F.5 Groundwater assessment

Gunlake Quarry Continuation Project (SSD-12469087)

Groundwater assessment

Prepared for Gunlake Quarries Pty Ltd
September 2021

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Gunlake Quarry Continuation Project (SSD-12469087)

Groundwater Assessment

Report Number

J190263 RP#18

Client

Gunlake Quarries Pty Limited

Date

15 September 2021

Version

v1 Final

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This report has been prepared in accordance with the brief provided by the client and has relied upon the information collected at the time and under the conditions specified in the report. All findings, conclusions or recommendations contained in the report are based on the aforementioned circumstances. The report is for the use of the client and no responsibility will be taken for its use by other parties. The client may, at its discretion, use the report to inform regulators and the public.

Executive Summary

ES1.1 Gunlake Quarry and the Continuation Project

Gunlake Quarries Pty Ltd (Gunlake) operates a hard rock quarry (the 'Quarry') located at 715 Brayton Road, Marulan NSW. The Quarry is approximately 7 kilometres (km) north-west of the centre of Marulan in the Goulburn Mulwaree local government area. The land surrounding the Quarry is rural land with a low population density. Gunlake commenced operations in 2009 under project approval 07-0074 granted in September 2008.

Since the Quarry received approval for the Extension Project in 2017 (SSD 7090, NSW Land and Environmental Court Approval 20017/108663), the tonnage of saleable product dispatched by the Quarry has steadily increased and, with an infrastructure boom across the State, Gunlake forecast that demand for products from the Quarry will continue to increase. In response to the increased demand for products from the Quarry, it is proposed to transport more saleable product along the Primary Transport Route. This will require an increase in truck movements than what is currently approved. The additional truck movements will all occur on the recently upgraded Primary Transport Route that has been designed to accommodate comfortably the additional truck movements. The Project is known as the Gunlake Quarry Continuation Project (the 'Continuation Project'). The ignimbrite hard-rock resource will continue to be extracted and processed using the methods currently employed at the Quarry.

The Continuation Project is classified as a State Significant Development (SSD) under Schedule 1, Clause 7 of the *State Environmental Planning Policy (State and Regional Development) 2011* (SRD SEPP). This report accompanies a new SSD application and environmental impact statement (EIS) for the Continuation Project. It considers the potential groundwater impacts of the Continuation Project and provides mitigation and management measures to prevent or minimise environmental impacts.

ES1.2 Assessment

Quarrying of the target fractured rock has the potential to cause groundwater impacts to groundwater levels/pressures, groundwater flow directions and groundwater quality.

An analytic element groundwater flow model was used to predict the potential groundwater impacts from the Continuation Project. The model was developed in accordance with the Australian groundwater modelling guidelines and satisfies the requirements for a class 1 flow model. The model was used to assess the impacts of Continuation Project on potentially sensitive groundwater receptors: registered landholder bores, potential groundwater dependant ecosystems (GDEs) and local watercourses.

ES1.3 Potential impacts

Groundwater impacts were predicted to be minor and locally confined to around the quarry pit. Groundwater inflows to the pit of up to 68 ML/year are predicted and licensing of these inflows is required from either market trading or obtaining a new licence from unallocated water in the *Groundwater Water Sharing Plan* under the *Water Management Act 2000*. There is sufficient water volume within the market or within the next controlled allocation order to allow the required WAL (or WALs) to be obtained.

A drawdown of 2 m is predicted to extend up to 1.3 km from the edge of the pit at the end of the Continuation Project. This is less than the predicted maximum extent of the 2 m drawdown predicted for the Extension Project due to refinements in the analytical model and the collection of additional groundwater monitoring data. There are no impacts predicted at landholder bores according to the minimal impact considerations described in the NSW Aquifer Interference Policy (AIP, DPI 201).

Small portions of PCT 1256 and PCT 1330 are predicted to be impacted at a local scale by groundwater drawdown. However, the prescribed impacts to GDEs arising from the Continuation Project are predicted to be minor in both extent and/or nature and represent a low risk of impact to GDEs.

With no groundwater discharge to the surrounding environment, the potential risks to the groundwater quality of and surface water resources are considered low.

The final landform will create an inward hydraulic gradient preventing the discharge of water from the pit into the fractured rock groundwater source. Salinities within the pit may increase slightly over time, however because of the inward gradient there is negligible risk to groundwater in the regional fractured rock or adjacent surface water features. There will be no impact on the beneficial use class of the groundwater source (ie less productive and used for stock).

No cumulative groundwater impacts are predicted.

ES1.4 Recommendations

The following actions are recommended to be instigated following approval of the Continuation Project:

- the groundwater level and quality monitoring program continues; and
- measured groundwater levels are periodically compared to staged drawdown predictions to validate predictions.

Given that discharges from seeps are not significant, in that they do not contribute to surface water flow and are not a significant consideration in determining potential impacts to terrestrial GDEs, it is recommended that the seep monitoring program is scaled back to only monitor seep 7.

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1 Introduction

1.1 Overview

Gunlake Quarries Pty Ltd (Gunlake) operates a hard rock quarry (the 'Quarry') located at 715 Brayton Road, Marulan NSW. The Quarry is approximately 7 kilometres (km) north-west of the centre of Marulan in the Goulburn Mulwaree local government area. The land surrounding the Quarry is rural land with a low population density. Gunlake commenced operations in 2009 under project approval 07-0074 granted in September 2008.

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1.2 Secretary's environmental assessment requirements

Secretary's environmental assessment requirements (SEARs) for the Continuation Project were issued on 6 May 2021. Table 1.1 lists the SEARs of relevance to this groundwater assessment and outlines the section(s) where they are addressed within this report.

Table 1.1 SEARs relevant to this groundwater assessment

Secretary's environmental assessment requirement	Where requirement is addressed
An assessment of the likely impacts on the quality and quantity of existing surface and groundwater resources, including a detailed assessment of proposed water discharge quantities and quality against receiving water quality and flow objectives.	Section 7 Surface water impacts discussed in the *Surface Water Assessment* (SWA), EIS Appendix F (EMM 2021a)
A detailed site water balance, water disposal methods, water supply infrastructure and water storage structures.	Provided in the SWA.
Identification of any licensing requirements or other approvals under the *Water Act 1912* and/or *Water Management Act 2000*.	Section 3.1 and 3.2 Section 7.2.3
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).	Section 3.1 and 3.2 Section 7.2.3
As assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure and other water users.	Section 7 Surface water impacts discussed in the SWA

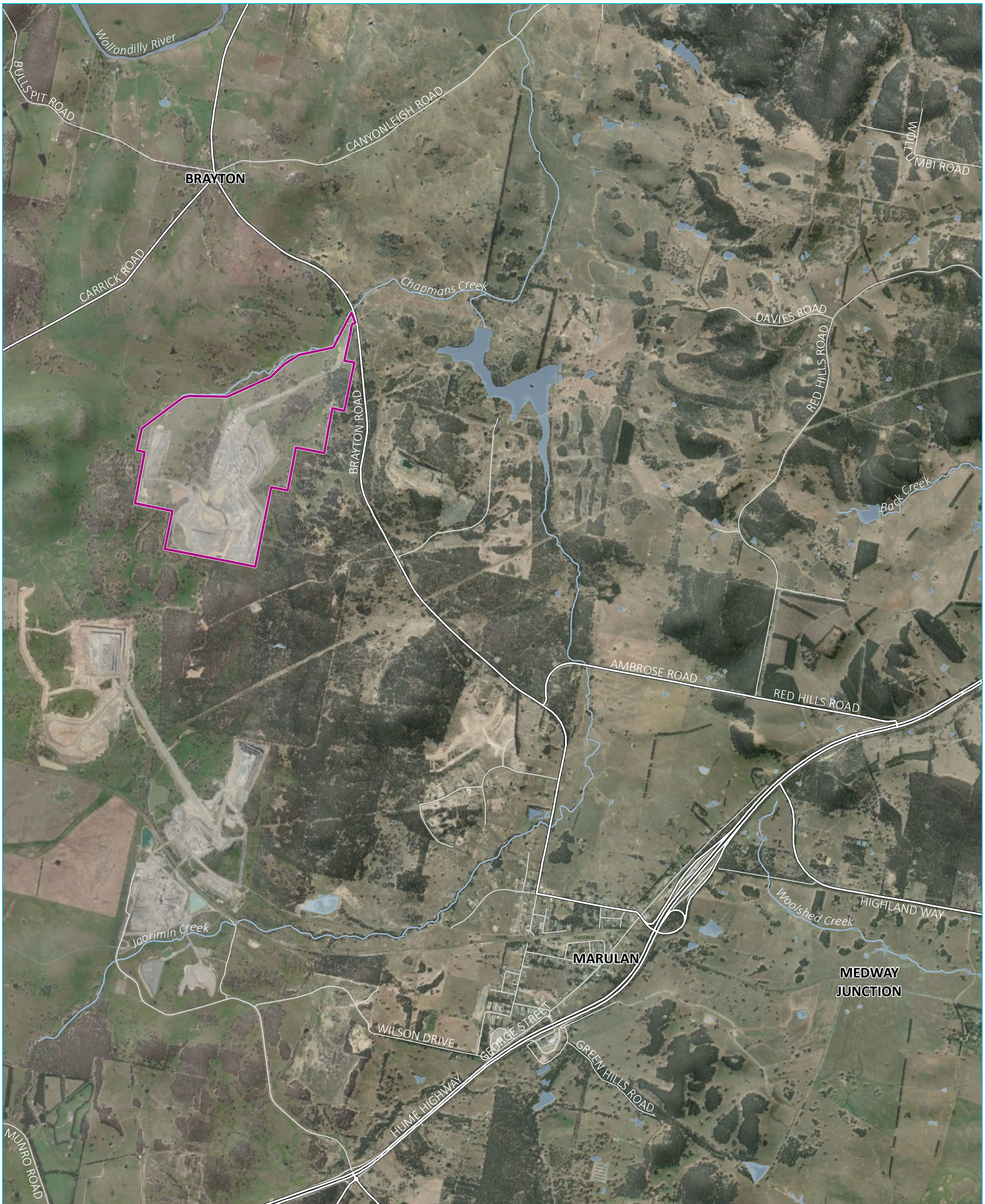
Table 1.1 SEARs relevant to this groundwater assessment

Secretary's environmental assessment requirement	Where requirement is addressed
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.	Section 7.2.3 Section 8.3
A detailed description of the proposed water management system (including sewage), water monitoring program and other measures to mitigate surface and groundwater impacts.	Section 8 Surface water management and monitoring discussed in the SWA

1.3 Assessment scope

EMM Consulting Pty Limited (EMM) was commissioned by Gunlake to prepare a groundwater assessment for the Continuation Project. The assessment includes:

- a review of publicly available literature relevant to the project:
  - *Gunlake Quarry Project, Environmental Assessment Volume II, Part 3 Groundwater Impact Assessment* (Larry Cook and Associates Pty Ltd 2008);
  - *Water Management Plan, Environmental Management System* (Olsen Consulting Group Pty Ltd 2009);
  - *Proposed Lynwood Quarry, Marulan Groundwater Impact Assessment* (Peter Dundon and Associates 2005);
  - *Lynwood Quarry Extraction Area Modification, Groundwater Assessment* (Scientific Systems 2015);
- the collation and assessment of baseline and operational groundwater monitoring data;
- a desktop review of local and regional groundwater users;
- an update of the quarry area hydrogeological conceptualisation;
- a review of the groundwater licensing requirements;
- development of an analytic element groundwater flow model to predict groundwater inflows to the pit and associated drawdown;
- an assessment of the potential risks and impacts to the groundwater resource and receptors using the predictions from the groundwater flow model; and
- recommendations for environmental mitigation and management measures.



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Source: EMM (2021); DFSI (2017); GA (2011); ASGC (2006)

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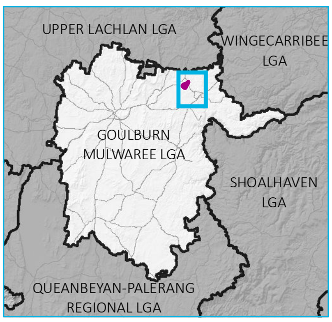

KEY

- Site boundary
- Major road
- Minor road
- Named watercourse
- Waterbody

Local context

Gunlake Quarry Continuation Project
Groundwater assessment
Figure 1.1

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2 Project description

2.1 Continuation Project description

Gunlake seeks a new development approval for the Continuation Project that allows:

- ongoing Quarry operations;
- a maximum of 375 inbound and 375 outbound daily truck movements with up to 4.2 million tonnes per annum (Mtpa) of Quarry products transported from the site in any calendar year;
- 24-hours Quarry operations Monday to Saturday, except 6 pm Saturday to 2 am Monday;
- an extraction depth of 546 metres Australian Hight Datum (mAHD); and
- a 30-year Quarry life (from the date of Continuation Project approval).

A summary of the key elements of the approved Extension Project compared to the Continuation Project is provided in Table 2.1.

Table 2.1 Extension Project compared to the Continuation Project

Project element	Approved Extension Project	Proposed Continuation Project
Extraction method	Blasting and excavation.	Blasting and excavation.
Resource	Ignimbrite hard-rock.	Ignimbrite hard-rock.
Extraction	Quarry pit - pit depth of 572 mAHD.	Quarry pit - pit depth of 546 mAHD (ie 26 m deeper than the Extension Project). No change to pit disturbance area.
Operations	Onsite rock processing, including crushing and screening.	Onsite rock processing, including crushing and screening.
Product transport	Transport of up to 2.6 million tonnes per annum (Mtpa) of Quarry products. Truck movements limited to: • a maximum of 295 inbound movements and 295 outbound movements, including no more than 38 outbound truck movements on the Secondary Transport Route, per working day; and • an average of 220 inbound movements and 220 outbound movements, including no more than 25 outbound movements on the Secondary Transport Route, per working day (averaged over the working days in each quarter).	Transport of up to 4.2 Mtpa of quarry products. Total truck movements limited to: • a maximum of 375 inbound movements and 375 outbound movements, including no more than 38 outbound laden movements on the Secondary Transport Route, per working day; • an average of no more than 25 outbound movements on the Secondary Transport Route, per working day (averaged over the working days in each quarter).
General infrastructure	Offices, amenity buildings, processing plant and other minor infrastructure.	Offices, amenity buildings, processing plant and other minor infrastructure.
Management of wastes	Overburden[1] is emplaced in designated emplacement areas. Receipt of up to 30,000 tonnes of cured concrete per calendar year for beneficial reuse/recycling. No other classified waste materials to be received on site.	Overburden is emplaced in designated emplacement areas. Receipt of up to 50,000 tonnes of cured concrete per calendar year for beneficial reuse/recycling. No other classified waste materials to be received on site.
Hours of operation	24-hours Quarry operations Monday to Saturday, except 6 pm Saturday to 2 am Monday.	24-hours Quarry operations Monday to Saturday, except 6 pm Saturday to 2 am Monday.
Blasting	Up to twice weekly, 9 am to 5 pm Monday to Friday.	Up to twice weekly, 9 am to 5 pm Monday to Friday.
Quarry life	To 30 June 2042.	Extension of the Quarry life to 30 years from the date of approval.

Further information on the project is available in the Continuation Project EIS.

1 'Overburden': any extracted unsalable material.

2.2 Resource

Quarry operations extract a hard rock resource from the Devonian Bindook Volcanic Complex. The Complex comprises a north to north-east trending series of volcanics. A resource of 180 million tonnes (Mt) of ignimbrite has been proven to depths in excess of 100 metres (m) below surface. The resource is suitable for use in a range of quarry products including concrete and sealing aggregates, rail ballast, manufactured sand and road base.

2.2.1 Pit development

The Continuation Project pit will be within the approved Extension Project footprint. It will be extracted in horizontal benches with the quarry floor reaching 572 m AHD over the 30-year quarry lifespan (ie by about 2051).

3 Regulation

3.1 Water Management Act 2000

The *Water Act 1912* (Water Act) and the *Water Management Act 2000* (WM Act) are the two key pieces of legalisation for the management of water in NSW.

The WM Act is based on the principles of ecologically sustainable development and the need to share and manage water resources for future generations. The WM Act recognises that water management decisions must consider economic, environmental, social, cultural and heritage factors. It recognises that sustainable and efficient use of water delivers economic and social benefits to the state of NSW.

One of the key components of the WM Act is the separation of the water licence from the land, providing the opportunity for water to be traded to the highest value use. The WM Act provides for water sharing between different water users, including environmental, basic landholder rights and licence holders. The licensing provisions of the WM Act apply to those areas where a water sharing plan (WSP) has commenced. The Quarry is in an area with two WSPs.

The WM Act requires that Gunlake licence the volume of predicted 'take' of surface water and groundwater in accordance with the *NSW Aquifer Interference Policy* (AIP) (NOW 2012). This includes water taken for use on site and water intercepted as a result of quarrying activities. Sufficient Water Access Licences (WALs) must be held to account for the take from the water source(s) at all times.

3.1.1 Water sharing plans

WSPs are statutory documents under the WM Act that apply to one or more defined water sources. Water sharing plans establish rules for sharing water between the environmental needs of rivers and/or aquifers and extractive water users. They differentiate between different types of water use such as town supply, rural domestic supply, stock watering, industry and irrigation. Water sharing plans are designed to ensure sustainable management and sharing of all water resources in NSW; typically, they are in place for 10-year periods.

The WSPs define how much water is available to be shared across all uses. They have water provisions for environmental purposes such as the needs of rivers and high priority groundwater dependent ecosystems (GDEs). Remaining water is then available to be shared across the existing and future extractive uses (such as town water supply, irrigation and domestic and stock).

The two WSPs that manage the water resources in the Quarry area are:

- The Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011 (Surface Water WSP); and
- The Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 (Groundwater WSP), Goulburn fractured rock groundwater source.

These plans will be replaced in June 2023.

Gunlake hold a WAL for 37 megalitres per year (ML/year) (WAL 42340) from the Goulburn Fractured Rock Groundwater Source in the Groundwater WSP, which was issued on 26 April 2019.

Water Access Licences can be obtained by trading from other users within the water source or via a controlled allocation release announced by the Department of Planning, Industry and Environment – Water Group (DPIE-Water). The licensed amount is required to be equivalent to the volume of water intercepted during each year of operation at the Continuation Project.

The long-term average annual extraction limit, the amount of water that can be taken for all purposes (ie domestic and stock, urban, industrial, agricultural and held environmental water) for the Groundwater WSP is 53,074 ML/year unit shares. This currently includes: 3,051 ML/year unit shares for aquifer access, 3,114 ML/year unit shares for domestic and stock rights and 100 ML/year unit shares for local water utility licences. There are 46,809 ML/year unallocated shares. In the 2020–21 Water Year, 6,916 unit shares were accessed and 1,868 unit shares were released via controlled allocation (as listed in the Government Gazette 2020).

3.2 Aquifer Interference Policy

Projects that intercept groundwater need to consider the NSW *Aquifer Interference Policy* (AIP) (NOW 2012). The AIP defines the regime for protecting and managing the impacts of aquifer interference activities on NSW's water resources. The AIP requires consideration of the potential impacts of an aquifer interference activity in respect to the water table, water pressure and water quality. Proponents must estimate the water take (including incidental take) from each water source and connected water sources. Changes to water table, water pressure and water quality are then assessed against minimal impact considerations for each water source.

The AIP defines water sources as being either 'highly productive' or 'less productive' based on levels of salinity and average available yields. The AIP categorises water sources by their lithological character, being one of alluvium, coastal sand, porous rock, or fractured rock, and identifies thresholds for minimal impact considerations. Based on the NSW Government's mapped areas of groundwater productivity in NSW (BoM 2021), the project area is within a 'less productive' porous and fractured rock water source. Applicable minimal harm considerations for the project have been reproduced in Table 3.1.

Table 3.1 Minimal impact criteria for 'less productive' porous and fractured rock water sources

Water table	Water pressure	Water quality
2. Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. A maximum of a 2 m decline cumulatively at any water supply work.	1. A cumulative pressure head decline of not more than a 2 m decline, at any water supply work.	1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.

Table 3.1 Minimal impact criteria for 'less productive' porous and fractured rock water sources

Water table	Water pressure	Water quality
2. If more than 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan then appropriate studies (including the hydrogeology, ecological condition and cultural function) will need to demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site.	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 will not prevent the long-term viability of the affected water supply works unless make good provisions apply.	2. If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.
3. If more than a 2 m decline cumulatively at any water supply work then make good provisions should apply.		

If an activity is assessed as being 'minimal impact' or the impacts are no more than the accuracy thresholds of the model, then it is defined as a 'minimal impact'. Where impacts are predicted to be 'greater than minimal impact' but additional studies show that impacts, although greater than 'minimal' do not prevent the long-term viability of the relevant water dependent asset, then the impacts will be defined as 'acceptable'. Where impacts are predicted to be 'greater than minimal impact' and the long-term viability of the water dependent asset is compromised, then the impact is subject to 'make good' provisions.

3.3 NSW policies and strategies

Other relevant NSW polices, guidelines and strategies include:

- NSW State Groundwater Policy Framework Document (DLWC 1997), which comprises three policies:
  - NSW State Groundwater Quantity Management Policy (DLWC 2001 (unpublished));
  - NSW State Groundwater Quality Protection Policy (DLWC 1998);
  - NSW State Groundwater Dependent Ecosystem Policy (DLWC 2002);
- *NSW Water Conservation Strategy* (DLWC 2000);
- *Guidelines for Groundwater Protection in Australia, National Water Quality Management Strategy* (ANZECC and ARMCANZ 1995); and
- State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011.

Guidelines listed in the SEARs not relevant to this project are:

- *Groundwater Monitoring and Modelling Plans – Information for Prospective Mining and Petroleum Exploration Activities* (DPI - Office of Water 2014).

3.4 Commonwealth legislation and guidelines

3.4.1 Commonwealth Environmental Protection and Biodiversity Conservation Act 1999

The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places which are defined as matters of national environmental significance.

The EPBC Act was amended in 2013 to include water resources as a matter of national environmental significance, in relation to coal seam gas and large coal mining developments (the 'water trigger'). The Gunlake Project is not subject to the water trigger as it is not a large coal mine or coal seam gas development.

3.4.2 Australian Groundwater Modelling Guidelines

The *Australian Groundwater Modelling Guidelines* (Barnett et al. 2012) were developed to provide a consistent and sound approach for the development of groundwater flow modelling in Australia. Measured groundwater data is used to conceptualise and describe all observed groundwater behaviour in the region. Groundwater level data is used to calibrate a groundwater model until there is acceptable agreement between model estimated and actual groundwater levels (Barnett et al. 2012).

3.4.3 National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia

The *National Water Quality Management Strategy Guidelines for Groundwater Quality Protection in Australia* (NWQMS) (Australian Government 2013) provides a risk-based management framework to protect and enhance groundwater quality for the maintenance of specified environmental values. The framework involves the identification of specific beneficial uses and values for the major groundwater systems, and several protection strategies that can emerge to protect each aquifer, including monitoring for all aquifers.

4 Environmental setting

4.1 The site

The Quarry is located wholly on Lot 13 DP 1123374 (the 'Quarry site'). There are biodiversity management areas in Lot 13 DP1123374, Lot 12 DP1123374, Lot 271 DP750053 and Lot 1 DP841147. These lots are owned by Gunlake Quarries Pty Ltd.

The Quarry is approximately 7 km north-west of the centre of Marulan and about 24 km north-east of the centre of Goulburn in the Goulburn Mulwaree local government area.

The land surrounding the Quarry is rural with low population density, predominately used for agriculture, generally grazing. Built features immediately surrounding the Quarry include dams, access tracks and fences. There are a small number of residences around the Quarry.

Johnniefelds Quarry is about 1 km east of Gunlake Quarry and Lynwood Quarry's Granite Pit is about 750 m south of the Gunlake Quarry site.

The area immediately surrounding the Quarry comprises cleared pasture with areas of native vegetation to the south and east. There are pockets of remnant native vegetation on steeper slopes to the south and along Chapmans Creek and its tributaries.

The topography around the project area is undulating, the elevation ranges from approximately 636 mAHD in the north to 680 mAHD in the south.

4.2 Climate

The climate in Goulburn is temperate, on average January is the hottest month of the year and July the coldest. Climate data has been obtained from the Bureau of Meteorology (BoM) Goulburn Tafe (070263) station, approximately 25 km from site and an overview is provided in Table 4.1.

Table 4.1 Temperature overview (BoM 070263, Goulburn)

Parameter	Range	Month	Unit
Mean maximum temperature	Highest	January	28.1 °C
	Lowest	July	11.6 °C
Mean minimum temperature	Highest	January	13.9 °C
	Lowest	July	1.6 °C
Mean annual evaporation	-	-	1,241 mm
Annual moisture deficit	-	-	618 mm

Rainfall data was obtained from the Bureau of Meteorology Brayton (Longreach) station (070143). The Brayton station is 3.5 km north of the Quarry site and maintains an intermittent rainfall record from 1959 to present. The annual mean rainfall is 623 mm and monthly mean rainfall is 55 mm/month with little variability over the year.

Cumulative deviation of rainfall from the mean is shown in Figure 4.1. The long-term cumulative deviation of rainfall from the mean represents discrete rainfall events as a continual trend over time. Periods of below average rainfall are plotted as downward trending slopes while periods of above average rainfall are upward trending slopes. Below average rainfall conditions were observed between 1993 and 2010, and this was followed by above average conditions until 2016. Since 2017 below average rainfall conditions have been observed, with a recent reversal in 2020 to above average rainfall conditions.

Data source: Bureau of Meteorology, weather station (site number: 070143).

Figure 4.1 Annual rainfall cumulative deviation from the mean

4.3 Surface water

The Quarry is located within the upper reaches of the Chapmans Creek catchment (Figure 1.1). Chapmans Creek is an ephemeral watercourse that drains to the north-east, flowing into Jaorimin Creek approximately 3 km downstream of the Quarry. The catchment area and riparian zones of Chapmans Creek have been predominantly cleared and are currently used as grazing land. The upper reaches of Chapmans Creek are predominantly dry and only flow following heavy rainfall events, while the lower section towards Brayton Road at the Quarry property boundary consists largely of unconnected stagnant pools which respond quickly to rainfall events and tend to dry rapidly in periods of dry weather.

Jaorimin Creek flows in a northerly direction to its confluence with the Wollondilly River, approximately 8.6 km downstream of the Quarry. The Wollondilly River is the major river in the region and is one of the key tributaries that flow into Lake Burragorang, which is located 65 km to the north-east of the Quarry. Johniefelds Dam is located on Jaorimin Creek upstream of its confluence with Chapmans Creek and does not receive runoff from Chapmans Creek or the Quarry site.

4.4 Geology

The Quarry is located within the Palaeozoic Lachlan Fold Belt. The Lachlan Fold Belt is a Palaeozoic litho-tectonic assemblage which extends over much of central southern NSW.

Reference to the Goulburn 1:100,000 geology map (Thomas et al 2013) shows that the Quarry intercepts the Bindook Porphyry Complex, a sequence of folded and deformed outcropping Devonian volcanics.

The Bindook Porphyry Complex incorporates a series of basement volcanic members that dip steeply with a series of anticline and syncline structures. The broad orientation of this sequence is north north-west (Cook 2008).

The Bindook Porphyry Complex is segregated into many geological units (Figure 4.2). The Quarry will extract the Barralier Ignimbrite and Joaramin Ignimbrite. The Joaramin Ignimbrite is observed in the south-east of the Quarry site, while the Barralier Ignimbrite is more widespread (Cook 2008).

Ignimbrites are poorly sorted, pyroclastic rocks comprised of pumice and ash. The Barralier Ignimbrite is a dark blue-grey, welded ignimbrite with fractured phenocrysts of quartz, plagioclase, hornblend, enstatite and minor biotite. The groundmass is fine-grained, aphanitic recrystallised quartz-feldspar. The Joaramin Ignimbrite is a densely welded, crystal-rich ignimbrite of rhyolitic composition and is pale pink to green-grey in colour. The Joaramin Ignimbrite is more acidic than the Barralier Ignimbrite due to a greater composition of potassium feldspar (Thomas *et al* 2013).

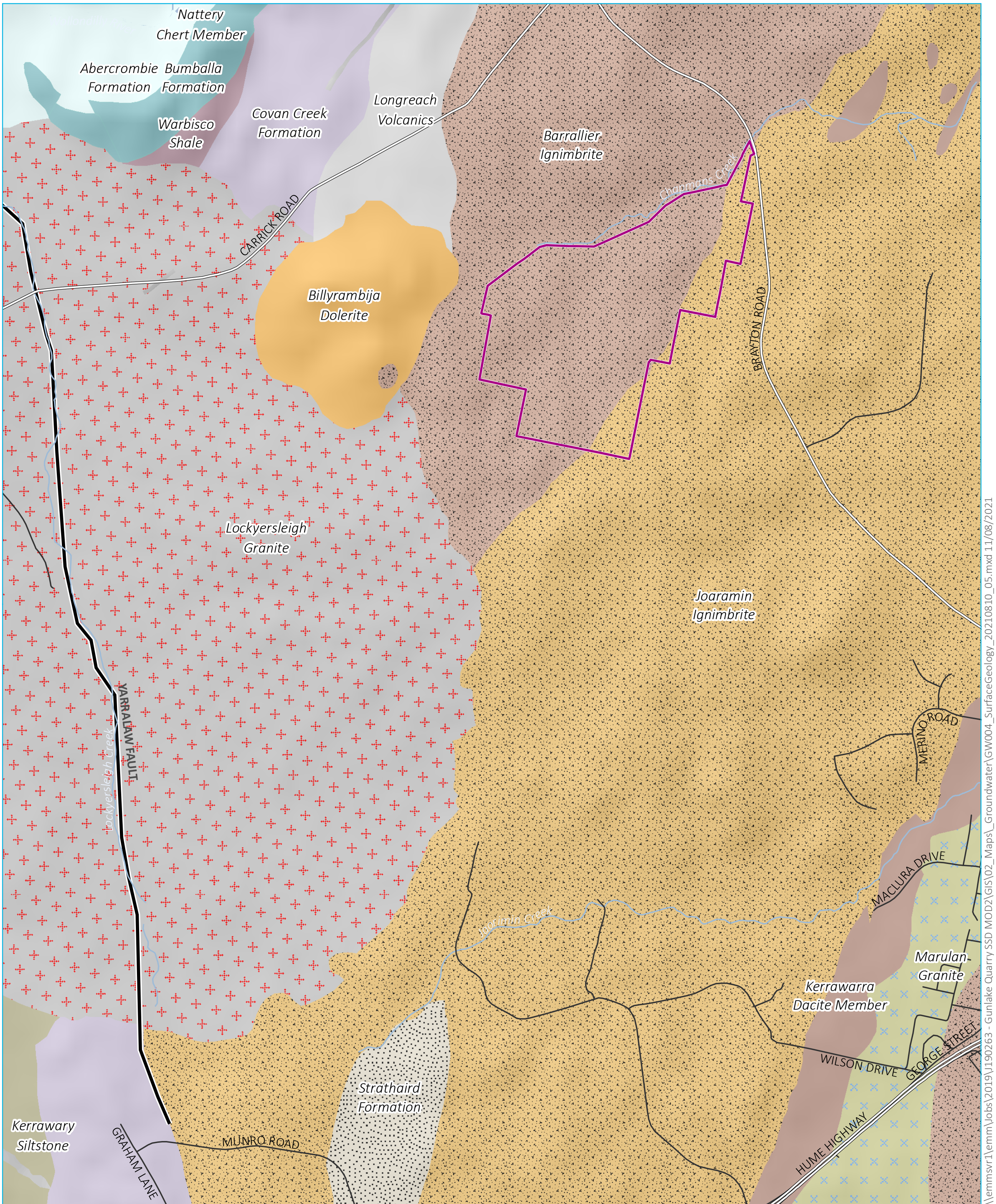
There are two massive intrusions, the Carboniferous Lockyersleigh Granite and the Palaeogene Billyrambija Dolerite, west of the Quarry (Figure 4.2).

4.4.1 Structural geology

The geology in the area has been subjected to several phases of progressive deformation including folding, faulting and thrusting, as well as nearby intrusions. Such tectonic upheavals have resulted in the imposition of structural discontinuities that dissect the rock masses and potentially create fluid pathways and conduits, or barriers to groundwater flow.

There are no mapped faults around the Quarry, however an extensive network of faults exists within the north north-east trending early Devonian sequence. The major Towrang and Yarralaw Faults, and some unnamed faults run north north-east to the west of the Quarry (Figure 4.3).

Cook (2008) suggests that the most recent tectonic activity in the area has been largely compressive, causing a closure of the fractures. Surface traces of pervasive sub-vertical structural discontinuities are likely represented as creek lines. This is expected to be the case for the linear segments of Chapmans Creek and Wollondilly River.



Source: EMM (2021); DFSI (2017); GA (2011)

0 1 2 km
GDA 1994 MGA Zone 55
N

KEY

Site boundary
Major road
Minor road
Named watercourse
Major fault
Geological period
Carboniferous
Lockyersleigh Granite

Devonian
Abercrombie Formation
Barrallier Ignimbrite
Bumballa Formation
Covan Creek Formation
Joaramin Ignimbrite
Kerrawarra Dacite Member
Kerraway Siltstone

Longreach Volcanics
Marulan Granite
Nattery Chert Member
Strathaird Formation
Warbisco Shale
Palaeogene
Billyrambija Dolerite

Surface geology and faults

Gunlake Quarry Continuation Project
Groundwater assessment
Figure 4.2

EMM
creating opportunities

4.5 Hydrogeology

Groundwater in the Quarry area is associated with a regional fractured rock system within the Bindook Porphyry Complex and other Palaeozoic fractured rock units. Localised, perched groundwater can be expected in alluvium/colluvium associated with Chapmans Creek.

4.5.1 Alluvial/colluvial deposits

The poorly developed alluvial/colluvial deposits along the alignment of Chapmans Creek and Joaramin Creek (and associated drainage channels) host an unconfined, perched water source. The alluvial/colluvial deposits are typically less than 5 m thick with low storage (Dundon 2005). Groundwater residence time is low with rapid recharge and discharge following rainfall. The groundwater flow direction is consistent with the overlying surface water drainage features. The extent of the alluvium/colluvium associated with Chapmans Creek is confined to a narrow band along the creek banks and is so marginal it is not mapped in the Goulburn 1:100,000 geology map.

The alluvial/colluvial deposits comprise a matrix of fine particles (clay and silt) with minor sand/gravel and have a low permeability. Given the low permeability and limited extent (and therefore storage capacity), the alluvial/colluvial aquifer is a marginal water source for extractive water supply at best. According to the WaterNSW real time database, no registered groundwater users access this alluvial/colluvial water source.

4.5.2 Fractured rock water bearing zone

The Goulburn fractured rock groundwater source covers an area of 8,175 square kilometres (km^2) with rock types that are mainly volcanic in origin (NSW Office of Water 2011). The porphyry rock mass at the project site hosts a fractured rock groundwater source with marginal extraction value (ie high electrical conductivity (EC), a measure of salinity) and low yield.

Regional groundwater flow is towards the north-east, with eventual discharge to the Wollondilly River. On a local scale, the groundwater flows north-east, following a muted reflection of topography. Groundwater flow may also follow structural discontinuities in the rock mass, as shown by seep discharges. Aquifer yields range from 0.1–1.3 litres per second (L/s) at bores drilled within the fractured rock (GW051574 and GW107158). The modelled depth to groundwater ranges from 2 to >25 metres below ground level (mbgl).

Dundon (2010) notes there is a weathering profile within the uppermost 10 m of the porphyry rock mass. The weathered zone has a marginally higher permeability than the underlying unweathered rock. The underlying, unweathered porphyry has very low primary permeability and low secondary permeability (ie the permeability associated with structural discontinuities). Secondary permeability is not anticipated to increase the overall rock mass groundwater flow given the compressive nature of tectonic activity that has resulted in minor and poorly connected fractures (see Section 4.4.1).

4.5.3 Groundwater recharge and discharge

The groundwater systems are recharged via the direct infiltration of rainfall and potentially overlying surface water sources where alluvium is located. The NSW Office of Water (2011) applied a recharge rate of 4% of average annual rainfall (AAR) for the Goulburn fractured rock groundwater source. This is a high estimate for low permeability fractured rock water sources, and rates of between 0.5 and 2% of AAR are considered more realistic rainfall recharge estimates. Recharge rates to alluvium and low lying areas beyond the Quarry area are expected to be higher than the fractured rock mass. This is because alluvium has a relatively high permeability and low lying areas receive more inundation from surface water flow. The alluvial/colluvial deposits along the upper Chapmans Creek are expected to have similar recharge rates to the adjacent fractured rock areas.

The local surface water features in the vicinity of the Quarry are ephemeral and do not receive large contributions from groundwater. The Wollondilly River to the north of the Quarry may receive some baseflow contributions from groundwater springs.

4.5.4 Seeps

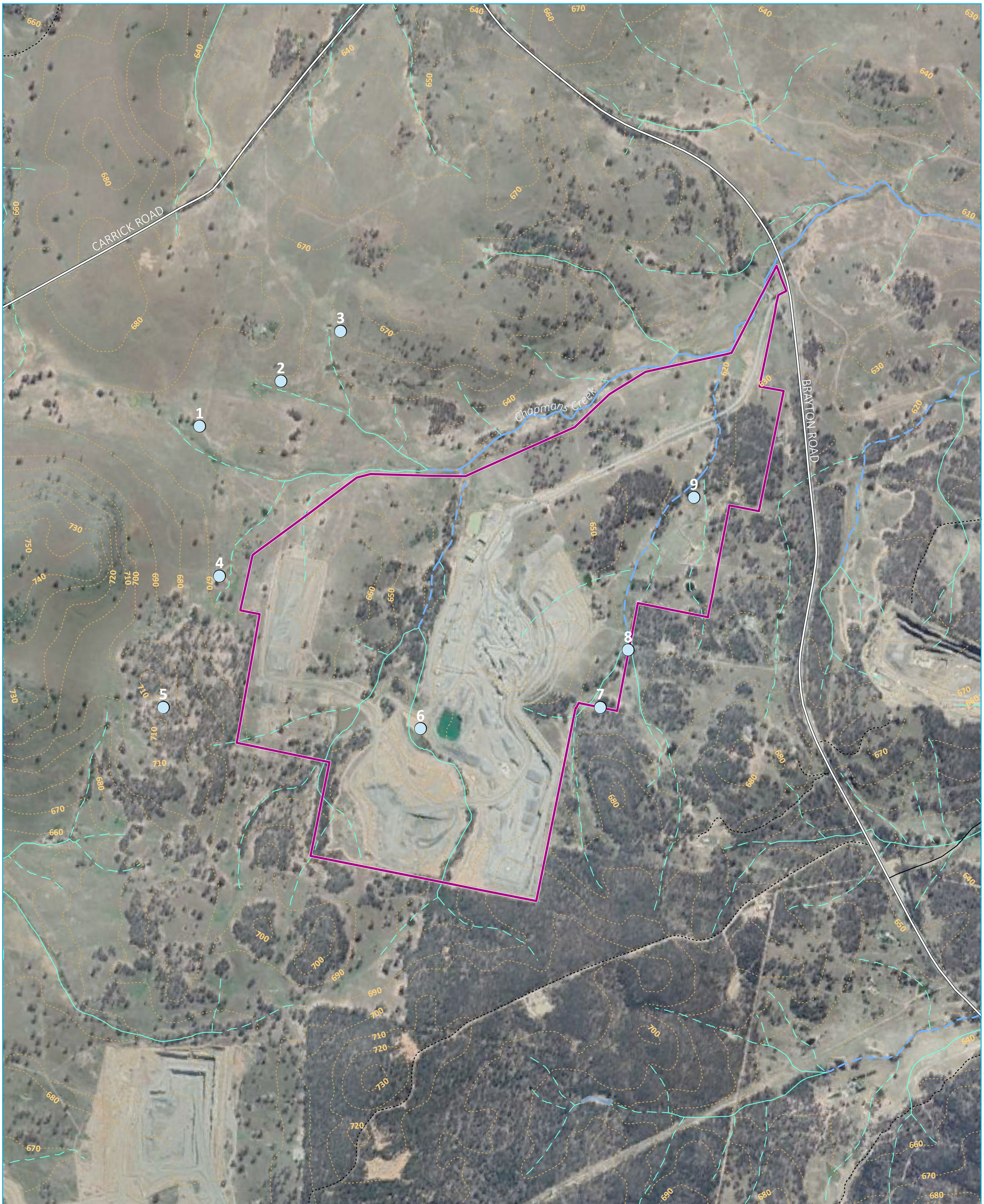
Groundwater discharge via seeps in the quarry area and surrounds was investigated in the initial *Groundwater Impact Assessment* for the Quarry (Cook 2008). Nine seeps have been identified within a 1.5 km radius of the centre of the Quarry (Figure 4.3). The seeps are associated with sub-vertical geological discontinuities which allow discrete groundwater discharge (fracture seeps). Cook (2008) made the following comments on the nature of the seeps:

- Seeps 1, 2, 3 and 4 are at elevations between 660 and 665 mAHD. These seeps appear to be controlled by sub-vertical discontinuities (such as a major joint or fracture or a network of closely spaced sub-parallel joints or fractures).
- Seep 5 is 20 m higher in elevation (685 mAHD).
- Seep 6 (655 mAHD), is within the approved Quarry pit area.
- Seeps 7, 8 and 9 are at elevations between 640 and 650 mAHD. These seeps appear to be controlled by a north north-east trending linear and continuous sub-vertical fracture. During field investigations in 2015, Seep 7 was difficult to locate and was considered to be in a general drainage depression that would also capture surface runoff.

The creeks within the Quarry site are ephemeral indicating that the groundwater system and groundwater seeps do not contribute significant baseflow to the streams. A reduction in groundwater discharge via seeps is unlikely to significantly impact the watercourse flow regimes.

The potential for changes to the depth of groundwater to impact groundwater dependent ecosystems is dependent on the local changes to groundwater depths rather than to changed seep discharge rates.

Given that discharges from these seeps are not significant, in that they do not contribute to surface water flow and are not a significant consideration in determining potential impacts to terrestrial GDEs, they have not been considered further in this assessment.



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Source: EMM (2021); Google Earth (2019); DFSI (2017); DPI (2015); GA (2011)

0 0.5 1 km

GDA 1994 MGA Zone 55

N

KEY

Site boundary

Major road

Minor road

Vehicular track

Surface elevation (mAHD)

Groundwater seep

Strahler stream order

1st order

2nd order

3rd order

4th order

Seep locations

Gunlake Quarry Continuation Project

Groundwater assessment

Figure 4.3

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4.6 Groundwater users

4.6.1 Registered groundwater works

A search of the WaterNSW real time database undertaken in July 2021 identified 39 groundwater works within a 5 km radius of the Quarry. The database contains varying levels of bore construction and formation information, as the information in the database depends on the level information provided by drillers on the Form A. The location of these works is presented in Figure 4.4.

Nine local groundwater works are registered for private use (stock or domestic/stock purposes) (Table 4.2). GW055436 is the closest private groundwater work to the Quarry, approximately 1.5 km south-west of the site boundary. The current status of these water supply bores is not known. The remaining identified groundwater works shown in Figure 4.4 are groundwater monitoring or exploration bores owned by the Holcim Lynwood Quarry or other industries.

Table 4.2 Registered groundwater works, stock and domestic (5 km radius)

Bore ID	Year drilled	Purpose	Depth (m)	Water level (mbgl)	Yield (L/s)	Monitored formation
GW015362	1957	Stock	52.7	12.2	0.8	Clay
GW114693	2013	Domestic/stock	109.1	50.4	0.1 & 0.4	Sandstone
GW056376	1982	Stock	51	12	0.2	Volcanics (granite)
GW105357	2002	Domestic/stock	60	NA	-	Volcanics (granite)
GW010600	1953	Stock	91.4	9.1	0.8	Sand
GW055436	1981	Domestic/stock	76.2	4.6	0.4	Volcanics
GW111929	2012	Water supply	96	1.5	1.3	Volcanics (granite)
GW051574	1980	Water supply	61	5	0.1	Granite/basalt
GW055436	1980	Water supply	76.2	4.6	0.40	Granite

mbgl = meters below ground level
NA = not available.
Source: WaterNSW real time water data, accessed on 27 July 2021

4.6.2 Groundwater dependent ecosystems

There are no high priority GDEs listed in the Greater Metropolitan Region Groundwater WSP, for the Goulburn Fractured Groundwater Source. A search of the National Atlas of Groundwater Dependent Ecosystems (BoM 2015) identified four creeks within the vicinity of the Quarry with the potential for groundwater interaction: Chapmans Creek, Jaorimin River, Lockyersleigh River and Wollondilly River.

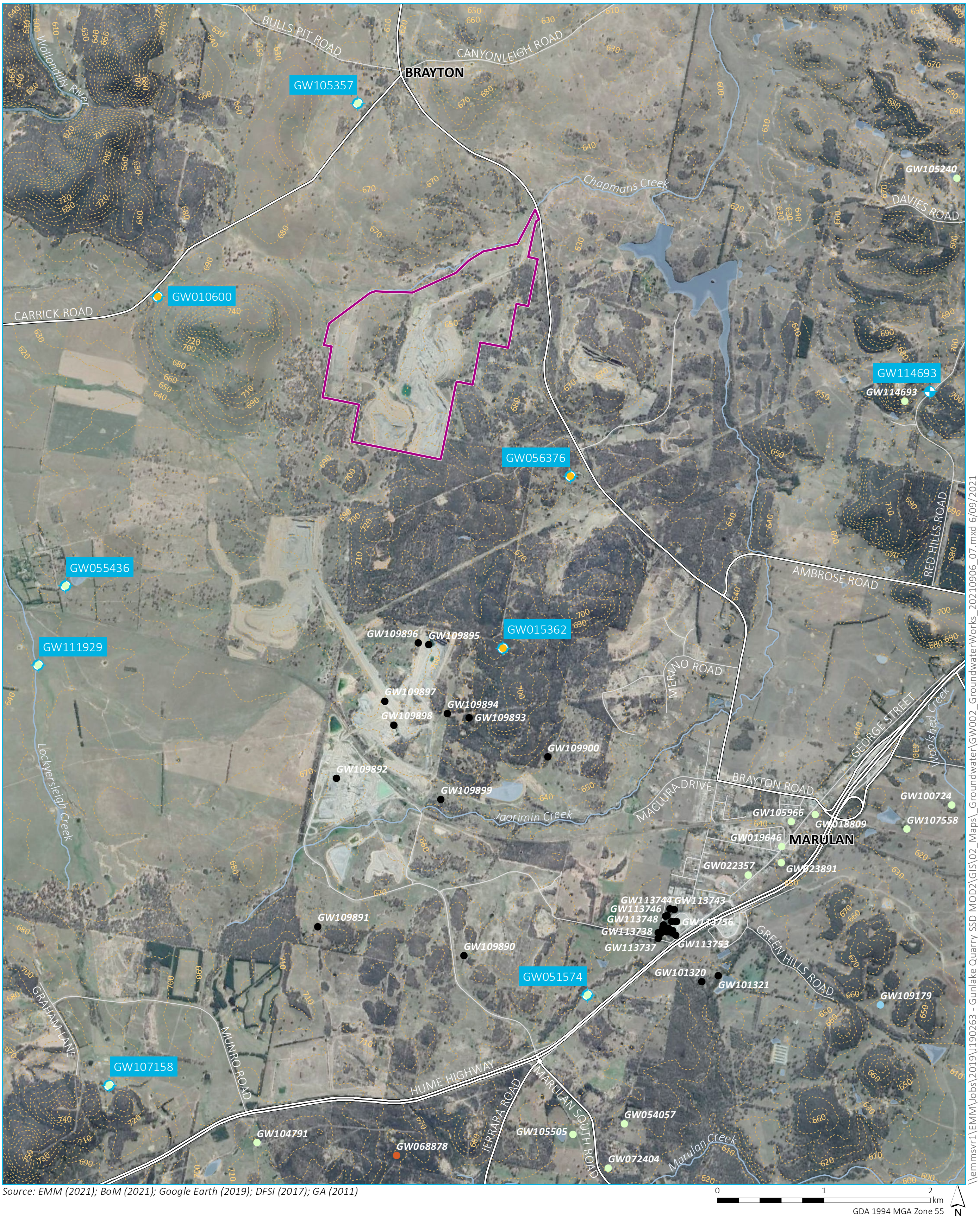
The *Continuation Project Biodiversity Development Assessment Report* (BDAR) (EMM 2021b, EIS Appendix F.7) identifies the following potentially terrestrial GDEs:

- PCT 1256 - Tableland swamp meadow on impeded drainage sites of the western Sydney Basin Bioregion and South Eastern Highlands Bioregion; and
- PCT 1330- Yellow Box - Blakely's Red Gum grassy woodland on the tablelands, South Eastern Highlands Bioregion (Box Gum Woodland).

Box Gum Woodland is identified in the *Atlas of Groundwater Dependent Ecosystems* (BoM 2015).

4.6.3 Surrounding quarries

There are two other quarries within 5 km of Gunlake Quarry Johnniefelds Quarry and Lynwood Quarry. Johnniefelds Quarry is approximately 1 km east of Gunlake Quarry and is currently in care and maintenance. Lynwood Quarry is extracting rock from the Granite Pit, located approximately 750 m south of the Gunlake site boundary. Groundwater inflows to the Granite Pit are predicted to peak at 38.7 ML/year (Scientific Systems 2015).



Source: EMM (2021); BoM (2021); Google Earth (2019); DFSI (2017); GA (2011)

KEY

- Site boundary
- Groundwater bore
- Major road
- Minor road
- Surface elevation (mAHD)
- Named watercourse
- Waterbody

Registered bore (NGIS) (BoM, 2021)

- Commercial and Industrial
- Irrigation
- Monitoring
- Stock and Domestic
- Water Supply

Groundwater works

Gunlake Quarry Continuation Project
Groundwater assessment
Figure 4.4

EMM
creating opportunities

5 Field investigation program

5.1 Groundwater monitoring network

A groundwater monitoring network was installed at the Quarry in April 2007 (Cook 2008). The monitoring network comprised four standpipe piezometers (monitoring bores) installed into and screening the Bindook Porphyry (Table 5.1 and Figure 5.1). Two bores, GM24 and GM36, have been removed as quarrying has progressed.

Table 5.1 Groundwater monitoring network

Bore ID	Coordinates MGA grid		Depth (mbgl)	Surface elevation (mAHD)	Screen depth (mbgl)
	Easting (m)	Northing (m)			
GM6	771916	6159367	25.9	657.4	22.8–22.9
GM13	771816	6159042	22.4	665.2	19.3–22.3
GM24 *	771676	6158934	21.0	659.9	17.9–19.9
GM36 *	771920	6158843	17.1	666.0	14.0–17.0

Notes: * monitoring bore destroyed.
mbgl = metres below ground level.
mAHD: metres Australian Height Datum.

The monitoring bores were constructed by installing 50 millimetre (mm) uPVC casing into old exploration holes, a 3 m screened interval was installed at the base of each monitoring bore to enable targeted monitoring of the Porphyry fractured rock.

Groundwater monitoring has been undertaken by Gunlake since 2007. Monitoring comprises quarterly measurements of groundwater level and groundwater quality indicators (pH, EC and temperature).

Source: EMM (2021); Google Earth (2019); DFSI (2017); DPI (2015); GA (2011)

0 0.5 1 km
GDA 1994 MGA Zone 55
N

KEY

- Site boundary
- Surface elevation (mAHD)
- Major road
- Minor road
- Watercourse
- Waterbody
- Groundwater seep

Groundwater montioring

- Bore no longer operational
- Groundwater bore

Groundwater monitoring network

Gunlake Quarry Continuation Project
Groundwater assessment
Figure 5.1

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EMM creating opportunities

5.2 Groundwater levels

Comprehensive groundwater level monitoring data from the Quarry monitoring network from May 2007 to August 2020 was used in this assessment. Groundwater levels range from 634.9 to 659.5 mAHD (6.3 to 22.5 mbgl). Groundwater level and cumulative deviation from the mean rainfall are plotted on Figure 5.2.

The groundwater level in GM6 generally reflects rainfall recharge; the groundwater level rises following heavy rainfall events or sustained periods of rainfall,and declines slightly in drier periods. More gradual or muted groundwater level fluctuations in response to rainfall recharge are observed in bores GM13 and GM36.

Groundwater levels in 2007 (prior to quarrying) were similar to those in 2020, indicating that quarry operations to date have not impacted ground level levels.

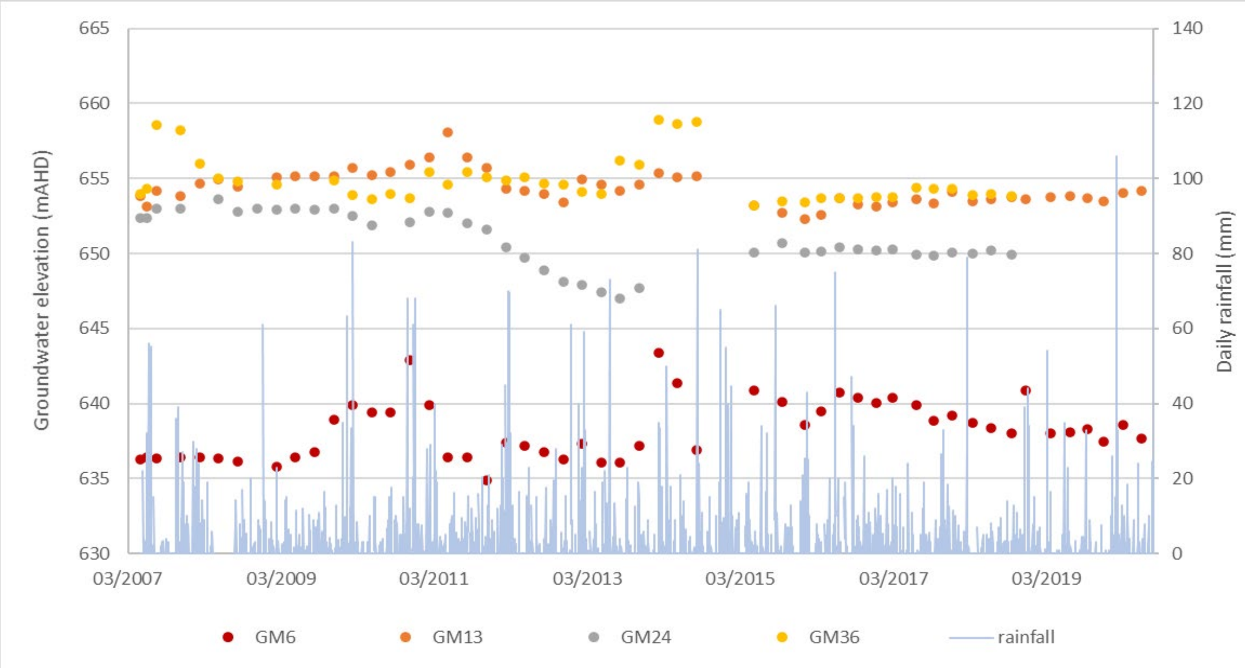


Figure 5.2 Groundwater levels and rainfall

5.3 Groundwater quality

Groundwater quality has been assessed based on monitoring data for July 2007 and from December 2014 to June 2021. Groundwater quality summary tables are included in Annexure A.

Groundwater in the Quarry area is generally of poor quality (as per the AIP total dissolved solids classification). The groundwater quality has been assessed against the default guideline values for the water quality objectives based on the end users. The receiving water catchment area, Lake Burragorang catchment, is a drinking water catchment and therefore groundwater quality results are compared against the Australian Drinking Water Guidelines (Drinking Water Guideline) (NRMMC 2011) for Health and Aesthetic categories. Groundwater quality results have also been compared to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Water Quality Guideline) (ANZG 2018) trigger values for the 95% protection of freshwater species, and moderately disturbed upland rivers.

5.3.1 Field results

Groundwater EC results are provided in Table 5.2, and pH results are provided in Table 5.3.

Table 5.2 Field water quality monitoring: EC

Monitoring bore	Range (µS/cm)	Average (µS/cm)
GM6	119–294	213.9
GM13	359–6,080	2,689
GM24	35–3,100	1,984
GM36	274–3,541	1,710

Notes: µS/cm = microsiemens per centimetre.
Sample size = 20 samples for GM24, GM36 and 27 samples for GM6 and GM13
Drinking Water Guideline upper limit: 402 µS/cm (using TDS conversion of 0.67), water quality guideline range: 125-2,200 µS/cm.

Table 5.3 Field water quality monitoring: pH

Monitoring bore	Range	Average
GM6	5.8–9.0	6.7
GM13	7.1–7.9	7.4
GM24	5.4–8.0	7.3
GM36	6.4–8.2	6.9

Notes: Sample size = 20 samples for GM24, GM36 and 27 samples for GM6 and GM13
Drinking Water Guideline range: 6.5–8.5 and Aquatic Ecosystem Protection Guideline range: 6.5–7.5.

Overall, EC (salinity) conditions range from fresh to moderately brackish with no distinct trends, although EC conditions are consistently fresh at GM6. Groundwater salinity levels generally exceed the ANZECC (2000)/ANZG (2018) default guideline value at bores GM13, GM24 and GM36 on numerous occasions. Most groundwater in the fractured volcanic rock is naturally brackish and fits the AIP definition of a 'less productive' water source as salinities are typically greater than 1,500 mg/L total dissolved solids. The physicochemical results at GM6 are an exception, ie consistently low salinity groundwater, again suggesting the local area receives direct rainfall recharge.

Average pH conditions are neutral, although there were multiple exceedances of the guideline values, both above and below the guideline range. Acidic and alkaline conditions were observed however, the pH is mostly neutral at GM6 with the notable exception of pH 9 recorded in May 2015. It is likely that this sampling event for GM6 is compromised and such fluctuations in results are not indicative of regional water quality trends.

i Laboratory results water type

The hydrogeochemistry of the porphyry groundwater has been evaluated by plotting a trilinear (Piper) diagram (Figure 5.3). The ion proportions in the groundwater samples are distributed across the diamond field suggests the chemical composition of the groundwater evolves as it moves through the porphyry rock mass. Carbonate is the dominant anion in the groundwater composition and there is no dominant cation.

The Piper diagram indicates a groundwater chemistry composition typical of a mixed groundwater resource, where rainfall is introduced to the system.

ii Dissolved metals

Groundwater concentrations of dissolved cadmium, chromium, lead and nickel were greater than the Drinking Water Guideline values (in Annexure A). Concentrations of cadmium, copper, nickel and zinc were also greater than the default guideline values for the protection of ecosystems. Elevated concentrations of dissolved metals are natural and are not attributable to quarry activities.

iii Nutrients

Groundwater ammonia, nitrite, nitrate and phosphorous concentrations frequently exceeded the default guideline values for the protection of ecosystems values, often by one order of magnitude. There were only three exceedances of the *Drinking Water Guideline* values, and this was for ammonia as N.

The maximum ammonia concentration was 1.9 milligrams per litre (mg N/L) at GM6 (November 2015) and the maximum nitrate concentration was 7.8 mg N/L also at GM6 (December 2016). Nutrient concentrations can be attributed to anthropogenic land use practices within the groundwater catchment (eg agriculture).

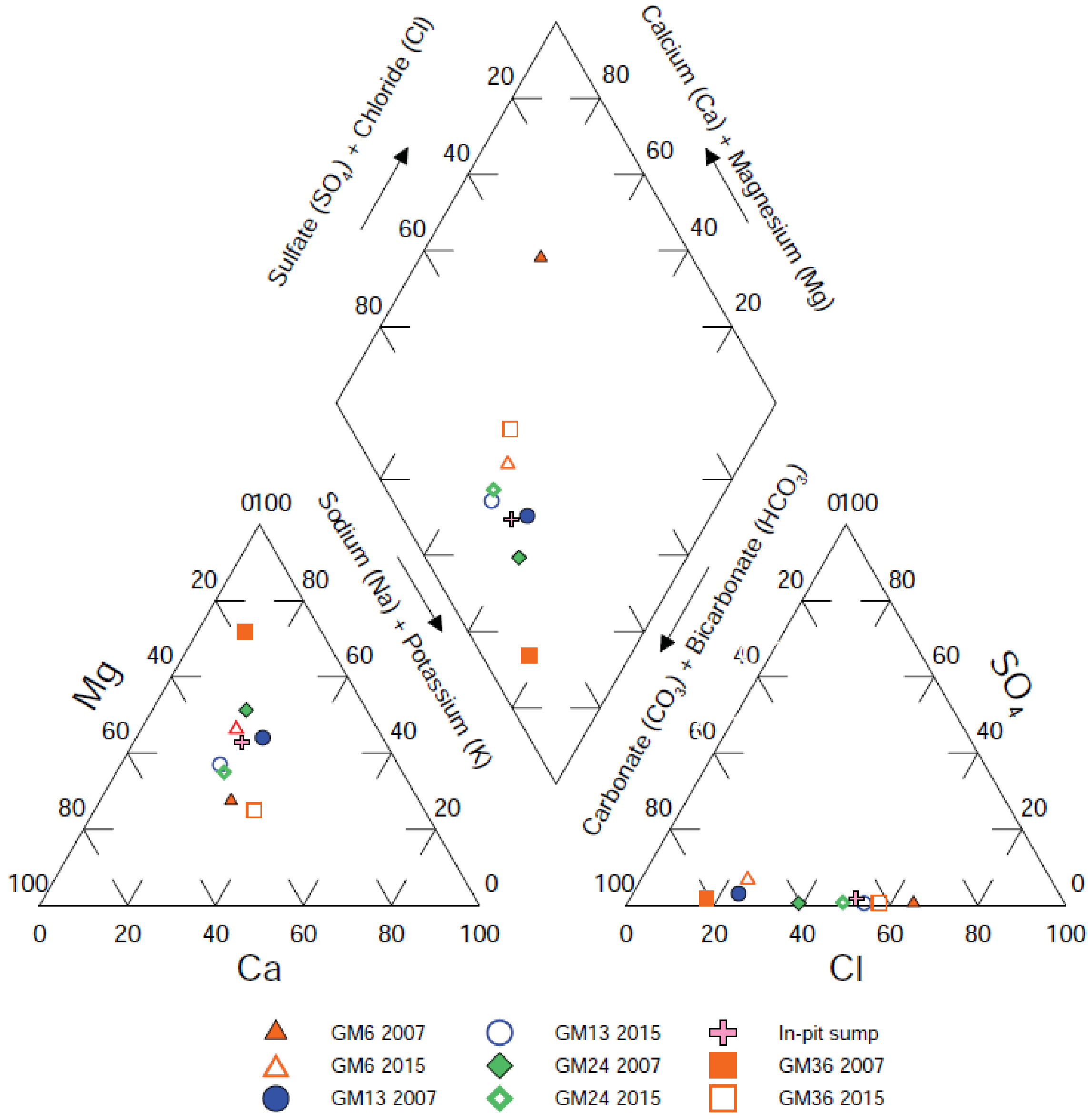


Figure 5.3 Trilinear (Piper) plot

5.4 Hydraulic testing

Rising and falling head tests (slug tests) were completed in June 2007 at eight shallow exploration boreholes at Gunlake Quarry (Cook 2008). Cook (2008) completed an assessment of the collected data using analytical solutions developed by Hvorslev (1951) and Bower and Rice (1976) to derive estimates of the physical properties of the fractured rock groundwater source (Table 5.4).

Table 5.4 Hydraulic testing results

Borehole	Hvorslev solution			Bower & Rice solution		
	K (m/day)	T (m^2/day)	S	K (m/day)	T (m^2/day)	S
GM5	0.78	5.06	$5x10^{-4}$	0.53	3.44	$5x10^{-4}$
GM11	0.03	0.33	$1x10^{-4}$	0.02	0.23	$1x10^{-4}$
GM13	0.04	0.17	$5x10^{-4}$	0.03	0.11	$1x10^{-4}$
GM21	0.03	0.29	$1x10^{-4}$	0.02	0.20	$5x10^{-4}$
GM22	0.77	2.82	$5x10^{-4}$	0.42	1.53	$5x10^{-4}$
GM24	0.04	0.61	$1x10^{-4}$	0.03	0.44	$1x10^{-4}$
GM35	0.02	0.28	$1x10^{-4}$	0.01	0.21	$1x10^{-4}$
GM36	0.02	0.13	$1x10^{-4}$	0.01	0.09	$1x10^{-4}$

Notes: 1. Information provided by Cook et al (2008).
2. K = hydraulic conductivity, T = transmissivity, S = storativity (dimensionless).

Results from the slug tests indicate the weathered Bindook Porphyry has a low permeability with the derived hydraulic conductivity ranging from 0.01 to 0.78 metres per day (m/day). This range is consistent with results from hydraulic testing at the nearby Lynwood Quarry reporting a range of 0.005 to 0.38 m/day (Dundon 2005). The groundwater salinity is also suggestive of a low flow system, such that groundwater residence times are sufficient to result in brackish conditions down hydraulic gradient.

6 Groundwater modelling

6.1 Analytical approach

An analytic element groundwater flow model was used to predict the potential groundwater impacts from the Continuation Project. The model was developed in accordance with the Australian Groundwater Modelling Guidelines and aligns with a class 1 model description (Barnett et al. 2012).

An analytical approach is considered appropriate for the Continuation Project given the:

- low hydraulic conductivities of the intercepted and surrounding strata (see Section 5.4); and
- low number of sensitive groundwater receptors (see Section 4.6).

The model was developed in the AnAqSim analytical element modelling platform (Fitts Geosolutions 2015). AnAqSim is capable of superimposing multiple analytical flow calculations to derive solutions as a function of location and time. The analytical model writes equations in two-dimensions and allows the representation of three-dimensional flow by using multiple, planar layers.

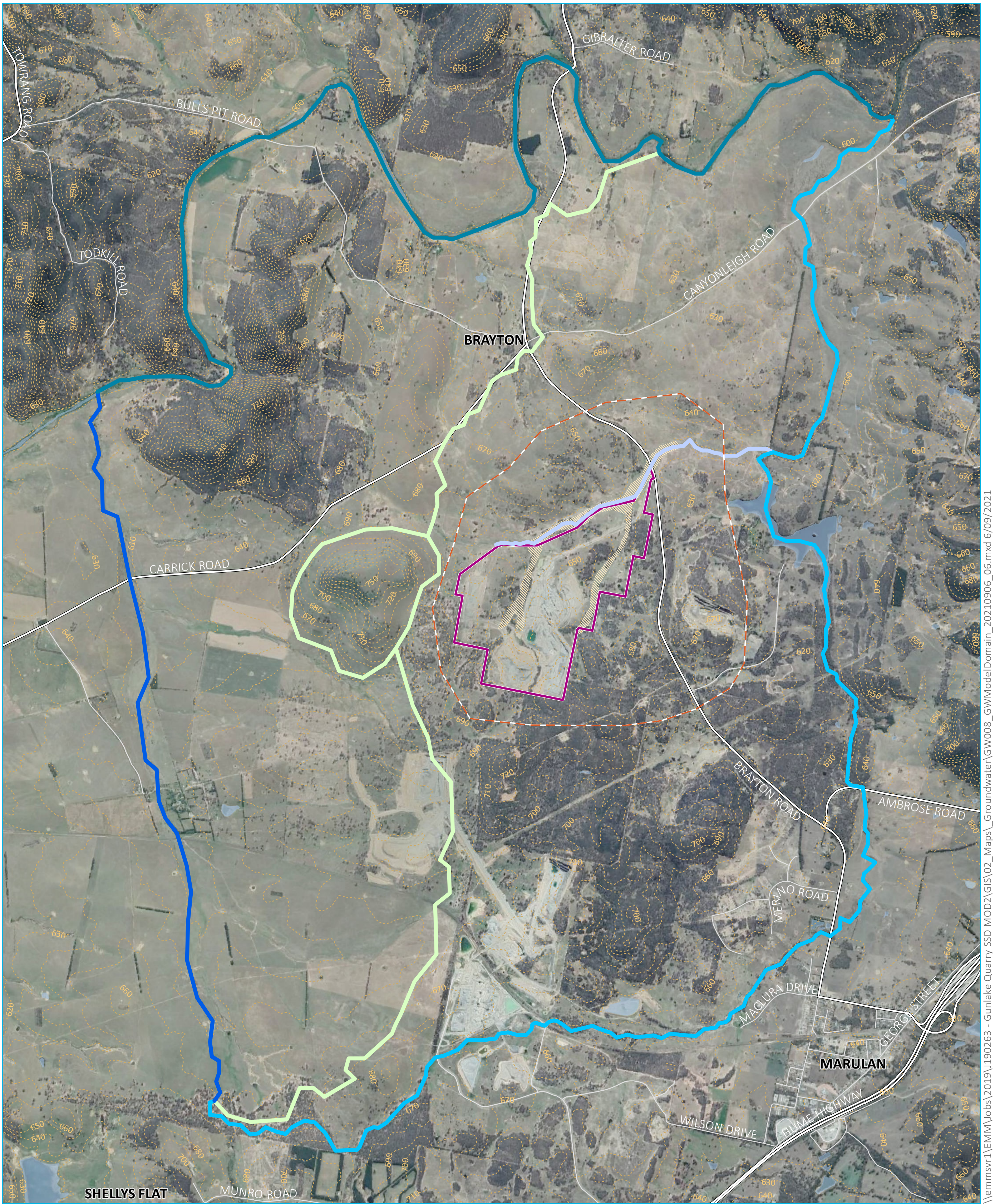
6.2 Model design

6.2.1 Model domain and spatial boundaries

The model domain encompasses a surface area of 6,190 ha (Figure 6.1). The model domain is constrained by surface watercourses represented in the model as head-specified boundaries:

- Lockyersleigh Creek defines the western boundary with a head distribution of 645 to 580 mAHD;
- Jaorimin Creek defines the southern and eastern boundary with a head distribution of 670 to 590 mAHD; and
- Wollondilly River defines the northern boundary with a head distribution of 600 to 590 mAHD.

The head-specified model boundaries maintain a constant hydraulic head inferred at the water table within the underlying hard rock strata. The depth of the water table in the hard rock was interpreted using available surface topography, water levels and surface water flow regimes.



Source: EMM (2021); Google Earth (2019); DFSI (2017); GA (2011)

0 1 2 km

GDA 1994 MGA Zone 55

N

KEY

Site boundary

Major road

Minor road

Surface elevation (mAHD)

Waterbody

Model information

Alluvium

Vertical refinement area

Geological boundary

Catchment boundary

Wollondilly River

Lockyersleigh Creek

Jaorimin Creek

Chapmans Creek

Groundwater model domain

Gunlake Quarry Continuation Project

Groundwater assessment

Figure 6.1

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6.2.2 Model geometry

The model domain is divided into six hydrostratigraphic units (HSUs) and three layers providing a simplified representation of the geological complexities at the Quarry. The model has three layers allowing three-dimensional flow and facilitating the calculation of hydraulic head losses within the surrounding strata.

Layer 1 includes Chapmans Creek, alluvial/colluvial deposits, weathered Bindook Porphyry, Lockyersleigh Adamellite (granite) and the Billyrambija Dolerite (Table 6.1). Layer 2 includes weathered and unweathered Bindook Porphyry and layer 3 includes unweathered Bindook Porphyry. A conceptual cross-section of the modelled layers and hydrostratigraphic units is presented in Figure 6.2 (not to scale horizontally). As described above, vertical refinement into multiple layers is only in the area of the Bindook Porphyry near the Quarry (shown in Figure 6.1). This unit is subdivided into two sections: weathered and unweathered. The weathered zone sits at the top of the profile to a base elevation of 590 mAHD. Alluvial/colluvial deposits are simulated adjacent to Chapmans Creek, with base elevation of 600 mAHD.

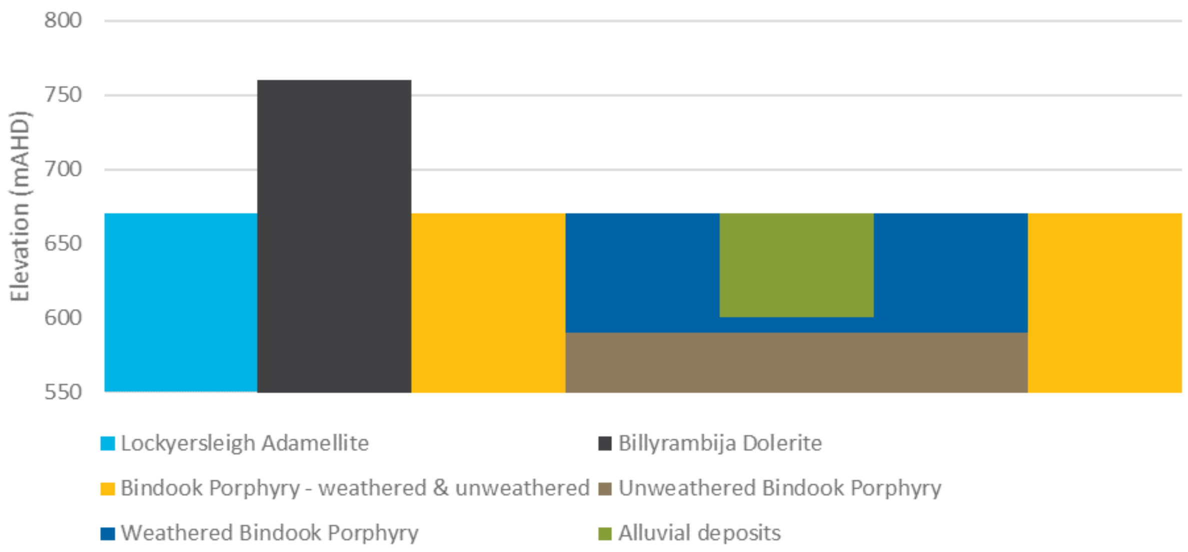


Figure 6.2 Conceptual cross-section of modelled layers and HSUs (West to East)

Flow at Chapmans Creek is simulated in the model using the stream function. Chapmans Creek flows from an elevation of 650 mAHD in the west to 600 mAHD in the east where it discharges to Jaorimin Creek. The creek was allowed to run dry to simulate its ephemeral properties.

6.2.3 Model hydraulic properties

Hydraulic properties assigned to the model are based on the results from monitoring and hydraulic testing at the Quarry (see Section 5.4) and groundwater studies completed in the area (Dundon 2005, Cook 2008 and Scientific Systems 2015). Minor adjustments to the hydraulic properties were made during calibration of the steady state model (see Section 6.2.6).

The Bindook Porphyry is represented in all three layers and assigned hydraulic conductivities to represent the influence of the weathering profile and increased overburden pressure with depth. The hydraulic parameters assigned to each geological formation are listed in Table 6.1. Hydraulic parameters of the Weathered Bindook Porphyry were updated in the history matching process, since the development of the initial model, lowering the hydraulic conductivity and specific yield.

Storativity values were applied based on model layer thickness (refer Figure 6.2) to give a resultant specific storage of 1 x 10^{-6} m^{-1}. Alluvial/colluvial deposits were simulated with the same hydraulic properties as the surrounding Weathered Bindook Porphyry, as the conceptualisation supported minimal hydrogeological influence of alluvium/colluvium. The HSU geometry was left in the model to allow for potential future testing of parameter value influence.

Table 6.1 Hydraulic parameters adopted in the groundwater flow model

Model layer	Geological description	Hydraulic conductivity (m/day)		Storativity	Specific yield
		horizontal	vertical		
1	Alluvium/colluvium	0.005	0.0001	0.00008	0.005
1	Bindook Porphyry – regional area, combined weathered & unweathered	0.005	0.00001	0.00012	0.01
1	Weathered Bindook Porphyry	0.005	0.0001	0.00008	0.005
1	Lockyersleigh Adamellite	0.006	0.00001	0.00012	0.01
1	Billyrambija Dolerite	0.004	0.00001	0.00021	0.01
2	Weathered Bindook Porphyry	0.005	0.0001	0.00001	0.01
2	Unweathered Bindook Porphyry	0.003	0.00001	0.00004	0.01
3	Unweathered Bindook Porphyry	0.003	0.00001	0.00004	0.01

Notes: m/day = metres per day.

A uniform recharge rate of 0.013 mm/day was applied across the model domain, equivalent to 0.7% of annual average rainfall.

6.2.4 Boundary conditions

The boundary conditions applied in the model are as follows:

- **Constant head-specified boundaries:** as described in Section 6.2.1, head-specified boundaries are applied at all edges of the model domain. The model boundaries follow identified rivers, and the hydraulic head at these boundaries is guided by river stage elevations.
- **Rivers:** Chapmans Creek is simulated within the model domain, as discussed in Section 6.2.2. The river boundary condition is used with stage elevation from 650 mAHD at the headwaters to 600 mAHD at the confluence with Jaorimin Creek, and a streambed conductance of 0.3 m/day.
- **Recharge:** A uniform recharge rate was applied across the model domain equal to 0.7% of annual average rainfall. The recharge rate varied during the history match period in accordance with annual measured rainfall, and was held constant for the predictive stress periods at the annual average rate of 0.013 mm/day. Following the end of quarrying, a net flux representing potential evaporation minus rainfall was applied to the Quarry footprint (-1.53 x 10^{-4} m/day) to simulate a simplified pit lake surface flux.
- **Temporal head-specified boundaries:** Dewatering for the Quarry was simulated using head-specified boundaries at the edge of the Quarry with stage elevation equal to the base of workings. These boundaries were activated once extraction progressed below 650 mAHD, with pit geometry and elevation provided. This boundary was deactivated following cessation of quarrying.

6.2.5 Temporal discretisation

The analytical model was run in two phases:

- steady state simulation with background fluxes and annual average recharge; and
- transient simulation from January 2007, incorporating annual history match stress periods, predictive mine plan through the end of 2051, and a 1,000 year post-closure period.

The transient model incorporated varying recharge based on measured rainfall and pit dewatering associated with the Quarry advancing. The transient model temporal setup is presented in Table 6.2, including the applied recharge rate and modelled pit base elevation.

Table 6.2 Transient model setup

Stress period	Start date	End date	Recharge (mm/day)	Updated groundwater model pit base elevation (mAHD)
1	1/01/2007	1/01/2008	0.016	Above watertable
2	1/01/2008	1/01/2009	0.012	Above watertable
3	1/01/2009	1/01/2010	0.008	Above watertable
4	1/01/2010	1/01/2011	0.017	Above watertable
5	1/01/2011	1/01/2012	0.012	Above watertable
6	1/01/2012	1/01/2013	0.017	Above watertable
7	1/01/2013	1/01/2014	0.013	Above watertable
8	1/01/2014	1/01/2015	0.015	Above watertable
9	1/01/2015	1/01/2016	0.014	Above watertable
10	1/01/2016	1/01/2017	0.016	Above watertable
11	1/01/2017	1/01/2018	0.010	Above watertable
12	1/01/2018	1/01/2019	0.009	Above watertable
13	1/01/2019	1/01/2020	0.006	Above watertable
14	1/01/2020	1/01/2021	0.018	Above watertable
15	1/01/2021	1/01/2022	0.013	Above watertable
16	1/01/2022	1/01/2023	0.013	Above watertable
17	1/01/2023	1/01/2024	0.013	Above watertable
18	1/01/2024	1/01/2025	0.013	Above watertable
19	1/01/2025	1/01/2026	0.013	Above watertable
20	1/01/2026	1/01/2027	0.013	Above watertable
21	1/01/2027	1/01/2028	0.013	637
22	1/01/2028	1/01/2029	0.013	637
23	1/01/2029	1/01/2030	0.013	637
24	1/01/2030	1/01/2031	0.013	637
25	1/01/2031	1/01/2032	0.013	624

Table 6.2 Transient model setup

Stress period	Start date	End date	Recharge (mm/day)	Updated groundwater model pit base elevation (mAHD)
26	1/01/2032	1/01/2033	0.013	624
27	1/01/2033	1/01/2034	0.013	624
28	1/01/2034	1/01/2035	0.013	611
29	1/01/2035	1/01/2036	0.013	611
30	1/01/2036	1/01/2037	0.013	611
31	1/01/2037	1/01/2038	0.013	598
32	1/01/2038	1/01/2039	0.013	598
33	1/01/2039	1/01/2040	0.013	598
34	1/01/2040	1/01/2041	0.013	598
35	1/01/2041	1/01/2042	0.013	585
36	1/01/2042	1/01/2043	0.013	585
37	1/01/2043	1/01/2044	0.013	585
38	1/01/2044	1/01/2045	0.013	572
39	1/01/2045	1/01/2046	0.013	572
40	1/01/2046	1/01/2047	0.013	572
41	1/01/2047	1/01/2048	0.013	559
42	1/01/2048	1/01/2049	0.013	559
43	1/01/2049	1/01/2050	0.013	559
44	1/01/2050	1/01/2051	0.013	546
45	1/01/2051	1/01/2052	0.013	546
46	1/01/2052	1/01/2053	0.013	546 (recovery period)
47	1/01/2053	1/01/2057	0.013	546 (recovery period)
48	1/01/2057	1/01/2062	0.013	546 (recovery period)
49	1/01/2062	1/01/2102	0.013	546 (recovery period)
50	1/01/2102	1/01/2152	0.013	546 (recovery period)
51	1/01/2152	1/01/3052	0.013	546 (recovery period)

6.2.6 History match approach

History matching was performed against measured groundwater levels at the site monitoring bores GM6, GM13, GM24 and GM36. No measured fluxes were available to further constrain hydraulic parameters. The history match assessment was performed in two stages:

- the steady state model was run with varying recharge rates to replicate approximate starting groundwater levels; and

- the transient model was run using the steady state model results as starting conditions and varying storage and hydraulic conductivity of the Weathered Bindook Porphyry.

6.3 Assumptions

The groundwater model is a simplified representation of a complex groundwater system. Model inputs are based on monitoring data, hydraulic testing, previous studies and a series of assumptions. The simplifications and assumptions used in this model are:

- the representation of complex geological units as homogeneous, porous medium HSUs;
- the exclusion of discrete structural features;
- the application of instantaneous stress at the commencement of each development stage to simulate progressive Quarry extraction; and
- the exclusion of nearby quarry operations (deemed outside of the zone of influence – see Section 7.2.6).

The uncertainty in the model predictions has been managed by using conservative model input parameters to provide expected 'worst possible scenario' predictions or the upper limit of adverse impacts. Actual impacts are anticipated to be within model predictions.

6.4 History match assessment

A steady state model was developed to simulate groundwater levels prior to any extraction or quarrying activity at Gunlake Quarry. The results of this model were used as starting conditions for a transient model, incorporating annual rainfall variations. Recharge as a percentage of rainfall and aquifer hydraulic parameters were varied to match measured groundwater levels.

Modelled steady state groundwater levels, used as starting conditions for the transient model, are presented in Figure 6.3, with associated yearly averaged rainfall rate. The highest groundwater elevation is towards the south of the model domain, above 680 mAHD. Groundwater flows radially away from this location towards the model boundaries. Groundwater leaves the model domain as baseflow to streams, including Chapmans Creek in the middle of the domain.

Groundwater elevations are matched reasonably well for GM6, GM24 and GM36, and are approximately 10 m low for GM13. There is minimal response in the model to variations in recharge, with only a slight improvement with low assigned values of specific yield. A specific yield value of 0.5% was assigned for the model, considered a conservative assumption.

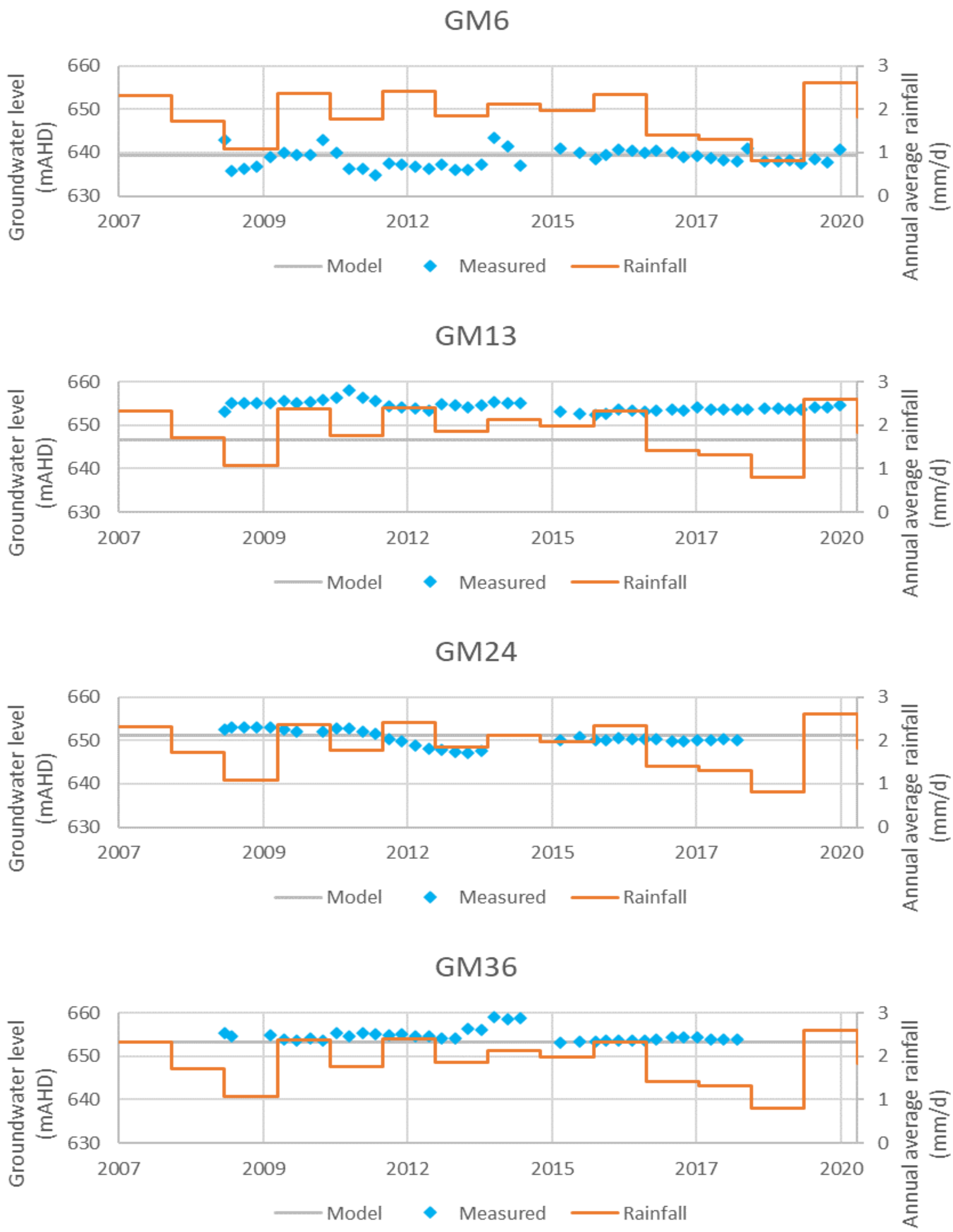


Figure 6.3 Transient history match hydrographs

6.5 Predictive modelling

Following the transient history match period, the groundwater model incorporates predictive stresses. The quarry plan as detailed in Table 6.2 was used, recharge was applied in accordance with long-term average rainfall, and dewatering/interception of groundwater was simulated once the quarry plan progressed below the water table. In order to negate the influence of temporally varying background groundwater levels, results of the predictive model were compared against a 'null scenario' with no quarry simulation.

6.5.1 Groundwater flux

Temporal detail of the progression of quarry depth is truncated in the AnAqSim model and modelled inflows to the Quarry are presented as an average during active quarrying. Average modelled groundwater flux to the Quarry area once quarrying is below the water table (ie from January 2027 to January 2052) is 188 kL/day (68 ML/year). Long-term seepage to the Quarry post-quarrying is estimated to be 77 kL/day (28 ML/year).

The steady-state model representing long-term average conditions simulates baseflow to Chapmans Creek of 79 kL/day. Groundwater dewatering for quarry development is predicted to intercept some of this baseflow, reducing flows by 3.7 kL/day at the end of quarrying, with a long-term decrease of 13.0 kL/day. This take is included in the total volume (68 ML/year) of take to be licenced by Gunlake.

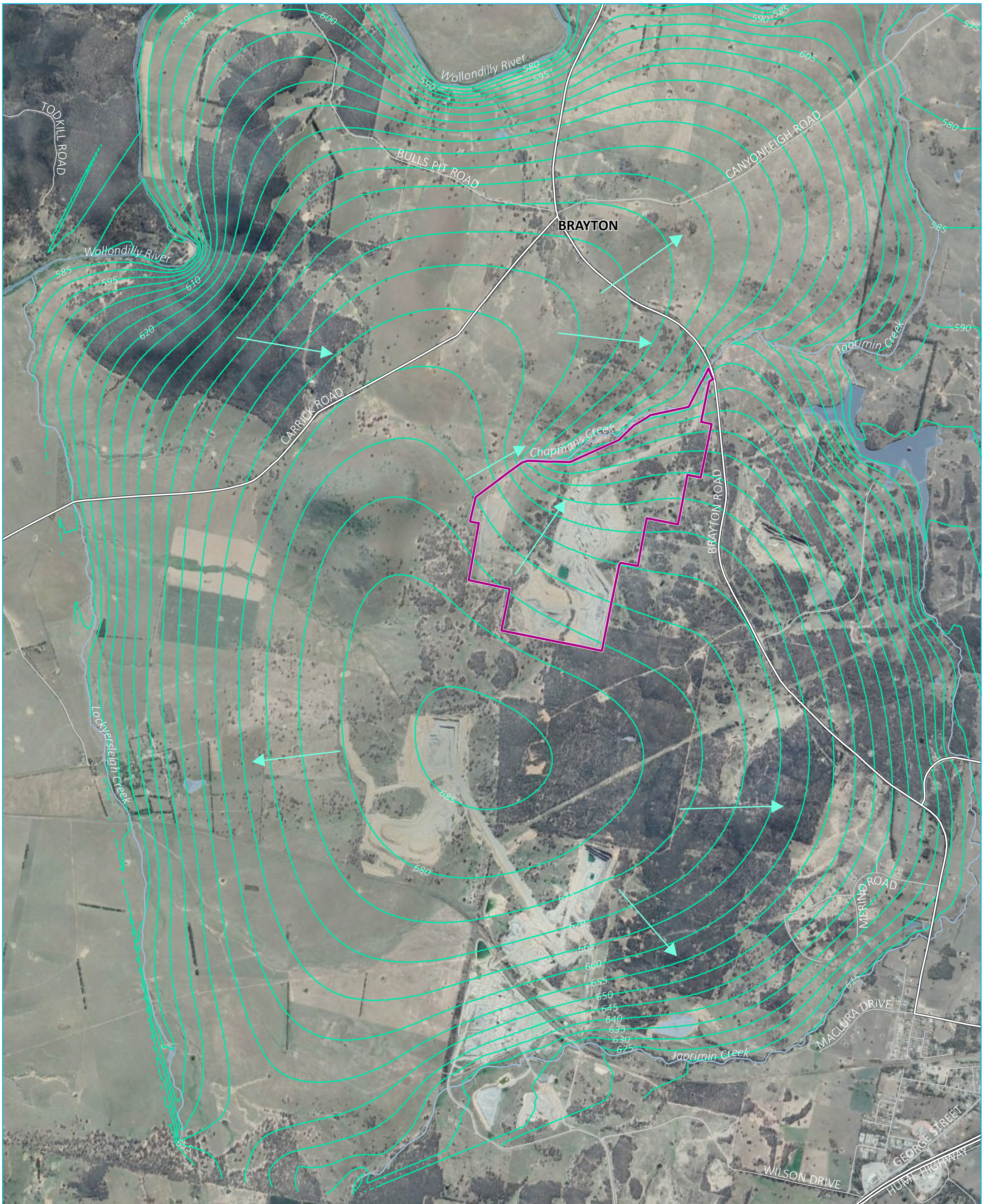
6.5.2 Drawdown

Modelled watertable elevation contours are presented prior to and at the cessation of quarrying in Figure 6.4 and Figure 6.5 respectively, and drawdown contours representing the simulated drawdown at the end of quarrying are presented in Figure 6.6.

Prior to quarrying (in 2007), the groundwater model simulates groundwater flow from the south of the site towards Chapmans Creek, with the primary source of groundwater being rainfall-derived recharge and discharge at surface water features (Chapmans Creek and the features representing the edges of the model domain). Following planned cessation of quarrying in 2052, and owing to the low permeability of surrounding materials, a steep watertable gradient is simulated around the edges of the Quarry. Groundwater elevation at the Quarry is predicted to reduce by over 100 m, resulting in a reversal of groundwater gradient to approximately 400 m north of the active quarry base.

At the end of quarrying, modelled drawdown of 2 m is predicted to extend approximately 1.3 km to the south-west of the site (Figure 7.1). Towards the north, the 2 m drawdown contour does not reach Chapmans Creek. None of the landowner bores are predicted to be impacted by the 2 m drawdown at the end of quarrying.

This is less that the predicted maximum extent the 2 m drawdown predicted for the Extension Project due to refinements in the model and the collection of additional groundwater monitoring data.



\\emmsvr1\EMM\Jobs\2019\J190263 - Gunlake Quarry SSD MOD2\GIS\02_Maps_Groundwater\GW007_PreQuarryGroundwater_20210906_07.mxd 6/09/2021

Source: EMM (2021); Google Earth (2019); DFSI (2017); GA (2011)

0 1 2 km

GDA 1994 MGA Zone 55

N

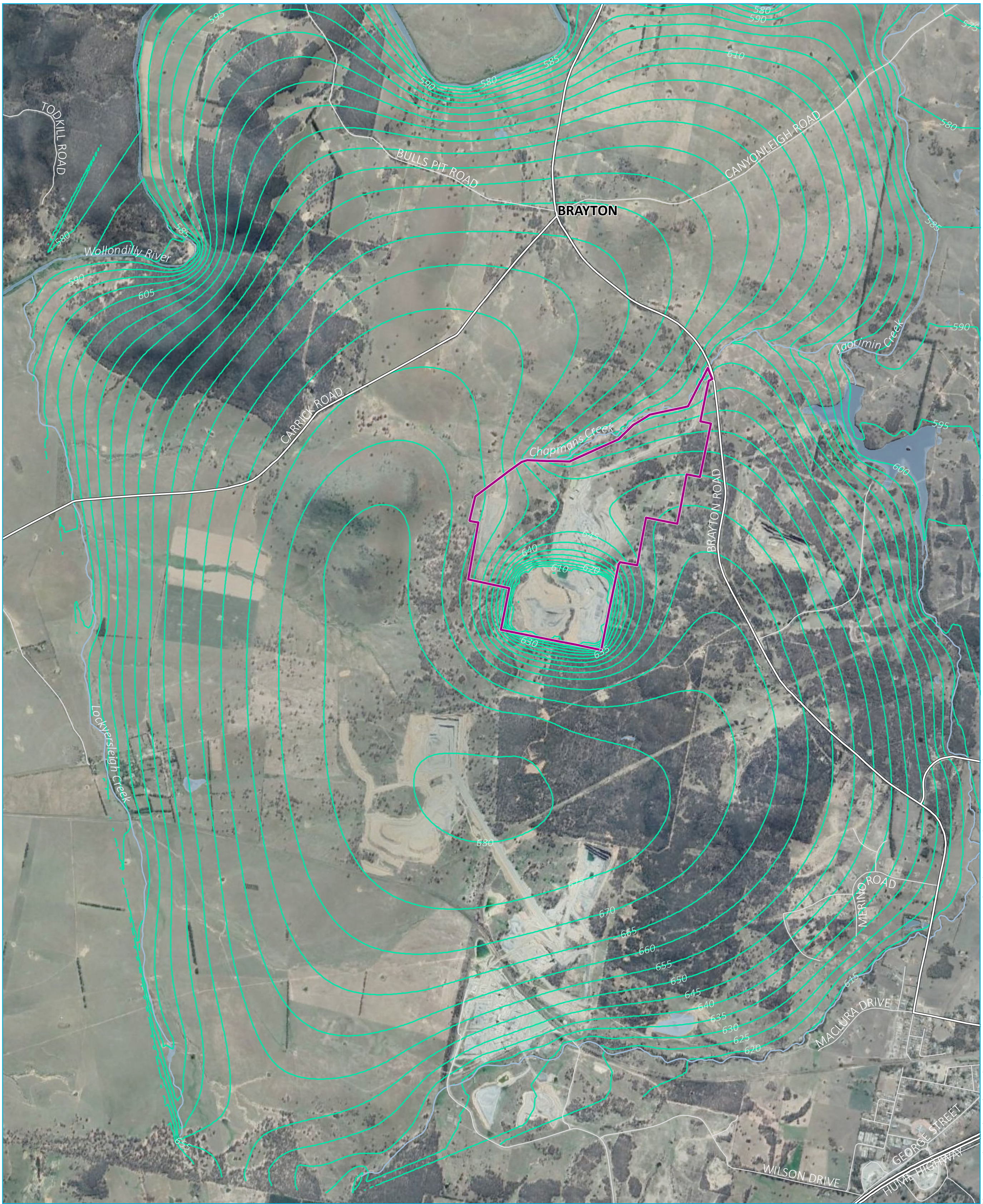
KEY

- Site boundary
- Major road
- Minor road
- Named watercourse
- Groundwater flow direction
- Groundwater surface elevation 2007 (mAHD)

Modelled pre-quarrying watertable elevation (2007)

Gunlake Quarry Continuation Project
Groundwater assessment
Figure 6.4

EMM
creating opportunities



Source: EMM (2021); Google Earth (2019); DFSI (2017); GA (2011)

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0 1 2 km
GDA 1994 MGA Zone 55
N

KEY

- Site boundary
- Major road
- Minor road
- Named watercourse
- Groundwater surface elevation post-quarrying (mAHD)

Modelled watertable elevation at end of quarrying (January 2052)

Gunlake Quarry Continuation Project
Groundwater assessment
Figure 6.5

EMM
creating opportunities

Source: EMM (2021); Google Earth (2019); DFSI (2017); GA (2011)

KEY

- Site boundary
- Major road
- Minor road
- Named watercourse

Modelled drawdown at 2052

- 2 m
- 4 m
- 10 m
- 20 m
- 30 m
- 50 m

Modelled watertable drawdown at end of quarrying (January 2052)

Gunlake Quarry Continuation Project
Groundwater assessment
Figure 6.6

EMM
creating opportunities

Temporal modelled drawdown at nearby landowner water bores are presented as hydrographs in Figure 6.7. The maximum impact threshold of 2 m defined by the AIP is presented for reference. None of the bores are predicted to experience drawdown greater than 1.5 m over the life of the quarry or post-quarrying.

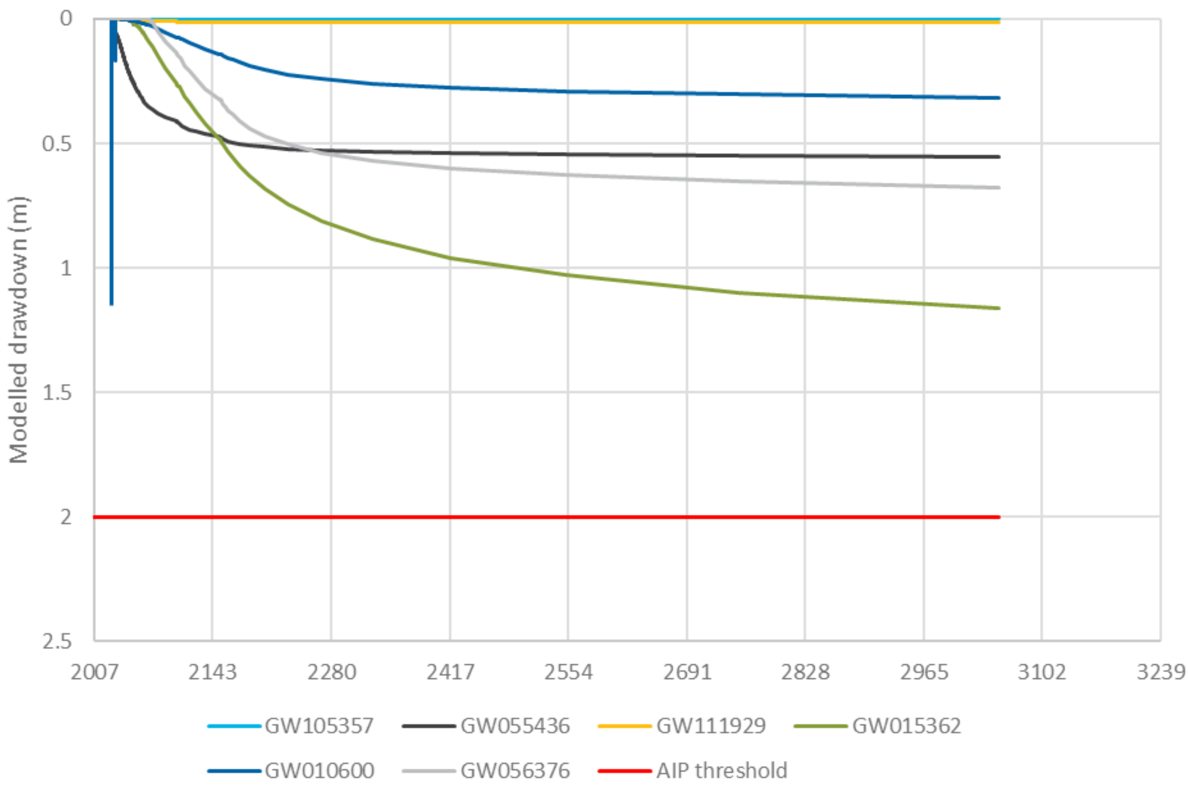

Figure 6.7 Landowner bore modelled drawdown hydrographs

7 Groundwater impact assessment

7.1 Potential impacts

The potential for interception and dewatering of groundwater at the Quarry has to impact the following matters has been assessed:

- groundwater levels and/or pressures, and therefore the availability of the groundwater resource;
- local and regional groundwater flow directions; and
- the chemical composition (quality) of the groundwater resource.

The potentially sensitive groundwater receptors considered in this groundwater assessment include identified seeps, registered landholder bores, Box Gum Woodlands and local watercourses with groundwater baseflows.

7.1.1 Minimal impact considerations for porous and fractured rock sources

As described in Section 3.2, the minimal impact considerations for a groundwater impact assessment are defined within the AIP (NOW 2012). The fractured rock groundwater resource is classified as 'less productive' with measured yields of less than 5 L/s (see Table 4.2) and marginal water quality (see Section 5.3).

The minimal considerations for porous and fractured rock units of less productive groundwater systems are adopted for this assessment. Thresholds for key minimal impact considerations for 'less productive' groundwater sources have been developed and deal with water table and groundwater pressure drawdown as well as groundwater and surface water quality changes (Section 5.3).

7.2 Predicted impacts

7.2.1 Groundwater level

The pre-quarrying water level is shown in Figure 6.4. A cone of depressurisation (drawdown) will form around the pit following the interception of the watertable. The minimal impact considerations define a drawdown (water level or pressure) of 2 m at a registered landowner bore as a significant impact requiring mitigation (Table 3.1). Modelling predicted the 2 m drawdown impact will extend up to 1.3 km from the edge of the pit footprint, but 2 m drawdowns are not predicted at any landholder bores.

i Chapmans Creek and alluvium/colluvium

Under natural conditions, following sustained rainfall Chapmans Creek gains baseflow from the adjacent alluvium/colluvium/weathered fractured rock. The rate is governed by the hydraulic conductivity of the strata underlying the creek. The Continuation Project will not impact on the hydraulic conductivity of strata outside of the pit and will not remove any alluvium/colluvium/weathered rock in the vicinity of the creek. Groundwater dewatering for quarry development is predicted to intercept some baseflow that would have discharged into this ephemeral watercourse. However, given that discharge from seeps is not resulting in perennial flow, any reduction in groundwater discharge is unlikely to significantly impact the watercourse flow regimes.

7.2.2 Groundwater-dependent ecosystems

The potential for groundwater drawdown to impact GDEs is considered in detail in *the Continuation Project* BDAR) (EMM 2021b, EIS Appendix F.7).

Analysis of the distribution of PCTs in relation to the regional groundwater levels indicate that PCT 1256 has a 'Facultative – proportional' groundwater dependency. Facultative association is used to describe an ecosystem that is not entirely dependent on groundwater and may rely on groundwater on a seasonal basis or only during extended drought periods. At other times, water requirements may be met by soil or surface water. Within the regional vegetation datasets, this PCT is mapped south of the Quarry. The PCT was classified as having a facultative-proportional reliance on groundwater because of the uncertainty in regional vegetation datasets, and the inherent uncertainty in the groundwater mapping.

It was determined that PCT 1330 has a 'Facultative – opportunistic' groundwater dependency. PCTs which are considered facultative – opportunistic are not considered to wholly depend on groundwater for survival; however, they are likely to use groundwater opportunistically to survive where surface water sources are absent or low, particularly during times of drought.

Small portions of PCT 1256 and PCT 1330 are predicted to be impacted at a local scale by groundwater drawdown (Figure 7.2). However, the prescribed impacts to GDEs arising from the Continuation Project are predicted to be minor in both extent and/or nature and represent a low risk of impact to GDEs.

Source: EMM (2021); Google Earth (2019); DFSI (2017); GA (2011)

0 1 2 km
GDA 1994 MGA Zone 55
N

\\emmsvr1\EMM\Jobs\2019\J190263 - Gunlake Quarry SSD MOD2\GIS\02_Maps_Groundwater\GW011_Receptors&PredictedDrawdown_20210906_06.mxd 6/09/2021

KEY

- Site boundary
- Major road
- Minor road
- Named watercourse
- Waterbody
- Groundwater seep
- Groundwater bore

Modelled drawdown at 2052

- 2 m
- 4 m
- 10 m
- 20 m
- 30 m
- 50 m

Groundwater receptors and predicted drawdown

Gunlake Quarry Continuation Project
Groundwater assessment
Figure 7.1

EMM
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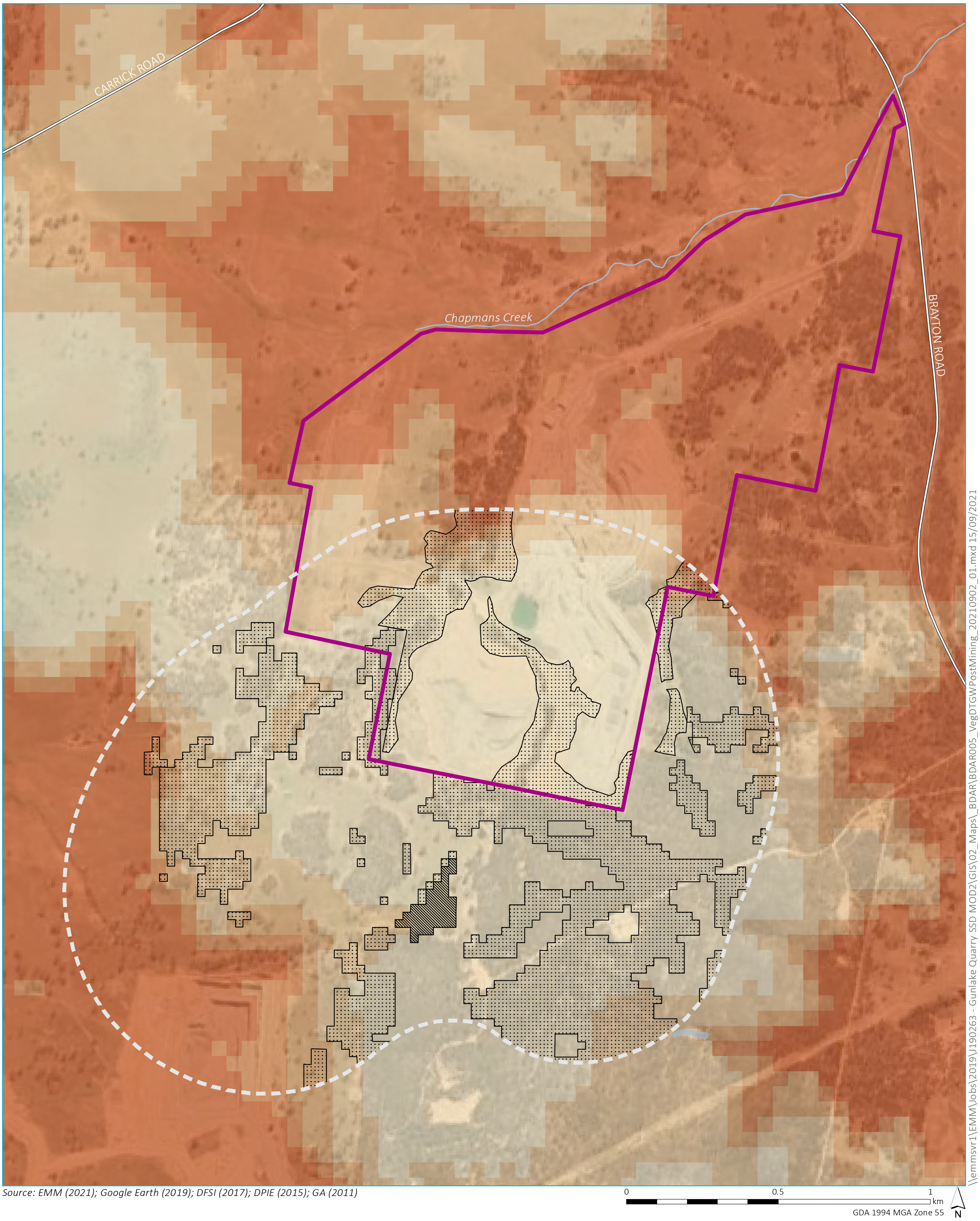

Source: EMM (2021); Google Earth (2019); DFSI (2017); DPIE (2015); GA (2011)

KEY

- Site boundary
- Prescribed impact area
- Major road
- Named watercourse
- Waterbody

Groundwater dependent ecosystem

- 1256 | Tableland swamp meadow on impeded drainage sites of the western Sydney Basin Bioregion and South Eastern Highlands Bioregion
- 1330 | Yellow Box - Blakely's Red Gum grassy woodland on the tablelands, South Eastern Highlands

Depth to groundwater (post-mining)

- < 2 mbgl
- 2 - 5 mbgl
- 5 - 10 mbgl
- 10 - 20 mbgl
- > 20 mbgl

Groundwater drawdown and GDEs

Gunlake Quarry Continuation Project
Groundwater assessment
Figure 7.2

EMM
creating opportunities

7.2.3 Groundwater flows

As extraction progresses below the water table, a hydraulic gradient will be created directing groundwater flow towards the depressurised strata and into the pit (groundwater inflow). The pore pressure behind the pit walls will reduce causing the formation to deform and expand slightly (pore pressure unloading). This leads to an expansion of the pore space and a reduction in pore pressure within the zone of relaxation (Read and Stacey 2009).

The maximum predicted groundwater inflow is 68 ML/year. The inflow rates are consistent with the low hydraulic conductivities of the intercepted strata combined with the effect of pore pressure unloading.

The predicted pit inflows comprise the entire groundwater take for the Continuation Project. The maximum annual take of 68 ML is well within the unallocated share volume for the Goulburn Fractured Rock Groundwater Source licence pool (46,809 ML/year, Section 3.1.1).

Groundwater inflows and captured surface water will be stored and/or re-used onsite during the Continuation Project (EMM 2021a, EIS Appendix F).

7.2.4 Final void

Following the completion of quarrying operations dewatering will be discontinued. The final void will continue to receive runoff from direct rainfall and a relatively small contribution from groundwater inflows. Water loss from the void will occur solely through evaporation.

Initially, water inputs are predicted to exceed outputs resulting in the gradual formation of a pit lake. The pit lake will gradually rise with equilibrium predicted to occur 60 to 70 years after the completion of quarrying at an elevation of 599 to 609 mAHD (EMM 2021a, EIS Appendix F).

The elevation of the pit lake will remain below the pre-quarrying groundwater level and consequently, the final landform will form a perpetual evaporative sink. Groundwater levels in the surrounding strata will partially recover however, a permanent depression will remain around the final void (Figure 6.6). Over time, as the surrounding strata dewaters the groundwater inflow rate will decline. The final void will contain all captured surface water and groundwater following the completion of the Continuation Project. The final landform will not discharge to the surrounding environment.

7.2.5 Water quality

Groundwater seepage to the pit is expected to have similar water quality to the established baseline groundwater quality data (Section 5.3). Quarrying will not impact groundwater quality.

With no groundwater discharge to the surrounding environment (see Section 7.2.3), the potential risks to the quality of groundwater and surface water resources are considered low.

The final landform will create an inward hydraulic gradient preventing the discharge of water from the pit into the fractured rock groundwater source. Salinities within the pit may increase slightly over time, however because of the inward gradient there is negligible risk to groundwater in the regional fractured rock or adjacent surface water features. There will be a neutral impact on the beneficial use class of the groundwater source (ie stock).

7.2.6 Cumulative impacts

There is potential for cumulative impacts from simultaneous extraction at the Continuation Project and the adjacent Holcim Lynwood Quarry. Groundwater drawdown from the two quarries may create enhanced drawdown in the area between the adjacent operations. However Scientific Systems report the groundwater drawdown from the nearest quarry does not propagate outside the granite pit quarry (Scientific Systems 2015). There are no groundwater receptors between the two quarries and therefore no cumulative impacts are predicted.

Each operation will licence their predictive groundwater take from within the *Groundwater WSP* license pool. Gunlake Quarry and Lynwood Quarries have a predicted combined take of up to 95 ML/year. There are 46,809 unit shares (ML/year) of unassigned water within the *Groundwater WSP* and therefore there is sufficient volume available within the market or from controlled allocations for the two operations.

8 Management and monitoring

8.1 Groundwater management and mitigation

Gunlake have an approved *Gunlake Quarry Soil and Water Management Plan* (Gunlake 2020) detailing groundwater management for the existing operations. The quarterly groundwater quality and level monitoring program facilitates the early identification of adverse impacts and allows model predictions to be tested.

The objectives of the *Soil and Water Management Plan* are to:

- Implement the commitments made in the 2016 Gunlake Extension Project EIS including specific conditions of Development Consent and the revised Statement of Commitments.
- Ensure compliance with relevant environmental legislation.
- Manage environmental risks associated with the Gunlake Quarry.
- Provide for continuous improvement in environmental performance.
- Provide a mechanism to identify and correct areas of non-compliance (Gunlake 2020).

The *Soil and Water Management Plan* will be reviewed and updated if the Continuation Project is approved.

Groundwater levels will continue to be monitored and data will be reported annually. Groundwater quality monitoring will also continue quarterly.

8.2 The groundwater trigger action response plan

The *Gunlake Quarry Soil and Water Management Plan* will continue to be applied, with revisions if required.

8.3 Groundwater licence requirement

Gunlake are required to hold water access licences for the predicted groundwater take over the lifespan of Continuation Project. Gunlake currently hold a licence for 37 ML/year allocation. A peak groundwater take of 68 ML/year is predicted for the Continuation Project, constituting 0.002% of the 46,809 unit shares (ML/year) of unassigned water within the Groundwater WSP. Gunlake is proposing to purchase an additional 31 ML/year allocation, likely via a controlled allocation order although this could also be sourced via a market trade. The 2019/2020 controlled allocation order released 1,868 units in the Goulburn Fractured Rock Groundwater Source.

9 Conclusions

The Continuation Project pit will intercept the underlying fractured rock, groundwater resource. A detailed groundwater assessment has established the baseline hydrogeological conditions and identified the potential groundwater impacts.

Groundwater flow is generally towards the north-east across the Quarry site and is associated with structural discontinuities in the fractured bedrock. Local groundwater discharges occurs at nine discrete seeps associated with sub-vertical geological discontinuities in the area. Rainfall infiltration recharges the groundwater system.

The fractured rock groundwater system is classified as 'less productive' water resource according to the AIP criteria. The hard rock strata has a low hydraulic conductivity, reported yields of less than 5 L/s, and salinities mostly in excess of 1,500 mg/L total dissolved solids. The groundwater quality is suitable for stock purposes, owing to slightly brackish salinity, and several dissolved metal and nutrient concentrations are above default guideline values for the protection of aquatic ecosystems.

An analytic element groundwater flow model was used to predict the potential groundwater impacts from the Continuation Project.

9.1 Potential impacts summary

Groundwater impacts were predicted to be minor and locally confined to around the quarry pit.

Groundwater inflows to the pit of up to 68 ML/year are predicted and licensing of these inflows is required from either market trading or obtaining a new licence from unallocated water in the *Groundwater WSP* under the WM Act. There is sufficient water volume within the market or within the next controlled allocation order to allow the required WAL (or WALs) to be obtained.

A drawdown of 2 m is predicted to extend up to 1.3 km from the edge of the pit, primarily to the south, at the end of the Continuation Project. There are no impacts predicted at nearby landholder bores and there are no high priority groundwater dependent ecosystems in the project vicinity in accordance with the minimal impact considerations under the NSW AIP (DPI 2012).

With no groundwater discharge to the surrounding environment, the potential risks to the groundwater quality of and surface water resources are considered low.

The final landform will create an inward hydraulic gradient preventing the discharge of water from the pit into the fractured rock groundwater source. Salinities within the pit may increase slightly over time, however because of the inward gradient there is negligible risk to groundwater in the regional fractured rock or adjacent surface water features. There will be a neutral impact on the beneficial use class of the groundwater source (ie stock).

No cumulative groundwater impacts are predicted.

9.2 Recommendations

The following actions are recommended to be instigated following approval of the Continuation Project:

- groundwater level and quality monitoring program continues; and
- measured groundwater levels are periodically compared to staged drawdown predictions to validate predictions.

Given that discharges from seeps are not significant, in that they do not contribute to surface water flow and are not a significant consideration in determining potential impacts to terrestrial GDEs, it is recommended that the seep monitoring program is scaled back to only monitor seep 7 – the only seep in where a drawdown of >2 m is predicted (see Figure 7.1).

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Annexure A

Groundwater quality results

Analyte	LOR	Unit	Australian drinking water guideline		ANZECC/ARMCANZ (2000) guideline for 95% protection of freshwater species									
			Health	Aesthetic										
Date						18/12/14	19/01/15	20/02/15	21/04/15	15/05/15	15/05/15	23/06/15	21/04/15	15/5/1915
Sampling method						Bailer	Bailer	Bailer	Pump	Pump	double check	double check		
Field parameters														
pH	0.01		ID	6.5-8.5	6.5-7.5*	**6.46**	**6.31**	**5.8**	**6.15**	6.5	**8.98**	**6.36**	**6.15**	6.5
Electrical Conductivity @ 25°C	0.1	µS/cm	-	-	125-2200	119	119	195	231	190	230.7	194	231	190
Dissolved oxygen	0.1	mg/L	-	-	-						15.87			
Oxidation reduction potential	0.1	mV	-	-	-						39.9			
Laboratory results														
Total dissolved solids	5	mg/L	-	600	ID	388	264	190	920	167		126	920	167
Alkalinity														
Hardness	1	mg/L	-	200	-	18	31	30	28	28		69	28	28
Bicarbonate Alkalinity as CaCO3	1	mg/L	-	-	-	26.6	12.7	14.3	154	35.8		39	154	35.8
Carbonate Alkalinity as CaCO3	1	mg/L	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1		<1	<0.1	<0.1
Hydroxide alkalinity	1	mg/L	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1		<1	<0.1	<0.1
Total alkalinity	1	mg/L	-	-	-	27	13	14	154	36		39	154	36
Cations & anions														
Chloride	1	mg/L	ID	250	-	14.7	24.2	22.8	24.7	10.2		24	24.7	10.2
Sulfate	1	mg/L	ID	250	-	4.2	12.7	16.7	26.6	16.3		10	26.6	16.3
Calcium	1	mg/L	-	-	-	2.73	3.54	3.75	4.1	3.5		11	4.1	3.5
Magnesium	1	mg/L	-	-	-	2.66	5.31	5.06	4.22	4.68		10	4.22	4.68
Potassium	1	mg/L	-	-	-	2.7	3.6	3.6	4.3	3.4		3	4.3	3.4
Sodium	1	mg/L	-	180	-	13.8	23.4	21.7	22.4	24.1		26	22.4	24.1
Total metals														
Arsenic	1	µg/L	10	-	24	5	<1	<5	0.0024	<0.0001		0.0001	24	<1
Cadmium	0.2	µg/L	2	-	0.2	<0.05	<0.05	0.1	0.00024	0.00009		<0.0001	2.3	0.09
Chromium	1	µg/L	5	-	ID	46	3	3	0.215	0.0002		0.0002	215	2
Copper	1.4	µg/L	2000	1000	1.4	89	9	9	0.109	0.0004		0.0004	109	4
Lead	1	µg/L	10	-	3.4	293	**22.2**	**27.9**	1.19	0.0014		0.0006	**1190**	**14.6**
Mercury	0.1	µg/L	1	-	0.6	0.1	<0.1	<0.1	0.00004	<0.000001		0.000001	0.4	<0.1
Nickel	1	µg/L	20	-	11	**64**	9	11	0.327	0.216		0.035	**327**	**216**
Zinc	1	µg/L	ID	3000	8	291	29	34	1.05	0.027		0.018	1050	27
Selenium	0.01	mg/L	10	-	11							<0.01		
Fluoride	0.1	mg/L	1500	-	-							0.2		
Iron (dissolved)	0.01	mg/L	-	-	-	0.64	0.27	0.45	0.82	0.09		0.11	0.82	0.09
Iron	1	mg/L	ID	300	ID	24.3	1.15	2.09	198	1.95		0.91	198	1.95
Nutrients														
Ammonia as N	0.1	mg/L	ID	0.5	0.013*	0.1	0.1	<0.1	**1.1**	<0.1		0.05	**1.1**	<0.1
Nitrite as N	0.01	mg/L	3	-	0.015*	<0.01	0.02	<0.01	0.05	<0.01		<0.01	0.05	<0.01
Nitrate as N	0.05	mg/L	50	-	0.015*	<0.05	6.26	4.73	2.13	4.19		1.06	2.13	4.19
Total Phosphorus as P	0.01	mg/L	-	-	0.02*	0.49	0.05	0.07	1.89	0.05		0.12	1.89	0.05
Reactive Phosphorous	0.02	mg/L	-	-	-	0.02	<0.02	<0.02	<0.02	0.02		<0.01	<0.02	0.02

Analyte																						
Date	23/06/15	20/08/15	28/09/15	24/11/15	13/01/16	27/06/16	27/12/16	29/06/17	22/01/18	21/6/18	25/09/18	20/12/18	02/04/19	:02/7/19	26/09/19	10/12/19	10/03/20	09/06/20	1/09/2020	15/12/2020	16/03/2021	15/06/2021
Sampling method																						
Field parameters																						
pH	**6.36**	6.52	6.61	6.81	6.88	**6.34**	**6.42**	6.68	7	6.62	6.84	6.97	7.21	6.83	6.99	7.01	**6.43**	6.75	6.98	6.5	7.0	**6.34**
Electrical Conductivity @ 25°C	194	196	144	203	224	154	236	285	254	205	254	176	201	230	281	294	289	280	206	224	239.0	165
Dissolved oxygen																						
Oxidation reduction potential																						
Laboratory results																						
Total dissolved solids	126	127	94	132	146	100	153	185	165	133	165	114	131	150	183		188	182	134	146	155	107
Alkalinity																						
Hardness	69	37	37	40	64	37	55	60	58	42	58	49	55	62	71	80	55	62	40	36	49	33
Bicarbonate Alkalinity as CaCO3	39	35	45	<1	71	34	30	63	81	67	90	60	66	79	88	93	42	67	33	47	56	38
Carbonate Alkalinity as CaCO3	<1	<1	<1	56	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Hydroxide alkalinity	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total alkalinity	39	35	45	56	71	34	30	63	81	67	90	60	66	79	88	93	42	67	33	47	56	38
Cations & anions																						
Chloride	24	19	18	18	24	16	29	32	30	18	24	20	20	24	30	35	32	34	42	39	37	23
Sulfate	10	11	5	6	5	7	4	4	8	13	<5	<1	1	2	<1	<1	6	6	3	7	3	5
Calcium	11	5	5	6	9	5	9	9	10	7	10	8	9	10	12	14	9	10	6	6	8	5
Magnesium	10	6	6	6	10	6	8	9	9	6	8	7	8	9	10	11	8	9	6	5	7	5
Potassium	3	3	3	4	5	3	4	5	4	3	3	5	4	4	4	4	5	29	4	3	4	4
Sodium	26	21	18	16	22	18	23	26	24	21	24	21	22	24	25	28	28	5	30	26	27	22
Total metals																						
Arsenic	0.001	<0.001	<0.001	0.002	0.002	0.001	<0.001	0.001	0.003	0.002	0.003	0.002	0.002	0.002	0.001	0.002	0.001	<0.001	<0.001	0.002	0.002	<0.0001
Cadmium	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.0003	0.0002	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	0.0001	<0.0001	0.0001	0.0004	0.0001
Chromium	0.002	<0.001	0.002	0.001	0.002	0.002	0.003	0.004	0.006	0.01	0.003	0.002	0.003	0.003	0.003	0.003	0.007	0.003	0.003	0.007	0.005	0.009
Copper	0.004	0.008	0.004	0.009	0.012	0.008	0.012	0.011	0.007	0.016	0.007	0.011	0.006	0.007	0.005	0.004	0.023	0.006	0.006	0.005	0.005	0.009
Lead	0.006	0.006	0.006	0.007	0.008	0.002	0.006	0.006	0.03	0.037	0.012	0.007	0.009	0.008	0.004	0.005	0.023	0.011	0.002	0.025	0.024	0.006
Mercury	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	0.035	0.036	0.031	0.047	0.041	0.009	0.01	0.017	0.019	0.019	0.022	0.012	0.015	0.016	0.014	0.014	0.011	0.012	0.032	0.01	0.019	0.008
Zinc	0.018	0.017	0.018	0.023	0.037	0.013	0.021	0.029	0.046	0.046	0.006	0.047	0.029	0.038	0.012	0.012	0.047	0.017	0.03	0.026	0.03	0.013
Selenium																						
Fluoride																						
Iron (dissolved)	0.11	0.09	0.12	0.24	0.34	0.3	0.06	0.11	1.34	1.01	1.09	0.26	1.94	2.61	0.58	2	0.1	0.07	<0.05	0.15	1.73	0.12
Iron	0.91	0.8	1	0.58	1.4	0.68	1.14	0.11	5.88	6.2	3.85	1.79	4.55	4.91	2.65	5.28	3.72	1.64	0.51	3.71	4.24	0.54
Nutrients																						
Ammonia as N	0.05	0.03	0.018	**1.9**	0.42	<0.01	0.06	0.02	0.12	0.21	0.17	**0.6**	**0.67**	**0.61**	0.45	0.38	0.11	<0.01	<0.01	0.02	0.06	<0.01
Nitrite as N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.26	0.02	0.02	<0.01	0.01	0.02	<0.01	<0.01	0.15	<0.01	0.03	<0.01	<0.01	<0.01	<0.01
Nitrate as N	1.06	1.42	0.92	0.09	0.49	2.26	7.78	2.26	0.36	0.62	0.33	0.57	0.13	0.3	0.11	0.15	7.27	2.07	0.16	0.2	0.14	0.5
Total Phosphorus as P	0.11	0.06	0.08	0.3	0.1	0.05	0.06	0.06	0.25	0.32	0.11	0.21	0.25	0.08	0.04	0.04	0.09	0.1	0.06	0.18	0.2	0.09
Reactive Phosphorous	<0.01	<0.01	<0.01	0.17	<0.01	0.01	<0.01	0.02	0.01	<0.01	<0.01	0.09	0.07	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Drinking water guideline

ANZECC 2000 guidelines - 95% protection for freshwater species

Bold - both guideline velaues exceeded

* = guideline value for upland/lowland rivers

ID = insifficent data to create value

Analyte	LOR	Unit	Australian drinking water guideline		ANZECC/ARMCANZ (2000) guideline for 95% protection of freshwater species											
			Health	Aesthetic												
Date						18/12/14	19/01/15	20/02/15	21/04/15	15/05/15	15/05/15	23/06/15	21/04/15	15/05/15	23/06/15	20/08/15
Sampling method						Bailer	Bailer	Bailer	Pump	Pump	double check	double check				
Field parameters																
pH	0.01		ID	6.5-8.5	6.5-7.5*	7.3	7.87	7.79	7.3	7.34	7.71	7.14	7.3	7.34	7.14	7.44
Electrical Conductivity @ 25°C	0.1	µS/cm	-	-	125-2200	1120	1220	1240	6080	5630	5032	5880	6080	5630	5880	3880
Dissolved oxygen	0.1	mg/L	-	-	-						12.75					
Oxidation reduction potential	0.1	mV	-	-	-						-77.4					
Laboratory results																
Total dissolved solids	5	mg/L	-	600	ID	644	710	729	4170	3850		3820	4170	3850	3820	2520
Alkalinity																
Hardness	1	mg/L	-	200	-	215	241	230	1870	1660		1900	1870	1660	1900	1120
Bicarbonate Alkalinity as CaCO3	1	mg/L	-	-	-	468	524	532	622	702		730	622	702	730	521
Carbonate Alkalinity as CaCO3	1	mg/L	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1		<1	<0.1	<0.1	<1	<1
Hydroxide alkalinity	1	mg/L	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1		<1	<0.1	<0.1	<1	<1
Total alkalinity	1	mg/L	-	-	-	468	524	532	622	702		730	622	702	730	521
Cations & anions																
Chloride	1	mg/L	ID	250	-	74.3	83.2	83.8	1800	1620		1520	1800	1620	1520	699
Sulfate	1	mg/L	ID	250	-	13.4	13.7	13.5	23.3	24		22	23.3	24	22	19
Calcium	1	mg/L	-	-	-	32.8	37.1	34.5	251	234		273	251	234	273	164
Magnesium	1	mg/L	-	-	-	32.3	36.1	35	302	260		297	302	260	297	172
Potassium	1	mg/L	-	-	-	12.2	13.5	13.2	27	26.4		21	27	26.4	21	17
Sodium	1	mg/L	-	180	-	166	168	171	480	484		501	480	484	501	331
Total metals																
Arsenic	1	µg/L	10	-	24	4	3	3	0.001	0.0007		0.001	10	7	0.001	<0.001
Cadmium	0.2	µg/L	2	-	0.2	<0.05	<0.05	<0.05	0.00025	0.00024		<0.0001	0.25	0.24	<0.0001	<0.0001
Chromium	1	µg/L	5	-	ID	4	2	<2	0.0004	0.0003		0.0002	4	3	0.002	<0.001
Copper	1.4	µg/L	2000	1000	1.4	10	5	6	0.0003	0.0008		0.0004	3	8	0.004	0.003
Lead	1	µg/L	10	-	3.4	5.4	2	2.4	0.00013	0.0003		0.0003	1.3	3	0.003	<0.001
Mercury	0.1	µg/L	1	-	0.6	<0.1	<0.1	<0.1	<0.00001	<0.00001		<0.00001	<0.1	<0.1	<0.0001	<0.0001
Nickel	1	µg/L	20	-	11	10	9	10	0.0021	0.002		0.0014	21	20	0.014	0.006
Zinc	1	µg/L	ID	3000	8	54	20	33	0.0076	0.017		0.0037	76	170	0.037	0.014
Selenium	0.01	mg/L	10	-	11							<0.01				
Fluoride	0.1	mg/L	1500	-	-							0.5				
Iron (dissolved)	0.01	mg/L	-	-	-	<0.01	<0.01	<0.01	<0.1	<0.01		<0.05	<0.01	<0.01	<0.05	0.3
Iron	1	mg/L	ID	300	ID	1.3	0.5	0.58	0.4	1.53		1.32	0.4	1.53	1.32	0.49
Nutrients																
Ammonia as N	0.1	mg/L	ID	0.5	0.013*	0.5	0.2	<0.1	<0.1	<0.1		0.01	<0.1	<0.1	0.01	0.03
Nitrite as N	0.01	mg/L	3	-	0.015*	0.01	<0.01	<0.01	0.35	<0.01		<0.01	0.35	<0.1	<0.01	<0.01
Nitrate as N	0.05	mg/L	50	-	0.015*	2.09	1.19	1.46	3.32	0.76		<0.01	3.32	0.76	<0.01	<0.01
Total Phosphorus as P	0.01	mg/L	-	-	0.02*	0.3	0.07	0.07	0.02	0.02		0.04	0.02	0.02	0.04	0.01
Reactive Phosphorous	0.02	mg/L	-	-	-	0.14	0.06	0.04	<0.02	0.02		<0.01	<0.02	0.02	<0.01	<0.01

Analyte										
Date	28/09/15	24/11/15	03/01/16	27/06/16	27/12/16	29/06/17	22/01/18	21/06/18	25/09/18	20/12/18
Sampling method										
Field parameters										
pH	7.66	7.75	7.84	7.35	7.49	7.37	7.72	7.06	7.29	7.33
Electrical Conductivity @ 25°C	379	535	650	359	524	665	912	3230	1640	2380
Dissolved oxygen										
Oxidation reduction potential										
Laboratory results										
Total dissolved solids	246	348	422	233	341	432	593	2100	1070	1550
Alkalinity										
Hardness	118	156	198	112	181	218	257	962	548	763
Bicarbonate Alkalinity as CaCO3	148	<1	247	140	234	224	257	383	282	292
Carbonate Alkalinity as CaCO3	<1	188	<1	<1	<1	<1	<1	<1	<1	<1
Hydroxide alkalinity	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total alkalinity	148	188	247	140	234	224	257	383	282	292
Cations & anions										
Chloride	28	38	55	21	22	68	132	800	384	582
Sulfate	6	8	7	11	9	7	8	13	11	10
Calcium	21	28	33	22	38	43	45	174	104	144
Magnesium	16	21	28	14	21	27	33	128	70	98
Potassium	5	6	6	4	5	5	6	10	9	12
Sodium	39	50	67	38	45	53	59	186	120	165
Total metals										
Arsenic	0.001	0.001	<0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	0.001	<0.001	0.001	0.002	0.001	0.002	0.002	0.001	<0.001	0.001
Copper	0.005	0.01	0.014	0.01	0.008	0.018	0.005	0.008	0.008	0.015
Lead	0.002	<0.001	<0.001	0.004	0.001	<0.001	<0.001	0.002	<0.001	<0.001
Mercury	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	0.006	0.006	0.009	0.004	0.005	0.009	0.019	0.016	0.037	0.013
Zinc	0.026	0.036	0.036	0.027	0.015	0.028	0.008	0.02	0.006	0.093
Selenium										
Fluoride										
Iron (dissolved)	0.07	<0.05	0.05	0.07	0.13	0.05	0.19	0.22	0.05	0.06
Iron	0.56	0.17	0.15	1.62	0.46	0.05	0.22	0.62	0.1	0.06
Nutrients										
Ammonia as N	0.026	0.05	0.1	<0.01	0.1	0.03	0.09	0.06	0.06	0.1
Nitrite as N	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	0.02	<0.01
Nitrate as N	0.1	0.18	0.35	1.22	0.11	0.56	1	0.58	0.2	0.16
Total Phosphorus as P	0.1	0.06	0.01	0.07	0.02	0.01	0.02	<0.01	0.01	<0.01
Reactive Phosphorous	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01

Analyte										
Date	02/04/19	02/7/19	26/09/19	10/12/19	10/03/20	09/06/20	1/09/2020	15/12/2020	16/03/2021	15/06/2021
Sampling method										
Field parameters										
pH	7.64	7.07	7.52	7.32	7.11	7.08	7.5	7.4	7.6	7.22
Electrical Conductivity @ 25°C	2340	3700	2840	5040	1230	2400	618.0	4100.0	1700.0	454
Dissolved oxygen										
Oxidation reduction potential										
Laboratory results										
Total dissolved solids	1520	2400	1850	3280	800	1560	402	2660	1100	295
Alkalinity										
Hardness	672	1180	994	1770	371	763	175	1350	517	149
Bicarbonate Alkalinity as CaCO3	235	325	283	409	174	194	90	370	168	156
Carbonate Alkalinity as CaCO3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Hydroxide alkalinity	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total alkalinity	235	325	283	409	174	194	90	370	168	156
Cations & anions										
Chloride	545	937	844	1440	280	636	154	1040	424	43
Sulfate	11	12	10	15	7	8	6	15	9	10
Calcium	124	206	177	308	63	134	32	243	90	30
Magnesium	88	163	134	244	52	104	23	181	71	18
Potassium	10	14	12	17	7	152	4	11	6	7
Sodium	149	243	208	338	102	9	52	252	110	38
Total metals										
Arsenic	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	0.0003	<0.0001	0.0005	0.0004	<0.0001
Chromium	0.001	0.008	0.003	0.003	0.002	0.001	0.001	0.002	0.003	0.003
Copper	0.011	0.027	0.013	0.015	0.009	0.006	0.007	0.005	0.014	0.012
Lead	<0.001	0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.002	0.002	0.005
Mercury	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	0.014	0.032	0.018	0.013	0.004	0.005	0.003	0.038	0.011	0.006
Zinc	0.033	0.156	0.033	0.052	0.014	0.015	0.011	0.013	0.018	0.019
Selenium										
Fluoride										
Iron (dissolved)	0.11	0.54	0.33	0.32	<0.05	<0.05	<0.05	<0.05	<0.05	0.08
Iron	0.2	1.13	0.47	0.71	0.64	0.23	0.3	0.81	1.08	1.74
Nutrients										
Ammonia as N	0.04	0.25	0.17	0.22	0.1	0.98	<0.01	<0.01	0.02	0.01
Nitrite as N	<0.01	<0.01	<0.01	<0.01	0.5	0.03	<0.01	0.05	0.02	<0.01
Nitrate as N	0.26	0.06	0.14	0.15	14.2	15.2	1.46	0.99	1.39	0.05
Total Phosphorus as P	<0.01	0.03	0.01	0.01	0.01	<0.01	0.01	0.01	0.04	0.07
Reactive Phosphorous	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Drinking water guideline
ANZECC 2000 guidelines - 95% protection for freshwater species
Bold - both guideline velaues exceeded
* = guideline value for upland/lowland rivers
ID = insifficent data to create value

Analyte	LOR	Unit	Australian drinking water guideline		ANZECC/ARMCANZ (2000) guideline for 95% protection of freshwater species																				
			Health	Aesthetic																					
Date						18/12/14	19/01/15	20/02/15	21/04/15	15/05/15	15/05/15	23/06/15	21/04/15	15/05/15	23/06/15	20/08/15	28/09/15	24/11/15	13/01/16	27/06/16	27/12/16	29/06/17	22/01/18	21/06/18	25/09/18
Sampling method						Bailer	Bailer	Bailer	Pump	Pump	double check	double check													
Field parameters																									
pH	0.01		ID	6.5-8.5	6.5-7.5*	5.4	7.06	6.47	7.5	7.56	7.96	7.44	7.5	7.56	7.44	7.62	7.48	7.5	7.64	7.21	7.12	7.17	7.58	7.15	7.41
Electrical Conductivity @ 25°C	0.1	µS/cm	-	-	125-2200	35	52	61	3040	3100	2949	3060	3040	3100	3060	2970	2460	2440	2400	1710	1210	1230	1300	1240	1220
Dissolved oxygen	0.1	mg/L	-	-	-						13.64														
Oxidation reduction potential	0.1	mV	-	-	-						-21.1														
Laboratory results																									
Total dissolved solids	5	mg/L	-	600	ID	17	52	58	1830	1960		1990	1830	1960	1990	1930	1600	1590	1560	1110	786	800	845	806	793
Alkalinity																									
Hardness	1	mg/L	-	200	-	8	14	15	900	902		1070	900	902	1070	905	776	707	730	515	350	356	314	329	351
Bicarbonate Alkalinity as CaCO3	1	mg/L	-	-	-	12.3	16.4	19	412	417		436	412	417	436	374	313	<1	344	258	200	204	217	213	192
Carbonate Alkalinity as CaCO3	1	mg/L	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1		<1	<0.1	<0.1	<1	<1	<1	330	<1	<1	<1	<1	<1	<1	<1
Hydroxide alkalinity	1	mg/L	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1		<1	<0.1	<0.1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total alkalinity	1	mg/L	-	-	-	12	16	19	412	417		436	412	417	436	374	313	330	344	258	200	204	217	213	192
Cations & anions																									
Chloride	1	mg/L	ID	250	-	1.9	4.6	6.2	763	764		747	763	764	747	554	555	586	598	389	296	275	300	272	296
Sulfate	1	mg/L	ID	250	-	0.5	0.8	0.8	11.9	12.4		16	11.9	12.4	16	16	13	13	13	10	<10	<1	<10	10	1
Calcium	1	mg/L	-	-	-	2.43	3.37	3.48	134	138		161	134	138	161	138	118	115	111	81	61	60	57	56	58
Magnesium	1	mg/L	-	-	-	0.47	1.24	1.61	137	135		162	137	135	162	136	117	102	110	76	48	50	51	46	50
Potassium	1	mg/L	-	-	-	2.2	2.4	2.6	12.6	12.5		12	12.6	12.5	12	12	11	10	10	9	8	8	8	7	8
Sodium	1	mg/L	-	180	-	1.2	2.5	3.3	232	228		257	232	228	257	231	206	178	195	147	103	106	108	100	108
Total metals																									
Arsenic	1	µg/L	10	-	24	<1	<1	<1	0.0006	0.0005		0.0001	6	5	0.001	<0.001	<0.001	<0.001	0.001	0.003	0.003	0.001	<0.001	<0.001	<0.001
Cadmium	0.2	µg/L	2	-	0.2	<0.05	<0.05	<0.05	0.00007	0.00007		<0.000001	0.07	0.07	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	0.0003
Chromium	1	µg/L	5	-	ID	4	<2	<2	0.0003	<0.0002		0.0001	3	<2	<0.001	<0.001	0.002	<0.001	<0.001	0.002	0.003	0.005	0.003	0.001	0.001
Copper	1.4	µg/L	2000	1000	1.4	4	4	3	0.0005	0.0005		0.001	5	5	0.01	0.008	0.009	0.004	0.006	0.004	0.004	0.012	0.03	0.004	0.007
Lead	1	µg/L	10	-	3.4	2.4	1.4	1	0.00011	0.00009		<0.0001	1.1	0.9	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury	0.1	µg/L	1	-	0.6	<0.1	<0.1	<0.1	<0.00001	<0.00001		<0.00001	<0.1	<0.1	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	1	µg/L	20	-	11	3	**71**	**49**	0.0016	0.0016		0.0012	16	16	0.012	0.01	0.009	0.136	0.268	0.029	0.009	0.01	0.02	0.03	0.048
Zinc	1	µg/L	ID	3000	8	<5	33	27	0.0029	0.0033		0.0045	29	33	0.045	0.026	0.027	0.022	0.027	0.009	0.014	0.092	0.034	0.022	0.008
Selenium	0.01	mg/L	10	-	11							<0.01													
Fluoride	0.1	mg/L	1500	-	-							0.7													
Iron (dissolved)	0.01	mg/L	-	-	-	0.05	0.02	0.05	<0.01	<0.01		<0.05	<0.01	<0.01	<0.05	<0.05	<0.05	0.1	0.18	2.44	2.33	2.66	0.19	0.36	0.82
Iron	1	mg/L	ID	300	ID	2.24	0.36	0.58	1.02	0.81		0.22	1.02	0.81	0.22	0.51	0.67	0.5	0.96	2.73	2.95	2.66	1.93	0.92	1.18
Nutrients																									
Ammonia as N	0.1	mg/L	ID	0.5	0.013*	<0.1	<0.1	<0.1	0.2	0.2		0.07	0.2	0.2	0.07	0.04	0.027	<0.01	0.02	<0.01	0.03	0.09	0.02	0.02	0.07
Nitrite as N	0.01	mg/L	3	-	0.015*	<0.01	<0.01	<0.01	0.06	0.02		<0.01	0.06	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Nitrate as N	0.05	mg/L	50	-	0.015*	0.43	0.61	<0.05	0.65	0.69		0.46	0.65	0.69	0.46	0.86	0.24	0.27	0.35	0.04	0.02	0.07	0.06	0.03	0.07
Total Phosphorus as P	0.01	mg/L	-	-	0.02*	0.18	0.09	0.1	0.02	0.02		0.1	0.02	0.02	0.1	0.01	0.14	0.2	0.03	0.02	0.03	0.02	0.03	<0.01	<0.01
Reactive Phosphorous	0.02	mg/L	-	-	-	0.05	0.06	0.03	0.02	0.02		<0.01	0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01

Drinking water guideline

ANZECC 2000 guidelines - 95% protection for freshwater species

Bold - both guideline velaues exceeded

* = guideline value for upland/lowland rivers

ID = insifficent data to create value

Analyte	LOR	Unit	Australian drinking water guideline		ANZECC/ARMCANZ (2000) guideline for 95% protection of freshwater species																				
			Health	Aesthetic																					
Date						18/12/14	19/01/15	20/02/15	21/04/15	15/05/15	15/05/15	23/06/15	21/04/15	15/05/15	23/06/15	20/08/15	28/09/15	24/11/15	13/01/16	27/06/16	27/12/16	29/06/17	22/01/18	21/06/18	05/08/18
Sampling method						Bailer	Bailer	Bailer	Pump	Pump	double check	double check													
Field parameters																									
pH	0.01		ID	6.5-8.5	6.5-7.5*	6.59	6.88	6.84	7.1	7.11	8.17	7.1	7.1	7.11	7.1	7.21	6.8	6.82	7.03	6.59	6.43	6.6	6.88	6.56	6.65
Electrical Conductivity @ 25°C	0.1	µS/cm	-	-	125-2200	1540	1320	1320	2430	2460	3541	3410	2430	2460	3410	3240	1600	1580	1500	496	274	282	298	300	310
Dissolved oxygen	0.1	mg/L	-	-	-						10.12														
Oxidation reduction potential	0.1	mV	-	-	-						98.2														
Laboratory results																									
Total dissolved solids	5	mg/L	-	600	ID	1130	910	827	1760	2020		2220	1760	2020	2220	2110	1040	1030	975	322	178	183	194	195	202
Alkalinity																									
Hardness	1	mg/L	-	200	-	487	418	410	777	802		1190	777	802	1190	1110	540	494	484	138	62	69	65	69	67
Bicarbonate Alkalinity as CaCO3	1	mg/L	-	-	-	200	213	221	285	292		340	285	292	340	314	210	<1	246	152	90	97	103	101	92
Carbonate Alkalinity as CaCO3	1	mg/L	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1		<1	<0.1	<0.1	<1	<1	<1	233	<1	<1	<1	<1	<1	<1	<1
Hydroxide alkalinity	1	mg/L	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1		<1	<0.1	<0.1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total alkalinity	1	mg/L	-	-	-	200	213	221	285	292		340	285	292	340	314	210	233	246	152	90	97	103	101	92
Cations & anions																									
Chloride	1	mg/L	ID	250	-	373	306	296	638	654		813	638	654	813	642	355	365	363	56	28	25	32	31	34
Sulfate	1	mg/L	ID	250	-	<0.4	<0.4	<0.4	13.4	12.8		13	13.4	12.8	13	13	<10	1	<1	<1	<10	<1	<10	<10	<5
Calcium	1	mg/L	-	-	-	92.8	85.8	82.4	148	159		230	148	159	230	212	106	102	95	32	15	16	16	16	17
Magnesium	1	mg/L	-	-	-	61.9	49.6	49.6	98.8	98.6		149	98.8	98.6	149	141	67	58	60	14	6	7	7	7	6
Potassium	1	mg/L	-	-	-	3.9	4.2	4.1	8.2	8.3		7	8.2	8.3	7	7	7	6	5	6	4	4	4	4	4
Sodium	1	mg/L	-	180	-	86.7	70.7	71.6	139	138		178	139	138	178	172	99	88	94	45	27	31	31	30	32
Total metals																									
Arsenic	1	µg/L	10	-	24	4	3	2	0.0006	0.0004		0.0002	6	4	0.002	<0.001	<0.001	<0.001	<0.001	0.002	0.002	0.001	0.001	0.001	0.001
Cadmium	0.2	µg/L	2	-	0.2	<0.05	0.09	<0.05	<0.00005	<.000005		<0.00001	<0.05	<0.05	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	0.0001
Chromium	1	µg/L	5	-	ID	4	6	<2	0.0003	<0.0002		0.0002	3	<2	0.002	0.003	0.004	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.002
Copper	1.4	µg/L	2000	1000	1.4	5	4	2	0.0003	0.0004		0.0004	3	4	0.004	0.013	0.007	0.004	0.008	0.011	0.01	0.01	0.005	0.006	0.006
Lead	1	µg/L	10	-	3.4	4.8	3.9	1.2	0.0002	0.00021		0.0001	2	2.1	0.001	0.002	0.002	0.001	<0.001	0.001	0.002	<0.001	<0.001	0.001	<0.001
Mercury	0.1	µg/L	1	-	0.6	<0.1	<0.1	<0.1	<0.000001	<0.000001		0.000001	<0.1	<0.1	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	1	µg/L	20	-	11	10	6	6	0.02	0.018		0.016	20	18	0.016	0.01	0.008	0.007	0.005	0.003	0.004	0.005	0.003	0.007	0.007
Zinc	1	µg/L	ID	3000	8	10	24	12	0.024	0.032		0.089	24	32	0.089	0.063	0.023	0.019	0.023	0.012	0.014	0.018	0.033	0.018	0.012
Selenium	0.01	mg/L	10	-	11							<0.01													
Fluoride	0.1	mg/L	1500	-	-							0.1													
Iron (dissolved)	0.01	mg/L	-	-	-	2.47	3.85	4.14	0.02	0.04		0.05	0.02	0.04	0.26	0.08	4.13	4.54	4.76	5.09	3.04	2.56	1.26	1.63	1.39
Iron	1	mg/L	ID	300	ID	4.41	5.31	4.92	0.8	0.81		0.05	0.8	1.05	0.89	1.33	4.95	5.21	5.66	5.56	4.05	2.56	2.2	1.95	1.65
Nutrients																									
Ammonia as N	0.1	mg/L	ID	0.5	0.013*	0.1	<0.1	0.1	<0.1	<0.1		0.01	<0.1	<0.1	0.16	0.11	0.023	<0.01	0.04	0.13	0.19	0.14	0.24	0.28	0.35
Nitrite as N	0.01	mg/L	3	-	0.015*	<0.01	<0.01	<0.01	<0.01	<0.01		0.01	<0.01	<0.01	<0.01	<0.01	0.14	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrate as N	0.05	mg/L	50	-	0.015*	<0.05	<0.05	<0.05	<0.05	<0.05		0.01	<0.05	<0.05	0.01	0.1	0.16	0.02	0.15	0.03	0.12	0.02	<0.01	0.1	0.09
Total Phosphorus as P	0.01	mg/L	-	-	0.02*	0.07	0.06	0.03	0.03	0.03		0.01	0.03	0.03	0.08	0.02	0.14	0.1	0.67	0.08	0.07	0.04	0.04	<0.01	<0.01
Reactive Phosphorous	0.02	mg/L	-	-	-		0.03	0.02	<0.02	0.03		0.01	<0.02	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.02	<0.01	<0.01	<0.01	<0.01

Drinking water guideline

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