwater source from a ‘less productive groundwater source’.

In accordance with the AIP (DPI, 2012), the Minimal Impact Considerations outlined in **Table 2.2** apply.

Table 2.2: AIP (DPI, 2012) Minimal Impact Considerations - Less Productive Groundwater Sources

Water Source	***Water Table***	***Water Pressure***	***Water Quality***
Porous and fractured rock groundwater sources	*1. Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any:* *(a) high priority GDE; or* *(b) high priority culturally significant site;* *listed in the schedule of the relevant water sharing plan.* *A maximum of a 2m decline cumulatively at any water supply work.* *2. If more than 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any:* *(a) high priority GDE; or* *(b) high priority culturally significant site;* *listed in the schedule of the relevant water sharing plan then appropriate studies would be required to demonstrate to the Minister's satisfaction that the variation would not prevent the long-term viability of the dependent ecosystem or significant site.* *If more than 2m decline cumulatively at any water supply work, then make good provisions should apply.*	*1. A cumulative pressure head decline of not more than a 2m decline, at any water supply work.* *2. If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline would not prevent the long-term viability of the affected water supply works unless make good provisions apply.*	*1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity.* *2. If condition 1 is not met then appropriate studies would be required to demonstrate to the Minister's satisfaction that the change in groundwater quality would not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.*

2.4 National Water Quality Management Strategy

The National Water Quality Management Strategy (NWQMS) (Australian Government, 2018) is the adopted national approach to protecting and improving water quality in Australia. It consists of several guideline documents, of which certain documents relate to protection of surface water resources and others relate to the protection of groundwater resources.

The primary document relevant to the assessment of groundwater risks for the proposal is the Guidelines for Groundwater Quality Protection in Australia (Australian Government, 2013). This document sets out a high-level risk-based approach to protecting or improving groundwater quality for a range of groundwater beneficial uses (called 'environmental values'), including aquatic ecosystems, primary industries (including irrigation and general water users, stock drinking water, aquaculture and human consumption of aquatic foods), recreational and aesthetic values (e.g. swimming, boating and aesthetic appeal of water bodies), drinking water, industrial water and cultural values.

For the purpose of this assessment, the following 'environmental values' are considered applicable:

- Aquatic ecosystems (due to groundwater providing potential baseflow to watercourses)
- Primary industries

Recreational / aesthetic and cultural values are not considered applicable as the watercourses in the vicinity of the Project are not used for these purposes. Drinking water is not considered applicable as groundwater is not extracted in the area for this purpose.

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG) (Australian and New Zealand Governments, 2018) provide a framework for conserving ambient water quality in rivers, lakes, estuaries and marine waters and list a range of environmental values assigned to that waterbody. The ANZG (2018) recommended guideline values have been considered in the assessment of existing groundwater quality.

3. Existing environment

3.1 Climate

For the purpose of this assessment climate data has been obtained using the Queensland Government's online SILO database of Australian climate data. Data was extracted for the location of Albion Park Post Office, which is Bureau of Meteorology (BoM) Station 068000, located approximately 5 km north west of the Project Area. It is noted that the Quarry has an onsite weather station. However, due to the onsite record only starting in 2013 and data gaps, preference has been given to the SILO data.

Key rainfall and evaporation statistics are provided in **Table 3.1**. Mean monthly pan evaporation exceeds mean monthly rainfall for all months except April, May, June and July. Mean monthly FAO56 Penman-Monteith evaporation exceeds mean monthly rainfall for all months except February through to July (inclusive).

Table 3.1: Albion Park Post Office, BOM Station 068000, rainfall and evaporation summary (Source: SILO)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
Mean monthly rainfall (mm) [1]	103	121	130	101	92	108	70	67	58	75	83	78	1084
Mean monthly pan evaporation (mm) [2]	195	155	139	101	75	60	69	96	124	156	171	202	1541
Mean daily pan evaporation (mm) [2]	6.30	5.54	4.47	3.36	2.41	2.00	2.22	3.09	4.12	5.02	5.69	6.50	1541
Mean monthly FAO56 evaporation (mm) [3]	138	111	104	79	60	47	54	73	95	118	125	142	1,144
Mean daily FAO56 evaporation (mm) [3]	4.44	3.96	3.36	2.62	1.92	1.55	1.75	2.35	3.15	3.80	4.17	4.59	1,144
Rainfall surplus (mm) [4]	-92	-34	-9	0	17	48	1	-29	-66	-81	-88	-124	-457

Notes: [1] Based on record from 1893 to end of 2019. [2] Based on record from 1970 to end of 2019. [3] Based on record from 1970 to 25/11/2020. [4] Calculated by subtracting pan evaporation from rainfall.

3.2 Topography

Colour ramps of a 5 m resolution LIDAR (Light Detection and Ranging) digital elevation model (DEM) obtained from ELVIS (ICSM, 2020) are shown in **Figure 3.1** and **Figure 3.2** for zoomed out and zoomed in views, respectively. **Figure 3.1** shows that the Project is located on a significant ridge that extends from Knights Hill some 12 km to 13 km south west of the Project Area and continues to near the coast with progressive decreasing elevation forming the Dunmore Hills. About 100 m to 200 m north of the Project Area, the elevation of this main ridge is about 130 mAHD to 140 mAHD. **Figure 3.2** shows that the Stage 7 area is located on a north west to south east aligned smaller ridge that diverges from the main ridge. In the area of Stage 7, the elevation of the ridge ranges from about 130 mAHD in the north to 100 mAHD in the south. The elevation of the western portion of the Stage 7 area does not vary significantly from the general ridge top elevation. However, the eastern portion of Stage 7 has elevations of about 70 mAHD to 80 mAHD and is therefore significantly lower than the general ridge top elevation.

The elevation of mapped watercourses present in the valleys east and west of the Stage 7 area is discussed in Section 3.3.

Approximately 300 m to 400 m west of the Stage 7 area, the sump of the existing quarry has an elevation of about 65 mAHD.

Contour lines are included on **Figure 3.4,** which is presented in Section 3.4.

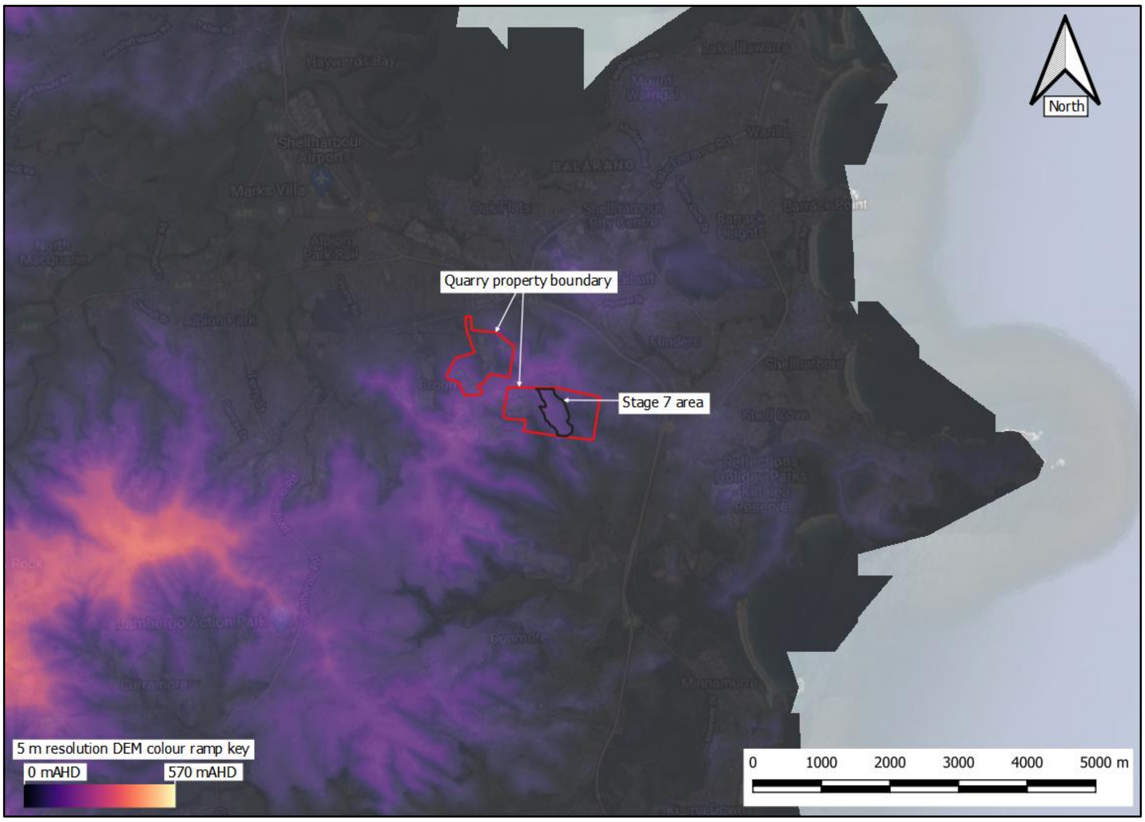


Figure 3.1: Topography colour ramp (sources: ELVIS for elevation data, Google for image)

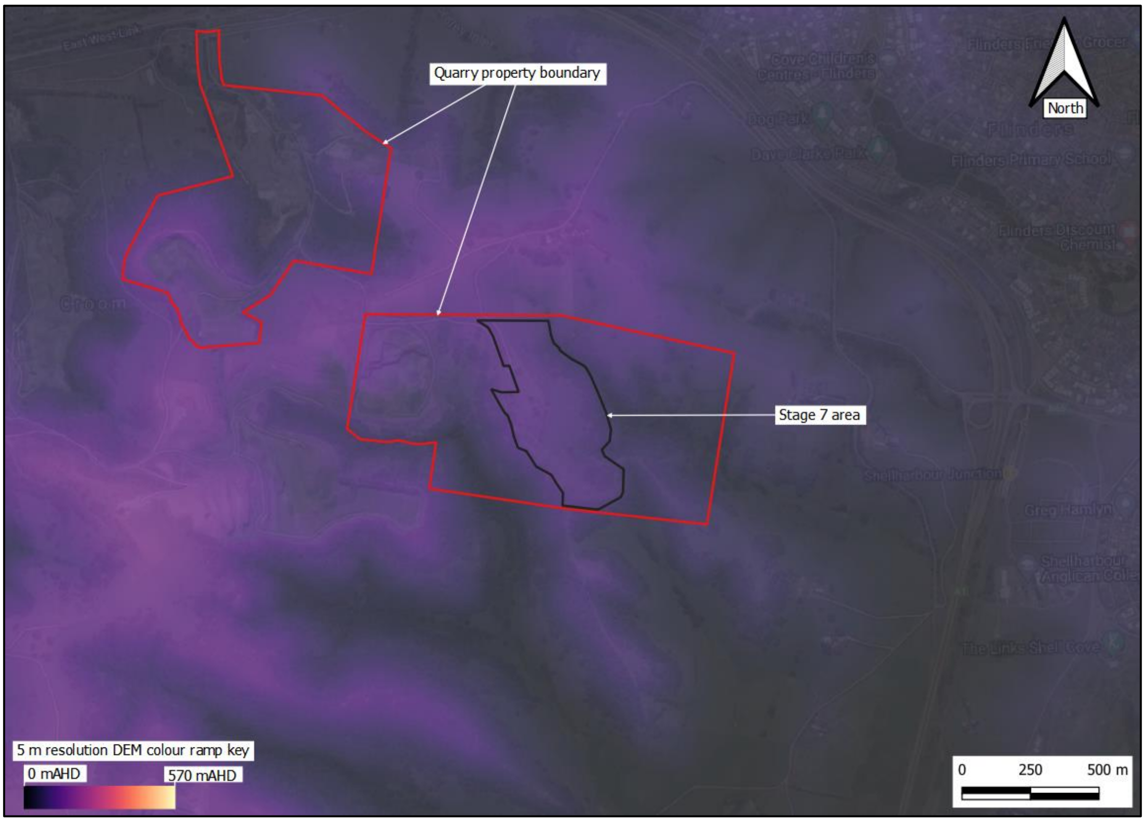


Figure 3.2: Topography colour ramp - close up (sources: ELVIS for elevation data, Google for image)

3.3 Surface water

There is no significant external catchment area, which contributes surface water flow to the Stage 7 area, due to the site being located on a ridge.

Mapped watercourses (NSW Foundation Spatial Data Framework – Water – NSW Hydro Line) within about 1 km of the Project Area are shown in **Figure 3.3**, with watercourses with a Strahler stream of ≥2 differentiated. Mapped watercourses with a stream of ≥2 close to the Project Area generally flow to the south east within narrow valleys flanked by steep slopes (up to about 22°).

There are four watercourses with a stream of ≥2 which are close to the Project Area. These watercourses are unnamed and are hereafter referred to as Watercourse 1, Watercourse 2, Watercourse 3 and Watercourse 6 (**Figure 3.3)**. Additionally, although less relevant to the groundwater assessment, there is a watercourse with a stream order of ≥2 located about 160 m south east of the Project (referred to as Watercourse 4).

Watercourse 6 has elevations ranging from about 77 mAHD in the north to about 30 mAHD in the south, where the drainage line crosses the Applicant's property boundary. Watercourse 1 and 3 (collectively) have elevations ranging from about 67 mAHD in the north (outside of the current extraction area) to about 30 mAHD in the south where the drainage line crosses the Applicant's property boundary.

It is noted that the majority of Watercourse 1 and its tributaries have been removed by the current extraction area. The NSW Foundation Spatial Data Framework – Water – NSW Hydro Line data does not reflect this.

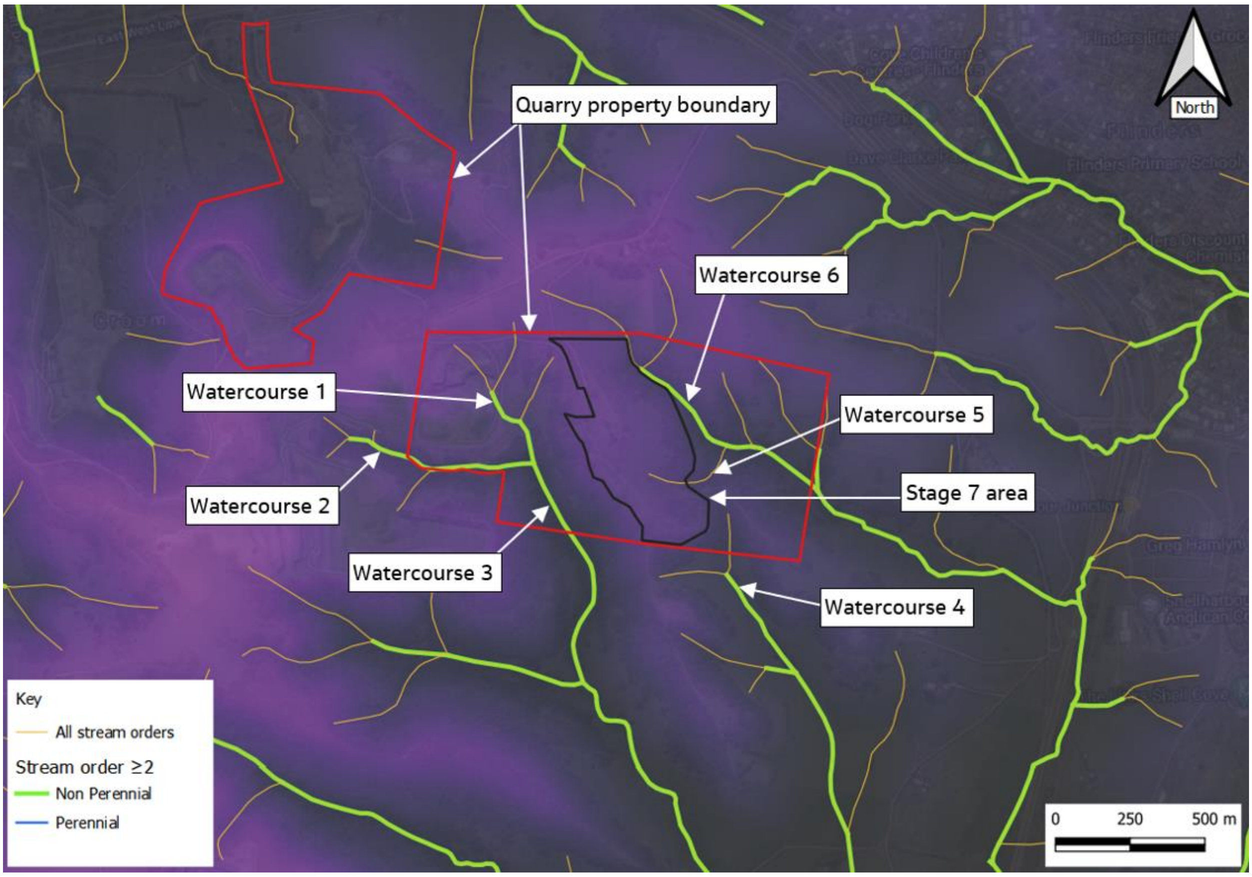


Figure 3.3: Watercourses within about 1 km of the Project (source: NSW Foundation Spatial Data Framework - Water - NSW Hydro Line)

3.4 Geology

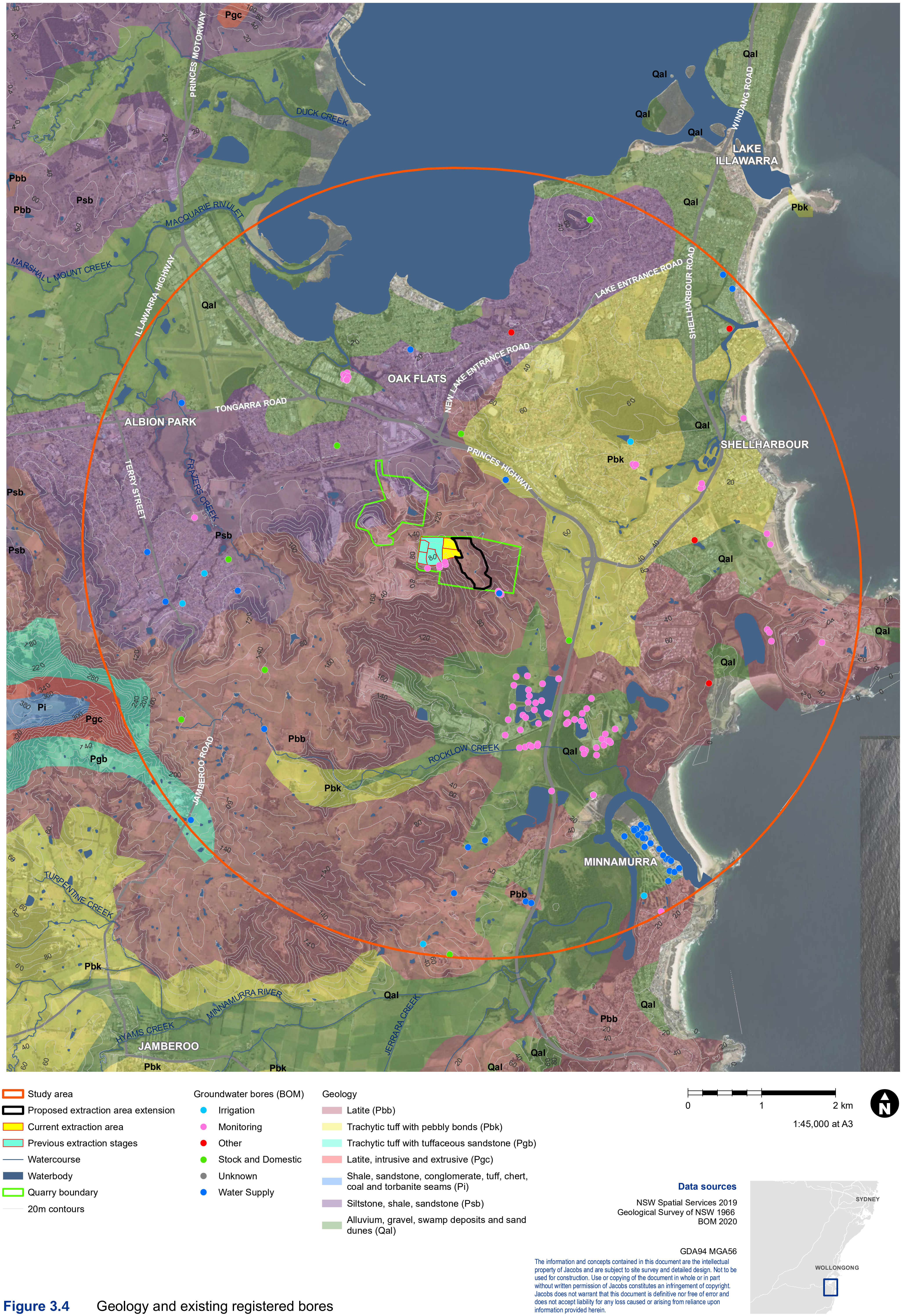
The Wollongong 1:250,000 Geological Sheet SI/56-09 (Geological Survey of NSW, 1966) mapping is superimposed on **Figure 3.4**. The mapping indicates the surface geology for the broader region of the Project Area comprises Bumbo Latite of the Gerringong Volcanics. Additionally:

- Quaternary alluvium is mapped at the surface at a minimum distance of approximately 650 m, to the south east of the proposed Quarry Extension area.
- Tuff is mapped at the surface at a minimum distance of approximately 700 m, to the east of the proposed Quarry Extension area.
- Undifferentiated siltstone, shale and sandstone of the Berry Formation is mapped at the surface at a minimum distance of approximately 650 m, to the north west of the proposed Quarry Extension area.

The are no mapped (Geological Survey of NSW, 1966) faults near the Project Area. The nearest mapped faults are greater than 10 km to the north west of the Project Area.

As outlined in Section 1.3.1, the latite in the area of Stage 7 includes overburden comprising clay and variably weathered Bumbo Latite collectively, which is between 2 m and 8 m thick in the Stage 7 area. Also, the latite comprises two flows referred to as the Upper Latite and the Lower Latite respectively, and an interburden layer of agglomerate or volcanic breccia which separates the Upper Latite and the Lower Latite.

The base of the Lower Latite occurs at approximately 52 mAHD to 17 mAHD respectively within the northern and southern ends of Stage 7. The Lower Latite is underlain finely bedded grey-green Kiama Sandstone.



Data sources

NSW Spatial Services 2019
Geological Survey of NSW 1966
BOM 2020

GDA94 MGA56

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Figure 3.4 Geology and existing registered bores

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3.5 Groundwater systems

Observations from resource definition drilling for the Project and the groundwater monitoring bores within the Project Area (**Figure 3.5**) suggest there are two broad groundwater systems applicable to the Project Area:

- A shallow (i.e. <10 m below ground level (mBGL)) water table system is generally consistent within the Project Area and is most likely associated with an upper weathered zone in the latite and agglomerate.
- Intermediate depth groundwater unconfined to semi-confined systems (in the latite and agglomerate) underly the shallow water table system, with the flow in these systems almost exclusively dependent on fracture/defect extent and unit contact planes (i.e. contact of latite and agglomerate).

Additionally, deep semi-confined to confined groundwater systems within Kiama Sandstone are conceptualised to underly the intermediate depth groundwater systems. However, these groundwater systems are of little relevance as extraction of the sandstone is not proposed for the Project.

Due to inferred poorly connected fracture flow paths and negligible matrix hydraulic conductivity (except for possibly the sandstone), there is poor hydraulic connection between:

- The water table and underlying intermediate and deep groundwater systems.
- The intermediate groundwater systems themselves.
- The deep sandstone groundwater system and overlying intermediate system.

Preferential flow could occur at the interface of the latite/agglomerate and lower latite/sandstone. However, groundwater monitoring bores MW2D, MW5 and MW6, which have screens that span across latite/agglomerate contact(s) do not have distinctly different estimates of hydraulic conductivity (Section 3.7).

The latite and agglomerate matrix hydraulic conductivity, fracture and contact plane hydraulic conductivity and storage is conceptualised to be sufficiently low that ‘aquifers’ in these systems are unlikely to exist. The lack of groundwater inflow (aside from flow from the lower latite and sandstone contact to the sump – refer Section 3.11.4) to the current extraction area evidences this.

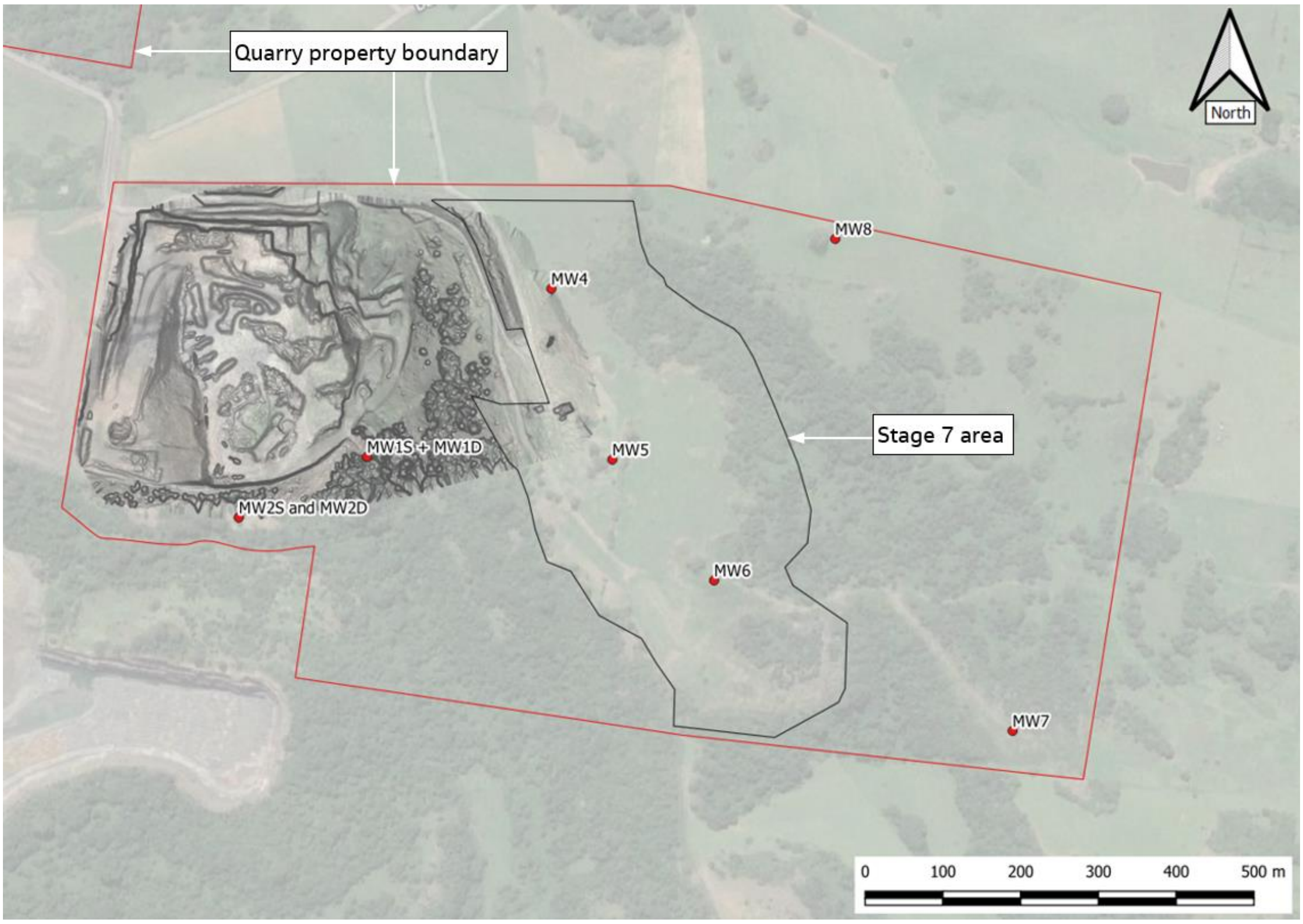


Figure 3.5: Existing groundwater monitoring bores

3.6 Groundwater levels

3.6.1 Project area

Details of the Quarry's groundwater monitoring bores are summarised in **Table 3.2**.

Table 3.2: Quarry monitoring bore details

Monitoring bore	Co-ordinates (MGA94z56)		Ground level (mAHD)	Screen depth (mBGL) and length (m) [1]	Screened material
	Easting	Northing			
MW1S	300328	6170396	69.84	4.50 - 10.29, 5.79 m long screen	Fresh lower latite
MW1D			69.84	18.30 – 25.11, 6.81 m long screen	Logged as tuff (but this is likely an error in rock type identification, instead the material is likely altered sandstone)
MW2S	300163	6170318	74.32	6.50 – 13.00, 5.50 m long screen	Fresh lower latite
MW2D			74.40	18.50 – 24.37, 5.87 m long screen	2.87 m of fresh lower latite, followed by 3 m length of material logged as tuff (but the 'tuff' is likely an error in rock type identification, instead the material is likely altered sandstone)
MW4	300565	6170612	116.92	11.00 – 27.00, 16 m long screen	Fresh upper latite
MW5	300643	6170392	116.89	36.00 – 56.00, 20 m long screen	Fresh upper latite Two separate agglomerate layers (3 m and 9 m thick) Fresh lower latite
MW6	300774	6170237	94.77	5.80 – 43.80, 38 m long screen	Fresh upper latite 12 m thick agglomerate layer Fresh lower latite 13.8 m of a 15 m thick agglomerate layer
MW7	301158	6170044	81.75	8.00 – 21.00, 13 m long screen	Fresh upper latite
MW8	300930	6170676	109.18	7.00 – 21.00, 14 m long screen	Generally slightly to moderately weathered upper latite

Groundwater levels observed in the Quarry's groundwater monitoring bores are summarised in **Table 3.3**. Hydrographs of bores MW1S, MW1D, MW2S, MW2D and cumulative rainfall departure (CRD) are provided in

Figure 3.6 and **Figure 3.7** in datums of mAHD and metres below ground level (mBGL) respectively. Hydrographs for MW4, MW5, MW6, MW7 and MW8 are provided in **Figure 3.8** (mAHD) and **Figure 3.9** (mBGL).

MW1S, MW1D, MW2S, MW2D have significantly longer datasets (dataset about 11 years) than MW4, MW5, MW6, MW7 and MW8, where the dataset is typically about two to three months long.

CRD is calculated from the cumulative sum of observed rainfall minus long-term average rainfall and sometimes displays correlation to groundwater levels, particularly where rainfall recharge is an important process. A climbing CRD line slope represents above average rainfall whilst a declining slope represents below average rainfall.

The groundwater levels do not appear to visually correlate well with CRD.

Groundwater levels range from about 46 mAHD to 115 mAHD and are generally about 3 mBGL to 10 mBGL. Notable exceptions include MW5, where the average ground level of 80.15 mAHD corresponds to about 37 mBGL and to a lesser degree, MW1D, where the average ground level of 51.33 mAHD corresponds to about 19 mBGL.

MW1S/MW1D and MW2S/MW2D are paired sites where shallow and relatively deeper monitoring bores are installed within a few metres of each other. There is a considerable head disparity (about 10 m to 20 m) between MW1S and MW1D, and at certain periods, between MW2S and MW2D too, although this disparity is relatively less (up to 12.5 m at commencement of monitoring and 5 m later in the monitoring period). These observations combined with the distinctly relatively lower groundwater levels observed in MW5 suggest poorly connected fracture flow paths and negligible matrix hydraulic conductivity of the latite/agglomerate. Furthermore, MW5 does not recover quickly after groundwater quality sampling, suggesting the groundwater system in the immediate vicinity of this bore is isolated, non-permanent and of limited extent.

Table 3.3: Quarry monitoring bore groundwater level summary

Monitoring bore	**Groundwater level (mAHD)**		
	Min.	**Average**	**Max.**
MW1S	63.03	66.36 (3.48 mBGL)	69.09
MW1D	45.54	51.33 (18.51 mBGL)	60.58
MW2S	63.12	65.35 (8.97 mBGL)	68.97
MW2D	56.18	64.49 (9.91 mBGL)	72.06
MW4	112.55	112.71 (4.21 mBGL)	115.05
MW5	76.15	80.15 (36.74 mBGL)	80.34
MW6	88.44	88.70 (6.07 mBGL)	92.21
MW7	70.15	71.01 (10.74 mBGL)	80.95
MW8	100.84	101.31 (7.87 mBGL)	102.27

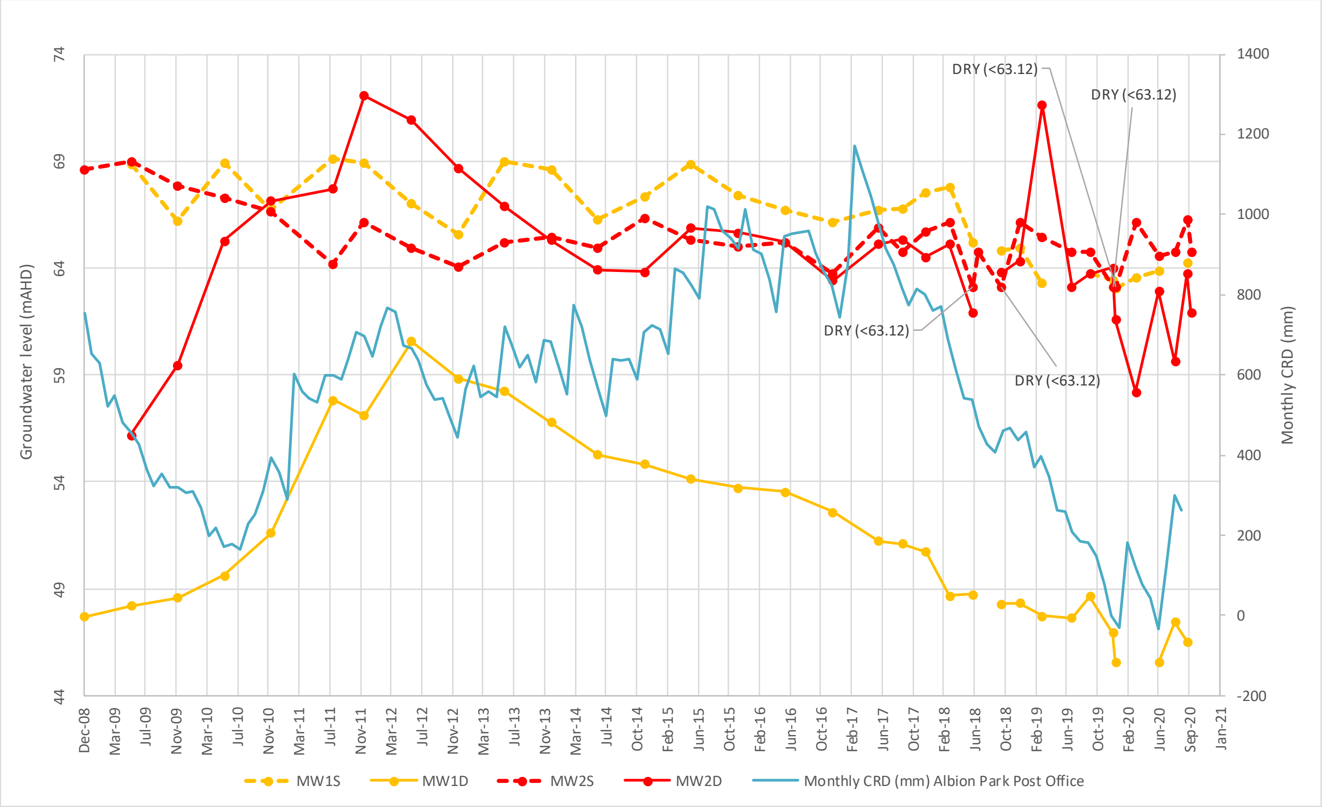


Figure 3.6: MW1S, MW1D, MW2S, MW2D groundwater level (mAHD) and monthly CRD (mm)

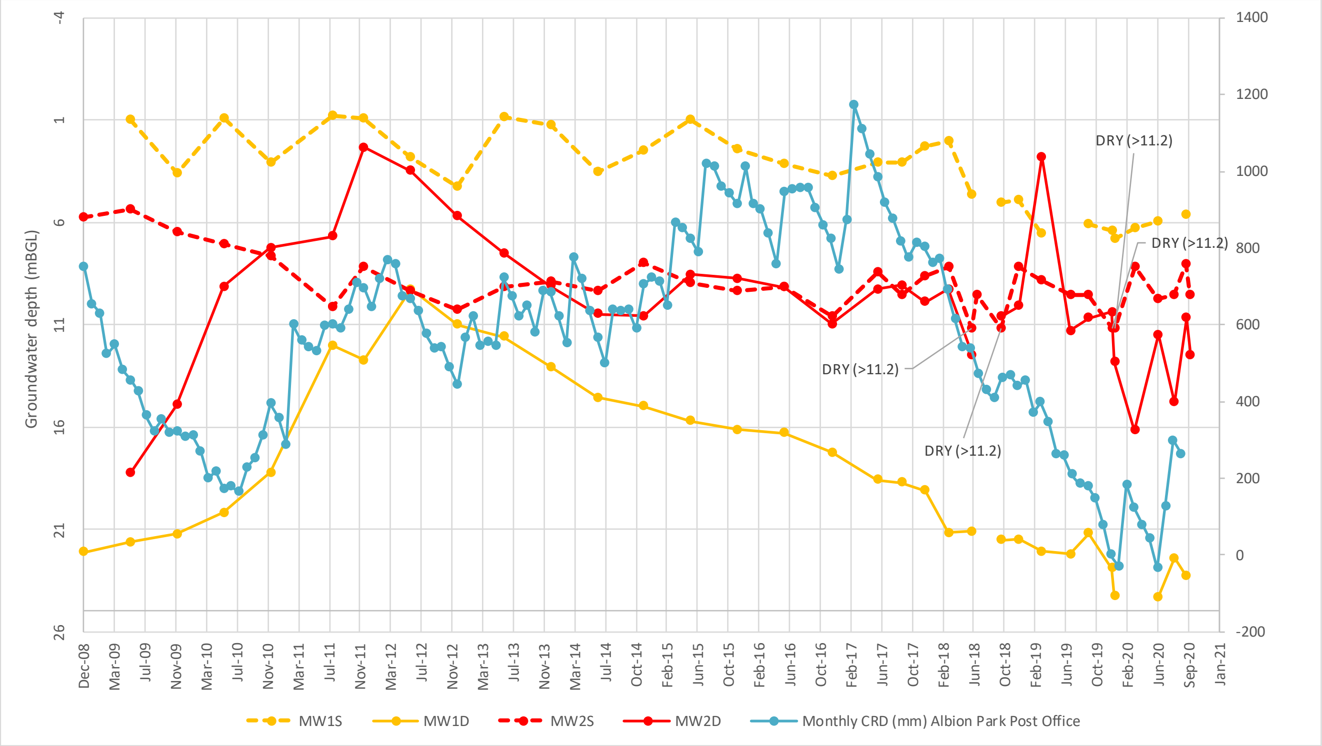


Figure 3.7: MW1S, MW1D, MW2S, MW2D groundwater depth (mBGL) and monthly CRD (mm)

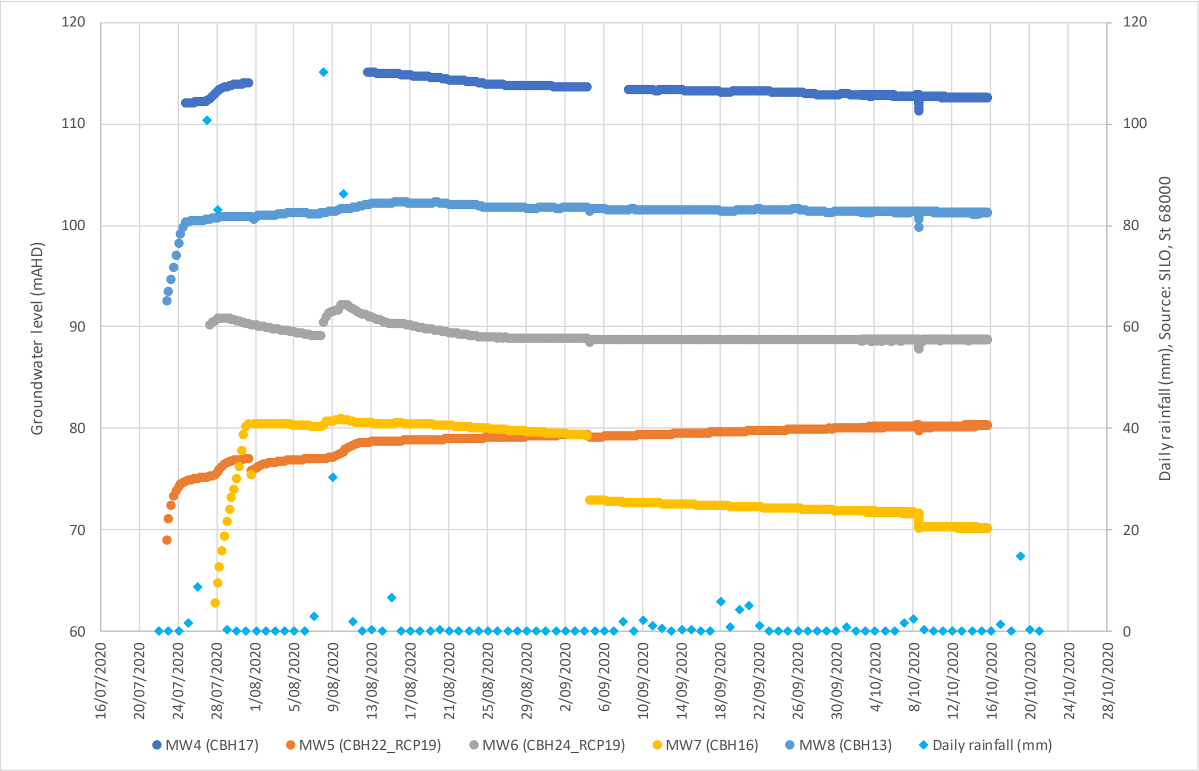


Figure 3.8: MW4, MW5, MW6, MW7 and MW8 groundwater level (mAHD) and daily rainfall (mm)

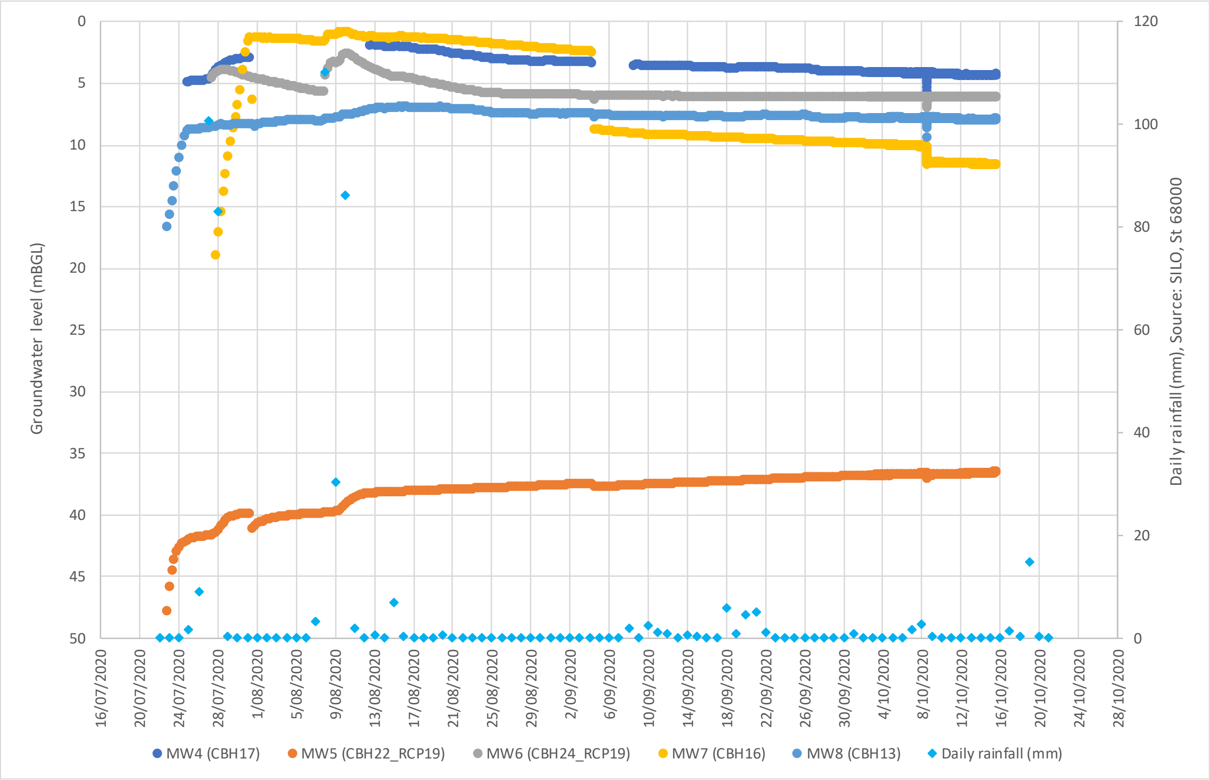


Figure 3.9: MW4, MW5, MW6, MW7 and MW8 groundwater level (mBGL) and daily rainfall (mm)

3.6.2 Regional groundwater levels

Groundwater levels from the groundwater monitoring bores within the Project Area, registered bores in the Water NSW (2020b) online bore database and three monitoring bores at Dunmore Quarry (EMM, 2016), located between 1.7 km to 2.4 km south west of the Project Area, were contoured to convey groundwater levels and flow directions.

Thirty-nine groundwater level locations and 379 additional control points were used to generate the contours. The control points were placed along the ocean, Macquarie Rivulet, Minnamurra River, Lake Illawarra and at Bass Point. No control points were placed near the Project Area. The maximum depth of a bore used as a contour interpolation point was 204 m.

The contours are shown in **Figure 3.10** and generally suggest that groundwater flows from areas of relatively high elevation towards areas of relatively low elevation, before discharging to Lake Illawarra, Macquarie Rivulet and Minnamurra River and other low lying areas, including the ocean. Groundwater levels are relatively elevated in the vicinity of the Project.

Although not apparent in the contours, it is noted that preferential flow, coincident with strata dip to the south east may occur.

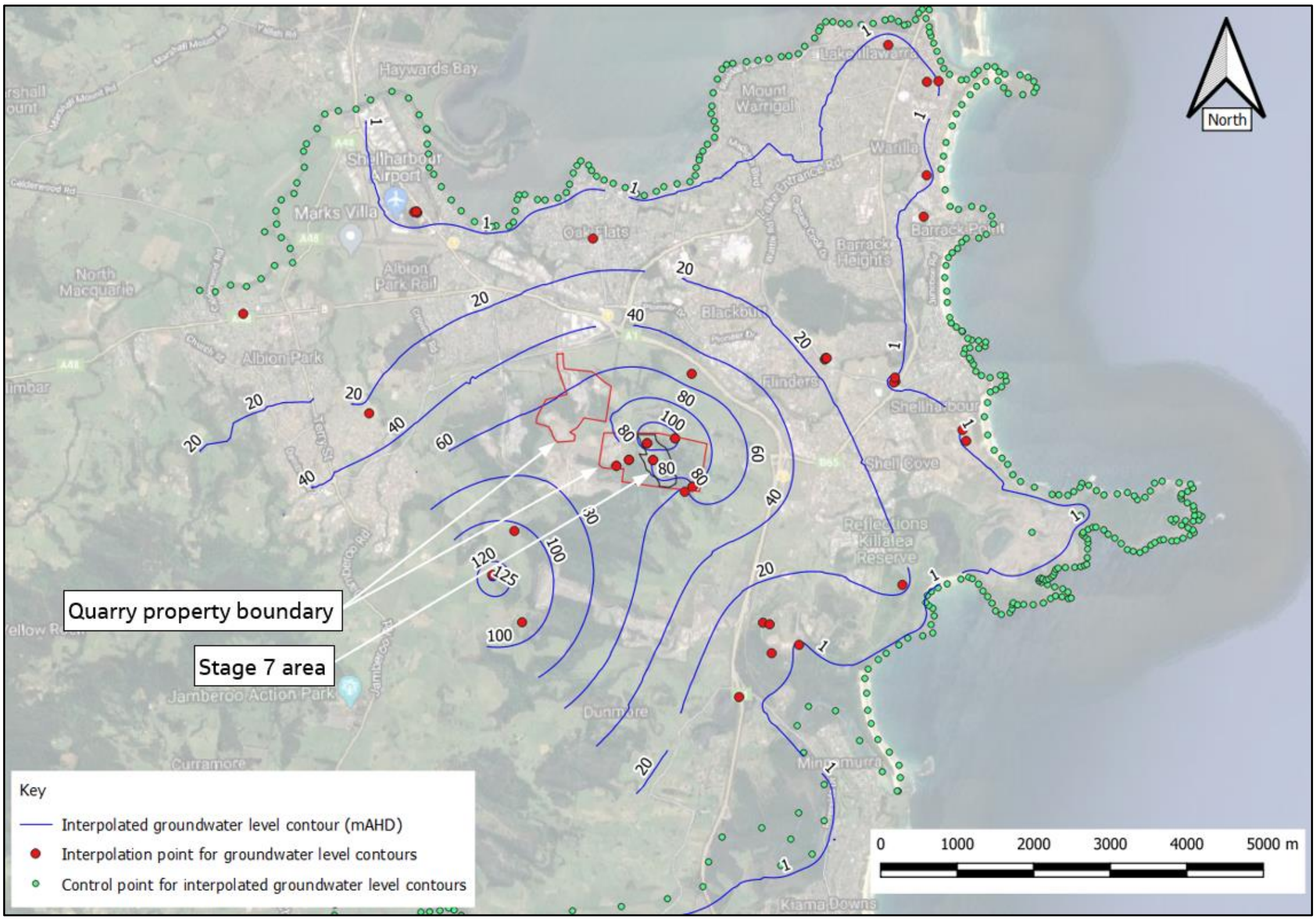


Figure 3.10: Contoured groundwater levels

3.7 Hydraulic conductivity

Slug test results for the groundwater monitoring bores within the Project Area are summarised in **Table 3.4**. Hydraulic conductivity of the latite and agglomerate in the Project Area ranged from 1.56×10^{-5} m/d to 7.64×10^{-3} m/d and is inferred to be generally low and typically less than 0.002 m/d based on a mean and geomean of 1.71×10^{-3} m/d and 3.51×10^{-4} m/d, respectively.

Further afield, at three monitoring bores at Dunmore Quarry (EMM, 2016), located between 1.7 km to 2.4 km south west of the Project, the average hydraulic conductivity at the three bores ranged from 1.9×10^{-8} m/d to 8.9×10^{-7} m/d.

It is noted that the Project's monitoring bores typically have relatively longer screen intervals compared to the monitoring bores at Dunmore Quarry. This may explain the relatively lower hydraulic conductivity values in the immediate vicinity of the Dunmore Quarry monitoring bores. Alternatively, rock mass discontinuities may be relatively less pronounced in the area of Dunmore Quarry.

Table 3.4: Quarry monitoring bore slug testing results summary

Bore ID	**Screen location (mBGL) and length (m)** [1]	**Screened material**	**Hydraulic conductivity (m/d)**
MW1S	4.50 - 10.29, 5.79 m long screen	▪ Fresh upper latite	1.73 x 10^{-4}
MW1D	18.30 – 25.11, 6.81 m long screen	▪ Logged as tuff	2.95 x 10^{-5}
MW2S	6.50 – 13.00, 5.50 m long screen	▪ Fresh upper latite	Not tested – bore dry
MW2D	18.50 – 24.37, 5.87 m long screen	▪ 2.87 m of fresh upper latite, followed by 3 m length in agglomerate (logged as tuff)	1.56 x 10^{-5}
MW4	11.00 – 27.00, 16 m long screen	▪ Fresh upper latite	1.41 x 10^{-3}
MW5	36.00 – 56.00 20 m long screen	▪ Fresh upper latite ▪ Two separate agglomerate layers (3 m and 9 m thick) ▪ Fresh lower latite	2.40 x 10^{-3}
MW6	5.80 – 43.80 38 m long screen	▪ Fresh upper latite ▪ 12 m thick agglomerate layer ▪ Fresh lower latite ▪ 13.8 m of a 15 m thick agglomerate layer	3.22 x 10^{-4}
MW7	8.00 – 21.00 13 m long screen	▪ Fresh upper latite	Not tested - bore water levels do not recover following water quality sampling events. Bore inferred to be monitoring an isolated non-permanent groundwater source.
MW8	7.00 – 21.00 14 m long screen	▪ Generally slightly to moderately weathered upper latite	7.64 x 10^{-3}
		Statistics	**Hydraulic conductivity (m/d)**
		Minimum	1.56 x 10^{-5} (MW2D)
		Median	3.22 x 10^{-4}
		Mean	1.71 x 10^{-3}
		Geomean	3.51 x 10^{-4}
		Maximum	7.64 x 10^{-3} (MW8)
		Range (i.e. max – min)	7.62 x 10^{-3}

Notes: [1] Documented screen length includes gravel pack interval immediately above screen prior to bentonite, and in the case of MW4, a 2 m long gravel packed sump beneath the bottom of the screen.

3.8 Storage (groundwater system)

Groundwater system storage properties are physical properties that characterise the capacity of a groundwater system to release groundwater. For water table groundwater systems, storage is discussed in terms of specific yield (Sy), which is also known as drainable porosity. Specific yield, quoted as a ratio, is generally less than or equal to the effective porosity (total connected pore space). Additionally, specific storage (Ss) is the amount of water that a portion of an aquifer releases from storage, per unit mass or volume of aquifer, per unit change in hydraulic head, while remaining fully saturated.

Groundwater system storage within the Project Area is inferred to be low for the latite/agglomerate. Specific yield is inferred be about 0.01 based on inferred poorly connected fracture flow paths and low primary porosity. This specific yield value aligns with a representative value for fractured igneous and metamorphic rock in Bair and Lahm (2006) of approximately 0.01.

Specific storage is conceptualised to be in the order of $1\text{x}10^{-6}$ based on the material type and literature values for moderately fissured rock in Younger (1993).

3.9 Groundwater quality

Comprehensive groundwater quality sampling has been undertaken on MW1S, MW1D, MW2S and MW2D on a six monthly, or more recently, quarterly basis, since 2008 / 2009. Additionally, monitoring bores MW4, MW5, MW6, MW7 and MW8 were sampled on 23 November 2020.

The historical analysis suite has generally included:

- Electrical conductivity (EC)
- pH
- temperature
- total dissolved solids (TDS)
- Major anions and cations (except magnesium)
- Nutrients
- Oil and grease
- Biological oxygen demand (BOD)
- Total organic carbon
- Dissolved heavy metals - arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel and zinc, with the specific heavy metal analytical suite for a sampling round selected based on EC values.

Plots of EC and pH for MW1S, MW1D, MW2S and MW2D are provided in **Figure 3.11** and **Figure 3.12,** respectively, and groundwater results for all analytes are tabulated and compared against ANZG guideline levels in Appendix A. A piper plot of the major anions and cations is provided in **Figure 3.13**. It is noted that in cases where analyte values were not available for use in the piper plot (e.g. missing magnesium values), missing values were assigned based on the available data and a range of assumptions.

The key points relating to groundwater quality are:

- EC is typically less than 2,000 µS/cm, but ranges from about 100 µS/cm to 2,500 µS/cm.
- TDS average at MW1S, MW1D, MW2S and MW2D is 794, 640, 793 and 843 mg/L, respectively. For the single sampling round undertaken on MW4, MW5, MW6, MW7 and MW8, TDS ranged from 217 mg/L to 760 mg/L. The average TDS values at MW1S, MW1D, MW2S and MW2D and values at MW4, MW5, MW6,

MW7 and MW8 are representative of ‘fresh’ water in accordance with salinity categories presented in Freeze and Cherry (1979). There are instances at MW1S, MW1D, MW2S and MW2D where the TDS is representative of ‘brackish’ water.

- pH is typically in the range of 6 to 7.5.
- Nitrogen species average values are:
  - Nitrate – 1.3 mg/L
  - Nitrite – 0.017 mg/L
  - Ammonia – 0.2 mg/L
  - Total Kjeldahl Nitrogen (TKN) – 1.5 mg/L
  - Total Nitrogen (TN) – 2.8 mg/L
- Total phosphorus average is 0.52 mg/L
- Water type, as shown by the piper plot (**Figure 3.13**) is typically mixed type, although some samples (MW1D and MW5) plot as sodium chloride type at times and some samples (MW1S, MW1D, MW2S, MW2D and MW8) plot as calcium bicarbonate or magnesium bicarbonate at times. Four of the MW1S samples plot as calcium chloride type. In general, the cations are either magnesium or sodium dominant. The anions either have no dominant type or are bicarbonate, chloride or sulfate dominant (i.e. all anion types are represented in the data)
- A sampling round undertaken by Jacobs on 16/12/2019 included detection of hydrocarbons. There is no nearby hydrocarbon contaminant source at one of the bores with a detection (MW4) and based on the chromatographs, the detections may be associated with some type of oil, either a natural oil, or an oil introduced due to cross contamination. It is noted that oil and grease detections in MW1S, MW1D, MW2S and MW2D occurred in 2009 and 2015. Oil and grease detection also occurred in 2008 and 2010 for MW2S and MW1S, respectively. The source of these detections is not known but could be pipe grease from the bore drilling. Aside from the 2015 instances, the oil and grease detections occur in the early phase of the data set (i.e. relatively close to the drilling date).
- The following ANZG guideline exceedances are noted:
  - ANZG (2018) Freshwater 95% species protection toxicant default guideline values (DGVs) for slightly to moderately disturbed ecosystems

    - Copper, zinc and nickel guideline levels are frequently exceeded. On rare occasions, cadmium, lead and mercury levels are exceeded.
  - Physical and chemical stressors for lowland rivers

    - TN and total phosphorous (TP) are frequently exceeded

    - pH is occasionally outside of the guideline range

    - On rare occasions, EC is exceeded

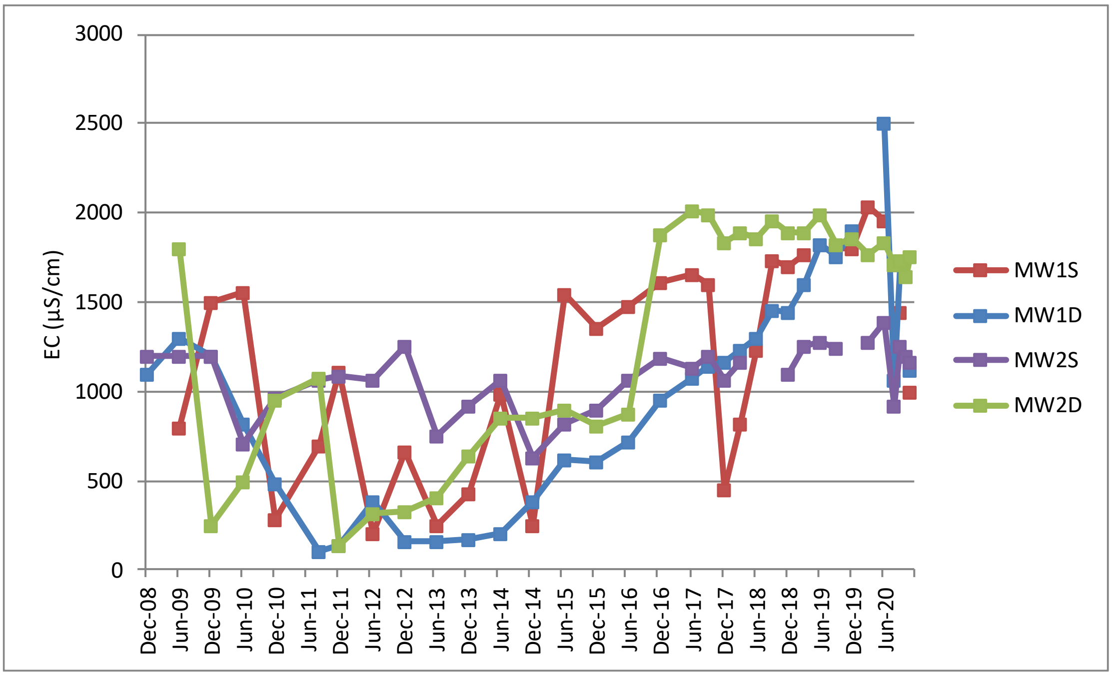


Figure 3.11: EC (µS/cm) at MW1S, MW1D, MW2S and MW2D

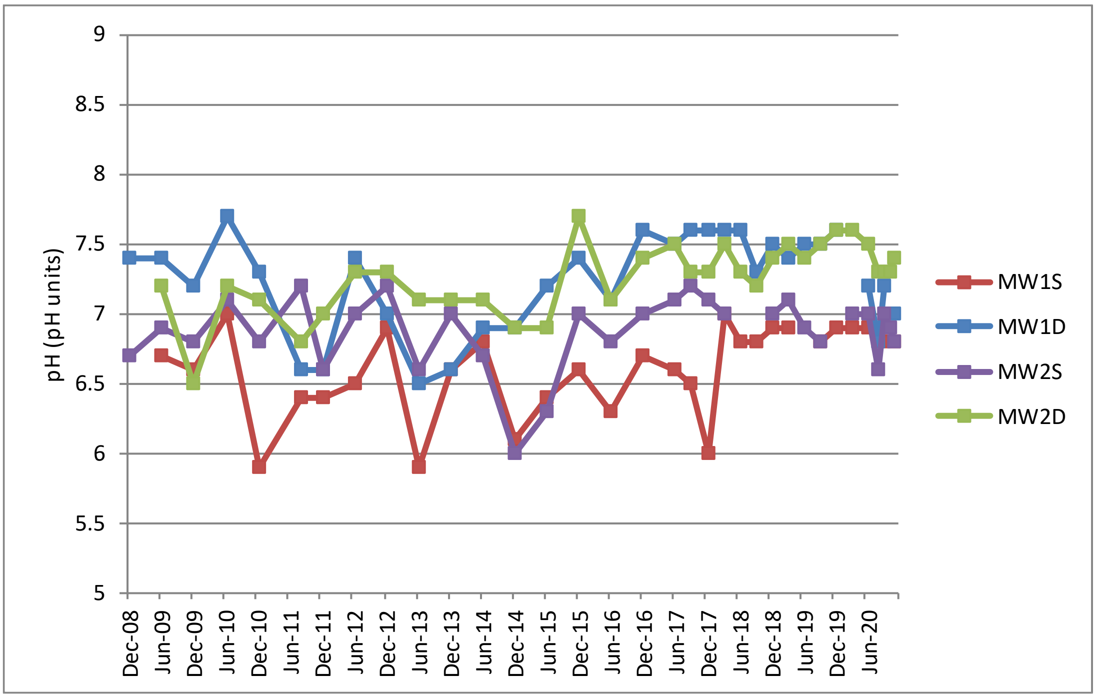


Figure 3.12: pH at MW1S, MW1D, MW2S and MW2D

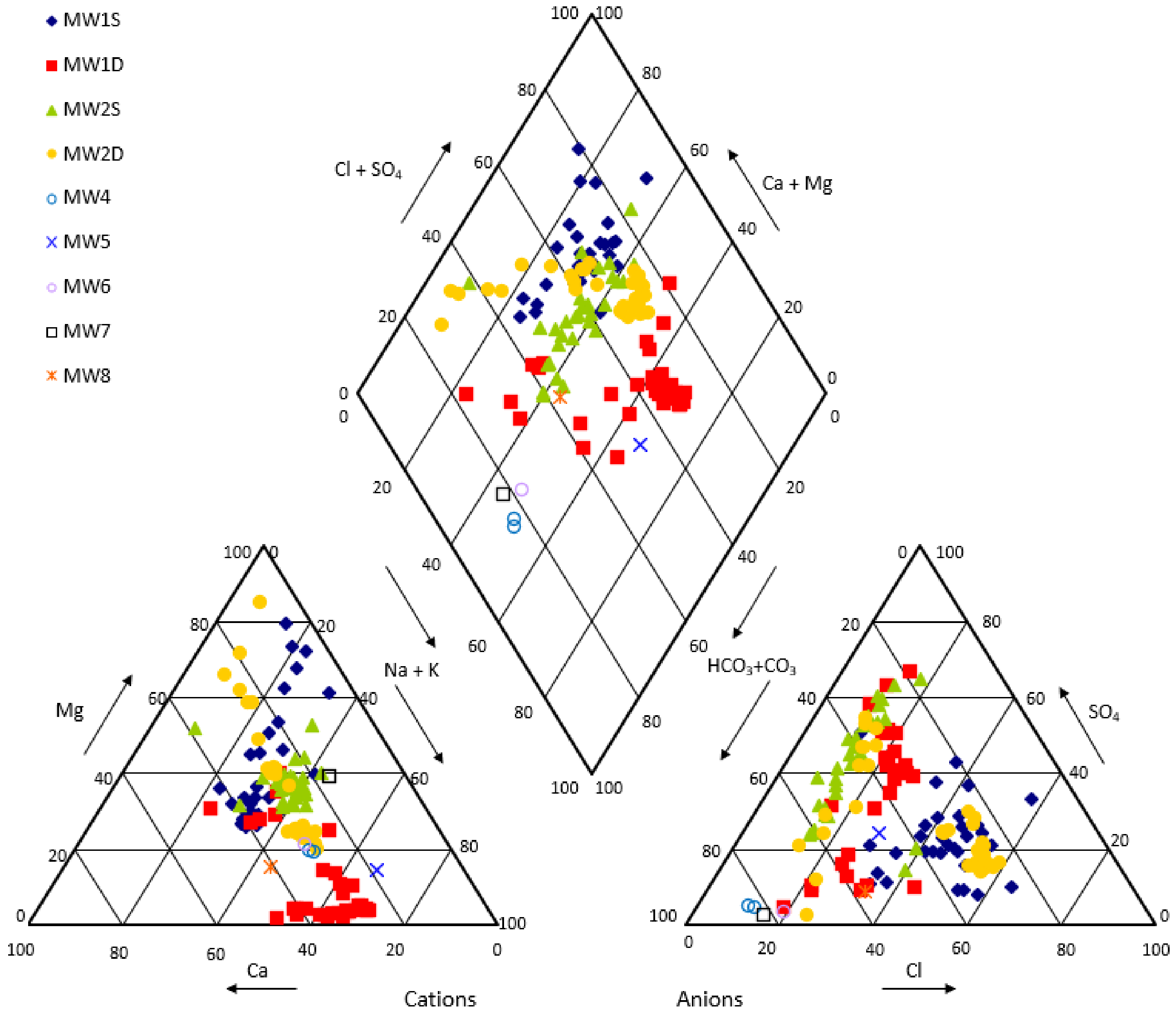


Figure 3.13: Piper plot of major anions and cations

3.10 Groundwater recharge

Groundwater recharge (via rainfall infiltration) within the Project Area is inferred to be low based on low formation hydraulic conductivity, clay overburden and reasonably steep slopes (which encourage runoff) which flank the ridges in the vicinity of the Project Area. Relatively higher recharge may occur on the ridge tops.

3.11 Groundwater discharge

Groundwater discharge within the Project Area is conceptualised to occur though evapotranspiration (ET), discharge to springs and discharge as baseflow to watercourses. Regionally, groundwater discharges to the adjacent water bodies of Lake Illawarra and the Pacific Ocean.

3.11.1 Springs

Springs occur in the general area around the Project Area, including to the north of Stage 7 (**Figure 3.14**). Such springs are conceptualised to be controlled by shallow groundwater flow systems that are poorly connected to underlying deeper groundwater systems. This same characterisation was adopted by EMM (2016) for springs at the nearby Dunmore Quarry and was evidenced by water quality analysis that showed that the springs in that area relied on shallow younger localised rainfall recharge and not deeper groundwater systems.

The vegetation in the area of these springs and surrounds has been cleared long ago and now appears to mostly comprise grass vegetation with standing water collected downstream in small on-stream dams. Cattle graze in the area of the springs and likely eat the greener vegetation in the area of the springs.

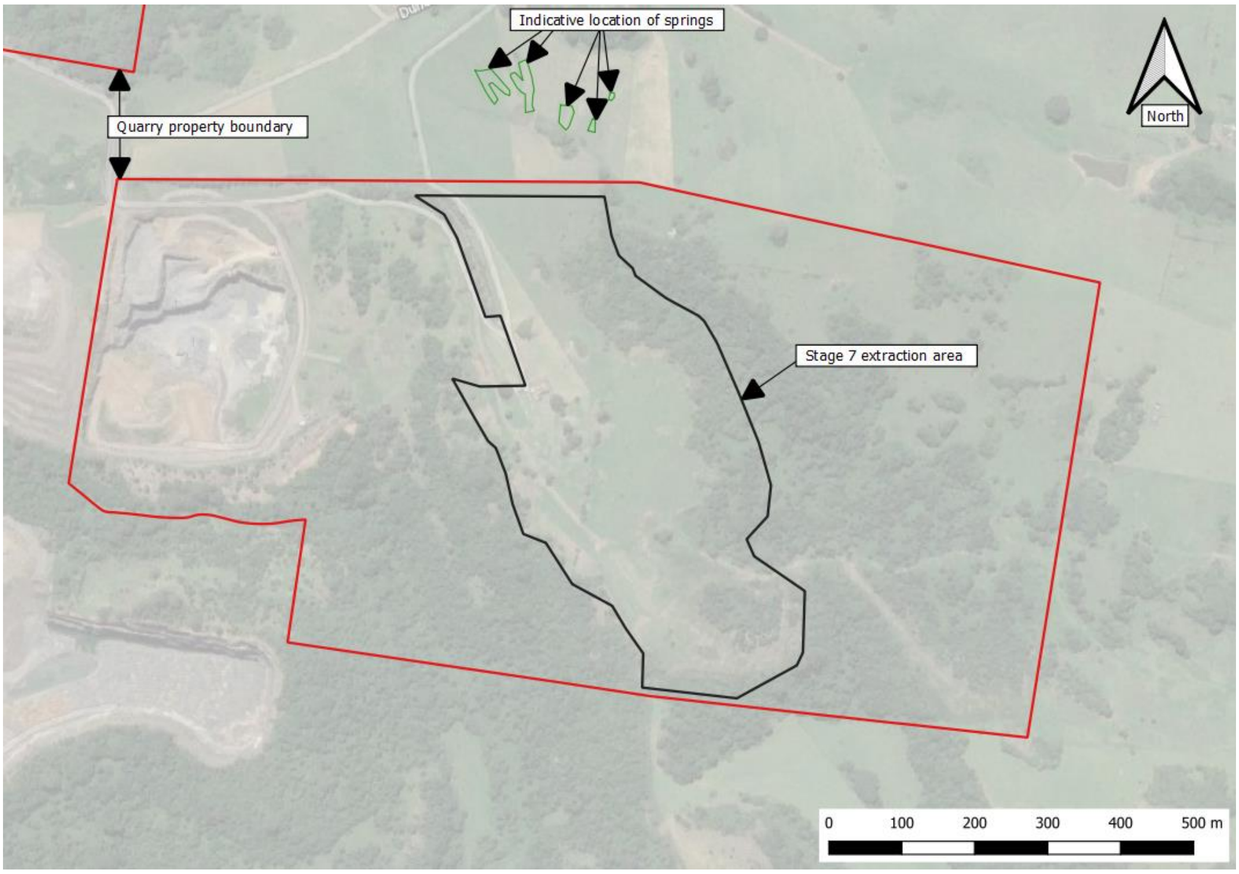


Figure 3.14: Indicative location of springs

3.11.2 Baseflow

Baseflow is inferred to occur to watercourses in the vicinity of the Project Area but is conceptualised to be low due to low hydraulic conductivity. Baseflow processes are unlikely significant to the existing environment in the vicinity of the Project Area and likely represent a negligible component of the water balance.

3.11.3 Groundwater extraction by existing registered bores

Groundwater extraction by existing registered bores in the vicinity of the Project Area is considered to be negligible. **Figure 3.4** shows that registered bores are sparse in the vicinity of the Project Area. The three closest water extraction bores to the Project are summarised **Table 3.5**.

Table 3.5: Registered water extraction bores close to Project (Source: Water NSW, 2020b and Bom, 2020a)

Bore I.D.	Purpose	Distance from potential Quarry extension area	Bore depth (m)	Yield (L/s)	Standing water level (mBGL)
GW100090	Water supply	160 – 200 m, south east of Stage 7	66	0.1	0.3
GW109000	Water supply	900 m, north east of Stage 7	78	0.8	27
GW044447	Stock and domestic	1,250 m, south east of Stage 7	0	No data	No data

3.11.4 Discharge to existing quarry

<u>**Existing quarry - site inspection (16.12.2019)**</u>

Groundwater is conceptualised to have been discharging at very low rates to the Quarry extraction area in general and in particular the extraction area's sump at the time of the site inspection (16.12.2019). This is because the approximate sump level of 65 mAHD is below the average groundwater level observed in the majority of the Quarry's monitoring bores. However, the discharge is considered to be very low, and is less than evaporation. The existing extraction area appeared dry at the time of a Jacobs site inspection except for the sump, and groundwater was not observed on the pit floor or side walls. A photo of the existing extraction area at the time of the Jacobs inspection is provided in **Figure 3.15a**.

Email correspondence between Jacobs - Cleary Bros (2020) concerning sump water level observations around the time of the site inspection is summarised as follows:

- Cardno (2018) estimate the sump is 1 m deep, 40 m x 50 m and has a capacity of approximately 2 ML.
- The sump extends through the lower latite and sandstone contact, whereas the rest of the pit terminates on the latite, just prior to the underlying sandstone.
- The sump always contains water, even in dry periods.
- The sump has a water level elevation of approximately 65 mAHD, which fluctuates with rainfall runoff.
- Cleary Bros do not propose to deepen the sump shown in **Figure 3.15a**. However, over time the location of the sump would transition to different portions of the extraction area.

Based on the above, groundwater is inferred to have been contributing to the sump's volume of water around the time of the site inspection. The inferred groundwater inflows are inferred to be from the latite/sandstone contact or the sandstone. The latite itself is considered unlikely to be providing significant groundwater flow to the sump, which is evidenced by the dry pit floor shown in **Figure 3.15a**.

<u>**Existing Quarry – January 2021**</u>

A photo of the existing extraction area during January 2021 is provided in **Figure 3.15b**. The photo shows that the sump area has increased since December 2019 and has transitioned to the east.

Cleary Bros have indicated that changes in water level within the sump are thought to be primarily associated with surface water flows, as after prolonged or significant rainfall, the volume of water in the sump increases. During dry periods, the volume of water in the sump decreases, but always contains some volume of water, even in dry periods.

Thus, groundwater inflows are thought to be contributing to the volume of water within the sump, albeit less significantly than surface water flows.

Proposed Quarry

Based on the negligible groundwater discharges to the existing extraction area, combined with other conceptualisation elements discussed in Sections 3.4, 3.5, 3.6, 3.7 and 3.8, groundwater discharges to the proposed extension area are conceptualised as likely to be low.

Figure 3.15a: View looking north east, showing extraction area with dry floor/walls, and sump (16/12/2019)

Figure 3.15b: View looking north east, showing extraction area with relatively larger sump that has transitioned to east (16/12/2019)

3.12 Existing drawdown

Based on existing observations, groundwater drawdown associated with the existing extraction area is likely to be limited in extent to within a few hundred metres of extraction.

3.13 Groundwater Dependent Ecosystems

The occurrence of potential GDEs was assessed through review of the BoM's GDE Atlas (BOM, 2020b), mapping within the Albion Park Rail Bypass groundwater report (RMS, 2015) and high priority GDE mapping in the Water Sharing Plan (WSP) (NSW Government, 2011a). Additionally, a site inspection was undertaken 16 – 17 December 2019.

3.13.1 BoM (2020b) Terrestrial GDEs

Low and moderate potential terrestrial GDEs are mapped in the south and east of Stage 7 area, and to the east, west and south. There are some small areas of land mapped as 'high potential GDE', including a small area near the eastern boundary of the Stage 7 area and a small area about 200m south west of the Stage 7 area. This mapping is shown in **Figure 3.16**.

3.13.2 BoM (2020b) Aquatic GDEs

There are no mapped potential aquatic GDEs within 1km of the Stage 7 area. Further afield, Lake Illawarra is mapped as a 'moderate potential GDE' and there are small water bodies formed from former sand dredging operations south east of the Project Area which are mapped as low to high potential GDEs. This mapping is shown in **Figure 3.16**.

3.13.3 Albion Park Rail bypass EIS

RMS (2015) mapped GDEs to the north-north west of the Stage 7 area. The GDEs comprise SEPP14 wetlands, including wetlands at Croom Voluntary Conservation Area, Macquarie Rivulet and north of Macquarie Rivulet, freshwater wetlands and Illawarra Lowlands Grassy Woodland. The nearest mapped GDE comprises a very small freshwater wetland, which is approximately 1.5km north west of the Stage 7 area.

It is noted that the proposed Stage 7 area is located in the south eastern corner of the mapping extent. Therefore, this study has not mapped GDEs south or east of the proposed Stage 7 area.

3.13.4 WSP High Priority GDEs

There are no High Priority GDEs close to the Project Area. The nearest High Priority GDEs are Macquarie Rivulet and the Minnamurra River Estuary (**Figure 3.16.**), which are greater than 3 km from the Project Area.

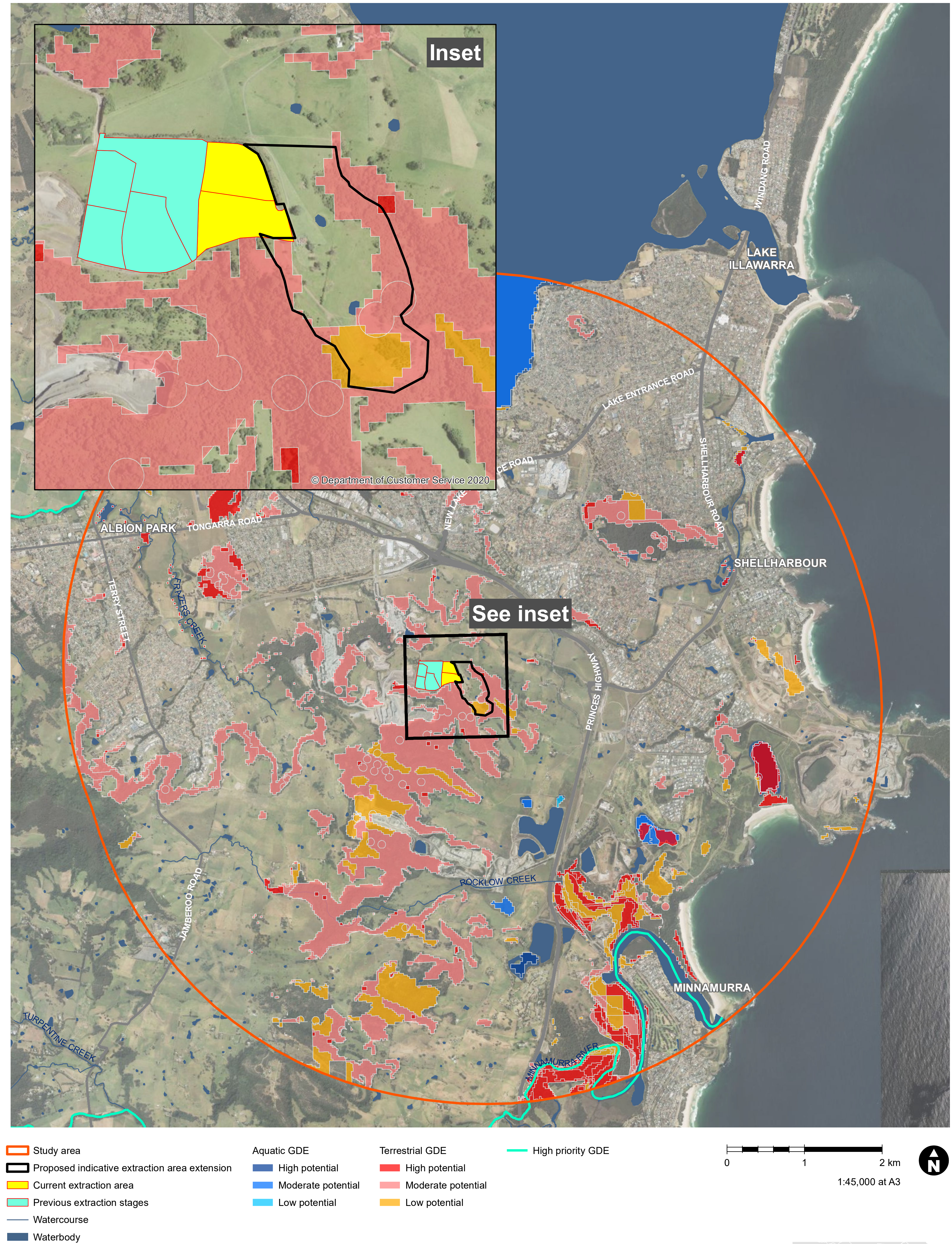
3.13.5 Springs

Springs are discussed in Section 3.11.1.

3.13.6 Site inspection

The drainage line/waterfall downgradient of MW1S/MW1D (i.e. near start of Watercourse 3, refer **Figure 3.3**) was inspected. No pooled water or any seepage was observed.

The vegetated area mapped as ‘High potential GDE’ by the BoM (2020b) to the east of Stage 7 was partially inspected. The area was difficult to traverse due to thick lantana coverage. However, animal tracks through the lantana enabled some limited access. The areas inspected did not appear to host areas of potential GDEs. Jacobs staff were able to inspect the vegetation in western portion of the area mapped as ‘High potential GDE’ by the BoM (2020b), but were unable to access the entire area, including the drainage line, due to lantana that was impassable. Of the areas inspected, the likelihood of GDEs was considered low and extensive lantana was observed.



Data sources

Jacobs 2019
NSW Spatial Services 2019
BOM 2019

GDA94 MGA56

Figure 3.16 Study area and Groundwater Dependent Ecosystems

Date: 7/05/2021 Path: J:\IE\Sales\04_Eastern\Sydney_SALES_SUPPORT\00 Proposals\1907 - RW Corkery & Co - Albion Park Quarry Extension\Data\GIS\22_Spatial\GIS\Directory\Templates\Figures\IAXXXXX_GIS_F002_GDE_r2v1.mxd
Created by : XX | QA by : XX

4. Conceptualisation

A conceptual hydrogeological model is a descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions. A conceptual model consolidates the current understanding of the key processes of the groundwater system, including the influence of stresses, and assists in the understanding of possible future changes.

4.1 Conceptual hydrogeological model

The conceptual hydrogeological model for the Project is summarised as follows:

- There are two broad groundwater systems applicable to the Quarry:
    - A shallow (i.e. <10 mBGL) water table system is generally consistent in the area of the Quarry, which is most likely associated with an upper weathered zone in the latite and agglomerate.
    - Intermediate depth groundwater unconfined to semi-confined systems (in the latite and agglomerate) underlying the shallow water table system, with the flow in these systems almost exclusively dependent on fracture/defect extent and unit contact planes (i.e. contact of latite and agglomerate).

Additionally, deep semi-confined to confined groundwater systems within Kiama Sandstone are conceptualised to underly the intermediate depth groundwater systems. However, these groundwater systems are of little relevance as extraction of the sandstone is not proposed for the Project.

- Due to inferred poorly connected fracture flow paths and negligible matrix hydraulic conductivity (except for possibly the sandstone), there is poor hydraulic connection between:
    - The water table and underlying intermediate and deep groundwater systems.
    - The intermediate groundwater systems themselves.
    - The deep sandstone groundwater system and overlying intermediate system.
- Preferential flow could occur at the interface of the latite/agglomerate and lower latite/sandstone. However, groundwater monitoring bores MW2D, MW5 and MW6, which have screens that span across latite/agglomerate contact(s), do not have distinctly different estimates of hydraulic conductivity (Section 3.7).
- The latite and agglomerate matrix hydraulic conductivity, fracture and contact plane hydraulic conductivity and storage is sufficiently low that ‘aquifers’ in these systems are unlikely to exist. The lack of groundwater inflow (aside from flow from the lower latite and sandstone contact) to the current extraction area evidences this.
- Low hydraulic conductivity typically of the order of 10^{-4} to 10^{-3}, although the variations beyond this are expected due to local fracture conditions
- Low storage of the order of 0.01 and 1×10^{-6} for specific yield and specific storage respectively
- Groundwater flow direction is similar to broad topography trend, with rainfall recharge occurring in areas of high elevation and discharge occurring in the midslope areas (at springs), foothills and drainage lines.
- Low rainfall recharge rate
- Springs exist in the area upslope of the Project Area and occur where the shallow groundwater system discharges to the surface. However, these springs are associated with shallow infiltration processes and operate independently from deeper groundwater processes.
- Groundwater is discharging to the current extraction area but at very low rates
- Baseflow may occur to watercourses but is likely to be at low rates

- Negligible groundwater extraction from existing registered bores within the vicinity of the Project
- Fresh to slightly brackish water (Freeze and Cherry, 1979).
- Based on observations from the current extraction area, groundwater inflows for the Project are anticipated to be low and groundwater level drawdown likely to be limited to be few hundred metres of the extraction area. Thus, cumulative impacts from other nearby quarries are not likely.

4.2 Conceptual hydrogeological cross sections

Conceptual hydrogeological cross sections are provided for the locations shown in **Figure 4.1**. The cross sections are shown in **Figure 4.2** and **Figure 4.3** and were developed in geological modelling software, Leapfrog, by creating 50 m resolution meshes from 3D contour lines of Upper Latite, agglomerate and Lower Latite layers that were provided by Cleary Bros. The cross sections simplify the geology and are considered suitable for demonstrating conceptual hydrogeology.

It is noted that in some locations, such as MW6, there are more agglomerate layers than depicted in the conceptual sections. For instance, at MW6 there are two separate agglomerate layers separated by an 8 m thick latite interval.

Also, in **Figure 4.2**, the sandstone is shown as close to the base of MW1S. However, MW1D (not shown on section), located adjacent to MW1S, extended to 25 mBGL and the rock type below the latite was logged as “tuff” from 14.5 to 25 mBGL. This was likely an error in rock type identification and the “tuff” is likely to be an altered sandstone. Thus, the actual level of the sandstone in this location is lower than indicated by the cross section. The discrepancy could be due to coarse mesh resolution in the Leapfrog model and/or inaccuracy in the initial 3D contours in this isolated area. Notwithstanding this, the cross sections are considered suitable for demonstrating conceptual hydrogeology, particularly in the area of Stage 7 as numerous resource definition drill holes located in this area where used by Cleary Bros to create the 3D contour lines.

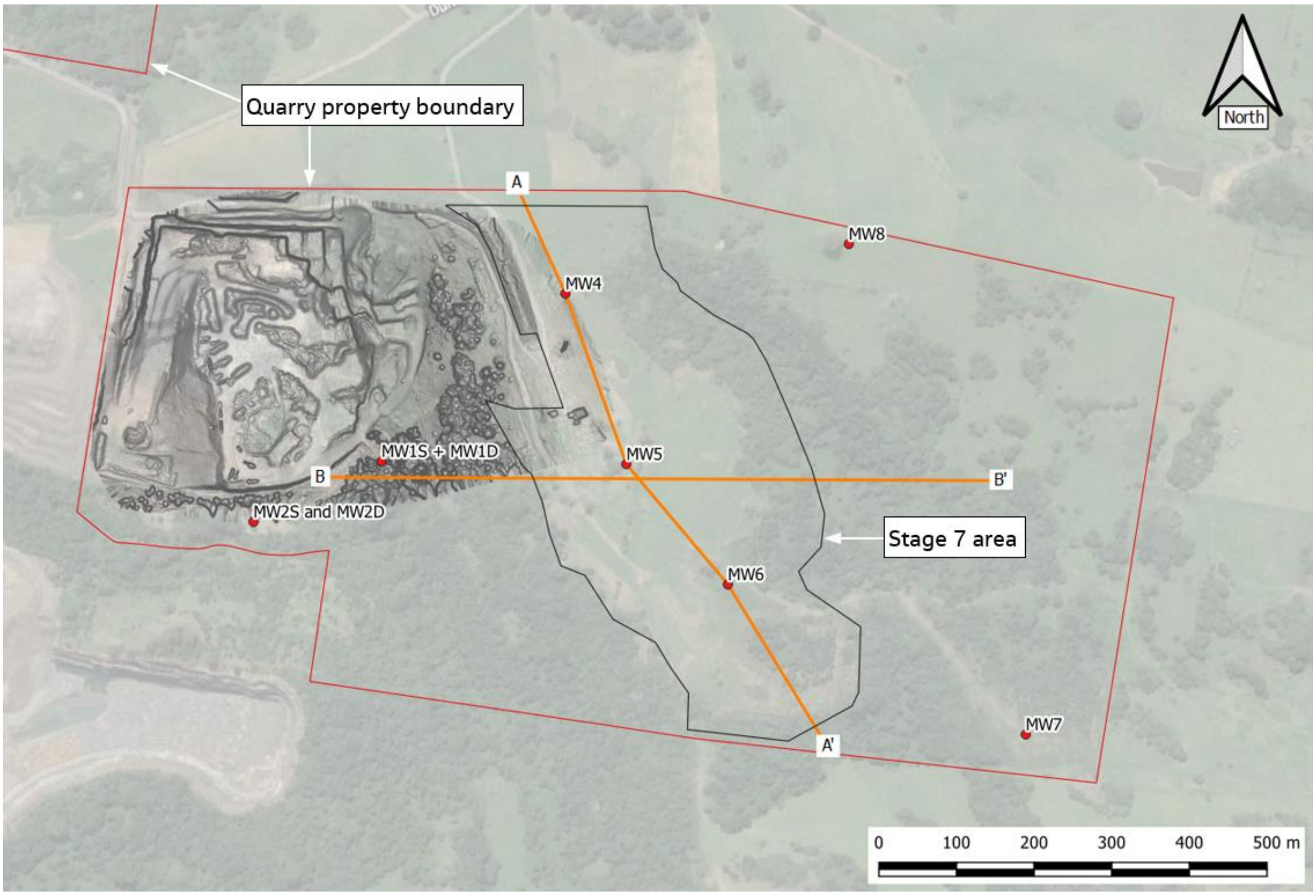


Figure 4.1: Conceptual hydrogeological cross section locations

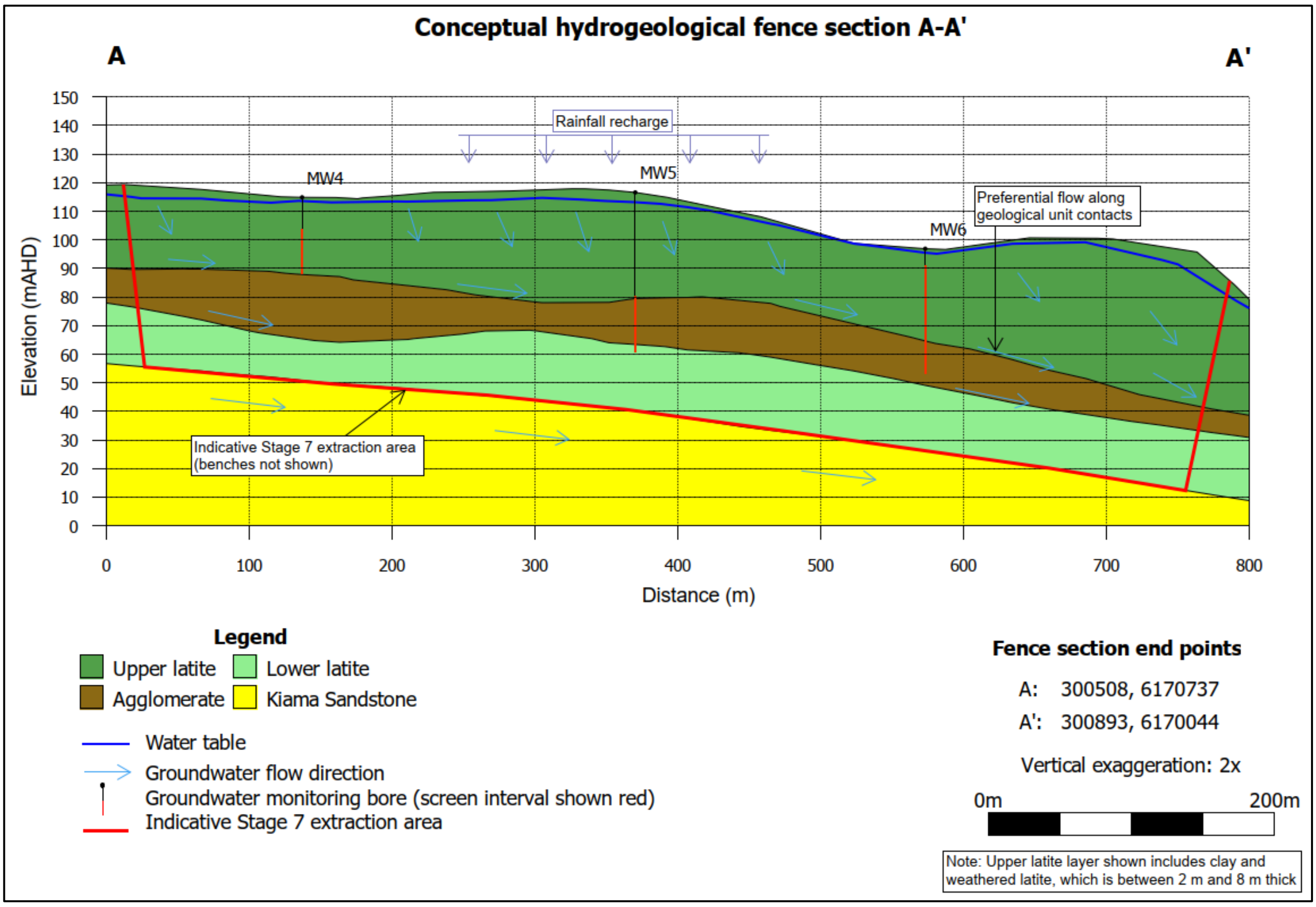


Figure 4.2: Conceptual hydrogeological fence section A-A'

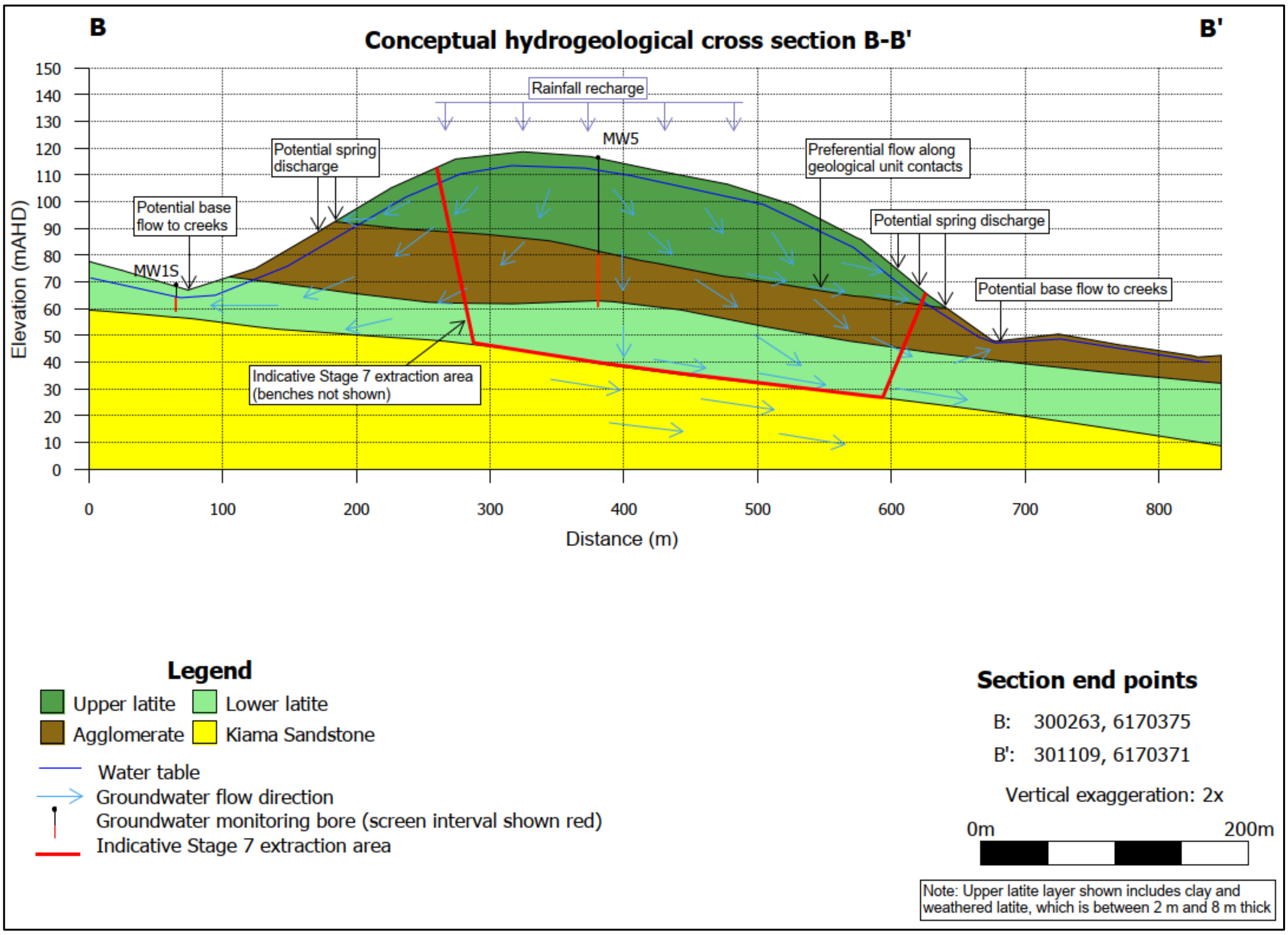


Figure 4.3: Conceptual hydrogeological cross section B-B'

5. Groundwater impact assessment

This section presents the results of the groundwater impact assessment. Results pertaining to groundwater inflow rates, groundwater level drawdown and baseflow reduction have been calculated by a numerical groundwater flow model. Full documentation of the numerical groundwater model's development, calibration and results is provided in Appendix B.

5.1 Groundwater inflow rates

Modelled groundwater inflow rate for the existing extraction area was 38 kL/d (**Table 5.1**). This modelled rate aligns with the lack of observed seepage to the extraction area, as a rate of 38 kL/d would readily evaporate in the site climatic conditions. Modelled groundwater inflow rates at the end of each Stage 7 extraction area is also provided in **Table 5.1**. Groundwater inflow rates increase as the extraction progresses and peaks at about 187 kL/d at the end of Stage 7d. One hundred years after quarrying has ceased, the groundwater inflow rate is 185 kL/d. Groundwater inflow rates at the end of each model period are plotted in **Figure 5.1**.

It is noted that as dewatering will be achieved via pumping from sumps within the extraction area, there is potential for significant evaporative losses as groundwater seeps from exposed faces or is directed around active work areas towards dewatering sumps. While these evaporative losses cannot be readily quantified, there is potential that the volume of active dewatering required, may be somewhat less than the modelled groundwater inflow rates.

Table 5.1: Modelled groundwater inflow rate

Extraction Stage	Model time (d)	Groundwater inflow rate (kL/d)
Existing extraction area	1	38
End of Stage 7a	4,381 (12 yrs)	125
End of Stage 7b	6,389 (17.5 yrs)	134
End of Stage 7c	10,040 (27.5 yrs)	149
End of Stage 7d	13507 (37 yrs)	187
100 years after extraction completed	50,011 (137 yrs)	185

Uncertainty analysis was undertaken to assess the effect of individually varying model input parameter values on model predictions and is documented in Appendix B. The results from uncertainty analysis model runs do not vary considerably from the base case results. The minimum and maximum groundwater inflow rate out of all the uncertainty scenarios was 106 kL/d and 259 kL/d, respectively. These minimum and maximum groundwater inflow rates are about 43% and 39% lower and higher than the base case rate.

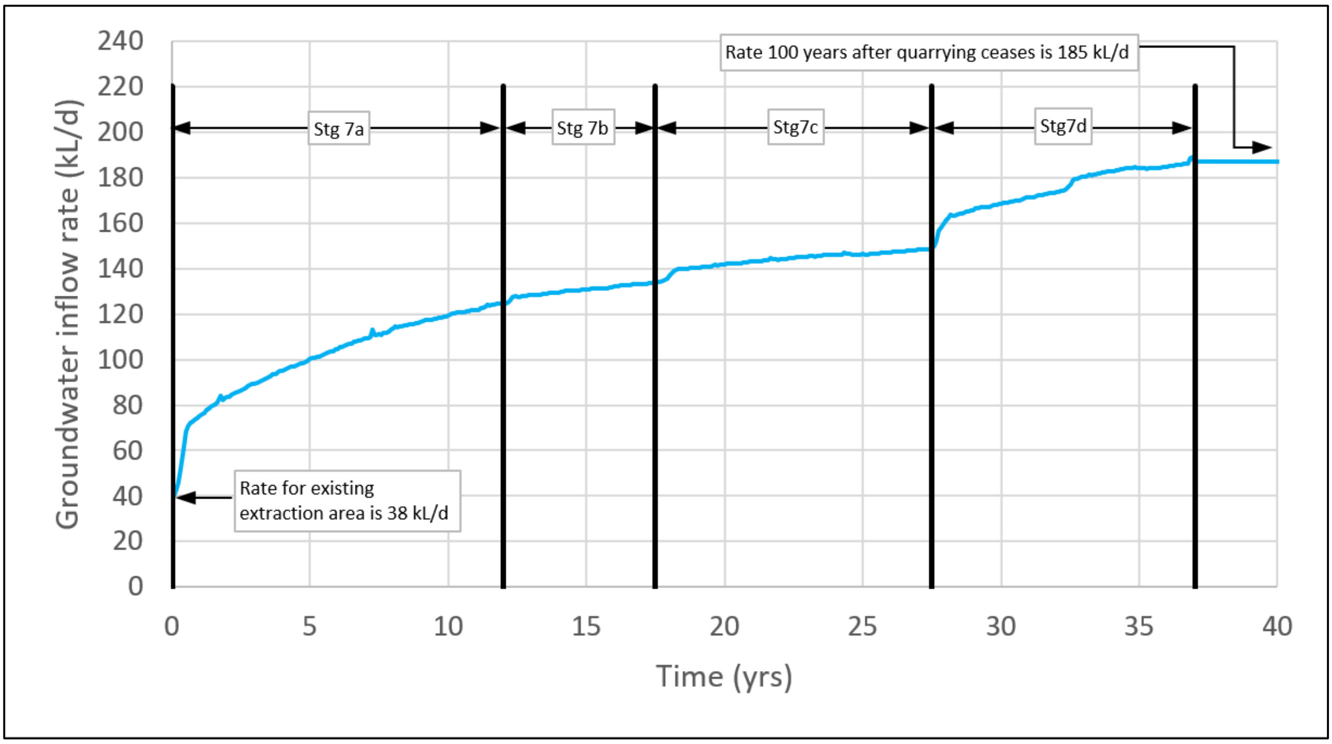


Figure 5.1: Modelled groundwater inflow rate

5.2 Groundwater level drawdown

Groundwater level drawdown at the end of quarrying (i.e. end of Stage 7d) is shown in **Figure 5.2**. 0.1 m contours from a geodetic survey undertaken in April 2019 are also shown in **Figure 5.2** for the eastern portion of the Project Area and convey the extent of the existing extraction area.

The 2 m groundwater level drawdown extends about 50 m to 250 m from the extraction areas. The 2 m drawdown contour is generally offset from the Stage 7 extraction areas by about 150 m.

At the end of the 100 year post-quarrying period, modelled drawdown would be similar because the groundwater inflow rate to the extraction area is very similar (i.e. 185 kL/d compared to 187 kL/d).

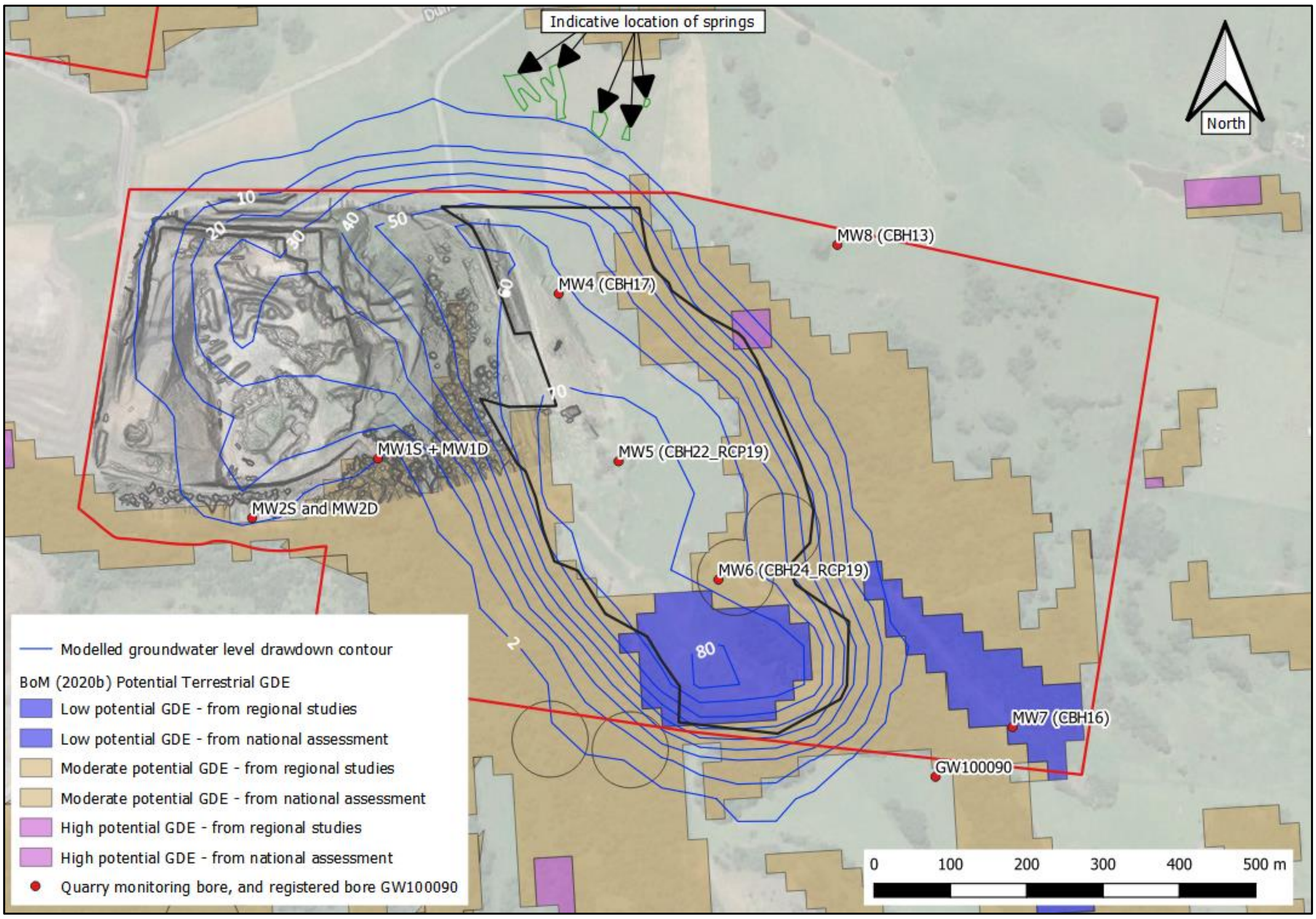


Figure 5.2: Modelled groundwater level drawdown at end quarrying (i.e. end of Stage 7d)

Uncertainty analysis was undertaken to assess the effect of individually varying model input parameter values on model predictions and is documented in Appendix B. The results from uncertainty analysis model runs do not vary considerably from the base case results. The 2 m drawdown contours plot similarly for all of the uncertainty runs. There is a maximum difference in the position of the 2 m drawdown contour of about 100 m.

5.2.1 Existing registered bores

The modelled 2 m drawdown contour does not encroach on any existing registered bore. The same is true for all model runs undertaken to assess uncertainty in the predictions.

5.2.2 BoM (2020b) Potential Terrestrial GDEs

The modelled groundwater level drawdown encroaches on areas mapped as low, moderate and high potential GDE. The maximum drawdown of about 80 m occurs in an area mapped as low potential GDE. A square shaped area mapped as high potential GDE near the eastern boundary of Stage 7 is located in an area where drawdown of about 20 m to 2 m is predicted. The majority of the predicted drawdown range (i.e. 60-70 m to 2 m) occurs in areas mapped as moderate potential GDE to the east, west and south of Stage 7.

The predicted drawdown is not anticipated to impact ecosystems mapped as potential GDEs. This is because groundwater potentially applicable to such ecosystems is conceptualised to be shallow and poorly connected to underlying deeper groundwater systems. It is anticipated that shallow groundwater flow systems would not be impacted by the Project.

5.2.3 High Priority GDEs

The modelled drawdown does not encroach on any mapped High Priority GDEs.

5.2.4 Springs

The modelled 2 m drawdown contour does not encroach on the mapped springs to the north of the Stage 7 area, despite approaching these springs. These springs are assessed as unlikely to be impacted by groundwater level drawdown as they are conceptualised to be controlled by shallow groundwater flow systems that are poorly connected to underlying deeper groundwater systems. This same characterisation was adopted by EMM (2016) for springs at nearby Dunmore Quarry and was evidenced by water quality analysis that showed that the springs in that area relied on shallow younger localised rainfall recharge and not deeper groundwater systems. The EMM (2016) assessment concluded that those springs would not be influenced by groundwater level drawdown as they rely on localised rainfall recharge. The same assessment is made for the Project.

5.3 Baseflow reduction

Groundwater level drawdown has potential to reduce baseflows to watercourses in the vicinity of the Project Area. This could occur due to the Project intercepting groundwater that would otherwise discharge to watercourses. Modelled baseflow reductions to watercourses in the vicinity of the Project Area is shown in **Figure 5.3** and ranges from less than 1 kL/d in early years of the Project before steadily increasing to peak of less than 5 kL/d.

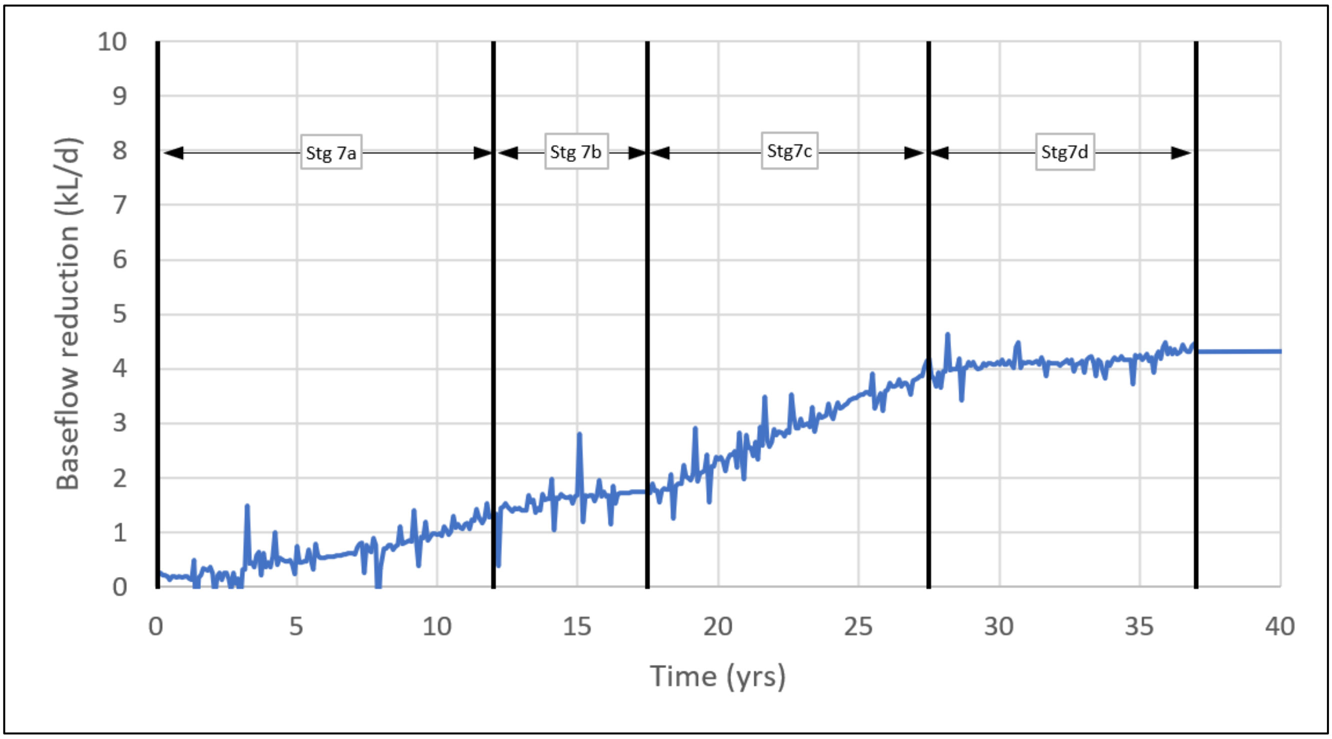


Figure 5.3: Modelled baseflow reduction rate

5.4 Water licensing

Without partition of groundwater and surface water take, based on the maximum groundwater inflow rate of up to 187 kL/d, an annual groundwater entitlement for a volume of 68 ML will be required from the Sydney Basin South Groundwater Source of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011. There is ample water available in this source to facilitate this (refer Section 2.2.1). Cleary Bros intend to apply for sufficient uncommitted entitlements to cover this requirement in the upcoming Controlled Allocation Order.

Due to some small baseflow reductions (maximum less than 5 kL/d), if the groundwater and surface water take is partitioned, annual entitlement of 2 ML would be required from the Minnamurra River Management Zone of the Illawarra Rivers Water Source of the Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011 to cover the baseflow reduction. With partitioning, the annual groundwater entitlement would be 2 ML less and therefore 66 ML. The takes associated with groundwater inflow and baseflow reduction would occur in perpetuity and are discussed in Section 5.6. Cleary Bros intend to secure the required entitlements for the Minnamurra River Management Zone through the purchase of existing entitlements on the open market.

5.5 Groundwater quality

The Project is assessed as unlikely to lower the groundwater beneficial use category beyond a distance of 40 m of the Project Area, which is an AIP (DPI, 2012) Minimal Impact Consideration criterion.

Although considered low risk, groundwater could become contaminated if accidental spills or leaks of hazardous materials (such as fuels, lubricants and hydraulic oils) occur during extraction.

Potential contamination impacts are assessed as low risk and would be mitigated as discussed in Section 6.1.

5.6 Final void

Groundwater impacts after project completion are assessed as likely to be practically the same as those applicable at the end of extraction.

It is considered unlikely that groundwater inflows would provide significant contribution to the formation of a potential pit lake following completion of extraction. The estimated groundwater inflow rates are low relative to the extraction area’s evaporation potential. The final landform of the completed quarry is further described in Section 3 of the Project EIS and would likely include a permanent or semi-permanent water feature collecting surface water running from much of the extraction area. The extent of this potential water feature would be primarily controlled by surface water rather than groundwater.

5.7 NSW AIP Minimal Impact Considerations Summary

Predicted groundwater level and quality reductions are less than the AIP (DPI, 2012) Minimal Impact Considerations (see Section 2.3).

6. Management and mitigation measures

Management and mitigation measures applicable to groundwater are outlined below in Sections 6.1, 6.2 and 6.3.

6.1 Potential contamination

If accidental spills or leaks occur, potential impacts would be minimised through the implementation Cleary Bros spill response procedures. These include training and standard practices for the control, containment, and clean up of any hydrocarbon or chemical spill. Furthermore, a Pollution Incident Response Management Plan will be maintained throughout the life of the Project in line with Environment Protection Licencing requirements which includes protocols for communicating pollution incidents with potentially affected parties.

The Project's groundwater monitoring program (Section 6.3) would also be used to identify contamination attributable to quarrying.

6.2 Impacts at existing registered bores

Although no significant drawdown is predicted to occur at any existing registered bore used for water extraction, bore GW100090 is considered somewhat close (about 160 m) to the Project Area. In accordance with the AIP (DPI, 2012) Minimal Impact Considerations, if this bore is impacted (beyond the Minimal Impact Considerations) by Project induced groundwater level drawdown, then make good previsions would apply. Under these conditions, the impacted bore would be replaced with a deeper bore or bore in a new position.

6.3 Groundwater monitoring program

Ongoing groundwater monitoring would occur during the Project's operational period at MW1S, MW1D, MW2S, MW2D, MW7 and MW8 indefinitely, as these bores will remain outside of the extraction area. Bores MW4, MW5 and MW6 would also be monitored during the Project but only up until their decommissioning due to being encroached by the extraction area. Once decommissioned, MW4, MW5 and MW6, would not be replaced.

Monitoring after extraction has ceased would be determined based on assessment of conditions at the end of the Project's operational period.

Groundwater level and quality monitoring for the Project is outlined in **Table 6.1**.

The groundwater quality monitoring analytes proposed for the Project's groundwater monitoring program are the same as those within the currently approved monitoring program (Cardno, 2018) for the existing quarry except for the following:

- Alkalinity is now speciated
- Magnesium has been added to the major cations
- Nitrate and total nitrogen added to the nitrogen analysis
- Manganese added to the dissolved heavy metals analysis
- Initially, all dissolved heavy metals are now to be tested regardless of EC levels. Previously, the extent of the dissolved heavy metals analysis depended on the EC.

  During the course of the monitoring, if concentrations of particular dissolved heavy metals are frequently below the limit of reporting at relatively low EC levels, then EC triggers may be developed, whereby a reduced dissolved heavy metals suite is analysed at low EC levels and the extended dissolved heavy metals suite analysed at relatively higher EC levels.

Table 6.1: Groundwater level and quality monitoring for the Project

Bore	Timing	Monitoring
Groundwater level monitoring		
MW1S, MW1D, MW2S, MW2D	Throughout entire Project	Dip meter, quarterly interval
MW7 and MW8		Data logger, 6 hourly interval, quarterly data download
MW4, MW5 and MW6	Up until decommissioning due to encroachment by the extraction area	Data logger, 6 hourly interval, quarterly data download
Groundwater quality monitoring		
MW1S, MW1D, MW2S, MW2D, MW7, MW8	Throughout entire Project	Quarterly analysis of: ▪ EC (to be analysed in field) ▪ pH (to be analysed in field) ▪ Temperature (to be analysed in field) ▪ Dissolved oxygen (to be analysed in field) ▪ Redox (to be analysed in field) ▪ TDS ▪ Nitrogen species (nitrate, nitrate, ammonia, TKN, total nitrogen) ▪ Total phosphorus ▪ Oil and grease ▪ Biological oxygen demand ▪ Total organic carbon ▪ Dissolved heavy metals (arsenic, copper, cadmium, chromium, iron, lead, mercury, nickel, zinc and manganese) ▪ Alkalinity (bicarbonate, carbonate and hydroxide) ▪ Major cations (sodium, potassium, calcium, magnesium) ▪ Major anions (sulfate, chloride, remainder included under alkalinity category)
MW4, MW5 and MW6	Up until decommissioning due to be encroached by the extraction area	

- Sampling frequency now quarterly (formerly twice per year)
- Total suspended solids have been removed from the groundwater analyses. This parameter is not considered very relevant to groundwater.
- Dissolved oxygen and redox have been added to the analysis as field parameters.

The groundwater monitoring program results would be assessed and reported in the Annual Review.

7. Conclusion

A groundwater impact assessment has been undertaken to assess potential impacts to groundwater due to the extension of the existing Quarry. The assessment was undertaken to support the EIS for the Project.

The groundwater impact assessment included:

- Review of relevant legislation, policy, guidelines and licences.
- Review of the Project's environmental setting, including development of a conceptual hydrogeological model.
- Calculation of groundwater inflows to the extraction area, groundwater level drawdown and baseflow reduction using an industry standard numerical groundwater flow model, MODFLOW.
- Assessment of potential impacts to groundwater due to the Project.
- Development of groundwater related mitigation and management measures.

The groundwater flow model calculated low groundwater inflow rates, a limited drawdown extent and small reductions to baseflow volume. The base case model predicts:

- a maximum groundwater inflow rate of up to 187 kL/d
- a 2 m drawdown contour that extends approximately 50 m to 250 m from the quarry's extraction areas
- a baseflow reduction to watercourses ranging from less than 1 kL/d in early years of the Project to a peak of less than 5 kL/d in later years of the Project.

Uncertainty analysis was undertaken to assess the effect of individually varying model input parameter values on model predictions. The results from uncertainty analysis model runs do not vary considerably from the base case results.

The model's predictions align with observations from the existing quarry, where drawdown extent is limited and groundwater inflows are very low (except for the sump, groundwater is generally not observed on the existing pit floor or side walls).

Identified springs are assessed as unlikely to be impacted by the Project, as they likely rely on localised rainfall recharge.

Potential groundwater impacts due to the Project were assessed against the NSW Aquifer Interference Policy's Minimal Impact Considerations. The 2 m groundwater level drawdown contour does not encroach on any existing registered bores used for water supply, nor are high priority GDEs subjected to drawdown. There are no mapped (NSW Government, 2011a) High Priority GDEs close to the Project. The closest mapped (NSW Government, 2011a) High Priority GDEs are located greater than 3 km from the Project Area. Also, the Project is unlikely to lower groundwater quality and reduce the beneficial use category of the groundwater source beyond 40 m of the Project Area. Potential impacts to groundwater due to the Project are assessed to be less than the NSW Aquifer Interference Policy's Minimal Impact Considerations.

With regards to water licensing, based on the maximum groundwater inflow rate of up to 187 kL/d, an annual groundwater entitlement of 68 ML will be required from the Sydney Basin South Groundwater Source of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011. Due to some small baseflow reductions (maximum less than 5 kL/d), if the groundwater and surface water take is partitioned, annual entitlement of 2 ML would be required from the Minnamurra River Management Zone of the Illawarra Rivers Water Source of the Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011 to cover the baseflow reduction. With partitioning, the annual groundwater entitlement would be 2 ML less, and therefore 66 ML. The takes associated with groundwater inflow and baseflow reduction would occur in perpetuity. That is, a WAL for 66 ML is required from the Sydney Basin South Groundwater Source of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011, and 2 ML is required from the Minnamurra River Management Zone of the Illawarra Rivers Water Source of the Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011. Entitlements for the Minnamurra River Management Zone will be secured through the purchase of existing entitlements on the market, while entitlements for the Sydney Basin South Groundwater Source will be secured through the upcoming Controlled Allocation Order.

It is considered unlikely that groundwater inflows would provide significant contribution to the formation of a potential pit lake following completion of quarrying. The estimated groundwater inflow rates are low relative to the extraction area's evaporation potential. The final landform of the completed quarry is further described in Section 3 of the Project EIS and would likely include a permanent or semi-permanent water feature collecting surface water running from much of the extraction area. The extent of this potential water feature would be controlled by surface water rather than groundwater.

Management and mitigation measures are outlined in the report, including recommendations for ongoing groundwater monitoring.

The Project is considered to constitute a low risk to groundwater systems.

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Appendix A. Groundwater quality results summary

Water Quality Data Table

		NA		Metals										
		Electrical Conductivity (EC)	Temp	Arsenic (filtered)	Cadmium (filtered)	Chromium (III+VI)	Chromium (III+VI) (filtered)	Copper (filtered)	Iron (filtered)	Lead (filtered)	Magnesium (filtered)	Manganese (filtered)	Mercury (filtered)	Nickel (filtered)
		µS/cm	Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L
EQL		1		1	0.1		1	1	10	1	0.5	5	0.05	1
ANZECC 2000 SE Aust Triggers - Lowland River		125-2200												
ANZG (2018) Freshwater 95% toxicant DGVs					$0.2^{\#1}$			$1.4^{\#1}$		$3.4^{\#2}$		$1{,}900^{\#3}$	$0.6^{\#4}$	$11^{\#4}$
Location Code	Date													
MW1D	1/12/2008	1,100	27.3	-	<10	<10	-	<10	250	<10	-	-	<1	<10
MW1D	1/06/2009	1,300	15.1	<10	<10	<10	-	<10	520	<10	-	-	<10	<10
MW1D	1/12/2009	1,200	19.5	<10	<10	<10	-	<10	180	<10	-	-	<10	10
MW1D	1/06/2010	820	16.3	1	0.2	<1	-	13	<50	3	-	-	<0.1	16
MW1D	1/12/2010	490	19.3	2	0.2	<1	-	22	1,070	47	-	-	<0.1	9
MW1D	1/08/2011	110	17.9	<1	<0.1	<1	-	10	90	2	-	-	<0.1	3
MW1D	1/12/2011	140	17.7	<1	<0.1	<1	-	11	<50	<1	-	-	<0.1	3
MW1D	1/06/2012	389	13.5	<1	<0.1	<1	-	10	<50	<1	-	-	<0.1	2
MW1D	1/12/2012	160	18.8	<1	<0.1	<1	-	13	50	<1	-	-	<0.1	5
MW1D	1/06/2013	161	18.1	-	-	-	-	6	820	-	-	-	-	4
MW1D	1/12/2013	173	18.1	-	-	-	-	6	1,140	-	-	-	-	5
MW1D	1/06/2014	211	17.5	-	-	-	-	12	1,060	-	-	-	-	11
MW1D	1/12/2014	380	19.1	-	-	-	-	2	970	-	-	-	-	6
MW1D	1/06/2015	620	17.3	-	-	-	-	27	110	-	-	-	-	12
MW1D	1/12/2015	612	18.7	-	-	-	-	7	110	-	-	-	-	17
MW1D	1/06/2016	720	17.4	-	-	-	-	13	290	-	-	-	-	18
MW1D	6/12/2016	948	18.8	-	-	-	-	5	340	-	-	-	-	24
MW1D	2/06/2017	1,080	17.3	-	-	-	-	19	300	-	-	-	-	33
MW1D	4/09/2017	1,140	17.8	-	-	-	-	<1	130	-	-	-	-	24
MW1D	5/12/2017	1,160	21.4	-	-	-	-	2	<50	-	-	-	-	25
MW1D	6/03/2018	1,230	19.4	-	-	-	-	<1	270	-	-	-	-	30
MW1D	5/06/2018	1,300	17.9	3	<0.1	<1	-	<1	80	<1	-	-	<0.1	24
MW1D	26/09/2018	1,460	15.3	3	<0.1	2	-	1	80	<1	-	-	<0.1	20
MW1D	6/12/2018	1,450	23.5	4	<0.1	<1	-	<1	<50	<1	-	-	<0.1	20
MW1D	5/03/2019	1,600	23.2	2	<0.1	<1	-	<1	60	<1	-	-	-	19
MW1D	27/06/2019	1,820	18	3	0.1	<1	-	4	<50	2	-	-	<0.1	19
MW1D	6/09/2019	1,760	20.8	1	<0.1	<1	-	<1	<50	1	-	-	<0.1	17
MW1D	6/12/2019	1,900	23.8	2	<0.1	<1	-	<1	<50	1	-	-	1	16
MW1D	16/12/2019	1,800	-	3	<0.1	-	<1	<1	19	<1	6.5	190	<0.05	17
MW1D	3/06/2020	2,500	18.3	1	<0.1	<1	-	2	<50	<1	-	-	<0.1	21
MW1D	4/08/2020	1,060	18.2	-	-	-	-	-	-	-	-	-	-	-
MW1D	22/09/2020	1,710	22.5	<1	<0.1	<1	-	2	<50	<1	-	-	<0.1	3
MW1D	23/11/2020	1,120	21.6	-	-	-	-	-	-	-	-	-	-	-
MW1S	1/06/2009	800	14.9	<10	<10	<10	-	<10	580	<10	-	-	<10	<10
MW1S	1/12/2009	1,500	18.9	<10	<10	<10	-	<10	1,800	<10	-	-	<10	<10
MW1S	1/06/2010	1,560	16.4	5	<0.1	<1	-	5	<50	<1	-	-	<0.1	4
MW1S	1/12/2010	280	19.4	6	0.2	<1	-	78	3,130	10	-	-	<0.1	4
MW1S	1/08/2011	700	15.2	1	<0.1	<1	-	16	<50	<1	-	-	<0.1	2
MW1S	1/12/2011	1,110	18	4	<0.1	<1	-	3	710	<1	-	-	<0.1	2
MW1S	1/06/2012	211	16.7	<1	<0.1	<1	-	52	90	<1	-	-	<0.1	3
MW1S	1/12/2012	659	18.4	3	<0.1	<1	-	20	<50	<1	-	-	<0.1	3
MW1S	1/06/2013	248	17.5	-	-	-	-	42	110	-	-	-	-	3
MW1S	1/12/2013	433	18.5	-	-	-	-	32	<50	-	-	-	-	1
MW1S	1/06/2014	983	17.9	-	-	-	-	12	770	-	-	-	-	4
MW1S	1/12/2014	255	18.6	-	-	-	-	22	160	-	-	-	-	2
MW1S	1/06/2015	1,540	17.9	-	-	-	-	15	<50	-	-	-	-	2
MW1S	1/12/2015	1,360	17.8	-	-	-	-	4	2,120	-	-	-	-	2
MW1S	1/06/2016	1,480	18	-	-	-	-	5	5,540	-	-	-	-	2
MW1S	1/12/2016	1,610	18.9	2	<0.1	<1	-	9	110	<1	-	-	<0.1	2
MW1S	1/06/2017	1,660	17.9	4	<0.1	<1	-	5	1,760	<1	-	-	<0.1	3
MW1S	1/09/2017	1,600	18.1	6	<0.1	<1	-	3	660	<1	-	-	<0.1	2
MW1S	1/12/2017	451	22.1	-	-	-	-	13	60	-	-	-	-	2
MW1S	1/03/2018	825	19.8	-	-	-	-	15	<50	-	-	-	-	3
MW1S	1/06/2018	1,230	18.6	-	-	-	-	16	<50	-	-	-	-	3
MW1S	1/09/2018	1,740	15.5	1	<0.1	1	-	17	<50	<1	-	-	<0.1	4
MW1S	1/12/2018	1,700	23.1	2	<0.1	<1	-	11	3	<1	-	-	<0.1	73
MW1S	1/03/2019	1,770	24.9	4	<0.1	<1	-	7	520	<1	-	-	-	4
MW1S	17/12/2019	1,700	-	10	<0.1	-	<1	4	1,900	<1	63	1,800	<0.05	2
MW1S	4/03/2020	2,040	20.6	<1	<0.1	1	-	16	<50	<1	-	-	-	1
MW1S	3/06/2020	1,960	18.6	<1	<0.1	<1	-	22	<50	<1	-	-	<0.1	1
MW1S	6/09/2020	1,800	24.1	5	<0.1	<1	-	<1	260	<1	-	-	<0.1	3
MW1S	22/09/2020	1,440	19.2	-	-	-	-	18	70	-	-	-	-	<1
MW1S	23/11/2020	994	21.6	-	-	-	-	-	-	-	-	-	-	-
MW1S	6/12/2020	1,800	24.9	<1	<0.1	<1	-	13	<50	<1	-	-	<0.1	3
MW2D	1/06/2009	1,800	15	<10	<10	<10	-	<10	580	<10	-	-	<10	<10
MW2D	1/12/2009	250	19	<10	<10	<10	-	<10	240	<10	-	-	<10	<10
MW2D	1/06/2010	500	15.9	<1	0.1	1	-	15	780	2	-	-	<0.1	4
MW2D	1/12/2010	950	19.6	<1	<0.1	<1	-	31	1,000	4	-	-	<0.1	4
MW2D	1/08/2011	1,080	17.6	<1	<0.1	<1	-	3	<50	<1	-	-	<0.1	1
MW2D	1/12/2011	140	18.3	<1	<0.1	<1	-	48	<50	<1	-	-	<0.1	2
MW2D	1/06/2012	322	15.7	<1	<0.1	<1	-	31	<50	<1	-	-	<0.1	3
MW2D	1/12/2012	333	19.8	<1	<0.1	<1	-	<1	460	<1	-	-	<0.1	2
MW2D	1/06/2013	411	17	-	-	-	-	13	<50	-	-	-	-	8
MW2D	1/12/2013	643	18.1	-	-	-	-	24	<50	-	-	-	-	8
MW2D	1/06/2014	856	17.4	-	-	-	-	13	<50	-	-	-	-	6
MW2D	1/12/2014	855	18.9	-	-	-	-	13	<50	-	-	-	-	6
MW2D	1/06/2015	894	16.6	-	-	-	-	32	<50	-	-	-	-	7
MW2D	1/12/2015	813	17.9	-	-	-	-	72	390	-	-	-	-	14
MW2D	1/06/2016	873	17.1	-	-	-	-	31	<50	-	-	-	-	11
MW2D	1/12/2016	1,880	18.7	2	0.4	<1	-	19	590	1	-	-	<0.1	7
MW2D	1/06/2017	2,010	16.4	<1	<0.1	<1	-	21	<50	<1	-	-	<0.1	4
MW2D	1/09/2017	1,990	18.1	<1	<0.1	<1	-	<1	640	<1	-	-	<0.1	1
MW2D	1/12/2017	1,840	21.9	1	0.1	<1	-	4	<50	<1	-	-	<0.1	2
MW2D	1/03/2018	1,890	18.1	<1	<0.1	<1	-	2	<50	<1	-	-	<0.1	3
MW2D	1/06/2018	1,860	16.9	2	<0.1	<1	-	<1	<50	<1	-	-	<0.1	3
MW2D	1/09/2018	1,960	14.7	2	<0.1	<1	-	2	260	2	-	-	<0.1	4
MW2D	1/12/2018	1,890	23.8	<1	<0.1	<1	-	3	<50	<1	-	-	<0.1	6
MW2D	1/03/2019	1,890	18.1	2	<0.1	<1	-	<1	70	<1	-	-	<0.1	4
MW2D	1/06/2019	1,990	17.2	3	<0.1	<1	-	2	<50	<1	-	-	0.2	4

Water Quality Data Table

		NA		Metals										
		Electrical Conductivity (EC)	Temp	Arsenic (filtered)	Cadmium (filtered)	Chromium (III+VI)	Chromium (III+VI) (filtered)	Copper (filtered)	Iron (filtered)	Lead (filtered)	Magnesium (filtered)	Manganese (filtered)	Mercury (filtered)	Nickel (filtered)
		µS/cm	Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L
EQL		1		1	0.1		1	1	10	1	0.5	5	0.05	1
ANZECC 2000 SE Aust Triggers - Lowland River		125-2200												
ANZG (2018) Freshwater 95% toxicant DGVs					0.2$^{\#1}$			1.4$^{\#1}$		3.4$^{\#2}$		1,900$^{\#3}$	0.6$^{\#4}$	11$^{\#4}$
Location Code	Date													
MW2D	17/12/2019	1,900	-	1	<0.1	-	<1	2	<10	<1	57	72	<0.05	3
MW2D	4/03/2020	1,770	21.3	-	-	-	-	3	<50	-	-	-	-	2
MW2D	3/06/2020	1,830	17.5	3	<0.1	<1	-	8	<50	<1	-	-	<0.1	3
MW2D	4/08/2020	1,710	17.4	-	-	-	-	-	-	-	-	-	-	-
MW2D	6/09/2020	1,820	22.8	2	<0.1	<1	-	2	<50	<1	-	-	<0.1	4
MW2D	22/09/2020	1,730	21.8	-	-	-	-	5	<50	-	-	-	-	<1
MW2D	8/10/2020	1,650	18.7	-	-	-	-	-	-	-	-	-	-	-
MW2D	23/11/2020	1,760	20.8	-	-	-	-	-	-	-	-	-	-	-
MW2D	6/12/2020	1,860	24.8	4	<0.1	<1	-	<1	<50	<1	-	-	<0.1	2
MW2S	1/12/2008	1,200	22.8	-	<10	<10	-	<10	20	<10	-	-	<1	<10
MW2S	1/06/2009	1,200	14.7	<10	<10	<10	-	<10	1,400	<10	-	-	<10	<10
MW2S	1/12/2009	1,200	19.5	<10	<10	<10	-	<10	180	<10	-	-	<10	<10
MW2S	1/06/2010	710	15.8	<1	<0.1	<1	-	9	<50	<1	-	-	<0.1	3
MW2S	1/12/2010	970	20.4	2	17.1	<1	-	88	5,450	12	-	-	<0.1	8
MW2S	1/08/2011	1,060	17.1	1	0.1	<1	-	8	<50	<1	-	-	<0.1	2
MW2S	1/12/2011	1,090	21.1	<1	<0.1	<1	-	12	<50	<1	-	-	<0.1	7
MW2S	1/06/2012	1,060	15.8	<1	<0.1	<1	-	4	<50	<1	-	-	<0.1	2
MW2S	1/12/2012	1,250	21.3	<1	0.1	<1	-	4	<50	<1	-	-	<0.1	2
MW2S	1/06/2013	747	17	-	-	-	-	8	100	-	-	-	-	6
MW2S	1/12/2013	915	18.4	-	-	-	-	5	<50	-	-	-	-	1
MW2S	1/06/2014	1,060	17.1	-	-	-	-	5	<50	-	-	-	-	3
MW2S	1/12/2014	627	19.1	-	-	-	-	10	<50	-	-	-	-	3
MW2S	1/06/2015	819	16.5	-	-	-	-	4	90	-	-	-	-	3
MW2S	1/12/2015	899	18.6	-	-	-	-	44	160	-	-	-	-	7
MW2S	1/06/2016	1,070	17.1	-	-	-	-	7	90	-	-	-	-	7
MW2S	1/12/2016	1,190	19.5	-	-	-	-	20	2,660	-	-	-	-	2
MW2S	1/06/2017	1,130	16.1	-	-	-	-	6	100	-	-	-	-	12
MW2S	1/09/2017	1,200	16.4	-	-	-	-	<1	170	-	-	-	-	4
MW2S	1/12/2017	1,060	24.3	-	-	-	-	4	<50	-	-	-	-	1
MW2S	1/03/2018	1,160	19.2	-	-	-	-	3	<50	-	-	-	-	7
MW2S	1/12/2018	1,100	22.6	-	-	-	-	5	<50	-	-	-	-	5
MW2S	1/03/2019	1,260	18.1	-	-	-	-	1	<50	-	-	-	-	1
MW2S	1/06/2019	1,280	17.4	-	-	-	-	5	<50	-	-	-	-	2
MW2S	4/03/2020	1,280	20.7	-	-	-	-	7	<50	-	-	-	-	3
MW2S	3/06/2020	1,390	17.7	<1	<0.1	<1	-	4	<50	<1	-	-	<0.1	1
MW2S	4/08/2020	925	18.1	-	-	-	-	-	-	-	-	-	-	-
MW2S	6/09/2020	1,240	22.8	-	-	-	-	6	<50	-	-	-	-	2
MW2S	22/09/2020	1,250	22.6	-	-	-	-	3	<50	-	-	-	-	<1
MW2S	8/10/2020	1,200	18.7	-	-	-	-	-	-	-	-	-	-	-
MW2S	23/11/2020	1,160	21.1	-	-	-	-	-	-	-	-	-	-	-
MW4	17/12/2019	840	-	<1	<0.1	-	<1	<1	200	<1	23	160	<0.05	<1
MW4	23/11/2020	842	19.2	-	-	-	-	-	-	-	-	-	-	-
MW5	23/11/2020	1,330	19.9	-	-	-	-	-	-	-	-	-	-	-
MW6	23/11/2020	776	19.8	-	-	-	-	-	-	-	-	-	-	-
MW7	23/11/2020	365	20.4	-	-	-	-	-	-	-	-	-	-	-
MW8	23/11/2020	1,280	19	-	-	-	-	-	-	-	-	-	-	-

Statistics

Number of Results	135	131	69	71	67	4	121	121	71	4	4	68	121
Number of Detects	135	131	36	10	4	0	95	62	12	4	4	2	108
Minimum Concentration	110	13.5	1	0.1	1	<1	1	3	1	6.5	72	<0.05	1
Minimum Detect	110	13.5	1	0.1	1	ND	1	3	1	6.5	72	0.2	1
Maximum Concentration	2,500	27.3	10	17.1	<10	<1	88	5,540	47	63	1,800	<10	73
Maximum Detect	2,500	27.3	10	17.1	2	ND	88	5,540	47	63	1,800	1	73
Average Concentration *	1,157	19	2.3	1	1.2	0.5	11	375	2.3	37	556	0.66	7
Standard Deviation *	545	2.5	2	2.6	1.6	0	15	858	5.8	27	831	1.6	9.1
95% UCL (Student's-t) *	1,234	19.3	2.656	1.516	1.545	0.5	13.76	504.3	3.431	69.25	1,534	0.984	8.325

* A Non Detect Multiplier of 0.5 has been applied.

Comments
#1 Very high reliability
#2 Moderate reliability
#3 Moderate reliability. DGV may not protect key test species from chronic toxicity (this refers to experimental chronic values or geometric mean for species). Check toxicant DGV technical brief for spread of data and its signific
#4 Low reliability
#5 High reliability
#6 Total Nitrogen calculate from the sum of TKN, Nitrates and Nitrites

Environmental Standards
ANZG (2018(Freshwatr 95% toxicant DGVs, ANZECC 2000 SE Aust Triggers - Lowland River

Water Quality Data Table

			Inorganics											
		Zinc (filtered)	Alkalinity (Hydroxide) as CaCO3	Alkalinity (total) as CaCO3	Ammonia	Bicarbonate Alkalinity as CaCO3	Calcium (filtered)	Carbonate Alkalinity as CO3	Chloride	Ionic Balance	Total Nitrogen$^{\#6}$	Kjeldahl Nitrogen Total	Nitrate (as N)	Nitrite (as N)
		µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	%	mg/L	mg/L	mg/L	mg/L
EQL		1	5	5	0.005	5	0.5	5	1			0.1	0.005	0.005
ANZECC 2000 SE Aust Triggers - Lowland River											0.5			
ANZG (2018) Freshwater 95% toxicant DGVs		8$^{\#5}$												
Location Code	Date													
MW1D	1/12/2008	<10	-	-	<0.02	310	100	-	210	-	1.22	0.12	1.1	<0.02
MW1D	1/06/2009	20	-	-	<0.02	200	70	-	80	-	0.8	0.35	0.45	<0.02
MW1D	1/12/2009	20	-	-	<0.1	170	65	-	79	-	2	0.6	1.4	<0.01
MW1D	1/06/2010	20	-	-	<0.01	183	56	-	66.1	-	2.84	1	1.84	<0.01
MW1D	1/12/2010	103	-	-	0.05	123	26	-	25	-	0.92	0.4	0.52	<0.01
MW1D	1/08/2011	177	-	-	0.04	28	7	-	9	-	0.49	0.2	0.29	<0.01
MW1D	1/12/2011	135	-	-	<0.01	33	9	-	11	-	1.18	0.4	0.78	<0.01
MW1D	1/06/2012	59	-	-	0.04	46	16	-	8	-	1.15	0.7	0.45	<0.01
MW1D	1/12/2012	86	-	-	0.02	52	15	-	12	-	0.4	0.3	0.1	<0.01
MW1D	1/06/2013	44	-	-	0.08	51	12	-	12	-	0.43	0.4	0.03	<0.01
MW1D	1/12/2013	24	-	-	0.22	51	14	-	21	-	0.71	0.6	0.09	0.02
MW1D	1/06/2014	29	-	-	0.26	53	10	-	23	-	2.08	1.9	0.15	0.03
MW1D	1/12/2014	8	-	-	<0.01	70	22	-	24	-	1.24	1.2	0.04	-
MW1D	1/06/2015	48	-	-	0.32	75	22	-	36	-	1.19	0.9	0.29	<0.01
MW1D	1/12/2015	43	-	-	0.15	123	37	-	62	-	0.49	0.3	0.19	<0.01
MW1D	1/06/2016	18	-	-	1.78	126	27	-	50	-	5.02	4.6	0.35	0.07
MW1D	6/12/2016	52	-	-	0.37	153	51	-	88	-	2.8	2.7	0.06	0.04
MW1D	2/06/2017	222	-	-	0.1	186	71	-	108	-	3.53	2.1	1.41	0.02
MW1D	4/09/2017	104	-	-	0.06	185	66	-	110	-	1.74	1.7	0.04	<0.01
MW1D	5/12/2017	61	-	-	0.06	206	78	-	133	-	1.36	1.3	0.06	<0.01
MW1D	6/03/2018	67	-	-	0.27	240	76	-	131	-	1.44	1.4	0.04	<0.01
MW1D	5/06/2018	<5	-	-	0.95	272	86	-	135	-	1.8	1.6	0.2	<0.01
MW1D	26/09/2018	<5	-	-	0.58	270	87	-	143	-	1.14	1	0.12	0.02
MW1D	6/12/2018	<5	-	-	0.99	311	110	-	132	-	1.58	1.4	0.17	0.01
MW1D	5/03/2019	30	-	-	3.49	321	113	-	136	-	4.72	4.6	0.09	0.03
MW1D	27/06/2019	82	-	-	0.82	347	145	-	146	-	1.68	0.8	0.81	0.07
MW1D	6/09/2019	68	-	-	0.66	348	148	-	151	-	2.74	1.8	0.85	0.09
MW1D	6/12/2019	<5	-	-	1.7	347	147	-	165	-	6.74	6.1	0.62	0.02
MW1D	16/12/2019	8	<5	390	3.2	390	140	<5	160	-1.0	10.71	10	0.49	0.22
MW1D	3/06/2020	48	-	-	0.19	252	250	-	138	-	16.8	3.2	13.5	0.1
MW1D	4/08/2020	-	-	-	-	-	95	-	42	-	-	-	-	-
MW1D	22/09/2020	25	-	-	0.03	237	165	-	75	-	9.95	1.4	8.53	0.02
MW1D	23/11/2020	-	-	-	-	-	91	-	43	-	-	-	-	-
MW1S	1/06/2009	40	-	-	<0.02	230	70	-	100	-	0.61	0.61	<0.04	<0.02
MW1S	1/12/2009	10	-	-	0.2	410	130	-	210	-	1.52	1.5	<0.01	0.02
MW1S	1/06/2010	14	-	-	0.98	444	120	-	206	-	1.6	1.6	<0.01	<0.01
MW1S	1/12/2010	53	-	-	0.07	40	14	-	44	-	3	2.9	0.1	<0.01
MW1S	1/08/2011	55	-	-	0.09	95	38	-	109	-	0.53	0.5	0.03	<0.01
MW1S	1/12/2011	18	-	-	0.04	193	68	-	197	-	0.53	0.5	0.03	<0.01
MW1S	1/06/2012	21	-	-	0.05	16	7	-	22	-	1.72	1.3	0.42	<0.01
MW1S	1/12/2012	9	-	-	0.06	149	48	-	83	-	1.02	0.9	0.12	<0.01
MW1S	1/06/2013	17	-	-	0.03	22	7	-	33	-	1.04	1	0.04	<0.01
MW1S	1/12/2013	13	-	-	0.01	76	24	-	55	-	0.92	0.7	0.22	<0.01
MW1S	1/06/2014	7	-	-	0.45	215	64	-	88	-	2.08	2	0.08	<0.01
MW1S	1/12/2014	14	-	-	<0.01	20	10	-	31	-	1.59	0.9	0.69	-
MW1S	1/06/2015	36	-	-	0.03	180	99	-	322	-	0.81	0.8	0.01	<0.01
MW1S	1/12/2015	7	-	-	0.08	272	116	-	332	-	0.32	0.3	<0.01	0.02
MW1S	1/06/2016	9	-	-	0.14	278	108	-	301	-	1.28	1.2	0.08	<0.01
MW1S	1/12/2016	42	-	-	0.04	209	116	-	335	-	1.96	1.9	0.06	<0.01
MW1S	1/06/2017	30	-	-	0.08	213	140	-	314	-	1.11	1	0.11	<0.01
MW1S	1/09/2017	<5	-	-	0.08	274	133	-	282	-	1.16	1.1	0.06	<0.01
MW1S	1/12/2017	92	-	-	0.67	12	9	-	56	-	26.62	7.6	18.8	0.22
MW1S	1/03/2018	140	-	-	0.06	137	51	-	121	-	13.57	3.6	9.83	0.14
MW1S	1/06/2018	8	-	-	0.02	250	95	-	188	-	4.79	1.5	3.25	0.04
MW1S	1/09/2018	10	-	-	0.02	352	130	-	338	-	0.58	0.5	0.07	0.01
MW1S	1/12/2018	<50	-	-	0.07	419	149	-	312	-	0.74	0.7	0.04	<0.01
MW1S	1/03/2019	303	-	-	0.12	404	153	-	329	-	1.01	0.9	0.11	<0.01
MW1S	17/12/2019	6	<5	350	0.53	350	140	<5	320	-6.0	1.284	1.2	0.084	<0.005
MW1S	4/03/2020	65	-	-	0.04	345	150	-	402	-	9.51	8.9	0.61	<0.01
MW1S	3/06/2020	50	-	-	<0.01	307	164	-	348	-	2.07	1.5	0.55	0.02
MW1S	6/09/2020	48	-	-	0.54	376	158	-	332	-	1.83	1.8	0.03	<0.01
MW1S	22/09/2020	52	-	-	0.06	226	102	-	199	-	2.99	1.5	1.49	<0.01
MW1S	23/11/2020	-	-	-	-	-	50	-	51	-	-	-	-	-
MW1S	6/12/2020	70	-	-	0.04	296	148	-	361	-	0.9	0.6	0.3	<0.01
MW2D	1/06/2009	20	-	-	<0.02	250	100	-	320	-	0.69	0.13	0.56	<0.02
MW2D	1/12/2009	70	-	-	<0.1	83	25	-	20	-	0.74	0.5	0.24	<0.01
MW2D	1/06/2010	373	-	-	0.52	110	36	-	34.2	-	2.11	1.1	1.01	<0.01
MW2D	1/12/2010	156	-	-	0.09	160	60	-	42	-	4.2	1	3.2	<0.01
MW2D	1/08/2011	52	-	-	<0.01	175	65	-	40	-	6.77	2	4.77	<0.01
MW2D	1/12/2011	168	-	-	<0.01	33	9	-	8	-	0.76	0.4	0.36	<0.01
MW2D	1/06/2012	103	-	-	0.04	106	36	-	16	-	1.99	0.9	1.09	<0.01
MW2D	1/12/2012	<5	-	-	0.04	103	36	-	22	-	0.41	0.3	0.11	<0.01
MW2D	1/06/2013	108	-	-	<0.01	102	38	-	20	-	0.99	0.3	0.69	<0.01
MW2D	1/12/2013	128	-	-	0.05	128	51	-	35	-	3.13	0.7	2.39	0.04
MW2D	1/06/2014	120	-	-	<0.01	153	61	-	36	-	4.84	0.6	4.18	0.06
MW2D	1/12/2014	123	-	-	<0.01	160	65	-	41	-	4.89	0.9	3.99	-
MW2D	1/06/2015	133	-	-	0.02	138	61	-	43	-	4.38	0.6	3.78	<0.01
MW2D	1/12/2015	190	-	-	0.03	183	67	-	62	-	4.75	1.2	3.55	<0.01
MW2D	1/06/2016	130	-	-	<0.01	174	65	-	56	-	3.98	0.7	3.28	<0.01
MW2D	1/12/2016	135	-	-	0.07	254	108	-	372	-	2.94	2.7	0.24	<0.01
MW2D	1/06/2017	53	-	-	0.03	281	132	-	416	-	1.14	0.7	0.44	<0.01
MW2D	1/09/2017	<5	-	-	0.13	290	120	-	396	-	0.53	0.5	0.03	<0.01
MW2D	1/12/2017	56	-	-	0.05	293	112	-	446	-	1.59	1.4	0.19	<0.01
MW2D	1/03/2018	158	-	-	<0.01	316	117	-	435	-	1.6	1.5	0.09	0.01
MW2D	1/06/2018	17	-	-	0.05	304	121	-	427	-	0.17	0.1	0.07	<0.01
MW2D	1/09/2018	16	-	-	0.1	273	111	-	456	-	0.35	0.2	0.13	0.02
MW2D	1/12/2018	62	-	-	0.04	311	113	-	409	-	1.52	1.4	0.1	0.02
MW2D	1/03/2019	77	-	-	0.13	286	110	-	415	-	1.59	1.4	0.15	0.04
MW2D	1/06/2019	65	-	-	0.08	300	116	-	349	-	0.61	0.4	0.19	0.02

Jacobs

Water Quality Data Table

			Inorganics											
		Zinc (filtered)	Alkalinity (Hydroxide) as CaCO3	Alkalinity (total) as CaCO3	Ammonia	Bicarbonate Alkalinity as CaCO3	Calcium (filtered)	Carbonate Alkalinity as CO3	Chloride	Ionic Balance	Total Nitrogen[#6]	Kjeldahl Nitrogen Total	Nitrate (as N)	Nitrite (as N)
		µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	%	mg/L	mg/L	mg/L	mg/L
EQL		1	5	5	0.005	5	0.5	5	1			0.1	0.005	0.005
ANZECC 2000 SE Aust Triggers - Lowland River											0.5			
ANZG (2018) Freshwater 95% toxicant DGVs		8[#5]												
Location Code	Date													
MW2D	17/12/2019	6	<5	290	<0.005	290	120	<5	410	-2.0	0.5	0.4	0.1	<0.005
MW2D	4/03/2020	57	-	-	<0.01	353	98	-	326	-	0.44	0.4	0.04	<0.01
MW2D	3/06/2020	63	-	-	<0.01	343	115	-	314	-	1.02	0.8	0.21	0.01
MW2D	4/08/2020	-	-	-	-	-	113	-	301	-	-	-	-	-
MW2D	6/09/2020	62	-	-	<0.01	302	110	-	381	-	0.13	0.1	0.03	<0.01
MW2D	22/09/2020	29	-	-	<0.01	326	119	-	319	-	0.62	0.4	0.22	<0.01
MW2D	8/10/2020	-	-	-	-	-	124	-	290	-	-	-	-	-
MW2D	23/11/2020	-	-	-	-	-	112	-	305	-	-	-	-	-
MW2D	6/12/2020	78	-	-	<0.01	289	109	-	389	-	0.01	<0.1	0.01	<0.01
MW2S	1/12/2008	<10	-	-	<0.02	220	130	-	52	-	1.284	0.28	1	0.004
MW2S	1/06/2009	50	-	-	<0.02	250	80	-	170	-	0.99	0.26	0.73	<0.02
MW2S	1/12/2009	20	-	-	<0.1	260	75	-	160	-	1.8	0.3	1.5	<0.01
MW2S	1/06/2010	24	-	-	0.02	242	77	-	40.5	-	0.25	0.2	0.05	<0.01
MW2S	1/12/2010	61	-	-	0.08	253	82	-	30	-	2.22	0.9	1.32	<0.01
MW2S	1/08/2011	107	-	-	0.02	168	67	-	52	-	4.77	0.2	4.57	<0.01
MW2S	1/12/2011	28	-	-	<0.01	226	65	-	48	-	2.23	0.5	1.73	<0.01
MW2S	1/06/2012	11	-	-	0.03	404	68	-	71	-	3.27	1.3	1.97	<0.01
MW2S	1/12/2012	13	-	-	0.04	389	90	-	77	-	2.22	0.8	1.42	<0.01
MW2S	1/06/2013	13	-	-	<0.01	143	50	-	37	-	1.05	0.4	0.65	<0.01
MW2S	1/12/2013	10	-	-	0.01	295	70	-	57	-	1.49	0.4	1.09	<0.01
MW2S	1/06/2014	20	-	-	0.02	154	68	-	40	-	2.96	1.5	1.46	<0.01
MW2S	1/12/2014	16	-	-	<0.01	50	26	-	37	-	0.34	0.3	0.04	-
MW2S	1/06/2015	10	-	-	<0.01	198	45	-	45	-	1.42	0.7	0.72	<0.01
MW2S	1/12/2015	58	-	-	0.05	288	65	-	59	-	2.44	1.1	1.34	<0.01
MW2S	1/06/2016	9	-	-	<0.01	335	76	-	54	-	1.19	0.6	0.59	<0.01
MW2S	1/12/2016	167	-	-	0.14	356	78	-	66	-	32.94	31.9	1.03	0.01
MW2S	1/06/2017	531	-	-	0.2	319	81	-	66	-	4.1	2.2	1.9	<0.01
MW2S	1/09/2017	176	-	-	0.34	378	87	-	66	-	3.23	2	1.21	0.02
MW2S	1/12/2017	61	-	-	0.16	310	77	-	60	-	6.03	3	3.03	<0.01
MW2S	1/03/2018	31	-	-	0.04	346	83	-	65	-	1.2	0.7	0.49	0.01
MW2S	1/12/2018	115	-	-	0.02	175	59	-	63	-	1.56	0.6	0.96	<0.01
MW2S	1/03/2019	102	-	-	<0.01	226	80	-	67	-	5.1	1.8	3.3	<0.01
MW2S	1/06/2019	86	-	-	0.03	181	71	-	54	-	4.54	0.6	3.94	<0.01
MW2S	4/03/2020	50	-	-	<0.01	270	66	-	63	-	3.84	1.8	2.04	<0.01
MW2S	3/06/2020	20	-	-	<0.01	390	101	-	69	-	2.18	0.6	1.55	0.03
MW2S	4/08/2020	-	-	-	-	-	46	-	45	-	-	-	-	-
MW2S	6/09/2020	94	-	-	0.01	165	72	-	63	-	4.67	1.2	3.47	<0.01
MW2S	22/09/2020	32	-	-	0.01	296	87	-	64	-	2.9	0.6	2.3	<0.01
MW2S	8/10/2020	-	-	-	-	-	93	-	55	-	-	-	-	-
MW2S	23/11/2020	-	-	-	-	-	74	-	56	-	-	-	-	-
MW4	17/12/2019	<1	<5	460	0.071	460	59	<5	48	-6.0	0.31	0.3	0.01	<0.005
MW4	23/11/2020	-	-	-	-	-	58	-	41	-	-	-	-	-
MW5	23/11/2020	-	-	-	-	-	48	-	205	-	-	-	-	-
MW6	23/11/2020	-	-	-	-	-	52	-	80	-	-	-	-	-
MW7	23/11/2020	-	-	-	-	-	16	-	60	-	-	-	-	-
MW8	23/11/2020	-	-	-	-	-	99	-	194	-	-	-	-	-

Statistics

Number of Results	121	4	4	121	121	135	4	135	4	121	121	121	117
Number of Detects	110	0	4	86	121	135	0	135	4	121	120	117	34
Minimum Concentration	<1	<5	290	<0.005	12	7	<5	8	-6	0.1	0.1	0.01	0.004
Minimum Detect	6	ND	290	0.01	12	7	ND	8	-6	-	0.1	0.01	0.004
Maximum Concentration	531	<5	460	3.49	460	250	<5	456	-1	32.94	31.9	18.8	0.22
Maximum Detect	531	ND	460	3.49	460	250	ND	456	-1	32.94	31.9	18.8	0.22
Average Concentration *	63	2.5	372	0.2	225	80	2.5	146	-3.8	2.82	1.5	1.3	0.017
Standard Deviation *	75	0	71	0.5	111	43	0	133	2.6	4.36	3.2	2.5	0.034
95% UCL (Student's-t) *	74.22	2.5	456.5	0.275	241.4	86.3	2.5	165	-0.655	2.166	2.024	1.645	0.0219

* A Non Detect Multiplier of 0.5 has been applied.

Comments
#1 Very high reliability
#2 Moderate reliability
#3 Moderate reliability. DGV may not protect key test :ance.
#4 Low reliability
#5 High reliability
#6 Total Nitrogen calculate from the sum of TKN, Nitra

Environmental Standards
ANZG (2018(Freshwatr 95% toxicant DGVs, ANZECC 2(

Water Quality Data Table

										Physiochemical parameters	TRH - NEPM 2013 Fractions			
		Nitrogen (Organic)	Phosphorus	Potassium (filtered)	Sodium (filtered)	Sulphate	Total Dissolved Solids	Total Organic Carbon	TSS	pH (Lab)	TRH >C6 - C10	TRH >C10 - C16	TRH >C16 - C34	TRH >C34 - C40
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	pH Units	µg/L	µg/L	µg/L	µg/L
EQL		0.2		0.5	0.5	1	5		5		10	50	100	100
ANZECC 2000 SE Aust Triggers - Lowland River			0.05							6.5-8				
ANZG (2018) Freshwater 95% toxicant DGVs														
Location Code	Date													
MW1D	1/12/2008	-	0.14	0.8	150	66	690	3	29	7.4	-	-	-	-
MW1D	1/06/2009	-	0.02	0.7	220	320	710	6	18	7.4	-	-	-	-
MW1D	1/12/2009	-	0.06	0.51	200	280	700	4	49	7.2	-	-	-	-
MW1D	1/06/2010	-	0.16	1	164	275	682	-	218	7.7	-	-	-	-
MW1D	1/12/2010	-	0.07	1	73	72	328	-	40	7.3	-	-	-	-
MW1D	1/08/2011	-	0.08	2	9	8	98	4	69	6.6	-	-	-	-
MW1D	1/12/2011	-	0.08	4	10	11	101	<1	50	6.6	-	-	-	-
MW1D	1/06/2012	-	0.09	4	7	3	84	4	640	7.4	-	-	-	-
MW1D	1/12/2012	-	0.01	5	12	8	113	14	17	7	-	-	-	-
MW1D	1/06/2013	-	0.01	5	13	7	87	4	8	6.5	-	-	-	-
MW1D	1/12/2013	-	0.16	4	13	8	94	5	39	6.6	-	-	-	-
MW1D	1/06/2014	-	0.33	7	21	10	98	7	68	6.9	-	-	-	-
MW1D	1/12/2014	-	0.2	4	44	15	120	5	14	6.9	-	-	-	-
MW1D	1/06/2015	-	0.14	3	51	65	265	4	22	7.2	-	-	-	-
MW1D	1/12/2015	-	0.11	4	90	141	403	5	<5	7.4	-	-	-	-
MW1D	1/06/2016	-	3.25	14	59	85	352	16	30	7.1	-	-	-	-
MW1D	6/12/2016	-	0.83	4	145	196	602	16	178	7.6	-	-	-	-
MW1D	2/06/2017	-	0.36	2	216	219	702	10	39	7.5	-	-	-	-
MW1D	4/09/2017	-	0.33	<1	208	219	780	8	419	7.6	-	-	-	-
MW1D	5/12/2017	-	0.32	<1	194	245	676	14	332	7.6	-	-	-	-
MW1D	6/03/2018	-	0.26	1	207	281	828	9	74	7.6	-	-	-	-
MW1D	5/06/2018	-	0.32	<1	219	281	857	13	111	7.6	-	-	-	-
MW1D	26/09/2018	-	0.41	<1	219	309	736	16	23	7.3	-	-	-	-
MW1D	6/12/2018	-	0.32	<1	237	350	987	8	80	7.5	-	-	-	-
MW1D	5/03/2019	-	0.34	1	255	370	929	9	62	7.4	-	-	-	-
MW1D	27/06/2019	-	0.13	1	286	413	1,210	11	128	7.5	-	-	-	-
MW1D	6/09/2019	-	0.2	1	282	420	1,220	6	61	7.5	-	-	-	-
MW1D	6/12/2019	-	0.77	<1	299	473	904	4	30	7.6	-	-	-	-
MW1D	16/12/2019	6.8	-	2.6	330	470	1,300	-	240	7.6	<10	58	880	180
MW1D	3/06/2020	-	0.1	1	321	877	1,740	2	67	7.2	-	-	-	-
MW1D	4/08/2020	-	-	<1	146	338	780	-	-	6.8	-	-	-	-
MW1D	22/09/2020	-	0.15	<1	254	566	1,250	4	24	7.2	-	-	-	-
MW1D	23/11/2020	-	-	<1	152	327	700	-	-	7	-	-	-	-
MW1S	1/06/2009	-	0.04	3.8	63	45	630	88	17	6.7	-	-	-	-
MW1S	1/12/2009	-	0.09	1.3	100	90	920	16	23	6.6	-	-	-	-
MW1S	1/06/2010	-	0.12	2	74	114	924	-	24	7	-	-	-	-
MW1S	1/12/2010	-	0.42	1	40	24	218	-	201	5.9	-	-	-	-
MW1S	1/08/2011	-	0.01	1	57	46	444	16	17	6.4	-	-	-	-
MW1S	1/12/2011	-	0.09	1	91	47	684	8	18	6.4	-	-	-	-
MW1S	1/06/2012	-	0.23	<1	22	36	167	15	84	6.5	-	-	-	-
MW1S	1/12/2012	-	0.39	<1	60	61	436	8	60	6.9	-	-	-	-
MW1S	1/06/2013	-	0.09	<1	37	40	161	12	6	5.9	-	-	-	-
MW1S	1/12/2013	-	0.05	<1	44	46	238	10	5	6.6	-	-	-	-
MW1S	1/06/2014	-	0.25	1	69	89	461	13	55	6.8	-	-	-	-
MW1S	1/12/2014	-	0.06	1	31	23	131	12	12	6.1	-	-	-	-
MW1S	1/06/2015	-	0.09	<1	121	68	982	9	23	6.4	-	-	-	-
MW1S	1/12/2015	-	0.04	1	103	62	1,060	11	23	6.6	-	-	-	-
MW1S	1/06/2016	-	0.21	1	110	69	932	12	31	6.3	-	-	-	-
MW1S	1/12/2016	-	0.3	2	112	177	1,100	16	96	6.7	-	-	-	-
MW1S	1/06/2017	-	0.08	4	148	204	1,200	14	34	6.6	-	-	-	-
MW1S	1/09/2017	-	0.08	2	131	164	1,050	13	31	6.5	-	-	-	-
MW1S	1/12/2017	-	0.4	17	55	44	348	22	62	6	-	-	-	-
MW1S	1/03/2018	-	0.55	6	76	118	568	16	32	7	-	-	-	-
MW1S	1/06/2018	-	0.15	4	98	177	924	14	33	6.8	-	-	-	-
MW1S	1/09/2018	-	0.04	3	139	220	1,080	14	<5	6.8	-	-	-	-
MW1S	1/12/2018	-	0.08	2	133	201	1,080	14	30	6.9	-	-	-	-
MW1S	1/03/2019	-	0.18	2	140	203	1,260	17	483	6.9	-	-	-	-
MW1S	17/12/2019	0.6	-	2.7	130	230	1,300	-	210	7.2	<10	54	250	<100
MW1S	4/03/2020	-	1.9	3	158	310	1,320	26	45	6.9	-	-	-	-
MW1S	3/06/2020	-	0.41	2	152	307	1,370	9	136	6.9	-	-	-	-
MW1S	6/09/2020	-	0.23	3	138	192	1,160	19	123	6.8	-	-	-	-
MW1S	22/09/2020	-	0.15	3	147	298	910	18	33	6.8	-	-	-	-
MW1S	23/11/2020	-	-	3	121	296	659	-	-	6.8	-	-	-	-
MW1S	6/12/2020	-	0.04	2	135	238	905	11	25	6.9	-	-	-	-
MW2D	1/06/2009	-	0.02	2.1	210	140	1,100	2	26	7.2	-	-	-	-
MW2D	1/12/2009	-	0.21	13	5.7	3.3	100	4	30	6.5	-	-	-	-
MW2D	1/06/2010	-	0.6	13	25	69	270	-	70	7.2	-	-	-	-
MW2D	1/12/2010	-	0.21	8	76	189	590	-	66	7.1	-	-	-	-
MW2D	1/08/2011	-	0.23	1	106	270	1,110	4	3,200	6.8	-	-	-	-
MW2D	1/12/2011	-	0.12	2	7	6	85	4	64	7	-	-	-	-
MW2D	1/06/2012	-	0.11	3	12	33	182	3	26	7.3	-	-	-	-
MW2D	1/12/2012	-	0.07	4	22	42	270	38	77	7.3	-	-	-	-
MW2D	1/06/2013	-	0.09	4	29	52	201	27	34	7.1	-	-	-	-
MW2D	1/12/2013	-	0.12	5	51	125	370	14	60	7.1	-	-	-	-
MW2D	1/06/2014	-	0.2	6	80	225	481	3	32	7.1	-	-	-	-
MW2D	1/12/2014	-	0.11	6	75	188	483	4	<5	6.9	-	-	-	-
MW2D	1/06/2015	-	0.17	5	81	209	521	3	14	6.9	-	-	-	-
MW2D	1/12/2015	-	0.12	5	82	237	565	5	29	7.7	-	-	-	-
MW2D	1/06/2016	-	0.14	5	86	179	548	4	35	7.1	-	-	-	-
MW2D	1/12/2016	-	0.37	3	205	206	1,040	19	156	7.4	-	-	-	-
MW2D	1/06/2017	-	0.07	2	272	165	1,240	5	38	7.5	-	-	-	-
MW2D	1/09/2017	-	0.06	<1	244	143	1,190	2	32	7.3	-	-	-	-
MW2D	1/12/2017	-	0.23	1	186	162	1,190	3	107	7.3	-	-	-	-
MW2D	1/03/2018	-	0.56	1	223	187	1,200	8	78	7.5	-	-	-	-
MW2D	1/06/2018	-	0.06	1	217	172	1,190	2	7	7.3	-	-	-	-
MW2D	1/09/2018	-	0.13	1	206	178	1,140	9	22	7.2	-	-	-	-
MW2D	1/12/2018	-	0.94	2	209	140	1,160	13	104	7.4	-	-	-	-
MW2D	1/03/2019	-	0.38	2	218	240	1,120	4	70	7.5	-	-	-	-
MW2D	1/06/2019	-	0.26	2	218	142	1,090	7	115	7.4	-	-	-	-

Water Quality Data Table

										Physiochemical parameters	TRH - NEPM 2013 Fractions			
		Nitrogen (Organic)	Phosphorus	Potassium (filtered)	Sodium (filtered)	Sulphate	Total Dissolved Solids	Total Organic Carbon	TSS	pH (Lab)	TRH >C6 - C10	TRH >C10 - C16	TRH >C16 - C34	TRH >C34 - C40
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	pH Units	µg/L	µg/L	µg/L	µg/L
EQL		0.2		0.5	0.5	1	5		5		10	50	100	100
ANZECC 2000 SE Aust Triggers - Lowland River			0.05							6.5-8				
ANZG (2018) Freshwater 95% toxicant DGVs														
Location Code	Date													
MW2D	17/12/2019	0.4	-	1.0	220	190	1,300	-	190	7.6	<10	<50	<100	<100
MW2D	4/03/2020	-	0.05	1	180	249	1,140	3	12	7.6	-	-	-	-
MW2D	3/06/2020	-	0.06	2	201	248	1,090	<1	37	7.5	-	-	-	-
MW2D	4/08/2020	-	-	1	198	234	1,200	-	-	7.3	-	-	-	-
MW2D	6/09/2020	-	0.07	1	209	153	1,010	4	35	7.5	-	-	-	-
MW2D	22/09/2020	-	0.04	1	201	248	1,130	<1	16	7.3	-	-	-	-
MW2D	8/10/2020	-	-	2	186	258	1,170	-	-	7.3	-	-	-	-
MW2D	23/11/2020	-	-	2	187	246	1,100	-	-	7.4	-	-	-	-
MW2D	6/12/2020	-	0.03	1	213	199	1,080	<1	12	7.6	-	-	-	-
MW2S	1/12/2008	-	0.1	0.53	110	350	770	5	75	6.7	-	-	-	-
MW2S	1/06/2009	-	0.03	1.3	120	120	880	3	27	6.9	-	-	-	-
MW2S	1/12/2009	-	0.07	0.85	110	81	600	4	34	6.8	-	-	-	-
MW2S	1/06/2010	-	0.27	1	21	91	438	-	86	7.1	-	-	-	-
MW2S	1/12/2010	-	0.74	1	92	181	576	-	41	6.8	-	-	-	-
MW2S	1/08/2011	-	0.09	6	101	274	772	4	95	7.2	-	-	-	-
MW2S	1/12/2011	-	0.42	<1	113	231	930	4	1,660	6.6	-	-	-	-
MW2S	1/06/2012	-	0.7	<1	129	163	863	2	588	7	-	-	-	-
MW2S	1/12/2012	-	2.09	<1	152	200	1,230	4	9,960	7.2	-	-	-	-
MW2S	1/06/2013	-	0.19	<1	94	158	494	6	174	6.6	-	-	-	-
MW2S	1/12/2013	-	0.21	<1	115	149	625	3	920	7	-	-	-	-
MW2S	1/06/2014	-	0.97	<1	113	309	718	7	214	6.7	-	-	-	-
MW2S	1/12/2014	-	0.07	<1	76	184	397	3	63	6	-	-	-	-
MW2S	1/06/2015	-	0.33	<1	98	191	596	2	108	6.3	-	-	-	-
MW2S	1/12/2015	-	0.16	<1	110	193	710	3	124	7	-	-	-	-
MW2S	1/06/2016	-	0.14	<1	120	185	694	4	93	6.8	-	-	-	-
MW2S	1/12/2016	-	26.2	2	121	194	942	14	17,800	7	-	-	-	-
MW2S	1/06/2017	-	1.25	1	160	162	1,130	3	765	7.1	-	-	-	-
MW2S	1/09/2017	-	0.9	<1	145	147	1,200	3	902	7.2	-	-	-	-
MW2S	1/12/2017	-	0.59	<1	106	227	736	6	230	7.1	-	-	-	-
MW2S	1/03/2018	-	0.22	<1	120	262	754	8	48	7	-	-	-	-
MW2S	1/12/2018	-	0.23	<1	119	303	566	5	93	7	-	-	-	-
MW2S	1/03/2019	-	1	<1	142	425	961	3	462	7.1	-	-	-	-
MW2S	1/06/2019	-	0.52	<1	142	368	1,040	4	454	6.9	-	-	-	-
MW2S	4/03/2020	-	0.8	<1	134	386	855	4	40	7	-	-	-	-
MW2S	3/06/2020	-	0.15	<1	148	332	1,020	2	63	7	-	-	-	-
MW2S	4/08/2020	-	-	<1	126	302	678	-	-	6.6	-	-	-	-
MW2S	6/09/2020	-	0.26	1	145	423	856	7	194	6.8	-	-	-	-
MW2S	22/09/2020	-	0.07	<1	145	328	874	1	45	7	-	-	-	-
MW2S	8/10/2020	-	-	<1	136	318	874	-	-	6.9	-	-	-	-
MW2S	23/11/2020	-	-	<1	132	309	810	-	-	6.8	-	-	-	-
MW4	17/12/2019	<0.2	-	0.6	110	25	500	-	2,300	7.6	<10	<50	1,300	200
MW4	23/11/2020	-	-	<1	114	28	516	-	-	7.6	-	-	-	-
MW5	23/11/2020	-	-	13	192	233	751	-	-	9	-	-	-	-
MW6	23/11/2020	-	-	19	83	20	494	-	-	7	-	-	-	-
MW7	23/11/2020	-	-	2	48	15	217	-	-	6.6	-	-	-	-
MW8	23/11/2020	-	-	2	121	68	760	-	-	7.3	-	-	-	-

Statistics

Number of Results	4	117	135	135	135	135	109	121	135	4	4	4	4
Number of Detects	3	117	97	135	135	135	105	118	135	0	2	3	2
Minimum Concentration	<0.2	0.01	0.51	5.7	3	84	1	5	5.9	<10	<50	<100	<100
Minimum Detect	0.4	0.01	0.51	5.7	3	84	1	5	5.9	ND	54	250	180
Maximum Concentration	6.8	26.2	19	330	877	1,740	88	17,800	9	<10	58	1,300	200
Maximum Detect	6.8	26.2	19	330	877	1,740	88	17,800	9	ND	58	1,300	200
Average Concentration *	2	0.52	2.4	129	190	757	8.9	393	7	5	40	620	120
Standard Deviation *	3.2	2.4	3.2	74	134	369	10	1,871	0.44	0	18	575	81
95% UCL (Student's-t) *	5.768	0.895	2.881	139.7	209	809.9	10.52	675.5	7.102	5	61.65	1,297	215.6

* A Non Detect Multiplier of 0.5 has been applied.

Comments
#1 Very high reliability
#2 Moderate reliability
#3 Moderate reliability. DGV may not protect key test
#4 Low reliability
#5 High reliability
#6 Total Nitrogen calculate from the sum of TKN, Nitra

Environmental Standards
ANZG (2018(Freshwatr 95% toxicant DGVs, ANZECC 20

		TPH - NEPM 1999 Fractions				Biological	TPH
		TPH C6 - C9	TPH C10 - C14	TPH C15 - C28	TPH C29-C36	Biological oxygen demand	Oil and Grease
		µg/L	µg/L	µg/L	µg/L	mg/L	mg/L
EQL		10	50	100	100		
ANZECC 2000 SE Aust Triggers - Lowland River							
ANZG (2018) Freshwater 95% toxicant DGVs							
Location Code	Date						
MW1D	1/12/2008	-	-	-	-	<2	<0.1
MW1D	1/06/2009	-	-	-	-	<2	0.4
MW1D	1/12/2009	-	-	-	-	<2	3
MW1D	1/06/2010	-	-	-	-	3	<5
MW1D	1/12/2010	-	-	-	-	7	<5
MW1D	1/08/2011	-	-	-	-	3	<5
MW1D	1/12/2011	-	-	-	-	3	<5
MW1D	1/06/2012	-	-	-	-	<2	<5
MW1D	1/12/2012	-	-	-	-	11	<5
MW1D	1/06/2013	-	-	-	-	<2	<5
MW1D	1/12/2013	-	-	-	-	<2	<5
MW1D	1/06/2014	-	-	-	-	3	<5
MW1D	1/12/2014	-	-	-	-	<2	<5
MW1D	1/06/2015	-	-	-	-	<2	8
MW1D	1/12/2015	-	-	-	-	<2	<5
MW1D	1/06/2016	-	-	-	-	3	<5
MW1D	6/12/2016	-	-	-	-	5	<5
MW1D	2/06/2017	-	-	-	-	3	<5
MW1D	4/09/2017	-	-	-	-	<2	<5
MW1D	5/12/2017	-	-	-	-	<2	<5
MW1D	6/03/2018	-	-	-	-	<2	<5
MW1D	5/06/2018	-	-	-	-	3	<5
MW1D	26/09/2018	-	-	-	-	<2	<5
MW1D	6/12/2018	-	-	-	-	5	<5
MW1D	5/03/2019	-	-	-	-	4	<5
MW1D	27/06/2019	-	-	-	-	5	<5
MW1D	6/09/2019	-	-	-	-	6	<5
MW1D	6/12/2019	-	-	-	-	12	<5
MW1D	16/12/2019	<10	53	430	550	-	-
MW1D	3/06/2020	-	-	-	-	2	<5
MW1D	4/08/2020	-	-	-	-	-	-
MW1D	22/09/2020	-	-	-	-	6	<5
MW1D	23/11/2020	-	-	-	-	-	-
MW1S	1/06/2009	-	-	-	-	150	13
MW1S	1/12/2009	-	-	-	-	<2	0.2
MW1S	1/06/2010	-	-	-	-	<2	5
MW1S	1/12/2010	-	-	-	-	7	<5
MW1S	1/08/2011	-	-	-	-	3	<5
MW1S	1/12/2011	-	-	-	-	<2	<5
MW1S	1/06/2012	-	-	-	-	<2	<5
MW1S	1/12/2012	-	-	-	-	4	<5
MW1S	1/06/2013	-	-	-	-	<2	<5
MW1S	1/12/2013	-	-	-	-	<2	<5
MW1S	1/06/2014	-	-	-	-	<2	<5
MW1S	1/12/2014	-	-	-	-	<2	<5
MW1S	1/06/2015	-	-	-	-	4	7
MW1S	1/12/2015	-	-	-	-	<2	<5
MW1S	1/06/2016	-	-	-	-	<2	<5
MW1S	1/12/2016	-	-	-	-	5	<5
MW1S	1/06/2017	-	-	-	-	2	<5
MW1S	1/09/2017	-	-	-	-	<2	<5
MW1S	1/12/2017	-	-	-	-	5	<5
MW1S	1/03/2018	-	-	-	-	4	<5
MW1S	1/06/2018	-	-	-	-	3	<5
MW1S	1/09/2018	-	-	-	-	<2	<5
MW1S	1/12/2018	-	-	-	-	4	<5
MW1S	1/03/2019	-	-	-	-	<2	<5
MW1S	17/12/2019	<10	<50	240	<100	-	-
MW1S	4/03/2020	-	-	-	-	2	<5
MW1S	3/06/2020	-	-	-	-	<2	<5
MW1S	6/09/2020	-	-	-	-	<2	<5
MW1S	22/09/2020	-	-	-	-	2	<5
MW1S	23/11/2020	-	-	-	-	-	-
MW1S	6/12/2020	-	-	-	-	2	<5
MW2D	1/06/2009	-	-	-	-	<2	1.9
MW2D	1/12/2009	-	-	-	-	<2	<0.1
MW2D	1/06/2010	-	-	-	-	<2	<5
MW2D	1/12/2010	-	-	-	-	11	<5
MW2D	1/08/2011	-	-	-	-	2	<5
MW2D	1/12/2011	-	-	-	-	3	<5
MW2D	1/06/2012	-	-	-	-	<2	<5
MW2D	1/12/2012	-	-	-	-	14	<5
MW2D	1/06/2013	-	-	-	-	<2	<5
MW2D	1/12/2013	-	-	-	-	<2	<5
MW2D	1/06/2014	-	-	-	-	<2	<5
MW2D	1/12/2014	-	-	-	-	<2	<5
MW2D	1/06/2015	-	-	-	-	<2	6
MW2D	1/12/2015	-	-	-	-	<2	<5
MW2D	1/06/2016	-	-	-	-	<2	<5
MW2D	1/12/2016	-	-	-	-	12	<5
MW2D	1/06/2017	-	-	-	-	4	<5
MW2D	1/09/2017	-	-	-	-	<2	<5
MW2D	1/12/2017	-	-	-	-	<2	<5
MW2D	1/03/2018	-	-	-	-	4	<5
MW2D	1/06/2018	-	-	-	-	<2	<5
MW2D	1/09/2018	-	-	-	-	<2	<5
MW2D	1/12/2018	-	-	-	-	7	<5
MW2D	1/03/2019	-	-	-	-	2	<5
MW2D	1/06/2019	-	-	-	-	5	<5

		TPH - NEPM 1999 Fractions				Biological	TPH
		TPH C6 - C9	TPH C10 - C14	TPH C15 - C28	TPH C29-C36	Biological oxygen demand	Oil and Grease
		µg/L	µg/L	µg/L	µg/L	mg/L	mg/L
EQL		10	50	100	100		
ANZECC 2000 SE Aust Triggers - Lowland River							
ANZG (2018) Freshwater 95% toxicant DGVs							

Location Code	Date						
MW2D	17/12/2019	<10	<50	<100	<100	-	-
MW2D	4/03/2020	-	-	-	-	4	<5
MW2D	3/06/2020	-	-	-	-	5	<5
MW2D	4/08/2020	-	-	-	-	-	-
MW2D	6/09/2020	-	-	-	-	<2	<5
MW2D	22/09/2020	-	-	-	-	2	<5
MW2D	8/10/2020	-	-	-	-	-	-
MW2D	23/11/2020	-	-	-	-	-	-
MW2D	6/12/2020	-	-	-	-	2	<5
MW2S	1/12/2008	-	-	-	-	<2	0.2
MW2S	1/06/2009	-	-	-	-	<2	0.7
MW2S	1/12/2009	-	-	-	-	<2	<0.1
MW2S	1/06/2010	-	-	-	-	<2	<5
MW2S	1/12/2010	-	-	-	-	8	<5
MW2S	1/08/2011	-	-	-	-	5	<5
MW2S	1/12/2011	-	-	-	-	<2	<5
MW2S	1/06/2012	-	-	-	-	<2	<5
MW2S	1/12/2012	-	-	-	-	<2	<5
MW2S	1/06/2013	-	-	-	-	<2	<5
MW2S	1/12/2013	-	-	-	-	<2	<5
MW2S	1/06/2014	-	-	-	-	<2	<5
MW2S	1/12/2014	-	-	-	-	<2	<5
MW2S	1/06/2015	-	-	-	-	<2	8
MW2S	1/12/2015	-	-	-	-	<2	<5
MW2S	1/06/2016	-	-	-	-	<2	<5
MW2S	1/12/2016	-	-	-	-	5	<5
MW2S	1/06/2017	-	-	-	-	<2	<5
MW2S	1/09/2017	-	-	-	-	4	<5
MW2S	1/12/2017	-	-	-	-	<2	<5
MW2S	1/03/2018	-	-	-	-	<2	<5
MW2S	1/12/2018	-	-	-	-	10	<5
MW2S	1/03/2019	-	-	-	-	<2	<5
MW2S	1/06/2019	-	-	-	-	<2	<5
MW2S	4/03/2020	-	-	-	-	<2	<5
MW2S	3/06/2020	-	-	-	-	<2	<5
MW2S	4/08/2020	-	-	-	-	-	-
MW2S	6/09/2020	-	-	-	-	<2	<5
MW2S	22/09/2020	-	-	-	-	<2	<5
MW2S	8/10/2020	-	-	-	-	-	-
MW2S	23/11/2020	-	-	-	-	-	-
MW4	17/12/2019	<10	<50	1,200	160	-	-
MW4	23/11/2020	-	-	-	-	-	-
MW5	23/11/2020	-	-	-	-	-	-
MW6	23/11/2020	-	-	-	-	-	-
MW7	23/11/2020	-	-	-	-	-	-
MW8	23/11/2020	-	-	-	-	-	-

Statistics

Statistics						
Number of Results	4	4	4	4	117	117
Number of Detects	0	1	3	2	50	12
Minimum Concentration	<10	<50	<100	<100	2	<0.1
Minimum Detect	ND	53	240	160	2	0.2
Maximum Concentration	<10	53	1,200	550	150	13
Maximum Detect	ND	53	1,200	550	150	13
Average Concentration *	5	32	480	202	3.9	2.6
Standard Deviation *	0	14	504	237	14	1.5
95% UCL (Student's-t) *	5	48.47	1,074	481.8	6.035	2.86

* A Non Detect Multiplier of 0.5 has been applied.

Comments
#1 Very high reliability
#2 Moderate reliability
#3 Moderate reliability. DGV may not protect key test
#4 Low reliability
#5 High reliability
#6 Total Nitrogen calculate from the sum of TKN, Nitra

Environmental Standards
ANZG (2018(Freshwatr 95% toxicant DGVs, ANZECC 2

Appendix B. Groundwater model report (Jacobs, 2021)

Albion Park Hard Rock Quarry Extension

Groundwater Assessment: Model Report

IA222501-A.CS.EV.TI-3-NW-RPT-0001 | D
3 August 2021

Cleary Bros (Bombo) Pty Ltd

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
A	17/12/2020	Draft	BR	CC	CC	CC
B	19/02/2021	Final draft	BR	BR	BR	BR
C	07/05/2021	Final	BR	BR	BR	BR
D	03/08/2021	Final amended	BR	BR	BR	BR

Distribution of copies

Revision	Issue approved	Date issued	Issued to	Comments
A	CC	17/12/2020	Cleary Bros	Draft
B	BR	19/02/2021	Cleary Bros	Final draft
C	BR	07/05/2021	Cleary Bros	Final
D	BR	03/08/2021	Cleary Bros	Final amended

Albion Park Hard Rock Quarry Extension

Project No:	IA222501
Document Title:	Groundwater Assessment: Model Report
Document No.:	IA222501-A.CS.EV.TI-3-NW-RPT-0001
Revision:	D
Document Status:	
Date:	3 August 2021
Client Name:	Cleary Bros (Bombo) Pty Ltd
Client No:	
Project Manager:	Ben Rose
Author:	Ben Rose
File Name:	IA222501-A.CS.EV.TI-3-NW-RPT-0001.docx

Jacobs Australia Pty Limited

Level 7, 177 Pacific Highway
North Sydney NSW 2060 Australia
PO Box 632 North Sydney
NSW 2059 Australia
T +61 2 9928 2100
F +61 2 9928 2444
www.jacobs.com

Contents

Important note about your report

The sole purpose of this report is to document the development and results of a numerical groundwater model, in connection with the proposed Albion Park Quarry extension Project, to enable key information to be drawn into the Project's standalone groundwater impact assessment report, which is developed to support the EIS for the Project. The report was commissioned by Cleary Bros (Bombo) Pty Ltd and was produced in accordance with, and is limited to the scope of services set out in, the proposal/contract between Jacobs and the Client. That scope of services, as described in this report, was developed with the Client.

All reports and conclusions that deal with sub-surface conditions are based on interpretation and judgement and as a result have uncertainty attached to them. This report contains interpretations and conclusions which are uncertain, due to the nature of the investigations. No study can investigate every risk, and even a rigorous assessment and/or sampling programme may not detect all problem areas within a site.

This report is based on assumptions that the site conditions as revealed through sampling are indicative of conditions throughout the site. The findings are the result of standard assessment techniques used in accordance with normal practices and standards, and (to the best of Jacobs knowledge) they represent a reasonable interpretation of the current conditions on the site. Sampling techniques, by definition, cannot determine the conditions between the sample points and so this report cannot be taken to be a full representation of the sub-surface conditions. This report only provides an indication of the likely sub surface conditions.

Conditions encountered during quarrying may be different from those inferred in this report, for the reasons explained in this limitation statement. If site conditions encountered during quarrying are different from those encountered during the Jacobs and others' site investigations, Jacobs reserves the right to revise any of the findings, observations and conclusions expressed in this report.

The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the Project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete, then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

Except as specifically stated in this report, Jacobs makes no statement or representation of any kind concerning the suitability of the site for any purpose or the permissibility of any use.

1. Introduction

1.1 Background

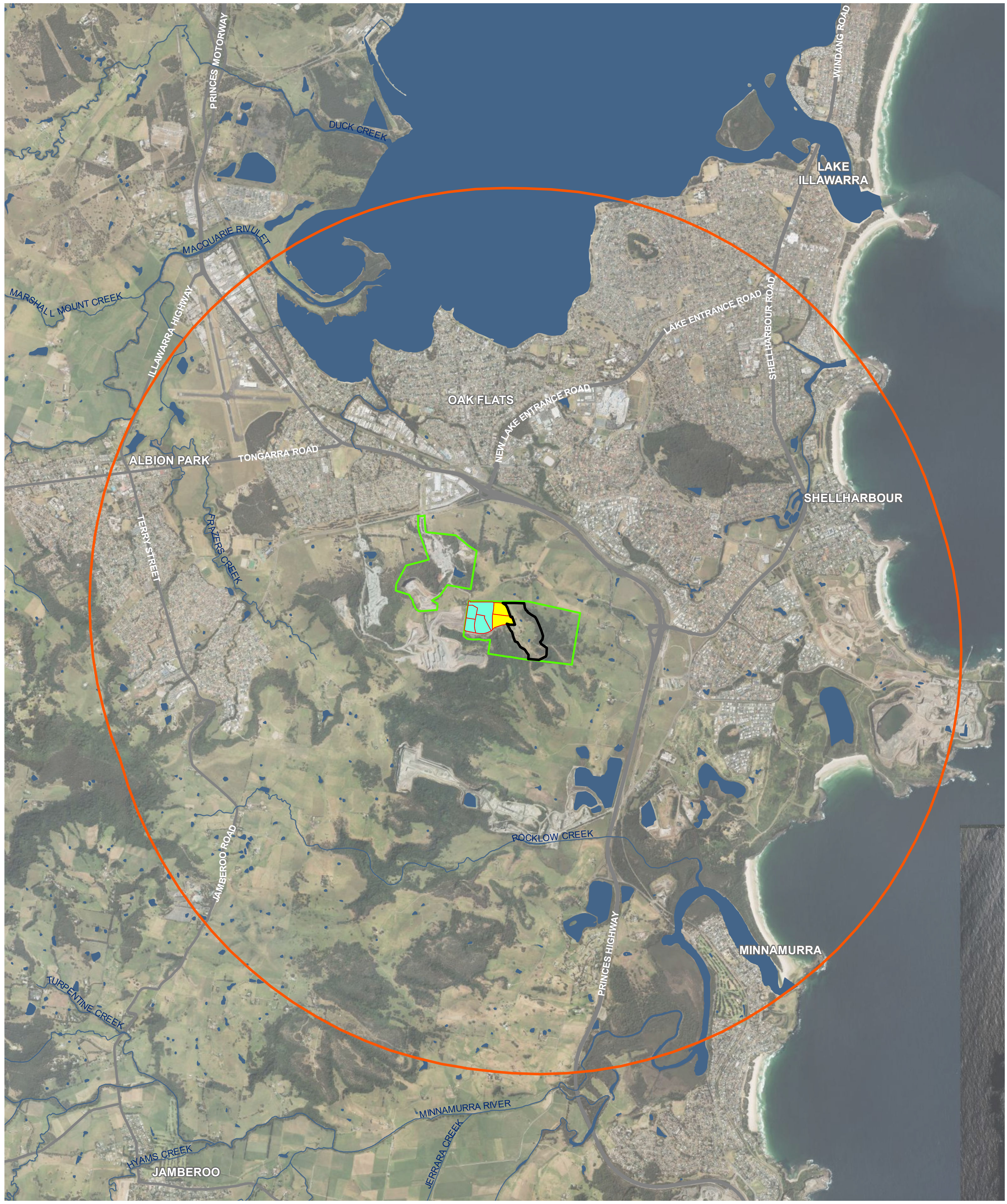
Cleary Bros (Bombo) Pty Ltd (Cleary Bros) (the Applicant) owns and operates the Albion Park Hard Rock Quarry ('the Quarry'), located at Croom, NSW (**Figure 1.1**). Cleary Bros is proposing to extend the current extraction area (the Project).

The Project has been classified as a "State Significant Development" under Schedule 1 (7) of the State Environmental Planning Policy (State and Regional Development) 2011.

This report is a technical appendix to a Groundwater Assessment prepared by Jacobs (2020) to support the environmental impact statement (EIS) for the Project. The report documents a conceptual and numerical groundwater model that was developed to inform assessment of potential impacts to groundwater due to the Project.

Whilst numerical groundwater model results are documented in this report, impact assessment is outside the scope of this report and is covered in the Project's Groundwater Assessment (Jacobs, 2020). Coverage of groundwater quality is also outside of scope and is covered in Jacobs (2020).

The groundwater model report content was separated from the main Groundwater Assessment (Jacobs, 2020) to limit the volume of technical content within that report.



🟧 Study area

⬛ Proposed extraction area extension

🟨 Current extraction area

▨ Previous extraction stages

— Watercourse

▬ Waterbody

🟩 Quarry boundary

0 1 2 km

1:45,000 at A3

N

Data sources

NSW Spatial Services 2019

GDA94 MGA56

Figure 1.1 Project location

Date: 9/12/2020 Path: \\Jacobs.com\ANZ\IE\Projects\04_Eastern\IA222500\STG1 Files\Data\GIS\22_Spatial\GIS\Directory\Templates\Figures\IA222501_GIS_F003_ProjectLocation _r1v1.mxd
Created by : HK | QA by : XX

1.2 Study area

A groundwater study area (**Figure 1.1)** consisting of an approximate 5km radius from the Project Area was adopted for this report, and is consistent with the study area used in the Project's groundwater assessment (Jacobs, 2020).

1.3 Project description

1.3.1 Overview

The Project would principally comprise extraction and in-pit crushing and screening to produce hard rock aggregates, armour rock and pavement products to meet the increasing supply demands of these markets over the next 30 to 40 years. In addition, ancillary Project elements would include elements such as, but not be limited to, the construction of internal haul roads, overburden stripping and emplacement, receipt of Virgin Excavated Natural Material (VENM) and Excavated Natural Material (ENM) and rehabilitation.

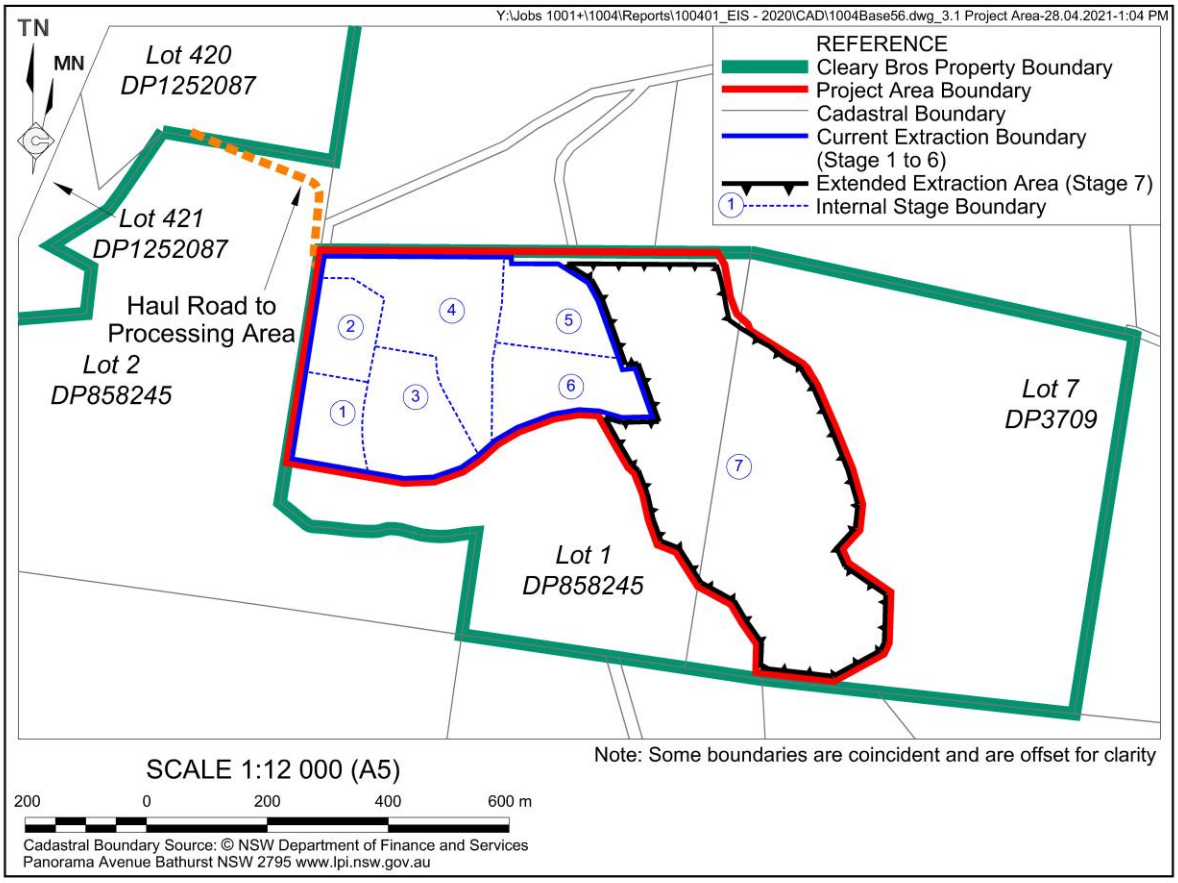
The Project Area (**Figure 1.2**) covers Stages 1 to 6 of the Quarry, which are currently approved extraction areas, and the proposed Stage 7 extension area. Stages 1 to 6 are included in the Project Area as a quantity of rock remains to be extracted in these stages and greater efficiencies would be achieved by extracting the remaining rock concurrently in Stages 5, 6 and 7. Furthermore, some of the overburden and soil from Stage 7 would be used for the rehabilitation of sections of Stages 1 to 4.

Figure 1.3 displays the area referred to as the Eastern Rim which forms the eastern half of Stages 7c and 7d and would be the final area to be extracted within Stage 7. This approach would enable the extraction activities in the western half of Stages 7c and 7d to be shielded visually from the east.

The Project activity would extract:

- Overburden comprising clay and variably weathered Bumbo Latite collectively, which is between 2 m and 8 m thick in the Stage 7 area.
- Bumbo Latite, which comprises two flows referred to as the Upper Latite and the Lower Latite, respectively, and an interburden layer of agglomerate or volcanic breccia which separates the Upper Latite and the Lower Latite.

The base of the Lower Latite occurs at approximately 52 mAHD and 17 mAHD within the northern and southern ends of Stage 7, respectively. The Lower Latite is underlain by the finely bedded, grey-green, Kiama Sandstone.



Cadastral Boundary Source: © NSW Department of Finance and Services Panorama Avenue Bathurst NSW 2795 www.lpi.nsw.gov.au

Figure 1.2: Project Area stages (source: RW Corkery & Co, 2021)

1.3.2 Extraction area design and timing

Figure 1.3 displays the design of the Project's ultimate extraction area. The Stage 7 extension area has been designed with parameters comparable to those already adopted in Stages 1 to 6, namely:

- bench heights = up to 14m
- operational bench widths = approximately 25m
- terminal bench widths = approximately 5m
- typical extraction face = 75° from the horizontal on the eastern extraction faces and up to 90° from the horizontal on all other faces.

The Stage 7 extraction sequence is summarised in **Table 1.1**

Table 1.1: Stage 7 extraction sequence

Stage	Area (ha)	Extraction Duration (years)
7a	10.5	12
7b	2.0	5
7c	5.0	10
4/5/6/7d	9.1	15

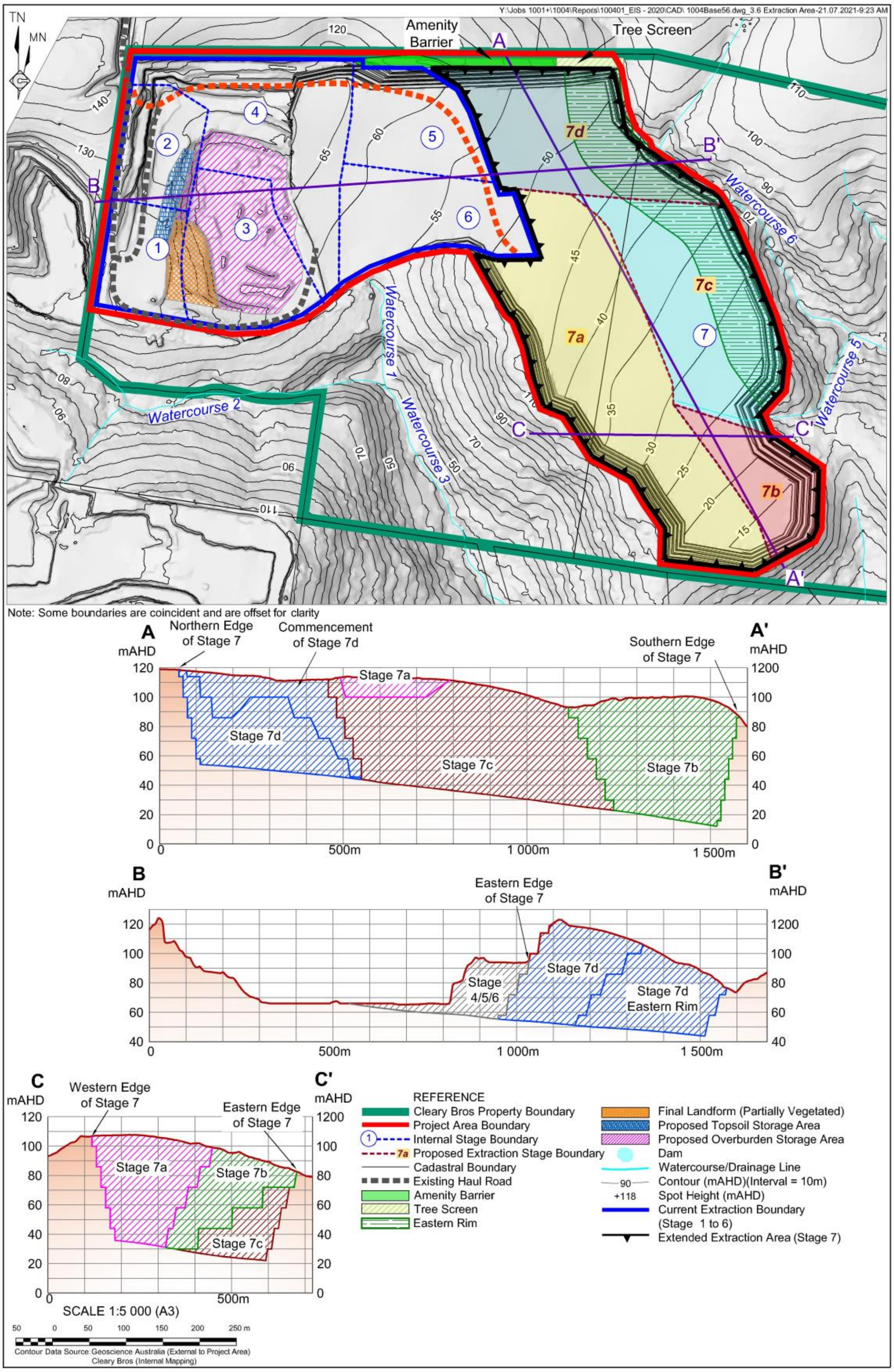


Figure 1.3: Extraction area design (source: RW Corkery & Co, 2021)

1.3.3 Water management and usage

Surface water will be managed through the construction of diversion banks to re-direct clean runoff away from the active extraction area where required and a series of sediment basins and a sump within the active extraction area to control sediment-laden runoff. Mitigation measures would be used to ensure no pollution occurs at surface water resources beyond the Project Area.

Expected maximum annual water usage would be 108 ML, principally for dust suppression. This water would be sourced principally from the on-site water storage, with additional water sourced from the sump. Further detail on water management is provided in the Project's Soil and Water Assessment (SEEC, 2021).

1.3.4 Final landform

Cleary Bros has defined five rehabilitation domains for the Project’s final landform:

- Terrace Domain – steeper terminal faces of the extraction area with 14 m benches, 5 m berms and face angles of between 75° and 90°. Overburden and other suitable materials would be placed on the berms to provide a growth medium with water holding capacity for trees and shrubs. Heights of some upper terminal faces would be reduced to soften visual impacts as described in Section 3 of the EIS.
- Slope Domain – the intermediate slope between the Terrace and Plain Domains with variable slopes of between 5° and 18° formed from overburden or other suitable back fill materials. Final slopes would be planted with trees and shrubs. Pasture species would be established on the lower gentler slopes grading to the Plains domain.
- Plains Domain – overburden or other suitable back fill would be placed on the floor of the extraction area to a variable depth with a gentle slope. The final profiled Plains Domain would incorporate a series of retained dams which would provide ongoing use for sediment control and stock watering
- Open Water Domain – due to the generally southerly dip of latite resource and the surrounding topography within the Project Area, extraction would create a low point at the southern end of Stage 7 which would form a permanent or semi-permanent water feature collecting surface water running from much of the extraction area.
- Foreshore Domain – the area between the Plains Domain and the Open Water Domain would be a low-gradient transitional area comprising wetland and water-loving vegetation.

Figure 1.4 displays a profile of each of the domains whilst **Figure 1.5** displays a plan of the areas covered by each domain.

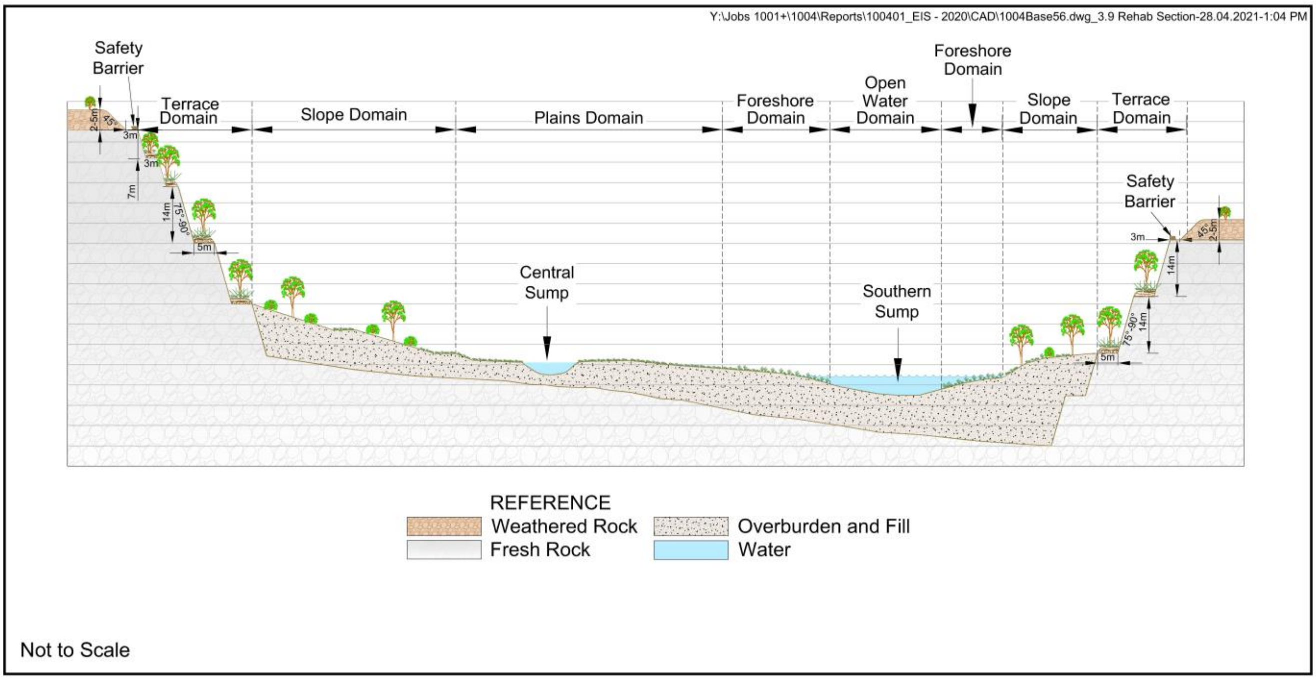


Figure 1.4: Profile of Project rehabilitation domains (source: RW Corkery & Co, 2021)

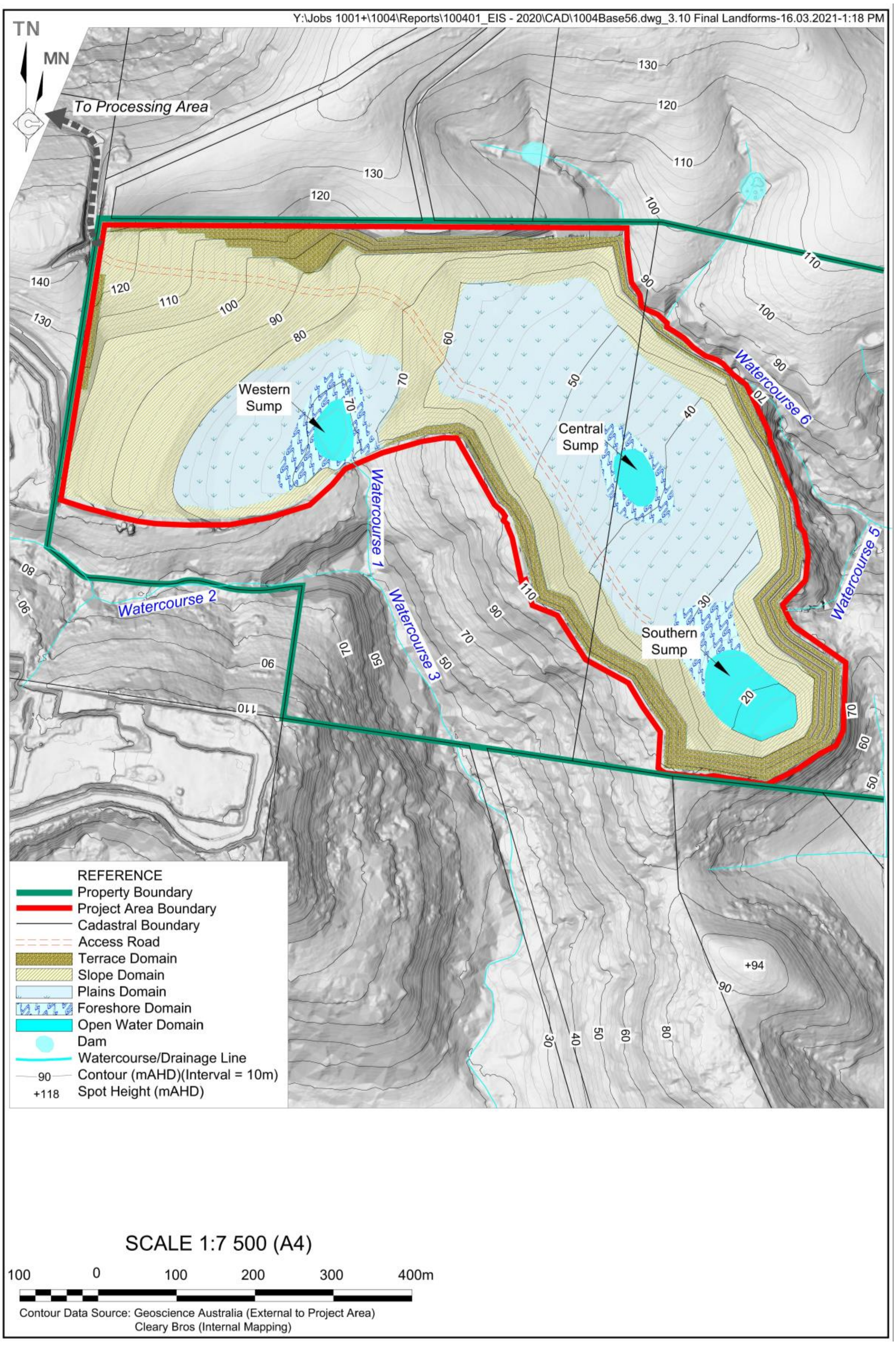


Figure 1.5: Plan of Project rehabilitation domains (source: RW Corkery & Co, 2021)

1.4 Report objective and layout

The purpose of this report is to document the development and results of a conceptual and numerical groundwater model that was used to inform assessment of potential impacts to groundwater due to the Project.

This groundwater modelling report is divided into the following sections:

- Section 1 – Introduction, introduces and describes the Project and outlines the objective of the report.
- Section 2 – Model Objectives, outlines the model objectives.
- Section 3 – Conceptualisation, conceptualises the hydrogeology.
- Section 4 – Model Design, documents the numerical model design and build.
- Section 5 – Model Calibration, documents calibration of the numerical model.
- Section 6 – Predictive Modelling, documents the predictive modelling scenarios and results
- Section 7 – Model Uncertainty Analysis, documents assessment of model uncertainty.
- Section 8 – Conclusion, provides a summary of model findings.

2. Model objectives

A numerical groundwater model is a computer simulation of a groundwater flow system that is used to simulate and predict groundwater flow. A numerical groundwater model has been developed to assess groundwater inflow to the Project's extraction area and aid in the assessment of potential groundwater related impacts due to the Project. Impacts may include issues such as groundwater level drawdown due to dewatering and reduction of baseflow to creeks.

The objectives of the numerical groundwater model were as follows:

- Calculate groundwater level drawdown due to the Project, including at any existing groundwater works and groundwater dependent ecosystems (GDEs)
- Calculate the Project's volumetric take of groundwater (due to either incidental or active dewatering)
- Calculate the incidental volumetric take from surface watercourses due to baseflow reduction.

3. Conceptualisation

A conceptual hydrogeological model is a descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions. A conceptual model consolidates the current understanding of the key processes of the groundwater system, including the influence of stresses, and assists in the understanding of possible future changes. The Australian Groundwater Modelling Guidelines (Barnett et al. 2012) provide the following guiding principles for the conceptualisation of a groundwater system:

Guiding Principle 1

- The level of detail within the conceptual model should be chosen, based on the modelling objectives, the availability of quality data, knowledge of the groundwater system of interest, and its complexity.

Guiding Principle 2

- Alternative conceptual models should be considered to explore the significance of the uncertainty associated with different views of how the system operates.

Guiding Principle 3

- The conceptual model should be developed based on observation, measurement and interpretation wherever possible. Quality-assured data should be used to improve confidence in the conceptual model.

Guiding Principle 4

- The hydrogeological domain should be conceptualised to be large enough to cover the location of the key stresses on the groundwater system (both the current locations and those in the foreseeable future) and the area influenced or impacted by those stresses. It should also be large enough to adequately capture the processes controlling groundwater behaviour in the study area.

Guiding Principle 5

- There should be an ongoing process of refinement and feedback between conceptualisation, model design and model calibration to allow revisions and refinements to the conceptual model over time.

3.1 Groundwater systems

The Wollongong 1:250,000 Geological Sheet SI/56-09 (Geological Survey of NSW, 1966) mapping is superimposed on **Figure 3.1**. The mapping indicates the surface geology for the broader region of the Quarry comprises Bumbo Latite of the Gerringong Volcanics. Additionally:

- Quaternary alluvium is mapped at the surface at a minimum distance of approximately 650 m, to the south east of the proposed Quarry Extension area.
- Tuff is mapped at the surface at a minimum distance of approximately 700 m, to the east of the proposed Quarry Extension area.
- Undifferentiated siltstone, shale and sandstone of the Berry Formation is mapped at the surface at a minimum distance of approximately 650 m, to the north west of the proposed Quarry Extension area.

The are no mapped (Geological Survey of NSW, 1966) faults near the Project. The nearest mapped faults are greater than 10 km to the north west of the Project.

Observations from resource definition drilling for the Project and the Quarry's groundwater monitoring bores (refer **Figure 3.2**, bore details are summarised in **Table 3.1**) suggest there are two broad groundwater systems applicable to the Quarry:

- A shallow (i.e. <10 m below ground level (mBGL)) water table system is generally consistent in the area of the Quarry and is most likely associated with an upper weathered zone in the latite and agglomerate.
- Intermediate depth groundwater unconfined to semi-confined systems (in the latite and agglomerate) underly the shallow water table system, with the flow in these systems almost exclusively dependent on fracture/defect extent and unit contact planes (i.e. contact of latite and agglomerate).

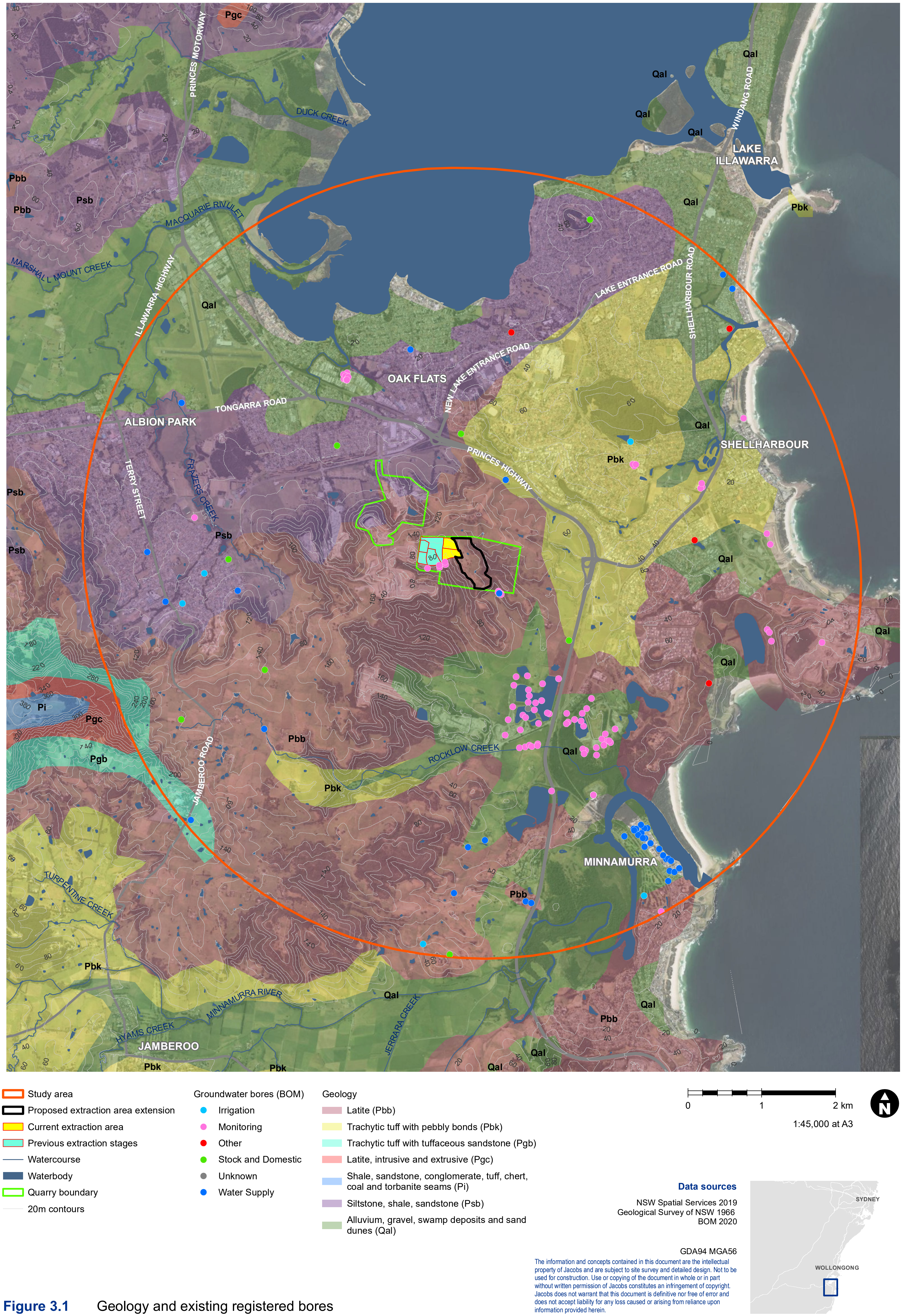
Additionally, deep semi-confined to confined groundwater systems within Kiama Sandstone are conceptualised to underly the intermediate depth groundwater systems. However, these groundwater systems are of little relevance as extraction of the sandstone is not proposed for the Project.

Due to inferred poorly connected fracture flow paths and negligible matrix hydraulic conductivity (except for possibly the sandstone), there is poor hydraulic connection between:

- The water table and underlying intermediate and deep groundwater systems.
- The intermediate groundwater systems themselves.
- The deep sandstone groundwater system and overlying intermediate system.

Preferential flow could occur at the interface of the latite/agglomerate and lower latite/sandstone. However, groundwater monitoring bores MW2D, MW5 and MW6, which have screens that span across latite/agglomerate contact(s), do not have distinctly different estimates of hydraulic conductivity (Section 3.4).

The latite and agglomerate matrix hydraulic conductivity, fracture and contact plane hydraulic conductivity and storage is conceptualised to be sufficiently low that ‘aquifers’ in these systems are unlikely to exist. The lack of groundwater inflow (aside from flow from the lower latite and sandstone contact to sump – refer Section 3.7.4) to the current extraction area evidences this.



🟧 Study area
⬛ Proposed extraction area extension
🟨 Current extraction area
🟩 Previous extraction stages
— Watercourse
▬ Waterbody
🟩 Quarry boundary
— 20m contours

Groundwater bores (BOM)
● Irrigation
● Monitoring
● Other
● Stock and Domestic
● Unknown
● Water Supply

Geology
▬ Latite (Pbb)
▬ Trachytic tuff with pebbly bonds (Pbk)
▬ Trachytic tuff with tuffaceous sandstone (Pgb)
▬ Latite, intrusive and extrusive (Pgc)
▬ Shale, sandstone, conglomerate, tuff, chert, coal and torbanite seams (Pi)
▬ Siltstone, shale, sandstone (Psb)
▬ Alluvium, gravel, swamp deposits and sand dunes (Qal)

Data sources

NSW Spatial Services 2019
Geological Survey of NSW 1966
BOM 2020

GDA94 MGA56

Figure 3.1 Geology and existing registered bores

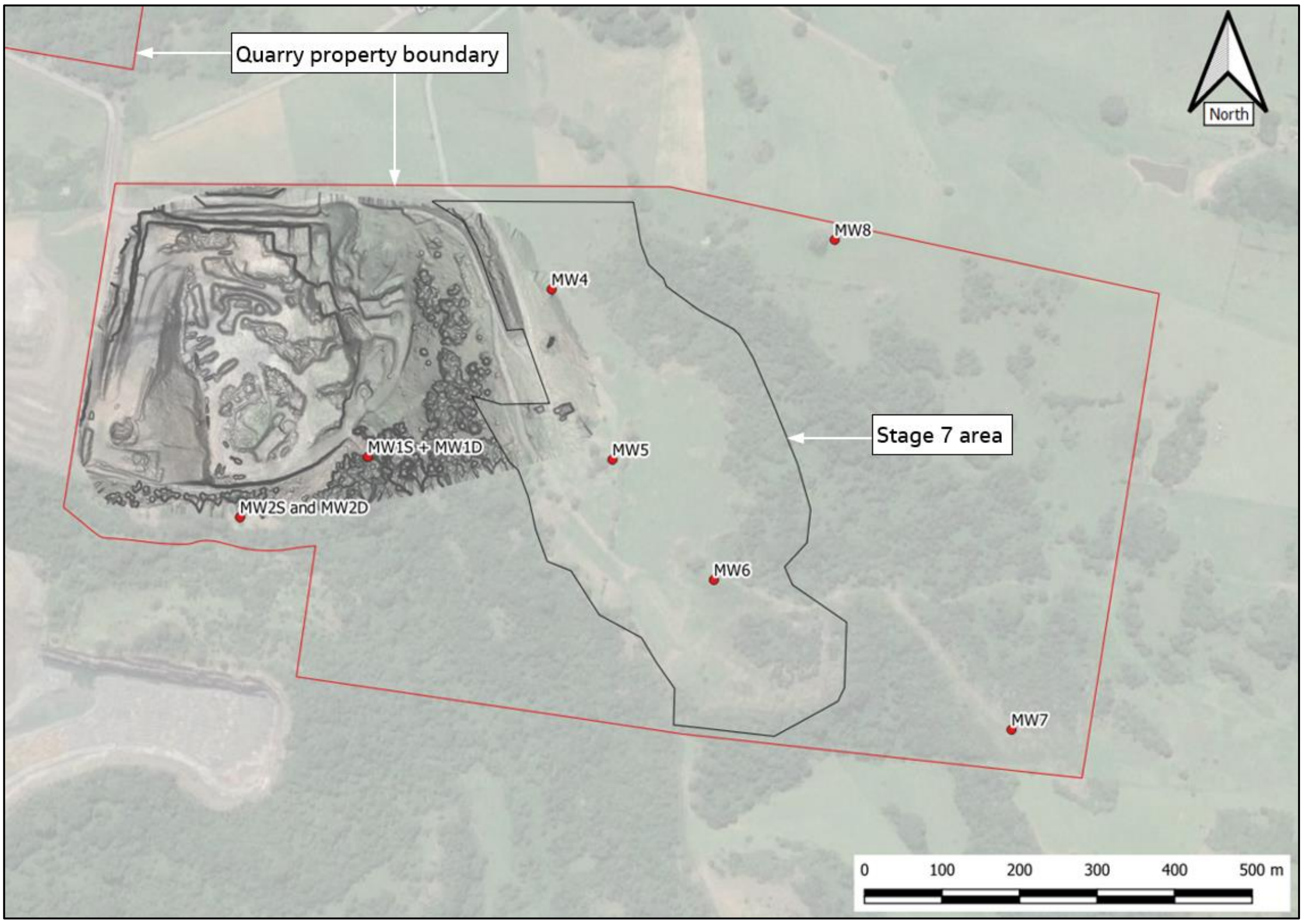


Figure 3.2: Existing groundwater monitoring bores

Table 3.1: Site groundwater monitoring bores

Monitoring bore	Co-ordinates (MGA94z56)		Ground level (mAHD)	Screen depth (mBGL) and length (m) [1]	Screened material
	Easting	Northing			
MW1S	300328	6170396	69.84	4.50 - 10.29, 5.79 m long screen	Fresh lower latite
MW1D			69.84	18.30 – 25.11, 6.81 m long screen	Logged as tuff (but this is likely an error in rock type identification, instead the material is likely altered sandstone)
MW2S	300163	6170318	74.32	6.50 – 13.00,	Fresh lower latite

Monitoring bore	Co-ordinates (MGA94z56)		Ground level (mAHD)	Screen depth (mBGL) and length (m) [1]	Screened material
	Easting	Northing			
				5.50 m long screen	
MW2D			74.40	18.50 – 24.37, 5.87 m long screen	2.87 m of fresh lower latite, followed by 3 m length of material logged as tuff (but the 'tuff' is likely an error in rock type identification, instead the material is likely altered sandstone)
MW4	300565	6170612	116.92	11.00 – 27.00, 16 m long screen	Fresh upper latite
MW5	300643	6170392	116.89	36.00 – 56.00, 20 m long screen	Fresh upper latite Two separate agglomerate layers (3 m and 9 m thick) Fresh lower latite
MW6	300774	6170237	94.77	5.80 – 43.80, 38 m long screen	Fresh upper latite 12 m thick agglomerate layer Fresh lower latite 13.8 m of a 15 m thick agglomerate layer
MW7	301158	6170044	81.75	8.00 – 21.00, 13 m long screen	Fresh upper latite
MW8	300930	6170676	109.18	7.00 – 21.00, 14 m long screen	Generally slightly to moderately weathered upper latite

3.2 Groundwater levels

3.2.1 Project area

Groundwater levels observed in the Quarry's groundwater monitoring bores are summarised in **Table 3.2**. Hydrographs of bores MW1S, MW1D, MW2S, MW2D and cumulative rainfall departure (CRD) are provided in **Figure 3.3** and **Figure 3.4** in datums of mAHD and metres below ground level (mBGL) respectively. Hydrographs for MW4, MW5, MW6, MW7 and MW8 are provided in **Figure 3.5** (mAHD) and **Figure 3.6** (mBGL).

MW1S, MW1D, MW2S, MW2D have significantly longer datasets (dataset about 11 years) than MW4, MW5, MW6, MW7 and MW8, where the dataset is typically about two to three months long.

CRD is calculated from the cumulative sum of observed rainfall minus long-term average rainfall and sometimes displays correlation to groundwater levels, particularly where rainfall recharge is an important process. A climbing CRD line slope represents above average rainfall whilst a declining slope represents below average rainfall.

The groundwater levels do not appear to visually correlate well with CRD.

Groundwater levels range from about 46 mAHD to 115 mAHD and are generally about 3 mBGL to 10 mBGL. Notable exceptions include MW5, where the average ground level of 80.15 mAHD corresponds to about 37 mBGL and to a lesser degree, MW1D, where the average ground level of 51.33 mAHD corresponds to about 19 mBGL.

MW1S/MW1D and MW2S/MW2D are paired sites where shallow and relatively deeper monitoring bores are installed within a few metres of each other. There is a considerable head disparity (about 10 m to 20 m) between MW1S and MW1D, and at certain periods, between MW2S and MW2D too, although this disparity is relatively less (up to 12.5 m at commencement of monitoring and 5 m later in the monitoring period). These observations combined with the distinctly relatively lower groundwater levels observed in MW5 suggest poorly connected fracture flow paths and negligible matrix hydraulic conductivity of the latite/agglomerate. Furthermore, MW5 does not recover quickly after groundwater quality sampling, suggesting the groundwater system in the immediate vicinity of this bore is isolated, non-permanent and of limited extent.

Table 3.2: Quarry monitoring bore groundwater level summary

Monitoring bore	Groundwater level (mAHD)		
	Min.	Average	Max.
MW1S	63.03	66.36 (3.48 mBGL)	69.09
MW1D	45.54	51.33 (18.51 mBGL)	60.58
MW2S	63.12	65.35 (8.97 mBGL)	68.97
MW2D	56.18	64.49 (9.91 mBGL)	72.06
MW4	112.55	112.71 (4.21 mBGL)	115.05
MW5	76.15	80.15 (36.74 mBGL)	80.34
MW6	88.44	88.70 (6.07 mBGL)	92.21
MW7	70.15	71.01 (10.74 mBGL)	80.95
MW8	100.84	101.31 (7.87 mBGL)	102.27

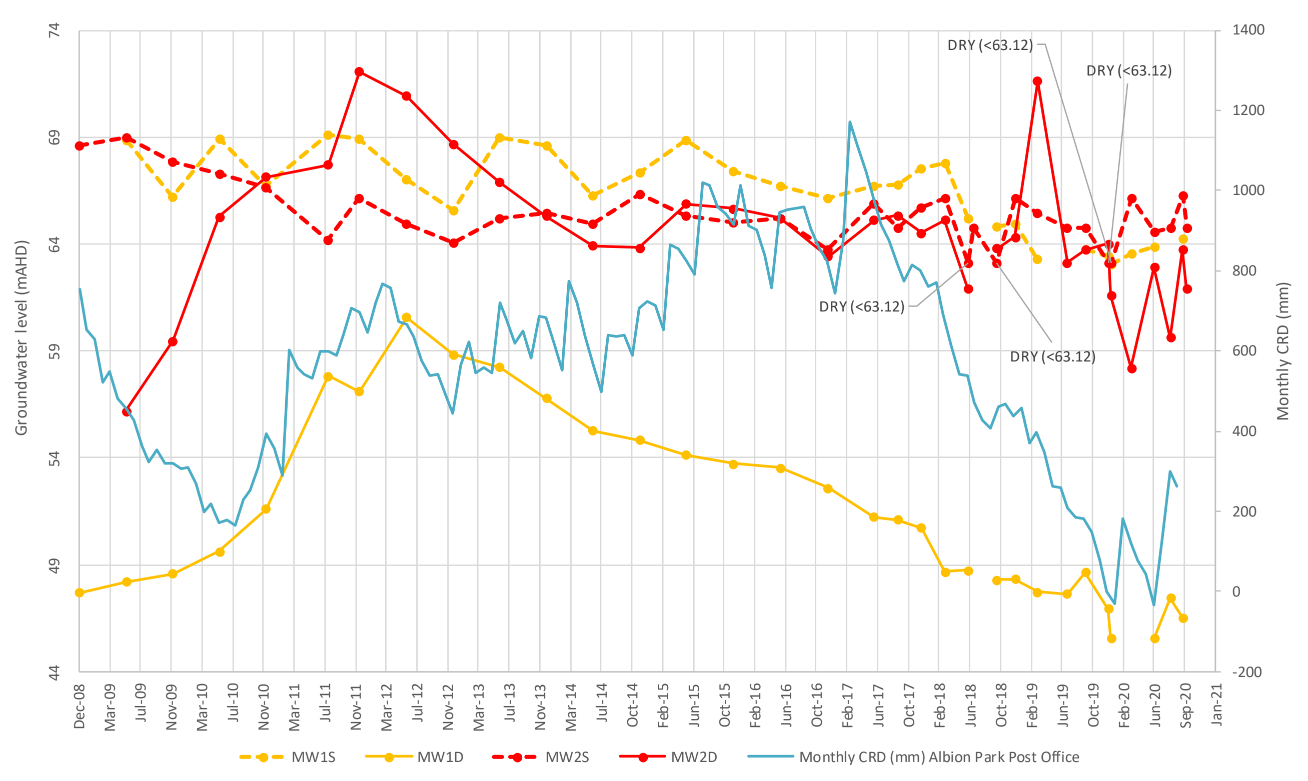


Figure 3.3: MW1S, MW1D, MW2S, MW2D groundwater level (mAHD) and monthly CRD (mm)

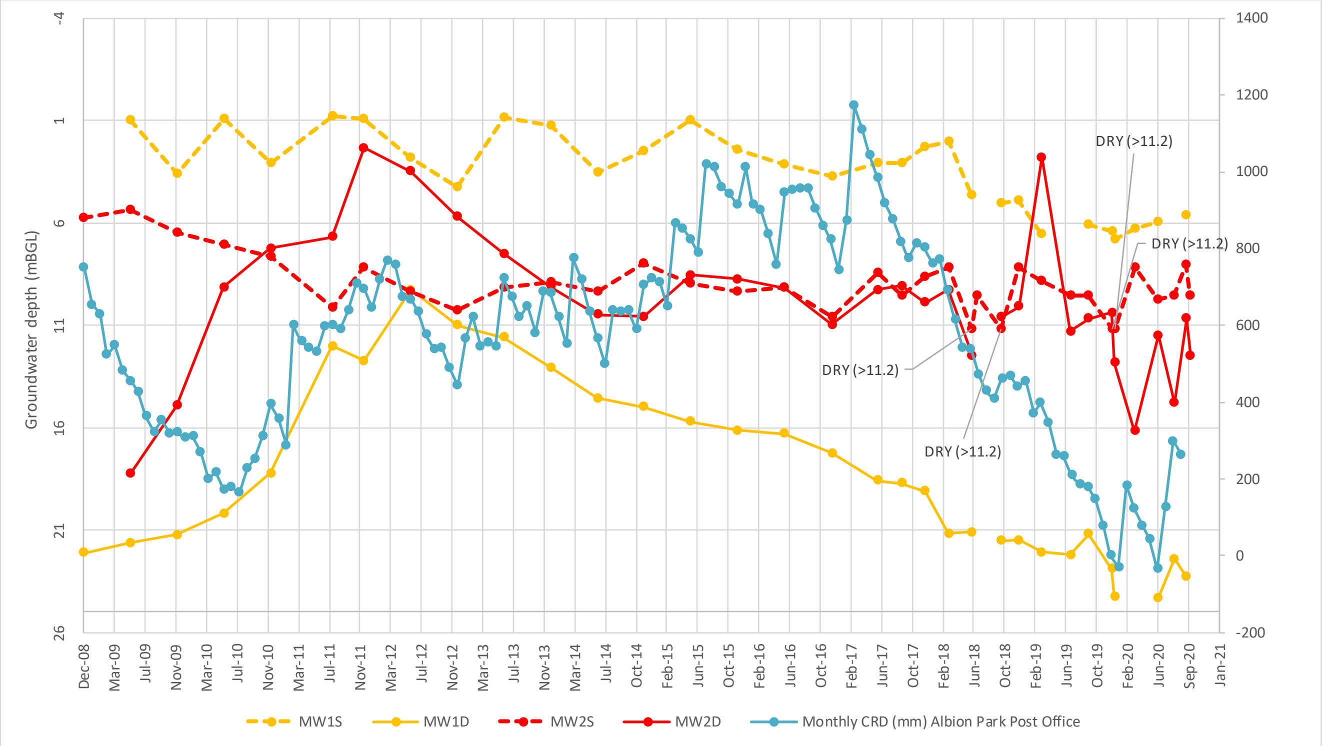


Figure 3.4: MW1S, MW1D, MW2S, MW2D groundwater depth (mBGL) and monthly CRD (mm)

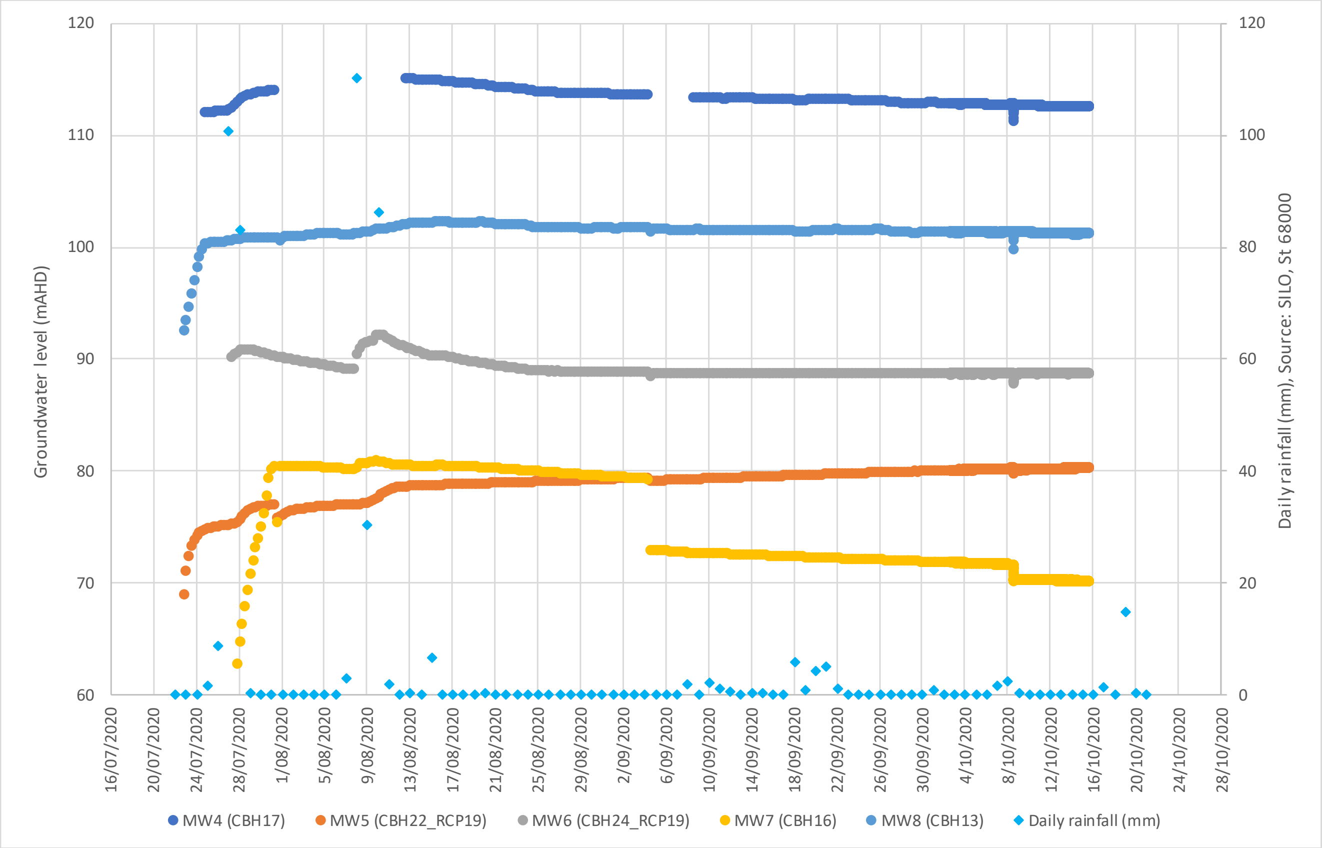


Figure 3.5: MW4, MW5, MW6, MW7 and MW8 groundwater level (mAHD) and daily rainfall (mm)

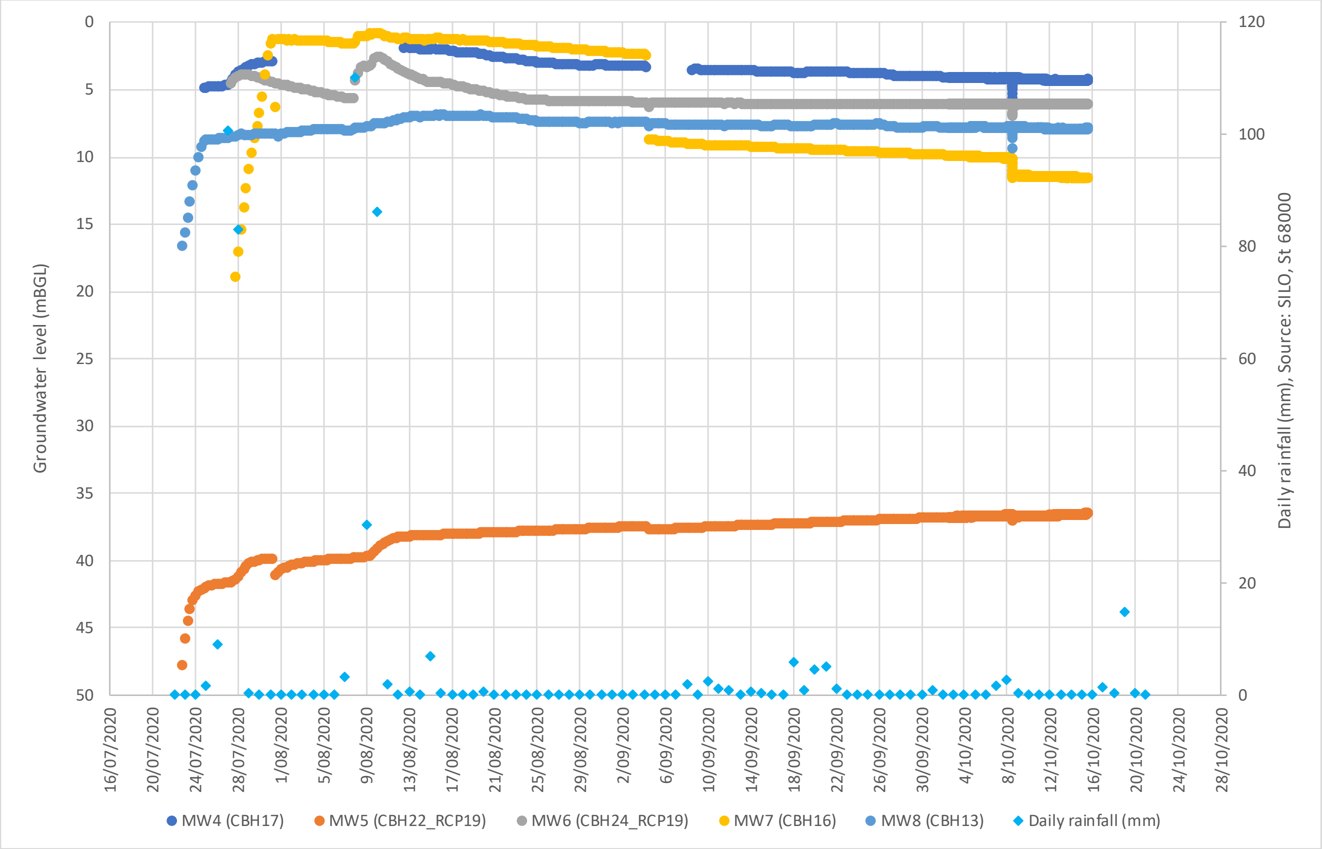


Figure 3.6: MW4, MW5, MW6, MW7 and MW8 groundwater level (mBGL) and daily rainfall (mm)

3.2.2 Regional groundwater levels

Groundwater levels from groundwater monitoring bores within the Project Area, registered bores in the Water NSW (2020) online bore database and three monitoring bores at Dunmore Quarry (EMM, 2016), located about 1.7 km to 2.4 km south west of the Project Area, were contoured to convey groundwater levels and flow directions.

Thirty-nine groundwater level locations and 379 additional control points were used to generate the contours. The control points were on placed along the ocean, Macquarie Rivulet, Minnamurra River, Lake Illawarra and at Bass Point. No control points were placed near the Project Area. The maximum depth of a bore used as a contour interpolation point was 204 m.

The contours are shown in **Figure 3.7** and generally suggest that groundwater flows from areas of relatively high elevation towards areas of relatively low elevation, before discharging to Lake Illawarra, Macquarie Rivulet and Minnamurra River and other low lying areas, including the ocean. Groundwater levels are relatively elevated in the vicinity of the Project.

Although not apparent in the contours, it is noted that preferential flow, coincident with strata dip to the south east may occur.

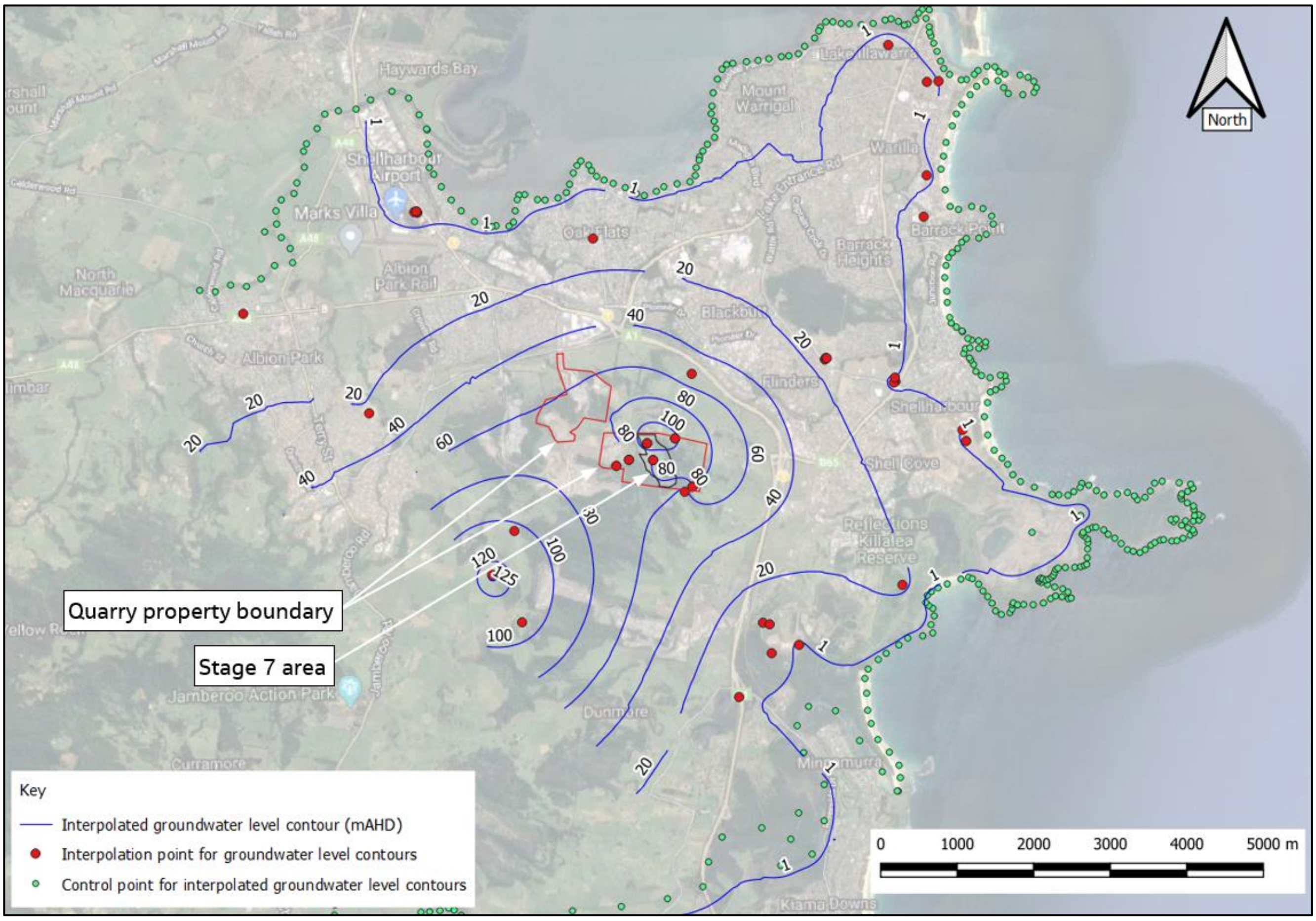


Figure 3.7: Contoured groundwater levels

3.3 Conceptual hydrogeological cross section

Conceptual hydrogeological cross sections are provided for the locations shown in **Figure 3.8**. The cross sections are shown on **Figure 3.9** and **Figure 3.10** and were developed in geological modelling software, Leapfrog, by creating 50 m resolution meshes from 3D contour lines of Upper Latite, agglomerate and Lower Latite layers that were provided by Cleary Bros. The cross sections simplify the geology and are considered suitable for demonstrating conceptual hydrogeology.

It is noted that in some locations, such as MW6, there are more agglomerate layers than depicted in the conceptual sections. For instance, at MW6 there are two separate agglomerate layers separated by an 8 m thick latite interval.

Also, in **Figure 3.9**, the sandstone is shown as close to the base of MW1S. However, MW1D (not shown on section), located adjacent to MW1S, extended to 25 mBGL and the rock type below the latite was logged as “tuff” from 14.5 to 25 mBGL. This was likely an error in rock type identification and the “tuff” is likely to be an altered sandstone. Thus, the actual level of the sandstone in this location is lower than indicated by the cross section. The discrepancy could be due to coarse mesh resolution in the Leapfrog model and/or inaccuracy in the initial 3D contours in this isolated area. Notwithstanding this, the cross sections are considered suitable for demonstrating conceptual hydrogeology, particularly in the area of Stage 7 as numerous resource definition drill holes located in this area where used by Cleary Bros to create the 3D contour lines.

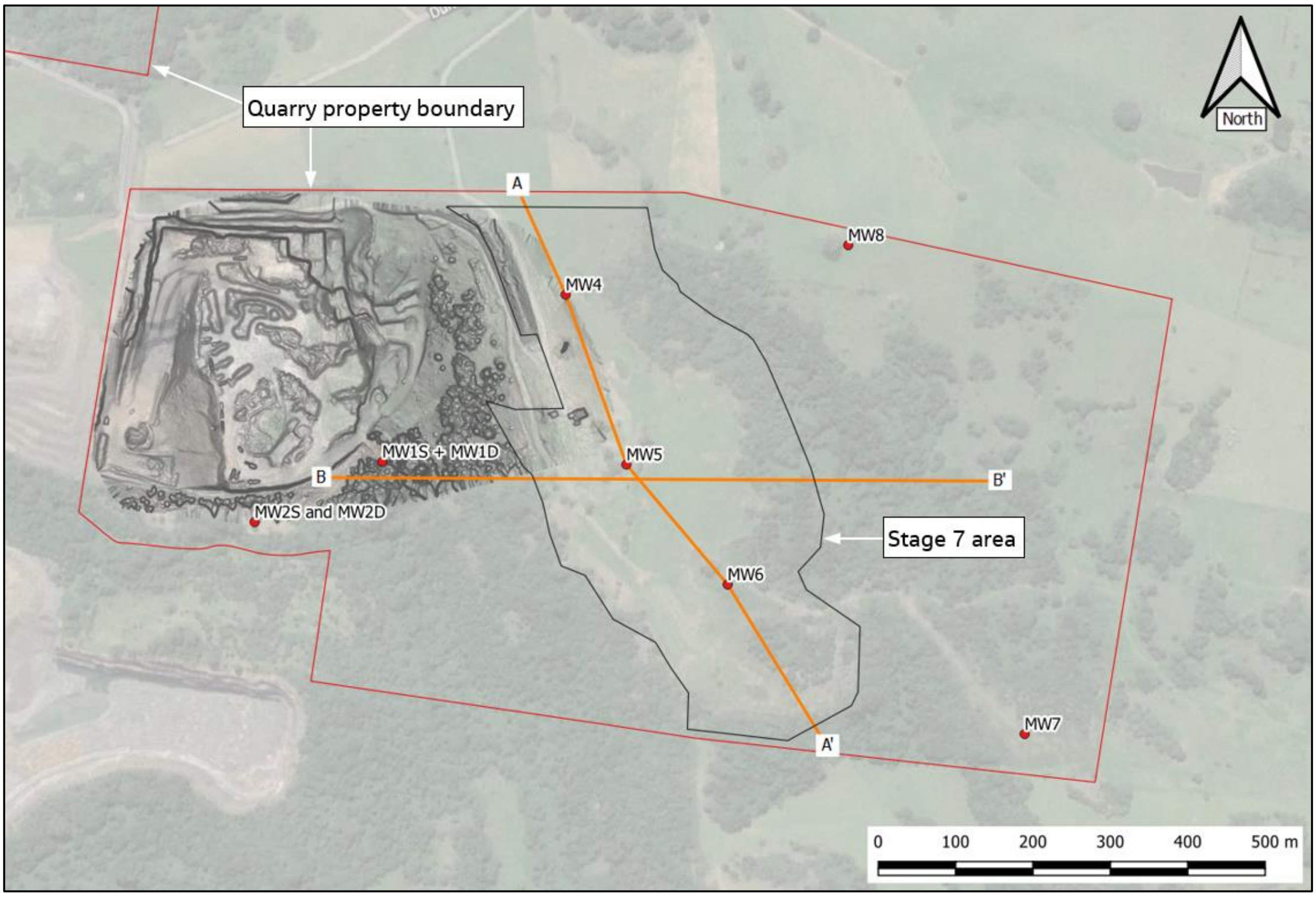


Figure 3.8: Conceptual hydrogeological cross section locations

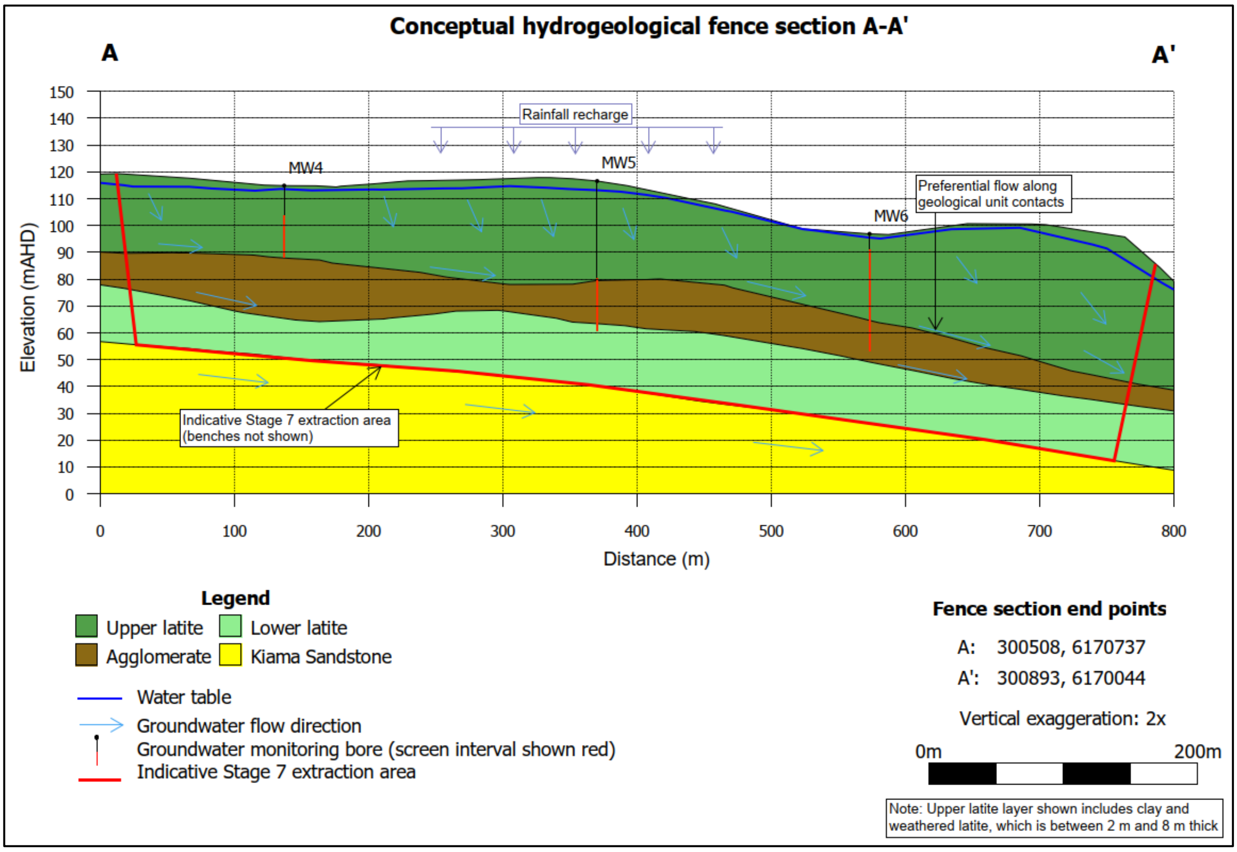


Figure 3.9: Conceptual hydrogeological fence section A-A'

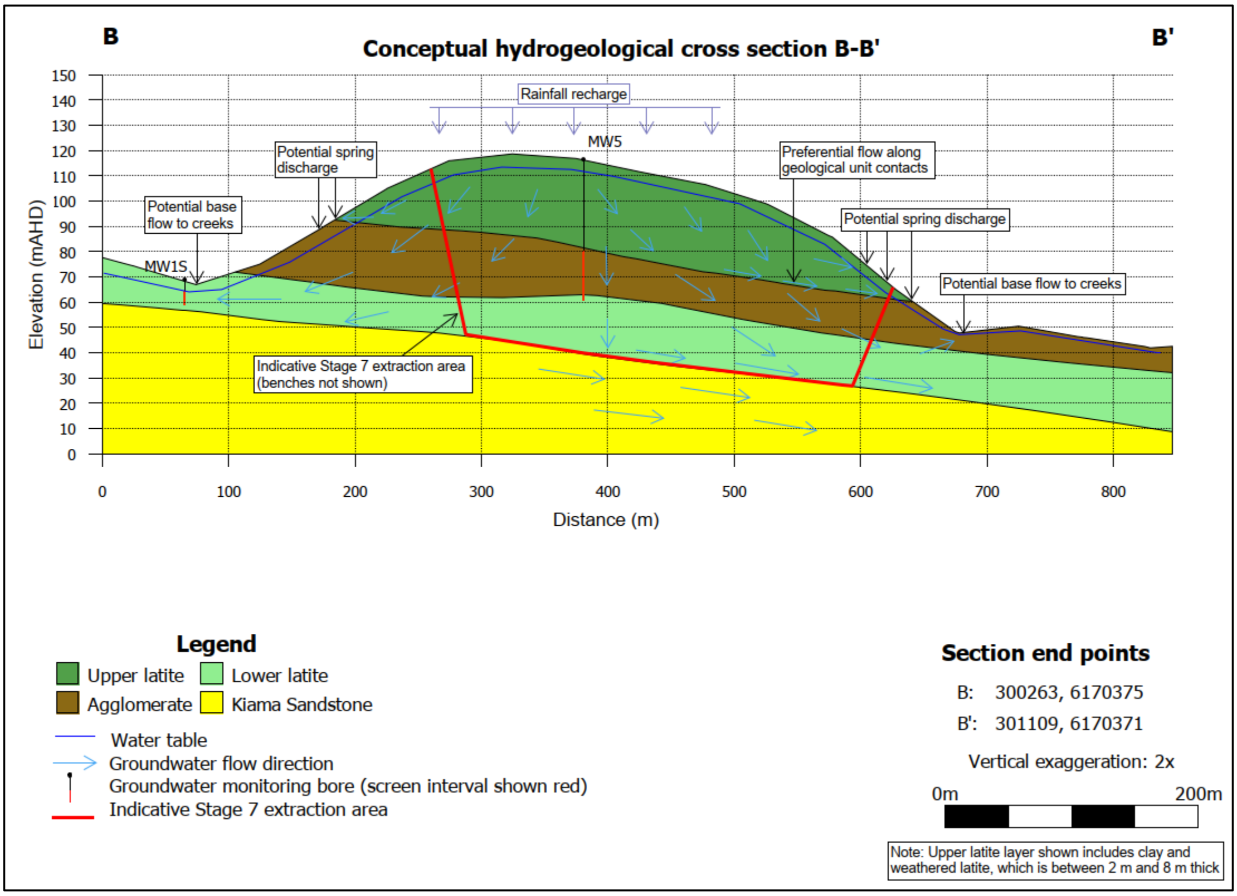


Figure 3.10: Conceptual hydrogeological cross section B-B'

3.4 Hydraulic conductivity

Slug test results for the groundwater monitoring bores within the Project Area are summarised in **Table 3.3**. Hydraulic conductivity of the latite and agglomerate in the Project Area ranged from 1.56x10^{-5} m/d to 7.64x10^{-3} m/d and is inferred to be generally low and typically less than 0.002 m/d based on a mean and geomean of 1.71x10^{-3} m/d and 3.51x10^{-4} m/d, respectively.

Further afield, at three monitoring bores at Dunmore Quarry (EMM, 2016), located between 1.7 km to 2.4 km south west of the Project, the average hydraulic conductivity at the three bores ranged from 1.9x10^{-8} m/d to 8.9x10^{-7} m/d.

It is noted that the Project's monitoring bores typically have relatively longer screen intervals compared to the monitoring bores at Dunmore Quarry. This may explain the relatively lower hydraulic conductivity values in the immediate vicinity of the Dunmore Quarry monitoring bores. Alternatively, rock mass discontinuities may be relatively less pronounced in the area of Dunmore Quarry.

Table 3.3: Quarry monitoring bore slug testing results summary

Bore ID	**Screen location (mBGL) and length (m)** [1]	**Screened material**	**Hydraulic conductivity (m/d)**
MW1S	4.50 - 10.29, 5.79 m long screen	▪ Fresh upper latite	1.73×10^{-4}
MW1D	18.30 – 25.11, 6.81 m long screen	▪ Logged as tuff	2.95×10^{-5}
MW2S	6.50 – 13.00, 5.50 m long screen	▪ Fresh upper latite	Not tested – bore dry
MW2D	18.50 – 24.37, 5.87 m long screen	▪ 2.87 m of fresh upper latite, followed by 3 m length in agglomerate (logged as tuff)	1.56×10^{-5}
MW4	11.00 – 27.00, 16 m long screen	▪ Fresh upper latite	1.41×10^{-3}
MW5	36.00 – 56.00 20 m long screen	▪ Fresh upper latite ▪ Two separate agglomerate layers (3 m and 9 m thick) ▪ Fresh lower latite	2.40×10^{-3}
MW6	5.80 – 43.80 38 m long screen	▪ Fresh upper latite ▪ 12 m thick agglomerate layer ▪ Fresh lower latite ▪ 13.8 m of a 15 m thick agglomerate layer	3.22×10^{-4}
MW7	8.00 – 21.00 13 m long screen	▪ Fresh upper latite	Not tested - bore water levels do not recover following water quality sampling events. Bore inferred to be monitoring an isolated non-permanent groundwater source.
MW8	7.00 – 21.00 14 m long screen	▪ Generally slightly to moderately weathered upper latite	7.64×10^{-3}
		Statistics	**Hydraulic conductivity (m/d)**
		Minimum	1.56×10^{-5} (MW2D)
		Median	3.22×10^{-4}
		Mean	1.71×10^{-3}
		Geomean	3.51×10^{-4}
		Maximum	7.64×10^{-3} (MW8)
		Range (i.e. max – min)	7.62×10^{-3}

Notes: [1] Documented screen length includes gravel pack interval immediately above screen prior to bentonite, and in the case of MW4, a 2 m long gravel packed sump beneath the bottom of the screen.

3.5 Storage (groundwater system)

Groundwater system storage properties are physical properties that characterise the capacity of a groundwater system to release groundwater. For water table groundwater systems, storage is discussed in terms of specific yield (Sy), which is also known as drainable porosity. Specific yield, quoted as a ratio, is generally less than or equal to the effective porosity (total connected pore space). Additionally, specific storage (Ss) is the amount of water that a portion of an aquifer releases from storage, per unit mass or volume of aquifer, per unit change in hydraulic head, while remaining fully saturated.

Groundwater system storage within the Project Area is inferred to be low for the latite/agglomerate. Specific yield is inferred be about 0.01 based on inferred poorly connected fracture flow paths and low primary porosity. This specific yield value aligns with a representative value for fractured igneous and metamorphic rock in Bair and Lahm (2006) of approximately 0.01.

Specific storage is conceptualised to be in the order of $1\text{x}10^{-6}$ based on the material type and literature values for moderately fissured rock in Younger (1993).

3.6 Groundwater recharge

Groundwater recharge (via rainfall infiltration) in the Project Area is inferred to be low based on low formation hydraulic conductivity, clay overburden and reasonably steep slopes (which encourage runoff) which flank the ridges in the vicinity of the Project Area. Relatively higher recharge may occur on the ridge tops.

3.7 Groundwater discharge

Groundwater discharge within the Project Area is conceptualised to occur though evapotranspiration (ET), discharge to springs and discharge as baseflow to watercourses. Regionally, groundwater discharges to the adjacent water bodies of Lake Illawarra and the Pacific Ocean.

3.7.1 Springs

Springs occur in the general area around the Project Area, including to the north of Stage 7 (**Figure 3.11**). Such springs are conceptualised to be controlled by shallow groundwater flow systems that are poorly connected to underlying deeper groundwater systems. This same characterisation was adopted by EMM (2016) for springs at the nearby Dunmore Quarry and was evidenced by water quality analysis that showed that the springs in that area relied on shallow younger localised rainfall recharge and not deeper groundwater systems.

The vegetation in the area of these springs and surrounds has been cleared long ago and now appears to mostly comprise grass vegetation with standing water collected downstream in small on-stream dams. Cattle graze in the area of the springs and likely eat the greener vegetation in the area of the springs.

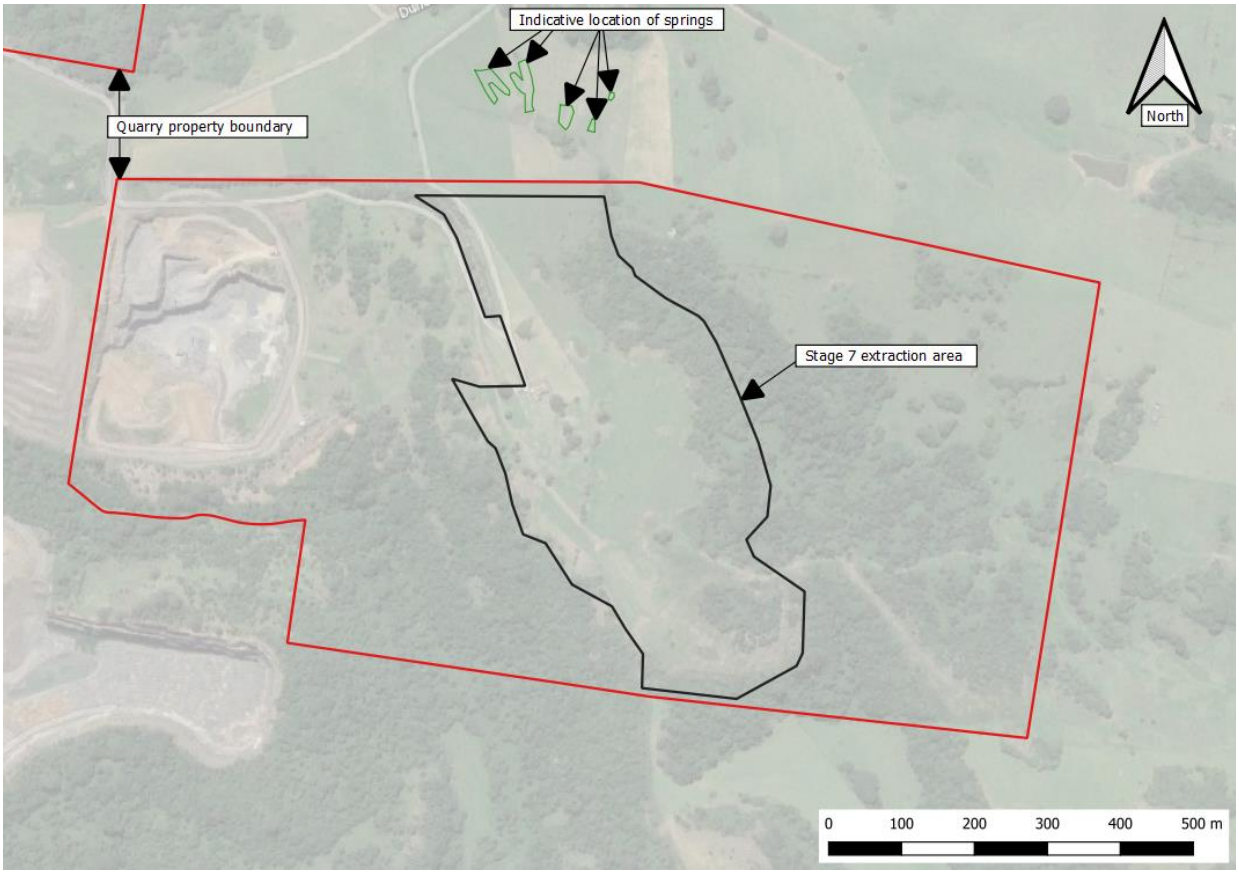


Figure 3.11: Indicative location of springs

3.7.2 Baseflow

Baseflow is inferred to occur to watercourses in the vicinity of the Project Area but is conceptualised to be low due to low formation hydraulic conductivity. Baseflow processes are unlikely significant to the existing environment in the vicinity of the Project Area and likely represent a negligible component of the water balance.

Watercourses in the area of the Project Area are discussed in Jacobs (2020) and are shown in **Figure 3.12** overlying a colour ramp of a 5 m resolution LIDAR (Light Detection and Ranging) digital elevation model (DEM) obtained from ELVIS (ICSM, 2020). It is noted that the majority of Watercourse 1 (refer **Figure 3.12)** and its tributaries have been removed by the Quarry's existing extraction area. The NSW Foundation Spatial Data Framework – Water – NSW Hydro Line data does not reflect this.

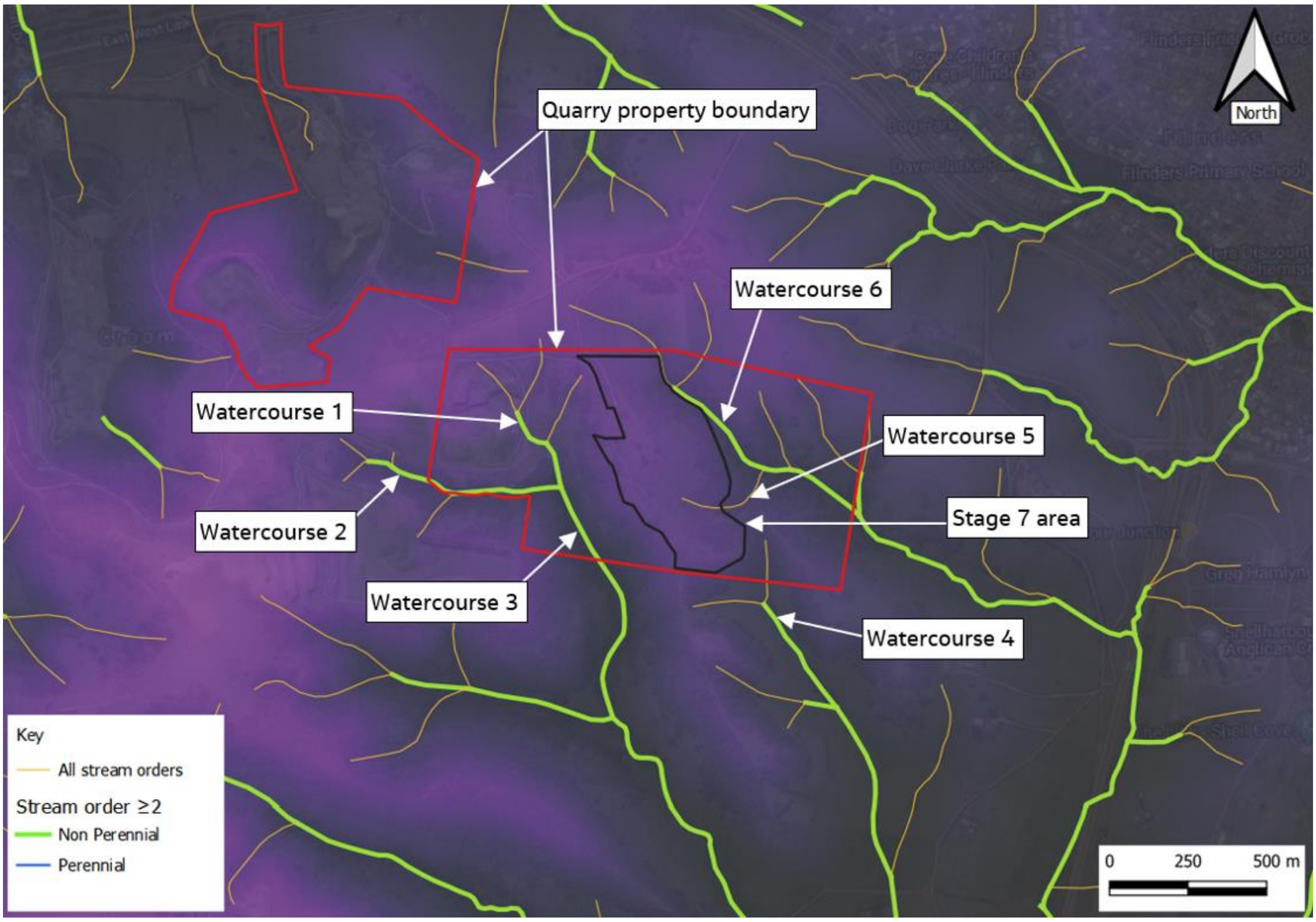


Figure 3.12: Watercourses within about 1 km of the Project (source: NSW Foundation Spatial Data Framework - Water - NSW Hydro Line)

3.7.3 Groundwater extraction by existing registered bores

Groundwater extraction by existing registered bores in the vicinity of the Project is considered to be negligible. **Figure 3.1** shows that registered bores are sparse in the region of the Project. The three closest water extraction bores to the Project are summarised **Table 3.4**.

Table 3.4: Registered water extraction bores close to Project (Source: Water NSW, 2020 and Bom, 2020a)

Bore I.D.	Purpose	Distance from potential Quarry extension area	Bore depth (m)	Yield (L/s)	Standing water level (mBGL)
GW100090	Water supply	160 – 200m, south east of Stage 7	66	0.1	0.3
GW109000	Water supply	900m, north east of Stage 7	78	0.8	27
GW044447	Stock and domestic	1250m, south east of Stage 7	0	No data	No data

3.7.4 Discharge to existing quarry/proposed extension

Existing quarry - site inspection (16.12.2019)

Groundwater is conceptualised to have been discharging at very low rates to the Quarry extraction area in general and in particular the extraction area's sump at the time of the site inspection (16.12.2019). This is because the approximate sump level of 65 mAHD is below the average groundwater level observed in the majority of the Quarry's monitoring bores. However, the discharge is considered to be very low, and is less than evaporation. The existing extraction area appeared dry at the time of a Jacobs site inspection except for the sump, and groundwater was not observed on the pit floor or side walls. A photo of the existing extraction area at the time of the Jacobs inspection is provided in **Figure 3.13a**.

Email correspondence between Jacobs - Cleary Bros (2020) concerning sump water level observations around the time of the site inspection is summarised as follows:

- Cardno (2018) estimate the sump is 1 m deep, 40 m x 50 m and has a capacity of approximately 2 ML.
- The sump extends through the lower latite and sandstone contact, whereas the rest of the pit terminates on the latite, just prior to the underlying sandstone.
- The sump always contains water, even in dry periods.
- The sump has a water level elevation of approximately 65 mAHD, which fluctuates with rainfall runoff.
- Cleary Bros do not propose to deepen the sump shown in **Figure 3.13a**. However, over time the location of the sump would transition to different portions of the extraction area.

Based on the above, groundwater is inferred to have been contributing to the sump's volume of water around the time of the site inspection. The inferred groundwater inflows are inferred to be from the latite/sandstone contact or the sandstone. The latite itself is considered unlikely to be providing significant groundwater flow to the sump, which is evidenced by the dry pit floor shown in **Figure 3.13a**.

Existing Quarry – January 2021

A photo of the existing extraction area during January 2021 is provided in **Figure 3.13b**. The photo shows that the sump area has increased since December 2019 and has transitioned to the east.

Cleary Bros have indicated that changes in water level within the sump are thought to be primarily associated with surface water flows, as after prolonged or significant rainfall, the volume of water in the sump increases. During dry periods, the volume of water in the sump decreases, but always contains some volume of water, even in dry periods.

Thus, groundwater inflows are thought to be contributing to the volume of water within the sump, albeit less significantly than surface water flows.

Proposed Quarry

Based on the negligible groundwater discharges to the existing extraction area, combined with other conceptualisation elements discussed in Sections 3.1, 3.2.1, 3.4 and 3.5, groundwater discharges to the proposed extension area are conceptualised as likely to be low.

Figure 3.13a: View looking north east, showing extraction area with dry floor/walls, and sump (16/12/2019)

Figure 3.13b: View looking north east, showing extraction area with relatively larger sump that has transitioned to east (16/12/2019)

3.8 Existing drawdown and future drawdown potential

Based on existing observations, groundwater drawdown associated with the existing extraction area and proposed extension area is conceptualised as likely to be limited in extent to within a few hundred metres of extraction.

3.9 Groundwater Dependent Ecosystems

The occurrence of potential GDEs was assessed through review of the BoM's GDE Atlas (BOM, 2020b), mapping within the Albion Park Rail Bypass groundwater report (RMS, 2015) and high priority GDE mapping in the Water Sharing Plan (WSP) (NSW Government, 2011). Additionally, a site inspection was undertaken 16 – 17 December 2019.

3.9.1 BoM (2020b) Terrestrial GDEs

Low and moderate potential terrestrial GDEs are mapped in the south and east of Stage 7 area, and to the east, west and south. There are some small areas of land mapped as 'high potential GDE', including a small area near the eastern boundary of the Stage 7 area and a small area about 200m south west of the Stage 7 area. This mapping is shown in **Figure 3.14**.

3.9.2 BoM (2020b) Aquatic GDEs

There are no mapped potential aquatic GDEs within 1km of the Stage 7 area. Further afield, Lake Illawarra is mapped as a 'moderate potential GDE' and there are small water bodies formed from former sand dredging operations south east of the Project Area which are mapped as low to high potential GDEs. This mapping is shown in **Figure 3.14**.

3.9.3 Albion Park Rail bypass EIS

RMS (2015) mapped GDEs to the north-north west of the Stage 7 area. The GDEs comprise SEPP14 wetlands, including wetlands at Croom Voluntary Conservation Area, Macquarie Rivulet and north of Macquarie Rivulet, freshwater wetlands and Illawarra Lowlands Grassy Woodland. The nearest mapped GDE comprises a very small freshwater wetland, which is approximately 1.5km north west of the Stage 7 area.

It is noted that the proposed Stage 7 area is located in the south eastern corner of the mapping extent. Therefore, this study has not mapped GDEs south or east of the proposed Stage 7 area.

3.9.4 WSP High Priority GDEs

Review of High Priority GDEs is covered in Jacobs (2020) and indicates that there are no High Priority GDEs close to the Project Area. The nearest HPGDEs are Macquarie Rivulet and the Minnamurra River Estuary (**Figure 3.14**.), which are greater than 3 km from the Project Area.

3.9.5 Springs

Springs are discussed in Section 3.7.1.

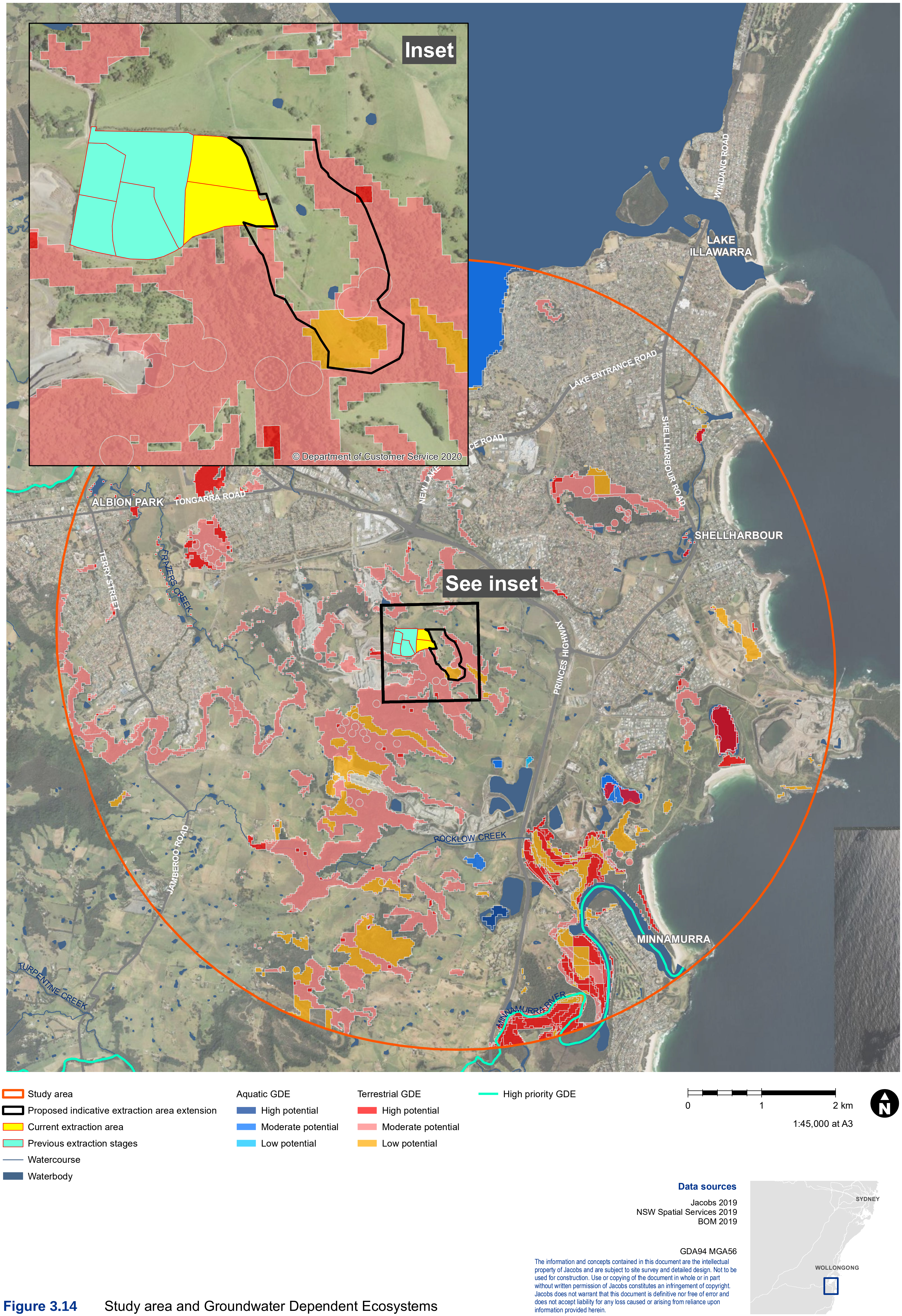
3.9.6 Site inspection

The drainage line/waterfall downgradient of MW1S/MW1D (i.e. near start of Watercourse 3, refer **Figure 3.12**) was inspected. No pooled water or any seepage was observed.

The vegetated area mapped as ‘High potential GDE’ by the BoM (2020b) to the east of Stage 7 was partially inspected. The area was difficult to traverse due to thick lantana coverage. However, animal tracks through the lantana enabled some limited access. The areas inspected did not appear to host areas of potential GDEs. Jacobs staff were able to inspect the vegetation in western portion of the area mapped as ‘High potential GDE’ by the BoM (2020b), but were unable to access the entire area, including the drainage line, due to lantana that was impassable. Of the areas inspected, the likelihood of GDEs was considered low and extensive lantana was observed.

3.10 Cumulative impact potential

Based on the area of the Project and the extraction area floor level relative to groundwater levels, combined with limited existing drawdown and anticipated limited drawdown due to Stage 7 extraction, cumulative impacts due to Project impacts combining with impacts from other Quarries in the region (**Figure 3.1**) are considered unlikely.



Data sources

Jacobs 2019
NSW Spatial Services 2019
BOM 2019

GDA94 MGA56

Figure 3.14 Study area and Groundwater Dependent Ecosystems

4. Model design

4.1 Model class

In accordance with the Australian Groundwater Modelling Guidelines (Barnett et al. 2012), the intended model confidence class is Class 1. Class 1 models are stated by Barnett et al. (2012) as including the following examples of specific uses:

- *Predicting long-term impacts of proposed developments in low value aquifers*
- *Estimating impacts of low-risk developments*
- *Understanding groundwater flow processes under various hypothetical conditions*

A Class 1 model was selected because the Project is considered low risk and the 'aquifers' within the resource to be extracted are considered low value due to their very low yields. Indeed, 'aquifers' are not conceptualised to typically be present within the resource to be extracted. These groundwater systems are considered to yield too low to constitute 'aquifers'.

4.2 Numerical code

Initially, a model was developed using AnAqSim, an analytical element computer program considered suitable for a Class 1 model. However, during model development, the model proved to be numerically unstable and had difficulties solving. As a result, the approach was changed, and a Class 1 numerical model was developed.

The numerical groundwater model was developed using the United States Geological Survey (USGS) modelling code, MODFLOW, which is an industry standard groundwater modelling code. The variant of MODFLOW used in this assessment was MODFLOW-USG. The input for MODFLOW, as well as output files from MODFLOW, were processed using the Groundwater Vistas Graphical User Interface (GUI) Version 7.15 Build 8.

The model represents the fractured rock groundwater system as an equivalent porous medium and uses a convertible layer type. The convertible layer type means confined flow equations are used when the head is above the top of the model and unconfined flow equations are used when the head is below the top of the model.

4.3 Model domain

The model domain is shown **Figure 4.1** and covers a total area of 189 square kilometres (sq km), of which 85 sq km is active model area. In GDA94/MGA zone 56, the domain origin coordinates are x: 294200 and y: 6163600. From the origin, the domain extends 13.3 km to the north and 14.2 km to the east.

The active model domain was bounded by the ocean in the east, Minnamurra River in the south, a no flow boundary in the west and Macquarie Rivulet and Lake Illawarra in the north.

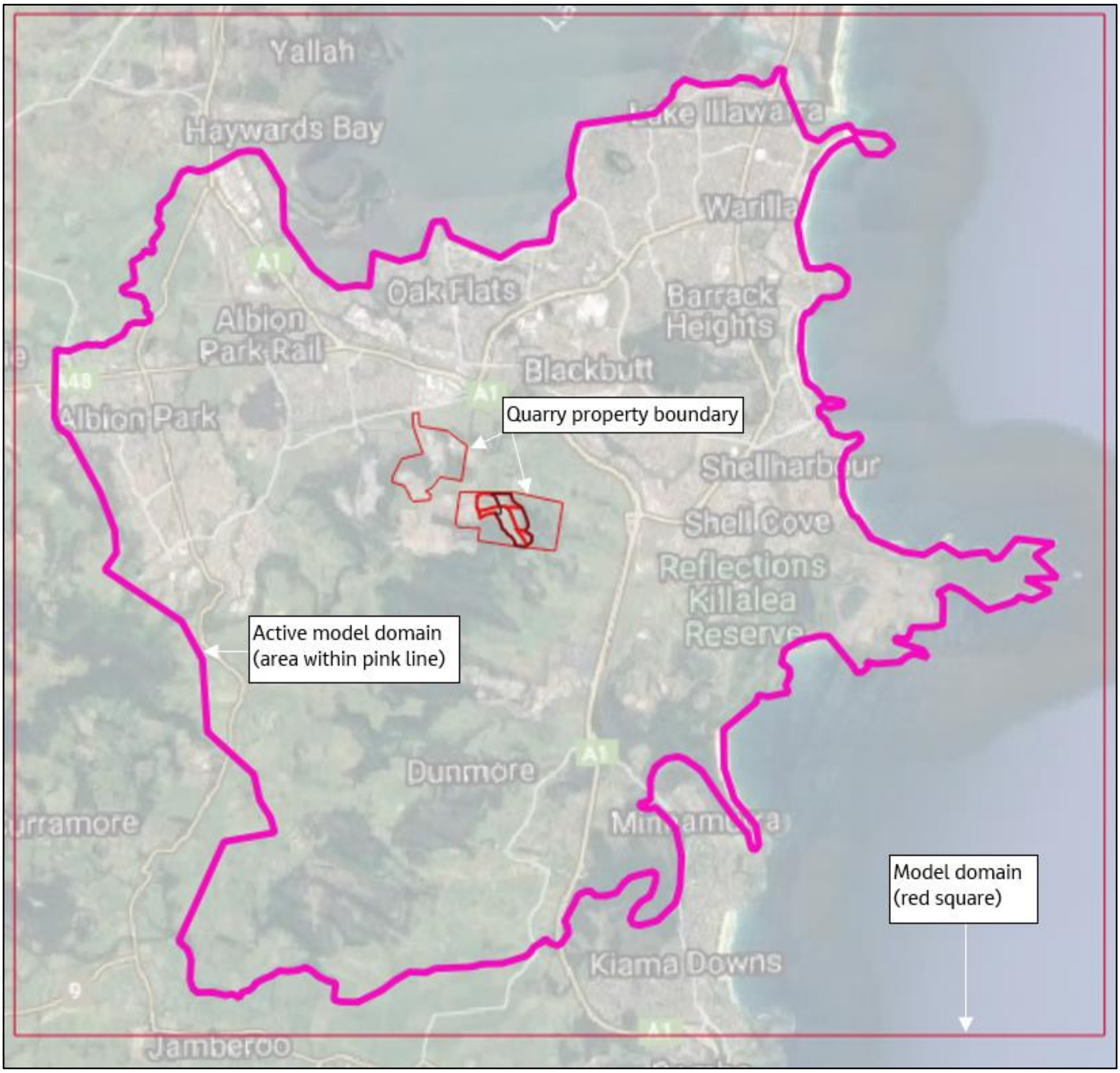


Figure 4.1: Model domain

4.4 Model grid

The model was discretised into a grid (**Figure 4.2**) consisting of 100 m x 100 m cells, which were then refined to 50 m x 50 m cells in area centred around the Project. The refined cell area extended to about 1 km from the Project.

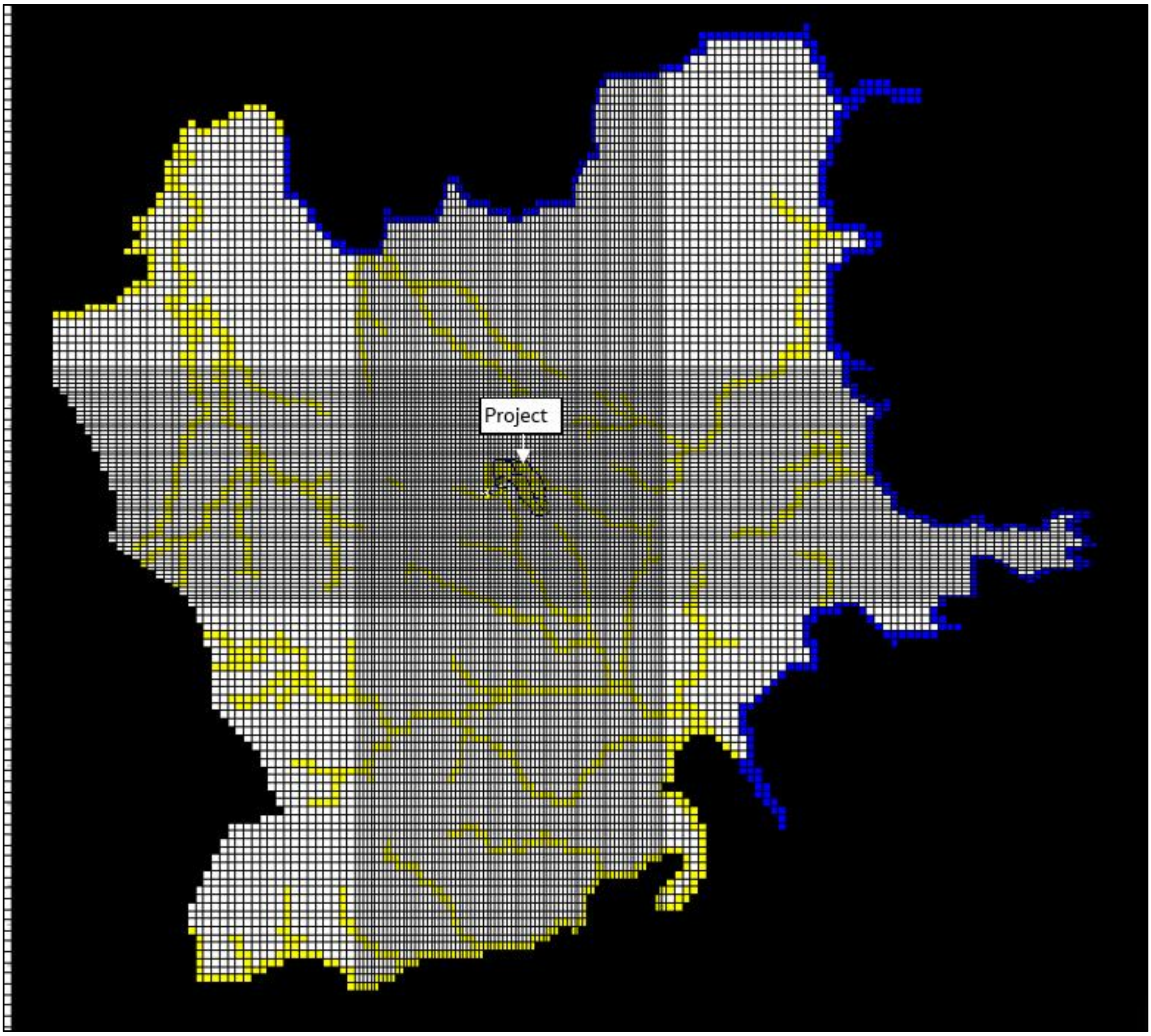


Figure 4.2: Model grid

4.5 Model layers

The model was discretised into a single layer with cell top elevations derived from a 100 m x 100 m DEM produced by the program SURFER (2D and 3D mapping software). The model's DEM was produced using ELVIS (ICSM, 2020) 5 m DEM LIDAR data.

The layer was assigned a uniform base elevation of -20 mAHD in order to maintain sufficient cell thickness in areas of the model where the elevation is very low (i.e. close to 0 mAHD). This bottom elevation is considered appropriate in light of the minimum proposed extraction level of about 15 to17 mAHD.

A single layer was applied based on the Stage 7 area extracting latite/agglomerate material, where site testing did not identify specific distinctly different hydrogeological layers, and to maintain a level of complexity in-line with the intended Class 1 model level.

The sandstone layer underlying the latite was not modelled because this unit is not proposed to be extracted. Also, areas of the existing quarry where the latite has been extracted very close to the top of the sandstone, but not through the latite/sandstone contact, display no signs of upward vertical leakage from the sandstone to the latite.

4.6 Model boundary conditions

Boundary conditions (including recharge and ET) were applied as follows:

- A constant head boundary with a level of 0 mAHD was applied along the land/ocean interface. These constant head cells are shown blue in **Figure 4.2**.
- A uniform recharge was applied over a single zone for the entire model area. The applied rate was based on SILO for Albion Park Post Office, Station 68000. The initial recharge was applied to the model was approximately 5 percent of mean annual rainfall (applied at a daily rate). The recharge rate was subsequently adjusted during model calibration.
- A uniform ET rate was applied over a single zone for the entire model area. The applied rate was based on FAO56 Penman-Monteith reference evapotranspiration data for Albion Park Post Office, Station 68000. The initial maximum daily ET rate applied to the model was approximately 30 percent of the daily average value from the FAO56 Penman-Monteith reference evapotranspiration data. The maximum ET rate was adjusted during the calibration. A uniform ET extinction depth of 3 m was applied to the model.
- Drain cells (shown yellow in **Figure 4.2**) were applied on drainage lines with a stream order of two and above. Drain cells were not applied to first order streams to reduce model complexity. Drain stage was set to be 1 m below the cell top, with conductance uniform for all cells based on a 4 m drain width, 50 m drain length, 1 m drain thickness and assumed streambed vertical hydraulic conductivity of 100 m/d. The computed uniform conductance rate was 20,000 m^2/d. The drains function to remove groundwater from the model with very little resistance once groundwater level exceeds the drain level. This simulates groundwater discharge to creeks. The drain cells remove groundwater from the model only and do not supply groundwater.

  Drain cells were applied on Macquarie Rivulet and Minnamurra River similar to above but slightly different using linear gradients. The linear gradients represent ground level or water level in the area of these systems and were applied in the initial AnAqSim model and the same assumptions were transferred to the MODFLOW model.

  Drain cells were also applied on the existing extraction area (applied at a uniform level of 65 mAHD) and on the Stage 7 area (predictive model only). The stage for the Stage 7 drain cells was applied using a linear gradient to represent the proposed extraction floor levels. Drain cells on areas of extraction were applied a conductance based on full cell width and length (50 m x 50 m), drain thickness of 1 m and vertical drain hydraulic conductivity of 100 m/d. The computed uniform conductance rate was 250,000 m^2/d, which effectively results in the model efficiently removing groundwater over the cell area if the groundwater head is higher than the drain stage.

5. Model calibration

5.1 Steady state calibration

5.1.1 Approach

The model was initially calibrated in steady state to:

- Average groundwater level observations from MW1S (the higher of MW1S/MW1D average groundwater levels) and MW2S (the higher of average MW1S/MW1D groundwater levels)
- Maximum groundwater level observations from MW4, MW6, MW7 and MW8, as these bores have only a short dataset of two to three months. MW5 was not included as a calibration target due to the groundwater level/depth being significantly deeper at this location compared to other nearby Quarry monitoring bores with a comparable surface elevation.
- One off groundwater level measurements from registered bores in the Water NSW (2020) online bore database.

Hydraulic conductivity was set to the geomean of the Quarry's monitoring bores, 3.51 x 10^{-4} m/d, for a single zone over the entire model. Recharge and ET were then iteratively adjusted to achieve an acceptable match between simulated and observed heads (groundwater levels).

Throughout the modelling process, a maximum head change criterion of 0.01 m was used. Often a value of less than this was used to obtain suitable mass balance errors.

5.1.2 Parameters and calibration results

Adopted final calibrated parameters were as follows:

- Hydraulic conductivity – 3.51 x 10^{-4} m/d, geomean of the Quarry's monitoring bores.
- Recharge rate – 12% of mean annual rainfall (1084 mm), which is an annual recharge rate of about 130 mm.

  It is acknowledged that this recharge is considered somewhat high for the groundwater system type. Crosbie et al. (2010) summarise recharge from field studies by hydrogeological division and for the 'fractured, extensive and low productivity' hydrogeological division, the geometric mean recharge rate is about 80 mm per year. Crosbie et al. (2010) also summarise recharge from field studies for different groups of surface geology. For volcanic, plutonic, metamorphic and weathered surface geology groups, the geometric mean recharge rates are about 13 mm, 63 mm, 210 mm and 38 mm per year respectively.

  The impact of a lower recharge rate has been incorporated into uncertainty analysis presented in Section 7.
- ET rate – 20% of mean annual SILO FAO56 Penman-Monteith reference evapotranspiration (1,143 mm), which is an annual rate of about 227 mm.

A comparison of modelled groundwater levels and observed groundwater levels is provided in **Figure 5.1** and **Table 5.1**. Steady state calibration statistics are provided in **Table 5.2**.

The scaled root mean square (scaled RMS) is one of the statistics often used to quantitatively assess the goodness-of-fit between simulated groundwater levels and actual observed groundwater levels. A scaled RMS error less than ten percent usually indicates a reasonably high degree of calibration. The scaled RMS error of 7.8% obtained in the calibrated steady state model indicates the model is well calibrated to measured heads.

Given the good match between simulated and observed heads in **Figure 5.1** and the acceptable calibration statistics (**Table 5.2**), it was concluded that the steady state model simulates average groundwater levels (heads) with reasonable accuracy.

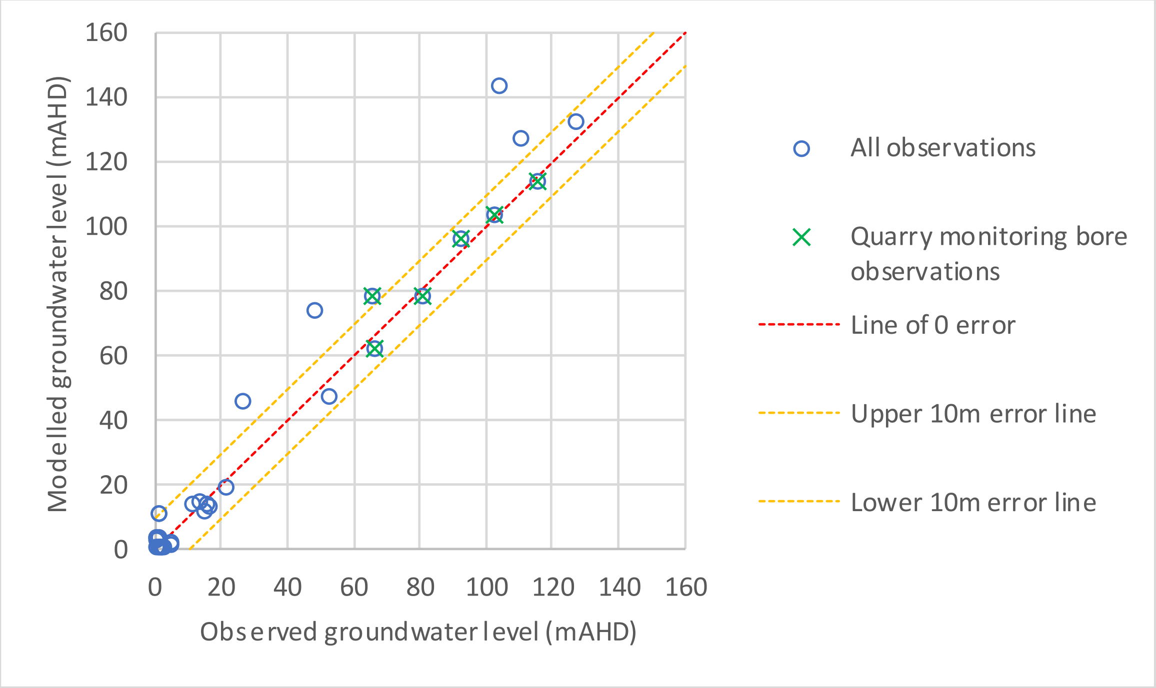


Figure 5.1: Steady state calibration plot

Table 5.1: Steady state calibration summary

Observation point	Observed groundwater level (mAHD)	Modelled groundwater level (mAHD)	Residual (m)	Observation point	Observed groundwater level (mAHD)	Modelled groundwater level (mAHD)	Residual (m)
GW110527	0.93	0.61	0.32	GW109000	48.21	74.49	-26.28
GW100009	-0.08	0.44	-0.52	GW114705	0.43	0.78	-0.35
GW114889	0.07	3.62	-3.55	GW110211	15.51	14.21	1.30
GW100090	52.63	47.42	5.21	GW101125	26.58	45.73	-19.15
GW114704	0.91	0.69	0.22	GW102287	2.02	1.07	0.95
GW109771	1.75	1.07	0.68	GW107819	14.61	11.74	2.87
GW110895	0.93	11.39	-10.46	GW110996	11.17	13.90	-2.73
GW114447	0.28	2.84	-2.56	GW111019	1.98	1.09	0.89
GW110896	-1.10	11.27	-12.37	GW108789	2.12	0.59	1.53
GW110210	16.12	13.50	2.62	MW1S	66.36	62.07	4.29
GW114890	0.95	3.60	-2.65	MW2S	65.35	78.60	-13.25
GW114888	-0.46	3.71	-4.17	MW4	115.05	114.61	0.44
GW114891	0.15	3.60	-3.45	MW6	92.21	96.28	-4.07
GW110894	0.90	10.97	-10.07	MW7	80.95	78.71	2.24
GW110212	12.99	15.01	-2.02	MW8	102.27	104.20	-1.93
GW108102	4.85	2.02	2.83	GW1 Dunmore Quarry	110.00	127.82	-17.82
GW108101	2.67	1.00	1.67	GW2 Dunmore Quarry	127.00	132.98	-5.98
GW108103	4.96	1.60	3.36	GW2 Dunmore Quarry	104.00	143.84	-39.84
GW068181	21.22	19.68	1.54				

Table 5.2: Steady state calibration statistics

Statistical Parameters	Value
Residual Mean	-4.06 m
Residual Standard Deviation	9.17 m
Absolute Residual Mean	5.84 m
Residual Sum of Squares	3,722
RMS Error	10.03 m
Minimum Residual	-39.84 m
Maximum Residual	5.21 m
Range of Observation	128.1 m
Scaled Residual Standard Deviation	0.07 m
Scaled Absolute Residual Mean	0.05 m
Scaled RMS	7.8%
Number of Observations	37

Groundwater level contours from the model are shown in **Figure 5.2**. The figure also displays the groundwater levels as a colour flood. **Figure 5.2** shows that groundwater levels are elevated in areas of relatively higher topography and decrease in areas with lower elevations. This aligns with the conceptual model and interpolated contours (**Figure 3.7**).

The water balance for the steady state model is shown in **Table 5.3**.

Table 5.3: Steady state water balance

Element	Inflow (kL/d)	Outflow (kL/d)
Constant head	0	45
Recharge	29305	-
Drain	-	405
ET	-	28859
Total	29305	29309
Percent error	-0.01	

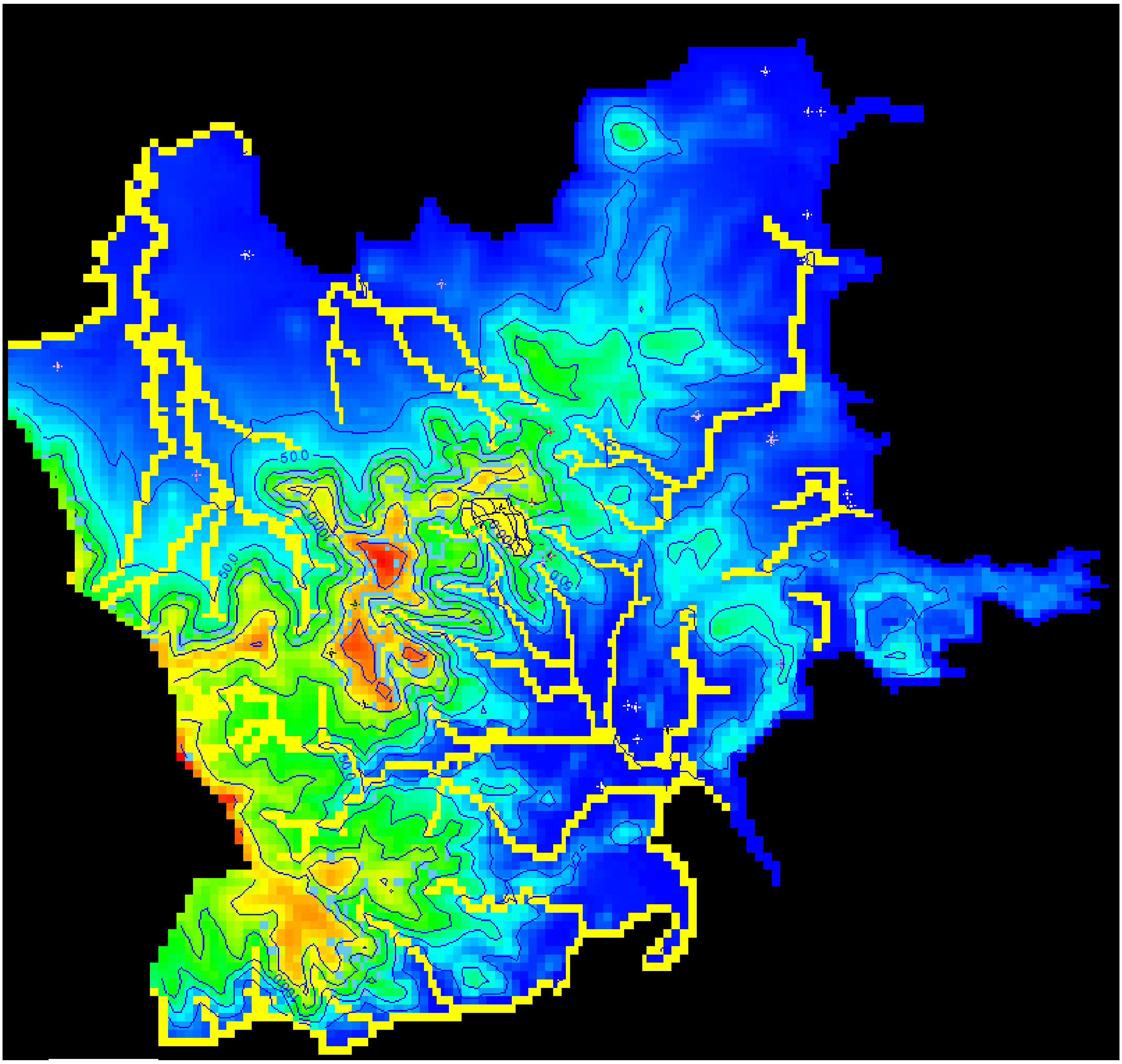


Figure 5.2: Steady state groundwater level contours (25 m interval) and colour flood

5.1.3 Sensitivity analysis

A sensitivity analysis of the steady state model was undertaken for the following parameters:

- Hydraulic conductivity
- Recharge
- ET

The adopted final calibrated parameters values were subjected to multipliers ranging from 0.1 to 1.5 to generate revised model parameters. The model was then run separately for each revised parameter value. The multipliers and parameter values are shown in **Table 5.4**.

The results are shown in **Table 5.5**, which tabulates the sum of squared residuals (of the head targets) for each model run. The sum of squared residuals for the model runs is plotted in **Figure 5.3**. The results indicate that the sensitivity of hydraulic conductivity and recharge is fairly similar. ET sensitivity is also similar, but only for the multipliers of 0.8 and above. For the ET multiplier of 0.5, the sum of squared residuals is substantially higher, about 2,434 times higher than the average sum of squared residuals from the other runs.

The results show that the model's sum of squared residuals is reduced when ET and hydraulic conductivity are increased, and recharge is reduced. However, the sensitivity of these parameters is reasonably similar except for the ET multiplier 0.5 scenario.

Table 5.4: Steady state sensitivity analysis parameter multipliers and values

Parameter	**Base value parameter multiplier**					
	0.1	**0.5**	**0.8**	**1 (i.e. base value)**	**1.2**	**1.5**
Hydraulic conductivity (m/d)	-	1.76×10^{-4}	2.81×10^{-4}	3.51×10^{-4}	4.21×10^{-4}	5.27×10^{-4}
Recharge (m/d)	3.56×10^{-5}	1.78×10^{-4}	2.85×10^{-4}	3.56×10^{-4}	4.28×10^{-4}	5.35×10^{-4}
ET (m/d)	-	3.15×10^{-4}	5.04×10^{-4}	6.30×10^{-4}	7.56×10^{-4}	9.45×10^{-4}

Table 5.5: Steady state sensitivity analysis results

Parameter	**Base value parameter multiplier**					
	0.1	**0.5**	**0.8**	**1 (i.e. base value)**	**1.2**	**1.5**
	Sum of squared residuals					
Hydraulic conductivity (m/d)	Model failed to converge – dry cells	3,820	3,770	3,722	3,690	3,650
Recharge (m/d)		3,350	3,630	3,722	3,840	4,060
ET (m/d)		9.06×10^{6}	3,830	3,722	3,680	3,620

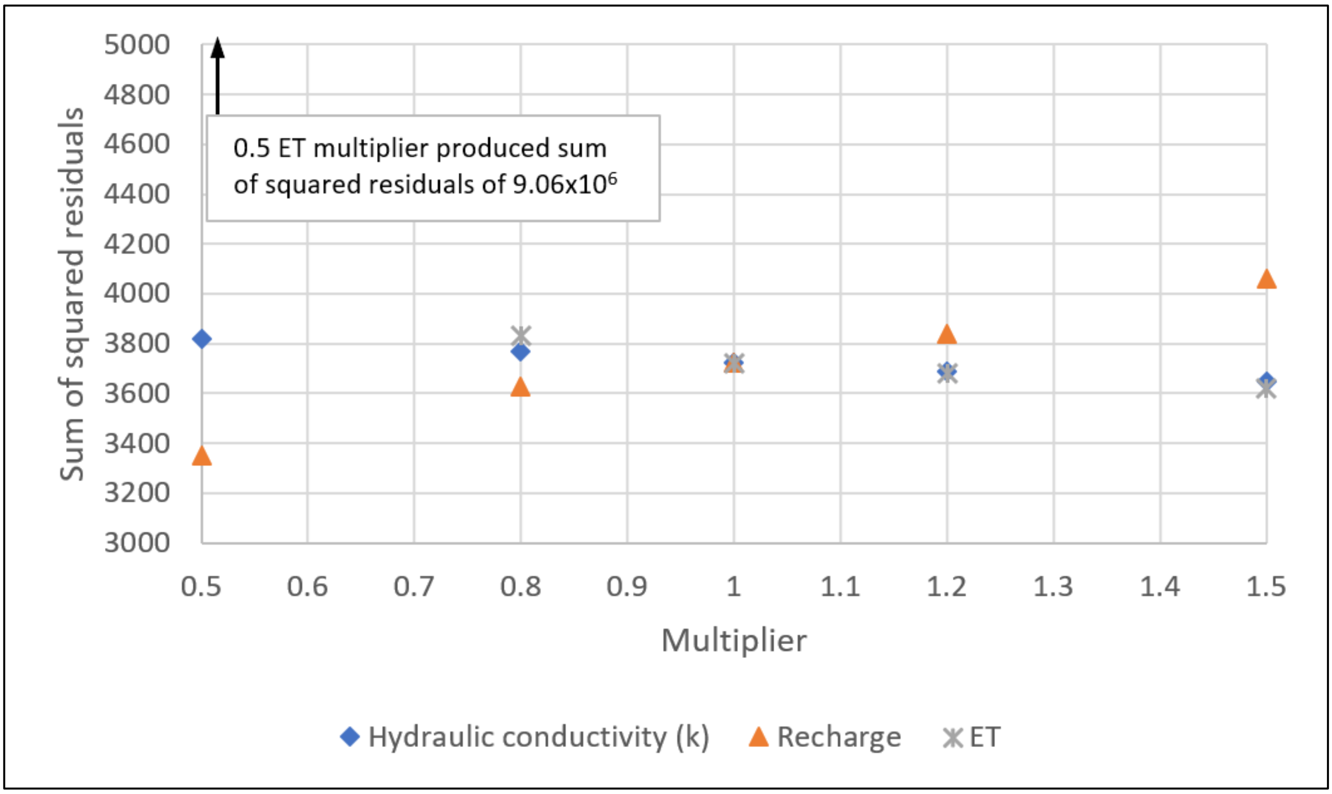


Figure 5.3: Steady state model sensitivity analysis results

5.2 Transient calibration

The model was also calibrated in transient mode. The transient model was calibrated to groundwater level observations at MW1 and MW2S between June 2009 and October 2020. The objective was to adjust storage parameters to achieve a reasonably good match between simulated and observed heads. The hydraulic conductivity value and recharge/ET multipliers from the calibrated steady state model were retained, with the recharge/ET multipliers applied to observed monthly rainfall/ET.

The model's initial time step was the calibrated steady state model and then progressed with monthly stress periods broken into ten time steps (time step multiplier 1.2) per period.

The mass balance error was considered acceptable and was generally less than ±1%. Out of a total of 1,371 time steps, there were 45 and 5 timesteps which had an error greater than ±1% or ±5% respectively.

Final calibration used specific yield and specific storage values of 0.01 and 1×10^{-6}, respectively. The adopted specific yield value aligns with a representative value for fractured igneous and metamorphic rock in Bair and Lahm (2006) of approximately 0.01. The adopted specific storage value is similar to a representative value of 1.63×10^{-6} for moderately fissured rock in Younger (1993).

Calibration hydrographs for MW1S and MW2S are provided in **Figure 5.4** and **Figure 5.5,** respectively. A qualitative assessment of the hydrographs shows a reasonably good match between simulated and observed head trends.

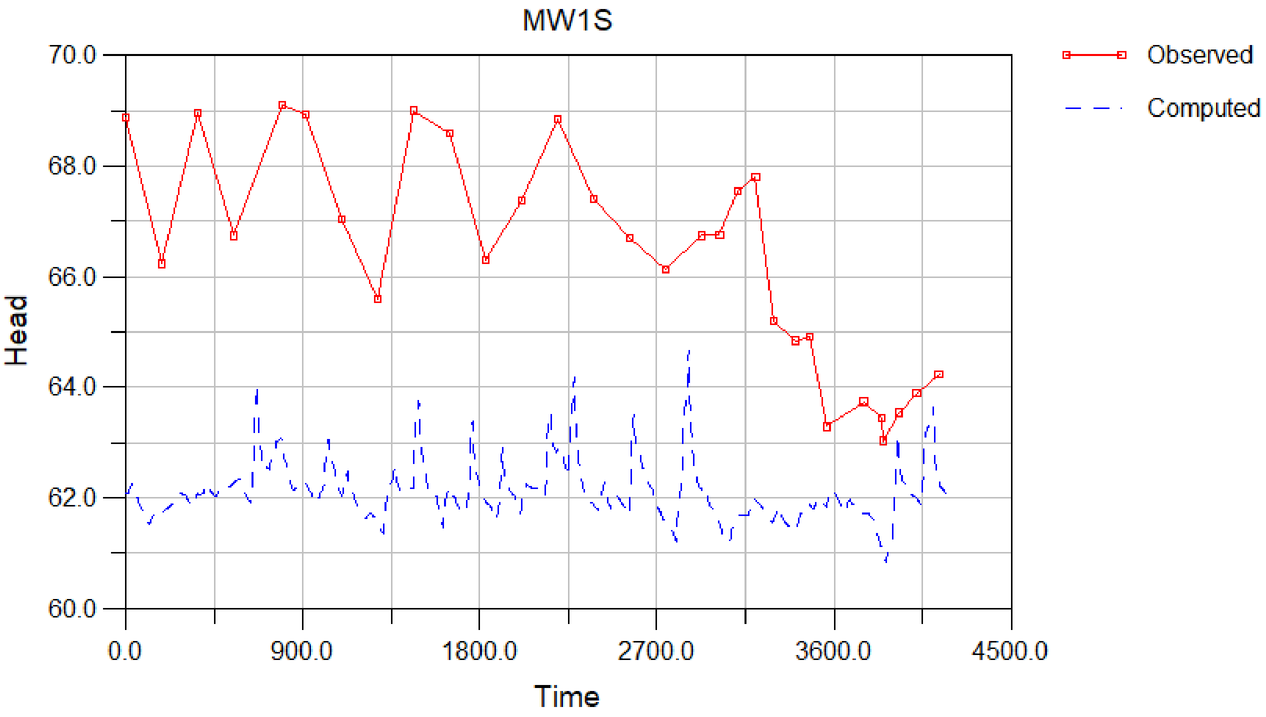


Figure 5.4: MW1S calibration hydrograph

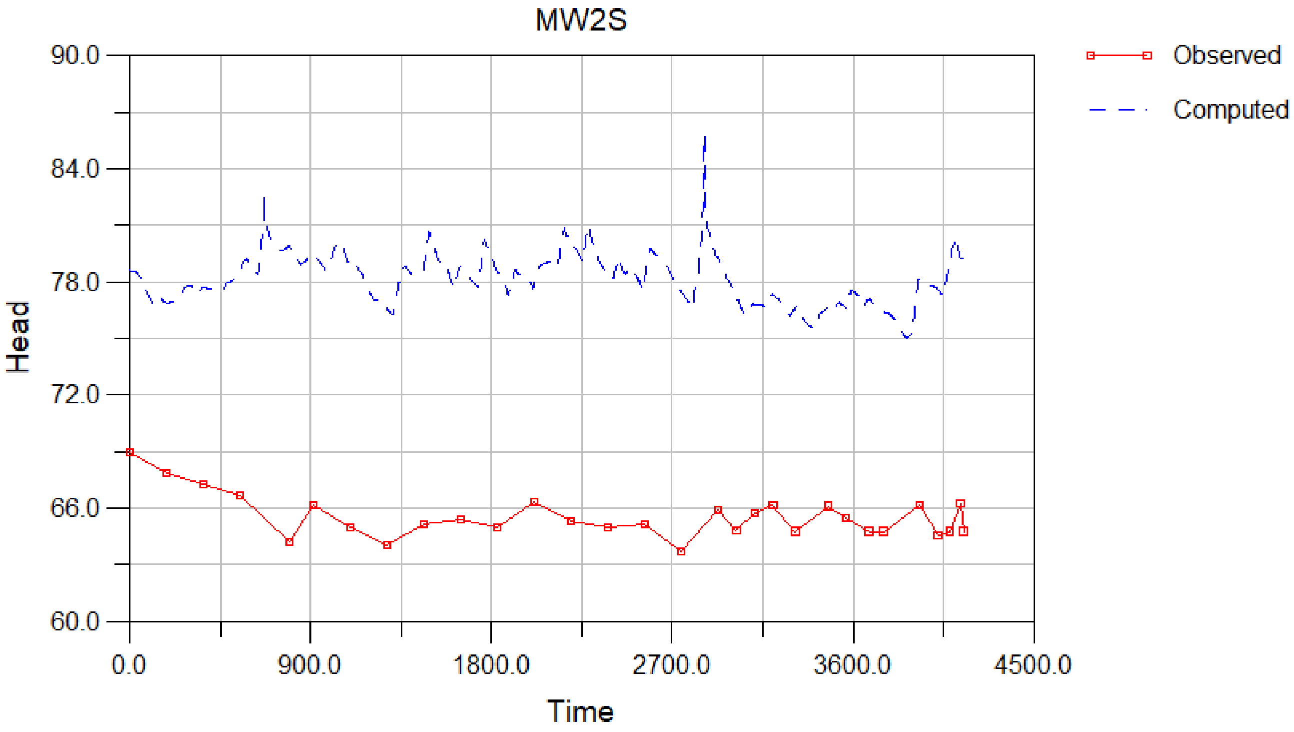


Figure 5.5: MW2S calibration hydrograph

5.3 Final adopted parameters

Adopted final calibrated parameters were as follows:

- Hydraulic conductivity – 3.51 x 10^{-4} m/d, geomean of the Quarry's monitoring bores.
- Recharge rate – 12% of mean annual rainfall (1,084 mm), which is an annual rate of about 130 mm.
- ET rate – 20% of mean annual SILO FAO56 Penman-Monteith reference evapotranspiration (1,143 mm), which is an annual rate of about 227 mm. Extinction depth of 3 m.
- Specific yield and specific storage values of 0.01 and 1×10^{-6}, respectively.

6. Predictive modelling

6.1 Approach

A groundwater model was established for predictive modelling with the initial steady state model as the first time period, which then progressed to 444 monthly stress periods and a final end of quarrying stress period of 100 years. The stress periods were broken down into three time-steps per period with a time step multiplier of 1.2.

Drains were used to simulate the existing extraction area and proposed Stage 7 area. The Stage 7 area was split into a group of drains cells for each of the four extraction stages 7a, 7b, 7c, and 7d. The drains were organised to progress from 7a to 7d to represent the proposed extraction staging.

There was no lateral progression within each specific group of drain cells. The progression was only vertical, with the drain stage commencing at ground level and progressing to the final extraction floor level. The drain stage was lowered linearly each monthly stress period until the final extraction floor levels were achieved. After this, the drain stage remained at the final extraction floor level.

The drain cell levels did not account for batter slopes/benches. This degree of complexity was not considered necessary.

For all stress periods, the calibrated recharge/ET multipliers were applied to long-term average annual rainfall and ET.

Potential recovery of extraction pit water levels in the post quarrying period was not undertaken within the model. This is covered in the Project EIS (RWC 2021).

A null case model identical to the prediction model, but with no quarry extraction drains cells, was run so that the results between the two models could be compared.

6.2 Results

6.2.1 Mass balance

The mass balance error (**Figure 6.1**) was within the bounds of ±1%, which is acceptable.

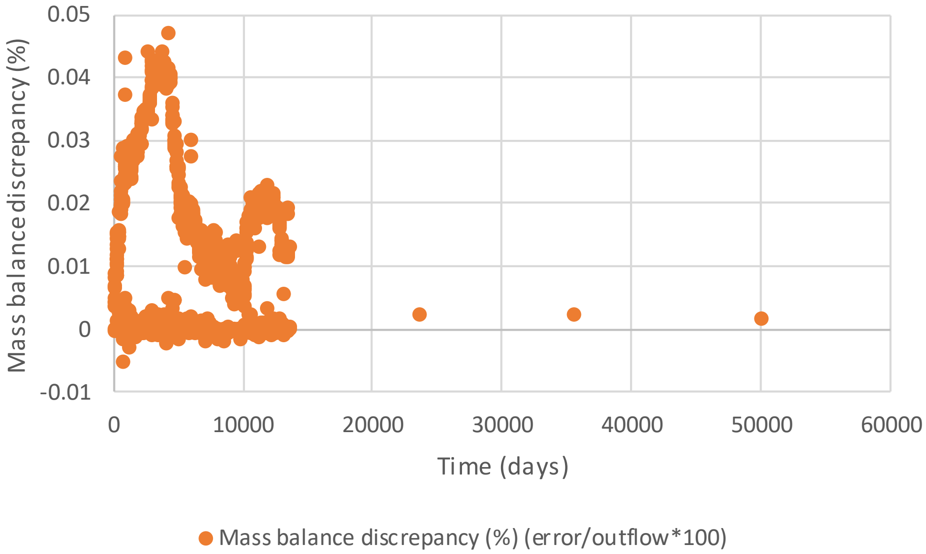


Figure 6.1: Prediction model mass balance discrepancy percentage

6.2.2 Groundwater inflows

Modelled groundwater inflow rate for the existing extraction area, as determined by the model's first period (steady state), was 38 kL/d (**Table 6.1**). This modelled rate aligns with the lack of observed seepage to the extraction area, as a rate of 38 kL/d would readily evaporate. Modelled groundwater inflow rate at the end of each Stage 7 extraction area is also provided in **Table 6.1**. Groundwater inflow rates increase as the extraction progresses and peaks at about 187 kL/d at the end of Stage 7d. One hundred years after quarrying has ceased, the groundwater inflow rate is 185 kL/d. Groundwater inflow rates at the end of each model period are plotted in **Figure 6.2**.

It is noted that dewatering of the pit following rainfall events will be achieved via pumping from sumps within the extraction area, and that there is likely to be significant evaporative losses as groundwater seeps from exposed faces or is directed around active work areas towards dewatering sumps. While these evaporative losses cannot be readily quantified, there is potential that some quantity of dewatering of groundwater inflows will be required, albeit these may be somewhat less than the modelled groundwater inflow rates.

Table 6.1: Modelled groundwater inflow rate

Extraction Stage	Model time (d)	Groundwater inflow rate (kL/d)
Existing extraction area	1	38
End of Stage 7a	4,381 (12 yrs)	125
End of Stage 7b	6,389 (17.5 yrs)	134
End of Stage 7c	10,040 (27.5 yrs)	149
End of Stage 7d	13507 (37 yrs)	187
100 years after extraction completed	50,011 (137 yrs)	185

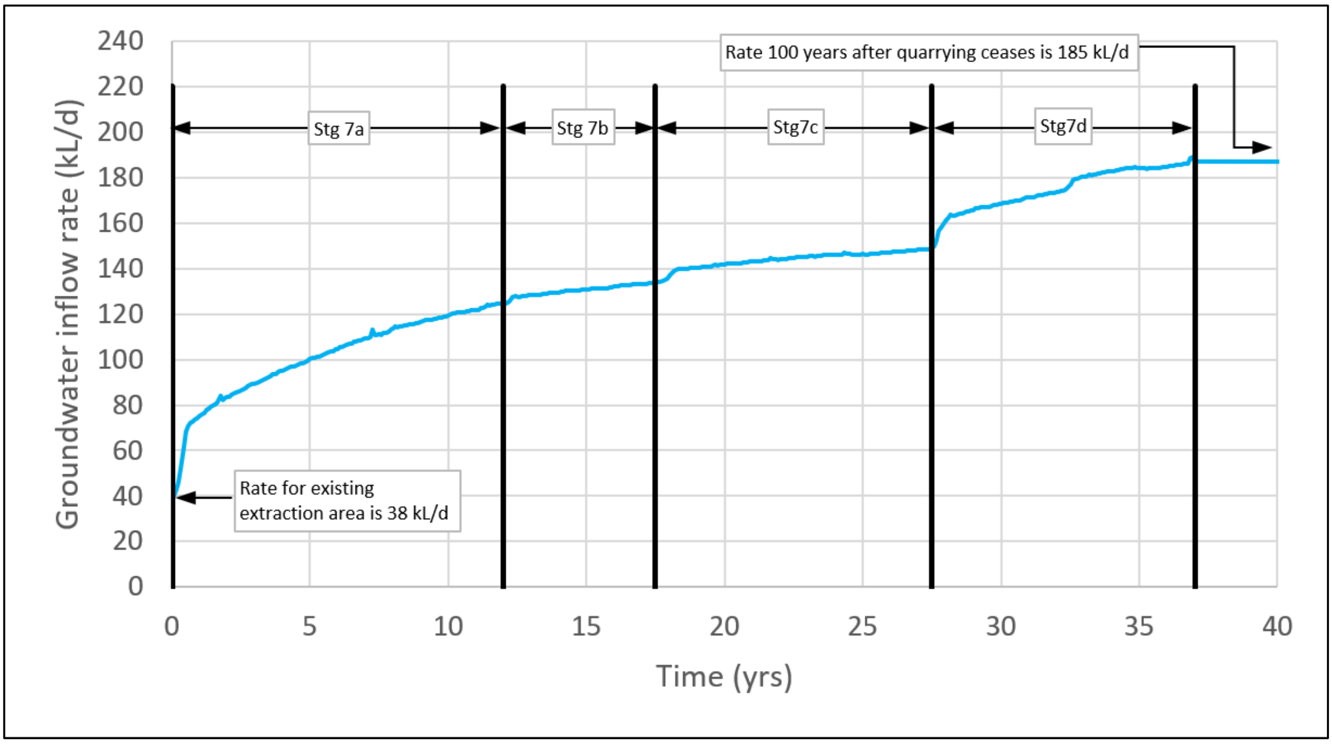


Figure 6.2: Modelled groundwater inflow rate

6.2.3 Groundwater level drawdown

Groundwater level drawdown at the end of quarrying (i.e. end of Stage 7d) is shown in **Figure 6.3**. 0.1 m contours from a geodetic survey undertaken in April 2019 are also shown in **Figure 6.3** for the eastern portion of the Project and convey the extent of the existing extraction area.

The 2 m groundwater level drawdown extends about 50 m to 250 m from the edge of the drain cells which were used to represent the quarry's extraction stages. The 2 m drawdown contour is generally offset from the Stage 7 extraction areas by about 150 m.

At the end of the 100 year post-quarrying period, modelled drawdown would be similar because the groundwater inflow rate to the extraction area is very similar (i.e. 185 kL/d compared to 187 kL/d).

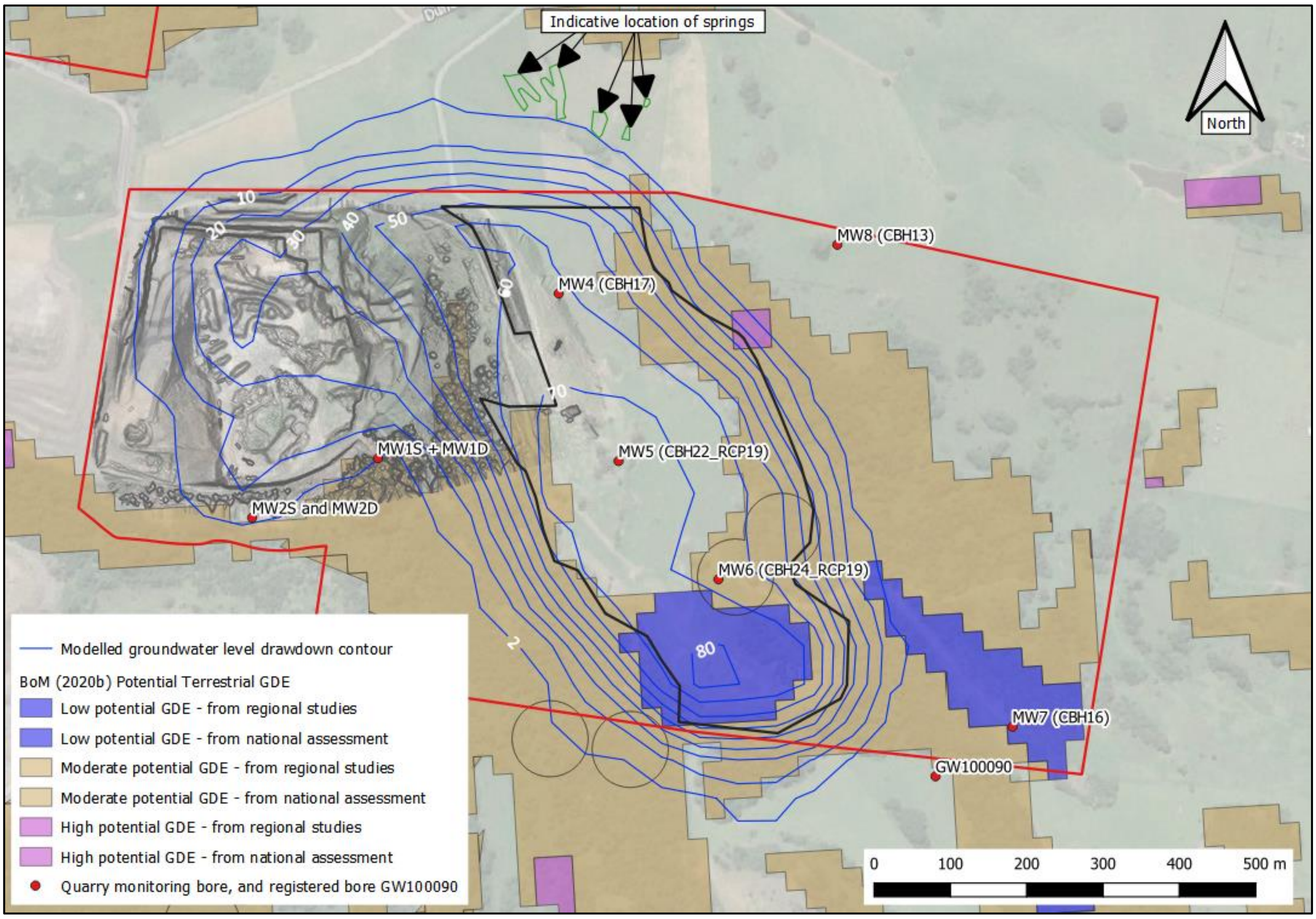


Figure 6.3: Modelled groundwater level drawdown at end quarrying (i.e. end of Stage 7d)

6.2.4 Baseflow reduction

Groundwater level drawdown has potential to reduce baseflows to creeks in the vicinity of the Project. This could occur due to the Project intercepting groundwater that would otherwise discharge to creeks. Potential baseflow reductions to creeks in the vicinity of the Project has been calculated from the change in drain boundary flux between the prediction model (excluding the fluxes from the drain cells used to represent the extraction stages) and the null case model.

Modelled baseflow reduction to watercourses is shown in **Figure 6.4** and ranges from less than 1 kL/d in early years of the Project before steadily increasing to peak of less than 5 kL/d.

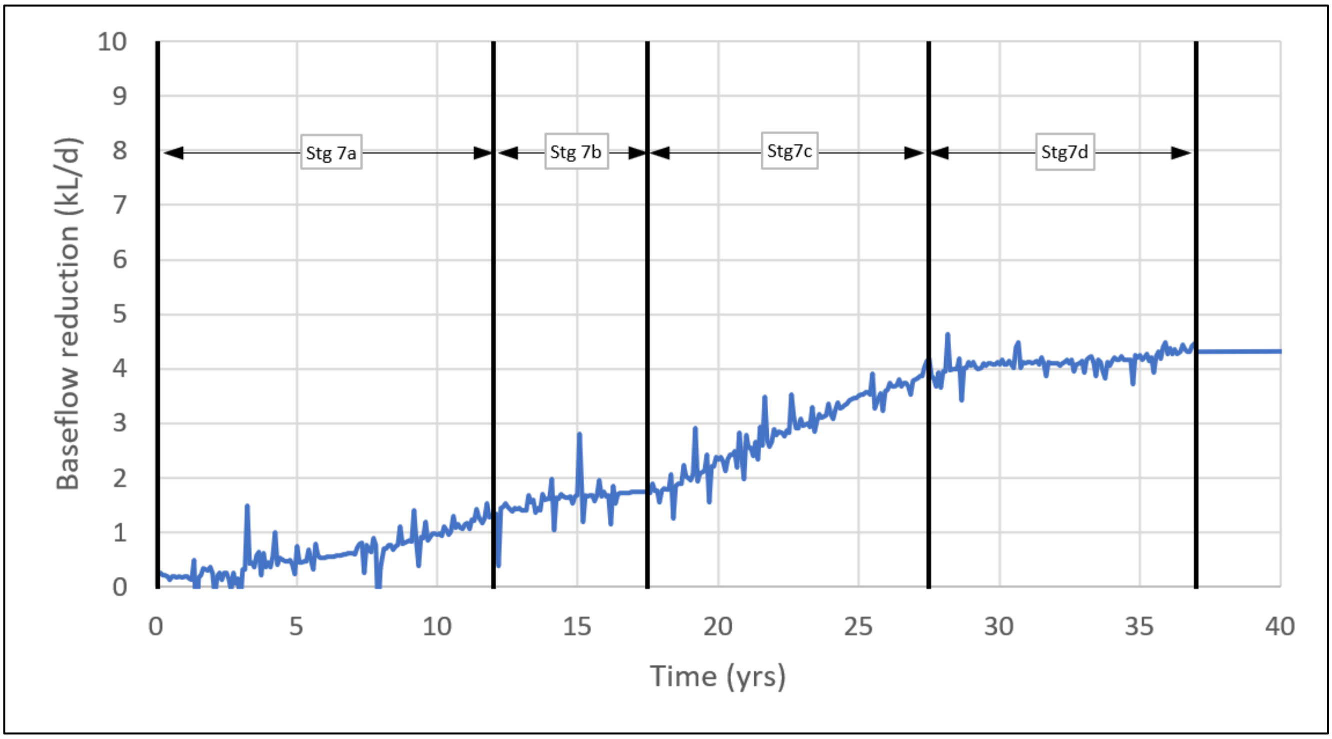


Figure 6.4: Modelled baseflow reduction rate

7. Model uncertainty analysis

7.1 Approach

Uncertainty analysis was undertaken to assess the effect of individually varying model input parameter values on model predictions.

The following uncertainty analysis models were developed:

- Steady state
  - **Low and high hydraulic conductivity –** 0.5 and 1.5 multiplier applied to base case model for the low and high scenarios, respectively.
  - **Low and high recharge –** 0.5 and 1.5 multiplier applied to base case model for the low and high scenarios, respectively. It is noted that a 0.1 multiplier was also applied but the associated model run did not converge.
  - **Low and high ET –** 0.8 and 1.5 multiplier applied to base case model for the low and high scenarios, respectively. It is noted that the minimum multiplier of 0.5 used in the sensitivity analysis was not applied because the sum of squared residuals for this run was very high (Section 5.1.3).
- Transient
  - **Low and high storage –** storage parameters decreased and increased from the base case model by an order of magnitude.

To assess the results, groundwater inflow rates to the extraction area and the 2 m drawdown contour at the end of Stage 7d (i.e. end of quarrying) were compared.

7.2 Results

Groundwater inflow rates for the uncertainty analysis model runs are shown in **Table 7.1** for the end of Stage 7d (i.e. end of quarrying). The 2 m drawdown contour for the uncertainty analysis model runs is shown in **Figure 7.1** for the end of Stage 7d (i.e. end of quarrying).

The uncertainty scenario groundwater inflow rates are considered reasonably similar to the base case value of 187 kL/d (groundwater inflow rate at end of Stage 7d). The minimum and maximum groundwater inflow rate out of all the uncertainty scenarios was 106 kL/d and 259 kL/d, respectively. These minimum and maximum groundwater inflow rates are about 43% and 39% lower and higher than the base case rate.

The 2 m drawdown contours plot similarly for all of the uncertainty runs. There is a maximum difference in the position of the 2 m drawdown contour of about 100 m.

Table 7.1: Uncertainty results summary - groundwater inflow rates

Uncertainty scenario	Groundwater inflow rate (kL/d) at end of Stage 7d (i.e. end of quarrying)
Low hydraulic conductivity	163
High hydraulic conductivity	202
Low recharge	106
High recharge	259
Low ET	186
High ET	184
Low storage	186
High storage	193
Base case	**187**

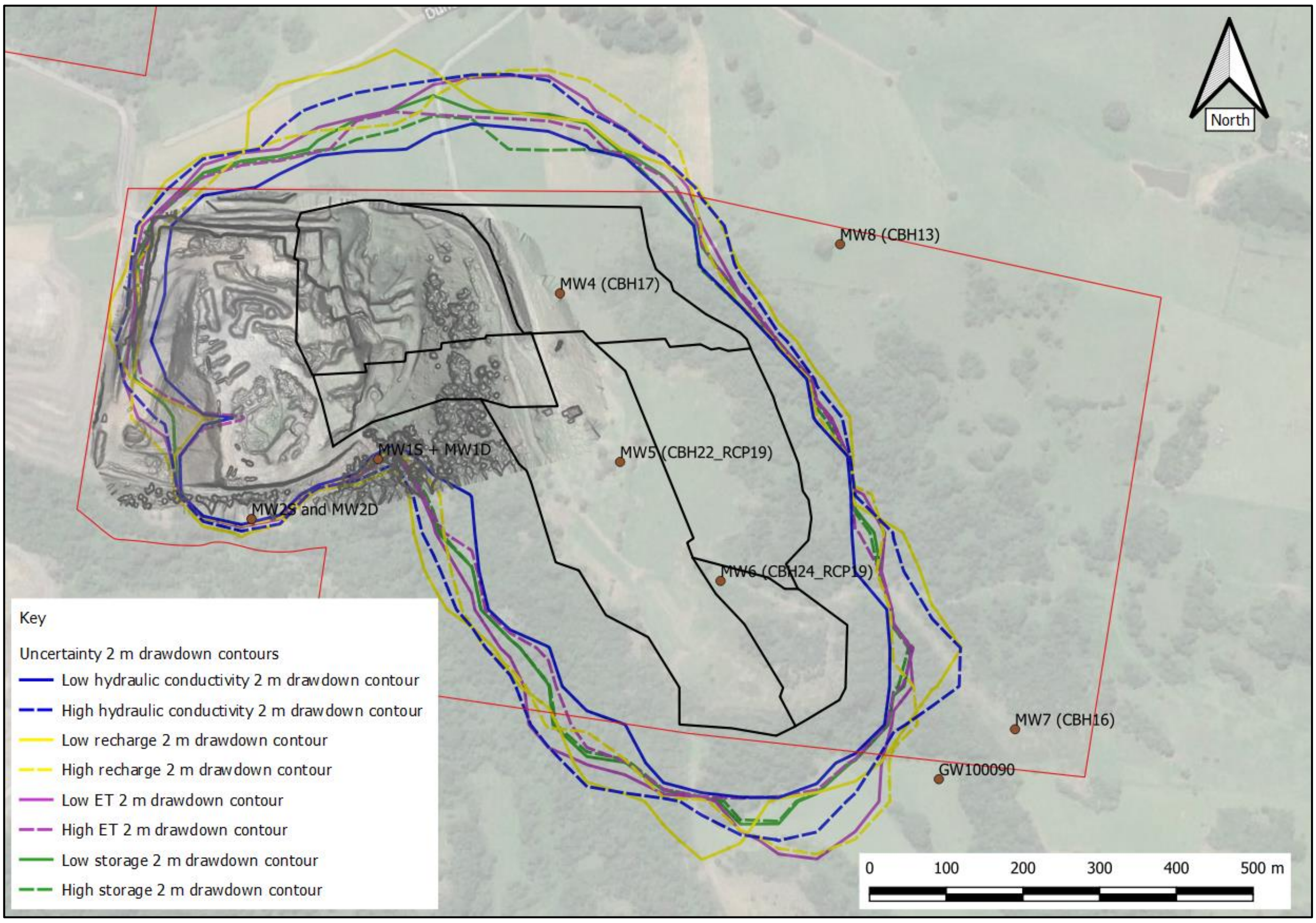


Figure 7.1: Uncertainty results - 2 m drawdown contours for all uncertainty scenarios

8. Conclusion

A Class 1 numerical groundwater model was developed to inform assessment of potential impacts to groundwater due to the proposed extension of the Cleary Bros Albion Park Hard Rock Quarry, located at Croom, NSW.

A Class 1 model was chosen because the Project is considered low risk and the 'aquifers' within the resource to be extracted are considered low value due to their very low yields. Indeed, 'aquifers' are not conceptualised to typically be present within the resource to be extracted. These groundwater systems' yields are considered too low to constitute 'aquifers'.

The objectives of the model were to calculate:

- groundwater level drawdown due to the Project, including at existing registered groundwater bores or GDEs
- Project related volumetric take of groundwater (due to either incidental or active dewatering)
- incidental volumetric take from surface watercourses due to baseflow reduction.

The base case model predicts:

- a groundwater inflow rate of up to 187 kL/d.
- a 2 m drawdown contour that extends about 50 m to 250 m from the quarry's extraction areas.
- a baseflow reduction to watercourses ranging from less than 1 kL/d in early years of the Project to a peak of less than 5 kL/d in later years of the Project.

Uncertainty analysis was undertaken to assess the effect of individually varying model input parameter values on model predictions. The results from uncertainty analysis model runs do not vary considerably from the base case results.

Potential recovery of extraction pit water levels in the post quarrying period was not assessed by the model. It is considered unlikely that groundwater inflows would provide significant contribution to the formation of a potential pit lake following completion of quarrying. The estimated groundwater inflow rates are low relative to the extraction area's evaporation potential. The final landform of the completed quarry is further described in Section 3 of the Project EIS and would likely include a permanent or semi-permanent water feature collecting surface water running from much of the extraction area. The extent of this potential water feature would be primarily controlled by surface water rather than groundwater.

The estimated maximum groundwater take of 187 kL/d would occur in perpetuity.

Impact assessment was outside the scope of this report and is covered in the Project's Groundwater Assessment (Jacobs, 2020).

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