



Appendix L

Groundwater Impact Assessment

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REPORT ON

MONARO QUARRY GROUNDWATER IMPACT ASSESSMENT

For: R.W. Corkery Pty Ltd

Project number: 4110

Date: 02/06/2025

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Monaro Rock Quarry Groundwater Impact Assessment

Prepared for

R.W. Corkery Pty Ltd

1. Introduction

Monaro Rock Pty Ltd (“Monaro Rock” or “the Applicant”) proposes to construct and operate the Monaro Rock Quarry (the Project) on land located in Royalla, approximately 5 km north of the intersection of the Monaro Highway and Old Cooma Road and adjacent to the border separating New South Wales (NSW) and the Australian Capital Territory (ACT). The Project would be developed on land within NSW with access to the Project via a dedicated access road and intersection with the Monaro Highway, within the ACT. Figure 1 presents the location of the Project in its local context.

R.W. Corkery and Co. Pty Ltd (RWC) is managing the environmental approvals for the Project. The Project is a proposed hard rock quarry, which involves the construction of a 30 to 35 year pit¹ covering a total surface area of 20 ha with a maximum depth of around 100 m below ground level (mbGL). The Project site and the proposed quarry extent is shown in Figure 1. This report forms the Groundwater Impact Assessment (GIA) for the Project approval.

1.1. Project description

The Applicant is seeking development consent to develop the Project which would include the following:

- the progressive development of the Project comprising an extraction area, processing and stockpiling area and Quarry Access Road;
- construction of two amenity barriers to mitigate potential environmental impacts;
- construction and use of a dedicated Quarry Access Road including a crossing of the Goulburn Bombala Rail Line and an intersection with the Monaro Highway;
- a maximum extraction and processing rate of up to 1 000 000 tonnes per annum (tpa) at full capacity;
- product transportation involving a maximum of 25 laden heavy vehicles per hour and no more than 200 laden heavy vehicles per day and 50 concrete agitators per day;
- ongoing operations for a period of 30 to 35 years from the commencement of operations; and
- the development of a groundwater supply bore within the site infrastructure area.

The Project components are shown in Figure 2.

¹ The Project life is proposed to be 30 to 35 years, however modelling has considered a 30-year timeframe to provide a more conservative assessment outcome. It is expected that the operation would continue beyond 30 years.

1.2. Scope of assessment

The scope of work for this groundwater assessment includes:

- A review of relevant groundwater, Project development, geological and environmental reports from the Project site to develop an appreciation of the hydrogeological setting of the Project.
- A review of the site exploration drilling data.
- A review of hydrogeological data collated by the Bureau of Meteorology to identify landholder water supply bores.
- A groundwater field investigation to develop a detailed understanding of the groundwater regime at the Project site. The groundwater field investigation included the drilling and installation of dedicated monitoring bores, the measurement of groundwater levels and groundwater quality, and the testing of aquifer hydraulic parameters.
- The development of a conceptual model of the groundwater regime of the Project site and its surrounds, based on all available data.
- The development of a numerical model for the predictive simulation of the scale and extent of potential quarrying development effects on groundwater levels during operations and post closure.
- An assessment of the groundwater impacts and development of feasible mitigation and management strategies, where necessary.
- The development of a groundwater monitoring program and management measures for the Project.

The GIA has been prepared in accordance with the Guidelines for Groundwater Documentation for State Significant Developments Projects (DPE, 2022). Additionally, the GIA addresses the requirements of the following guidelines and policies:

- DPE (2022) Minimum groundwater modelling requirements for Major Projects in NSW;
- Peeters and Middlemis (2023). Information Guidelines Explanatory Note: Uncertainty analysis for groundwater modelling, A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of Climate Change, Energy, the Environment and Water, Commonwealth of Australia, 2023;
- Barnett *et al.* (2012) Australian groundwater modelling guideline;
- DPI-Water (2012) NSW Aquifer Interference Policy – NSW Government Policy for the licensing and assessment of aquifer interference activities;
- NSW Water Management Act (2000); and
- compliance with the relevant Water Sharing Plans.

1.3. Report structure

This report is structured as follows:

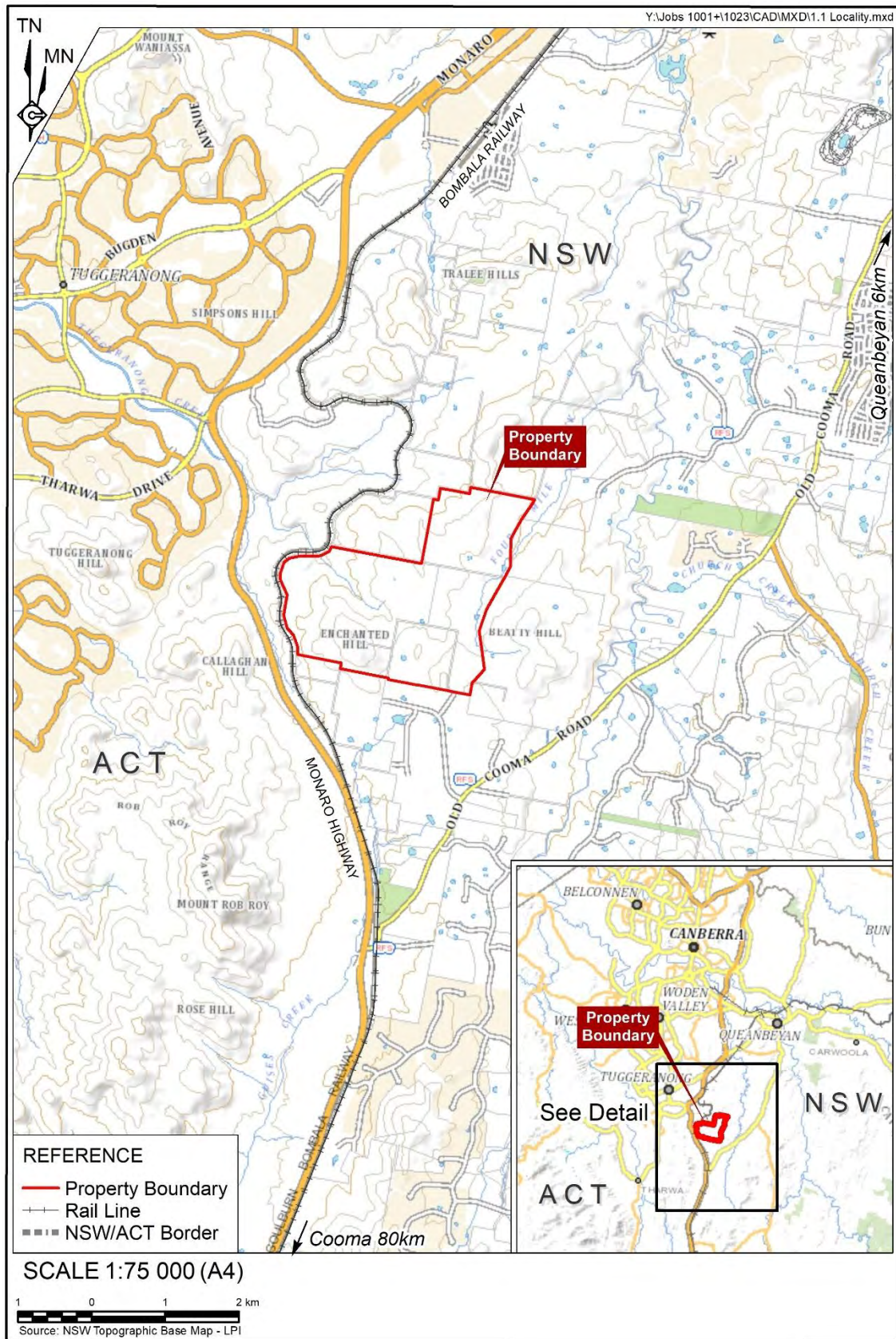
- Section 1 - provides background to the Project and describes the report scope and structure.
- Section 2 - describes the regulatory setting relating to groundwater, and the Secretary issued Environmental Assessment Requirements (SEARs) and guidelines that have been used to inform this assessment.
- Section 3 - describes the environmental and geological setting of the Project including relevant land uses, local topography and drainage, climate and local stratigraphy and geology.
- Section 4 - describes the assessment method including the collection of relevant data, the groundwater field investigation and numerical groundwater modelling.
- Section 5 - describes the existing groundwater regime for the Project site and surrounding area.
- Section 6 - provides a detailed description of the proposed quarrying activities and the predicted effects of quarrying on the local groundwater regime. This section also presents an assessment of the potential impacts on groundwater users and the receiving environment.
- Section 7 - describes the proposed groundwater monitoring program for the Project.
- Section 8 - describes the conclusions.
- Section 9 - lists the references.

Appendix A summarises the registered bores located within 3 km of the Project site.

Appendix B presents the results of the field investigation, including drilling logs, permeability test results and initial groundwater water level and quality results.

Appendix C provides a detailed description of the numerical modelling undertaken for the Project, including details on model construction, calibration, predictive simulations, and uncertainty analyses.

Appendix D provides the third party peer review report from Manewell Groundwater Pty Ltd.



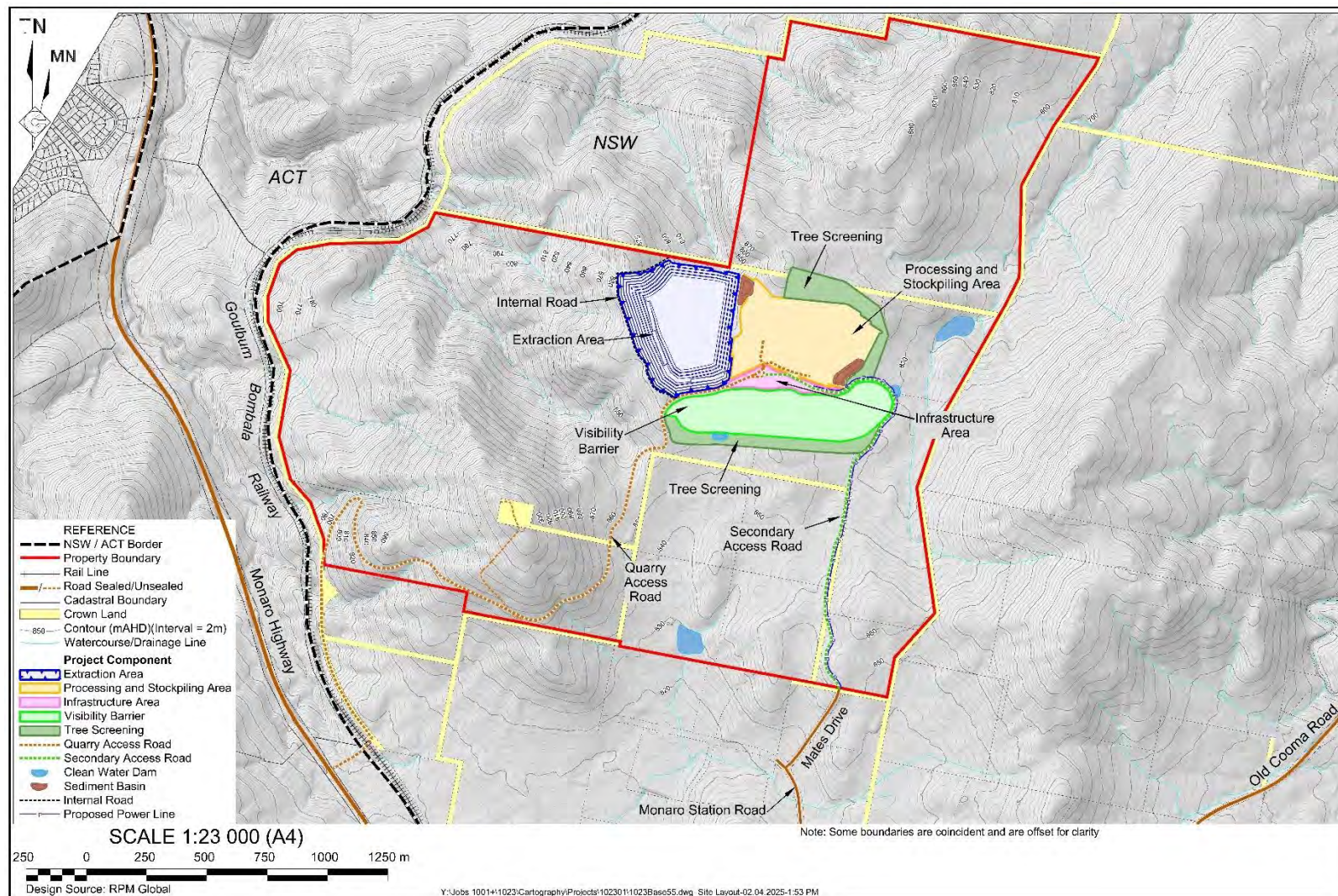


Figure 2 Principal Project components

2. Regulatory framework

2.1. Secretary's Environmental Assessment Requirements

Under the NSW *Environmental Planning and Assessment Act (1979)* and the NSW *Environmental Planning and Assessment Regulation (2000)*, the NSW Planning Secretary issued Environmental Assessment Requirements (SEARs) that are required to be addressed as part of the Project. The key groundwater related requirements of the SEARs are summarised Table 1, along with reference to the report section which addresses the requirements.

Table 1 SEARs requirements

SEARs requirements	Section addressed
Identification of any licensing requirements or other approvals under the Water Act 1912 and/or Water Management Act 2000.	Sections 2.3.1 and 6.3.2
Demonstration that water for 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).	Sections 2.3.1 and 6.3.2
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 6.3.2
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, flow objectives and sensitive downstream receiving environments.	Sections 6.3, 6.4.3, 6.4.4 and 6.4.5
An assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users in particular for domestic and commercial purposes.	Sections 6.4.1 and 6.4.2
A detailed description of the proposed water management system (including sewage), water monitoring program and other measures to mitigate surface and groundwater impacts.	Section 7

The SEARs for the Project (SSD-27223807) were provided by the NSW Department of Planning and Environment on the 18 August 2023. The sections below summarise the intent of the legislation, policy and guidelines listed in the SEARs and how they relate to the Project.

2.2. Water Act

The *Water Act 1912* regulates water sources in NSW, including rivers, lakes and groundwater aquifers. However, the *Water Management Act 2000* has replaced the *Water Act 1912* in relation to the local aquifers in NSW and therefore is not applicable to the Project.

2.3. Water Management Act

The *Water Management Act 2000* (WM Act) aims to provide for the sustainable and integrated management of water resources in NSW, while balancing competing environmental, social and economic considerations. Under the WM Act, water sharing plans (WSPs) have been developed. The aim of a WSP is to maintain the health of river and groundwater systems, while also providing equitable access for water users and the opportunity to trade water.

The Project site is covered by the Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2020.

2.3.1. NSW Murray Darling Basin Fractured Rock Groundwater Sources 2020

The Project is located within the Lachlan Fold Belt MDB Groundwater Source. The extent of the Project site falls within this WSP and is specifically covered by Lachlan Fold Belt MDB (Other) Management Zone, which encompasses the parishes of Galambine, Wilbertree, Eurundury, and Bumberra, in the County of Phillip.

The rules of the Lachlan Fold Belt MDB Groundwater Source WSP apply to all water contained within all rocks within outcropped and buried areas and all alluvial sediments within the outcropped areas, within the boundaries of the Lachlan Fold Belt MDB Groundwater Source.

A water access licence (WAL) is generally required to extract water from rivers or aquifers to use for irrigation, industrial or commercial purposes. The *Water Management Act 2000* governs the issue of WALs and approvals for water sources in NSW where water sharing plans have commenced.

WALs entitle licence holders to specified shares in the available water within a particular water management area or water source (the share component), and to take water at specified times, rates or circumstances from specified areas or locations (the extraction component).

It is understood that the Applicant currently does not hold any WALs for the Lachlan Fold Belt MDB Groundwater Source. The Applicant is committed to obtaining the necessary WALs prior to undertaking operations and will seek to have this commitment conditioned into the Development Consent.

2.4. Aquifer interference policy

The NSW Aquifer Interference Policy (AIP) provides a framework for the assessment of impacts of the extraction of water for proposed developments. Groundwater sources are divided into “highly productive” and “less productive” categories based on salinity and aquifer yield as shown in Table 2. The geology within the Project site boundary is considered to generally fall within the “less productive” category.

Table 2 NSW Aquifer Interference Policy – salinity and aquifer yield criteria

Criteria		Salinity (Total dissolved solids)	
		Less than 1,500 mg/L	More than 1,500 mg/L
Aquifer yield	More than 5 L/s	Highly productive	Less productive
	Less than 5 L/s	Less productive	

The AIP also specifies minimal impact considerations for both “highly productive” and “less productive” aquifers within each WSP. These comprise thresholds for water table and groundwater pressure drawdown, and changes in groundwater and surface water quality. The thresholds are ranked as being either ‘level 1 minimal impact’ or ‘level 2 exceeding minimal impact’. The Project is considered to be within a ‘less productive’ fractured rock source. There are no ‘highly productive’ groundwater sources in the Project site. The applicable minimal impact considerations are summarised in Table 3.

Table 3 Minimal impact considerations for aquifer interference activities

Water table	Water pressure	Water quality
1. 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.
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 if appropriate studies demonstrate to the Minister’s satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than a 2 m decline cumulatively at any water supply work then make good provisions should apply.	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.

2.5. Guidelines for Groundwater Documentation for SSD/SSI Projects

The Guidelines for Groundwater Documentation for SSD/SSI Projects (DPE, 2022) assists proponents to demonstrate if an activity can operate and be compliant with the principles and objects of the WM Act and the requirements described within the NSW groundwater policy documents.

The Guidelines for Groundwater Documentation for SSD/SSI Projects (DPE, 2022) have been considered throughout this GIA, including during the development of:

- a baseline groundwater monitoring network and a demonstrated period of baseline monitoring (Section 4.2);
- the conceptual hydrogeological model and an understanding of baseline groundwater conditions (Section 5);
- the impact assessment of groundwater flow and quality including the development of a suitable numerical groundwater flow model (Section 6);
- the groundwater management, monitoring and mitigation measures to be implemented (Section 7); and
- the obligations and regulatory requirements for water licensing (Section 2).

3. Project setting

3.1. Land use

The Project site is currently used for grazing and passive biodiversity conservation. A summary of the principal sensitivities and constraints is provided as follows.

- The majority of the land to be disturbed for quarrying is on cleared land with some remnant paddock trees. However, areas of native vegetation and grasses have been retained within the area, including dense remnant vegetation on the northern and western edges of the extraction area (Capital Ecology, 2024).
- The extraction area is located on comparatively steep-sloping land which constrains land uses and impacts upon the productivity of the land with land generally only suitable for grazing.
- The proposed alignment of the Quarry Access Road traverses areas of comparatively steep, heavily vegetated terrain.

Land uses surrounding the Project site predominantly comprise grazing and rural lifestyle activities. Infrastructure within the area surrounding the Project site includes the Monaro Highway and Old Cooma Road. The Goulburn Bombala Rail Line runs parallel to the Monaro Highway immediately to the west of the Project site. Passenger services ceased in 1989 with some tourist based service running since that time but now ceased due to the deterioration of the line.

A rural residential subdivision has recently been approved for the south of the Project site, and it is noted that another subdivision is proposed to the east.

3.2. Climate

An interpolated climate dataset (from 1900 to 2024) was downloaded from the DES Scientific Information for Land Owners (SILO) database for the Project site (at location 35.42°S, 149.10°E). This service aggregates climatological data from all nearby sources and presents interpolated grid-point data for a given region.

A summary of average monthly temperatures, monthly rainfall and monthly evaporation from the SILO dataset is shown below in Table 4.

Table 4 Climate averages

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean minimum temperature (°C)	11.98	11.95	9.82	6.09	2.68	0.59	-0.47	0.46	2.67	5.32	8.12	10.32
Mean maximum temperature (°C)	26.54	25.75	22.96	18.56	14.30	10.97	10.18	11.78	14.95	18.35	21.63	24.71
Mean rainfall (mm)	60.7	54.1	59.3	46.7	40.3	43.4	39.4	42.7	47.8	57.2	62.6	60.6
Mean evaporation (mm)	130.1	101.1	81.3	46.8	25.0	18.7	20.8	33.8	60.5	92.7	116.1	133.7

The annual average rainfall for the area is approximately 676 mm and the annual average evaporation is 861 mm. On average, evaporation is higher than the rainfall, however only between the months of September through to March. Rainfall shows no discernible seasonal trend.

The monthly rainfall for the SILO site is shown in (Figure 3) with a monthly average of 56.39 mm.

Monthly rainfall has been put into historical context using the Cumulative Rainfall Departure (CRD) method. This method illustrates the difference in monthly rainfall from the long-term average monthly rainfall. Figure 3 presents the CRD graph for the site. A rising trend in the CRD plot indicates periods of above average rainfall, whilst a falling slope indicates periods when rainfall is below average.

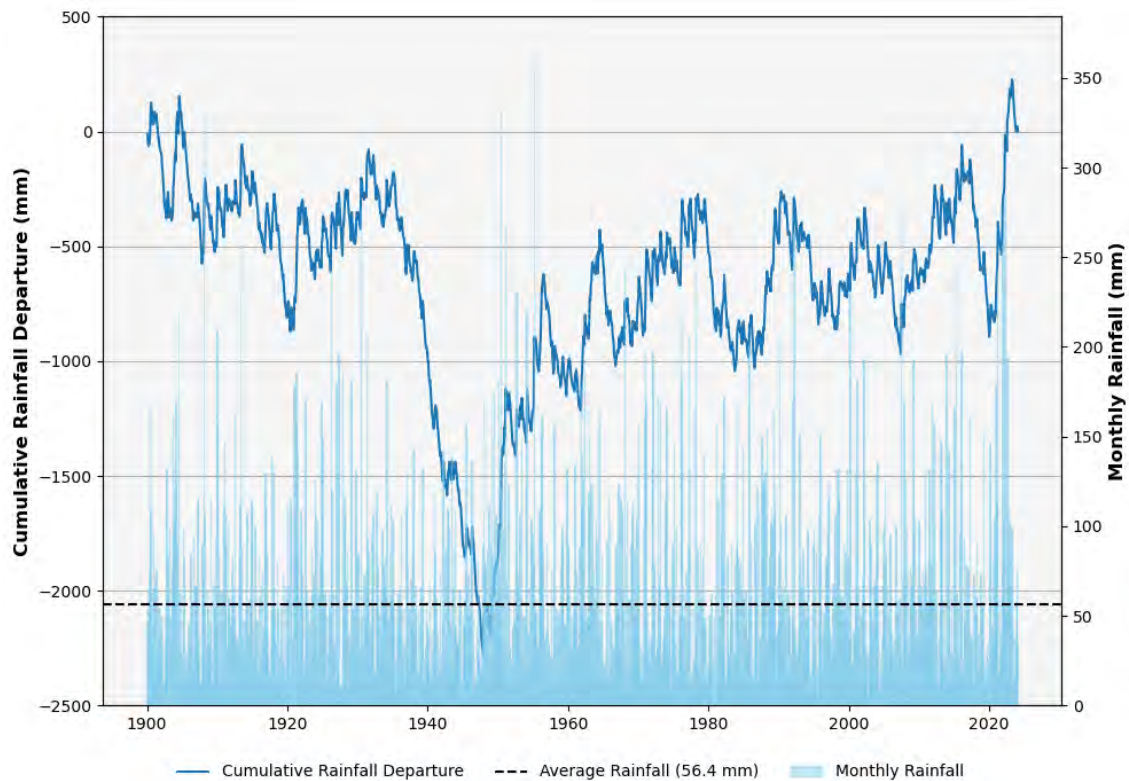


Figure 3 SILO rainfall data from 1900 to 2024 (35.42°S, 149.10°E)

The SILO dataset also provides monthly calculated evapotranspiration rates using the Morton actual evapotranspiration over land formula. Average monthly rainfall and evapotranspiration are shown in Figure 4. The bimodal plot indicates that rainfall is relatively steady across the year, with evapotranspiration highest during the summer months (wet season). During the colder mid-year months (dry season), evapotranspiration is its lowest (Figure 4).

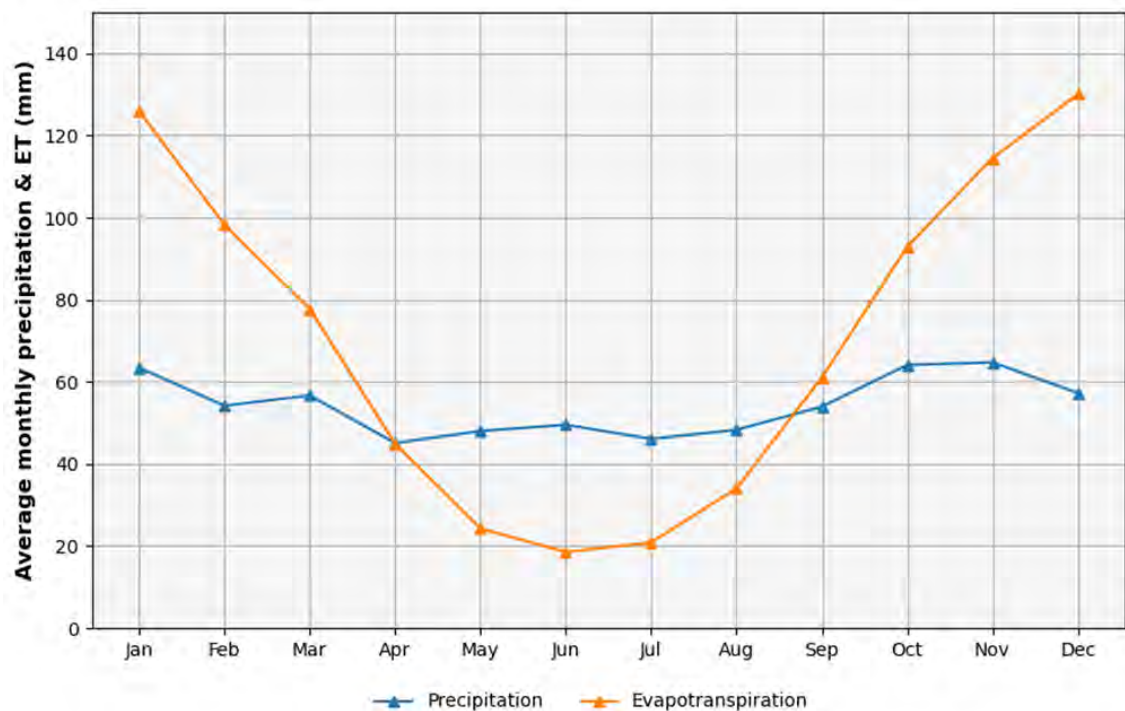


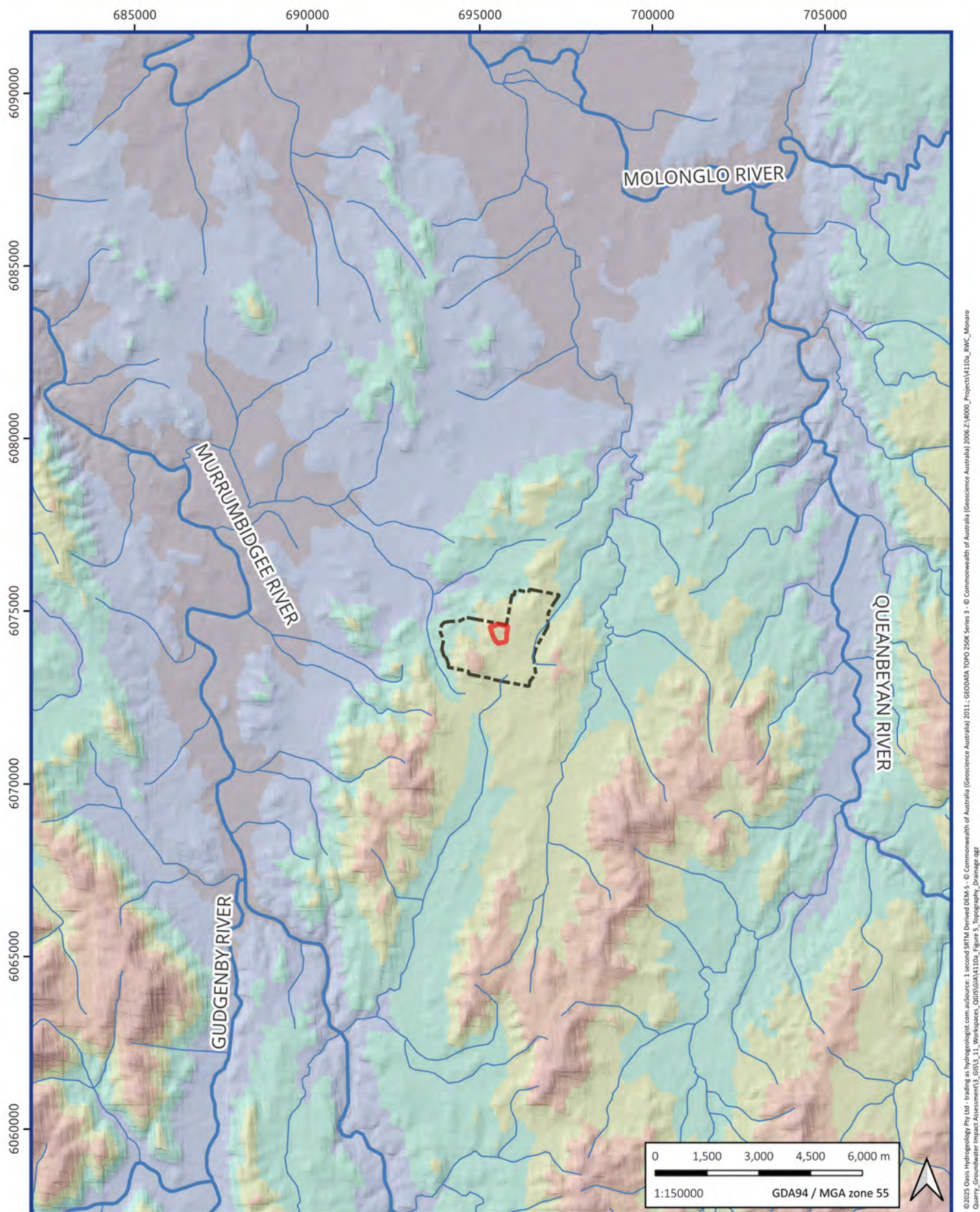
Figure 4 Calculated monthly rainfall vs evapotranspiration rates

3.3. Topography and drainage

The Project is located on a north-east to south-west oriented ridgeline. The DEM (digital elevation model) data sampled at 5 m intervals, indicates that the topographic elevation within the Project site ranges from 785 metres Australian Height Datum (mAHD) to 955 mAHD. Within the proposed extraction area, the elevation steepens from 835 mAHD in the north-east to 895 mAHD in the west.

The Project is located in the Murray-Darling Basin, approximately 5.6 km east of the Murrumbidgee River and 7.9 km west of the Queanbeyan River. Minor, ephemeral watercourses and drainage features intersect and surround the Project site. Figure 5 presents the regional topography and watercourses surrounding the Project site.

There is no evidence of springs, swamps, or groundwater baseflow to creeks on the Project site or adjacent to it (Strategic Environmental and Engineering Consulting, 2025).



Legend

Topography and drainage

(4110a) Monaro Rock Quarry - Groundwater Impact Assessment

Figure 5

16/04/2025

- Major watercourse
- Minor watercourse
- - - Project boundary
- Monaro quarry

Elevation (mAHD)

- | | |
|-----------|-------------|
| 500 - 600 | 800 - 900 |
| 600 - 700 | 900 - 1000 |
| 700 - 800 | 1000 - 1100 |

3.4. Geology

The mapped surface geology of the Project site and its surrounds (based on NSW government data) is shown in Figure 6. The Project site is located within the Deakin Volcanics (tuff rhyolite) of the Lachlan Fold Belt which is truncated to the east by the Royalla Fault. The geology to the east of the Royalla Fault comprises the Colinton Volcanic (dacitic tuff).

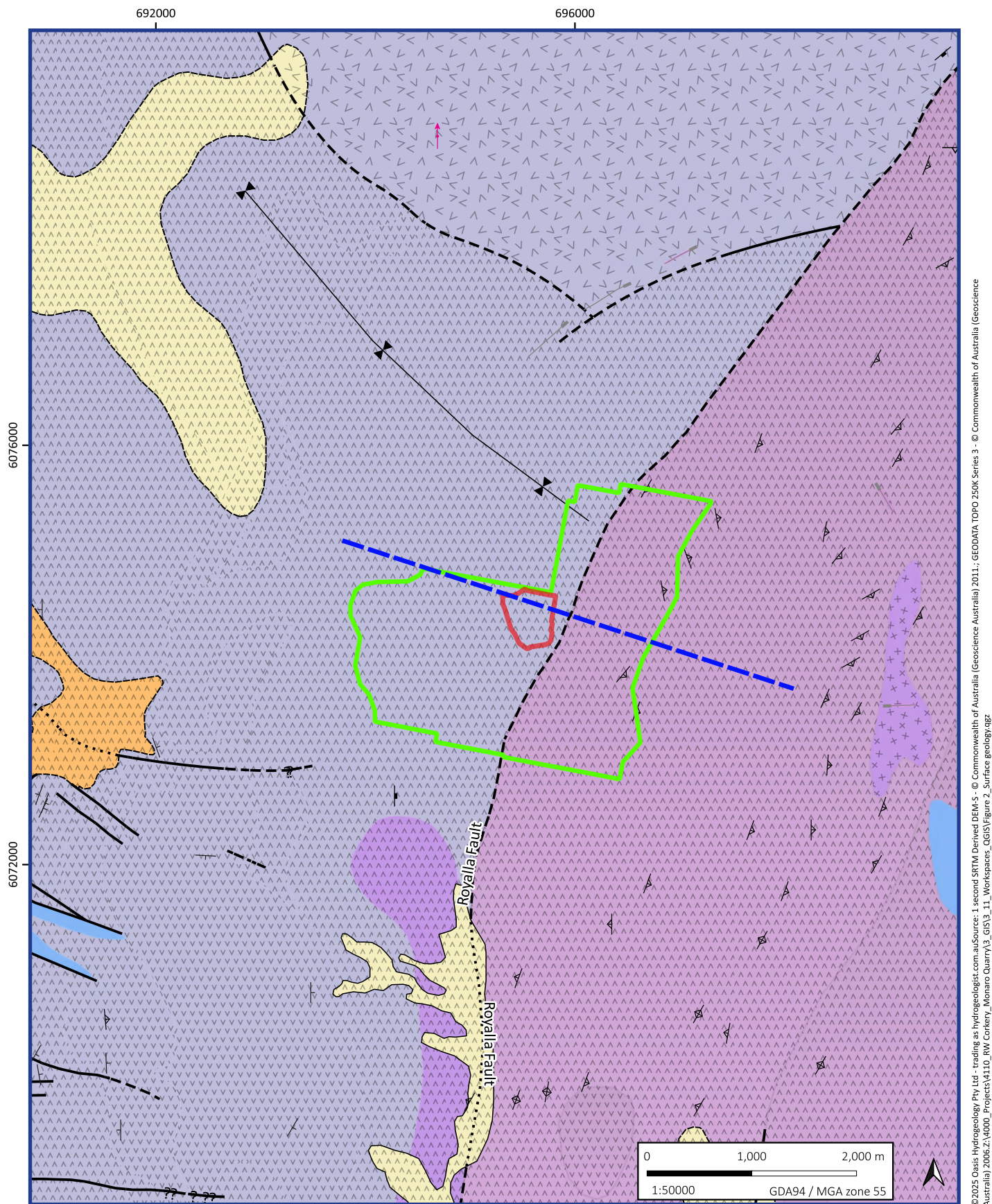
Information on the geology of the Project site (Deakin Volcanics, Colinton Volcanics and the Royalla Fault) is supported by exploration drilling which is summarised by Graham Lee & Associates Pty. Ltd. (2021).

The Deakin Volcanics are described in the public domain as pale, green-grey, rhyolitic crystal tuff, white and purple rhyolite. The site exploration drilling describes the Deakin Volcanics as rhyodacite with a mottled mix of cream, brown, grey, purple colours. The Deakin Volcanics are steeply dipping and generally structurally conformable with the adjacent Colinton Volcanics. The proposed quarrying operations are entirely within the Deakin Volcanics.

The Colinton Volcanics are described in the public domain as dacitic crystal tuff, mostly sheared. Field mapping shows that this rock appears as elongated disc shaped pieces, dipping steeply (70° to 85°) to the east due to structurally induced foliation. The Colinton Volcanics are not intersected by the quarrying operations.

The Royalla Fault is an NNE-SSW trending reverse fault that occurs immediately adjacent to the Project site (Figure 6). The full length of the Royalla Fault is mapped over 20 km. The fault zone was investigated and mapped in the field by Graham Lee & Associates Pty. Ltd. (2021). The fault zone dips steeply to the east and is assessed as being up to 100 m wide. The Colinton Volcanics (to the east of the Royalla Fault) are observed as heavily sheared compared to the blocky, massive Deakin Volcanics to the west. The depth of weathering within the Royalla Fault zone is deeper than the surrounding volcanics. The Royalla Fault is not intersected by the quarrying operations.

Within about 5 km of the site, there are mapped extents of Cenozoic alluvium, associated with drainage features. The closest mapped Cenozoic alluvium is approximately 1.5 km to the south of the Project. It has been confirmed through site specific exploration drill hole data that no alluvial sediments occur within the Project site boundary (Figure 6).



© 2025 Oasis Hydrogeology Pty Ltd - trading as hydrogeologist.com.au Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2006.Z\4000_Projects\4110_RW_Corkery\3_GIS\3_11_Workspaces_GGIS\Figure 2_Surface geology.qgz

Legend

- Conceptual cross-section alignment
- - Fault
- Project site
- Monaro quarry

Geology units

- | | |
|---|---|
| ■ Alluvium | ■ Colinton Volcanics |
| ■ Fanglomerate | ■ Deakin Volcanics |
| ■ Water bodies | ■ Laidlaw Volcanics |

Surface Geology

(4110a) Monaro Rock Project - Groundwater Impact Assessment

Figure 6

16/05/2025



4. Assessment methodology

4.1. Desktop study

4.1.1. Groundwater bore database searches

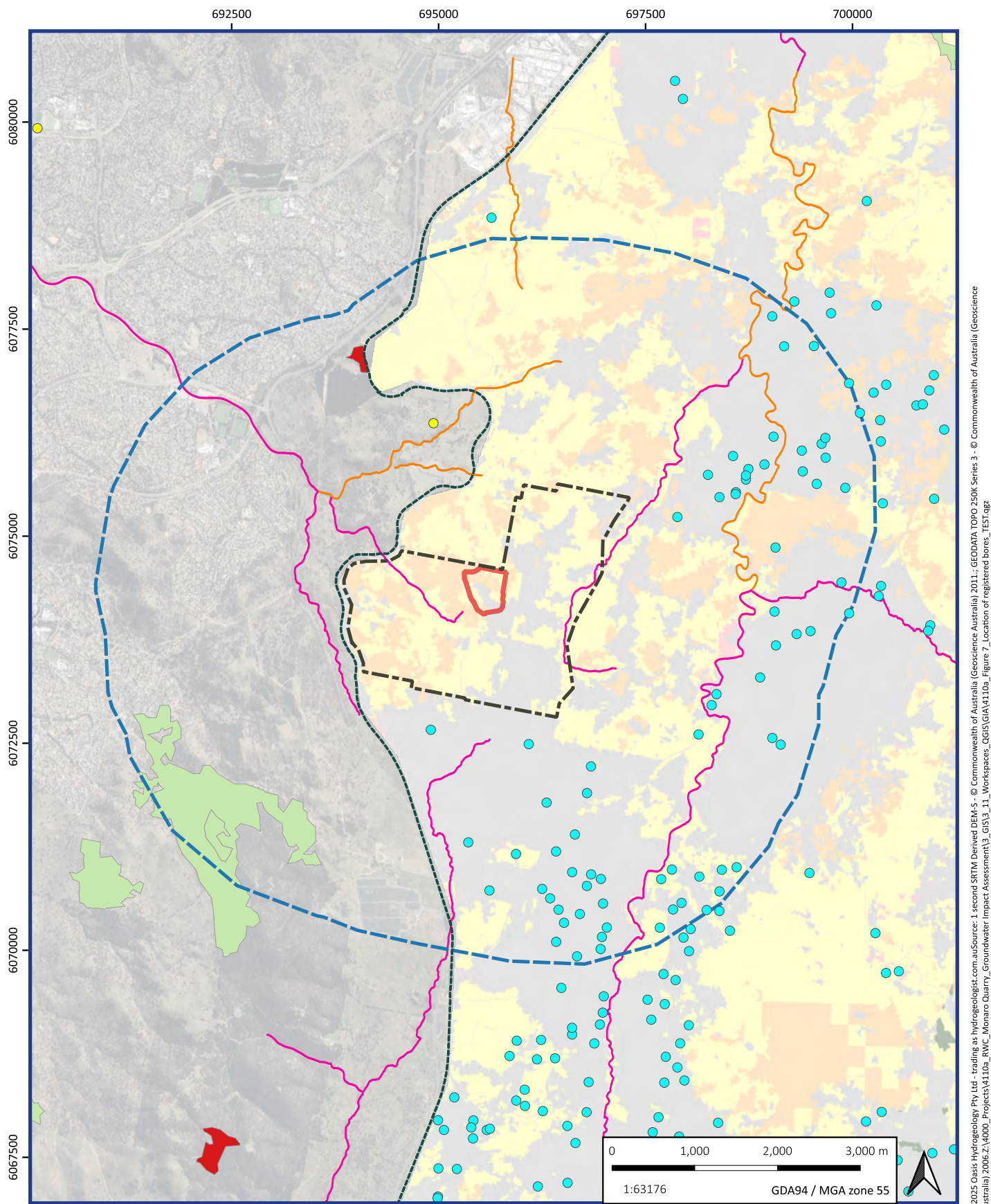
Groundwater data from state agencies (including ACT and NSW) is collated by the Bureau of Meteorology and published as the NGIS (National Groundwater Information System) database. This is a national database featuring bore data for all registered bores in relevant states. Data for ACT and NSW was downloaded from the NGIS database from the Australian Groundwater Explorer in November 2024. The data was then collated (Appendix A) and used to assess the presence of bores in the study area, site geology, groundwater levels, and groundwater quality.

The registered groundwater bores located within a 3 km radius of the Project site boundary are shown in Figure 7. A total of 70 registered groundwater bores were identified, all of which are located outside the Project site boundary. The available information on these bores is tabulated in Appendix A. The status and use of these bores are summarised in Table 5. Of these bores, 69 are in NSW and only one water supply bore is located within the ACT.

This information has been used to inform the conceptual understanding of the groundwater regime and numerical groundwater model discussed in Section 5.

Table 5 Purpose and status of registered groundwater bores within 3 km of site boundary (NGIS, 2024)

Purpose	Status	Number of bores
Household water supply	In use	38
	Unknown	21
Livestock water supply	In use	1
	Unknown	1
Irrigation	Unknown	2
Groundwater monitoring	Unknown	1
Community water supply	Unknown	1
Unknown	Unknown	5



© 2025 Oasis Hydrogeology Pty Ltd - trading as hydrogeologist.com.au Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011 - GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006 Z:\4000_P\Projects\4110a_RWC_Monaro Quarry_Groundwater Impact Assessment\3_GIS\3_11_Workspaces_QGIS\GIA4110a_Figure 7_Location of registered bores_TEST.qgz

Legend

Locations of registered bores

(4110a) Monaro Rock Quarry - Groundwater Impact Assessment

- Registered Bore (NGIS 2024, ACT)
- Registered Bore (NGIS 2024, NSW)
- Project boundary
- State/Territory border
- Project site - 3 km buffer
- Monaro quarry

Groundwater dependent ecosystems - Terrestrial

- High potential GDE
- from national assessment
- Low potential GDE
- from national assessment

Groundwater dependent ecosystems - Aquatic GDE

- High potential GDE
- from national assessment
- Moderate potential GDE
- from national assessment

GDE Probability

- Medium
- Low
- Non GDE
- Non native vegetation

Figure 7

20/05/2025



4.1.2. Other database searches and government mapping

Supporting data were also collected from a search of the following databases and maps:

- NSW state geological mapping and explanatory notes;
- SILO climate data online (precipitation and evapotranspiration data used in groundwater modelling);
- NSW records for stream discharge from state gauging stations; and
- NSW records for GDEs locations and types.

Climate data were compiled and analysed to inform the Project setting and to provide inputs to the numerical modelling. Databases regarding water management and regulation were accessed to ensure that this report meets the legislative requirements for assessing impacts to prescribed resources.

4.2. Project site investigations

A hydrogeological field investigation program was undertaken between September 2022 and November 2024. The purpose of the field investigation was to characterise the hydrogeological conditions within the Project site. The field investigation involved:

- Constructing two monitoring bores within exploration drill holes.
- Drilling and constructing five site-specific groundwater monitoring bores. The monitoring bores were installed within the Deakin Volcanics and the Colinton Volcanics.
- Measuring static groundwater levels following bore completion and development.
- Installing automatic water level loggers in each groundwater monitoring bore following bore completion and development.
- Permeability testing (falling head testing, constant head testing and a pumping test) to measure the hydraulic conductivity of the screened hydrostratigraphic unit.
- Regular field measurement and laboratory analysis of groundwater samples to characterise and compare the groundwater quality within key formations.

The location of the groundwater monitoring bores installed as part of the field investigation program are shown in Figure 8 and are summarised in Table 6. Appendix B contains the schematic bore logs for the Project groundwater monitoring bores. A private landholder bore (existing 'Dam' bore) has also been monitored and tested as part of the field investigation program (Figure 8).

A total of 28 months of groundwater level data was collected from the Project groundwater monitoring network to support the numerical model development. Groundwater level monitoring has been on-going (Section 7), and data was recorded at 6-hour intervals between September 2021 and January 2024. A total of seven field measurements and laboratory samples were collected for a range of water quality characteristics over a single monitoring round in January 2024.

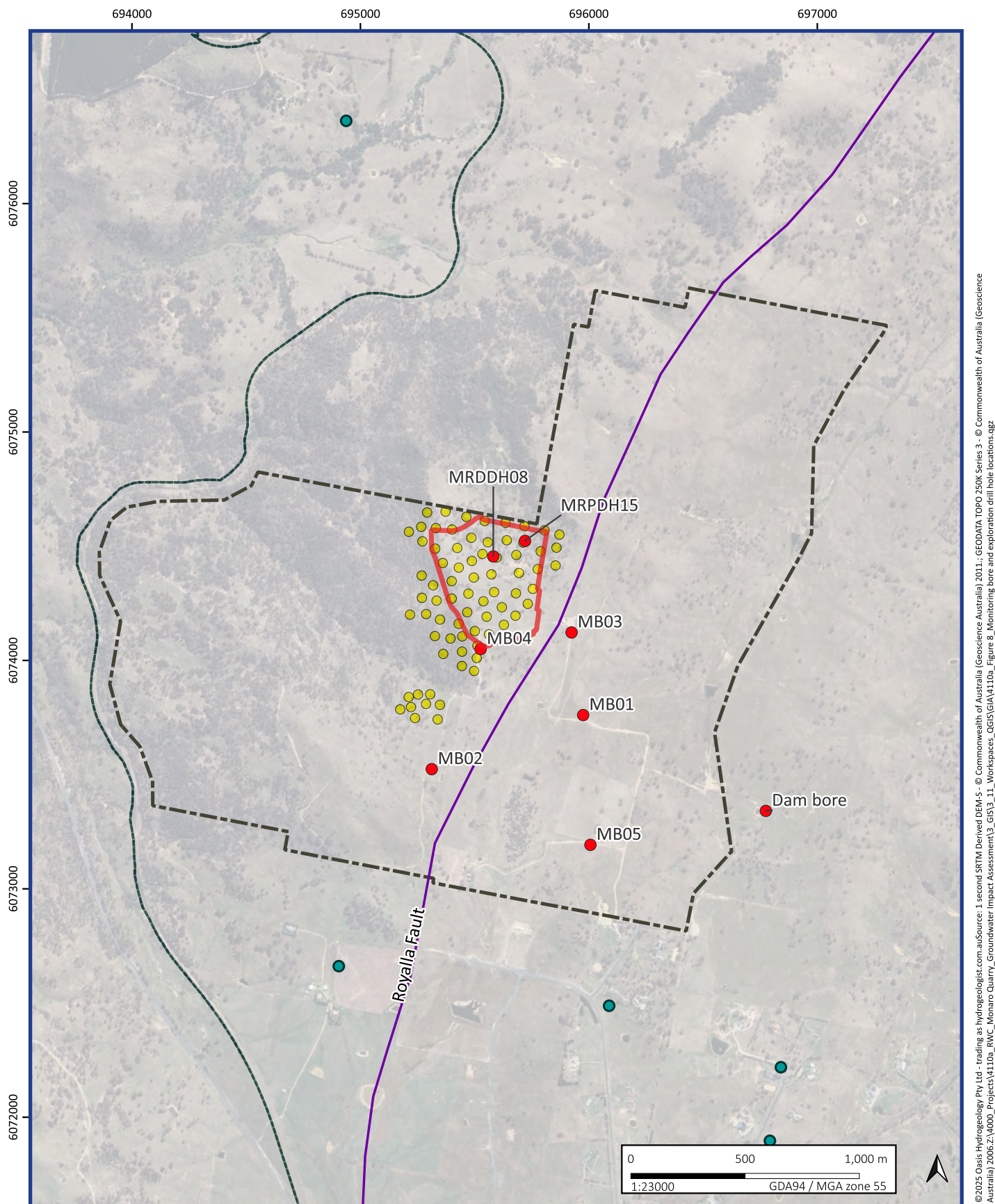
One off groundwater level measurements were also captured from historical exploration drill holes (Graham Lee & Associates Pty. Ltd, 2021) in the quarry footprint.

Table 6 Project monitoring bore details

Bore ID	Easting ¹	Northing ¹	Ground elevation (mAHD) ²	Water level (mAHD) ²	Total depth (mbGL) ³	Bore diameter (mm)	Casing type
MB01	695975	6073761	859.1	839.85	52.0	130	PVC
MB02	695312	6073524	854.6	832.30	47.5	130	PVC
MB03	695924	6074123	864.8	Dry	50.5	130	PVC
MB04	695526	6074050	878.1	Dry	50.0	130	PVC
MB05	696007	6073193	849.8	839.22	33.5	130	PVC
MRDDH08	695586	6074456	869	810.25	100	96	PVC
MRPDH15	695717	6074520	841	839.18	50	96	PVC
Existing 'Dam' bore	696775	6073343	859	848.02			

Notes:

- 1: Coordinates provided in (datum)
- 2: mAHD denotes metres above Australian Height Datum
- 3: mbGL denotes metres below ground level



© 2025 Oasis Hydrogeology Pty Ltd - trading as hydrogeologist.com.au Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011, GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.Z:\4000_P\Projects\4110a_RWC_Monaro Quarry_Groundwater Impact Assessment\3_GIS\3_11_Workspaces_QGIS\GIA\4110a_Figure 8_Monitoring bore and exploration drill hole locations.qgz

Legend

Monitoring bore and exploration drill hole locations

(4110a) Monaro Rock Quarry - Groundwater Impact Assessment

Figure 8

16/05/2025

- Exploration hole
- Monitoring bore
- Registered bore
- Royalla Fault alignment
- Monaro quarry
- State/Territory boundary
- Project boundary

4.3. Data analysis

All relevant data was collated and analysed to develop a conceptual understanding of the groundwater regime, including the key geology, groundwater flow and groundwater quality characteristics. The conceptualised groundwater regime is discussed in Section 5.

Groundwater data from a total of eight groundwater bores within the vicinity of the Project were used to support the conceptual model (Figure 8). Appendix A provides a summary of data available from the 70 registered bores that are within 3 km of the Project site. These are also shown in Figure 7.

The collated groundwater dataset includes the following relevant measurements:

- Geological data collected from the Project monitoring bores completed as part of the hydrogeological field investigation for the Project.
- Groundwater level data collected from the Project monitoring bores. This includes manual groundwater level data and long-term logger data collected for the Project.
- Groundwater quality data collected from the Project monitoring bores, including detailed field measurements and laboratory results.
- Hydraulic conductivity measurements interpreted from falling head tests (six monitoring bores), a pumping test and constant head tests.
- Publicly available data (groundwater level, quality and yield data) from the registered bores.

5. Conceptual groundwater model

5.1. Hydrostratigraphy

The local groundwater regime comprises of the following geological units:

- Weathered profile;
- Deakin Volcanics;
- Royalla Fault; and
- Colinton Volcanics.

These geological units are simplified into the following hydrostratigraphic units:

- Weathered profile; and
- Fractured, basement aquitard / aquifer.

The site resource drilling logs show that 31 out of 73 drill holes show a thin layer of sand or sand/clay/soil, mostly to a depth of 1 m to 2 m but sometimes as deep as 5 m. These are interpreted as colluvial sediments comprising a thin and shallow soil profile over much of the Project site. These colluvial sediments are unsaturated and do not form a hydrostratigraphic unit within the Project site.

Below these colluvial sediments is the weathered profile which is up to 30 m thick across the Project site and is deepest along the alignment of the Royalla Fault. The weathered profile comprises a veneer of slightly higher permeability regolith when compared to the underlying parent rock. The weathered profile within the Project site is typically dry and unsaturated except immediately after significant rainfall events. Groundwater levels across the site demonstrate a temporal pulse of groundwater that migrates vertically through the weathered profile into the underlying bedrock. A conceptual cross section from west to east is shown in Figure 9.

The Deakin Volcanics are assessed to be a low permeability, confined, bedrock aquitard and this is evident through the lack of significant groundwater intersections during the exploration drilling. Only two out of 88 resource drill holes intersected groundwater during drilling, while the other drill holes were drilled dry. The Deakin Volcanics is the target formation for the quarrying activities.

The Colinton Volcanics are assessed to be a low to moderate permeability, fractured bedrock aquifer supporting numerous private groundwater supply bores to the east of the Project site. Quarrying activities will not occur within the Colinton Volcanics.

The Royalla Fault separates the Deakin Volcanics and the Colinton Volcanics. The Royalla Fault is a 100 m wide zone of heavily sheared material. There is no evidence in the exploration drill hole data to indicate that the fault zone is of high permeability, rather the fault zone is likely to contain a significant amount of clay gouge and is assessed to be a low to moderate permeability aquitard, promoting similar hydrogeological conditions to the Deakin Volcanics and the Colinton Volcanics. Quarrying activities will not intersect the Royalla Fault.

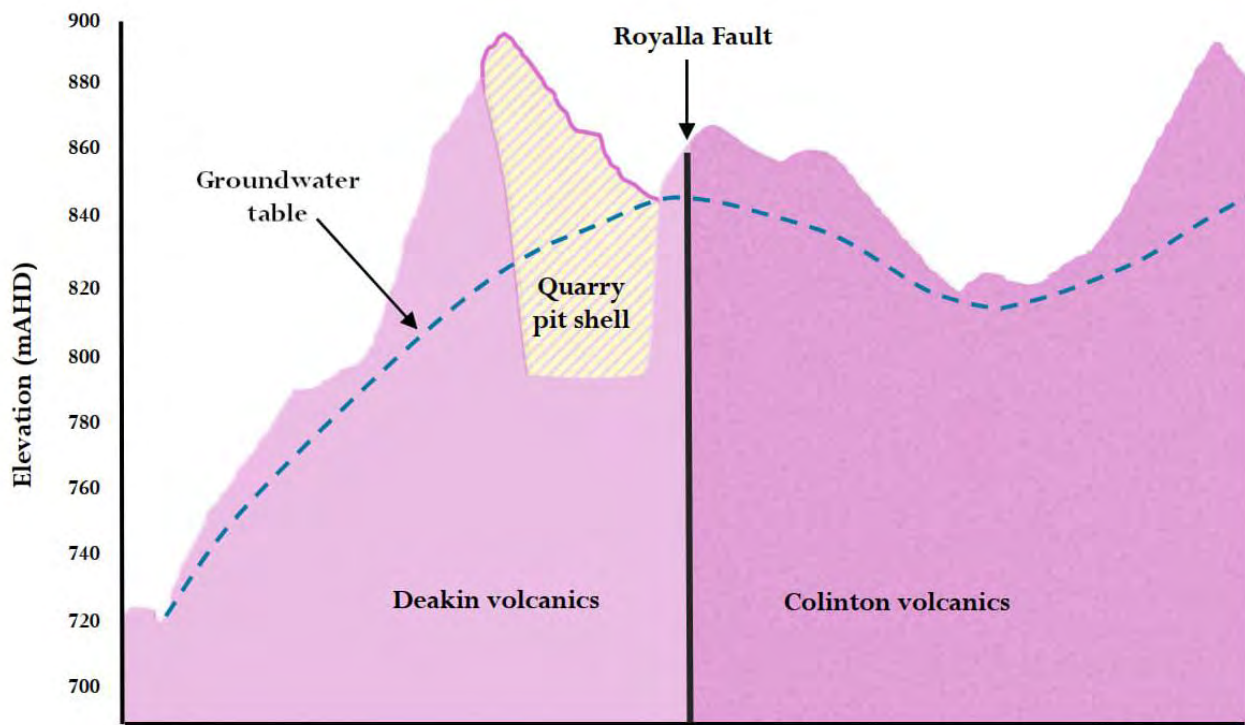


Figure 9 Conceptual cross-section

5.2. Groundwater flow

Spatially distributed groundwater level data from site monitoring bores were used to characterise groundwater flow directions, gradients, and velocities. Figure 10 presents the groundwater level hydrographs which were used to inform the conceptualisation of the site groundwater flow regime. Time variant variations in groundwater level were also used to interpret the rate and distribution of recharge/discharge, and pre-development variability in groundwater level.

Groundwater flow in the vicinity of the Project site is from the north-east, to the south-west and west towards the region of lower topography (Figure 11). The groundwater flow contours were supplemented by the single groundwater level measurements collected at the exploration drill holes (see Section 4.2). However, groundwater intersected at the Project site is influenced by the fault behaviour and compartmentalisation. This is evident with steep hydraulic gradients observed in the Project site and some bores observed to be dry. Fault zones can create barriers to fluid flow, separating previously interconnected areas into distinct compartments.

The groundwater level hydrographs show that generally there is a static or subdued groundwater level response in the majority of monitoring bores (Figure 10). Groundwater level observation for each bore is listed below:

- MB01 screened in the Colinton Volcanics shows a steady decrease in water level over the monitoring period from 841.86 mAHD in October 2022 to 838.27 mAHD in November 2024. The water level response shows evidence of a groundwater recharge response to rainfall.
- MB02 screened in the Deakin Volcanics shows a steady decrease in water level over the monitoring period from 833.05 mAHD in October 2022 to 831.54 mAHD in November 2024.
- MB03 screened in the Deakin Volcanics and MB04 screened in the Colinton Volcanics are both dry. These bores are located the closest to the mining area and MRDDH08 and MRDDH15.
- MB05 screened in the Colinton Volcanics shows a steady decrease in water level over the monitoring period from 841.58 mAHD in October 2022 to 837.57 mAHD in November 2024.

- MRDDH08 and MRDDH15 are both screened in the Deakin Volcanics. The water levels show a very rapid increase and decrease in water levels. This indicates water is entering the bore hole rapidly and then dissipating over time. The increases in water levels are consistent with rainfall in the region. MRDDH08 water level is stabilising at depths around 810 mAHD and MRDDH15 water level is stabilising at depths around 816 mAHD. Water level measurements at MRDDH15 are highly variable and are necessarily representative of groundwater table conditions. MRDDH08 and MRDDH15 are in the quarry footprint area and there was a lack of significant groundwater intersections during the exploration drilling. Only 2 out of 88 resource drill holes intersected groundwater during drilling. The Deakin Volcanics are assessed to be a low permeability, confined, bedrock aquitard which is supported by a lack of registered bores in the area. It is possible the water level responses in MRDDH08 and MRDDH15 are an indication of compromised bore construction which is allowing water to enter the annulus or casing near surface and filling the bore hole with fresh rainwater.
- Existing 'Dam' bore screened in the Colinton Volcanics shows a steady increase and then decrease in water level over the monitoring period from 843.56 mAHD in August 2021 to 848.17 October 2022 to 846.32 mAHD in November 2024.

The model simulated groundwater table is currently located at depths between 5 m and 50 m below ground level within the majority of the Project site (Figure 12). The groundwater table is generally shallower to the east and south-east of the Project site. The groundwater table is located in the Deakin Volcanics in the Project site and within the Colinton Volcanics to the east of the Project site. The groundwater table broadly reflects topography.

However, the groundwater table does not intersect the ground surface in the creek beds in the vicinity of the Project site. Hence, groundwater does not provide baseflow to creeks locally.

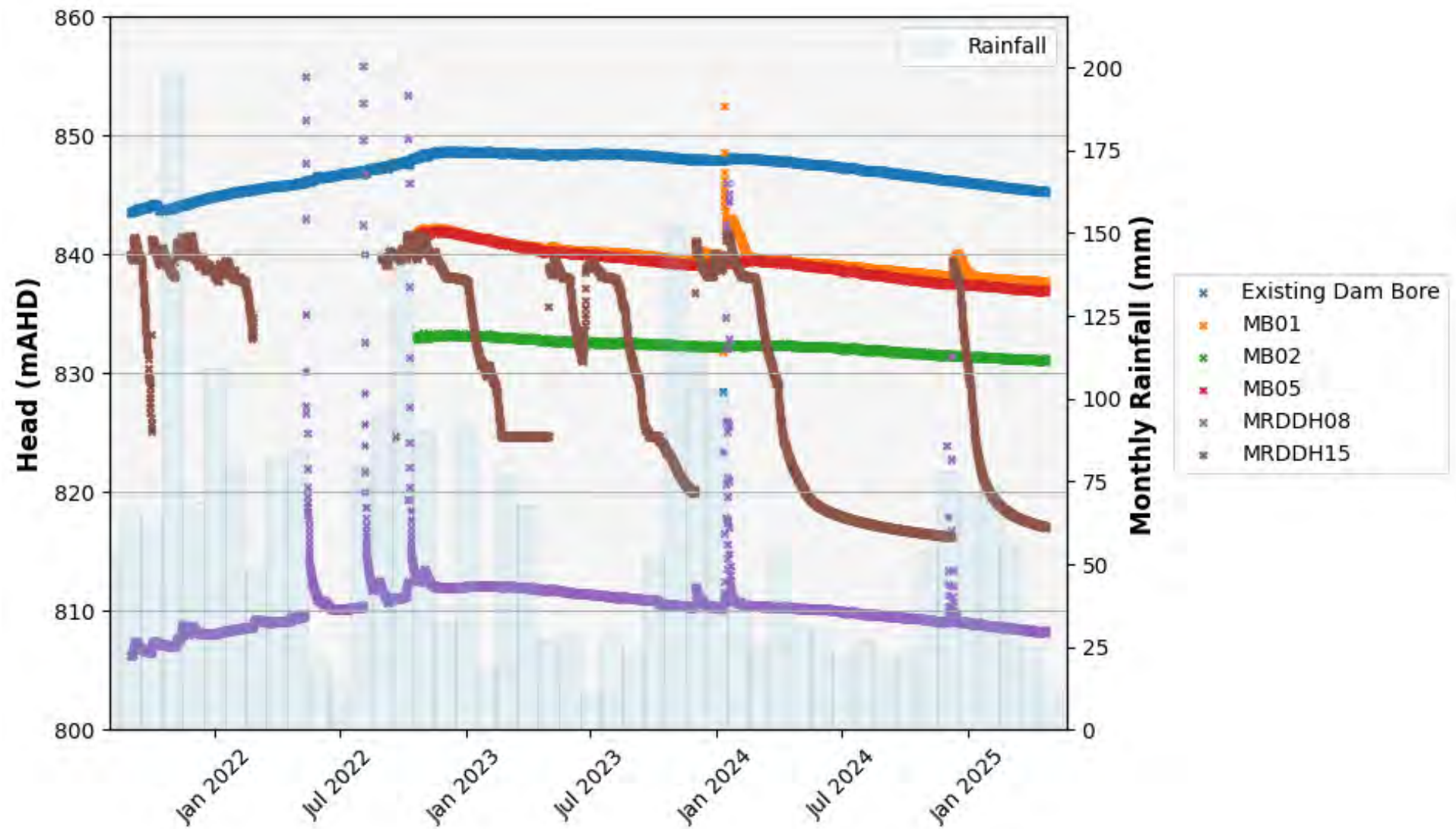
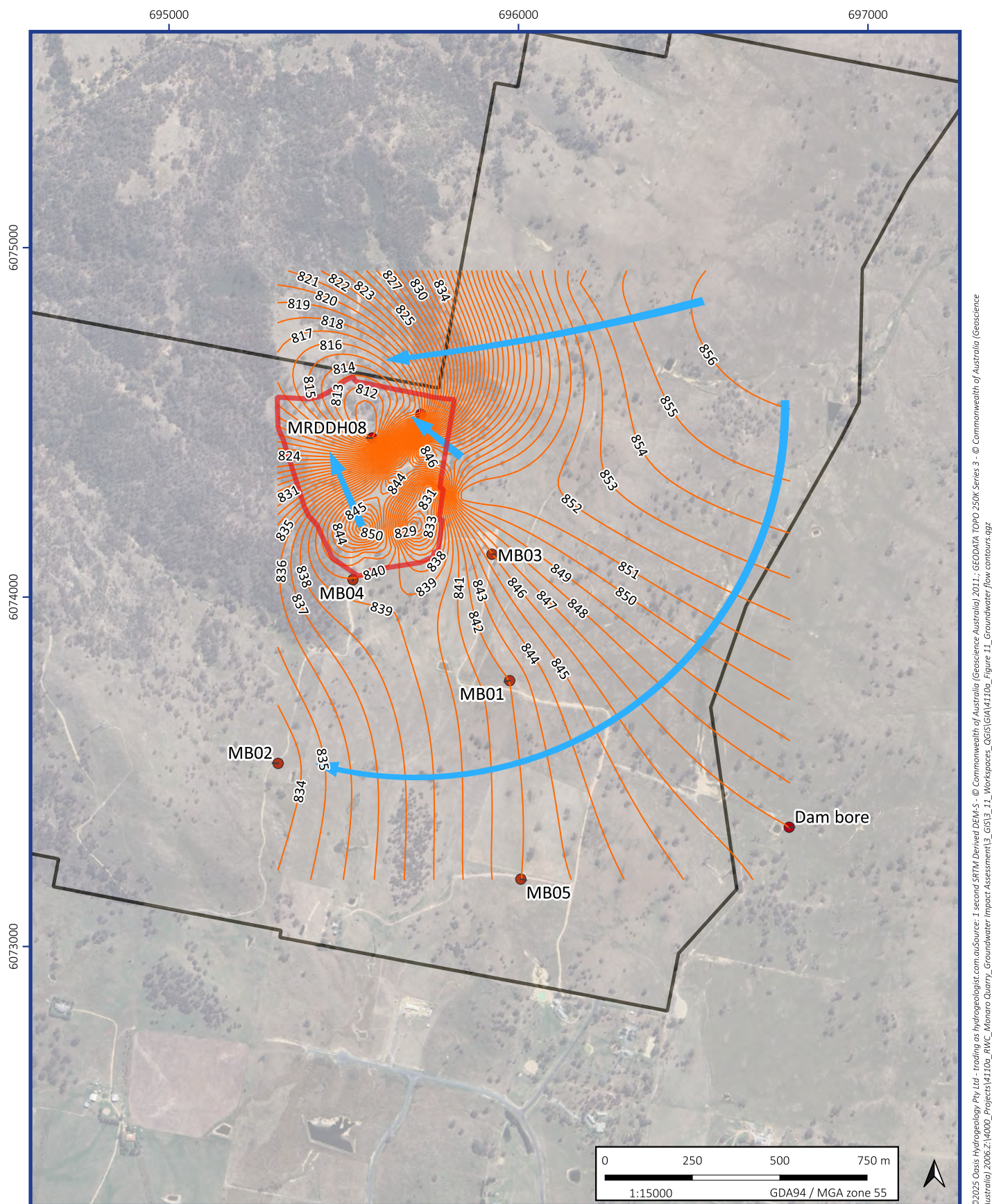


Figure 10 Project groundwater hydrographs



© 2025 Oasis Hydrogeology Pty Ltd - trading as hydrogeologist.com.au Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006; 4000_Projects\4110a_Monaro Quarry_Groundwater Impact Assessment\3_GIS\3_11_Workspaces_GIS\4110a_Figure 11_Groundwater flow contours.gxd

Legend

Groundwater flow contours

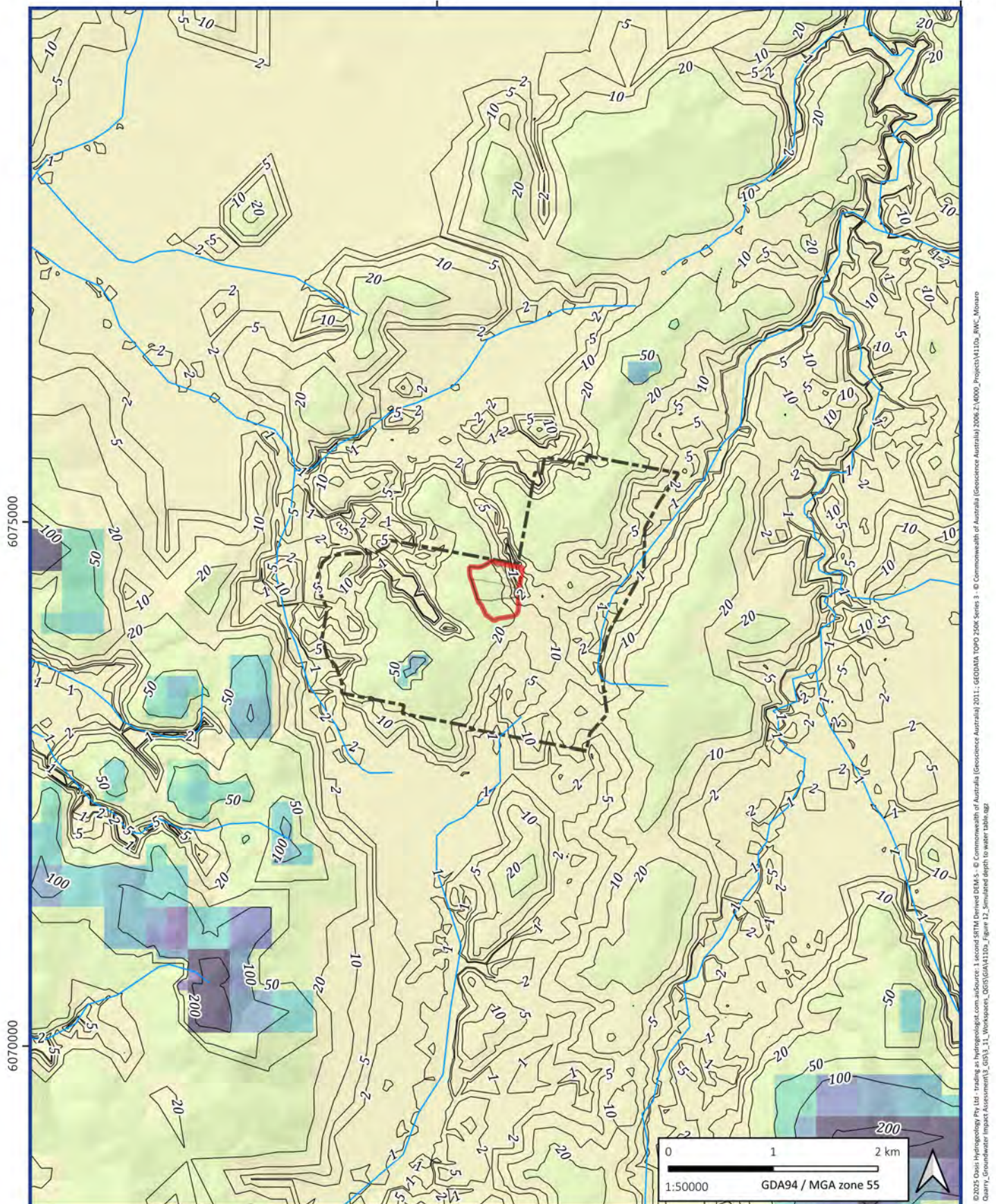
(4110a) Monaro Rock Quarry - Groundwater Impact Assessment

Figure 11

26/05/2025

- Monitoring bore
- ➡ Flow vector
- Head contour (mAH)
- Project boundary
- ▭ Monaro quarry





Legend

Simulated depth to groundwater table

(4110a) Monaro Rock Quarry - Groundwater Impact Assessment

Figure 12

16/05/2025



— Depth contours (mbgl)	0 - 20	60 - 80	120 - 140	180 - 200
— Project boundary	20 - 40	80 - 100	140 - 160	
□ Monaro quarry	40 - 60	100 - 120	160 - 180	

5.3. Hydraulic parameters

Within the Project site, field studies were conducted at the Project monitoring bores and the Existing 'Dam' bore in January 2024 to obtain estimates of local hydraulic conductivity. These studies comprised constant head tests (CHT) at MB01, MB03 and MB04, falling head tests (FHTs) at MB02 and MB05, and a pumping test at the Existing 'Dam' bore. A CHT was also attempted at MRDDH08, however this was unsuccessful due to rapid rate of water flow out of the bore making testing impossible. This indicates the presence of a feature above the standing water level with a high hydraulic conductivity. A high bulk hydraulic conductivity value can therefore be inferred for at this drill hole. Results from the field studies are summarised in Table 7 and the distribution of estimated hydraulic conductivities is presented as Figure 13. These results were used to inform the parameter ranges included in the numerical groundwater model.

Excluding MRDDH08, the monitoring bores all exhibit low to moderate permeability, ranging from 1.7×10^{-3} m/d to 0.14 m/d (Table 7). The Deakin Volcanics and Colinton Volcanics (Section 3.4) at the Project site, are described respectively as comprising interbedded volcanoclastic and sedimentary units; and massive and foliated dacitic ignimbrite with sedimentary interbeds (Graham Lee & Associates Pty. Ltd., 2021). The low to moderate permeability of the bores (Table 7) suggests that the Deakin Volcanics and Colinton Volcanics act as aquitards with localised fractures providing increased hydraulic conductivity.

These hydraulic conductivity values (Table 7) are conceptualised to reflect the hydraulic properties of a fractured basement. Hence, the bulk hydraulic conductivity of the basement (including fractured and unfractured) is expected to be significantly lower than these values.

Given the hard rock geology at the site it is likely that the hydraulic conductivity of both the Colinton Volcanics and Deakin Volcanics will reduce with depth below ground. This concept occurs due to the increased pressure at depth which closes fractures and reduces hydraulic conductivity.

Table 7 Summary of hydraulic conductivity data

Bore ID	Hydrostratigraphic unit	SWL (mbtoc)	Screened interval (mbGL)	FHT Hvorslev K (m/day)	FHT Bouwer & Rice K (m/day)	CHT K (m/day)	Pump Test - Cooper and Jacob K (m/day)
MB01	Colinton Volcanics	17	44.0-50.0	-	-	0.014	-
MB02	Deakin Volcanics	22	44.5-47.5	0.12	0.14	-	-
MB03	Colinton Volcanics	Dry	47.5-50.5	-	-	0.0017	-
MB04	Deakin Volcanics	Dry	44.0-50.0	-	-	0.072	-
MB05	Colinton Volcanics	7	30.5-33.5	0.11	0.098	-	-
MRDDH08	Deakin Volcanics	58	81.4-86.6	-	-	X	-
MRPDH15	Deakin Volcanics	2.91	38.1-43.3	-	-	0.10	-
Existing 'Dam' bore	Colinton Volcanics	11	unknown	-	-	-	0.0071

Note: X - a constant head test was attempted at MRDDH08 however the bore could not be filled to the top of the casing.

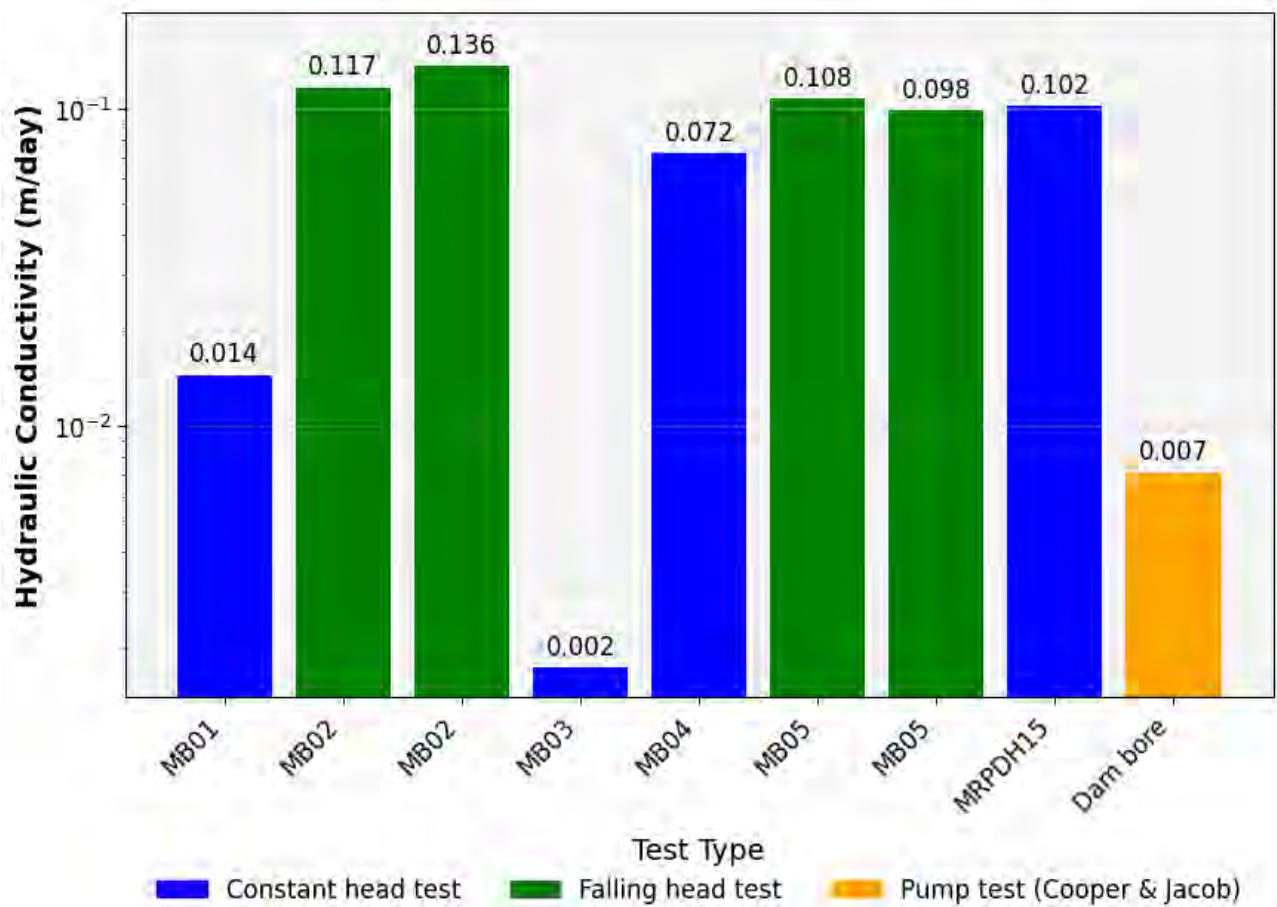


Figure 13 Hydraulic conductivity field measurements

5.4. Groundwater quality

Groundwater quality data provides useful information on the hydrogeological regime, as it is influenced by interaction with the aquifer matrix, and groundwater recharge/discharge processes. Table 8 presents a summary of the water quality results.

Most groundwater bores within the Project site have a neutral to slightly acidic pH, brackish to moderately salinity, with low concentrations of metals, metalloids, and other solutes. The exception to this is MRDDH08 and MRDDH15 which has the lowest concentrations of metals, metalloids, and other solutes. Including low salinity with electrical conductivity values at 121 $\mu\text{S}/\text{cm}$ and 133 $\mu\text{S}/\text{cm}$ respectively and very low chloride values at 3 mg/L and 4 mg/L, respectively.

The groundwater is likely derived from rainwater as the chloride concentrations are less than 10 mg/L, and the electrical conductivity is fresh. This is supported by the groundwater level responses to rainfall events hydrographs shown in Figure 10, indicating an influx of water during recharge events.

Figure 14 provides a piper diagram illustrating the ionic composition of the groundwater samples collected within the Project site. This facilitates categorising water based on the normalised, relative proportion of each major cation and anion. Piper plots are useful for assessing groundwater mixing and evolution (e.g., through water-rock interaction) and identifying potential zones of groundwater recharge and discharge. All bores are within the dominant cation anion, calcium magnesium bicarbonate type. However, MRDDH08 and MRDDH15 have lower cations and anions concentrations compared to other bores.

Salinity is a key constraint to the usability of groundwater resources for productive applications such as potable supply, irrigation, stock watering and industrial applications. If waters with elevated salinity levels are used for incompatible purposes or applications it may result in impacts to agricultural productivity, health, and the environment.

A categorisation scheme for salinity proposed by the United Nations Food and Agriculture Organisation (FAO, 2013) is presented in Table 9. Excluding MRDDH08 and MRDDH15, the groundwater salinity has been categorised using these criteria. At the Project site, salinity data has been observed between 1,121 mg/L at MB02 (brackish) and 2253 mg/L at MB05 (moderately saline).

Table 8 Summary of groundwater quality data

Sample location		MB01	MB02	MB05	MB25	MRDDH08	MRDPH15	Existing 'Dam' bore	Units
Major cations (mg/L)	Calcium	140	150	130	130	8.4	14	170	mg/L
	Magnesium	<0.5	31	150	150	2	1	80	mg/L
	Sodium	71	41	130	130	10	12	72	mg/L
	Potassium	29	3	5.3	5.2	4	1	2	mg/L
Major anions (mg/L)	Sulphate	21	3	39	40	3	1	22	mg/L
	Chloride	13	72	320	320	3	4	270	mg/L
	Hydroxide as CaCO ₃	400	<5	<5	<5	<5	<5	<5	mg/L
	Carbonate as CaCO ₃	92	<5	<5	<5	<5	<5	<5	mg/L
	Bicarbonate as CaCO ₃	<5	510	670	660	37	60	510	mg/L
Metals (Dissolved) (µg/L)	Aluminium	860	10	<10	<10	120	340	<10	µg/L
	Arsenic	<1	<1	<1	<1	<1	<1	<1	µg/L
	Boron	<20	<20	<20	<20	<20	<20	<20	µg/L
	Cadmium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	µg/L
	Chromium	32	<1	<1	<1	<1	<1	<1	µg/L
	Cobalt	<1	<1	<1	<1	1	1	<1	µg/L
	Copper	34	<1	1	1	100	5	<1	µg/L
	Iron	90	220	<10	10	260	440	20	µg/L
	Lead	<1	<1	<1	<1	<1	<1	<1	µg/L
	Manganese	<5	230	37	38	110	72	21	µg/L
	Mercury	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	µg/L
	Molybdenum	38	<1	<1	<1	3	5	<1	µg/L
	Nickel	7	3	7	7	62	29	<1	µg/L
	Selenium	2	<1	<1	<1	<1	<1	<1	µg/L
	Zinc	3	13	20	20	120	23	2	µg/L
Nutrients (mg/L)	Nitrate as N	0.13	0.46	1.4	1.2	3.6	0.073	0.85	mg/L
	Nitrite as N	15	<0.005	0.007	<0.005	<0.005	<0.005	<0.005	mg/L
	Ammonia as N	0.091	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	mg/L
	TKN	0.7	1	0.7	0.5	0.7	0.6	0.4	mg/L
	Phosphorus - Total	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	<0.05	mg/L

Sample location		MB0 1	MB0 2	MB0 5	MB2 5	MRDDH 08	MRDPH 15	Existing 'Dam' bore	Units
Physical parameters	pH (lab)	11.8	7.0	6.8	6.9	6.6	6.1	6.9	-
	pH (field)	11.9	6.8	6.7	6.7	6.4	6	6.8	-
	EC (lab)	2100	1100	2300	2300	120	130	1800	µS/cm
	EC (field)	2245	1121	2253	2253	121	133	1810	µS/cm
	TDS (grav)	720	670	1800	1700	120	240	1200	mg/L

Table 9 Salinity Classification (FAO, 2013)

Salinity classification	TDS concentration (mg/L)
Fresh water	<500
Brackish (slightly saline)	500 to 1,500
Moderately saline	1,500 to 7,000
Saline	7,000 to 15,000
Highly saline	15,000 to 35,000
Brine	>35,000

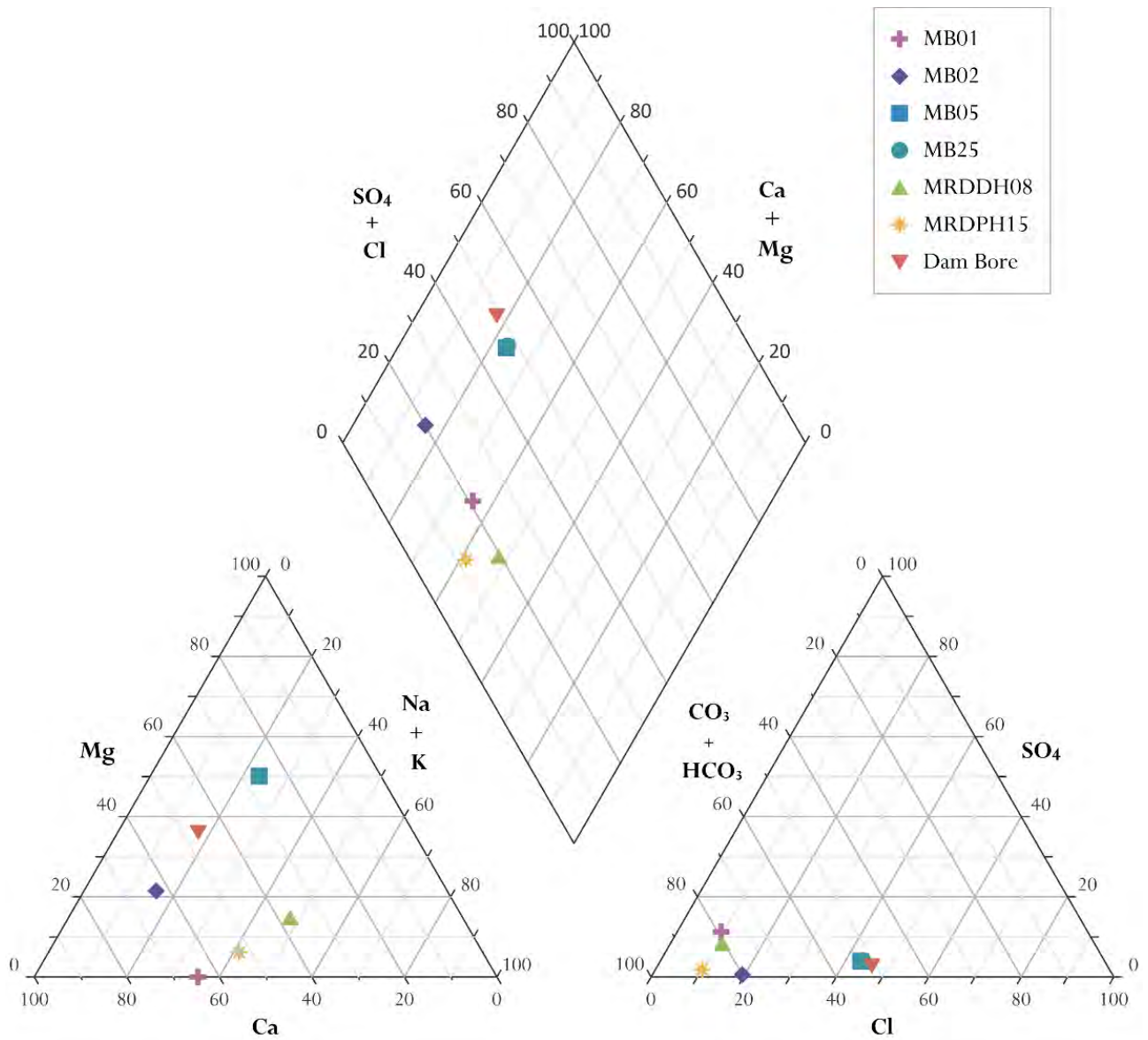


Figure 14 Piper diagram

5.5. Groundwater yield and use

A desktop assessment of registered bores has been carried out (see Section 4.1) and these bores are shown in Figure 7. The landholders of the closest registered bores (GW402921, GW402076 and GW402075) have been contacted to enable further data to be collected from the bores however access was refused.

The Colinton Volcanics (dacitic tuff) supports numerous private groundwater supply bores. These private groundwater supply bores are used for stock water supply and irrigation purposes (Figure 7). The closest of these private groundwater supply bores is located approximately 1.5 km from the extraction area.

There is generally a lack of private groundwater supply bores within the Deakin Volcanics.

5.6. Groundwater dependent ecosystems

The presence of groundwater dependent ecosystems (GDEs) in the Project site was assessed by Capital Ecology (2025) in the Project Ecology Assessment. The following spatial data resources were assessed:

- The GDE Ecological Value (HEAVE) spatial database, which categorises the ecological value of each groundwater dependent vegetation community from very high to very low. No vegetation in the Project site is mapped on this database.
- The GDE Atlas, which maps the potential for groundwater/ecosystem interaction. No terrestrial GDEs or terrestrial Inflow Dependent Ecosystems (IDE) are recorded in the Project site. No Subterranean GDEs are recorded in the Project site. Rock Gully Creek and Four Mile Creek, which occur in the Project site but outside the development footprint, are identified as having a high potential to support aquatic GDE that are likely to be inflow dependent. These areas of high potential aquatic GDEs are presented as Figure 7.
- The Spatial Layer of Probable Vegetation Groundwater Dependent Ecosystems in NSW, which identifies vegetation communities that have a probability of being a GDE. Probability categories are limited to high, medium, low, and non-GDEs
 - Areas that do not support a canopy have low or no GDE probability.
 - Patches of PCT3376 are identified as having moderate GDE probability. Mapped areas are restricted vegetation in the western half of the Project site (Figure 7).
 - Patches of PCT3375 are identified as having low GDE probability. Mapped areas are restricted vegetation in the western half of the Project site (Figure 7).

With respect to the above, none of the vegetation in the Project site has a high probability of being a GDE. Furthermore, there is no evidence of springs, swamps, or groundwater baseflow to creeks on the subject land or adjacent to it (Strategic Environmental and Engineering Consulting, 2025). Therefore, it is unlikely that there are GDEs within Four Mile Creek or Rocky Creek given the absence of permanent flow.

5.7. Numerical groundwater modelling

A 3D numerical groundwater flow model was developed using MODFLOW-6 software to represent the conceptual hydrogeological model and hydrogeological regime. A detailed description of the modelling methodology is provided in Appendix C. The Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012) were considered throughout the modelling process.

A two-layered geological model was used to represent site hydrostratigraphy in the groundwater model. This layering comprised a weathered rock aquifer (layer 1) and underlying fresh basement rock aquifer (layer 2). Initial modelling indicated that this simplification of site hydrostratigraphy was appropriate as vertical variations in properties is relatively low and minimal differences in observed data and model responses across Deakin volcanics and Colinton volcanics.

The model domain extends approximately 20 km north-south and 20 km east-west, with the Project site located in the centre of the model domain. Physical structure of the model was based on the captured DEM with 5 m resolution and 30 m SRTM (Shuttle Radar Topography Mission). A 40 m uniform thickness was used for the base of weathering, corresponding to the base of layer 1. This is based on the maximum observed depth of weathering from the extensive geological investigations undertaken within the Project site.

For this assessment, it was necessary to perform a transient (time-variant) calibration which considered the change in groundwater levels and flow from pre-development conditions up to and including current (January 2024) conditions. The groundwater flow model was calibrated to transient groundwater levels from six observation sites, where transient data was available. A detailed description of the calibration method is provided in Appendix C.

The calibration achieved a 2.74% scaled root mean squared (SRMS) error for calibration targets, which is within acceptable limits (i.e., 10%) as recommended by Barnett *et al.* (2012). Furthermore, the calibrated groundwater levels and flow patterns replicate measured data and groundwater trends. The model calibration is therefore robust and fit for purpose.

The calibrated groundwater model was used to predict groundwater inflows and changes in groundwater levels in response to the open cut quarrying and associated well pumping at the Project. No other groundwater impacting activities were simulated in the model (i.e. no cumulative impact).

Uncertainty analysis was performed to assess the degree of uncertainty surrounding model parameterisation and subsequent predictions. Appendix C provides a detailed discussion of the uncertainty analyses undertaken. The following sections describe the predictions of the groundwater model.

The 3D numerical groundwater flow model was peer reviewed by Neil Manewell of Manewell Groundwater. Neil has over 15 years' experience as a hydrogeologist and groundwater modeller. The peer review was carried out in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012). The peer review report is provided in Appendix D.

6. Impact assessment

6.1. Overview of quarrying

The Project involves the development of the extraction area (Figure 2) over thirty (30) years of quarrying operations. Stages 1, 2 and 3 of the quarrying operations will be excavated down to a minimum elevation of 853 mAHD. Based on groundwater level data from the site (Figure 11 and Figure 12), the base elevation of Stages 1, 2 and 3 will be above the groundwater table and are highly unlikely to intersect groundwater. Therefore, it is likely that only Stage 4 of the proposed quarrying operations (minimum excavated elevation of 795 mAHD) will intersect the groundwater table and will result in potential impact and take of groundwater.

A groundwater supply bore is also proposed as part of the Project water supply. This bore is to be located within the site infrastructure area and is expected to supply a maximum rate of 1 L/s to the Project water demand.

6.2. Quarrying effects on groundwater

Based on the available excavation schedule for quarrying operations and the available groundwater level data, it is assessed that only the Stage 4 quarrying operations will intersect the groundwater table. Excavation for Stages 1, 2 and 3 will remain above the groundwater table. The maximum excavated depth (during Stage 4) is greater than 50 m below the groundwater table and this occurs within the deepest (central) part of the excavation area.

The low to moderate permeability of the geology would be expected to generally constrain the drawdown resulting from the Project around the excavation area. However, there would likely be high potential for this drawdown to propagate some hundreds of metres from the pit crest. Drawdown will likely also be influenced by an assumed reduction in permeability with depth, variable topography and a sloping groundwater table.

There are 70 registered bores within 3 km of the site boundary. It is likely that some of these private landholder bores may experience some measurable drawdown over the life of the Project associated with Project development. The predicted extent of drawdown has been modelled and the potential for impact exceeding the minimal impact considerations for aquifer interference activities (Table 3) has been assessed in Section 6.4.

6.3. Groundwater modelling predictions

6.3.1. Drawdown during quarrying operations

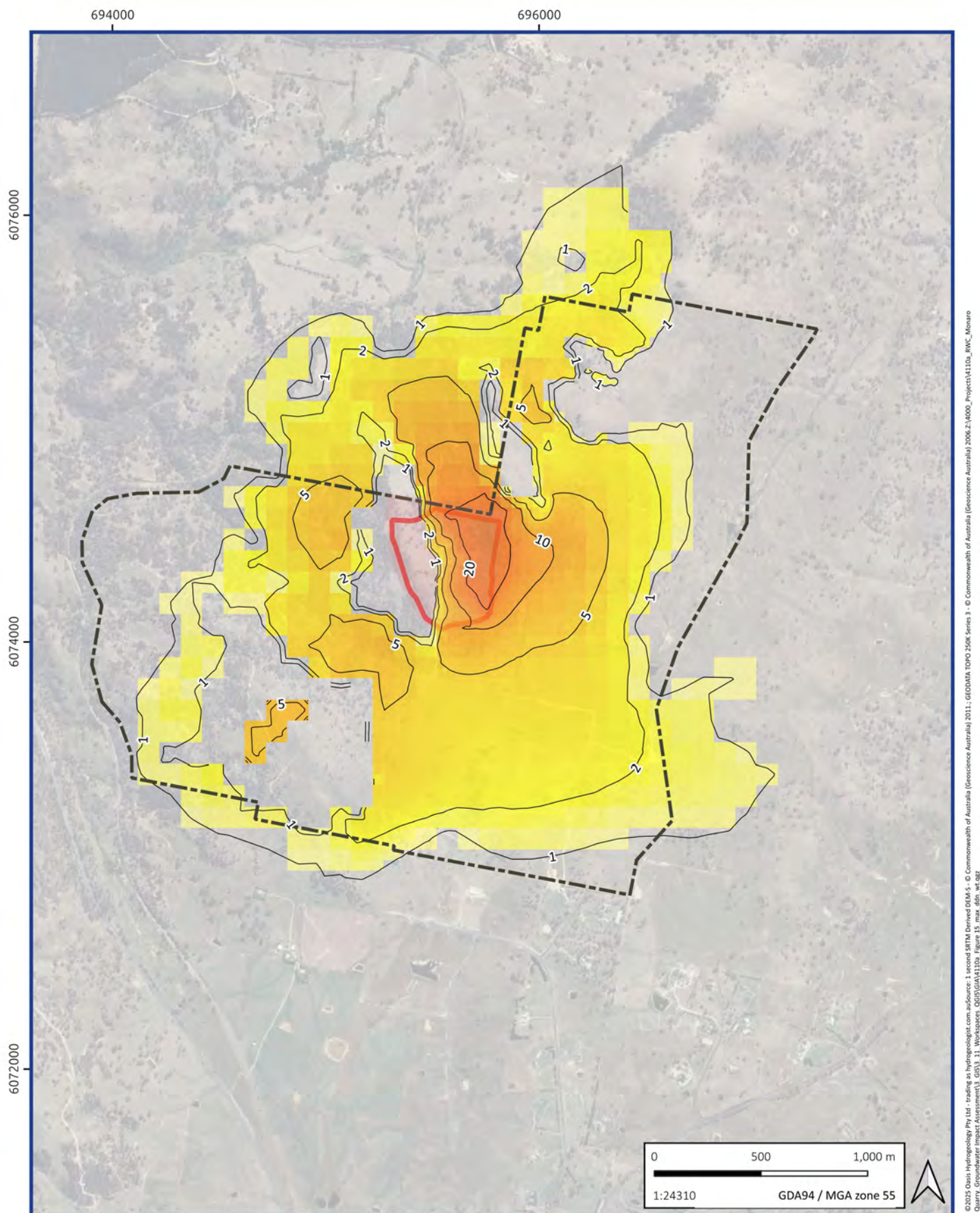
Groundwater assessments are typically based on the zones of maximum drawdown and depressurisation at the end of quarrying operations. However in this assessment, drawdown or depressurisation zones represent the maximum predicted drawdown or depressurisation on the baseline groundwater conditions at any time in the life of the Project, hence removing any spatial or temporal bias from the quarrying schedule or quarry plan from the predictions.

This approach is appropriate and conservative for assessing the effects of quarrying on the groundwater regime and ensures that the potential worst-case impacts on groundwater users and sensitive environmental features are assessed.

For the purposes of the Project groundwater assessment, the limit of the zone of depressurisation or drawdown is conservatively defined by a predicted 1 m change in the elevation of the unconfined groundwater table. These pressure and water level changes were adopted because they represent the reasonable limit of precision that can be inferred from groundwater modelling.

The maximum predicted drawdown on the groundwater table, weathered rock (layer 1) and basement rock (layer 2) are presented as Figure 15, Figure 16 and Figure 17, respectively. Within the groundwater table and weathered rock, the maximum drawdown magnitude is predicted to be less than 40 m and is localised to the eastern portion of the extraction area. The zone of impact for the groundwater table is not predicted to extend further than 1 km away from the site boundary. In the basement rock, drawdown is centred around the Project water supply bore, decreasing radially with distance from the bore. The zone of impact for the deeper basement rock is not predicted to extend further than approximately 2.2 km from the extraction area.

Groundwater monitoring will be undertaken during quarrying operations to confirm the groundwater drawdown predictions and identify any unexpected changes in groundwater levels. Section 7 describes the proposed groundwater monitoring program and management measures.



Legend

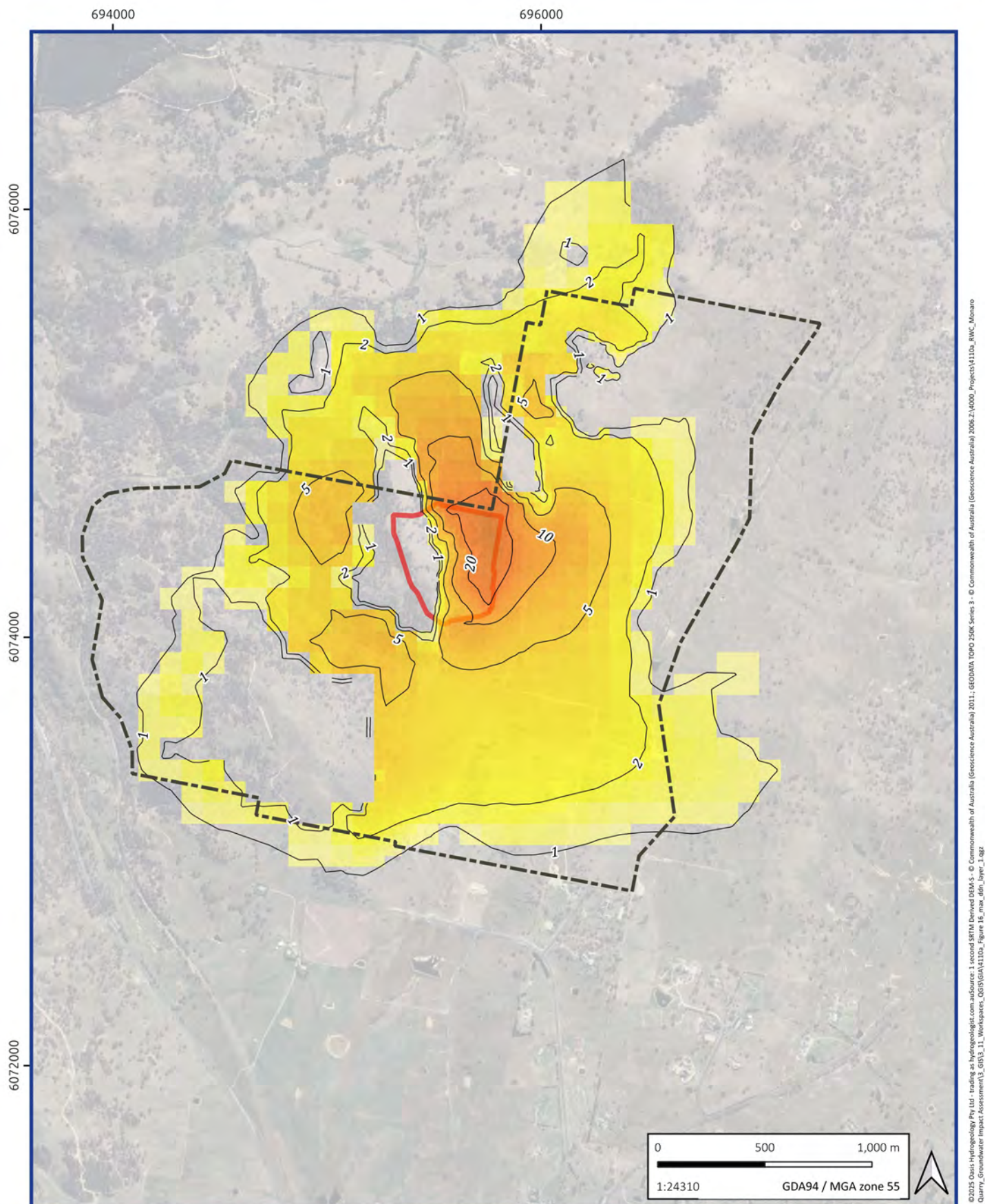
- Drawdown contour (m)
 - Project boundary
 - Monaro quarry
- | Drawdown (m) | |
|--------------|---------|
| 0 - 1 | 5 - 10 |
| 1 - 2 | 10 - 20 |
| 2 - 5 | |

Maximum predicted project drawdown on water table

(4110a) Monaro Rock Quarry - Groundwater Impact Assessment

Figure 15

20/05/2025



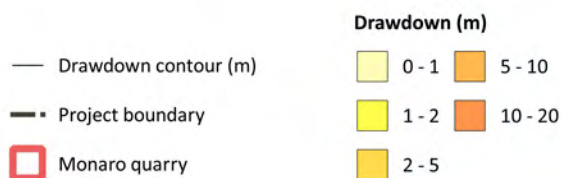
Legend

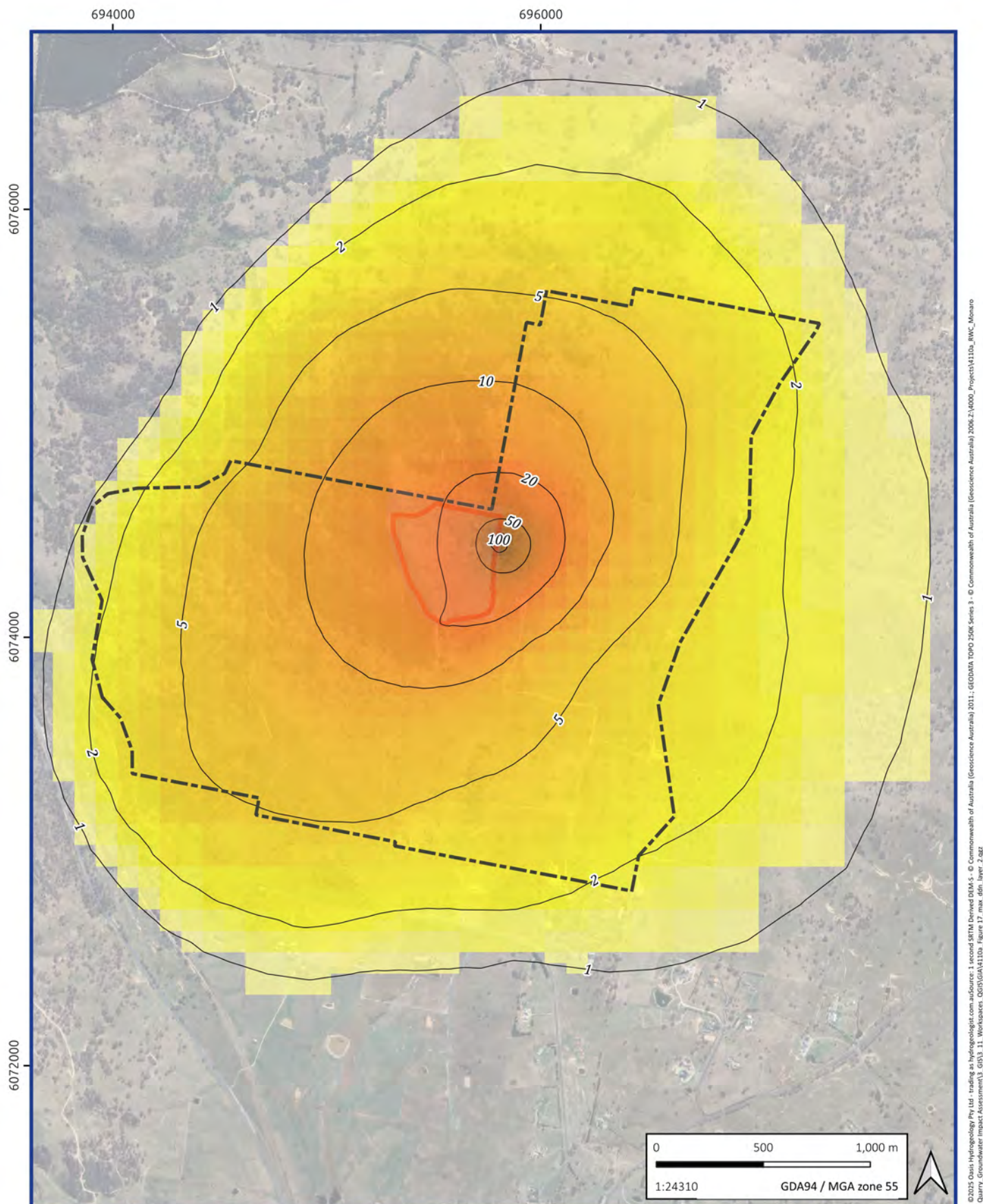
Maximum predicted project drawdown on weathered rock (model layer 1)

(4110a) Monaro Rock Quarry - Groundwater Impact Assessment

Figure 16

20/05/2025





Legend

Maximum predicted project drawdown on basement rock (model layer 2)

(4110a) Monaro Rock Quarry - Groundwater Impact Assessment

Figure 17

20/05/2025



6.3.2. Groundwater take

The predicted groundwater inflow rates represent the theoretical volume of direct groundwater take from the groundwater regime. The actual volume of groundwater pumped from the Project extraction area will be less than the inflows predicted by the numerical model, as a large component of the groundwater inflow will be lost to evaporation, which is not accounted for by the model.

Modelled groundwater inflow rates to the Project extraction area are presented in Figure 18. The calibrated model predicts that the Project's direct groundwater take will peak rapidly to approximately 50 m³/day (18.25 ML per annum) during dewatering of the Project extraction area. As the groundwater table is simulated below the quarried elevation throughout Stages 1 to 3, pit inflows are not predicted until the commencement of Stage 4. Predicted inflows then gradually decrease over the life of the Project, to a rate of approximately 29 m³/day (10.6 ML per annum) at the end of the Project quarrying operations.

Appendix C discusses the uncertainty analysis carried out on the numerical groundwater model. Figure 18 also presents the uncertainty associated with the predicted groundwater inflow rates. The 10th, 33rd, 67th and 90th percentile groundwater inflow rates from the uncertainty analysis are predicted to be 24.8, 62.7, 118.9 and 240.4 m³/day. These inflow rates are equivalent to 10.9, 22.9, 43.4 and 87.7 ML per annum, respectively.

The groundwater inflow rates predicted by the model assume a groundwater supply bore is active as part of Project development. The groundwater supply bore is assumed to be located within the site infrastructure area. This water supply bore is represented with a modelled extraction rate of 1 L/s. However, actual modelled pumping rates are limited by the availability of water in the model and are presented in Figure 19. The modelled extraction rate of the groundwater supply bore is very conservative, and it is highly likely that demand from the groundwater supply bore will be less than 1 L/s.

Cumulative groundwater take is assessed as the sum of predicted quarry inflow volume and predicted groundwater supply bore extraction volumes. The cumulative direct water take for each model year is summarised in Table 10. The Project is predicted to result in total groundwater take of approximately 916 ML over the life of the Project. The maximum annual cumulative groundwater take for the Project is 42.4 ML.

There is no predicted indirect groundwater take for the Project. Indirect groundwater take can occur when an aquifer interference activity induces water to flow from another connected groundwater or surface water source. There is no predicted change in modelled baseflow as a result of the Project.

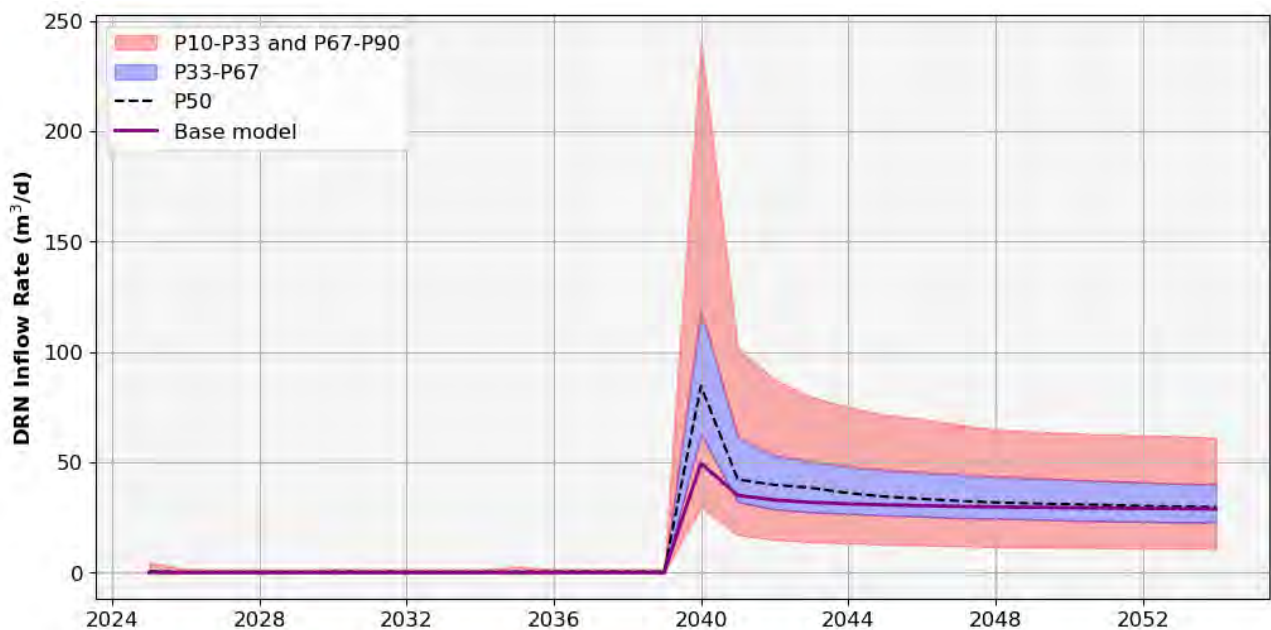


Figure 18 Predicted groundwater inflow rate during quarrying

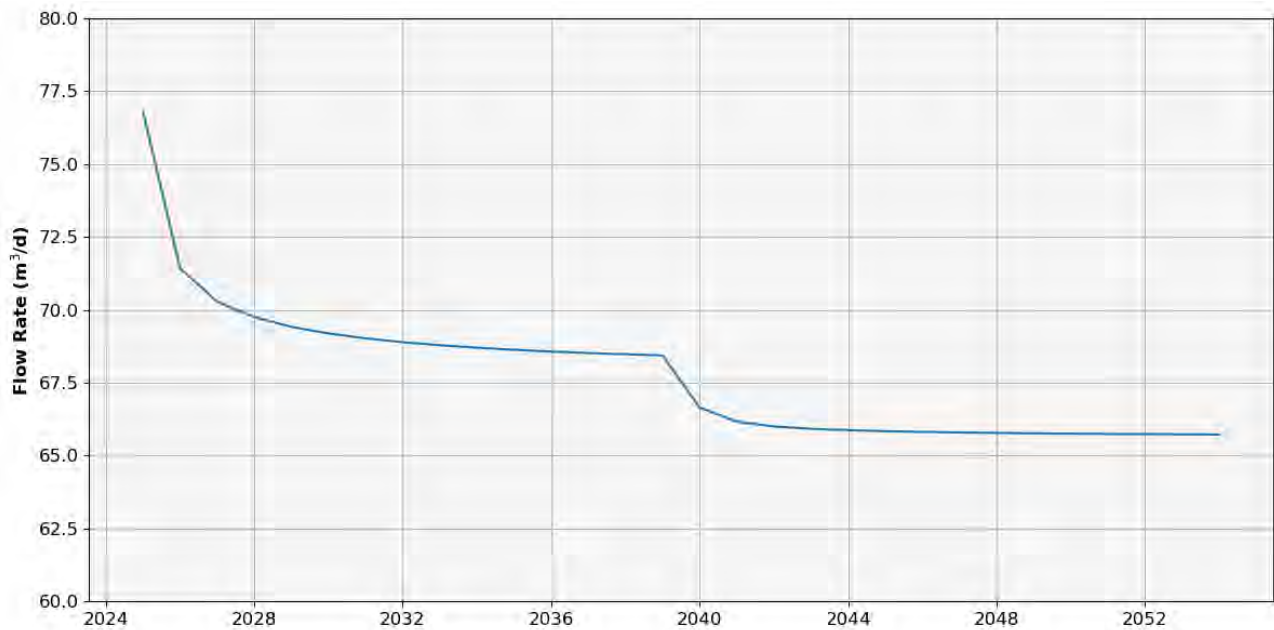


Figure 19 Predicted well water extraction rate

Table 10 Predicted groundwater take

Year	Pit inflow rate (m³/day)	Well extraction rate (m³/day)	Combined rates Pit inflows and well extraction (m³/day)	Combined rates Pit inflows and well extraction (ML/year)
1	0.00	76.81	76.81	28.0
2	0.00	71.43	71.43	26.1
3	0.00	70.28	70.28	25.7
4	0.00	69.75	69.75	25.5
5	0.00	69.42	69.42	25.3
6	0.00	69.19	69.19	25.3
7	0.00	69.02	69.02	25.2
8	0.00	68.89	68.89	25.1
9	0.00	68.79	68.79	25.1
10	0.00	68.70	68.70	25.1
11	0.00	68.63	68.63	25.0
12	0.00	68.57	68.57	25.0
13	0.00	68.52	68.52	25.0
14	0.00	68.48	68.48	25.0
15	0.00	68.44	68.44	25.0
16	49.51	66.65	116.16	42.4
17	34.99	66.17	101.16	36.9
18	32.87	66.00	98.87	36.1
19	31.81	65.92	97.73	35.7

Year	Pit inflow rate (m ³ /day)	Well extraction rate (m ³ /day)	Combined rates Pit inflows and well extraction (m ³ /day)	Combined rates Pit inflows and well extraction (ML/year)
20	31.14	65.87	97.01	35.4
21	30.67	65.84	96.51	35.2
22	30.30	65.81	96.11	35.1
23	30.01	65.80	95.81	35.0
24	29.76	65.78	95.54	34.9
25	29.55	65.77	95.32	34.8
26	29.36	65.76	95.12	34.7
27	29.20	65.75	94.95	34.7
28	29.06	65.74	94.80	34.6
29	28.94	65.73	94.67	34.6
30	28.82	65.72	94.54	34.5

6.3.3. Post closure groundwater conditions

A post closure final void is proposed for the Project. Post extraction operations, the void left behind by quarrying will gradually fill with water, forming a final void lake. The water inputs to the final void will be rainfall, runoff and groundwater inflows. The water outputs to the final void will be evaporative loss and groundwater outflows.

A series of steady state models were developed to evaluate the inflow to the final void at various lake levels (stage elevations). Figure 20 presents the results from these models. This recovery curve indicates that simulated pit inflows are zero when the stage elevation is approximately 809 mAHD. This elevation is consistent with the pre-development groundwater table within the extraction area.

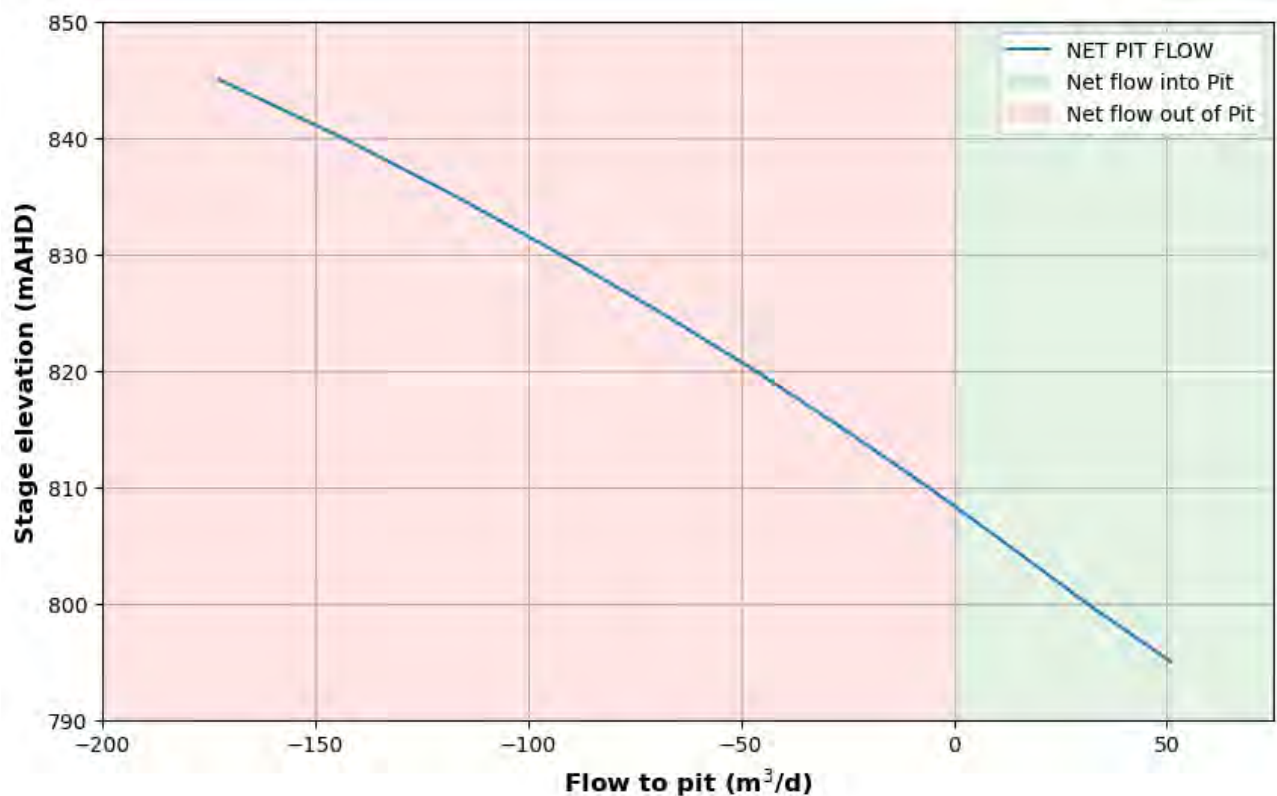
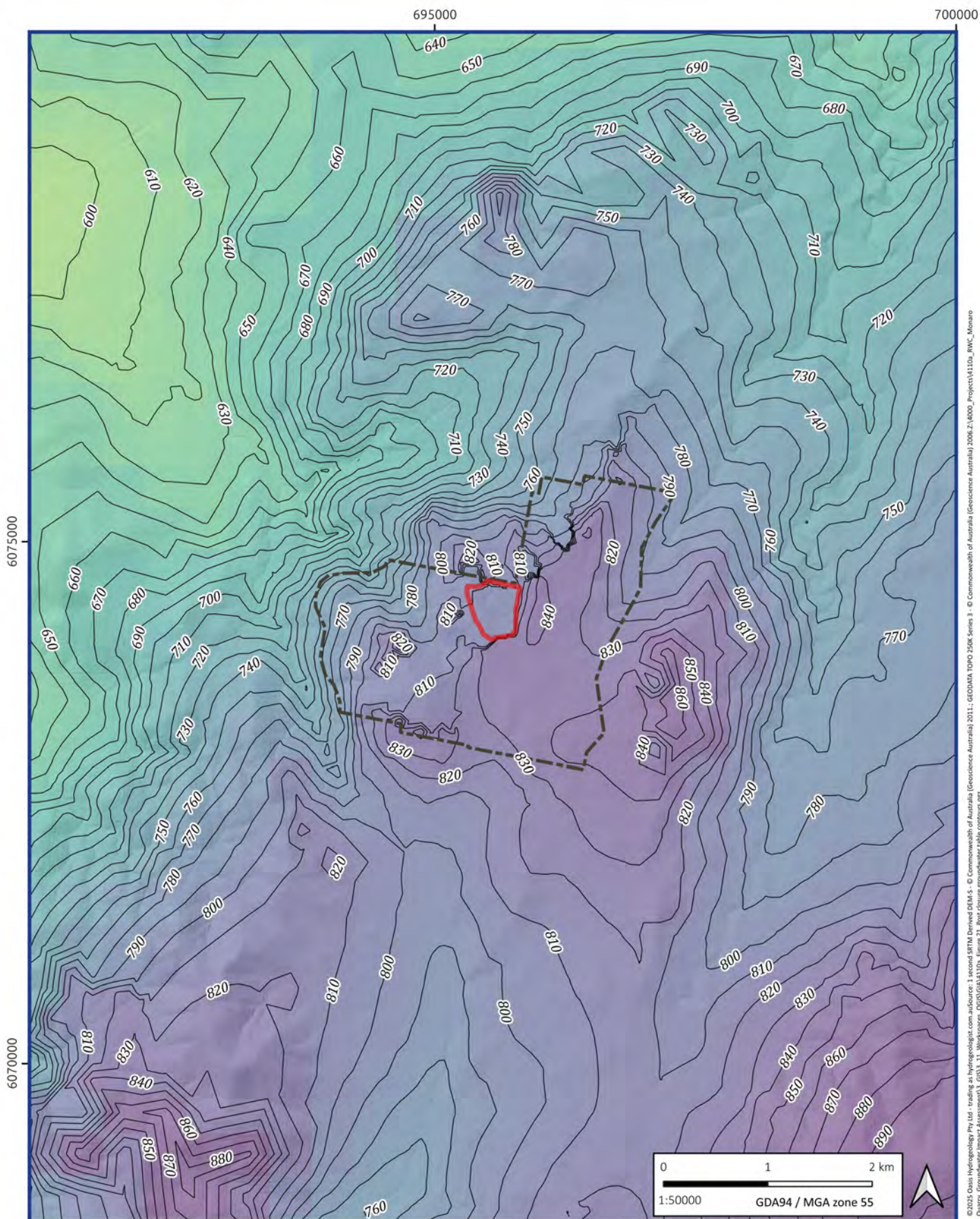


Figure 20 Pit inflow curve

The Project surface water consultant has developed a pit lake water balance model which incorporates the groundwater inflows to the final void, rainfall and runoff contributions to the pit void and catchment, and evaporative losses from the developing pit lake. The pit lake recovery curve was incorporated into the groundwater model to assess the post closure groundwater conditions. The pit lake is predicted to stabilise at approximately 800 mAHD. The Project surface water consultant has predicted that the average annual evaporation loss from the pit lake is 89 ML/yr.

Post closure groundwater modelling for the Project shows that with a pit lake elevation of 800 mAHD, flow through conditions are predicted to occur. Groundwater will flow into the pit lake from the eastern side of the final void, and water will be lost to the groundwater system on the western side of the final void. The post closure groundwater table contours are shown in Figure 21.



Legend

Post closure groundwater table contours

(4110a) Monaro Rock Quarry - Groundwater Impact Assessment

Figure 21

20/05/2025

- Head contour (mAHD)
- - - Project boundary
- Monaro quarry

6.4. Project impacts

The predicted effects of quarrying on groundwater levels were used to assess the potential impacts of the Project on groundwater users and the surrounding environment. Potential impacts include:

- impacts on the regulated groundwater resources;
- impacts on groundwater supply bores;
- impacts on surface drainage;
- impacts on Groundwater Dependent Ecosystems; and
- cumulative impacts (i.e., due to operation of the Project and other groundwater users) on creeks, surface water features, ecosystems, and groundwater resources and users.

Section 6.4 describes potential impacts related to predicted changes in groundwater levels.

These potential impacts on groundwater quality are discussed in Section 6.4.1.

6.4.1. Impacts on groundwater resources

As discussed in Section 2.5, the Project site is located within the Lachlan Fold Belt MDB Groundwater Source. Groundwater take from the Lachlan Fold Belt MDB Groundwater Source is managed under the Water Sharing Plan.

Drawdown is predicted to occur associated with groundwater inflows to the extraction area and pumping from the groundwater supply bore within the site infrastructure area. The Project is predicted to result in total groundwater take of approximately 916 ML over the life of the Project, see Section 6.3.2 and Table 10 for a summary of water take associated with the Project for each year of Project development. The maximum annual cumulative groundwater take for the Project is 42.4 ML.

As discussed in Section 6.3.2, the modelled extraction rate of the water supply bore is very conservative, and it is highly likely that actual extraction will be less than 1 L/s. Hence impacts are likely to be over-predicted.

There is no predicted indirect groundwater take for the Project.

As per Section 2.3.1, it is understood that the Applicant currently does not hold any WALs for the Lachlan Fold Belt MDB Groundwater Source. The Applicant is committed to obtaining the necessary WAL prior to undertaking operations and will seek to have this commitment conditioned into the Development Consent.

Post quarrying, the final void will be allowed to fill with water, forming a pit lake. The evaporative losses from the pit lake will require a take of 89 ML/yr into perpetuity. The Applicant is committed to obtaining the necessary WAL to account for this post closure take of groundwater, and will seek to have this commitment conditioned into the Development Consent.

6.4.2. Impacts on groundwater users

The NGIS bore database (downloaded November 2024) for ACT and NSW indicates that there are two (2) bores in NSW within the predicted impact zone of the Project (Figure 22). The bores identified as GW402921 and GW402076 are located in NSW, within 2 km of the extraction area. GW402921 and GW402076 are predicted to experience Project related drawdowns of up to 2.1 m and 1.1 m, respectively.

The predicted drawdown at these two bores has been assessed as part of the uncertainty analysis (see Appendix C). Table 11 presents the predicted drawdown at bores GW402921 and GW402076 under the calibrated model and the uncertainty realisations. The calibrated model predictions result in drawdown that sits at the upper end of the uncertainty analysis predictions. Hence, it is likely that drawdown at these two landholder bores will be less than that predicted by the calibrated model.

Table 11 Predicted drawdown – uncertainty analysis

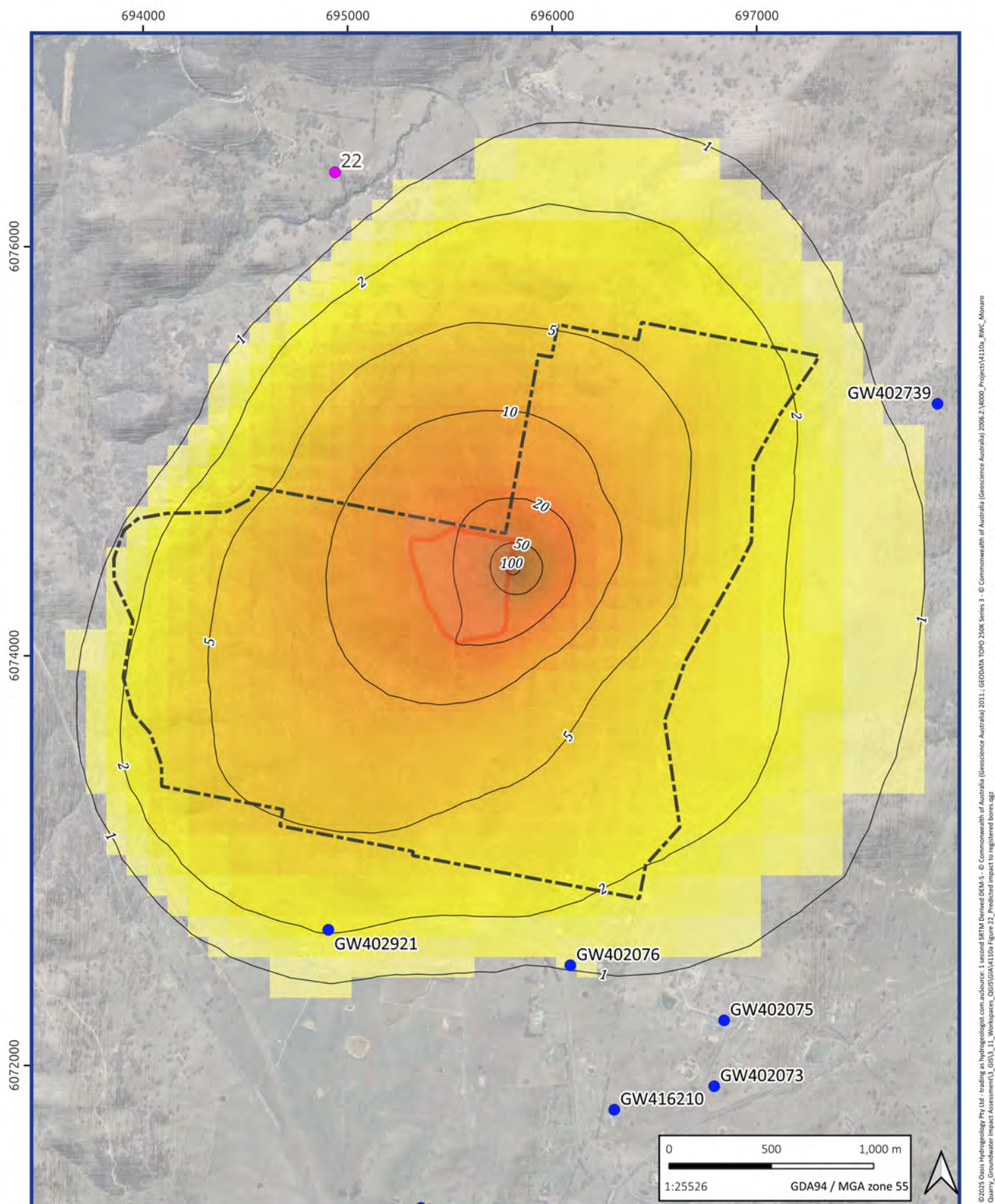
Bore ID	Calibrated	P10	P33	P50	P67	P90
GW402921	2.13	0.21	0.51	0.75	1.13	2.28
GW402076	1.08	0.08	0.26	0.41	0.66	1.39

GW402076 is an irrigation bore, while GW402921 is used for stock and domestic purposes. Bore GW402921 is predicted to experience a 2.1 m drawdown, it is essential to determine the status and purpose of this bore to assess if minimal impact considerations for aquifer interference activities have been reached (Table 3). To date, the landholders of GW402076 and GW402921 have refused access to these bores to understand baseline groundwater conditions (levels and quality).

A bore survey should be conducted to confirm the location of the bore, assess the status, construction, purpose and baseline condition of this bore to determine possible consequences of impact.

The Applicant commits to negotiating make good provisions with the landholder of this bore. The make good provisions should be conditioned to include on-going groundwater monitoring and regular assessment of impacts.

There are no bores in ACT that are predicted to be impacted due to development at the Project.



©2025 Oasis Hydrogeology Pty Ltd - trading as hydrogeologist.com.au Source: 1. second SRTM Derived DEM.s - © Commonwealth of Australia (Geoscience Australia) 2006; 2. 4000 Projects (4110a, RWC, Monaro Quarry, Groundwater Impact Assessment) 3. GDA94 / MGA zone 55; 4. Workspace_0000 (4110a Figure 22, Predicted impact to registered bores.gz)

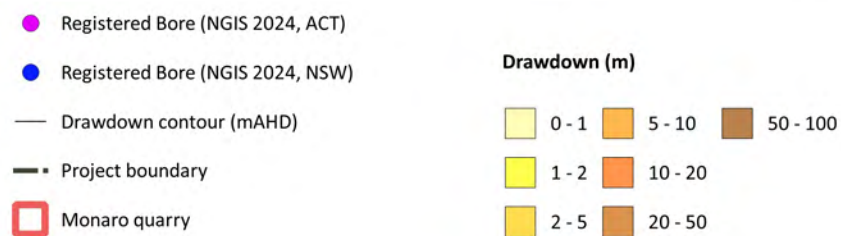
Legend

Predicted Impact to registered bores

(4110a) Monaro Rock Quarry - Groundwater Impact Assessment

Figure 22

20/05/2025



6.4.3. Impacts on surface drainage

As discussed in Section 5.6, there is no evidence of springs, swamps, or groundwater baseflow to creeks on the Project site or adjacent to it (Strategic Environmental and Engineering Consulting, 2025). All creeks within the study area are ephemeral, with no baseflow contribution to stream flow (see Section 3.3).

The numerical groundwater model does not predict any reduction in baseflow over the model domain as a result of the Project. Development of the Project will, therefore, not affect surface drainage in the study area.

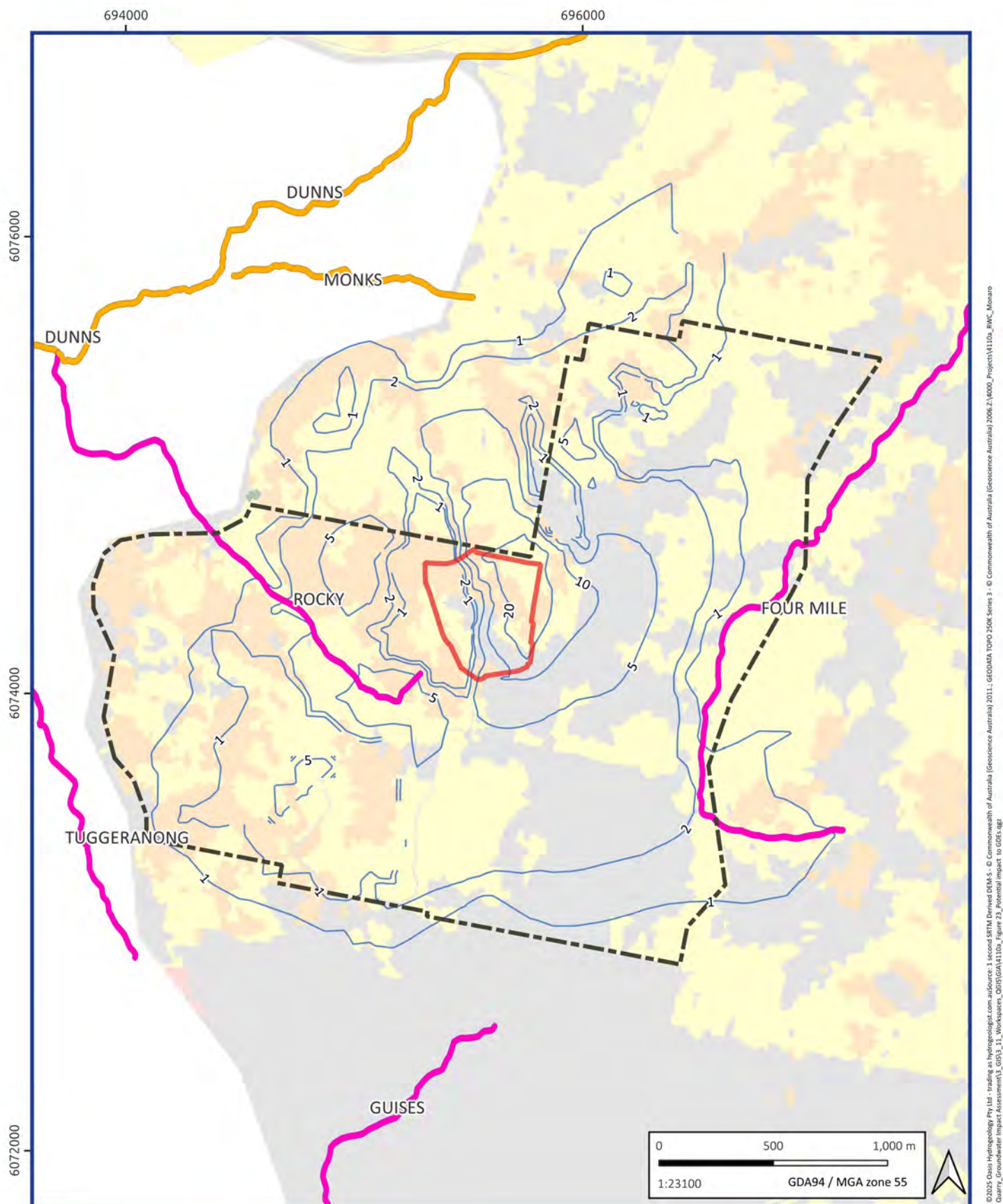
6.4.4. Impacts on groundwater dependent ecosystems

The locations of potential GDEs relevant to the Project site are presented as Figure 23. These GDE locations have been obtained from the BoM Groundwater Dependent Ecosystem Atlas (downloaded November 2024). The mapping indicates two high probability aquatic GDEs exist within the site boundary associated with Four Mile Creek and Rocky Creek. These two high probability aquatic GDEs are located within the drawdown extent of the Project. There are moderate probability aquatic GDEs to the north of the Project site however these are not within the predicted extent of Project drawdown.

As discussed in Section 5.6, none of the vegetation in the Project site has a high probability of being a GDE and there is no evidence of springs, swamps, or groundwater baseflow to creeks on the subject land or adjacent to it (Strategic Environmental and Engineering Consulting, 2025). Therefore, it is unlikely that there are GDEs within Four Mile Creek or Rocky Creek given the absence of permanent flow.

As discussed in Section 5.6, patches of PCT3376 across the western half of the Project site are mapped as having a moderate GDE probability in the Spatial Layer of Probable Vegetation Groundwater Dependent Ecosystems in NSW (Capital Ecology, 2025). Groundwater is predicted to be located at depths between 5 mbGL and 50 mbGL within the majority of the Project site. Where PCT3376 is mapped as having moderate GDE potential, the groundwater table occurs at a depth of approximately 5 mbGL to 10 mbGL. Capital Ecology (2025) have assessed that because an ecological community is more likely to rely on groundwater when it occurs close to the surface, the vegetation west of the Project site would likely be more reliant on soil moisture in the capillary zone and groundwater at the soil-rock interface, rather than on the deeper regional groundwater table.

It is assessed that the Project development is unlikely to impact GDEs.



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Quarry_Groundwater Impact Assessment\3_GDA\3_11_Workspace_QGIS\GDA4110a_Figure 23_Potential impact to GDEs.qgd

Legend

Potential impact to GDEs

(4110a) Monaro Rock Quarry - Groundwater Impact Assessment

Figure 23

20/05/2025

- Drawdown contour (m)
- Project boundary
- Monaro quarry
- Groundwater dependent ecosystems - Aquatic**
 - High potential GDE - from national assessment
 - Moderate potential GDE - from national assessment

6.4.5. Impacts on groundwater quality

Given the inert characteristics of the local host rock and the generally fresh to brackish salinity of the groundwaters, the potential risk of groundwater contamination from Project activities is considered low. The primary risks are associated with potential hydrocarbon contamination during operational activities, such as machinery leaks and refuelling spills. Implementation of a site management plan for handling hydrocarbons would be sufficient to greatly reduce the risk of a groundwater contamination event occurring. Any change in groundwater quality associated with the Project is expected to be negligible and is not predicted to lower the beneficial use category of the groundwater. The Project, therefore, does not exceed the groundwater quality requirement for the minimal impact considerations for aquifer interference activities (Table 3).

6.5. Cumulative impacts

There are no approved activities within 10 km of the Project (in both NSW and the ACT) with the ability to cause aquifer interference and result in the cumulative impact of groundwater. The Project will, therefore, not contribute to any cumulative impacts.

6.6. Aquifer Interference Policy considerations

The minimal impact considerations have been addressed (in bold) within Table 12. It is demonstrated that the Project complies with the majority of AIP requirements for “less productive” groundwater sources. The Project does not contain any “highly productive” groundwater sources.

Table 12 Minimal impact considerations – Aquifer Interference Policy

Category	Water table	Water pressure	Water quality
Less Productive Groundwater Sources	1. 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. No high priority groundwater dependent ecosystems or high priority culturally significant sites have been identified within the Project site or within the extent of groundwater table drawdown. A maximum of a 2 m decline cumulatively at any water supply work. Model predictions show that the maximum predicted drawdown at the closest water supply bore (GW402921) is 2.1 m (see Section 5.5, Section 6.4.2 and Figure 22). 2. If more than a 2 m decline cumulatively at any water supply work then make good provisions should apply. Attempts have been made by the Applicant to engage with the landholder to gain access to the bore with the intent to establish baseline conditions. To date the landholder has refused access to the bore. The Applicant commits to establishing make good provisions with the landholder of the affected bore.	1. A cumulative pressure head decline of not more than a 2 m decline, at any water supply work. Model predictions show that the maximum predicted drawdown at the closest water supply bore (GW402921) is 2.1 m (see Section 5.5, Section 6.4.2 and Figure 22). 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. Attempts have been made by the Applicant to engage with the landholder to gain access to the bore with the intent to establish baseline conditions. To date the landholder has refused access to the bore.	1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. No change in groundwater quality is predicted by the Project.

7. Groundwater monitoring program

It is recommended that all existing Project monitoring bores, as detailed in Table 6 (Section 4.2), be sampled for water quality on a monthly basis over a 12-month period to establish baseline groundwater quality and assess any seasonal effects. Following this initial 12-month period, quarterly monitoring is recommended to evaluate whether quarrying activities are influencing water quality at the monitoring bores. Additionally, it is recommended that high-resolution water level data be retrieved from the dataloggers at monitoring bores during each sampling event. The adequacy of the groundwater monitoring program will be assessed on an annual basis to ensure the frequency of monitoring and parameters are appropriate, and that the Project groundwater monitoring network remains fit for purpose.

No additional groundwater monitoring bores are recommended at this time, as the existing network is considered suitable for confirming baseline trends and verifying groundwater impacts. It is important to note that the Project is not expected to intersect the groundwater table until Stage 4 of quarry development.

Groundwater take from the groundwater supply bore is to be metered to quantify the take of groundwater. Further, any pumpable volumes of groundwater inflow to the extraction area should also be metered. However, the predicted groundwater inflows to the extraction area are low and much of this water will be lost to evaporation.

Subject to accessibility and suitability of the bores, monitoring of private landholder bores GW402921 and GW40276 should be carried out on an annual basis to understand the groundwater level behaviour and quality of the bores. Monitoring of these private bores will enable an assessment of potentially adverse impacts under Make Good Provisions.

Examples of Make Good Provisions on private landholder bores include compensatory water supply to any landowner of privately-owned land whose rightful water supply (groundwater, surface water and/or tank water) is adversely and directly impacted (other than an impact that is minor or negligible) as a result of operations. The compensatory water supply measures must provide an alternative long-term supply of water that is equivalent, in quality and volume, to the loss attributable to the development. Typically if the Applicant is unable to provide an alternative long-term supply of water, then the Applicant must provide compensation to the landowner.

8. Conclusions

The groundwater impact assessment was completed in accordance with the regulatory framework and requirements outlined in Section 2. Site specific groundwater data and long-term groundwater monitoring gathered during the desktop study informed the development of the site conceptual model, which underpinned the design of the 3D numerical groundwater model. This numerical model was used to assess the potential for impacts to groundwater resources and key receptors (i.e., users, surface drainage and GDEs).

The key conclusions of the groundwater assessment are as follows:

- The Project will not impact surface drainage features or sensitive environmental features because:
 - The groundwater table is typically located at depths 5 m and 50 m below drainage features within and adjacent to the Project site and the groundwater table does not intersect the ground surface. Hence, groundwater does not provide local baseflow to the drainage features in the Project site.
 - There are no other identified sensitive environmental features within the Project site and surrounding area.
 - There is no evidence of springs, swamps, or groundwater baseflow to creeks on the Project site or adjacent to it.
- The impact assessment identified the potential for aquifer drawdown exceeding the minimal impact considerations threshold (2 m) at one registered private bore. A baseline assessment of this private bore is recommended to determine the status, purpose and baseline conditions at this bore. The Applicant commits to establishing Make Good Provisions as per the minimal impact considerations outlined in the Aquifer Interference Policy.
- There is a very low potential for groundwater contamination as a result of the Project and no impacts to groundwater quality are predicted to occur.
- Post closure groundwater modelling for the Project shows that a pit lake will develop with an elevation of approximately 800 mAHD. At this pit lake elevation, a flow through system will develop with groundwater entering the pit lake from the east and discharge from the pit lake to the groundwater system to the west. An evaporative loss of 89 ML/year is predicted into perpetuity.

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Appendix A Summary of Registered Bores Within 3 km of the Project site



State bore ID	Easting GDA94/MGA Zone 55 (m)	Northing GDA94/MGA Zone 55 (m)	Bore depth (m)	Status	Drilled date	Purpose
GW416680	696613	6070944	60	Unknown	1/01/2003	Water Supply
GW035176	695358	6071304	45.7	Unknown	1/04/1973	Water Supply
GW414723	696791	6070778	80	In use	1/01/2003	Water Supply
GW405005	699568	6075632	66	In use	22/09/2008	Water Supply
GW404718	695935	6071164	78	In use	25/07/2008	Water Supply
GW414724	698140	6072607	100	In use	24/03/2011	Water Supply
GW414330	698421	6070973	78	In use	23/04/2009	Water Supply
GW404245	696986	6070565	90	In use	2/04/2002	Water Supply
GW414739	696515	6070333	43	In use	9/04/2003	Water Supply
GW411306	699325	6073819	36	In use	22/04/2010	Stock and Domestic
GW414353	699031	6072564	114	In use	11/05/2010	Water Supply
GW416210	696304	6071784	102	In use	7/10/2009	Water Supply
GW400502	698588	6075509	38	Unknown	23/11/1994	Water Supply
GW404828	699046	6076202	36	In use	25/02/2008	Water Supply
GW414351	697832	6070494	63	In use	3/06/2009	Water Supply
GW401683	699913	6075584	121	Unknown	23/05/2001	Water Supply
GW402076	696089	6072490	84	Unknown	26/05/2000	Irrigation
GW402073	696793	6071899	67	Unknown	4/03/2002	Monitoring
GW400503	698713	6075734	60.8	Unknown	28/11/1994	Unknown
GW403929	695614	6070723	66	Unknown	27/04/2007	Water Supply
GW402075	696841	6072221	67	Unknown	4/03/2002	Water Supply
GW067945	698253	6075741	0	Unknown	4/01/1989	Water Supply
GW400504	699388	6076034	60.8	Unknown	5/12/1994	Water Supply
GW401777	699133	6072484	84	Unknown	20/08/2001	Water Supply
GW400813	699672	6076187	54	Unknown	22/04/1998	Water Supply

State bore ID	Easting GDA94/MGA Zone 55 (m)	Northing GDA94/MGA Zone 55 (m)	Bore depth (m)	Status	Drilled date	Purpose
GW414751	696706	6070439	63	In use	17/08/2011	Water Supply
GW414365	697688	6070860	36	In use	23/09/2009	Water Supply
GW404248	696251	6070742	41	In use	25/06/2005	Water Supply
GW402285	698591	6075531	66	Unknown	18/12/2002	Water Supply
GW416428	699958	6076848	78	In use	8/01/2014	Water Supply
GW414757	696672	6069928	37	In use	3/04/2003	Water Supply
GW403664	696347	6070628	50	Unknown	12/09/2006	Unknown
GW414758	696420	6070103	66	In use	9/04/2003	Water Supply
GW414364	697818	6070976	36	In use	3/10/2009	Water Supply
GW401991	699676	6075948	48	Unknown	5/02/1992	Stock and Domestic
GW414681	696957	6070016	55	In use	20/04/2011	Water Supply
GW414408	698150	6070890	54	In use	21/09/2009	Water Supply
GW414392	698393	6070712	78	In use	1/10/2009	Water Supply
GW414721	699031	6077655	94	In use	8/04/2003	Water Supply
GW414704	696449	6070491	53	In use	1/01/2003	Water Supply
GW414373	697672	6070274	114	In use	25/06/2009	Water Supply
GW414386	698238	6070487	96	In use	15/06/2009	Water Supply
GW414688	696842	6070917	57	In use	3/05/2011	Water Supply
GW402921	694906	6072663	84	In use	10/11/2004	Stock and Domestic
GW414699	697032	6070276	77	In use	12/05/2011	Water Supply
GW414766	696419	6071194	60	In use	22/01/2003	Water Supply
GW414812	699533	6077296	60	In use	1/03/2002	Water Supply
GW414765	699075	6073682	5	In use	15/09/2011	Water Supply
GW414393	698600	6071004	78	In use	2/10/2009	Water Supply
GW404566	698357	6073093	42	In use	28/06/1999	Water Supply
GW414689	696973	6070162	42	In use	3/05/2011	Water Supply

State bore ID	Easting GDA94/MGA Zone 55 (m)	Northing GDA94/MGA Zone 55 (m)	Bore depth (m)	Status	Drilled date	Purpose
GW404883	699399	6075783	10	In use	1/11/1991	Water Supply
GW403879	699058	6074090	71	Unknown	30/10/2006	Water Supply
GW404389	699174	6077293	58	Unknown	26/10/1988	Water Supply
GW401352	698743	6075811	78	Unknown	31/12/1991	Water Supply
GW401068	699493	6073854	36	Unknown	21/10/1999	Water Supply
GW404208	698936	6075867	82	In use	7/02/2003	Water Supply
GW404954	698393	6075472	102	In use	11/12/2008	Water Supply
GW404291	696960	6070862	79	In use	26/05/2003	Water Supply
GW414407	697935	6070573	60	In use	4/06/2010	Water Supply
GW400062	698713	6075684	90	Unknown	4/02/1992	Water Supply
GW403198	698299	6072961	60	Unknown	11/12/2001	Water Supply
GW402438	698884	6073295	75	Unknown	26/05/2003	Water Supply
GW402739	697884	6075232	138	Unknown	19/02/2004	Water Supply
GW403582	699070	6074863	42	Unknown	30/10/2002	Unknown
GW402231	698557	6075968	62	Unknown	31/01/1992	Water Supply
GW402298	699627	6076116	85	Unknown	24/03/2003	Water Supply
GW020890	699866	6074441	19.8	Unknown	1/10/1952	Unknown
GW059247	696646	6071399	42	Unknown	1/10/1982	Irrigation
22	694938	6076364	0	Unknown		Water Supply

Appendix B Field Investigation Results

Borehole ID: MB01

Project No.: 2021-GD027

Project Name: Monaro Rock Quarry

Client: Monaro Rock

Site Address: Mates Drive, Royalla, NSW



Ground Doctor Pty Ltd

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SUBSURFACE PROFILE				SAMPLE		CONSTRUCTION	
Depth (m)	Symbol	Description	Depth/Elev.	Sample ID	PID / Odour	Well Diagram	Materials Used
-2							
-1							
0		Ground Surface	0.0				
1		Silty Sandy Clay: Dark brown, moist, fine to medium sand, low plasticity.	2.0				0.7m Stickup protected by Steel Monument Annulus filled with concrete (0-0.2m)
2		Weathered Shale: Light brown and grey, soft, dry.					
3		Weathered Shale Light brown and grey, soft with some clayey lenses, dry.					
4							
5							
6							
7							
8							
9							
10							
11							
12			13.0				
13		Weathered Shale: Light grey and light brown, soft with some clayey lenses, dry.					50mm ID Class 18 uPVC Screw Threaded Blank Casing (-0.7-44.0m) and 2m sump at bottom.
14							
15							
16							
17							
18							
19							
20			21.0				Annulus sealed with cement grout using tremmie pipe positioned at 36m bgl (0.2-38.5m).
21		Shale: Grey, hard, dry.					
22							
23							
24		Minor dust drop during drilling at 24m.					
25							
26		Minor moisture on cuttings at 28m rod change and subsequent rod changes.					
27							
28							
29		Notable dust drop 46-47m and poor cutting returns beyond 46m.					
30							
31							
32		Water injected to help return cuttings at base borehole. When circulation was returned estimated bore yeild was 0.01L/s.					
33							
34							
35							
36							
37							
38							Annulus Sealed with Coated Bentonite Pellets (38.5-40.0m)
39							
40							
41							
42							Annulus filled with 3-7mm rounded river gravel (40.0-52.0m)
43							
44							
45							50mm ID Class 18 uPVC Screw Threaded Screen, Mechanically slotted (44.0-50.0m)
46							
47							
48							
49							
50							
51			52.0				PVC End Cap (52.0m)
52		Hole ended at 52m in Shale.					
53							
54							
55							
56							
57							
58							

Drilled By: Ivan Drilling

Drill Method: Air Rotary Down Hole Hammer

Drill Date: 29 September 2022

Hole Size: 130mm

Datum:

Sheet: 1 of 1

Borehole ID: MB02

Project No.: 2021-GD027

Project Name: Monaro Rock Quarry

Client: Monaro Rock

Site Address: Mates Drive, Royalla, NSW



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SUBSURFACE PROFILE				SAMPLE		CONSTRUCTION	
Depth (m)	Symbol	Description	Depth/Elev.	Sample ID	PID / Odour	Well Diagram	Materials Used
-2							
-1							
0		Ground Surface	0.0				
1		Silty Clayey Sand: Dark brown, moist, fine to medium sand.					0.7m Stickup protected by Steel Monument Annulus filled with concrete (0-0.2m)
2		Ryodacite: Purple with grey and brown mottling, hard, dry.					
3							
4							
5							
6							
7							
8			8.5				
9		Ryodacite: Grey and brown, hard, dry	10.0				
10		Ryodacite: Purple with grey and brown mottling, hard, dry.					
11							
12							
13							
14			15.0				
15		Ryodacite: Grey and brown, hard, dry	16.5				50mm ID Class 18 uPVC Screw Threaded Blank Casing (-0.7-44.5m)
16		Ryodacite: Purple with grey and brown mottling, hard, dry.					
17							
18							
19							
20							
21		Dust drop and moist cuttings 30-31m and 33-34m.					Annulus sealed with cement grout using tremmie pipe positioned at 38m bgl (0.2-40.5m).
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							
32							
33							
34			35.0				
35		Ryodacite: Grey with brown and pink mottling, hard.					
36							
37		Notable dust drop and moist cuttings 35.5-36.0m.					
38							
39							
40		Wet cuttings 43-44m. Hole airlifted at 46m rod change and produced approximately 0.2L/s.					Annulus Sealed with Coated Bentonite Pellets (40.5-42.0m)
41							
42							
43							Annulus filled with 3-7mm rounded river gravel (42.0-47.5m)
44							
45							50mm ID Class 18 uPVC Screw Threaded Screen, Mechanically slotted (44.5-47.5m)
46							
47			47.5				PVC End Cap (47.5m)
48		Hole ended at 47.5m in Ryodacite					
49							
50							
51							
52							
53							
54							
55							
56							
57							
58							

Drilled By: Ivan Drilling

Drill Method: Air Rotary Down Hole Hammer

Drill Date: 28 September 2022

Hole Size: 130mm

Datum:

Sheet: 1 of 1

Borehole ID: MB03

Project No.: 2021-GD027

Project Name: Monaro Rock Quarry

Client: Monaro Rock

Site Address: Mates Drive, Royalla, NSW



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SUBSURFACE PROFILE				SAMPLE		CONSTRUCTION	
Depth (m)	Symbol	Description	Depth/Elev.	Sample ID	PID / Odour	Well Diagram	Materials Used
-2							
-1							
0		Ground Surface	0.0				0.7m Stickup protected by Steel Monument Annulus filled with concrete (0-0.2m)
1		Silty Clayey Sand: Dark brown, moist, fine to medium sand.	2.0				
2		Ryodacite: Purple and brown, hard, dry	4.0				
3							
4		Ryodacite: Light brown, hard, dry					
5							
6							
7							
8							
9							
10			11.0				
11		Ryodacite: Purple-brown with pink and green mottling, hard, dry.					
12							
13							
14		Fracturing encountered between 14-17m.					
15							
16		Minor fracture encountered 21.5m.					
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30			31.0				
31		Ryodacite: Grey- brown with pink and purple mottling, dry, hard.					
32							
33							
34							
35							
36							
37							
38							
39							
40							
41							
42							
43							
44							
45							
46							
47							
48							
49							
50			50.5				
51		End of Hole at 50.5m in Ryodacite.					
52							
53							
54							
55							
56							
57							
58							

Drilled By: Ivan Drilling

Drill Method: Air Rotary Down Hole Hammer

Drill Date: 20-21 September 2022

Hole Size: 130mm

Datum:

Sheet: 1 of 1

Borehole ID: MB04

Project No.: 2021-GD027

Project Name: Monaro Rock Quarry

Client: Monaro Rock

Site Address: Mates Drive, Royalla, NSW



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SUBSURFACE PROFILE				SAMPLE		CONSTRUCTION	
Depth (m)	Symbol	Description	Depth/Elev.	Sample ID	PID / Odour	Well Diagram	Materials Used
-2							
-1							
0		Ground Surface	0.0				
1		Silty Sand: Grey and orange, moist, fine to medium sand.					0.7m Stickup protected by Steel Monument Annulus filled with concrete (0-0.2m)
2		Ryodacite: Light brown with grey, orange and pink mottling, hard, dry.					
3							
4							
5			6.0				
6		Ryodacite: Grey with brown, black, orange and pink mottling, hard and dry.					
7							
8							
9							
10		Fracturing identified regularly 16-19m.					
11							
12							
13							
14							
15							50mm ID Class 18 uPVC Screw Threaded Blank Casing (-0.7-44.0m)
16							
17							
18			19.0				
19		Ryodacite: Light brown with grey, orange, pink mottling, hard, dry.					Annulus sealed with cement grout using tremmie pipe positioned at 38m bgl (0.2-40.5m).
20			21.0				
21		Fracturing encountered at regular intervals 19-21m.					
22		Ryodacite: Grey- brown with pink and purple mottling, dry, hard.					
23							
24							
25							
26							
27							
28			29.0				
29		Ryodacite: Light brown, soft, white clay mixed in cuttings (29-30m). dry.					
30			31.0				
31		Ryodacite: Grey- brown with pink and purple mottling, dry, hard.					
32							
33		Weathered / soft 42-43m					
34							
35							
36							
37							
38							
39							
40							
41							Annulus Sealed with Coated Bentonite Pellets (40.5-42.0m)
42							
43			44.0				Annulus filled with 3-7mm rounded river gravel (42.0-50.0m)
44		Ryodacite: Orange-brown and black, hard, weathered / soft.					
45			46.0				
46		Ryodacite: Grey with black and brown mottling, hard and dry.					50mm ID Class 18 uPVC Screw Threaded Screen, Mechanically slotted (44.0-50.0m)
47							
48							
49			50.0				
50		End of hole at 50m in Ryodacite.					PVC End Cap (50.0m)
51							
52							
53							
54							
55							
56							
57							
58							

Drilled By: Ivan Drilling

Drill Method: Air Rotary Down Hole Hammer

Drill Date: 21 September 2022

Hole Size: 130mm

Datum:

Sheet: 1 of 1

Borehole ID: MB05

Project No.: 2021-GD027

Project Name: Monaro Rock Quarry

Client: Monaro Rock

Site Address: Mates Drive, Royalla, NSW



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SUBSURFACE PROFILE				SAMPLE		CONSTRUCTION	
Depth (m)	Symbol	Description	Depth/Elev.	Sample ID	PID / Odour	Well Diagram	Materials Used
-2							
-1							
0		Ground Surface	0.0				0.7m Stickup protected by Steel Monument Annulus filled with concrete (0-0.2m)
1		Silty Sandy Clay: Dark brown, moist, fine to medium sand, low plasticity.					
2		Weathered Shale: Brown, soft, clayey, dry.	3.0				
3		Weathered Shale Light grey and brown, soft, dry.					
4							
5			6.0				
6		Weathered Shale: Light brown, soft, dry.					
7			8.0				
8		Weathered Shale: Grey-brown, soft, dry.					
9							
10			11.0				
11		Shale: Darker grey-brown, harder, dry.					
12							
13		Soft clayey layer at 12.5-13.0m and at 13.5-14.0m.					
14			15.0				
15		Shale: Dark grey and black, alternating between hard and soft.					50mm ID Class 18 uPVC Screw Threaded Blank Casing (-0.7-30.5m).
16							
17							
18		Some wet chips identified in cutting 15-16m. Hole was left for 10 minutes at the 16m rod change but did not make water at restart of air circulation. Wet cutting identified at restart.					Annulus sealed with cement grout using tremmie pipe positioned at 26m bgl (0.2-27.5m).
19							
20							
21		Fracture encountered 18.0-18.5m and subsequent dust drop. Left hole for 20 minutes at 19m rod change. Only wet cutting on restart.					
22							
23							
24		Weathered layer encountered 21.5-22.0m.					
25							
26							
27		Notable water strike encountered 30-32m with estimated inflow 0.1L/s.					Annulus Sealed with Coated Bentonite Pellets (27.5-29.0m)
28							
29							Annulus filled with 3-7mm rounded river gravel (29.0-33.5m)
30							
31							
32							
33			33.5				50mm ID Class 18 uPVC Screw Threaded PVC End Cap (33.5m)
34		Hole ended at 33.5m in Shale.					
35							
36							
37							
38							
39							
40							
41							
42							
43							
44							
45							
46							
47							
48							
49							
50							
51							
52							
53							
54							
55							
56							
57							
58							

Drilled By: Ivan Drilling

Drill Method: Air Rotary Down Hole Hammer

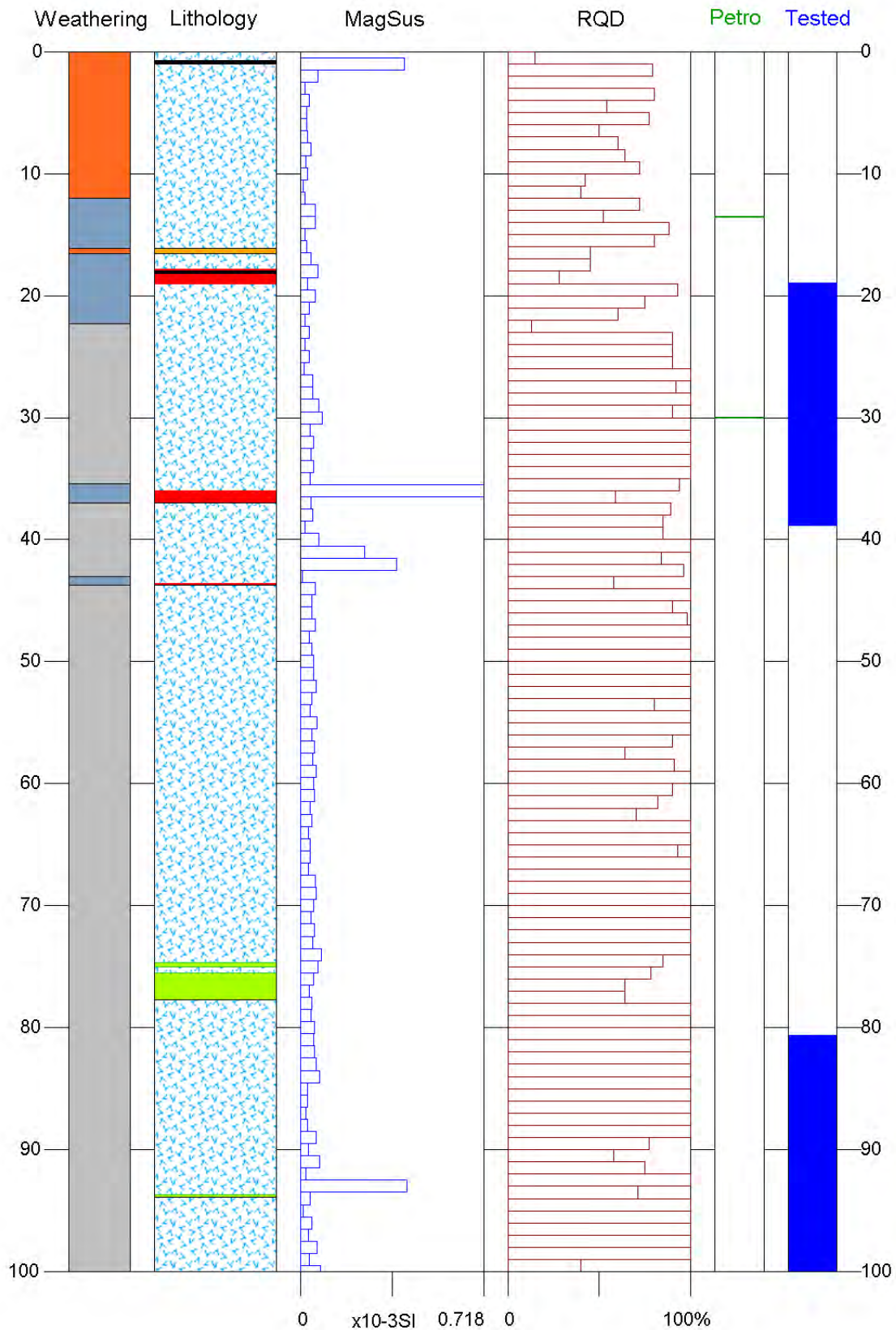
Drill Date: 23 September 2022

Hole Size: 130mm

Datum:

Sheet: 1 of 1

Log for MRDDH08



Legends

WEATHERING LEGEND:

- Extremely weathered
- Highly weathered
- Moderately weathered
- Slightly weathered
- Fresh

LITHOLOGY LEGEND:

- Soil
- Rhyodacite
- Core Loss
- Fault
- Alteration
- Clay

MAGNETIC SUSCEPTIBILITY



PENETRATION RATE

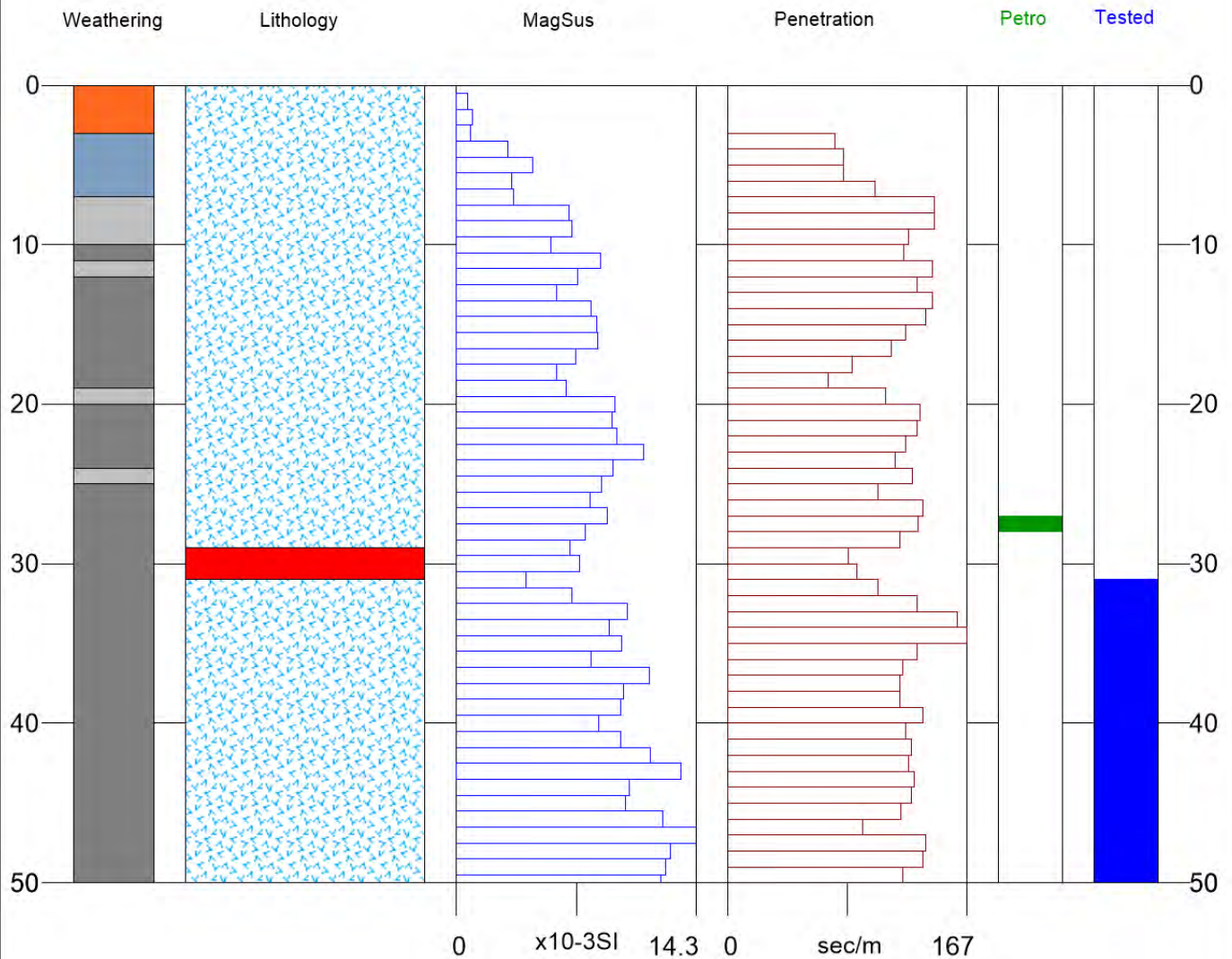
(Percussion holes only)



Petro = Interval sampled for petrographic study

Tested = Interval sampled for source rock quality

Log for MRPDH15



Legends

WEATHERING LEGEND:

	Extremely weathered
	Highly weathered
	Moderately weathered
	Slightly weathered
	Fresh

LITHOLOGY LEGEND:

	Soil
	Rhyodacite
	Core Loss
	Fault
	Alteration
	Clay

MAGNETIC SUSCEPTIBILITY



PENETRATION RATE

(Percussion holes only)



Petro = Interval sampled for petrographic study

Tested = Interval sampled for source rock quality

CERTIFICATE OF ANALYSIS 341340

Client Details

Client	Ground Doctor Pty Ltd
Attention	James Morrow
Address	PO Box 6278, Dubbo, NSW, 2830

Sample Details

Your Reference	<u>Monaro Rock January 2024</u>
Number of Samples	7 Water
Date samples received	11/01/2024
Date completed instructions received	11/01/2024

Analysis Details

Please refer to the following pages for results, methodology summary and quality control data.
 Samples were analysed as received from the client. Results relate specifically to the samples as received.
 Results are reported on a dry weight basis for solids and on an as received basis for other matrices.
Please refer to the last page of this report for any comments relating to the results.

Report Details

Date results requested by	18/01/2024
Date of Issue	18/01/2024
NATA Accreditation Number 2901. This document shall not be reproduced except in full.	
Accredited for compliance with ISO/IEC 17025 - Testing. Tests not covered by NATA are denoted with *	

Results Approved By

Diego Bigolin, Inorganics Supervisor
 Loren Bardwell, Development Chemist

Authorised By

Nancy Zhang, Laboratory Manager

Ion Balance						
Our Reference		341340-1	341340-2	341340-3	341340-4	341340-5
Your Reference	UNITS	MB01	MB02	MB05	MB25	MRDDH08
Date Sampled		09/01/2024	09/01/2024	09/01/2024	09/01/2024	10/01/2024
Type of sample		Water	Water	Water	Water	Water
Date prepared	-	11/01/2024	11/01/2024	11/01/2024	11/01/2024	11/01/2024
Date analysed	-	11/01/2024	11/01/2024	11/01/2024	11/01/2024	11/01/2024
Calcium - Dissolved	mg/L	140	150	130	130	8.4
Potassium - Dissolved	mg/L	29	3	5.3	5.2	4
Sodium - Dissolved	mg/L	71	41	130	130	10
Magnesium - Dissolved	mg/L	<0.5	31	150	150	2
Hardness	mgCaCO ₃ /L	360	500	950	940	29
Hydroxide Alkalinity (OH ⁻) as CaCO ₃	mg/L	400	<5	<5	<5	<5
Bicarbonate Alkalinity as CaCO ₃	mg/L	<5	510	670	660	37
Carbonate Alkalinity as CaCO ₃	mg/L	92	<5	<5	<5	<5
Total Alkalinity as CaCO ₃	mg/L	490	510	670	660	37
Sulphate, SO ₄	mg/L	21	3	39	40	3
Chloride, Cl	mg/L	13	72	320	320	3
Ionic Balance	%	2.0	-2.0	3.0	3.0	11

Ion Balance			
Our Reference		341340-6	341340-7
Your Reference	UNITS	MRDPH15	Dam Bore
Date Sampled		09/01/2024	10/01/2024
Type of sample		Water	Water
Date prepared	-	11/01/2024	11/01/2024
Date analysed	-	11/01/2024	11/01/2024
Calcium - Dissolved	mg/L	14	170
Potassium - Dissolved	mg/L	1	2
Sodium - Dissolved	mg/L	12	72
Magnesium - Dissolved	mg/L	1	80
Hardness	mgCaCO ₃ /L	38	760
Hydroxide Alkalinity (OH ⁻) as CaCO ₃	mg/L	<5	<5
Bicarbonate Alkalinity as CaCO ₃	mg/L	60	510
Carbonate Alkalinity as CaCO ₃	mg/L	<5	<5
Total Alkalinity as CaCO ₃	mg/L	60	510
Sulphate, SO ₄	mg/L	1	22
Chloride, Cl	mg/L	4	270
Ionic Balance	%	-1.0	1.0

Client Reference: Monaro Rock January 2024

HM in water - dissolved						
Our Reference		341340-1	341340-2	341340-3	341340-4	341340-5
Your Reference	UNITS	MB01	MB02	MB05	MB25	MRDDH08
Date Sampled		09/01/2024	09/01/2024	09/01/2024	09/01/2024	10/01/2024
Type of sample		Water	Water	Water	Water	Water
Date prepared	-	12/01/2024	12/01/2024	12/01/2024	12/01/2024	12/01/2024
Date analysed	-	15/01/2024	15/01/2024	15/01/2024	15/01/2024	15/01/2024
Arsenic-Dissolved	µg/L	<1	<1	<1	<1	<1
Cadmium-Dissolved	µg/L	<0.1	<0.1	<0.1	<0.1	<0.1
Chromium-Dissolved	µg/L	32	<1	<1	<1	<1
Copper-Dissolved	µg/L	34	<1	1	1	100
Lead-Dissolved	µg/L	<1	<1	<1	<1	<1
Mercury-Dissolved	µg/L	<0.05	<0.05	<0.05	<0.05	<0.05
Nickel-Dissolved	µg/L	7	3	7	7	62
Zinc-Dissolved	µg/L	3	13	20	20	120
Aluminium-Dissolved	µg/L	860	10	<10	<10	120
Boron-Dissolved	µg/L	<20	<20	<20	<20	<20
Cobalt-Dissolved	µg/L	<1	<1	<1	<1	1
Iron-Dissolved	µg/L	90	220	<10	10	260
Manganese-Dissolved	µg/L	<5	230	37	38	110
Molybdenum-Dissolved	µg/L	38	<1	<1	<1	3
Selenium-Dissolved	µg/L	2	<1	<1	<1	<1

HM in water - dissolved			
Our Reference		341340-6	341340-7
Your Reference	UNITS	MRDPH15	Dam Bore
Date Sampled		09/01/2024	10/01/2024
Type of sample		Water	Water
Date prepared	-	12/01/2024	12/01/2024
Date analysed	-	15/01/2024	15/01/2024
Arsenic-Dissolved	µg/L	<1	<1
Cadmium-Dissolved	µg/L	<0.1	<0.1
Chromium-Dissolved	µg/L	<1	<1
Copper-Dissolved	µg/L	5	<1
Lead-Dissolved	µg/L	<1	<1
Mercury-Dissolved	µg/L	<0.05	<0.05
Nickel-Dissolved	µg/L	29	<1
Zinc-Dissolved	µg/L	23	2
Aluminium-Dissolved	µg/L	340	<10
Boron-Dissolved	µg/L	<20	<20
Cobalt-Dissolved	µg/L	1	<1
Iron-Dissolved	µg/L	440	20
Manganese-Dissolved	µg/L	72	21
Molybdenum-Dissolved	µg/L	5	<1
Selenium-Dissolved	µg/L	<1	<1

Miscellaneous Inorganics

Our Reference		341340-1	341340-2	341340-3	341340-4	341340-5
Your Reference	UNITS	MB01	MB02	MB05	MB25	MRDDH08
Date Sampled		09/01/2024	09/01/2024	09/01/2024	09/01/2024	10/01/2024
Type of sample		Water	Water	Water	Water	Water
Date prepared	-	11/01/2024	11/01/2024	11/01/2024	11/01/2024	11/01/2024
Date analysed	-	11/01/2024	11/01/2024	11/01/2024	11/01/2024	11/01/2024
pH	pH Units	11.8	7.0	6.8	6.9	6.6
Electrical Conductivity	µS/cm	2,100	1,100	2,300	2,300	120
Total Dissolved Solids (grav)	mg/L	720	670	1,800	1,700	120
Ammonia as N in water	mg/L	0.091	<0.005	<0.005	<0.005	<0.005
Nitrate as N in water	mg/L	0.13	0.46	1.4	1.2	3.6
Nitrite as N in water	mg/L	15	<0.005	0.007	<0.005	<0.005
TKN in water	mg/L	0.7	1	0.7	0.5	0.7

Miscellaneous Inorganics

Our Reference		341340-6	341340-7
Your Reference	UNITS	MRDPH15	Dam Bore
Date Sampled		09/01/2024	10/01/2024
Type of sample		Water	Water
Date prepared	-	11/01/2024	11/01/2024
Date analysed	-	11/01/2024	11/01/2024
pH	pH Units	6.1	6.9
Electrical Conductivity	µS/cm	130	1,800
Total Dissolved Solids (grav)	mg/L	240	1,200
Ammonia as N in water	mg/L	<0.005	<0.005
Nitrate as N in water	mg/L	0.073	0.85
Nitrite as N in water	mg/L	<0.005	<0.005
TKN in water	mg/L	0.6	0.4

Metals in Waters - Total						
Our Reference		341340-1	341340-2	341340-3	341340-4	341340-5
Your Reference	UNITS	MB01	MB02	MB05	MB25	MRDDH08
Date Sampled		09/01/2024	09/01/2024	09/01/2024	09/01/2024	10/01/2024
Type of sample		Water	Water	Water	Water	Water
Date prepared	-	12/01/2024	12/01/2024	12/01/2024	12/01/2024	12/01/2024
Date analysed	-	12/01/2024	12/01/2024	12/01/2024	12/01/2024	12/01/2024
Phosphorus - Total	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05

Metals in Waters - Total			
Our Reference		341340-6	341340-7
Your Reference	UNITS	MRDPH15	Dam Bore
Date Sampled		09/01/2024	10/01/2024
Type of sample		Water	Water
Date prepared	-	12/01/2024	12/01/2024
Date analysed	-	12/01/2024	12/01/2024
Phosphorus - Total	mg/L	0.05	<0.05

Method ID	Methodology Summary
Inorg-001	pH - Measured using pH meter and electrode in accordance with APHA latest edition, 4500-H+. Please note that the results for water analyses are indicative only, as analysis outside of the APHA storage times.
Inorg-002	Conductivity and Salinity - measured using a conductivity cell at 25°C in accordance with APHA latest edition 2510 and Rayment & Lyons.
Inorg-006	Alkalinity - determined titrimetrically in accordance with APHA latest edition, 2320-B.
Inorg-018	Total Dissolved Solids - determined gravimetrically. The solids are dried at 180+/-10°C. NOTE: Where the EC of the sample is <100µS/cm, the TDS will typically be below 70mg/L (as the sample is very likely to be at least drinking water quality). Therefore to ensure data quality for TDS, the TDS is typically calculated as per the equation below:- $\text{TDS} = \text{EC} * 0.6$
Inorg-040	The concentrations of the major ions (mg/L) are converted to milliequivalents and summed. The ionic balance should be within +/- 15% ie total anions = total cations +/-15%.
Inorg-055	Nitrate - determined colourimetrically. Waters samples are filtered on receipt prior to analysis. Soils are analysed following a water extraction.
Inorg-055	Nitrite - determined colourimetrically based on APHA latest edition NO2- B. Waters samples are filtered on receipt prior to analysis. Soils are analysed following a water extraction.
Inorg-057	Ammonia - determined colourimetrically, based on APHA latest edition 4500-NH3 F. Waters samples are filtered on receipt prior to analysis. Soils are analysed following a KCl extraction.
Inorg-062	TKN - determined colourimetrically based on APHA latest edition 4500 Norg. Alternatively, TKN can be derived from calculation (Total N - NOx).
Inorg-081	Anions - a range of Anions are determined by Ion Chromatography, in accordance with APHA latest edition, 4110-B. Waters samples are filtered on receipt prior to analysis. Alternatively determined by colourimetry/turbidity using Discrete Analyser.
Metals-020	Determination of various metals by ICP-AES.
Metals-021	Determination of Mercury by Cold Vapour AAS.
Metals-022	Determination of various metals by ICP-MS. Please note for Bromine and Iodine, any forms of these elements that are present are included together in the one result reported for each of these two elements. Salt forms (e.g. FeO, PbO, ZnO) are determined stoichiometrically from the base metal concentration.

Client Reference: Monaro Rock January 2024

QUALITY CONTROL: Ion Balance					Duplicate			Spike Recovery %		
Test Description	Units	PQL	Method	Blank	#	Base	Dup.	RPD	LCS-W1	341340-2
Date prepared	-			11/01/2024	1	11/01/2024	11/01/2024		11/01/2024	11/01/2024
Date analysed	-			11/01/2024	1	11/01/2024	11/01/2024		11/01/2024	11/01/2024
Calcium - Dissolved	mg/L	0.5	Metals-020	<0.5	1	140	140	0	101	#
Potassium - Dissolved	mg/L	0.5	Metals-020	<0.5	1	29	30	3	94	96
Sodium - Dissolved	mg/L	0.5	Metals-020	<0.5	1	71	70	1	90	114
Magnesium - Dissolved	mg/L	0.5	Metals-020	<0.5	1	<0.5	<0.5	0	99	98
Hardness	mgCaCO ₃ /L	3	Metals-020	[NT]	1	360	340	6	[NT]	[NT]
Hydroxide Alkalinity (OH ⁻) as CaCO ₃	mg/L	5	Inorg-006	<5	1	400	390	3	[NT]	[NT]
Bicarbonate Alkalinity as CaCO ₃	mg/L	5	Inorg-006	<5	1	<5	<5	0	[NT]	[NT]
Carbonate Alkalinity as CaCO ₃	mg/L	5	Inorg-006	<5	1	92	97	5	[NT]	[NT]
Total Alkalinity as CaCO ₃	mg/L	5	Inorg-006	<5	1	490	490	0	95	[NT]
Sulphate, SO ₄	mg/L	1	Inorg-081	<1	1	21	22	5	109	[NT]
Chloride, Cl	mg/L	1	Inorg-081	<1	1	13	13	0	95	[NT]
Ionic Balance	%		Inorg-040	[NT]	1	2.0	1.0	67	[NT]	[NT]

QUALITY CONTROL: Ion Balance					Duplicate			Spike Recovery %		
Test Description	Units	PQL	Method	Blank	#	Base	Dup.	RPD	[NT]	341340-3
Date prepared	-			[NT]	[NT]	[NT]	[NT]	[NT]	[NT]	11/01/2024
Date analysed	-			[NT]	[NT]	[NT]	[NT]	[NT]	[NT]	11/01/2024
Sulphate, SO ₄	mg/L	1	Inorg-081	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]	91
Chloride, Cl	mg/L	1	Inorg-081	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]	#

Client Reference: Monaro Rock January 2024

QUALITY CONTROL: HM in water - dissolved					Duplicate			Spike Recovery %		
Test Description	Units	PQL	Method	Blank	#	Base	Dup.	RPD	LCS-W3	341340-2
Date prepared	-			12/01/2024	1	12/01/2024	12/01/2024		12/01/2024	12/01/2024
Date analysed	-			15/01/2024	1	15/01/2024	15/01/2024		15/01/2024	15/01/2024
Arsenic-Dissolved	µg/L	1	Metals-022	<1	1	<1	<1	0	93	94
Cadmium-Dissolved	µg/L	0.1	Metals-022	<0.1	1	<0.1	<0.1	0	94	94
Chromium-Dissolved	µg/L	1	Metals-022	<1	1	32	33	3	92	96
Copper-Dissolved	µg/L	1	Metals-022	<1	1	34	35	3	91	91
Lead-Dissolved	µg/L	1	Metals-022	<1	1	<1	<1	0	95	91
Mercury-Dissolved	µg/L	0.05	Metals-021	<0.05	1	<0.05	[NT]		104	[NT]
Nickel-Dissolved	µg/L	1	Metals-022	<1	1	7	8	13	92	93
Zinc-Dissolved	µg/L	1	Metals-022	<1	1	3	3	0	98	94
Aluminium-Dissolved	µg/L	10	Metals-022	<10	1	860	890	3	89	73
Boron-Dissolved	µg/L	20	Metals-022	<20	1	<20	<20	0	98	106
Cobalt-Dissolved	µg/L	1	Metals-022	<1	1	<1	<1	0	91	93
Iron-Dissolved	µg/L	10	Metals-022	<10	1	90	90	0	92	#
Manganese-Dissolved	µg/L	5	Metals-022	<5	1	<5	<5	0	93	#
Molybdenum-Dissolved	µg/L	1	Metals-022	<1	1	38	38	0	97	102
Selenium-Dissolved	µg/L	1	Metals-022	<1	1	2	2	0	87	83

QUALITY CONTROL: HM in water - dissolved					Duplicate			Spike Recovery %		
Test Description	Units	PQL	Method	Blank	#	Base	Dup.	RPD	[NT]	341340-4
Date prepared	-			[NT]	3	12/01/2024	12/01/2024		[NT]	12/01/2024
Date analysed	-			[NT]	3	15/01/2024	15/01/2024		[NT]	15/01/2024
Arsenic-Dissolved	µg/L	1	Metals-022	[NT]	3	<1	[NT]		[NT]	[NT]
Cadmium-Dissolved	µg/L	0.1	Metals-022	[NT]	3	<0.1	[NT]		[NT]	[NT]
Chromium-Dissolved	µg/L	1	Metals-022	[NT]	3	<1	[NT]		[NT]	[NT]
Copper-Dissolved	µg/L	1	Metals-022	[NT]	3	1	[NT]		[NT]	[NT]
Lead-Dissolved	µg/L	1	Metals-022	[NT]	3	<1	[NT]		[NT]	[NT]
Mercury-Dissolved	µg/L	0.05	Metals-021	[NT]	3	<0.05	<0.05	0	[NT]	80
Nickel-Dissolved	µg/L	1	Metals-022	[NT]	3	7	[NT]		[NT]	[NT]
Zinc-Dissolved	µg/L	1	Metals-022	[NT]	3	20	[NT]		[NT]	[NT]
Aluminium-Dissolved	µg/L	10	Metals-022	[NT]	3	<10	[NT]		[NT]	[NT]
Boron-Dissolved	µg/L	20	Metals-022	[NT]	3	<20	[NT]		[NT]	[NT]
Cobalt-Dissolved	µg/L	1	Metals-022	[NT]	3	<1	[NT]		[NT]	[NT]
Iron-Dissolved	µg/L	10	Metals-022	[NT]	3	<10	[NT]		[NT]	[NT]
Manganese-Dissolved	µg/L	5	Metals-022	[NT]	3	37	[NT]		[NT]	[NT]
Molybdenum-Dissolved	µg/L	1	Metals-022	[NT]	3	<1	[NT]		[NT]	[NT]
Selenium-Dissolved	µg/L	1	Metals-022	[NT]	3	<1	[NT]		[NT]	[NT]

QUALITY CONTROL: Miscellaneous Inorganics					Duplicate			Spike Recovery %		
Test Description	Units	PQL	Method	Blank	#	Base	Dup.	RPD	LCS-W1	341340-3
Date prepared	-			11/01/2024	1	11/01/2024	11/01/2024		11/01/2024	11/01/2024
Date analysed	-			11/01/2024	1	11/01/2024	11/01/2024		11/01/2024	11/01/2024
pH	pH Units		Inorg-001	[NT]	1	11.8	11.8	0	100	[NT]
Electrical Conductivity	µS/cm	1	Inorg-002	<1	1	2100	2100	0	96	[NT]
Total Dissolved Solids (grav)	mg/L	5	Inorg-018	<5	1	720	[NT]		116	[NT]
Ammonia as N in water	mg/L	0.005	Inorg-057	<0.005	1	0.091	0.097	6	96	84
Nitrate as N in water	mg/L	0.005	Inorg-055	<0.005	1	0.13	0.13	0	98	95
Nitrite as N in water	mg/L	0.005	Inorg-055	<0.005	1	15	15	0	112	108
TKN in water	mg/L	0.1	Inorg-062	<0.1	1	0.7	0.6	15	87	115

Client Reference: Monaro Rock January 2024

QUALITY CONTROL: Metals in Waters - Total					Duplicate			Spike Recovery %		
Test Description	Units	PQL	Method	Blank	#	Base	Dup.	RPD	LCS-W1	[NT]
Date prepared	-			12/01/2024	1	12/01/2024	12/01/2024		12/01/2024	[NT]
Date analysed	-			12/01/2024	1	12/01/2024	12/01/2024		12/01/2024	[NT]
Phosphorus - Total	mg/L	0.05	Metals-020	<0.05	1	<0.05	<0.05	0	93	[NT]

Result Definitions

NT	Not tested
NA	Test not required
INS	Insufficient sample for this test
PQL	Practical Quantitation Limit
<	Less than
>	Greater than
RPD	Relative Percent Difference
LCS	Laboratory Control Sample
NS	Not specified
NEPM	National Environmental Protection Measure
NR	Not Reported

Quality Control Definitions

Blank	This is the component of the analytical signal which is not derived from the sample but from reagents, glassware etc, can be determined by processing solvents and reagents in exactly the same manner as for samples.
Duplicate	This is the complete duplicate analysis of a sample from the process batch. If possible, the sample selected should be one where the analyte concentration is easily measurable.
Matrix Spike	A portion of the sample is spiked with a known concentration of target analyte. The purpose of the matrix spike is to monitor the performance of the analytical method used and to determine whether matrix interferences exist.
LCS (Laboratory Control Sample)	This comprises either a standard reference material or a control matrix (such as a blank sand or water) fortified with analytes representative of the analyte class. It is simply a check sample.
Surrogate Spike	Surrogates are known additions to each sample, blank, matrix spike and LCS in a batch, of compounds which are similar to the analyte of interest, however are not expected to be found in real samples.
Australian Drinking Water Guidelines recommend that Thermotolerant Coliform, Faecal Enterococci, & E.Coli levels are less than 1cfu/100mL. The recommended maximums are taken from "Australian Drinking Water Guidelines", published by NHMRC & ARMC 2011.	
The recommended maximums for analytes in urine are taken from "2018 TLVs and BEIs", as published by ACGIH (where available). Limit provided for Nickel is a precautionary guideline as per Position Paper prepared by AIOH Exposure Standards Committee, 2016.	
Guideline limits for Rinse Water Quality reported as per analytical requirements and specifications of AS 4187, Amdt 2 2019, Table 7.2	

Laboratory Acceptance Criteria

Duplicate sample and matrix spike recoveries may not be reported on smaller jobs, however, were analysed at a frequency to meet or exceed NEPM requirements. All samples are tested in batches of 20. The duplicate sample RPD and matrix spike recoveries for the batch were within the laboratory acceptance criteria.

Filters, swabs, wipes, tubes and badges will not have duplicate data as the whole sample is generally extracted during sample extraction.

Spikes for Physical and Aggregate Tests are not applicable.

For VOCs in water samples, three vials are required for duplicate or spike analysis.

Duplicates: >10xPQL - RPD acceptance criteria will vary depending on the analytes and the analytical techniques but is typically in the range 20%-50% – see ELN-P05 QA/QC tables for details; <10xPQL - RPD are higher as the results approach PQL and the estimated measurement uncertainty will statistically increase.

Matrix Spikes, LCS and Surrogate recoveries: Generally 70-130% for inorganics/metals (not SPOCAS); 60-140% for organics/SPOCAS (+/-50% surrogates) and 10-140% for labile SVOCs (including labile surrogates), ultra trace organics and speciated phenols is acceptable.

In circumstances where no duplicate and/or sample spike has been reported at 1 in 10 and/or 1 in 20 samples respectively, the sample volume submitted was insufficient in order to satisfy laboratory QA/QC protocols.

When samples are received where certain analytes are outside of recommended technical holding times (THTs), the analysis has proceeded. Where analytes are on the verge of breaching THTs, every effort will be made to analyse within the THT or as soon as practicable.

Where sampling dates are not provided, Envirolab are not in a position to comment on the validity of the analysis where recommended technical holding times may have been breached.

Where matrix spike recoveries fall below the lower limit of the acceptance criteria (e.g. for non-labile or standard Organics <60%), positive result(s) in the parent sample will subsequently have a higher than typical estimated uncertainty (MU estimates supplied on request) and in these circumstances the sample result is likely biased significantly low.

Measurement Uncertainty estimates are available for most tests upon request.

Analysis of aqueous samples typically involves the extraction/digestion and/or analysis of the liquid phase only (i.e. NOT any settled sediment phase but inclusive of suspended particles if present), unless stipulated on the Envirolab COC and/or by correspondence. Notable exceptions include certain Physical Tests (pH/EC/BOD/COD/Apparent Colour etc.), Solids testing, total recoverable metals and PFAS where solids are included by default.

Samples for Microbiological analysis (not Amoeba forms) received outside of the 2-8°C temperature range do not meet the ideal cooling conditions as stated in AS2031-2012.

Report Comments

Ion Balance - # Percent recovery is not applicable due to the high concentration of the analyte/s in the sample/s. However an acceptable recovery was obtained for the LCS.

8 HM in water - dissolved - # Percent recovery is not applicable due to the high concentration of the element/s in the sample/s. However an acceptable recovery was obtained for the LCS.

Appendix C Numerical Groundwater Modelling Report

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Monaro Rock Quarry - Numerical Groundwater Modelling Report

Prepared for

R.W. Corkery and Co. Pty Ltd (RWC)

1. Introduction

Monaro Rock Pty Ltd (“Monaro Rock”) has engaged hydrogeologist.com.au to develop and run a three-dimensional (3D) numerical groundwater model to simulate baseline conditions and predict operational and post closure groundwater effects of the Monaro Rock Quarry (the Project). The Project is a proposed hard rock quarry, which involves the construction of a 30-year pit covering a total surface area of 20 ha with a maximum depth of around 100 m below ground level (mbgl).

The numerical groundwater model supports the Groundwater Impact Assessment (GIA) for the Project and is designed to represent the site’s conceptual hydrogeological model (refer to GIA Section 4.3). The model simulates the potential impacts of quarrying activities on groundwater levels during operations and post-closure, in line with the requirements of the GIA. Specifically, the model has been developed to achieve the following objectives:

- predict the extent and magnitude of maximum groundwater depressurisation (drawdown) associated with quarrying activities;
- estimate groundwater inflow rates to the quarry throughout operations;
- forecast extraction flowrates for a proposed production well; and
- simulate post-closure groundwater conditions to assess the long-term behaviour of the final void.

The Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012) have been considered throughout the modelling process to ensure that the model aligns with industry best practice and fulfils the requirements of the GIA. The model has been developed to achieve a target Class 2 and 3 confidence level classification, which is suitable for simulating groundwater responses to changes in applied stress anywhere across the model domain. This targeted classification is appropriate given the model objectives are to predict the potential impacts of quarrying activities on groundwater conditions.

The report is structured as follows:

- Section 2 outlines model design, including code selection, domain extents, and discretisation.
- Section 3 summarises calibration process and results.
- Section 4 presents predicted pit inflows, extraction rates, heads, and drawdowns.
- Section 5 presents simulated post-closure groundwater levels.
- Section 6 assesses model confidence classification.
- Section 7 discusses predictive uncertainty.
- Section 8 lists references.

2. Model design

2.1. Model code selection

The model was developed using the latest version of MODFLOW 6 (Langevin *et al.*, 2017) which is the current core version of the U.S. Geological Survey MODFLOW groundwater modelling code. A 3D numerical model was established using an unstructured quadtree grid. Spatial data management, pre-processing, and map output generation were performed using QGIS, FloPy (Bakker *et al.*, 2016) and Python code.

2.2. Model domain

The model domain is shown in Figure 1. The domain covers an approximate area of 375 km², extending approximately 20 km east to west and 20 km north to south. The model domain extents were designed to be large enough to:

- encompass the full extent of groundwater drawdown associated with the Monaro Rock Quarry Project site; and
- limit potential for interaction (i.e., boundary effects) between the drawdown associated with quarry activities and the model boundaries.

Natural geological, hydrological and hydrogeological features such as groundwater units, geological structures, watercourses and catchment boundaries were considered in determining the extents of the model domain. Major rivers form the western, eastern and southern boundaries of the model.

2.3. Model processing and discretisation

The model mesh was generated using GRIDGEN (Lien *et al.*, 2015), which was implemented in FloPy. The program prepares a three-dimensional base grid with variable row and column widths, as well as spatially variable cell top and bottom elevations. GRIDGEN then refines the mesh based on user-provided features (such as points, lines, and polygons) into smaller cells, continuously refining the grid until the desired level of refinement is achieved.

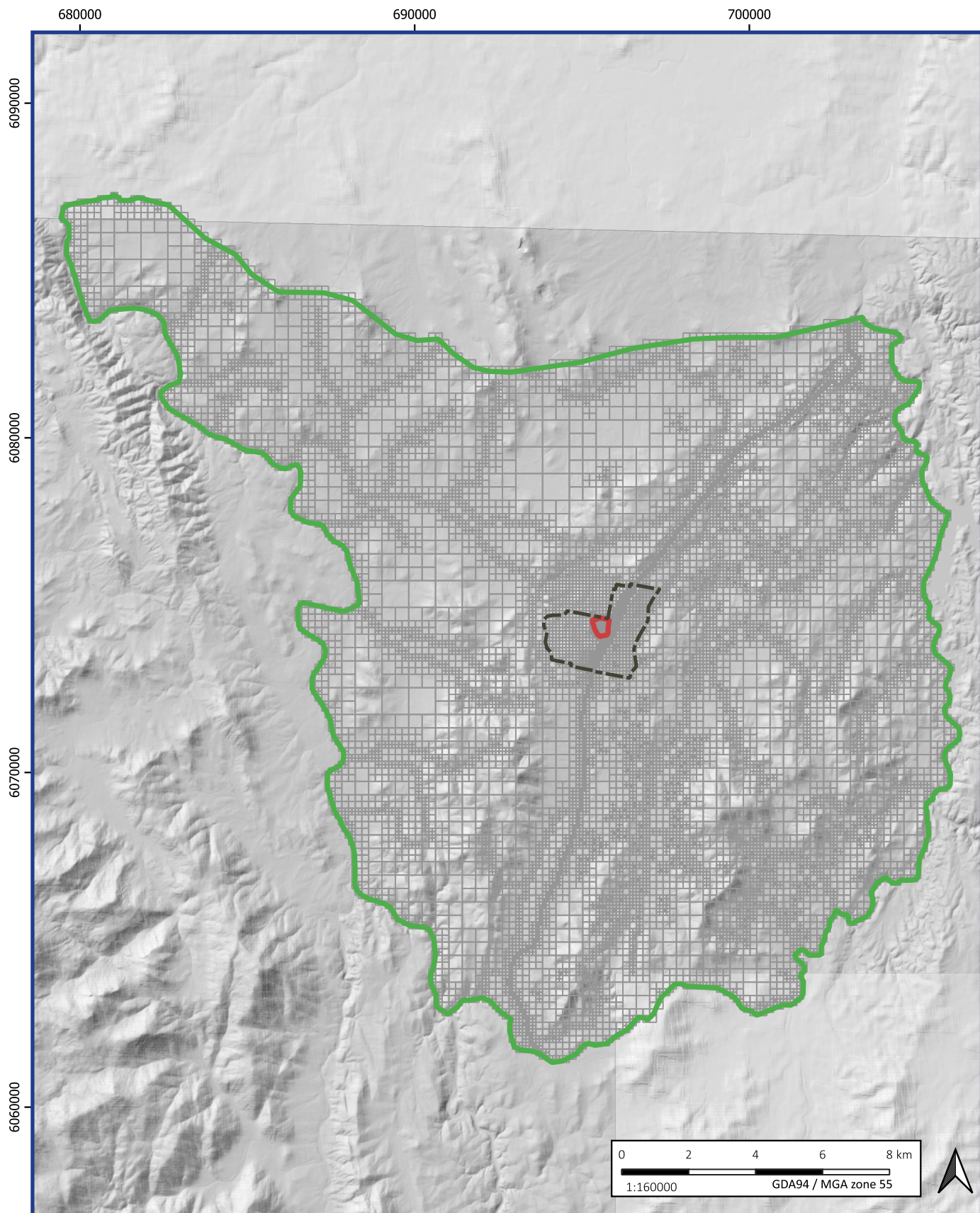
In this model, the base grid size was set to 800 m, and refinements were applied to specific areas, including the model boundaries (100 m), surface drainage (100 m), Royalla Fault, quarry areas, and monitoring bores (25 m). There are 35,732 active cells in the entire model, equally distributed across two model layers. The model mesh is shown in Figure 1.

Separate models were developed to represent the calibration, prediction and post-closure periods. Excluding stress period 1 (which was steady state), the calibration model utilised monthly stress periods to make optimal use of the available observation data. Meanwhile, the predictive model utilised yearly stress periods to simulate quarry development stages which were provided by the client. A steady state post-closure model was developed to assess long-term groundwater conditions at equilibrium following Project closure. Model timing is summarised in Table 1. The post-closure model is steady state and follows on from the prediction model.

The transient calibration encompassed the period of September 2021 to January 2024, with 29 monthly stress periods applied. In the predictive model, 30 yearly stress periods were implemented to accommodate the quarrying stages provided by the client. To achieve better model convergence during the automatic calibration process, the Adaptive Time Stepping (ATS) package was employed for time steps. This package allows for dynamic adjustment of time steps, enhancing the efficiency and accuracy of the model convergence.

Table 1 Model temporal discretisation

Stress periods	Stress period length	Dates	Model	Type	Phase
1	N/A	N/A	Calibration	Steady state	Pre-development
29	1 month	01/09/2021 – 31/01/2024		Transient	
30	1 year	01/01/2024 – 31/12/2053	Prediction	Transient	Development
1	N/A	N/A	Post-closure	Steady state	Post- closure



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Legend

- Project boundary
- Monaro quarry
- Model mesh
- Model domain

Model mesh

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Figure 1

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2.4. Model layers

The model was initially designed with eight layers to account for the varying hydraulic properties across the thick sequence of volcanic rocks. However, both manual and automated calibration process suggested that the vertical variations in parameters were not as significant as in sedimentary rocks. Furthermore, minimal differences were observed in the model's response and the observation data between the Deakin volcanics and Colinton volcanics, despite being separated by the Royalla Fault. Additionally, the fault exhibited very similar properties based on the model's response during the calibration process. Consequently, the model was simplified to include only two layers: the weathered rock aquifer and the underlying basement rock aquifer with fault cells treated the same as regular cells.

The top elevation of Layer 1 (surface topography) was determined using a DEM (digital elevation model) with 5-metre (m) resolution sourced from the Elvis Elevation and Depth spatial datasets. This DEM data covered approximately 95% of the model area with the remaining area sourced from the 30 m SRTM (Shuttle Radar Topography Mission). Layer 1 was assumed to have a uniform thickness of 40 m across the model domain.

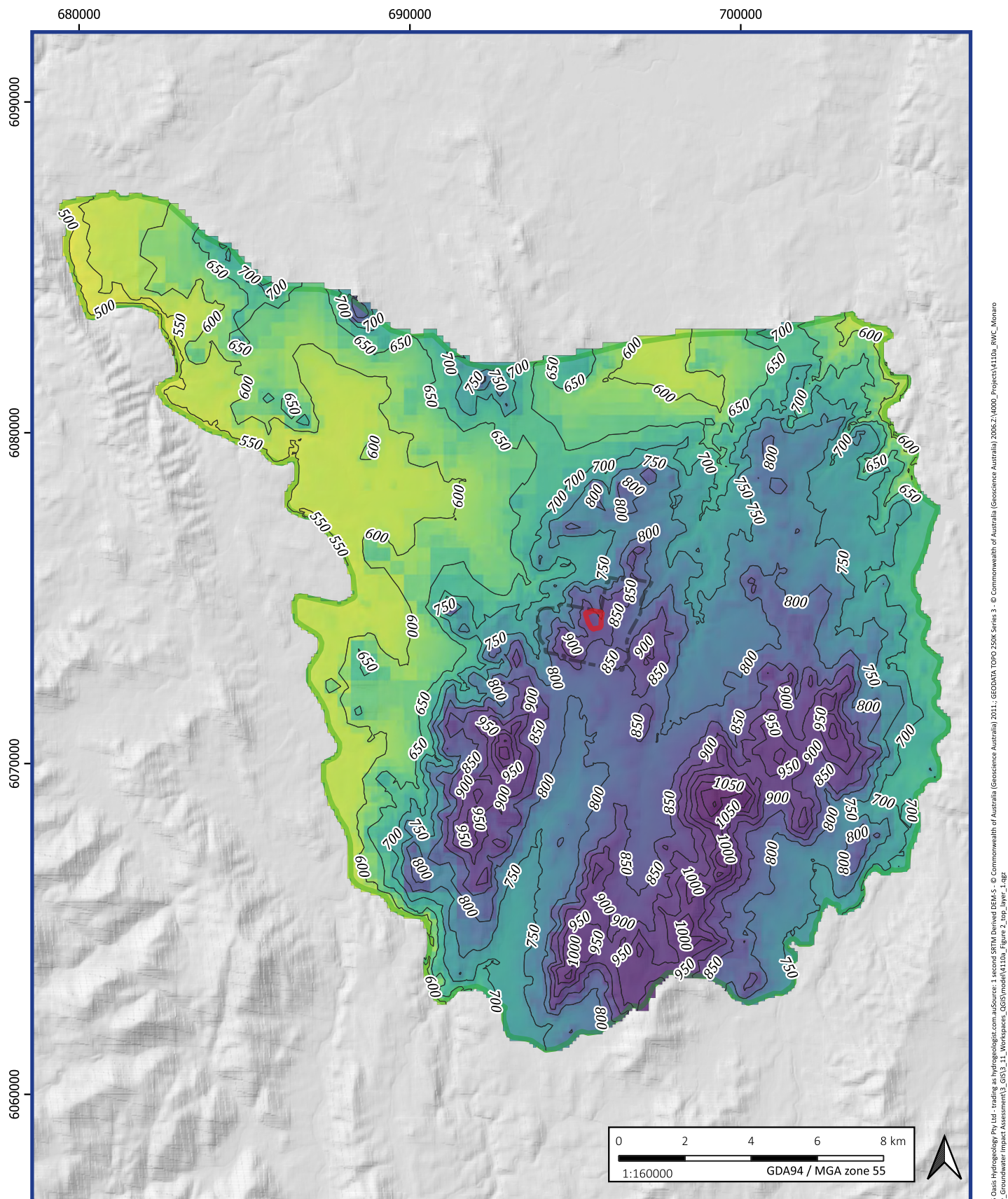
To account for the diverse topography within the model area while avoiding significant fluctuations in cell thickness, an algorithm using a Gaussian filter was implemented to smooth model layers. This algorithm generates a smoothed surface (model bottom) that conforms to the topography. Additional constraining factors were also applied to maintain the cell thickness within a reasonable range.

Table 2 summarises the model layer specifications including represented hydrostratigraphic units, average and maximum layer thicknesses, number of cells per layer and cell types. Figure 2 to Figure 4 present elevation maps representing the top of model layer 1 and base of model layers 1 and 2, respectively.

Convertible cell types are applied across the model domain, enabling the simulation of confined conditions where the model head is above the top of the layer, and unconfined conditions where heads fall below the layer top. Hydraulic conductivity is defined with vertical anisotropy, such that horizontal hydraulic conductivity in the x-direction (K_x) equals that in the y-direction (K_y) but differs from vertical hydraulic conductivity (K_v).

Table 2 Model layer definition

Model layer	Hydrogeological unit	Average thickness (m)	Maximum thickness (m)	# Cells per layer	Cell type
1	Weathered rock	40	40	17,866	Convertible, vertical anisotropy
2	Basement rock	117	412	17,866	Convertible, vertical anisotropy



Legend

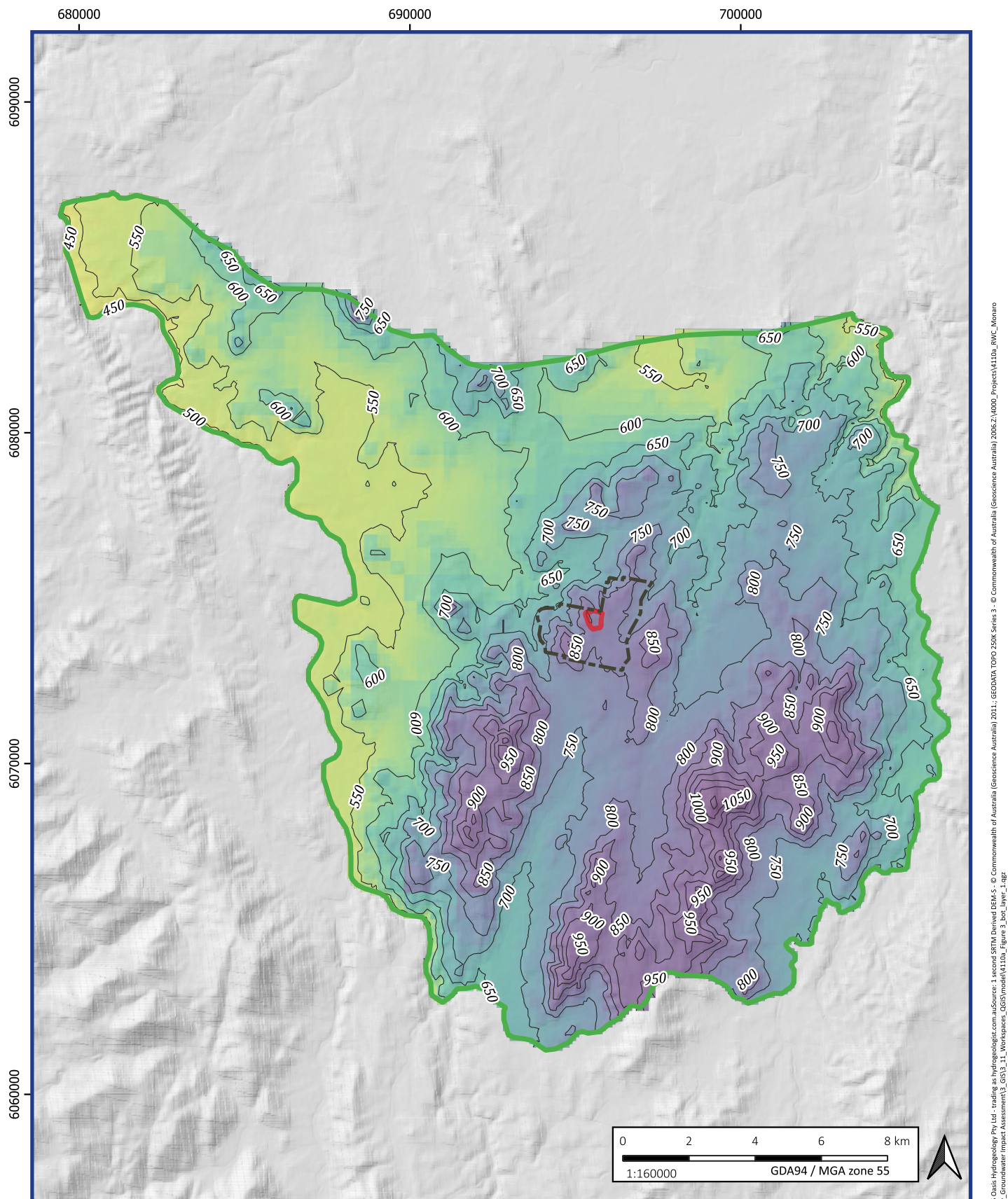
Top elevation of Layer 1

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Figure 2

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- Top of layer 1 (contour)
- Project boundary
- Monaro quarry
- Model domain



Legend

- Bottom of layer 1 (contour)
- - - Project boundary
- Monaro quarry
- Model domain

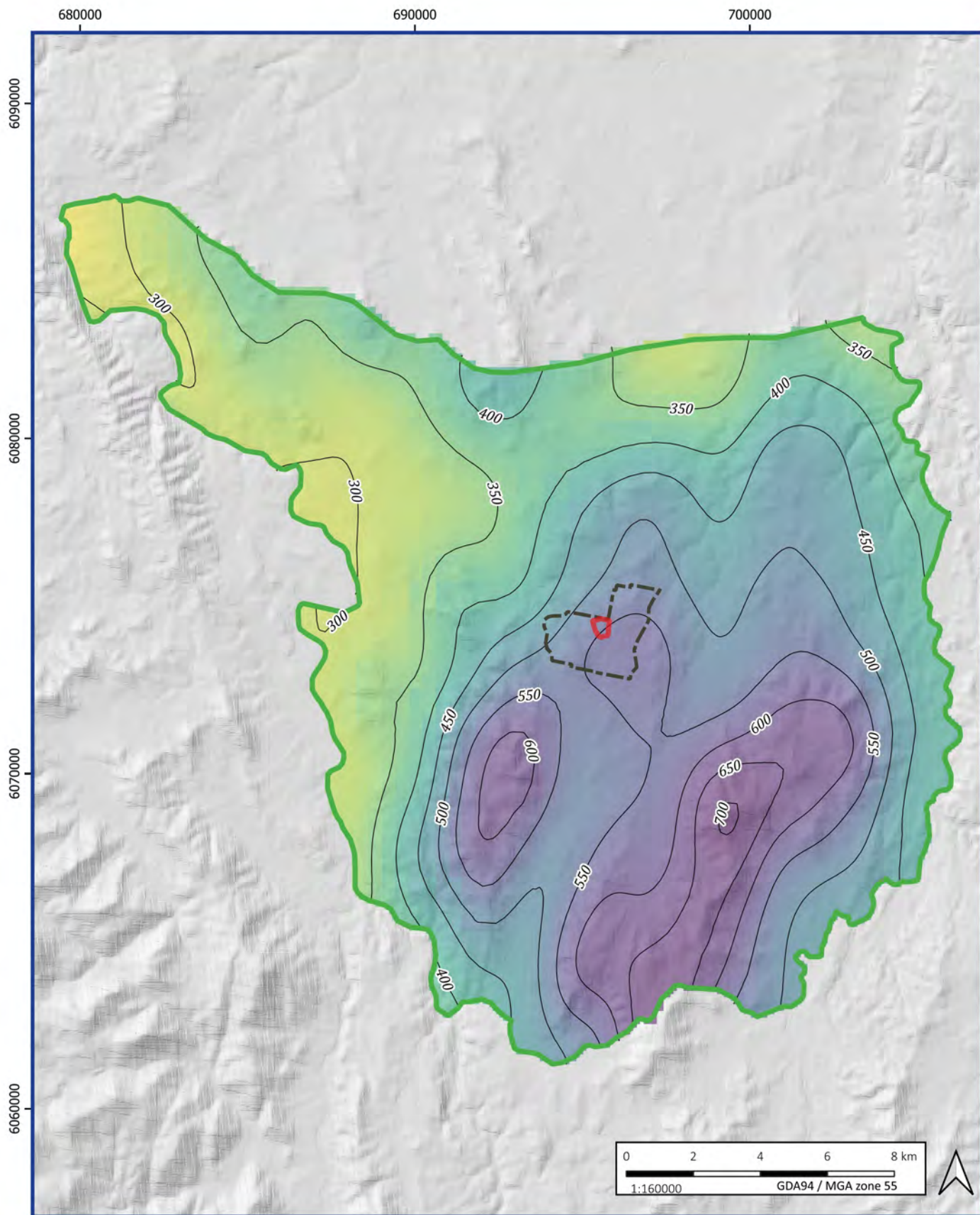
Bottom elevation of Layer 1

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Figure 3

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Legend

- Bottom of layer 2 (contour)
- - - Project boundary
- Monaro quarry
- Model domain

Bottom elevation of Layer 2

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Figure 4

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2.5. Initial conditions

Model heads for both layers were initialised to 0.5 m below the topographic surface elevation. From this initial condition, a steady state model was run which provided the starting heads for the calibration model. The climate conditions represented in the initial steady-state period reflect the average climatic conditions over the period 1900 to 2024.

2.6. Model boundary conditions

Boundary conditions provide a means by which auxiliary groundwater fluxes and stresses can be specified within the model. The following boundary conditions have been adopted in the model.

SILO gridded rainfall and Mortons' actual evapotranspiration data covering the period from 1900 to 2024 was downloaded and processed for the model area (station 70064). For the steady state model and predictive model, the long-term average daily rainfall and actual evapotranspiration were utilised. Daily averages of the historical data were used for the transient monthly stress periods of the calibration model.

2.6.1. Rainfall recharge

Recharge was applied using the MODFLOW 6 Recharge (RCH) package. Applied recharge rate was calculated as a percentage of daily rainfall with a uniform value assigned to all surficial model cells. The calibrated recharge rate was 0.035, equivalent to 3.5% of rainfall.

2.6.2. Evapotranspiration

Evapotranspiration was applied across the entire top cells of the model using the MODFLOW 6 Evapotranspiration (EVT) package. The extinction depth was calibrated to 2.0 m below ground level and the rate of evapotranspiration factor was calibrated to 20% of Mortons' actual evapotranspiration.

2.6.3. Surface drainage

Surface water drainage was implemented using the MODFLOW 6 River (RIV) package. The RIV package was applied to the major rivers representing the eastern, western and southern boundaries of the model, as well as to minor drainage features and tributaries within the model domain. Additionally, a river cell was used to represent the dam adjacent to "Dam Bore" to improve the model fit at this location. Locations of surface water drainage features represented by the model are presented in Figure 5.

The RIV package simulates a head-dependent flux boundary and is an appropriate boundary type to simulate the ephemeral drainage features in the model area. Modelled drainage features were set as dry, and act as drains to remove water from the system. For watercourses, river bottom elevation and the river stage were set to the model surface elevation. For the dam, stage height was set to model surface elevation, and the bottom elevation of the dam was set to 1 m below surface.

For riverbed properties, vertical hydraulic conductivity for each river cell was obtained from the MODFLOW 6 Node Property Flow (NPF) package. Standardised stream dimensions, including a stream width of 10 m for the bound rivers and 3 m for the inside rivers, and a bed thickness of 2 m were uniformly assigned to all river cells representing watercourses. Dimensions of 30 m wide by 30 m long were applied for the dam, with a bed thickness of 1 m. Hydraulic conductance was then calculated for each individual river cell based on its geometry and stream dimensions. Hydraulic conductance of the dam was adjusted as a unique parameter during calibration to reduce the model to measurement misfit at the Existing Dam Bore.

2.6.4. No-flow boundary

No-flow boundaries are used to represent the northern edge of the model and a short (~700 m) section between major rivers, along the southern model edge. These boundaries are placed far enough from the Project site to avoid interaction with simulated drawdown. It is assumed that groundwater flow across the boundaries is negligible. The locations of no-flow boundaries are presented in Figure 5.

2.6.5. Quarrying

Quarry dewatering within the model area was simulated using the MODFLOW 6 Drain (DRN) package, which was solely applied in the predictive model. The drain cells allow for one-way flow of water out of the model. When the modelled head drops below the specified elevation of the drain, the drain cells become inactive. This is the conventional way of simulating the removal of water caused by quarrying.

The client supplied approximate quarry stages in two formats:

1. Elevation contours were provided to ascertain the spatial extent for each stage.
2. Progressing elevations were outlined for each stage by the client. A 30-year life of quarry was confirmed by the client. Polygons with elevation information for each stress period were subsequently created using this information, and it was assumed that the predictive model commences immediately after the calibration model.

To simulate the quarrying, drain cells were kept active until the end of the model. The conductance values of the drain cells were set as constant value of 100 m²/day to facilitate rapid removal of water from the system. Table 3 presents the quarry stages and elevations corresponding to years / stress periods. The quarry progression for the predictive model from Stage 1 to Stage 4 is also shown in Figure 6.

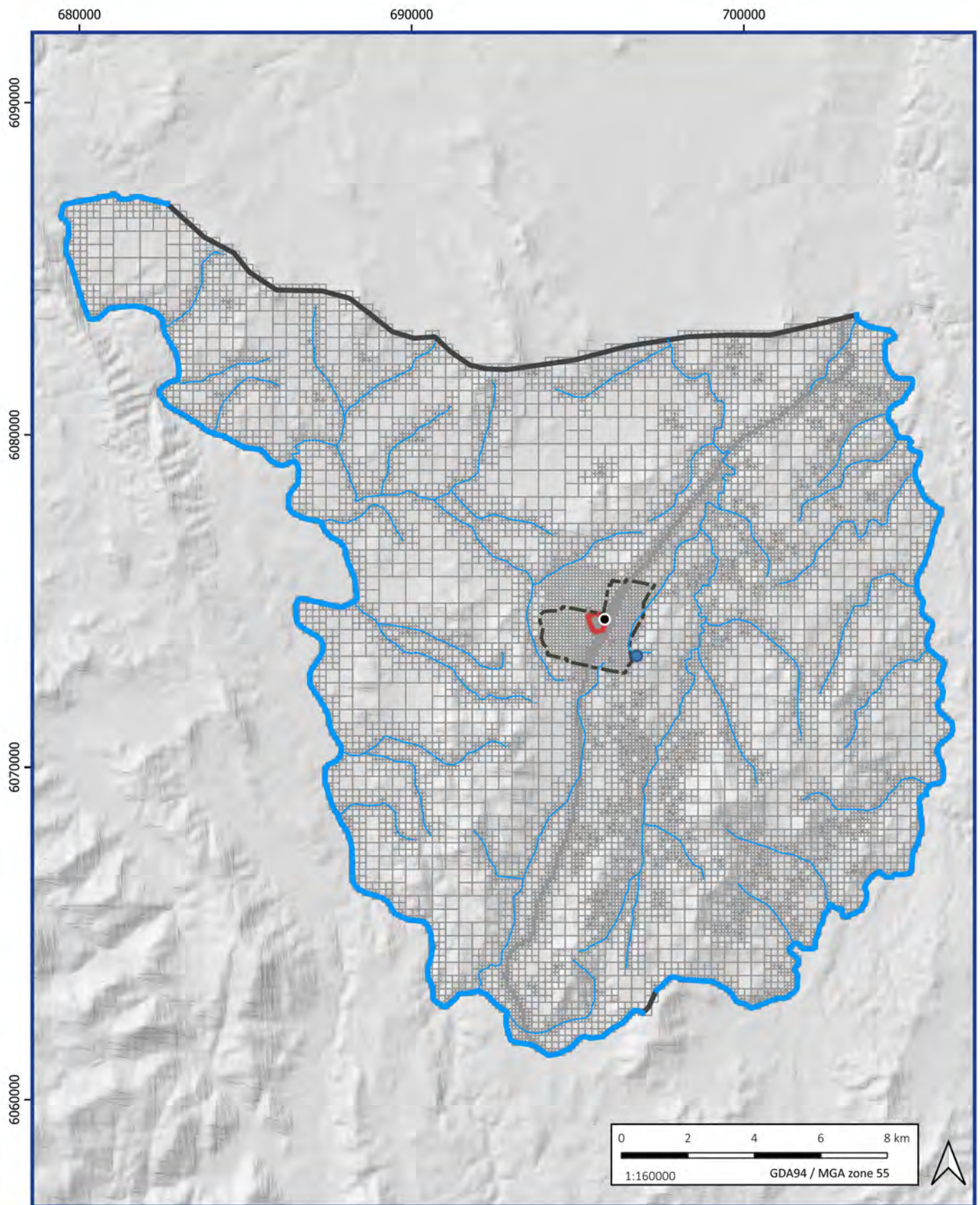
Table 3 Quarry stages and corresponding elevations

Years	Stage	Excavated elevation (mAHD)
1 – 5	Stage 1	852.5
6 – 10	Stage 2	852.5
11 – 15	Stage 3	852.5
16 – 30	Stage 4	795.0

Note: mAHD - metres above Australian Height Datum

2.6.6. Extraction bore

The MODFLOW 6 Wells package (WEL) was used to represent the removal of pumped water from a future extraction bore positioned near Northern Dam (location shown in Figure 5). Pumping at this well was simulated throughout the duration of the predictive model, with the target pumping rate set to 1 litre per second (L/s). The *autoflowreduce* option in the WEL package was used to restrict well water extraction to the amount of water available within the model, and so, simulated extraction rates were generally below the targeted 1 L/s.



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Legend

Boundary conditions

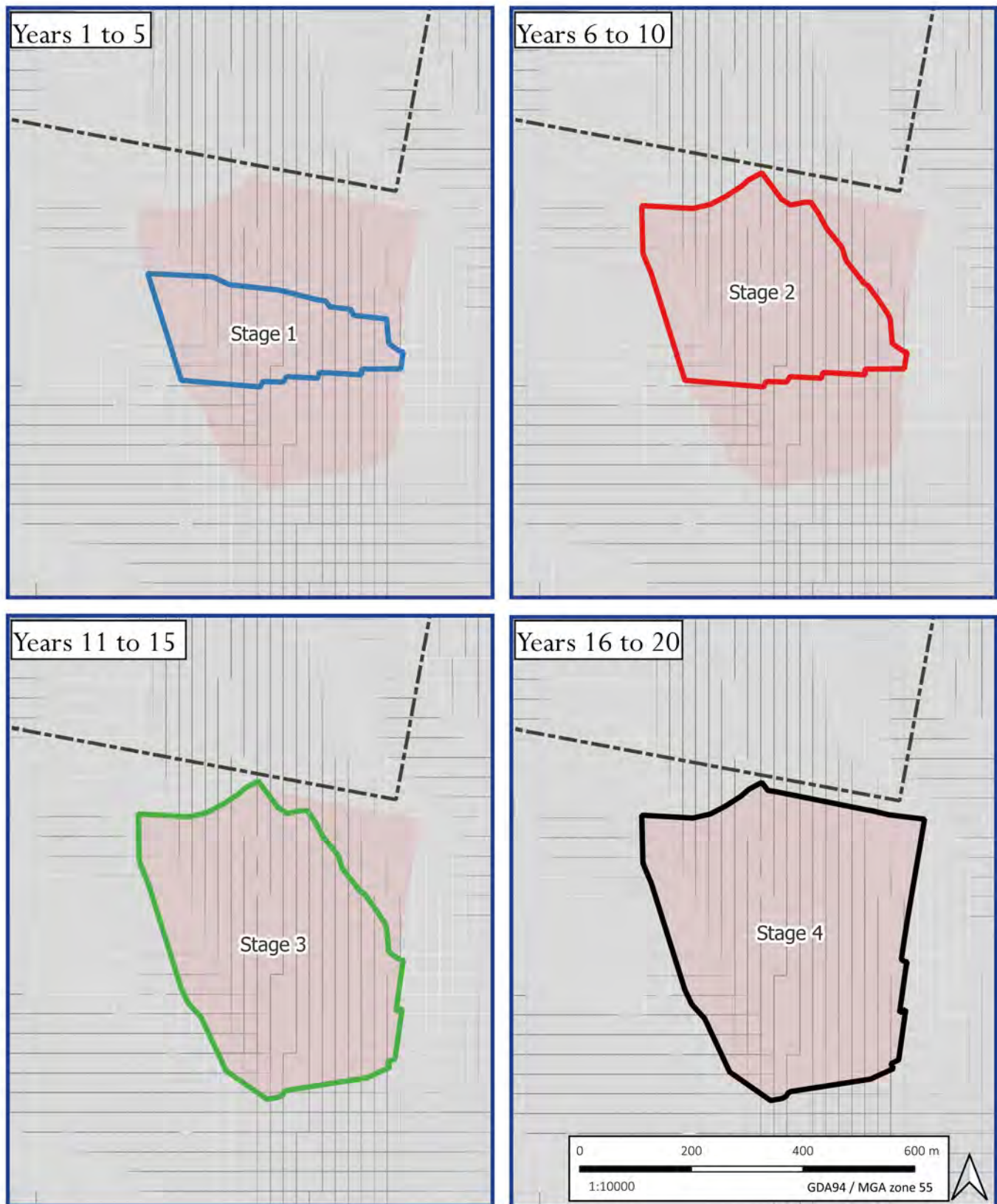
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Figure 5

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- Dam
- Extraction well
- No-flow boundary
- Major river
- Minor drainage feature
- Project boundary
- Monaro quarry
- Model mesh



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Legend

Quarry stages

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Figure 6

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- Project boundary
- Stage 1
- Stage 2
- Stage 3
- Stage 4
- Final quarry area

3. Model calibration

Model calibration is the process of adjusting model parameters (hydraulic properties and boundary conditions) so that the model replicates the observed behaviour of the groundwater system. The quality of this replication can be assessed by comparing observations with model outputs at corresponding model times.

Calibration of the model was achieved using PESTPP-IES (White *et al.*, 2020) software. PESTPP-IES is a widely accepted software for calibration of groundwater models and is discussed in further depth in Section 3.2. The heads at the end of the calibration process provide the initial conditions for the transient predictive simulations which is used to assess potential Project related impacts.

3.1. Calibration approach

PESTPP-IES was used to obtain an ensemble of calibrated parameter realisations from a sample of the prior distribution of parameters. For each realisation in the prior parameter ensemble, calibration was done to minimize the model to measurement misfit, as quantified by the objective function given here:

$$\phi = \sum_{i=1}^n w_i (O_i - S_i)^2$$

Where:

- ϕ : Objective function value.
- O_i : Observed data for observation i .
- S_i : Simulated data corresponding to observation i .
- w_i : Weight assigned to the observation i .
- n : Total number of observations.

A base parameter set was obtained from the calibrated ensemble of realisations for use in model predictions for the groundwater impact assessment. This base parameter set was selected from the ensemble as that which minimised the scaled root mean squared (SRMS) statistic.

Measurement noise wasn't directly specified during calibration and so, PESTPP-IES generated samples of noise from the observation weights.

The following model properties were adjusted during the calibration process to achieve fit with observed data:

- hydraulic conductivity (Kh);
- vertical hydraulic conductivity anisotropy (Kv/Kh), also referred to as the Kv factor (Kvf);
- specific storage (Ss);
- specific yield (Sy);
- dam conductance (Dam cond);
- recharge factor (r fact);
- evapotranspiration depth (evt depth); and
- evapotranspiration factor (evt fact).

3.2. PESTPP-IES overview

PESTPP-IES serves as a powerful tool for calculating samples from the posterior parameter probability distribution, making it adaptable to a range of modelling scenarios. It does not rely on the assumption of linearity; therefore no Jacobian matrix needs to be calculated during the iterations. For models with a substantial number of parameters, PESTPP-IES has better computational efficiency.

PESTPP-IES assimilates calibration data by using an iterative ensemble smoother algorithm. The process starts with the generation of an ensemble of parameter fields characterised by a prior distribution, which are based on pre-calibration parameter uncertainty, combining expert knowledge and available measurements of system properties. The prior distribution is defined by the user, or PESTPP creates it using the parameter data provided in the pest control file. Through successive iterations, PESTPP-IES adjusts these parameter fields to conform with calibration data constraints. The algorithm combines Bayesian principles with subspace methods to efficiently update the parameter realisations.

A key benefit of using PESTPP-IES for calibration is that it generates an ensemble of calibrated models, enabling quantification of both parameter and predictive uncertainty. Predictive uncertainty is discussed in Section 7.

3.3. Pilot points

Pilot points were employed to capture spatial heterogeneity in layer hydraulic properties. These pilot points were distributed regionally at 1500 m spacing, with finer spacing (250 m) utilised within the Project site boundary where more information is available. Further refinement was applied along the Royalla Fault trace. Increasing density of pilot points along the fault trace and within the Project site boundary allows the model to capture more detailed spatial variations in these areas. In total, 738 pilot points were applied over the model domain, with identical distribution across both model layers. Figure 7 presents the distribution of pilot points over the model domain.

Spatial covariance between pilot points was applied to account for patterns of heterogeneity that may emerge in hydraulic properties as part of the calibration process. This also ensures that adjustments made to pilot point parameters reflect a spatially coherent field, rather than independent random variation. Due to limited site-specific information to characterise spatial variability, the following simplifying assumptions were adopted when constructing the semi variogram:

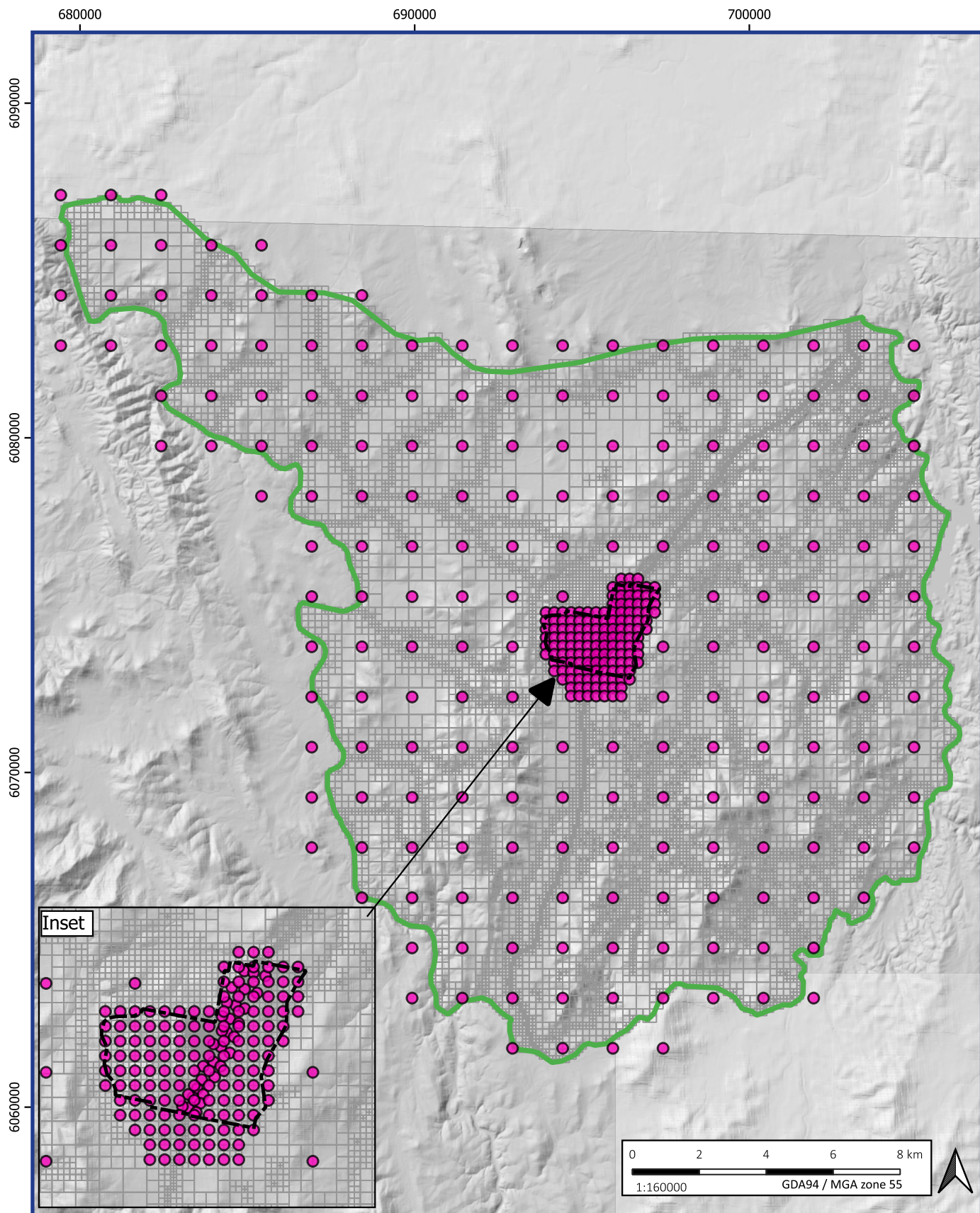
- nugget effect was assumed to be 0;
- sill was set to 1;
- horizontal anisotropy (Hanis) was set to 1 (isotropic); and
- bearing (azimuth of maximum continuity) was set to 0 degrees.

These assumptions represent a simplifying approach, imposing an isotropic covariance structure by setting horizontal anisotropy to 1 and bearing to 0 degrees. While this does not introduce directional bias, it still reflects a specific assumption about spatial continuity, namely that no preferential flow direction is imposed in the horizontal plane.

Parameter-specific standard deviations were derived based on the logarithmic spacing between the defined upper and lower parameter bounds used in the PESTPP-IES inversion. The resulting covariance properties for each spatially varying parameter are summarised as Table 4. The software PLPROC (Doherty, 2021) was used to perform Kriging interpolation to interpolate pilot points parameters to each cell in the model mesh.

Table 4 Pilot point covariance characterisation

Spatially varying parameter	Model layer	Standard deviation	Nugget	Sill	Hanis	Bearing
Kh	1	2.00	0.00	1.00	1.00	0.00
	2	2.50	0.00	1.00	1.00	0.00
Kvf	1	1.00	0.00	1.00	1.00	0.00
	2	1.00	0.00	1.00	1.00	0.00
Ss	1	1.50	0.00	1.00	1.00	0.00
	2	1.50	0.00	1.00	1.00	0.00
Sy	1	2.00	0.00	1.00	1.00	0.00
	2	2.00	0.00	1.00	1.00	0.00



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Legend

Pilot points

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Figure 7

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- Pilot points
- Project boundary
- Model mesh
- Model domain

3.4. Model convergence

PESTPP-IES completed ten (10) iterations, resulting in a total of 5,267 successful model runs. It was found that the parameter ensemble from the final iteration (iteration 10) were suitably constrained to effectively explore model parameter and predictive uncertainty. Reduction in the objective function (Φ) with successive model runs is presented as Figure 8. At the end of the calibration process, the objective function for the base realisation was reduced from 28000 m² to 83 m². The term 'base model' in this report refers to the calibrated parameter set that minimised the SRMS statistic from the final ensemble (iteration 10).

The parameter 'ies_num_reals' in PESTPP-IES defined the initial number of models, which was set to 500, representing 500 distinct realisations. During each iteration, some models were terminated by the run manager due to prolonged run times, controlled by the variable 'overdue_giveup_fac' in PESTPP-IES. In total 76 realisation were terminated by the run manager, leaving 424 calibrated realisations in the posterior ensemble.

Calibration statistics were computed across each of the 424 model realisations to evaluate the reliability of model predictions. The distribution of SRMS values across the 424 calibrated realisations is presented as Figure 9.

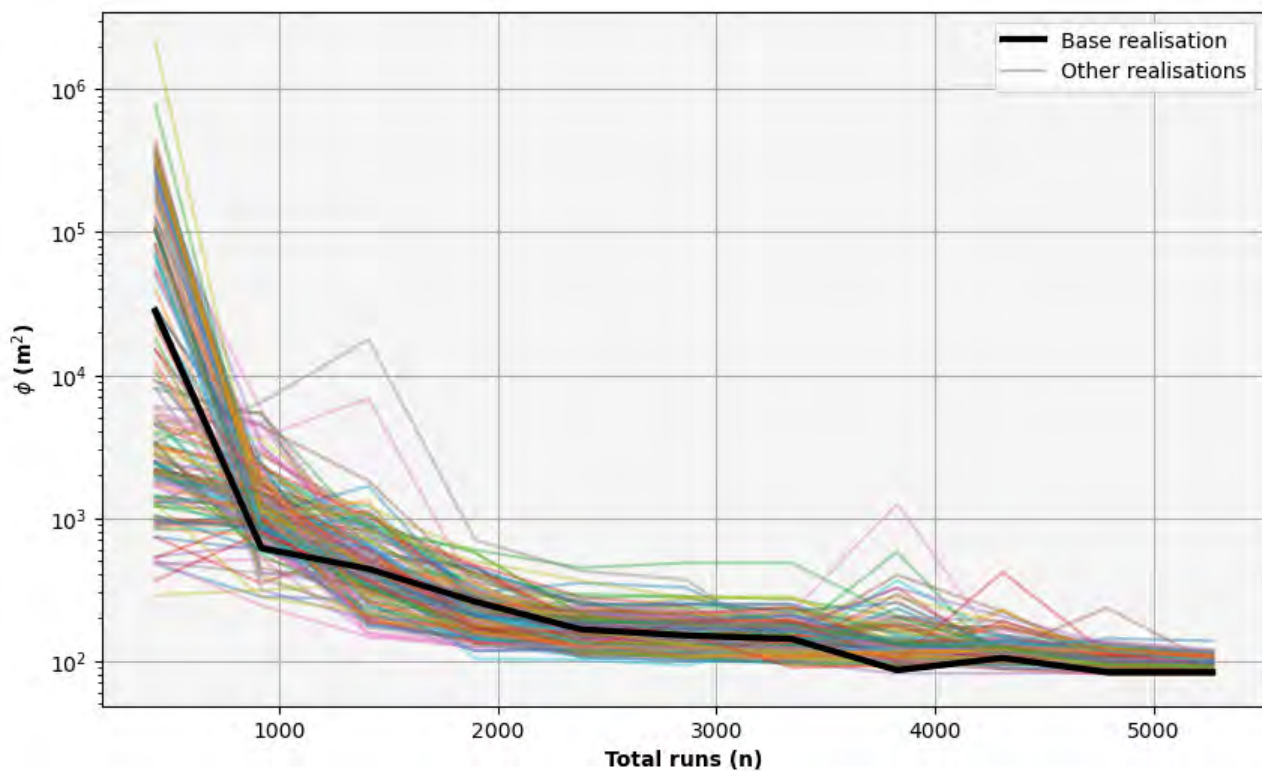


Figure 8 Ensemble objective function reduction

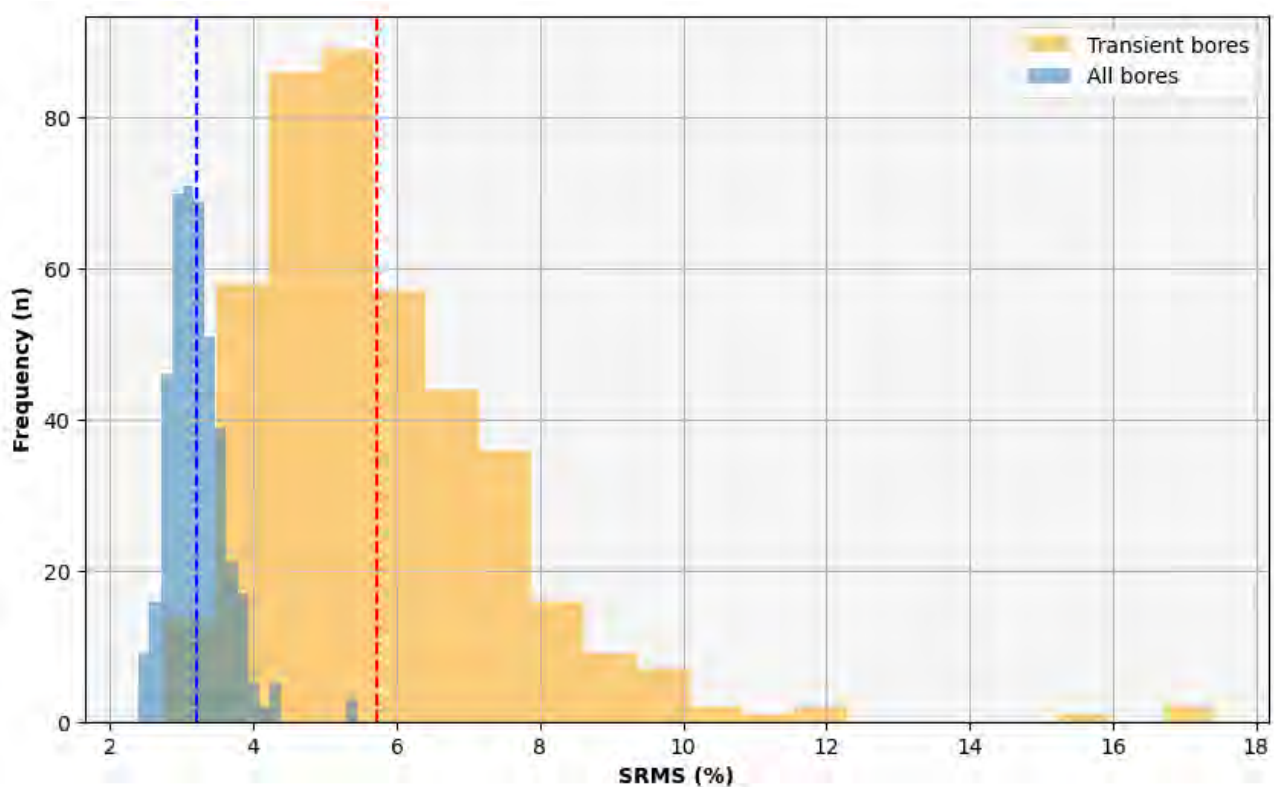


Figure 9 Posterior ensemble distribution of SRMS

3.5. Parameter distribution

The sampling distributions for each parameter in the prior ensemble (iteration 0) and the posterior ensemble (iteration 10) are depicted graphically as a side-by-side comparison in Appendix A. This comparison between the two iterations reveals a reduction in uncertainty of select parameters as a result of model calibration. This is demonstrated by a notable reduction in the posterior standard deviation for parameters relative to the prior standard deviation. The main parameters where significant reduction in uncertainty was achieved were:

- horizontal hydraulic conductivities of model layers 1 and 2;
- vertical hydraulic conductivity anisotropy factors of model layer 2; and
- specific yield in model layer 1.

Other parameters show lesser to no reductions in uncertainty as measured by the standard deviation. In theory, progressive iterations should yield reductions in the standard deviation of the parameter fields which results in better performance in history matching (lower phi) compared to the initial ensemble. A reduction in the standard deviation of the parameter fields reflects a reduction in parameter uncertainty. In the current project, the minimal reduction in standard deviation of some parameters can be explained by the following reasons:

- The model has been calibrated, and the initial ensemble was created using the calibrated parameters as the base realisation, the parameters have been constrained to reasonable ranges in the pest file.
- The `ies_center_on(base)` option was used to instruct PESTPP-IES to use the base realisation as the “centre” of the ensemble. Limited testing has shown this can improve the resulting phi associated with the base realisation. This should also reduce the variability of the parameter distribution during iterations. Note: the ensemble ‘base’ used for centering differs from the final calibrated base model, which was selected based on minimum SRMS.

3.6. Calibration targets

A total of 507 individual head observations and 501 temporal head differences from six observation bores were used as targets for the model calibration. The six observation bores selected for calibration are Existing Dam bore, MB01, MB02, MB05, MRDDH08 and MRPDH15. These bores were selected as each had a history of observations, spanning September 2021 through to January 2024. Pre-processing of observations was done to remove outliers at Existing Dam bore and MRPDH15. Observed data was then resampled to weekly averages which provided the final calibration targets.

Weights were assigned to observation targets to ensure equal importance of each observation in the objective function. Weights for transient head difference observations were boosted to increase the visibility of these observations in the objective function. This was necessary due to the vast difference in scale between head measurements and their respective transient head difference.

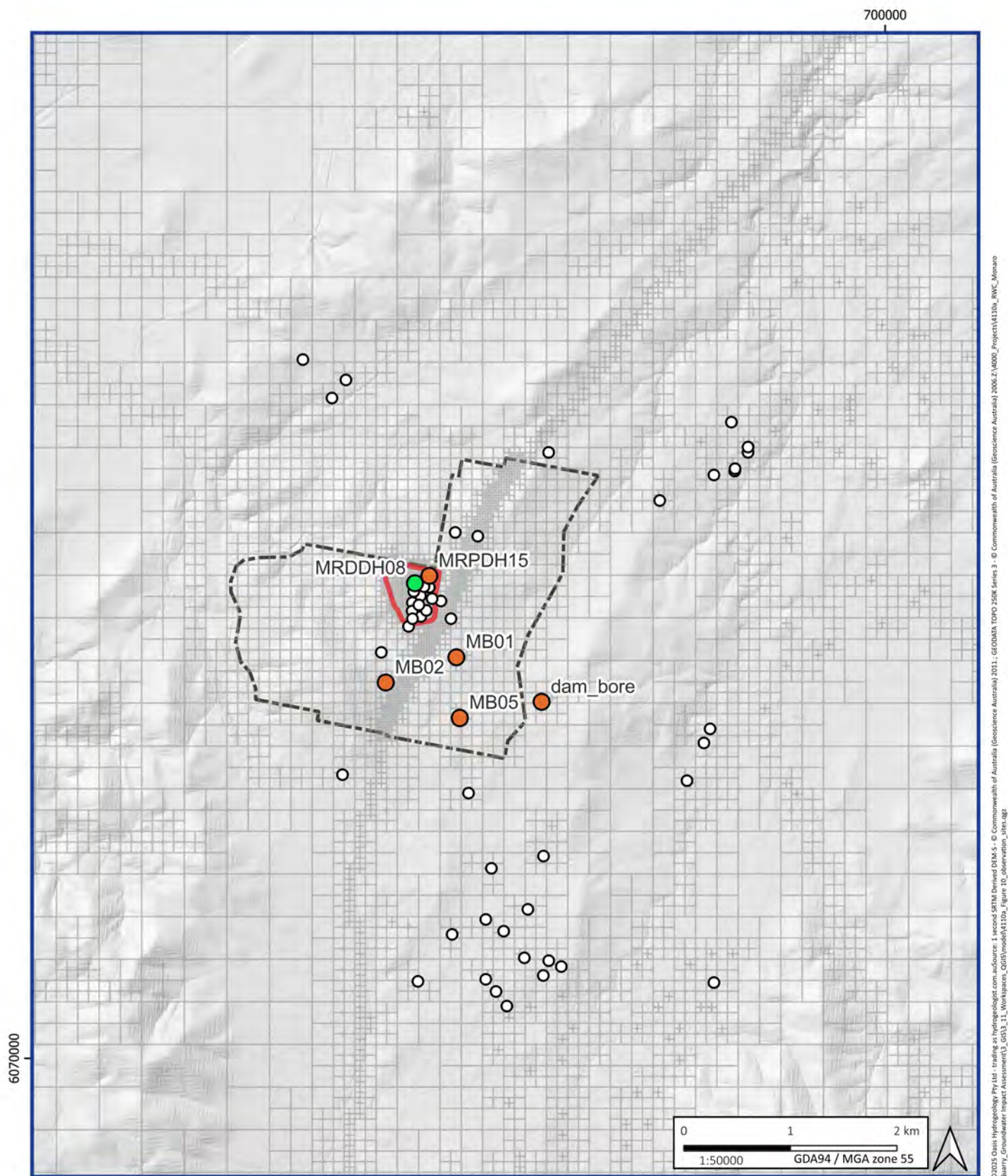
Single head measurements from 34 additional sites within the model domain were included in the observation dataset. However, to prioritise transient data these single observations were not used as calibration targets. Base model calibration statistics are presented as Table 5 for calibration targets and all observations (transient and single observations). Note that temporal head differences were not considered in the calculation of summary statistics. The location of the six target sites along with ‘singular observation’ sites are shown in Figure 10.

The base model transient calibration resulted in a SRMS of 2.74% for calibration targets, and 2.87% when considering all available observations. The SRMS obtained by model calibration is below the 10% threshold recommended by the Australia Groundwater Modelling Guidelines (Barnett *et al.*, 2012), indicating an acceptable calibration has been achieved.

A scatter plot of modelled versus observed hydraulic heads for the base model calibration targets is presented as Figure 11, and for all observations as Figure 12. Base model hydrographs of observed and modelled heads are provided as Appendix B.

Table 5 Summary of model calibration performance – non-weighted and weighted (head observations only)

Statistic		Unit	Non-weighted	Weighted	Non-weighted	Weighted
			Transient targets		All observations	
Number of observations	n	-	507	507	541	541
Range of measured heads	-	m	42.3	42.3	155.1	155.1
Sum of squared residuals	SSQ, Φ	m ²	684.4	7.5	10695.9	7.5
Residual mean	$\bar{R}$	m	0.58	0.06	0.33	0.05
Scaled absolute residual mean	$S \bar{R} $	%	2.16	0.22	1.10	0.06
Root mean squared error	RMS	m	1.16	0.12	4.45	0.12
Scaled root mean squared error	SRMS	%	2.74	0.29	2.87	0.76



Legend

Observation sites

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Figure 10

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- Observation targets in Layer 1
- Observation targets in Layer 2
- Observation site with single measurement
- Project boundary
- Monaro quarry
- Model mesh

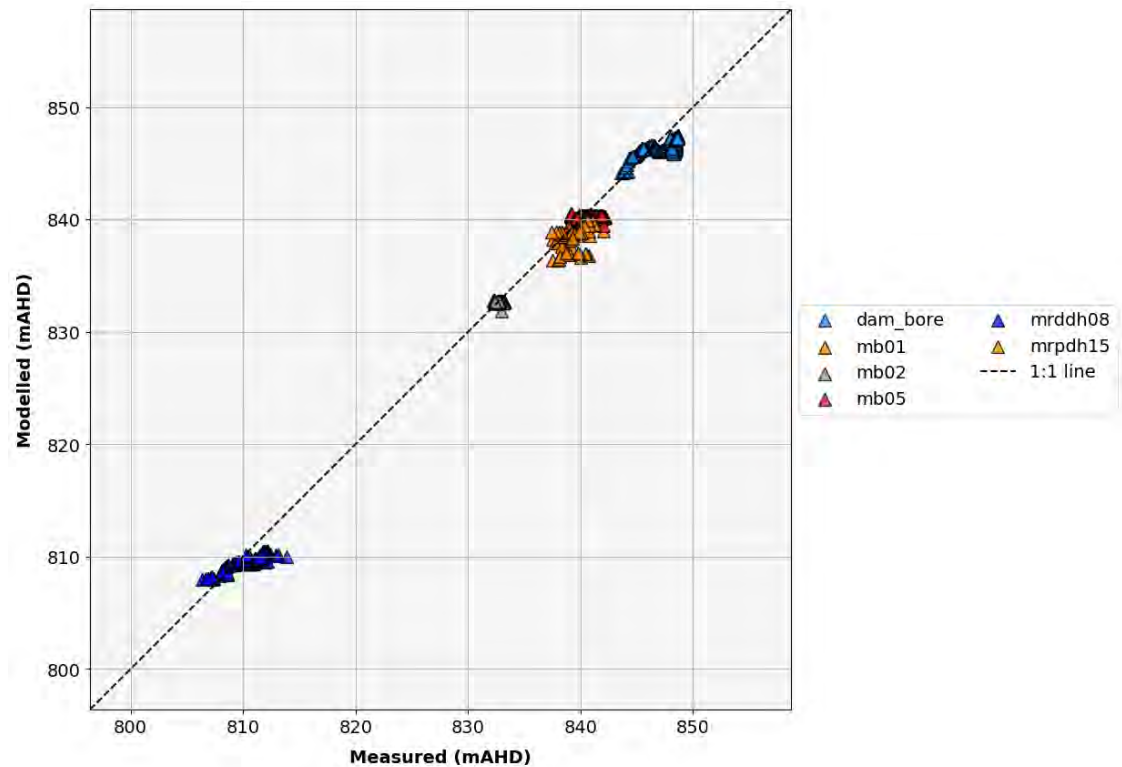


Figure 11 Transient residual scatter (calibration targets)

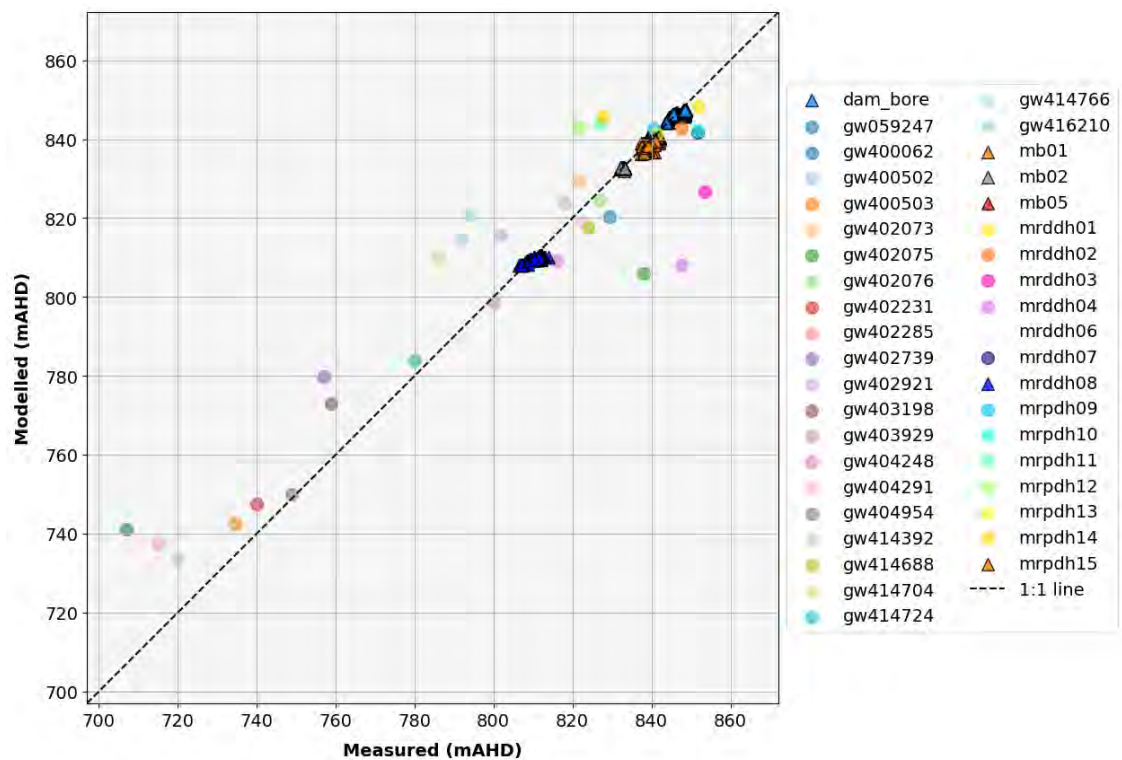


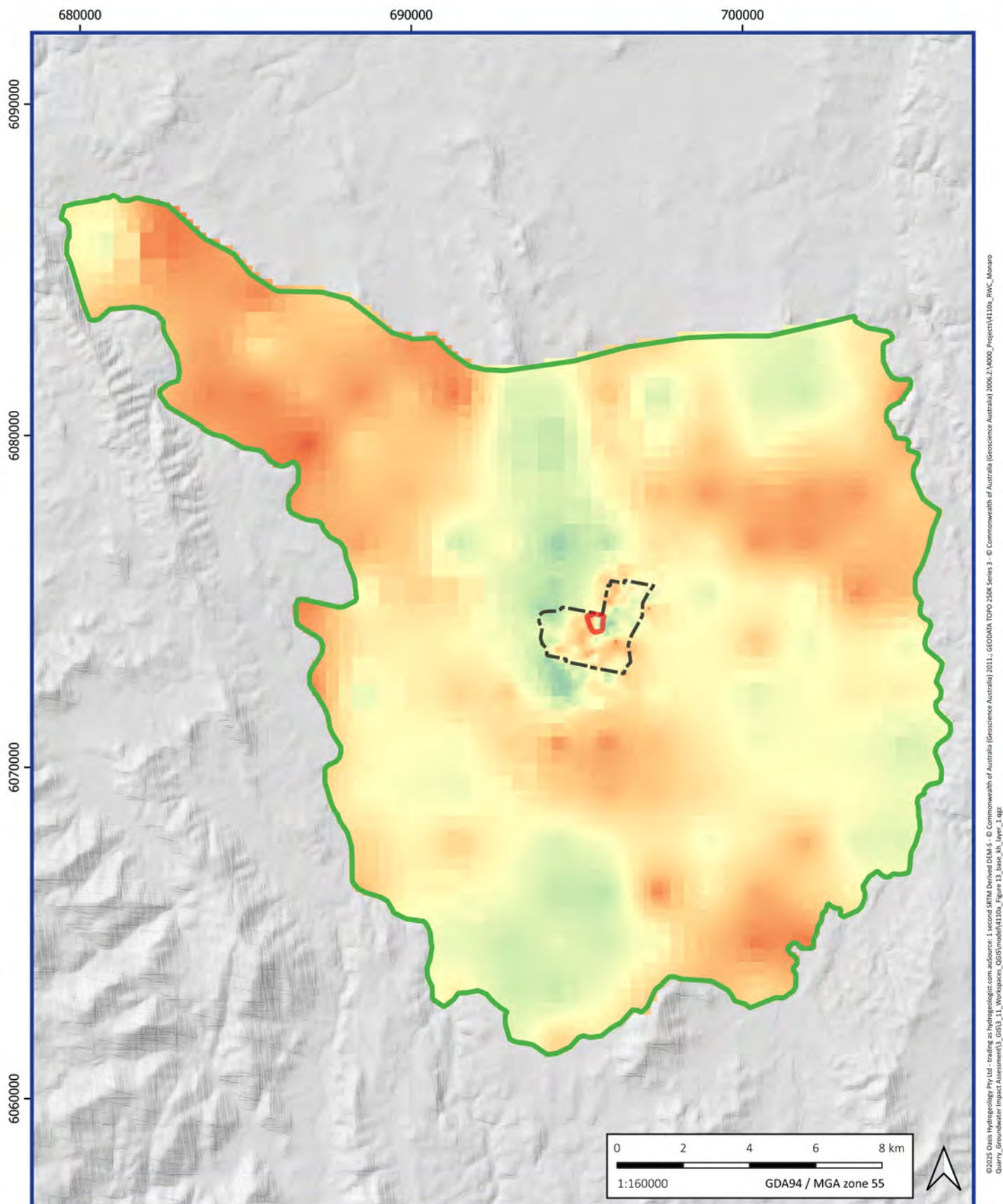
Figure 12 Transient residual scatter (all observations)

3.7. Calibrated parameters

Table 6 presents statistics for the base model parameters for both spatially varying layer properties and constant parameters. Maps of base calibrated layer properties are presented as Figure 13 through Figure 20.

Table 6 Summary of calibrated parameters

Parameter	Units	Layer	Min	Median	Max	Std
Spatially varying parameters						
Kh	m/day	1	1.51e-03	1.47e-02	1.35e-01	1.73e-02
		2	4.50e-04	4.38e-03	4.04e-02	5.18e-03
Kv		1	1.10e-04	2.56e-03	3.13e-02	2.89e-03
		2	2.14e-05	4.97e-04	6.09e-03	5.63e-04
Ss	m ⁻¹	1	5.12e-07	2.97e-06	3.83e-05	3.72e-06
		2	5.45e-07	3.15e-06	4.07e-05	3.96e-06
Sy	-	1	3.75e-04	3.92e-03	3.59e-02	4.76e-03
		2	1.55e-05	1.62e-04	1.48e-03	1.97e-04
Constant parameters						
r fact	-	-	-	3.50e-02	-	0
evt depth	m	-	-	4.26	-	0
evt fact	-	-	-	2.03e-01	-	0
Dam cond	m ² /day	-	-	2.16e-03	-	0



Legend

$\log_{10}(Kh)$



— Project boundary

□ Monaro quarry

□ Model domain

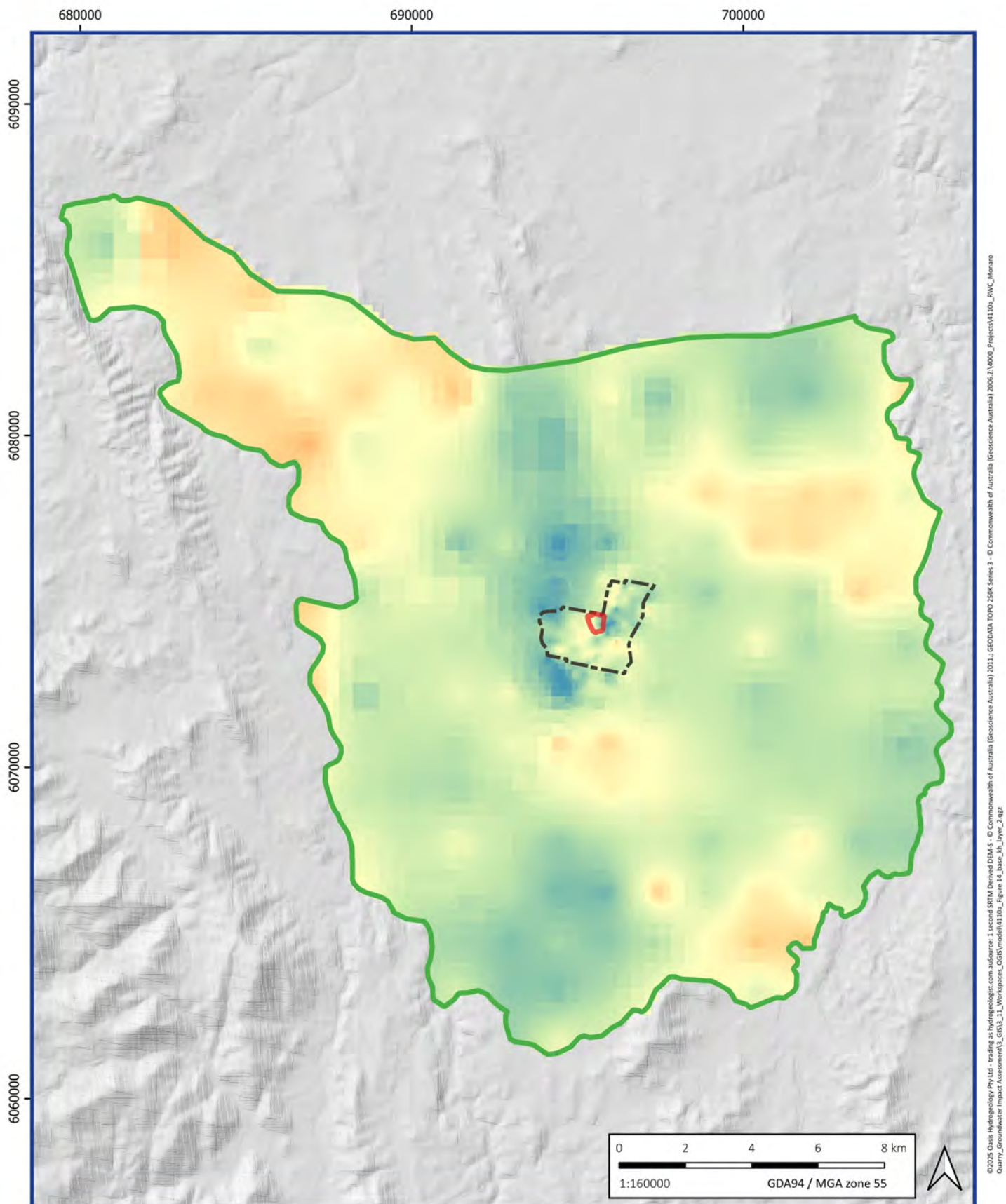
Base calibrated horizontal hydraulic conductivity (Kh) in Layer 1
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Figure 13



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Legend

$\log_{10}(Kh)$



— Project boundary

□ Monaro quarry

□ Model domain

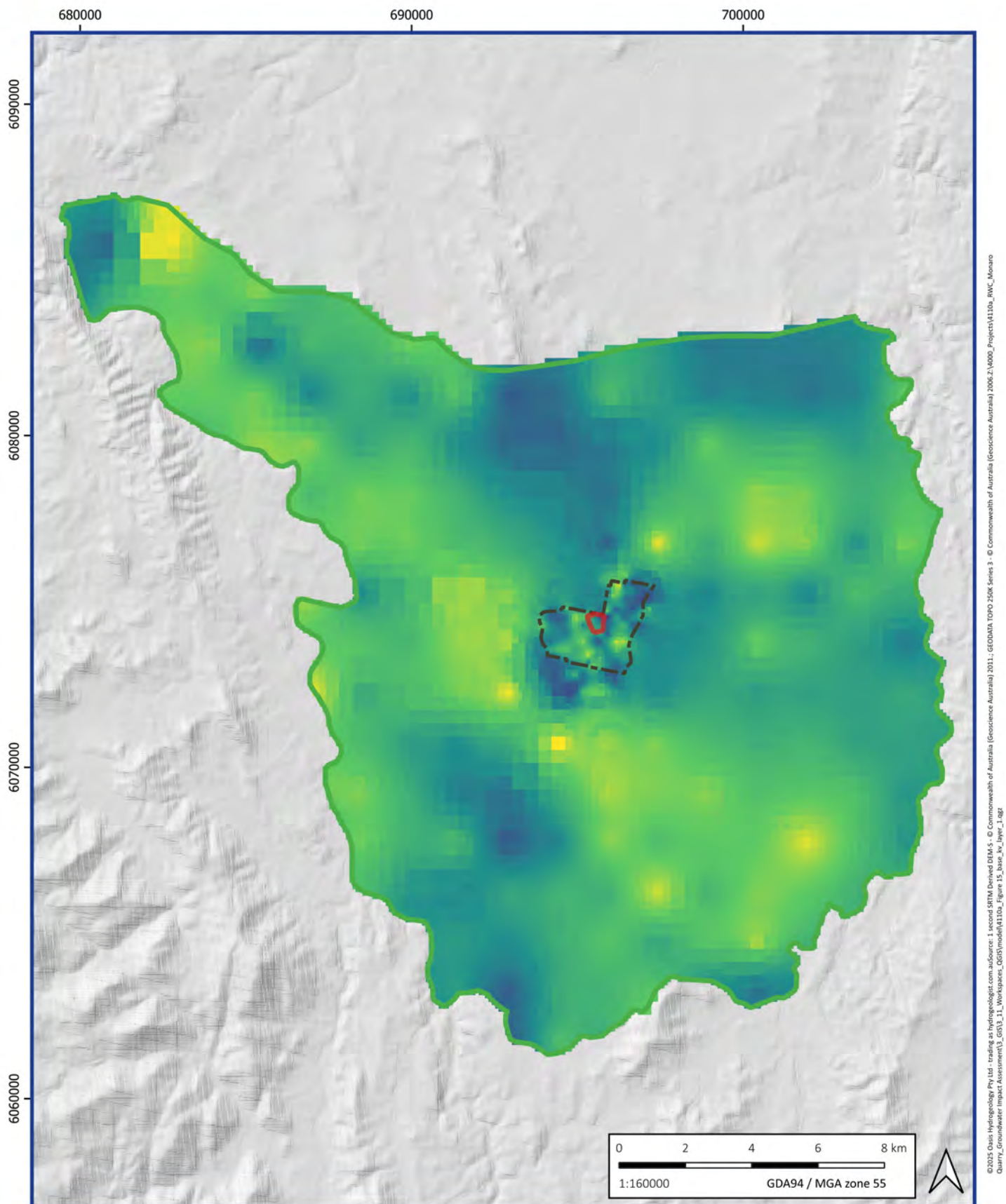
Base calibrated horizontal hydraulic conductivity (Kh) in Layer 2
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Figure 14

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Legend

log₁₀(Kv)



— Project boundary

□ Monaro quarry

□ Model domain

Base calibrated vertical hydraulic conductivity (Kv) in layer 1

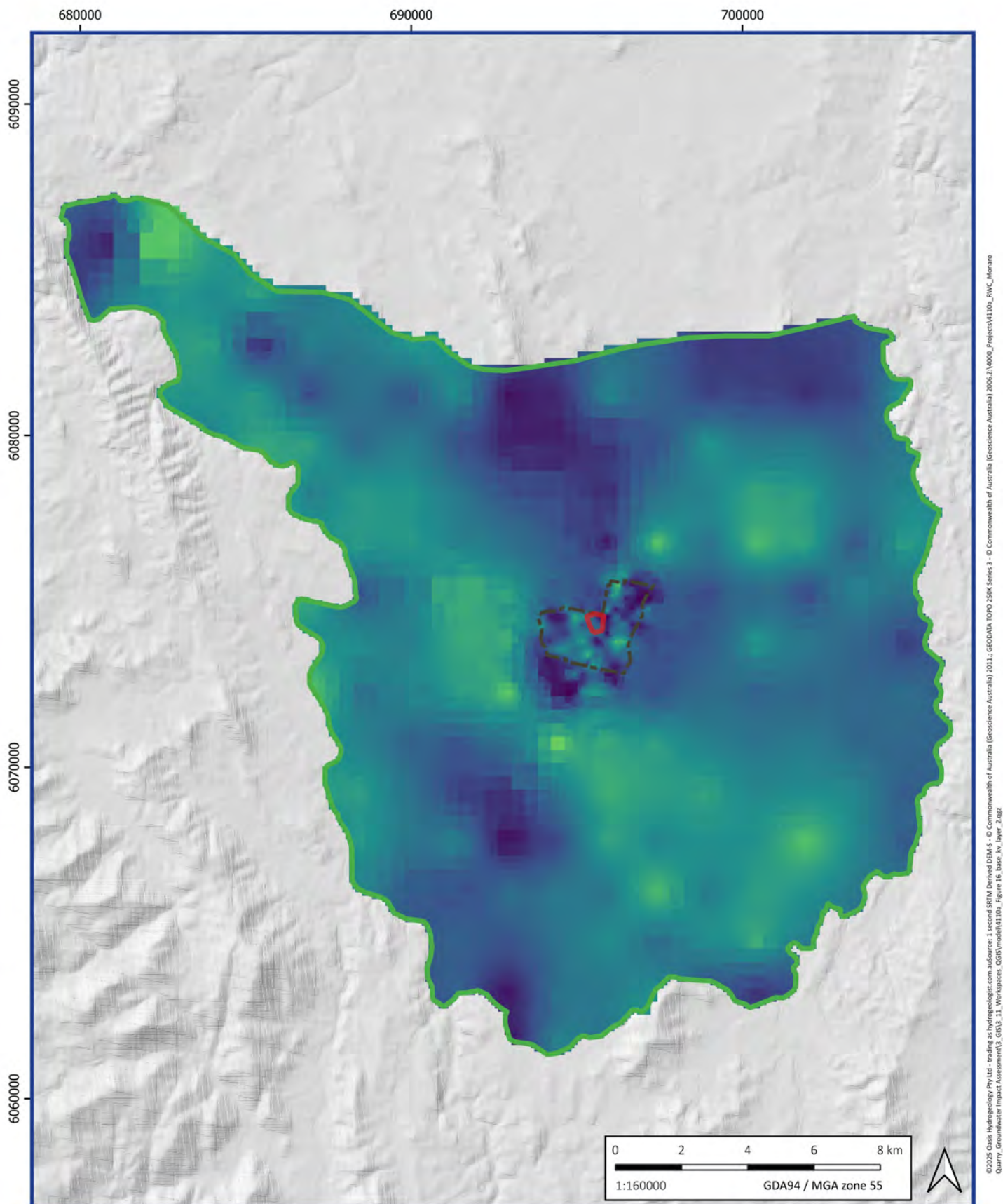
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Figure 15

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Legend

log₁₀(Kv)



—•— Project boundary

□ Monaro quarry

□ Model domain

Base calibrated vertical hydraulic conductivity (Kv) in Layer 2

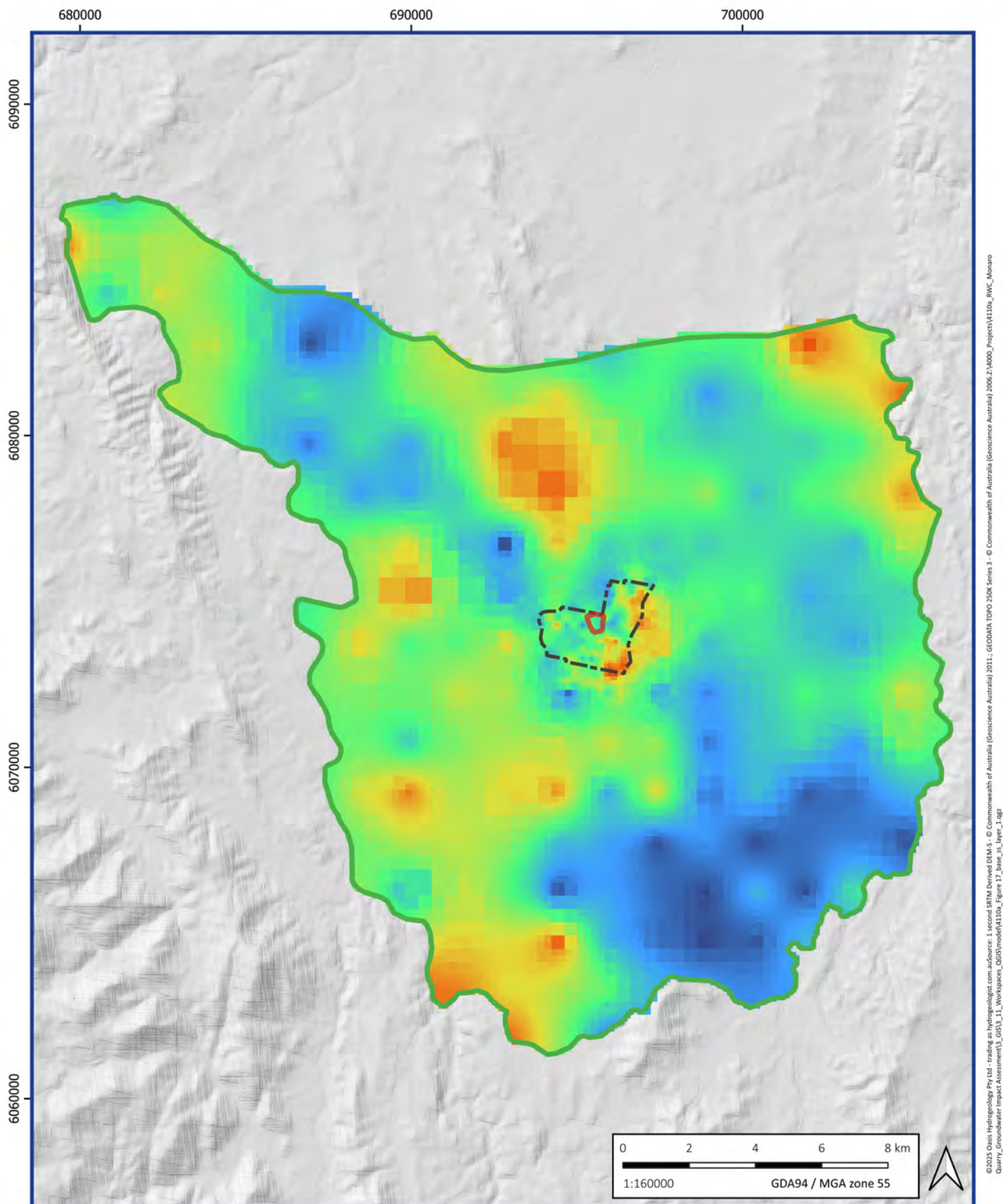
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Figure 16

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Legend

Base calibrated specific storage (Ss) in layer 1

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Figure 17

$\log_{10}(Ss)$



— Project boundary

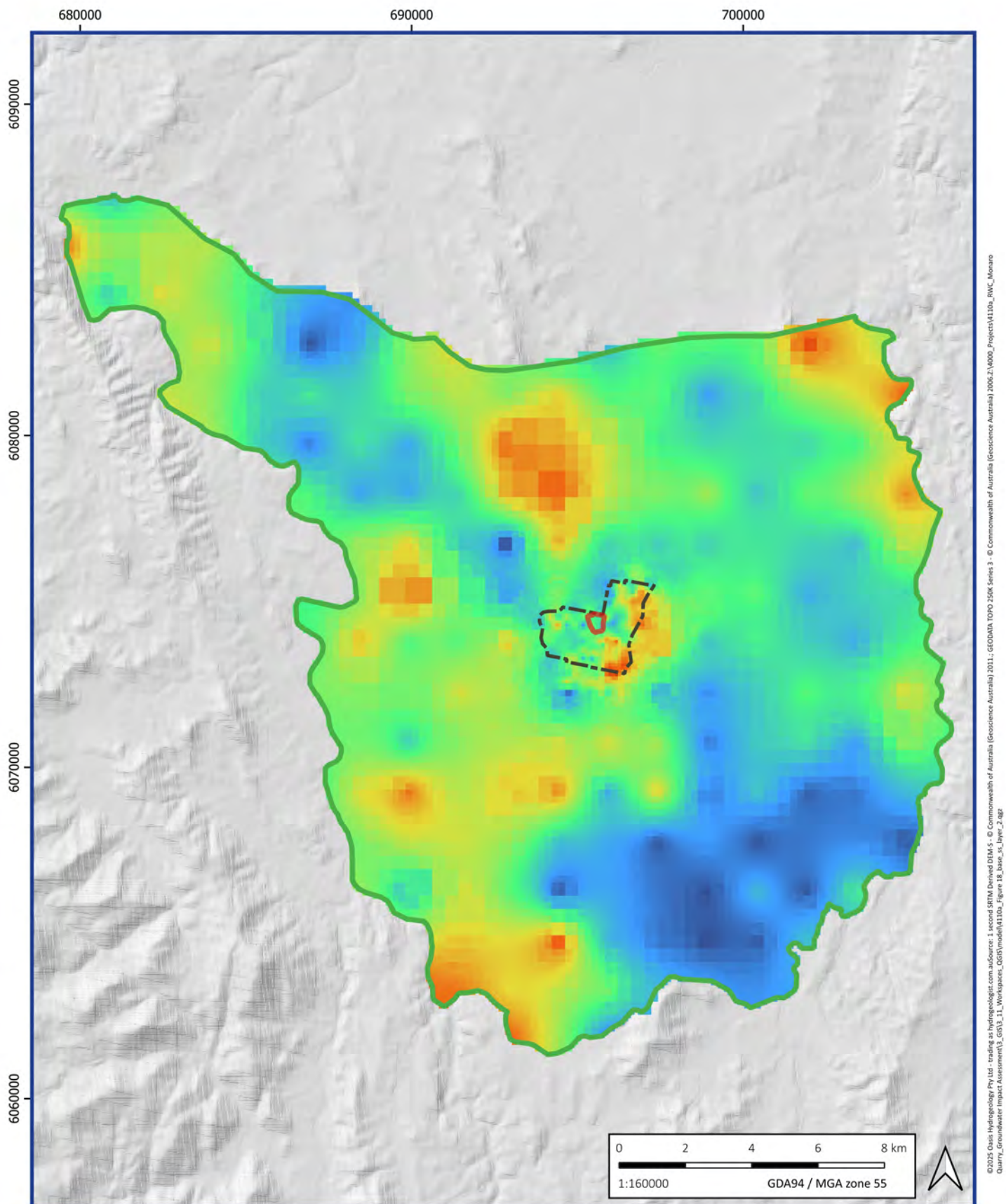
□ Monaro quarry

□ Model domain



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Legend

Base calibrated specific storage (Ss) in layer 2

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Figure 18

log10(Kh)



— Project boundary

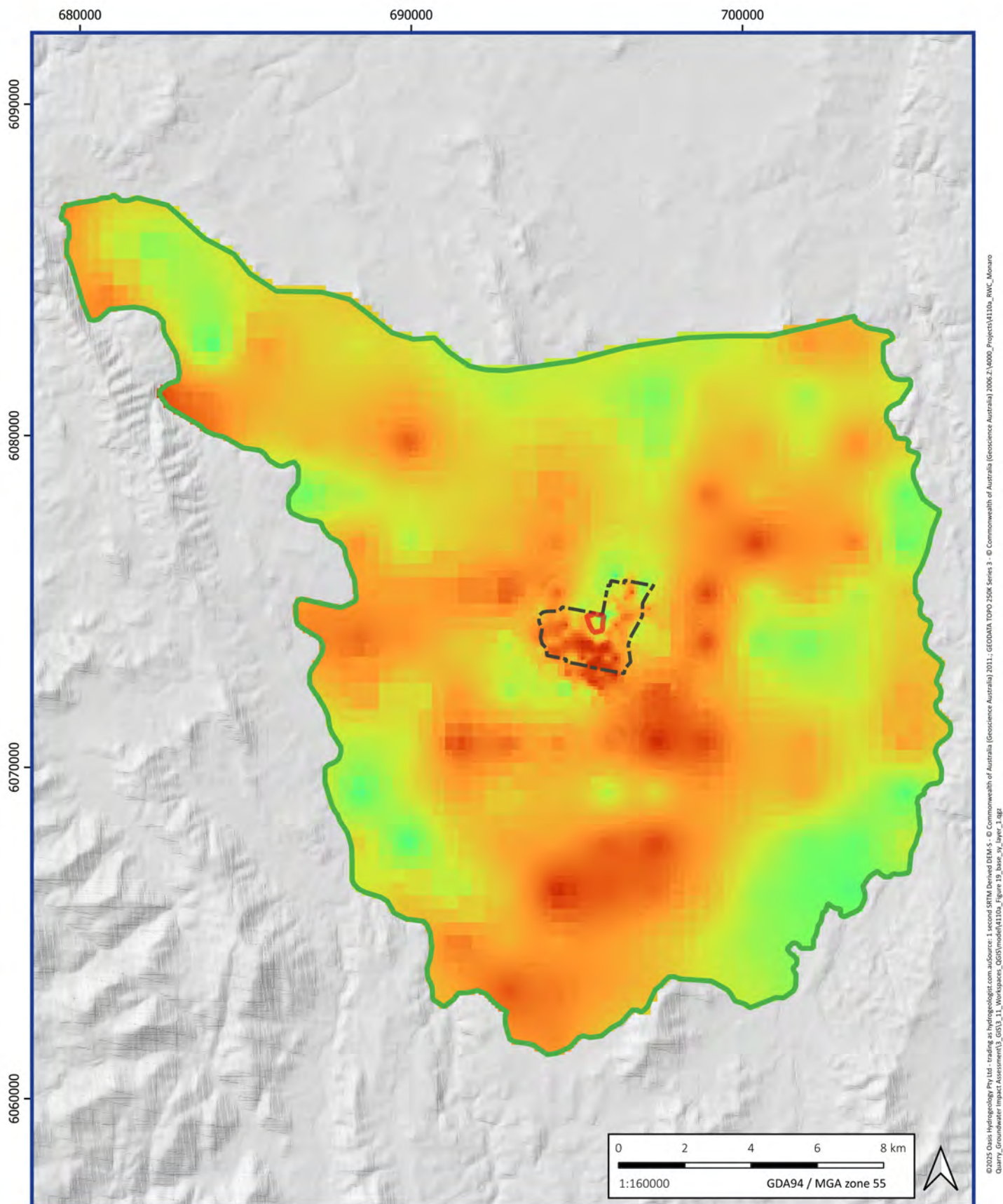
□ Monaro quarry

□ Model domain



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Legend

Base calibrated specific yield (Sy) in layer 1

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Figure 19

log₁₀(Sy)



— Project boundary

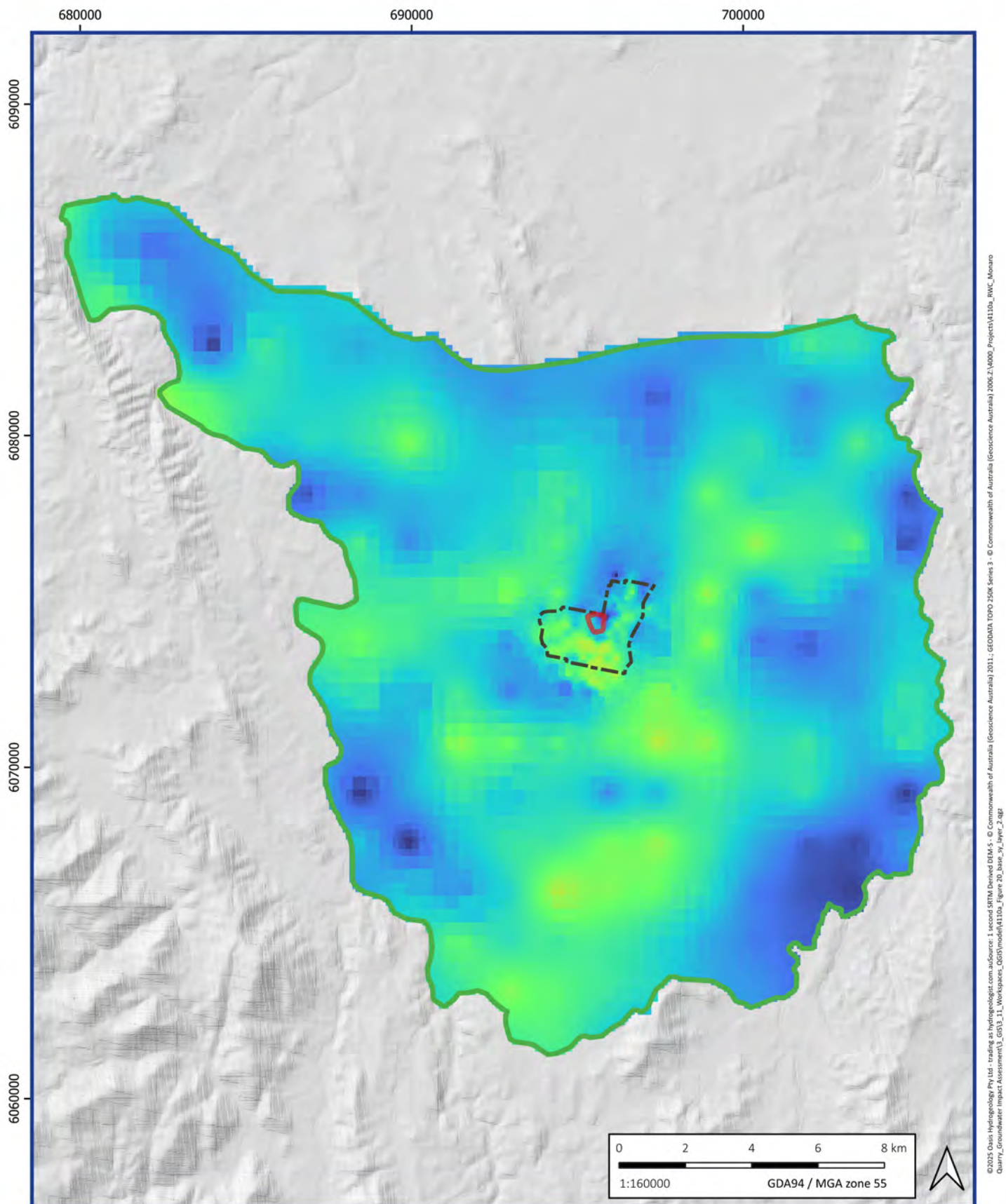
□ Monaro quarry

□ Model domain



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Legend

Base calibrated specific yield (Sy) in layer 2

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Figure 20

log₁₀(Sy)



— Project boundary

□ Monaro quarry

□ Model domain



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3.8. Sensitivity and identifiability

Sensitivity and identifiability of adjustable parameters have been assessed through analysis of the relative reduction of parameter uncertainty. Relative reduction of uncertainty is a suitable surrogate for identifiability because it directly reflects the extent to which available observations constrain parameter values, providing a quantifiable measure of how well parameters are informed by the calibration process. Parameters that are high in identifiability also tend to exhibit greater sensitivity, meaning that changes in these parameters have a greater influential on model outputs.

The relative reduction calculation is defined in the below equation. This reduction varies between 0 and 1, with the closer the values are to 1, the more strongly the parameter is constrained by observations and, therefore, the more identifiable it is within the calibration process.

$$r_i = 1 - \frac{\sigma_i^{posterior}}{\sigma_i^{prior}}$$

Where:

- r_i : Relative reduction of uncertainty for parameter i ;
- σ_i^{prior} : Prior uncertainty of the parameter i ;
- $\sigma_i^{posterior}$: Posterior uncertainty of parameter i .

Table 7 presents the relative reduction of uncertainty for model parameters. While reduction in uncertainty for all parameters is achieved, uncertainty is most reduced for Kh in layers 1 and 2, Kvf in layer 2, Sy in layer 1 and evapotranspiration factor. Distributions of prior and posterior pilot point uncertainty are presented as Figure 21 and corroborate the reduction of uncertainty for all spatially varying parameters.

Maps of relative reduction of uncertainty for spatially varying parameters are presented as Figure 22 through Figure 29. These maps illustrate that reduction of uncertainty after calibration is generally highest at locations where information is available to constrain the calibration, i.e. within the Project site boundary. This is most apparent for Kh and Sy in layer 1 (Figure 22 and Figure 28).

Table 7 Relative reduction of uncertainty

Parameter	Layer	Prior uncertainty*	Posterior uncertainty*	Relative reduction of uncertainty*
<i>Spatially varying parameters</i>				
Kh	1	1.40	0.68	0.51
	2	1.68	0.68	0.59
Kvf	1	1.01	0.86	0.15
	2	1.02	0.72	0.30
Ss	1	1.24	0.96	0.23
	2	1.27	1.01	0.20
Sy	1	1.52	0.67	0.56
	2	1.51	1.14	0.24
<i>Constant parameters</i>				
r fact		0.43	0.26	0.27
evt depth		0.29	0.26	0.12
evt fact		0.18	0.13	0.39
Dam cond		2.48	2.07	0.16

Notes: *median values are presented for spatially varying parameters
 *Standard deviations used to represent uncertainty.

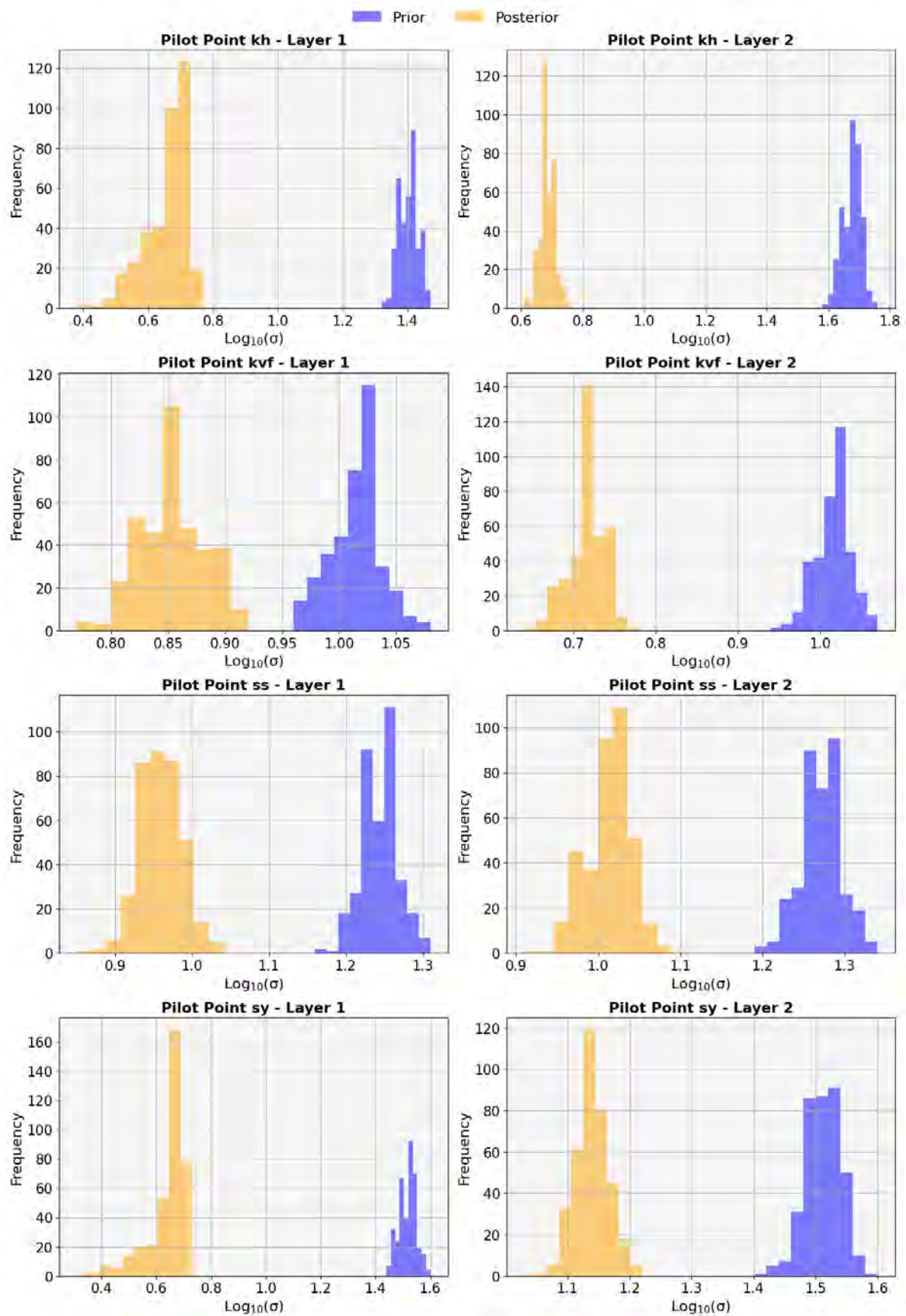
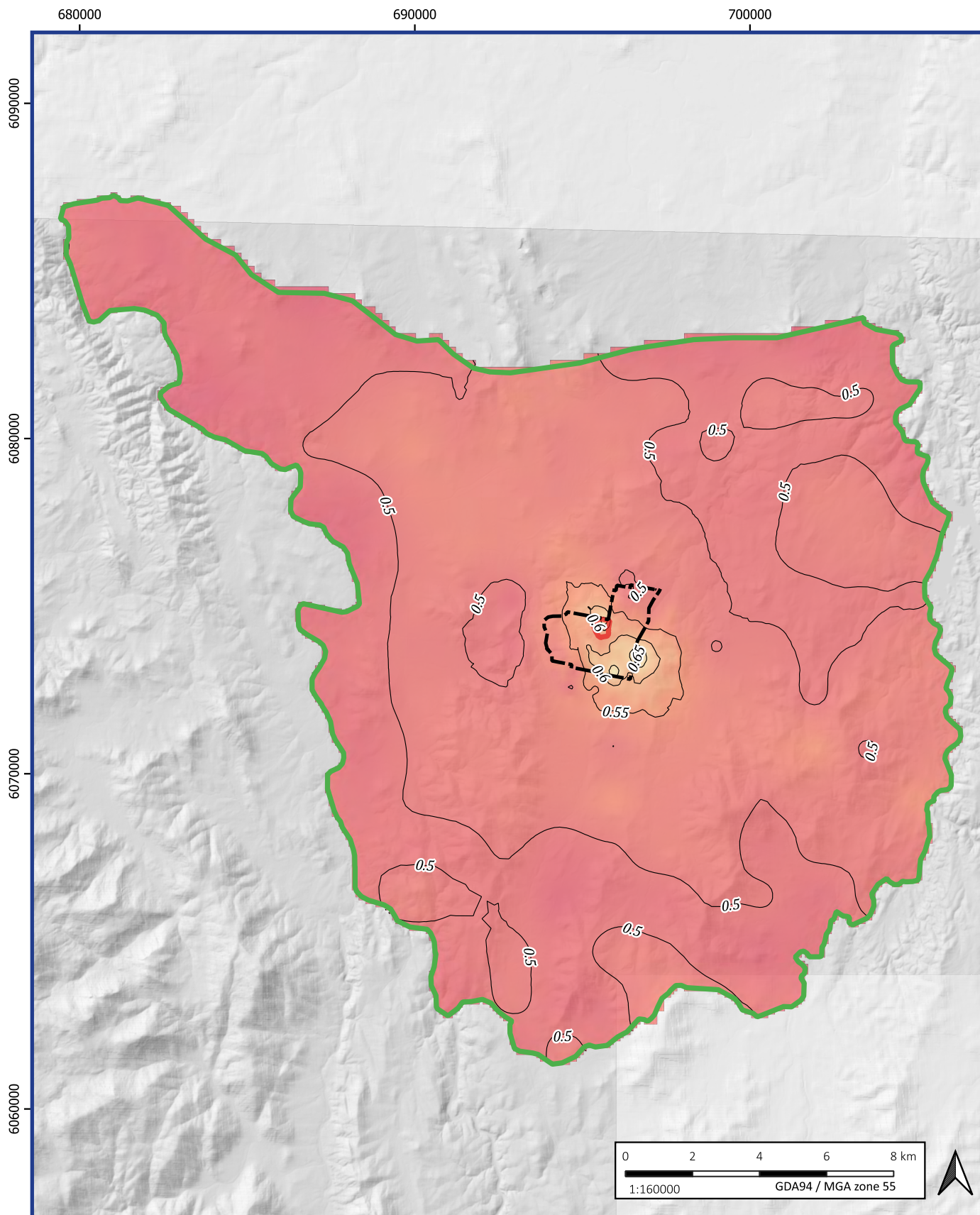


Figure 21 Prior and posterior pilot point uncertainty distribution



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Legend

Relative reduction of uncertainty for horizontal hydraulic conductivity (Kh) in layer 1

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Figure 22

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Relative uncertainty reduction

0.7+
0.1

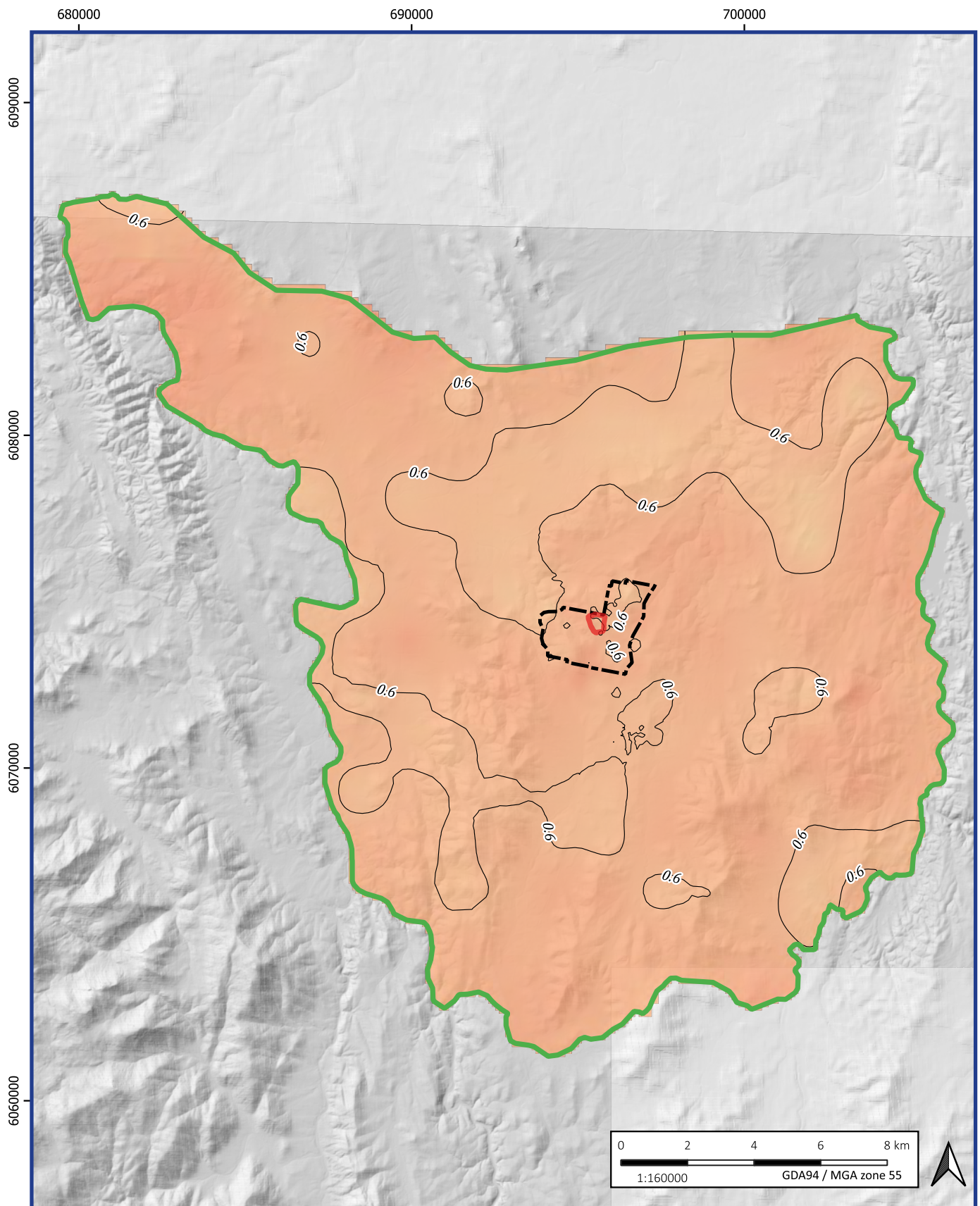
— Contour

— Project boundary

Monaro quarry

Model domain





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Legend

Relative reduction of uncertainty for horizontal hydraulic conductivity (Kh) in layer 2

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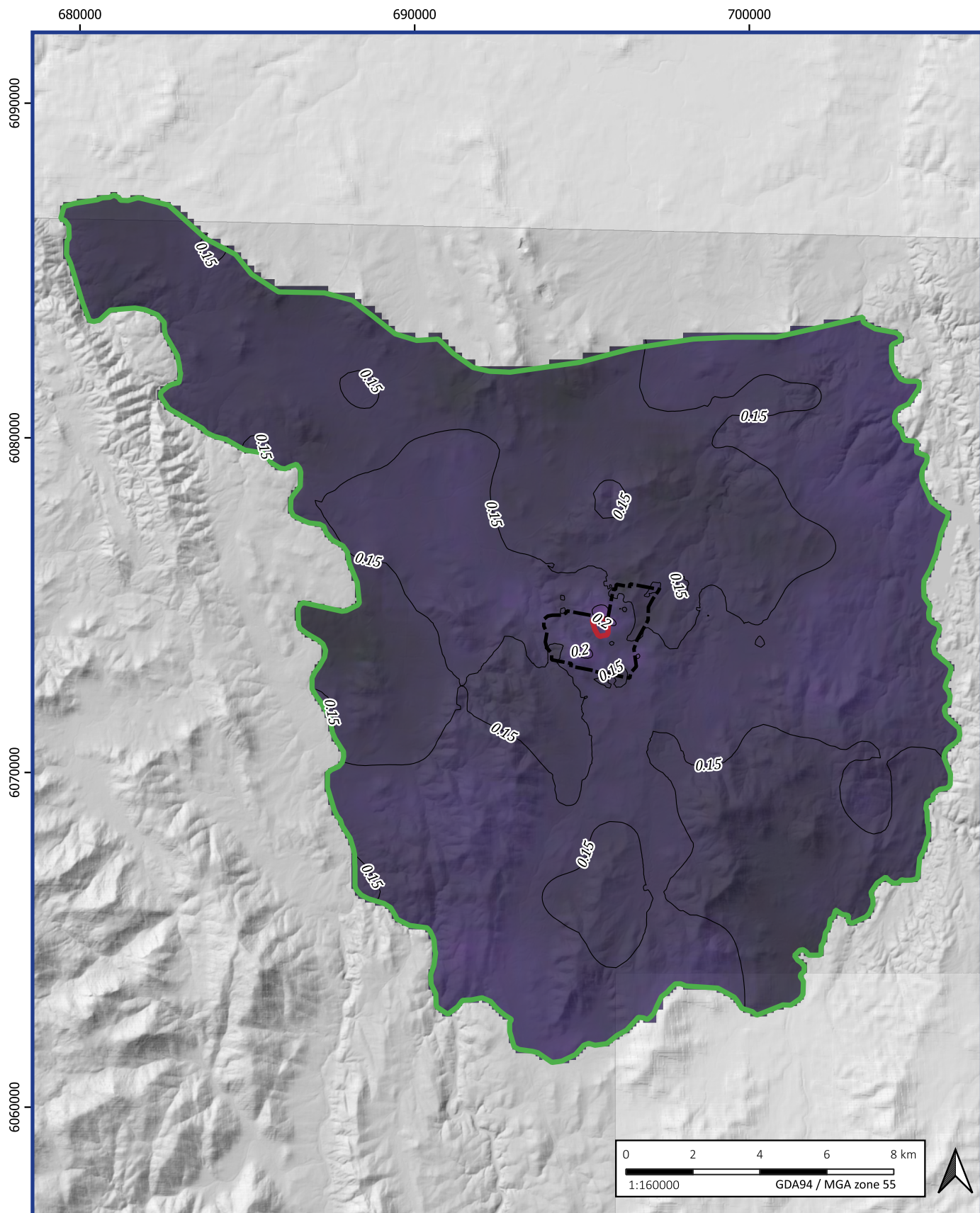
Relative uncertainty reduction

- 0.7+
- 0.1
- Contour
- Project boundary
- Monaro quarry
- Model domain

Figure 23

19/05/2025





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Legend

Relative reduction of uncertainty for vertical anisotropy factor (Kvf) in layer 1

(4110a) Monaro Rock Quarry - Numerical Groundwater Modelling Report

Figure 24

19/05/2025

Relative uncertainty reduction

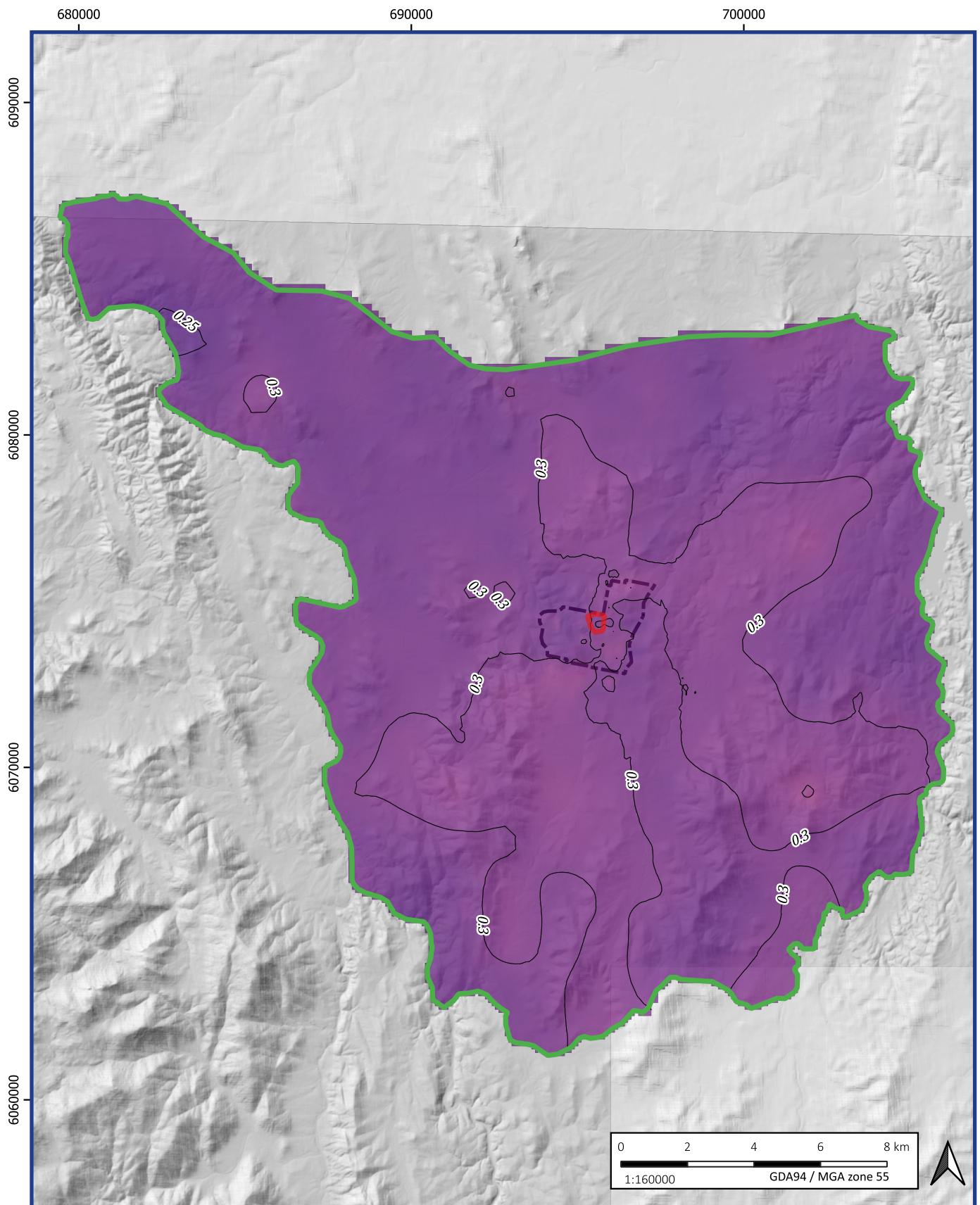


— Contour

— Project boundary

□ Monaro quarry

□ Model domain



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Legend

Relative uncertainty reduction



— Contour

— Project boundary

□ Monaro quarry

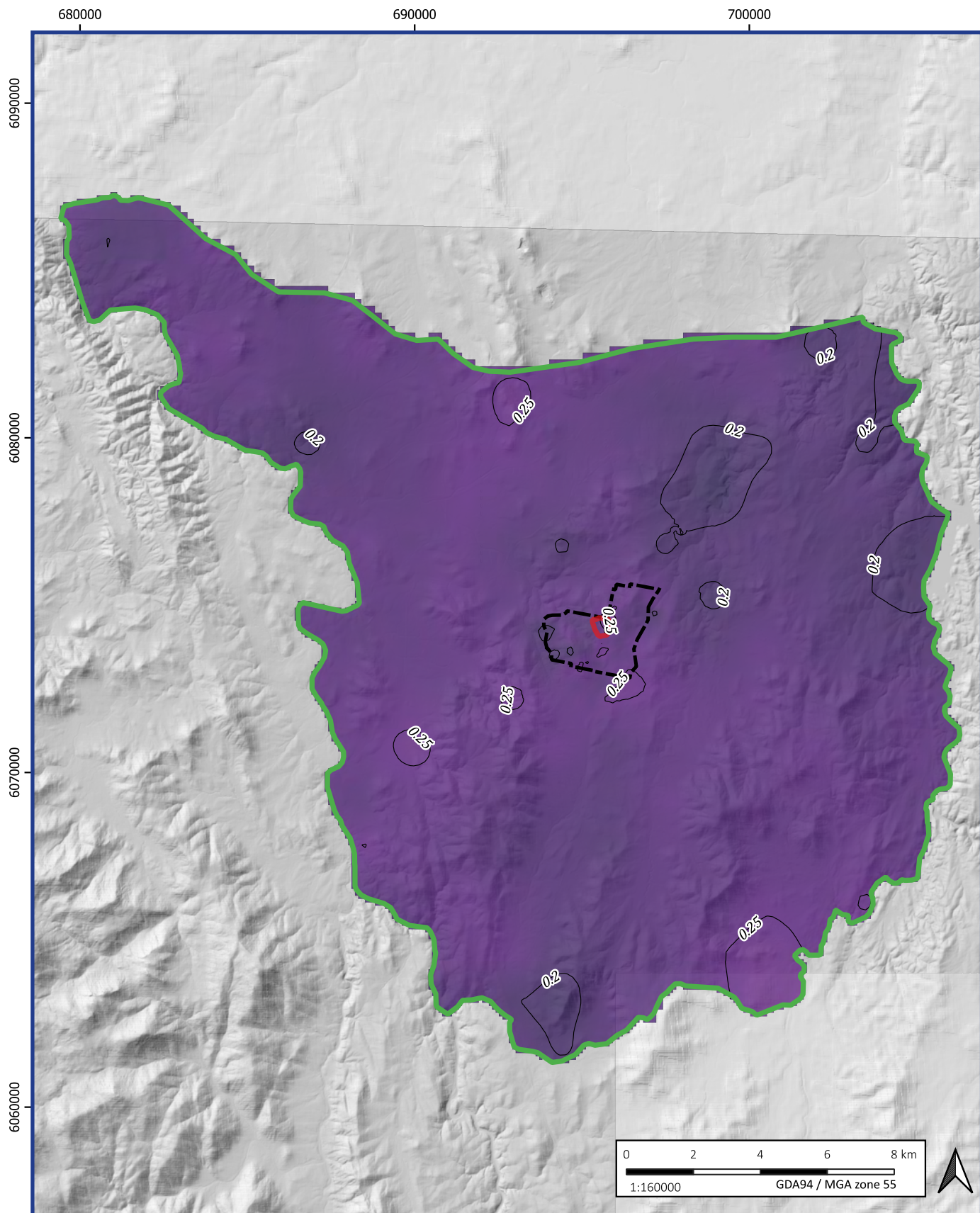
□ Model domain

Relative reduction of uncertainty for vertical anisotropy factor (Kvf) in layer 2

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Figure 25

19/05/2025



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Legend

Relative reduction of uncertainty for specific storage (Ss) in layer 1

(4110a) Monaro Rock Quarry - Numerical Groundwater Modelling Report

Figure 26

19/05/2025

Relative uncertainty reduction



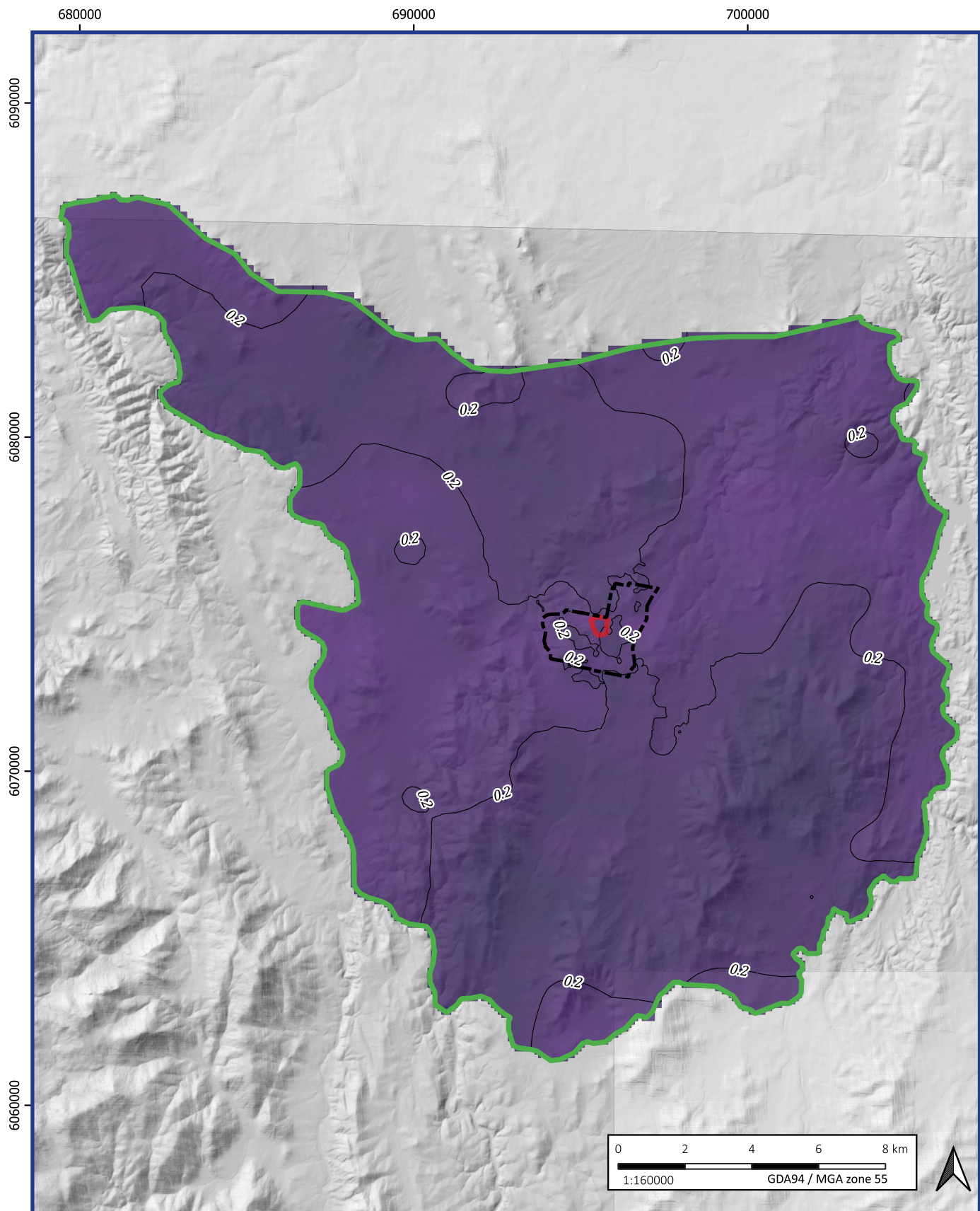
— Contour

--- Project boundary

■ Monaro quarry

■ Model domain





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Legend

Relative uncertainty reduction



- Contour
- Project boundary
- Monaro quarry
- Model domain

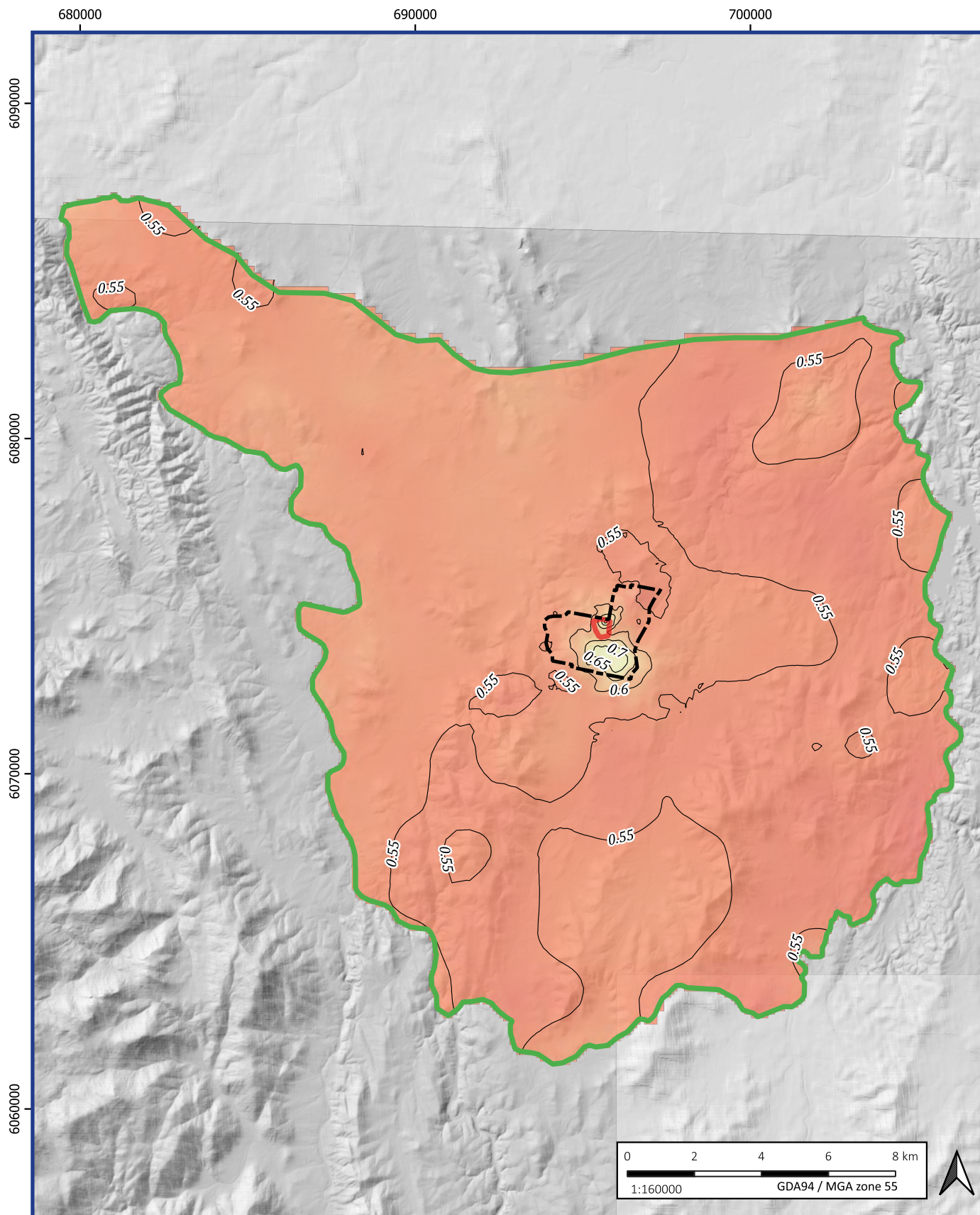
Relative reduction of uncertainty for specific storage (Ss) in layer 2

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Figure 27

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Legend

Relative uncertainty reduction



— Contour

— Project boundary

□ Monaro quarry

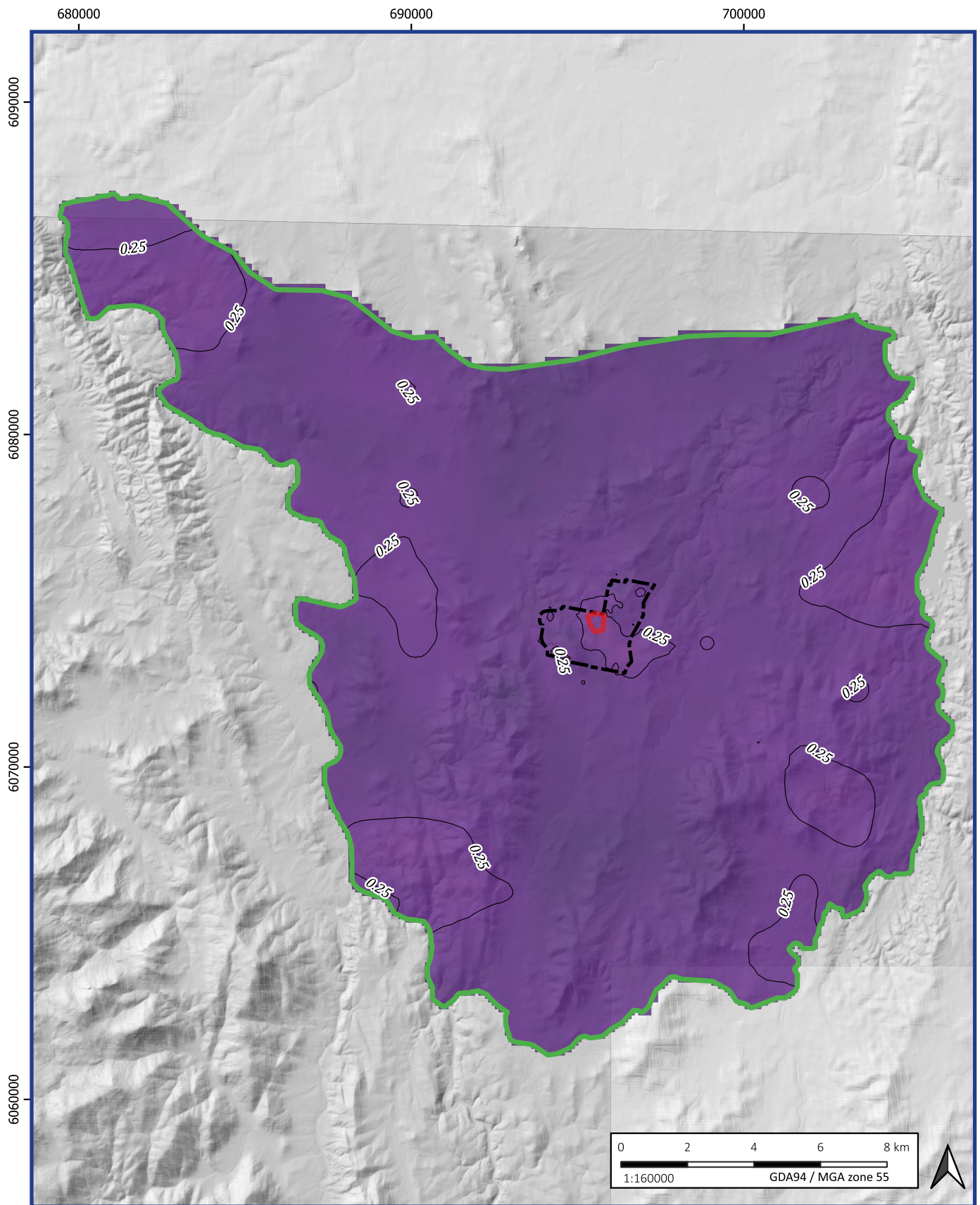
□ Model domain

Relative reduction of uncertainty for specific yield (Sy) in layer 1

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Figure 28

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Legend

Relative reduction of uncertainty for specific yield (Sy) in layer 2

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Figure 29

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Relative uncertainty reduction



— Contour

— Project boundary

□ Monaro quarry

□ Model domain



3.9. Budgets

The water budget of the numerical model reflects and quantifies flows entering and leaving the model domain. The water budget summary for the complete calibration model is presented as Table 8 and includes all model inflow and outflow components. Model inflows are primarily recharge (RCH) driven, with negligible contributions from river leakage (RIV), while outflows occur via baseflow discharge to rivers (RIV) and evapotranspiration (EVT). Time series for all budget components for the calibration period are presented in Appendix C.

Baseflow to the streams and evapotranspiration occurs in low lying areas, where the water table elevation is near land surface. Zonal budgets have been computed for the model domain to assess the spatial distribution of baseflow contributions. Analysis of the zone budgets reveals the elevated terrain within 5 km of the Project site boundary comprises approximately 16 % of the total river outflows. In contrast, other regions of the model domain accommodate the majority of baseflow discharge. This is consistent with the conceptual understanding of the area, as these surrounding regions encompass larger, more significant river systems that naturally receive greater groundwater discharge.

The mass balance error of the model is calculated as the difference between model inflows and model outflows. For the mass balance error, a value of approximately 1% or lower is generally considered acceptable and indicates a stable model. The calibration model has maintained a mass balance error of zero at every timestep and cumulatively for the complete model duration. As the incremental and cumulative mass balance errors are zero, the numerical solution obtained by the base model is considered numerically stable, with no accumulation or deficit of water over the model simulation period.

Table 8 Summary water budget for calibrated base model

	Budget item	Cumulative volume (m ³)	Average flow rate (m ³ /day)*
Inflows	surface drainage (RIV)	2	0
	recharge (RCH)	28,474,547	32,211
Outflows	surface drainage (RIV)	2,987,751	3,380
	Evapotranspiration (EVT)	21,992,413	24,878
Cumulative mass balance error (%)			0.00

Notes: Rounding effects may cause totals to vary slightly.
 * duration = 884 days

3.10. Calibrated heads

The groundwater levels at the end of the calibration period for the base model across each model layer and the water table are presented in Figure 30 through Figure 32. Depth to groundwater is presented as Figure 33. These maps represent simulated groundwater conditions at the end of January 2024.

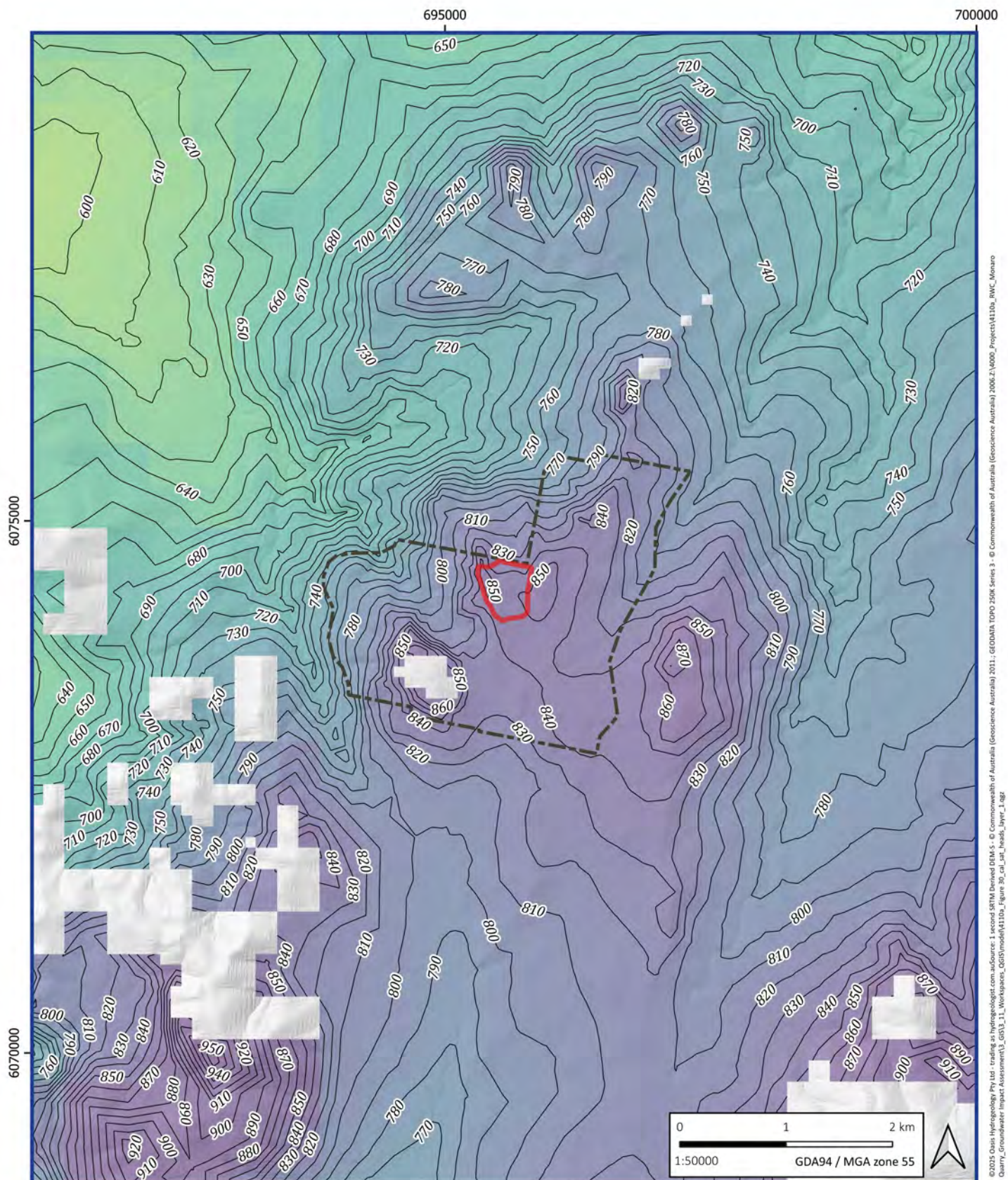
3.11. Overall calibration performance

Following 10 successive iterations of calibration with PESTPP-IES, the model has been appropriately calibrated to transient conditions so far as the available data and model assumptions will allow. This calibration process reduced the model objective function of the base model from 28000 m² to 83 m².

Model parameters are consistent with the site's conceptual hydrogeological model (refer to GIA Section 5). Noting that parameters presented in the GIA are understood to reflect the hydraulic properties of the Monaro site fracture network and as such, typical bulk layer properties are expected to be significantly lower than values presented in the GIA. Additionally, the relative contributions of recharge and discharge processes to the model water balance fall within expected ranges.

Base model hydrographs, presented in Appendix B, indicate that long term and seasonal groundwater level trends are replicated at transient calibration targets (notably MRPDH15). Variability in the uncertainty hydrographs indicates that the posterior ensemble has not collapsed, and that there is minimal posterior data conflict (Appendix D). Uncertainties are therefore well-characterised and reflective of the available calibration data.

The base model is therefore considered appropriate for predictive modelling of groundwater flow impacts associated with the project.



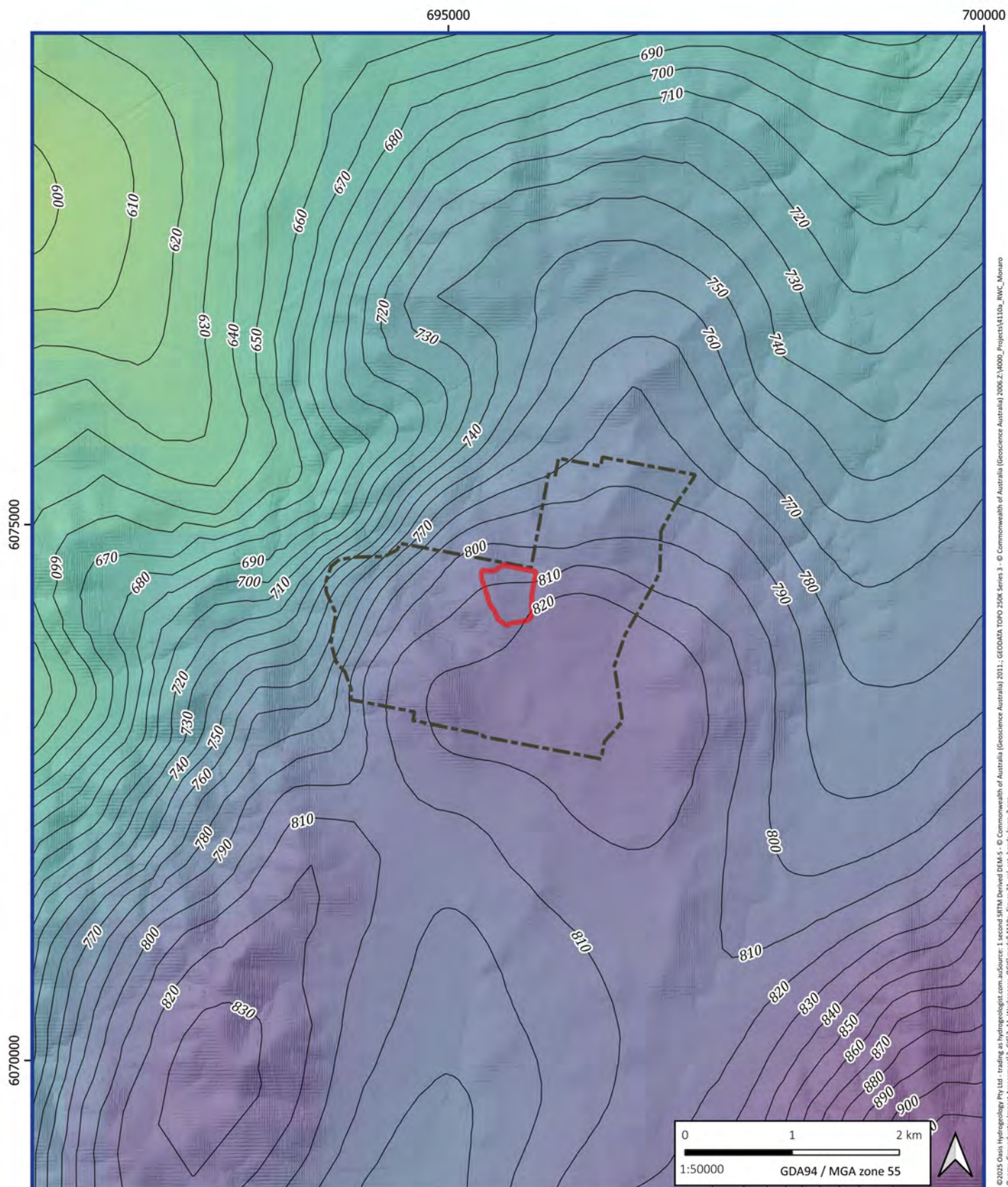
Legend

- Head contour (mAHd)
- - - Project boundary
- Monaro quarry

Modelled saturated heads in Layer 1 at the end of calibration
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Figure 30

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Legend

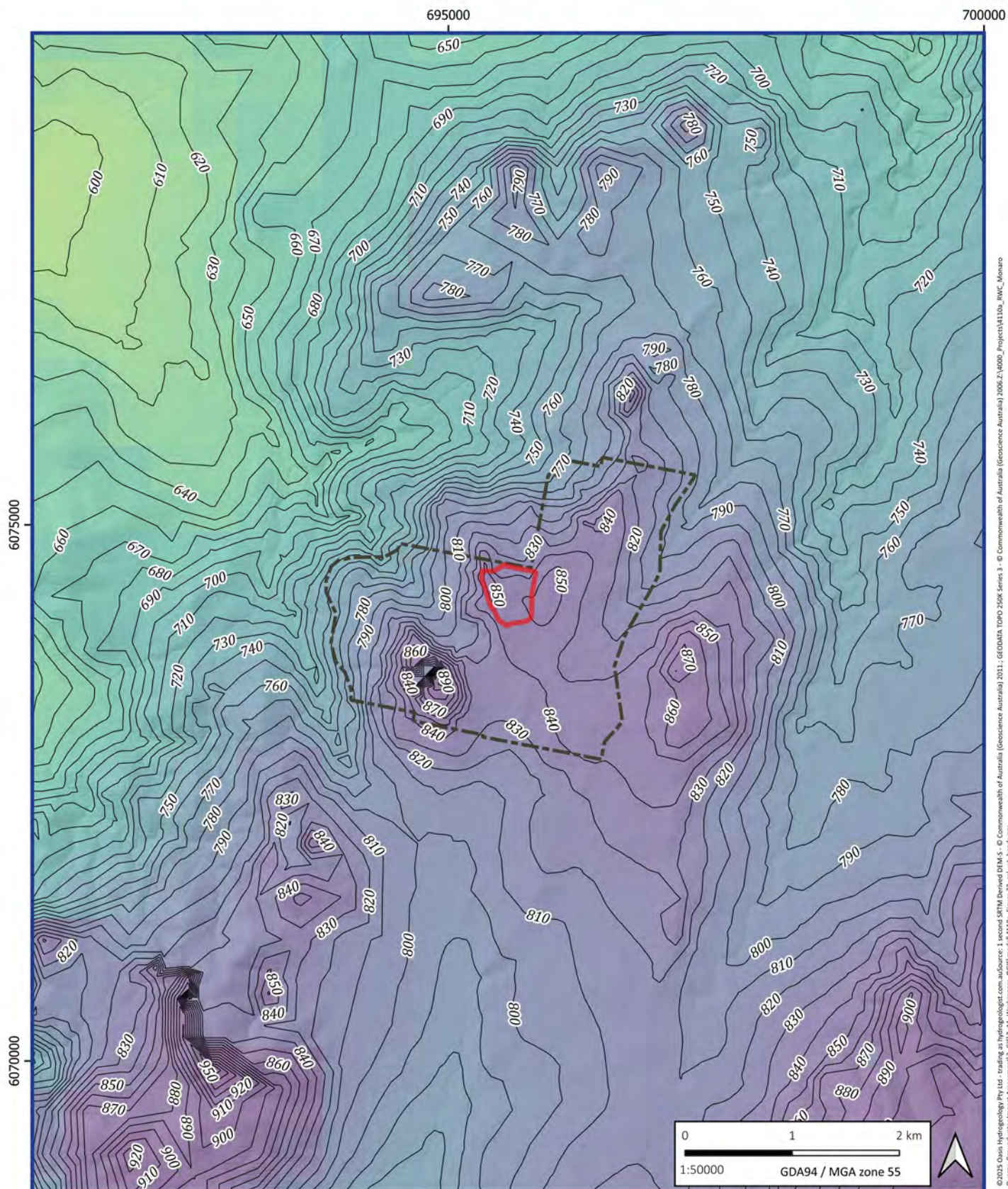
- Head contour (mAHD)
- - Project boundary
- Monaro quarry

Modelled saturated heads in Layer 2 at the end of calibration

(4110a) Monaro Rock Quarry - Numerical Groundwater Modelling Report

Figure 31

19/05/2025



Legend

- Head contour (mAHd)
- - - Project boundary
- Monaro quarry

Modelled water table heads at the end of calibration

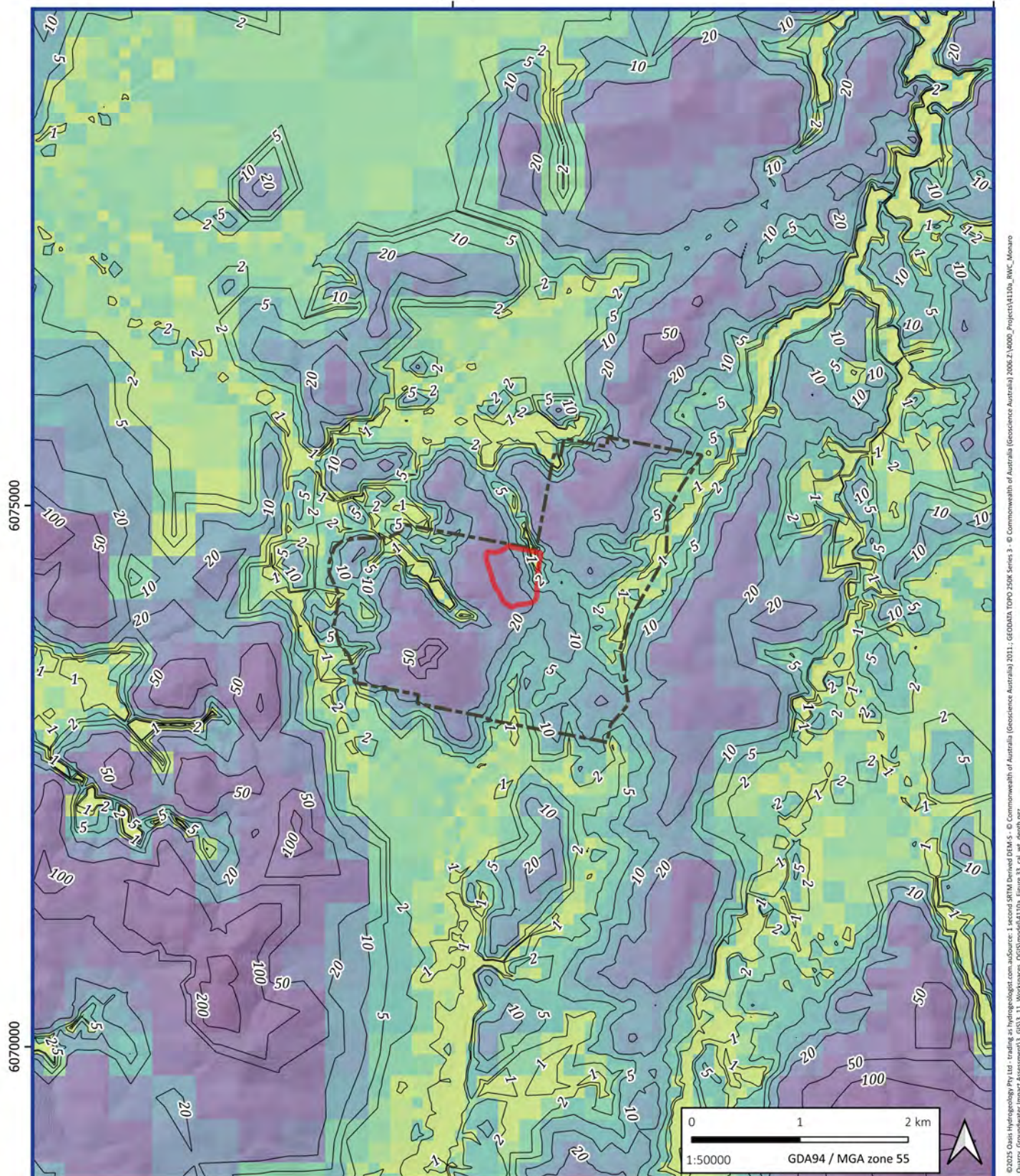
(4110a) Monaro Rock Quarry - Numerical Groundwater Modelling Report

Figure 32

19/05/2025

695000

700000



Legend

Modelled depth to water table at the end of calibration

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Figure 33

19/05/2025

- Depth contour (mbgl)
- - - Project boundary
- Monaro quarry

4. Predictive modelling

4.1. Modelling approach

The predictive model is a transient simulation comprising yearly stress periods. It extends from the end of the transient calibration model and continues through to Project closure at the end of 2053. The predictive model is used to simulate aquifer responses to quarrying and well dewatering over the life of the project.

Two predictive simulations were run to determine groundwater impacts associated with the Project. These scenarios, referred to as the Project scenario and the null scenario are defined as:

- project scenario: includes simulated operations at Monaro Rock Quarry; and
- null scenario: no quarrying or extraction is simulated.

Direct comparison of simulated groundwater levels between the Project scenario and the null scenario enables the assessment of Project-related impacts on groundwater conditions.

4.2. Budgets

The inflows into the model domain are through recharge (RCH) during the prediction/post-closure period. The outflows from the model domain occur via surface drainage (RIV), evapotranspiration (EVT), well extraction (WEL) and excavation (DRN) during the prediction period. Water removed by DRNs during operations comprise both the direct removal of water and ongoing pit inflows.

The flow rates and volumes across individual boundaries are summarised in Table 9. Notably the inflow rates to the pit are predicted to be low, at an average 16 m³/day. This low inflow rate is consistent with the relatively low calibrated hydraulic conductivity values. The modelled groundwater discharge due to excavation and pumped water extraction (m³/day) over the 30-year stress period are presented as Figure 34 and Figure 35, respectively. Time series for all budget components for the predictive period Project scenario are presented as Appendix C.

Changes in baseflow resulting from the Project were assessed by comparing baseflows under the Project scenario to those under the null scenario. This assessment revealed that predicted baseflow changes associated with the Project are negligible.

The predictive model maintained a mass balance error of zero for every timestep and cumulatively for the complete predictive model duration, indicating numerical stability of the solution.

Table 9 Summary water budget for predictive base model (project scenario)

	Budget item	Cumulative volume (m ³)	Average flow rate (m ³ /day)*
Inflows	surface drainage (RIV)	24	0
	recharge (RCH)	245,704,932	22,422
	wells (WEL)	742,676	68
Outflows	drains (DRN)	173,856	16
	surface drainage RIV	29,945,415	2,733
	evapotranspiration EVT	218,531,854	19,943
Cumulative mass balance error (%)		0.00	

Notes: Rounding effects may cause totals to vary slightly.
* duration = 10,958 days

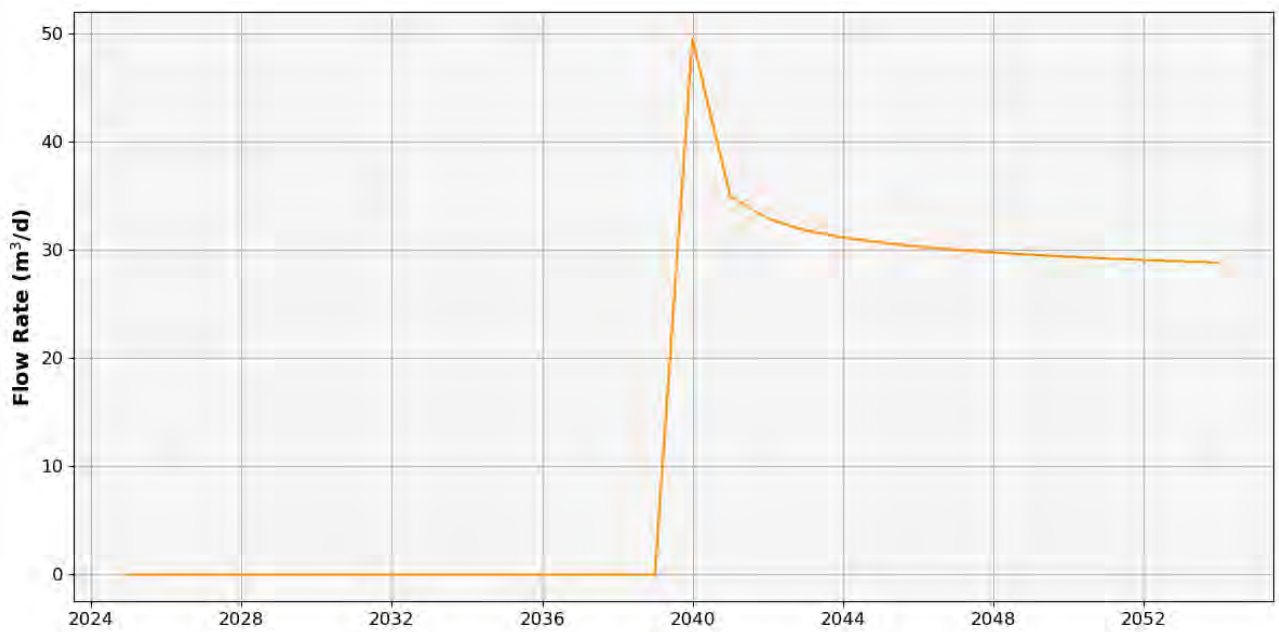


Figure 34 Modelled groundwater discharge via drains

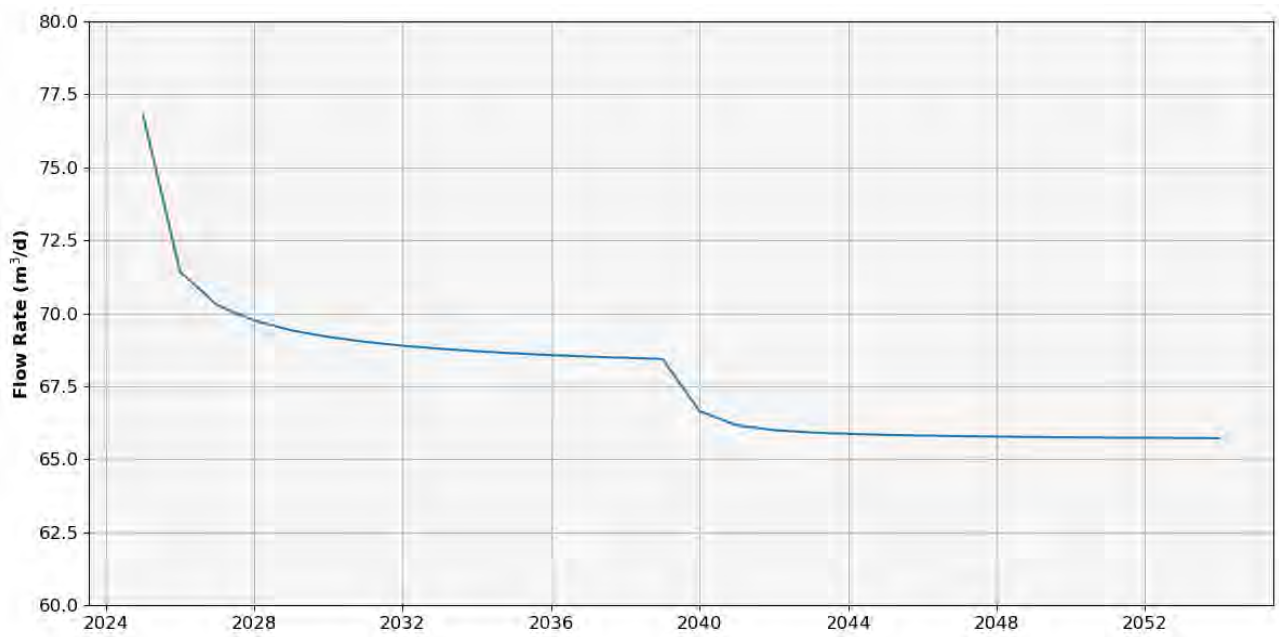


Figure 35 Modelled groundwater discharge via Wells

A series of steady state recovery models were also run to determine the relationship between pit lake elevation and inflow rates to the pit. In these models, average climatic conditions (recharge and evapotranspiration) were simulated, and project related discharge packages (WEL and DRN) were deactivated. This allowed groundwater levels to recover and long-term pit inflow rates to be predicted. Pit inflows at 5 m stage height intervals between 795 mAHD (base of pit) and 845 mAHD were assessed with results presented as Figure 36.

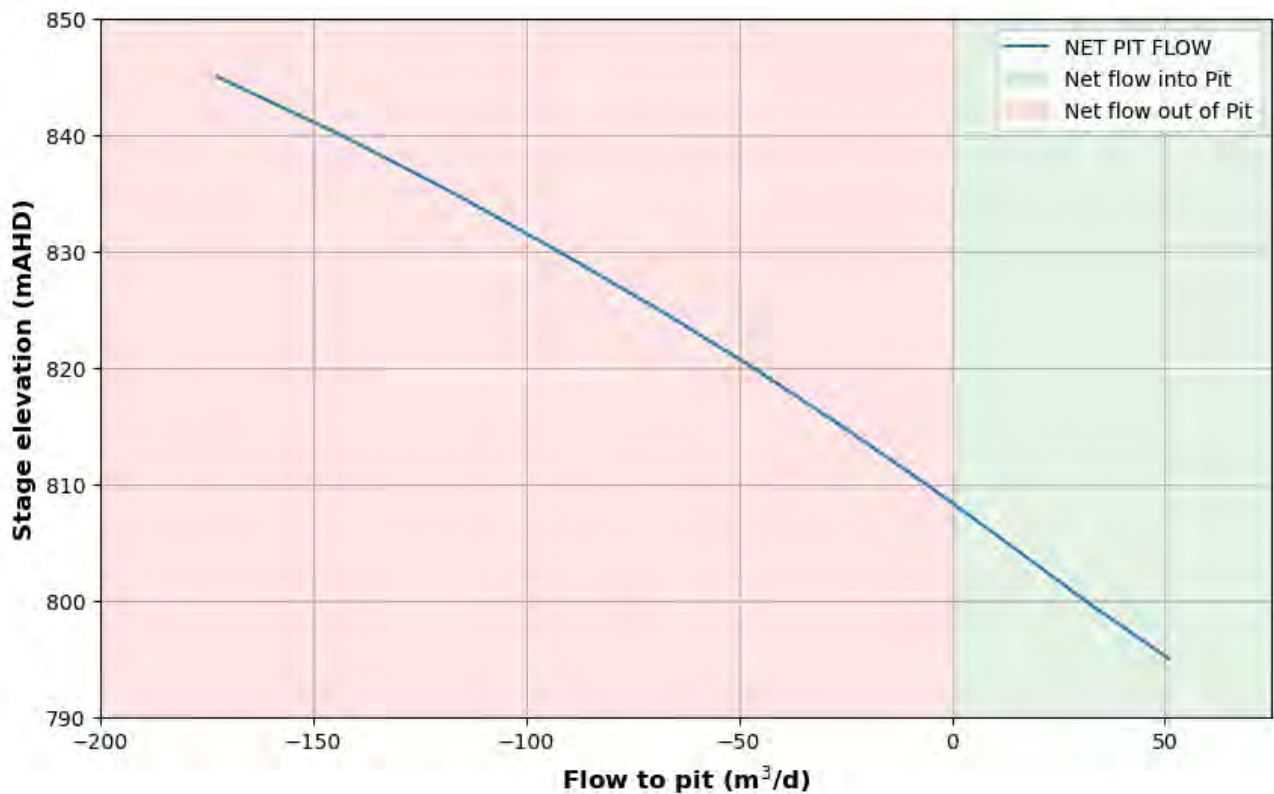
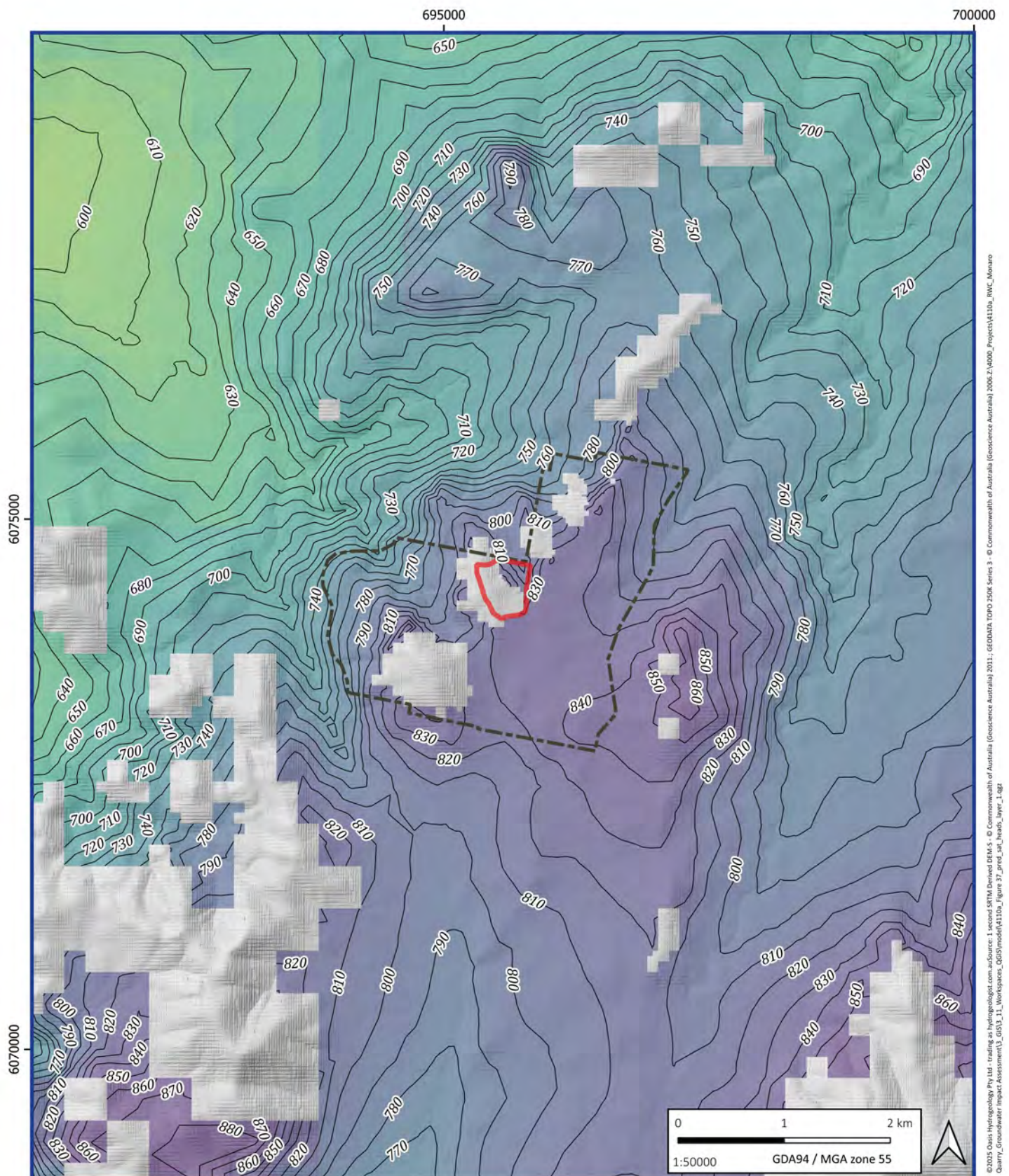


Figure 36 Pit inflow curve

4.3. Heads and drawdowns

The saturated modelled heads for model layers 1 and 2 at the end of operations are shown in Figure 37 and Figure 38, respectively. The predicted water table elevation and depth to water at end of operations are shown in Figure 39 and Figure 40. The predicted maximum all-time drawdowns for each layer and the water table are shown in Figure 41 through to Figure 43.



Legend

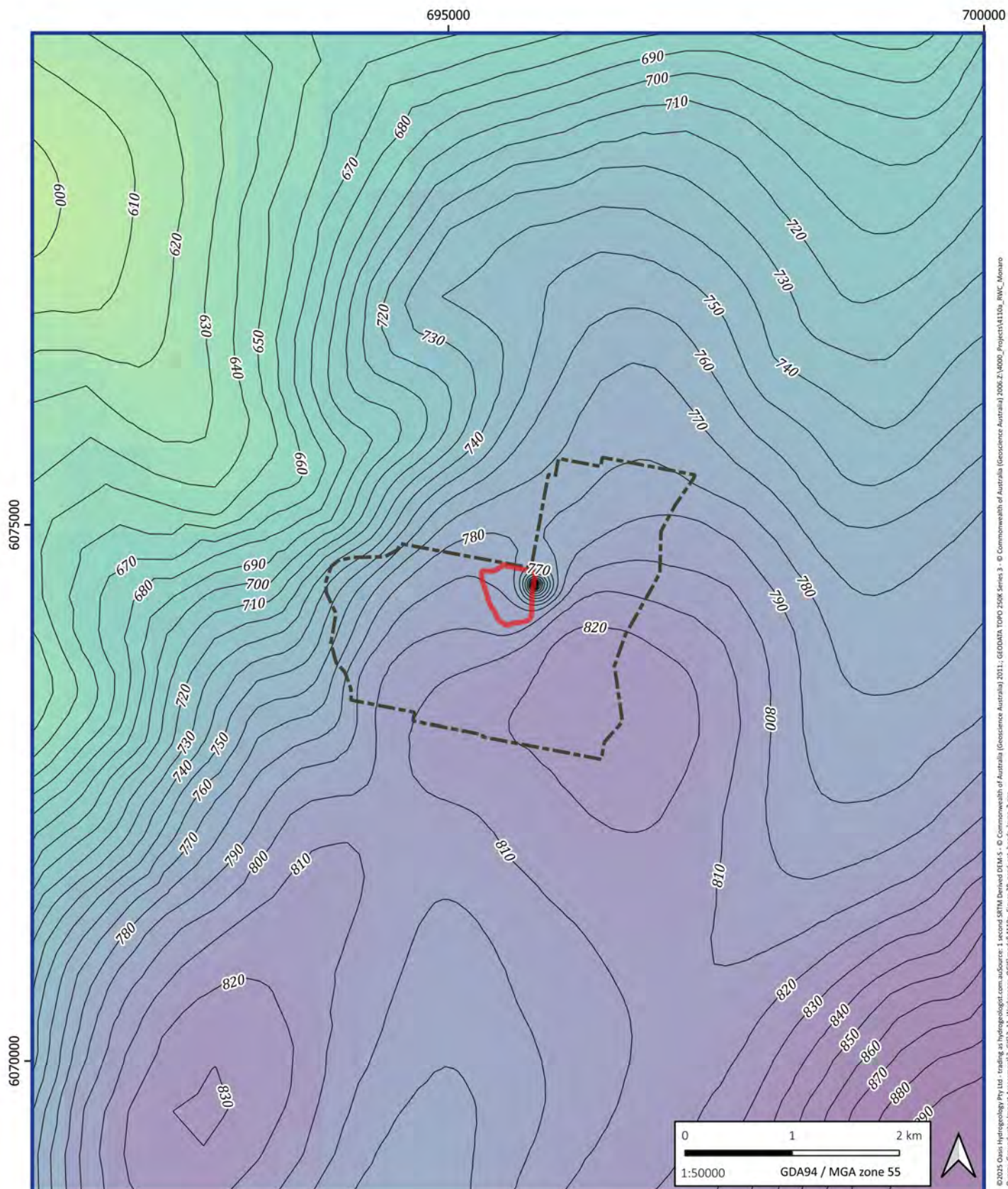
- Head contour (mAHD)
- - - Project boundary
- Monaro quarry

Modelled saturated heads in Layer 1 at the end of operations

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Figure 37

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Legend

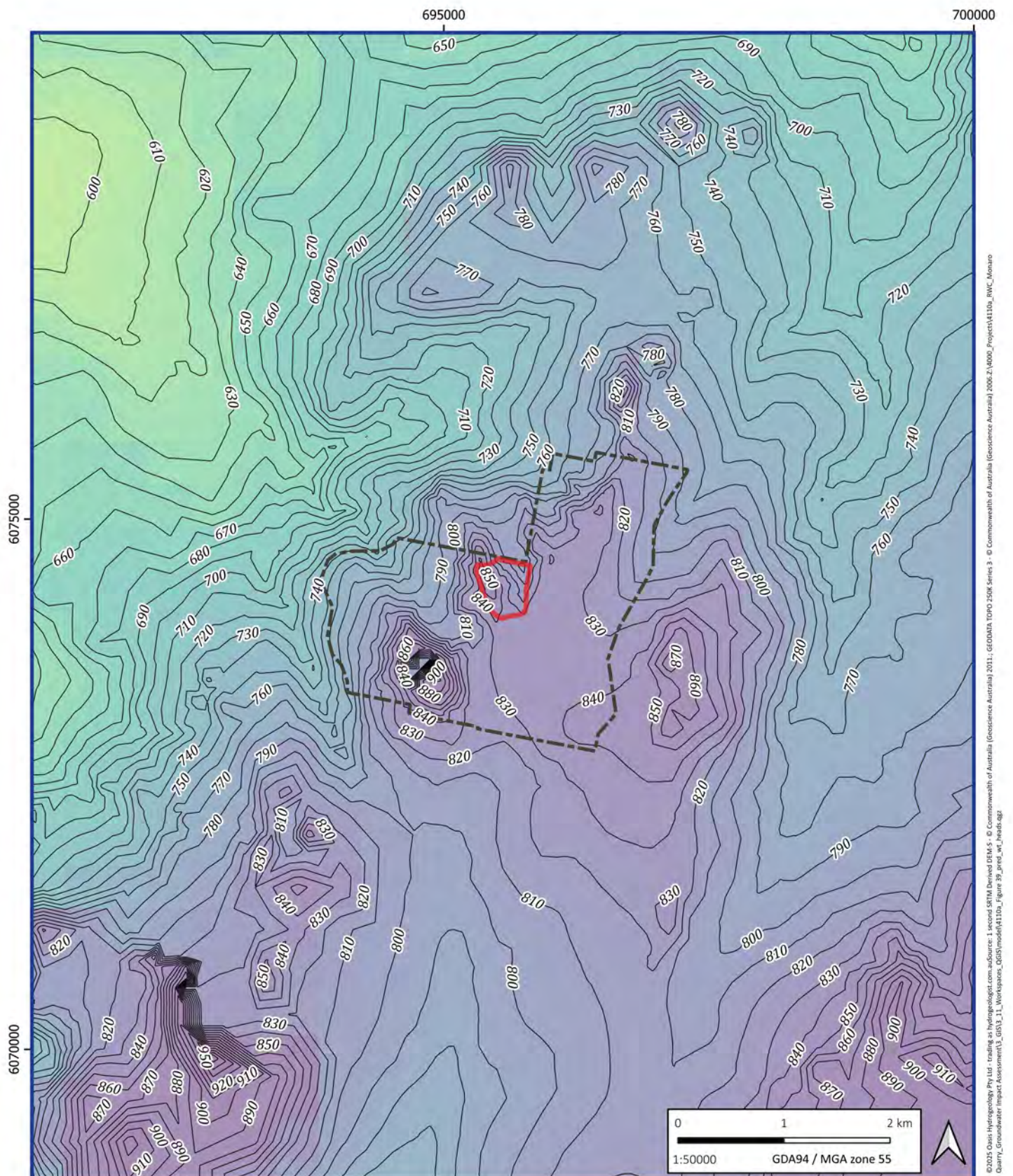
- Head contour (mAHD)
- - - Project boundary
- Monaro quarry

Modelled saturated heads in Layer 2 at the end of operations

(4110a) Monaro Rock Quarry - Numerical Groundwater Modelling Report

Figure 38

19/05/2025



Legend

- Head contour (mAHD)
- - - Project boundary
- Monaro quarry

Modelled water table heads at the end of operations

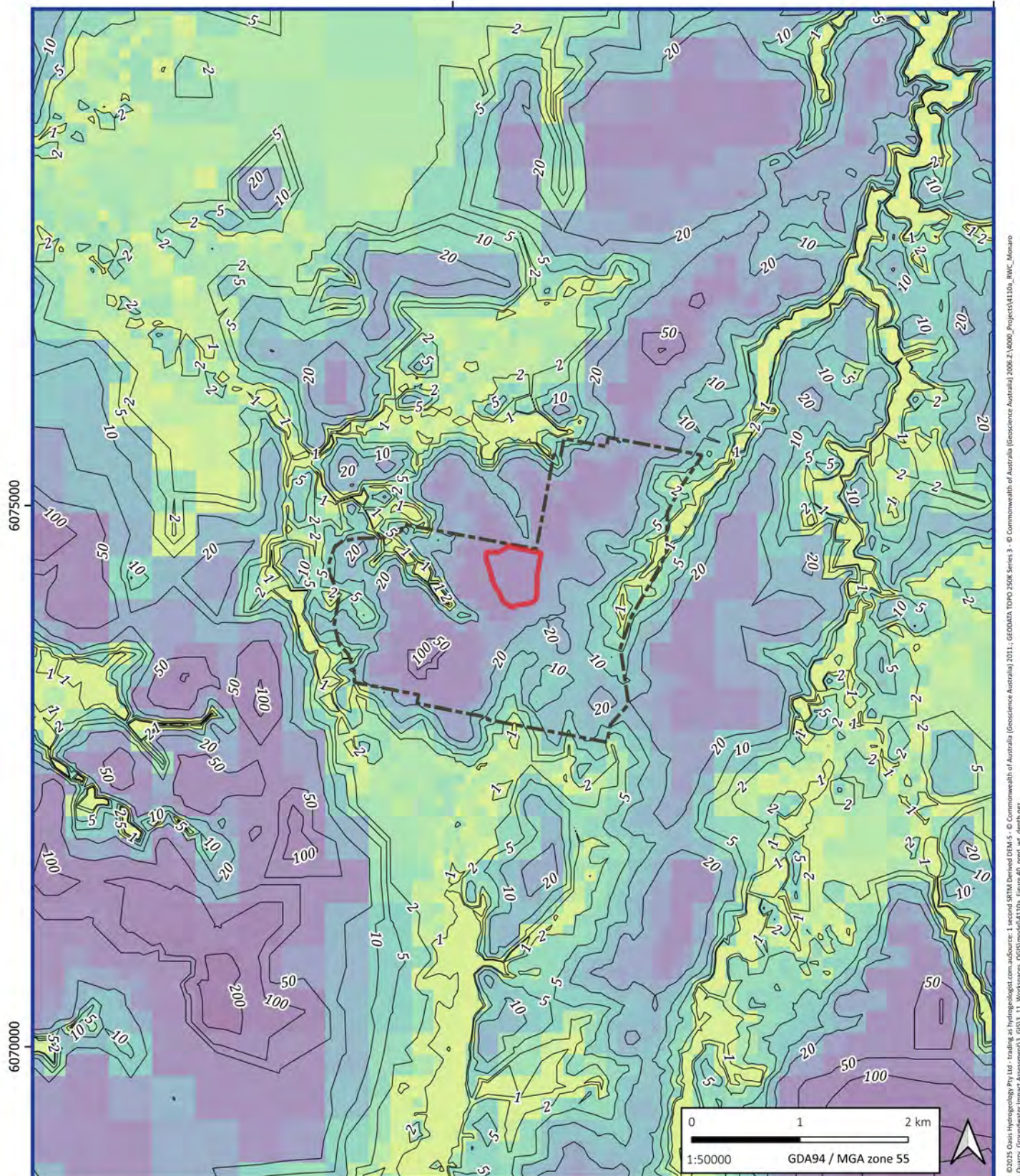
(4110a) Monaro Rock Quarry - Numerical Groundwater Modelling Report

Figure 39

19/05/2025

695000

700000



Legend

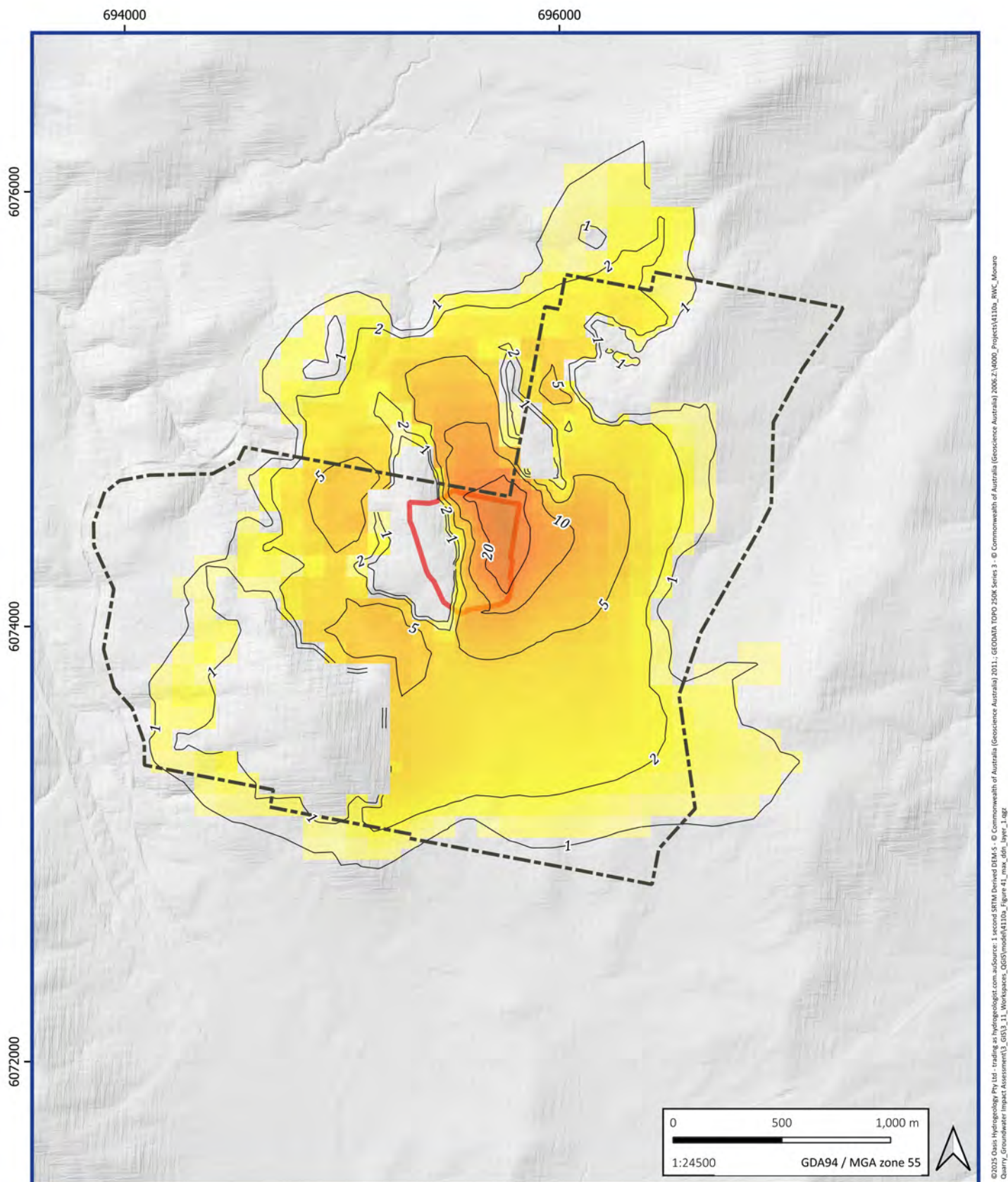
- Depth contour (mbgl)
- - - Project boundary
- Monaro quarry

Modelled water table depth at the end of operations

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Figure 40

19/05/2025



Legend

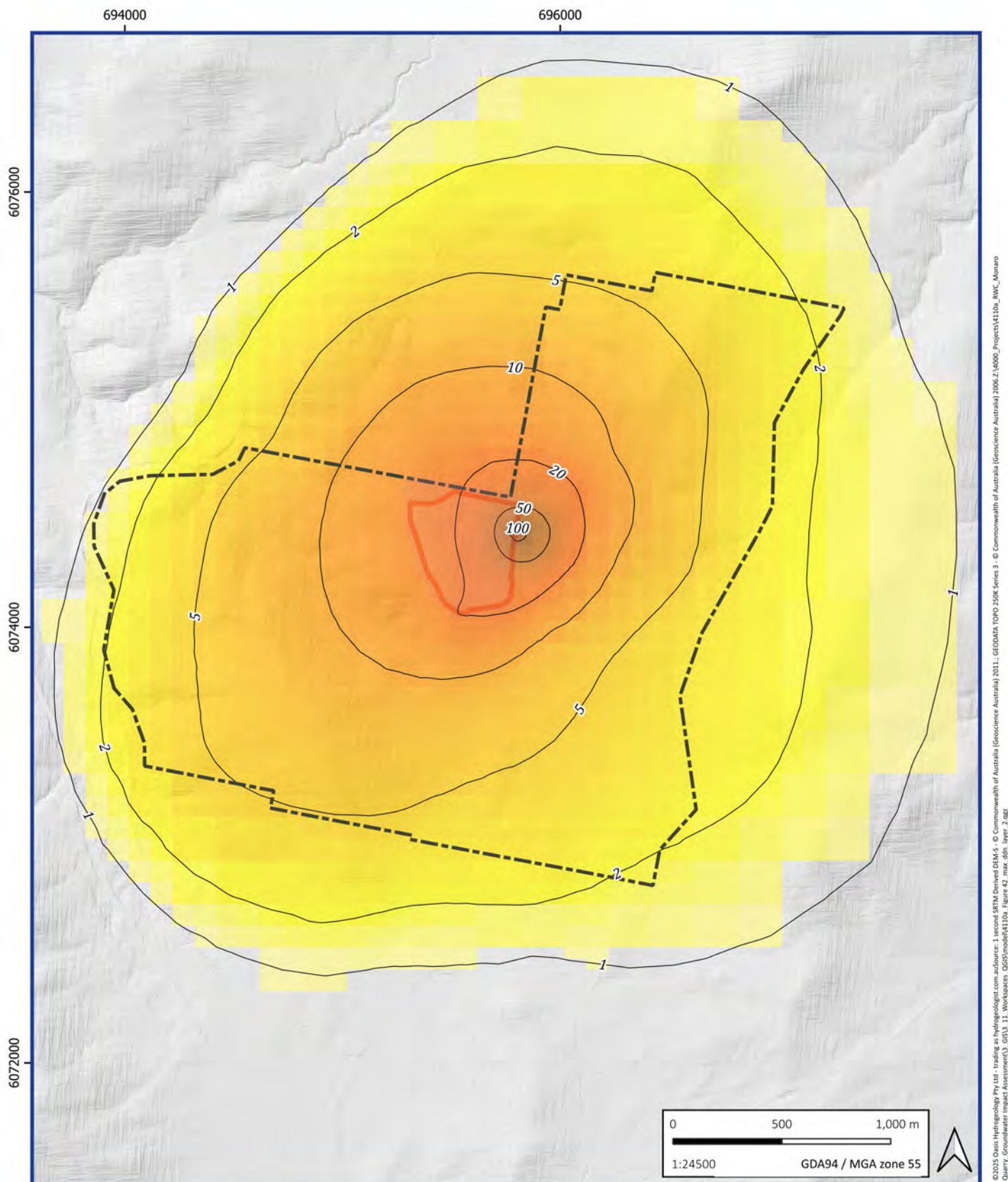
- Drawdown contour (m)
- - - Project boundary
- Monaro quarry

Maximum all-time Project drawdown in Layer 1

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Figure 41

19/05/2025



Legend

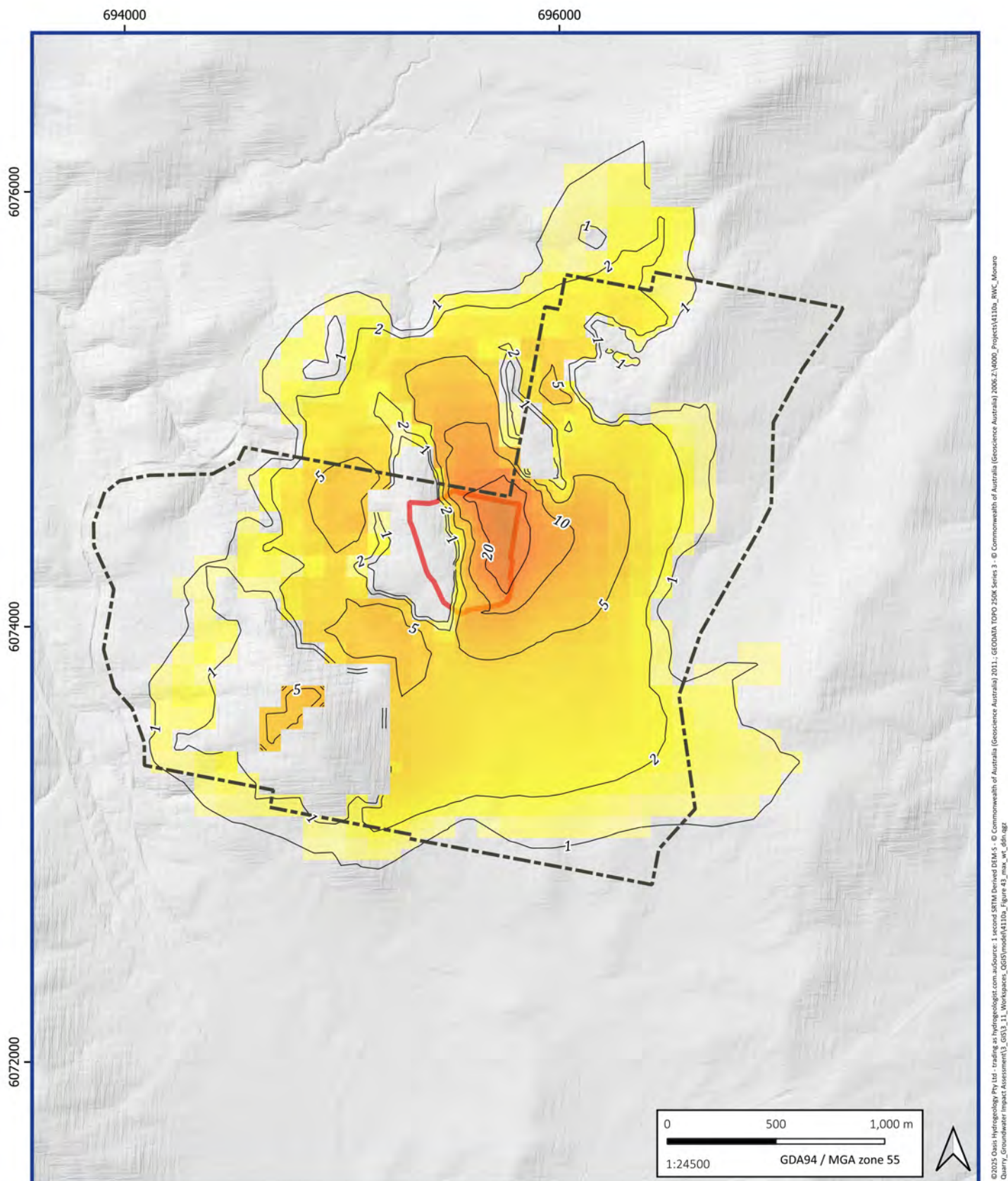
- Drawdown contour (m)
- - - Project boundary
- Monaro quarry

Maximum all-time Project drawdown in Layer 2

(4110a) Monaro Rock Quarry - Numerical Groundwater Modelling Report

Figure 42

28/05/2025



Legend

- Drawdown contour (m)
- - - Project boundary
- Monaro quarry

Maximum all-time Project drawdown in water table

(4110a) Monaro Rock Quarry - Numerical Groundwater Modelling

Figure 43

28/05/2025

5. Post-closure model

Following the predictive project scenario model, a post-closure recovery model was run to assess the long-term influence of the pit lake on the groundwater system. The post-closure model simulated steady-state conditions using long-term average climatic conditions and incorporating a recovered pit lake stage of 800 mAHD. This pit lake was represented with the MODFLOW6 RIV package using a vertical hydraulic conductivity (K_v) of 100 m/day and a riverbed thickness of 0.1 m. The stage elevation of 800 mAHD was provided by SEEC (Strategic Environmental and Engineering Consulting, 2025).

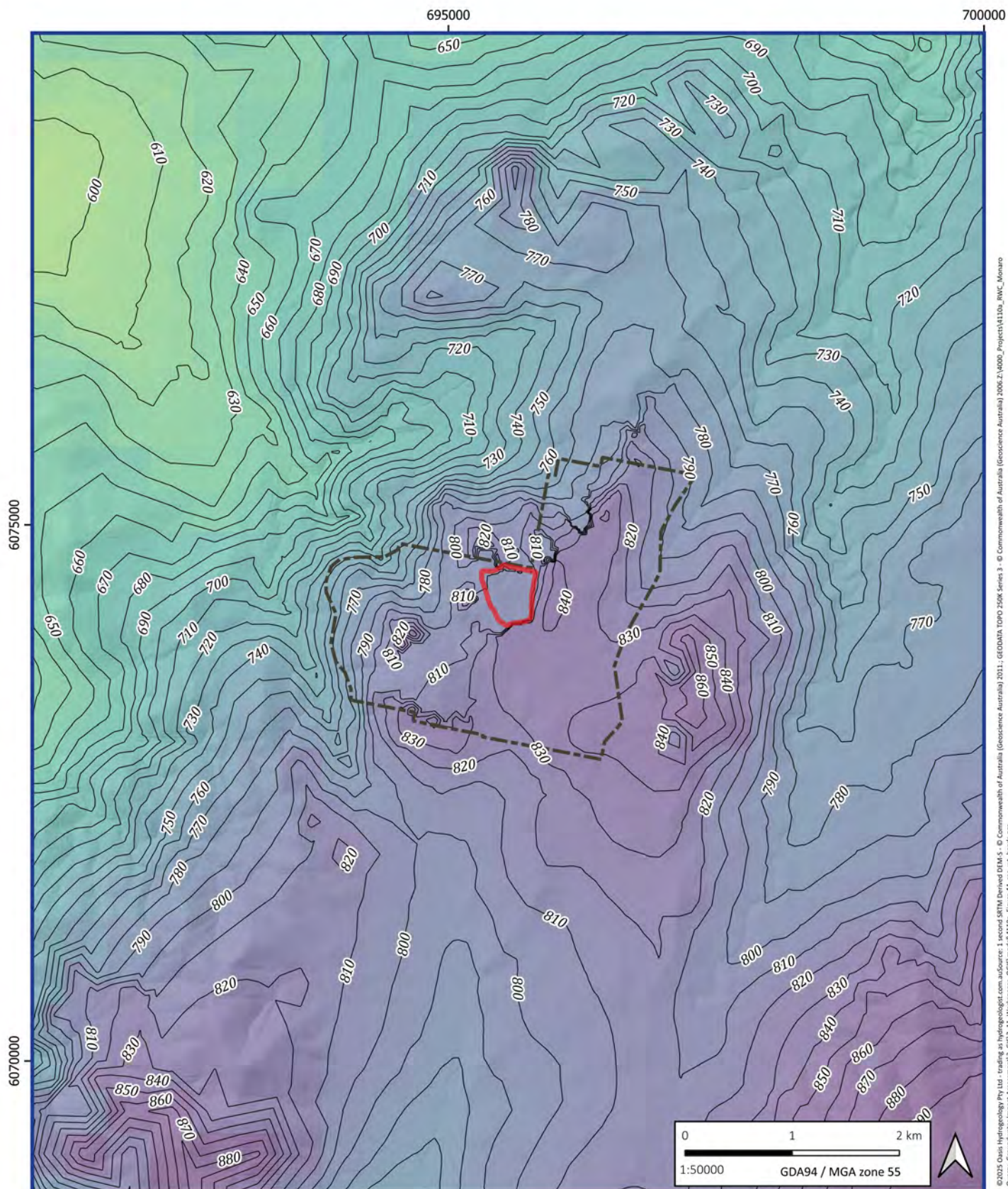
The recovered water table elevation is presented as Figure 44 and indicates that the pit lake is predicted to behave as a flow-through feature, with groundwater generally entering from the east and discharging towards the north-west.

Residual drawdowns associated with the Project were assessed for each model layer (Figure 45 and Figure 46) and for the groundwater table (Figure 47). These drawdowns represent the long-term post-closure impacts of the quarry following groundwater level recovery. They were calculated by comparing groundwater heads from the post-closure model with those from a 'null' scenario. The null scenario represents a steady-state continuation of the predictive null scenario and excludes a pit lake.

Maximum residual drawdowns of 11.5 m are predicted for the Project, with impacts diminishing radially with distance from the quarry. Figure 46 shows locations of registered bores and indicates that one registered bore (GW402921) is predicted to experience residual drawdown exceeding one metre. Section 4.2 has already assessed maximum baseflow impacts associated resultant of the Project to be negligible and so, no residual impacts to baseflow are predicted to occur.

Maximum drawdowns for the base model over the life of the quarry are on the high end of the range predicted by the ensemble¹. While uncertainty surrounding residual drawdowns was not explicitly calculated, it is reasonable to expect that the residual impacts associated with the base model would also represent the higher end of potential outcomes during the post-closure phase. As such, the residual drawdowns presented here are conservative.

¹ Visual comparison of drawdown extents presented in Section 4.3 with those presented in Section 7.2.2.



Legend

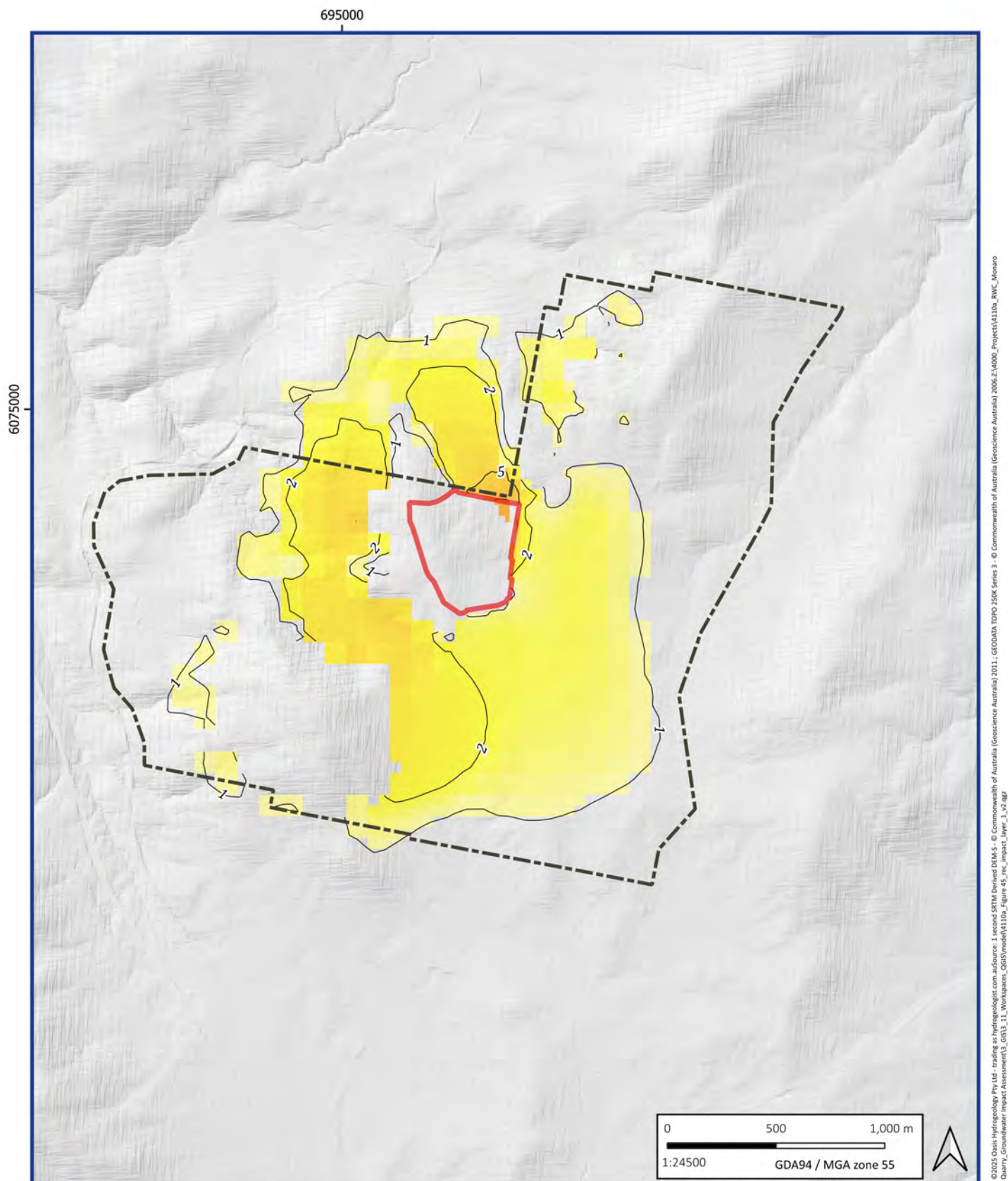
- Head contour (mAHD)
- - - Project boundary
- Monaro quarry

Modelled water table heads - post recovery

(4110a) Monaro Rock Quarry - Numerical Groundwater Modelling Report

Figure 44

19/05/2025



Legend

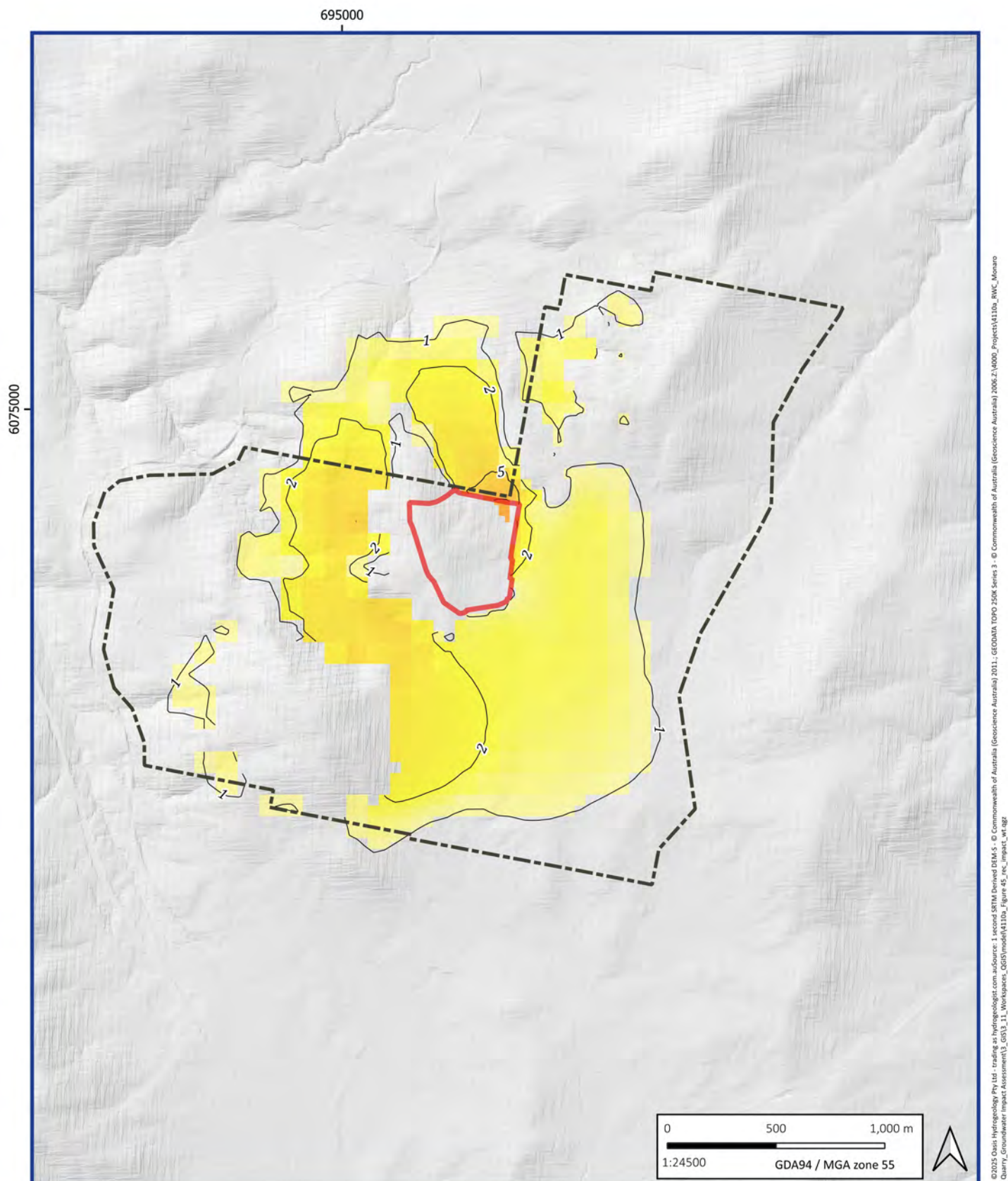
- Drawdown contour (m)
- - - Project boundary
- Monaro quarry

Residual Project drawdown in Layer 1

(4110a) Monaro Rock Quarry - Numerical Groundwater Modelling Report

Figure 45

28/05/2025



Legend

- Drawdown contour (m)
- - - Project boundary
- Monaro quarry

Residual Project drawdown in water table

(4110a) Monaro Rock Quarry - Numerical Groundwater Modelling Report

Figure 47

28/05/2025

6. Model confidence level classification

The model confidence level classification has been assessed against the Class 3 criteria outlined in the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012). The full assessment is presented in Table 10. The model is shown to satisfy most Class 3 requirements, with few criteria aligning with Class 2, and no criteria classified as Class 1. Given the overall weighting towards Class 3 and the absence of Class 1 criteria, the model is considered to have achieved a Class 2 to 3 confidence level classification.

Table 10 Class 3 confidence level justification

Component	Class 3 requirement	Evidence demonstrated in this model	Confidence level achieved
Data	Spatial and temporal distribution of groundwater head observations adequately define groundwater behaviour, especially in areas of greatest interest and where outcomes are to be reported.	Adequate distribution of observation targets around Project site (Figure 9). Targets from September 2021 until January 2024.	Class 3
	Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry.	Model represents a single unit with a weathered profile. This is suitably informed by bore logs.	Class 3
	Reliable metered groundwater extraction and injection data is available.	N/A. No groundwater extraction or injection has taken place in the model area.	N/A
	Rainfall and evaporation data is available	SILO rainfall and evaporation data for BoM station 70064 available from 1900 to present (Section 2.5).	Class 3
	Streamflow and stage measurements are available with reliable baseflow estimates at a number of points	Watercourses within the model domain are ephemeral with no baseflow contribution to stream flow (GIA, 6.4.3)	Class 2
Calibration	Adequate validation is demonstrated.	Mass balance errors are negligible cumulatively and for every time step. Budgets are consistent with the conceptual model and groundwater head contours conform with conceptual understanding of flow directions.	Class 3
	Scaled RMS error or other calibration statistics are acceptable.	SRMS of 2.74% is below the 10% threshold recommended by Australia Groundwater Modelling Guidelines (Barnett <i>et al.</i> , 2012)	Class 3
	Long-term trends are adequately replicated where these are important.	Yes, long-term trends are generally well represented across sites. See Appendix B for hydrographs	Class 3
	Seasonal fluctuations are adequately replicated where these are important.	Yes, see Appendix B for hydrographs. Notably, MRPDH15.	Class 3
	Transient calibration is current, i.e. uses recent data.	Calibration data available from September 2021 until January 2024.	Class 3
	Model is calibrated to heads and fluxes.	Calibrated to heads only.	Class 2
	Observations of the key modelling outcomes dataset is used in calibration.	The key modelling outcome is heads, which is used as the calibration target.	Class 3

Component	Class 3 requirement	Evidence demonstrated in this model	Confidence level achieved
Prediction	Length of predictive model is not excessive compared to length of calibration period.	Length of calibration period is 2.5 years vs 30 years for the predictive period. Difference in length satisfies Class 2 requirement.	Class 2
	Temporal discretisation used in the predictive model is consistent with the transient calibration.	Calibration uses monthly, while predictive uses annual. Fulfills Class 2 requirement.	Class 2
	Level and type of stresses included in the predictive model are within the range of those used in the transient calibration.	Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration. (Class 2) Stresses not used in calibration but included in prediction	Class 2
	Model validation suggests calibration is appropriate for locations and/or times outside the calibration model.	True (refer to Section 3.11)	Class 3
	Steady-state predictions used when the model is calibrated in steady-state only.	N/A	N/A
Key indicator	Key calibration statistics are acceptable and meet agreed targets.	True. Key calibration statistics are within acceptable ranges (Section 3.2).	Class 3
	Model predictive time frame is less than 3 times the duration of transient calibration.	False. Model predictive time frame is between 3 and 10 times the duration of transient calibration.	Class 2
	Stresses are not more than 2 times greater than those included in calibration.	Stresses used in the predictive period are averages of those used for the calibration period.	Class 3
	Temporal discretisation in predictive model is not the same as that used in calibration.	False. Annual discretisation is used for predictive model, whereas monthly discretisation is used for calibration model.	Class 2
	Mass balance closure error is less than 0.5% of total.	True. Mass balance error is 0.00% for each time step and cumulatively over the model duration.	Class 3
	Model parameters consistent with conceptualisation.	True. Budget rates and parameterisation are consistent with the hydrogeological conceptual model presented in the GIA.	Class 3
	Appropriate computational methods used with appropriate spatial discretisation to model the problem.	True. MODFLOW6 and PESTPP-IES are industry standard software for groundwater model simulation and calibration. Cell refinement in key areas (i.e. Project site and along water courses, geological features) with coarser spatial discretisation elsewhere is appropriate for representing the Project.	Class 3
	The model has been reviewed and deemed fit for purpose by an experienced, independent hydrogeologist with modelling experience.	The model has been reviewed by Manewell Groundwater (May 2024).	Class 3

7. Predictive uncertainty analysis

In the context of model-based decision support or risk assessment, uncertainty can be defined as *any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system* (Walker *et al.*, 2003). Understanding where the unknowns are hidden and what their impact on modelling prediction is (or might be) is a strength of the model and a necessary tool supporting the decision-making effort.

In more current (and Australian) context, Peeters *et al.* (2018) pilot a combination of approaches to discuss impact of limitations of knowledge on modelling predictions in the context of decreasing risks associated with environmental impact assessments. Authors further refined their recommendations in the form of IESC Information Guidelines Explanatory Note: Uncertainty analysis for groundwater modelling guidelines (2018 and 2023) where they recommend both qualitative and quantitative approach to uncertainty analysis. These guidelines were considered during the undertaking of uncertainty analysis for the current model.

7.1. Qualitative uncertainty

Qualitative uncertainties are defined by lack of knowledge with respect to either structure or processes within the groundwater flow system. They can usually be reduced by collecting more data from existing observation sites, or collecting data from areas that were not previously sampled or monitored. The potential qualitative uncertainty issues identified during the project impact assessment are detailed below, and include:

- heterogeneity of hydraulic properties;
- heterogeneity of recharge and evapotranspiration;
- the impact of Royalla fault on the groundwater system; and
- timing and location of system stresses.

Heterogeneity of hydraulic properties

Each hydrostratigraphic unit has natural heterogeneity that causes horizontal and vertical variations in hydraulic properties. Due to computational, data and model design constraints, it is not possible for a groundwater model to precisely capture these real-world spatial variations of hydraulic properties. Hence, the groundwater model provides a simplified representation of the true system properties. This simplified approach introduces uncertainty into the groundwater models as the true system properties cannot be known or represented at respective locations in the model.

Heterogeneity of recharge and evapotranspiration

Recharge and evapotranspiration rates are key components of a groundwater system, influencing groundwater inflows and outflows, respectively. As these parameters are variable with time, rates cannot be reliably predicted far into the future. Consequently, long-term average values have been used in the project modelling to represent future rates. This approach simplifies the representation of these dynamic processes and inevitably introduces an additional source of uncertainty into the model, as it cannot capture potential fluctuations from this average.

The impact of Royalla Fault on the groundwater system

Faults can act as barriers to groundwater flow, impeding movement due to low-permeability materials such as clays or gouge, or as conduits, enhancing flow along preferential fractured pathways. The tendency of the fault to act as a flow barrier or a conduit significantly influences the propagation of operation-related impacts. That is, a fault acting as a barrier could limit the extent of drawdown, while a fault behaving as a conduit could accelerate and extend the propagation of drawdown across greater distances.

The influence of the Royalla Fault on the behaviour of the groundwater system is not currently understood and is a limitation of the conceptual model. The presence of the Royalla Fault is, therefore, likely to have consequences for the propagation of groundwater impacts associated with the project and the lack of understanding at present, surrounding the fault behaviour introduces uncertainty to the model.

The timing and location of system stresses

System stresses simulated in the model include quarry dewatering via the model DRN cells and pumped water extraction from the dewatering well simulated with the WEL package. The proponent provided quarry stage plans for each development phase, outlined in Section 2.6.5. While each stage lasts for five years or longer, the progression within each stage is unknown and so, is a source of model uncertainty. Additionally, potential for variations from the provided stage plan schedule and excavated elevations is possible which adds further uncertainty to the modelling.

The dewatering modelled well had a targeted production rate of 1 L/s. However, the ultimate production rate and location is yet to be finalised. The lack of information surrounding the final production rate and location of the well are further sources of model uncertainty.

7.2. Quantitative uncertainty

Quantitative uncertainty analysis is a technique that aims to understand behaviour of the groundwater system by using a mathematical and statistical approach to evaluate modelling inputs and outputs and assign probabilities of occurrence to selected effects.

7.2.1. Methodology

The parameter ensemble used for quantitative predictive uncertainty comprised a subset of the full calibrated parameter ensemble discussed in Section 3.4. A cutoff SRMS threshold of 5% was applied which resulted in 164 suitably calibrated “qualified” models for predictive uncertainty. These realisations had corresponding ϕ ranging from 80 m² to 138 m². Comparison of the simulated water levels from these qualified models with observed data shows that observations lie (almost entirely) within the range of values predicted by the qualified model ensemble, thus supporting the use of these models for predictions ().

Predictive simulations (both Project and null scenarios) were conducted for each of the 164 qualified models, and predictions of interest were extracted. These included Project-related drawdowns, pit inflows, and well extraction rates. For each prediction, key summary statistics were evaluated, including the minimum, maximum, and selected percentiles (10th, 33rd, 67th, and 90th).

It is important to note that each of the 164 qualified predictions of interest is assumed to be equally probable. However, in reality, the parameter set encompasses a range of values from representative to extreme. When applied across the model domain or in combination, these parameter sets yield outcomes with significantly varying probabilities. Consequently, the statistics presented reflect the range of modelling outcomes based on the most extreme parameter combinations that meet the 5% SRMS criterion. While the ensemble results represent a broad range of plausible outcomes, they are intended to inform the range of potential groundwater responses, not replace the base case used for impact assessment.

7.2.2. Uncertainty of predictions

The uncertainty associated with predicted pit inflow and well extraction rates are presented in Figure 48 and Figure 49. In these figures, the original model prediction (the base model scenario) is represented as a purple line. These uncertainty ranges indicate that the base model prediction is not ‘over-calibrated’ nor unrealistic. However, peak pit inflows predicted in stage 4 of the project may be on the low end of the possible range of outcomes.

Figure 50 to Figure 52 illustrate the uncertainty surrounding maximum project drawdown zones in model layers 1, 2 and the water table, respectively. These figures present the areas within the project’s 1 m drawdown zone corresponding to the minimum, 10th, 33rd, 67th, 90th percentiles, and maximum of the qualified realisations.

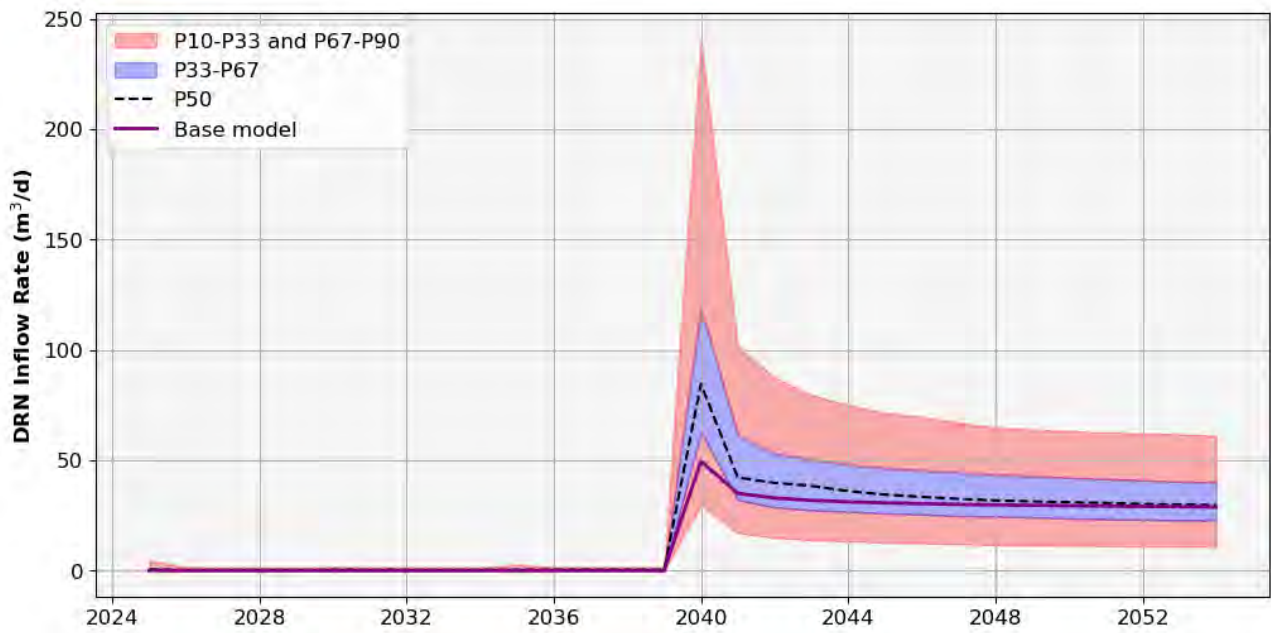


Figure 48 Uncertainty surrounding pit inflows

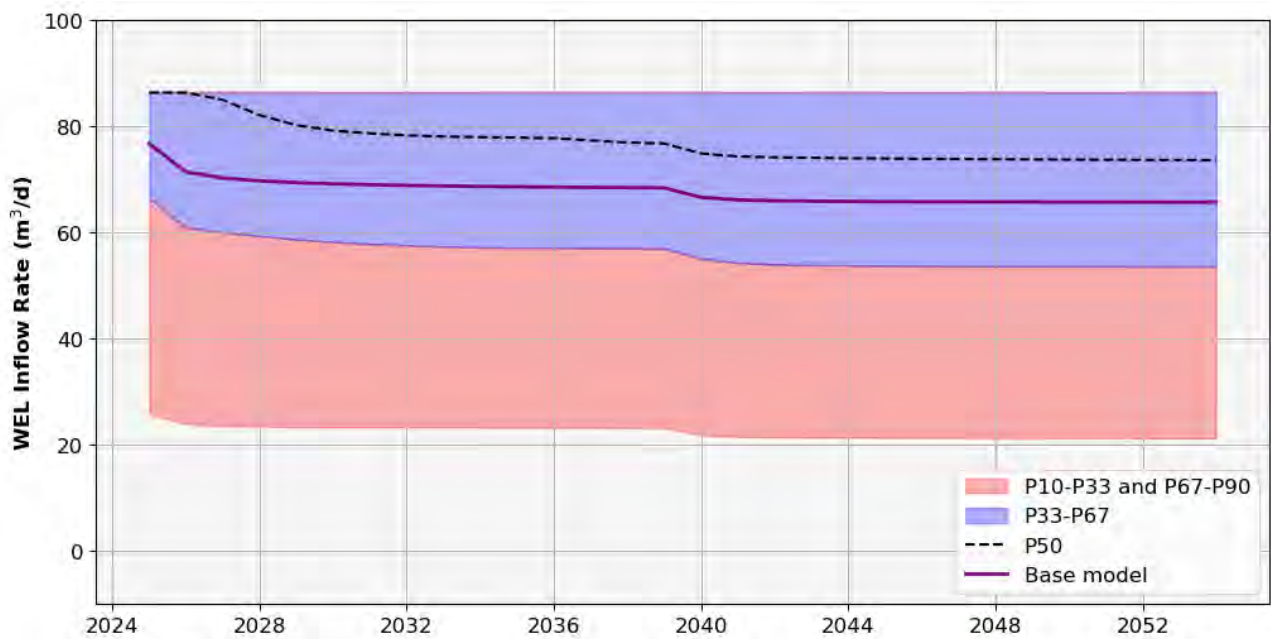
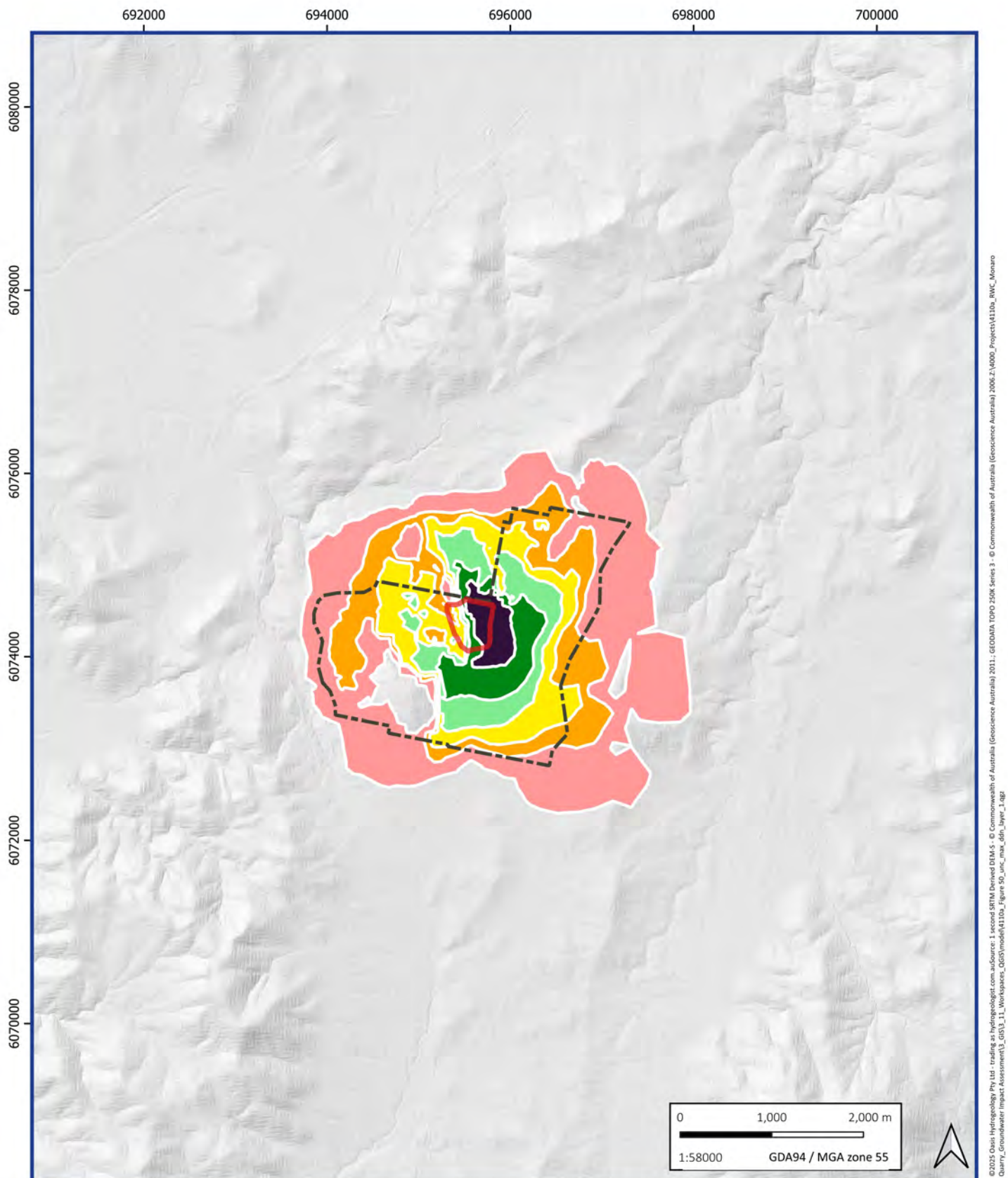


Figure 49 Uncertainty surrounding well extraction



Legend

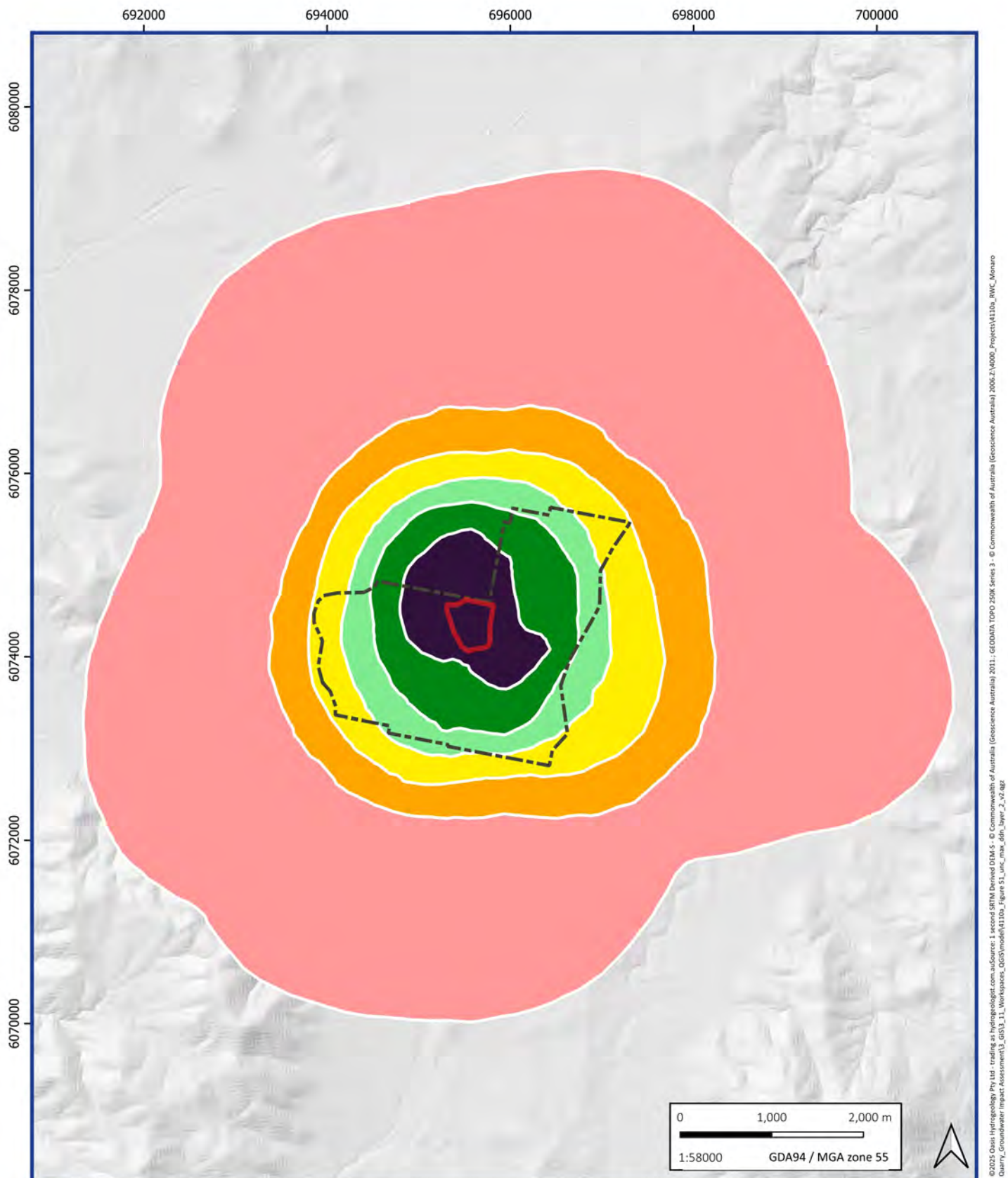
- Project boundary
- Monaro quarry
- Minimum area of drawdown of all 164 realisations
- Area of drawdown less than 10th percentile of 164 realisations
- Area of drawdown less than 33rd percentile of 164 realisations
- Area of drawdown less than 67th percentile of 164 realisations
- Area of drawdown less than 90th percentile of 164 realisations
- Area of drawdown within all 164 realisations

Uncertainty of 1-m Project drawdown in Layer 1

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Figure 50

28/05/2025



Legend

— Project boundary

□ Monaro quarry

■ Minimum area of drawdown of all 164 realisations

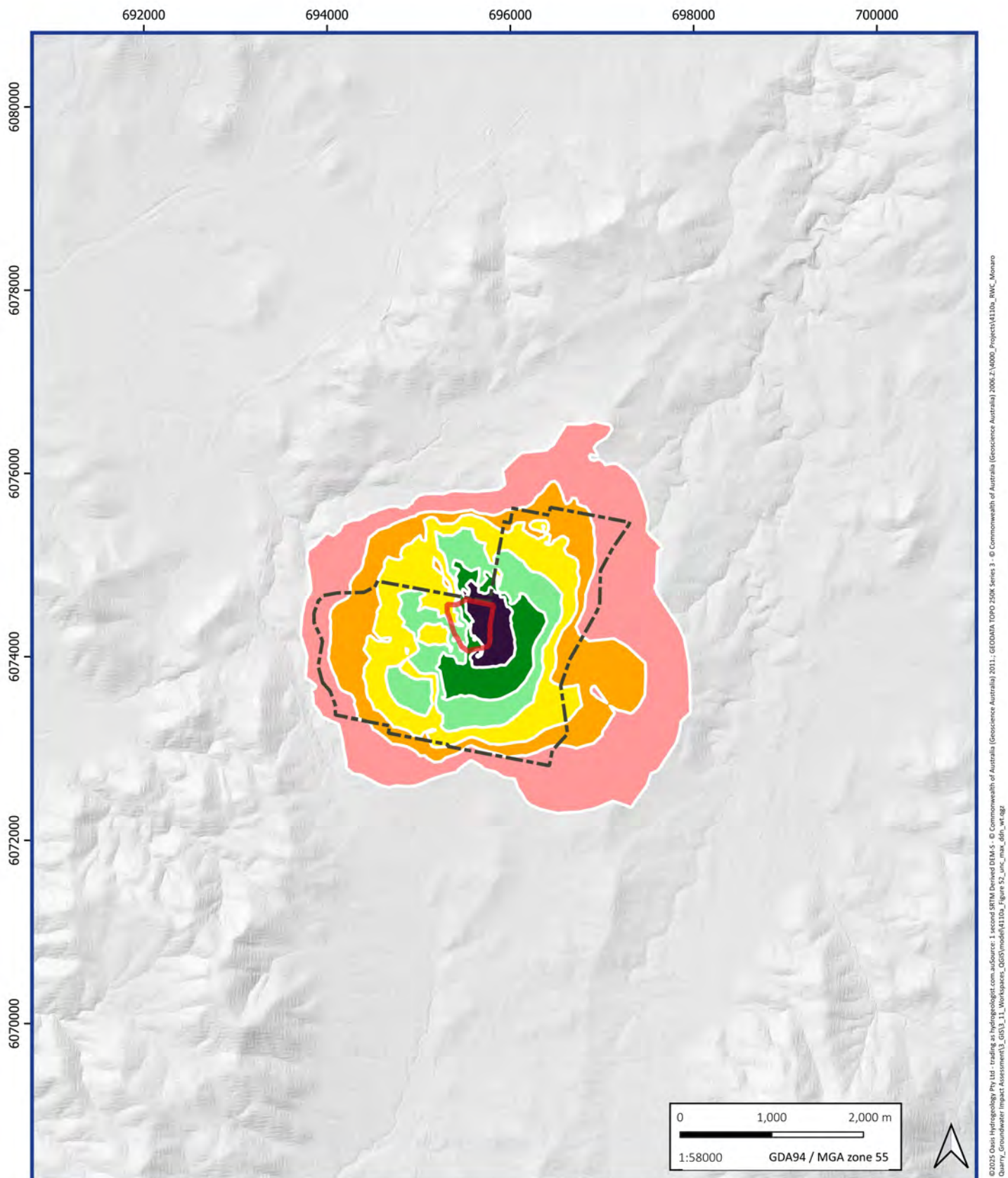
■ Area of drawdown less than 10th percentile of 164 realisations

■ Area of drawdown less than 33rd percentile of 164 realisations

■ Area of drawdown less than 67th percentile of 164 realisations

■ Area of drawdown less than 90th percentile of 164 realisations

■ Area of drawdown within all 164 realisations



Legend

- Project boundary
- Monaro quarry

- Minimum area of drawdown of all 164 realisations
- Area of drawdown less than 10th percentile of 164 realisations
- Area of drawdown less than 33rd percentile of 164 realisations
- Area of drawdown less than 67th percentile of 164 realisations
- Area of drawdown less than 90th percentile of 164 realisations
- Area of drawdown within all 164 realisations

Uncertainty of 1-m Project drawdown in water table

(4110a) Monaro Rock Quarry - Numerical Groundwater Modelling Report

Figure 52

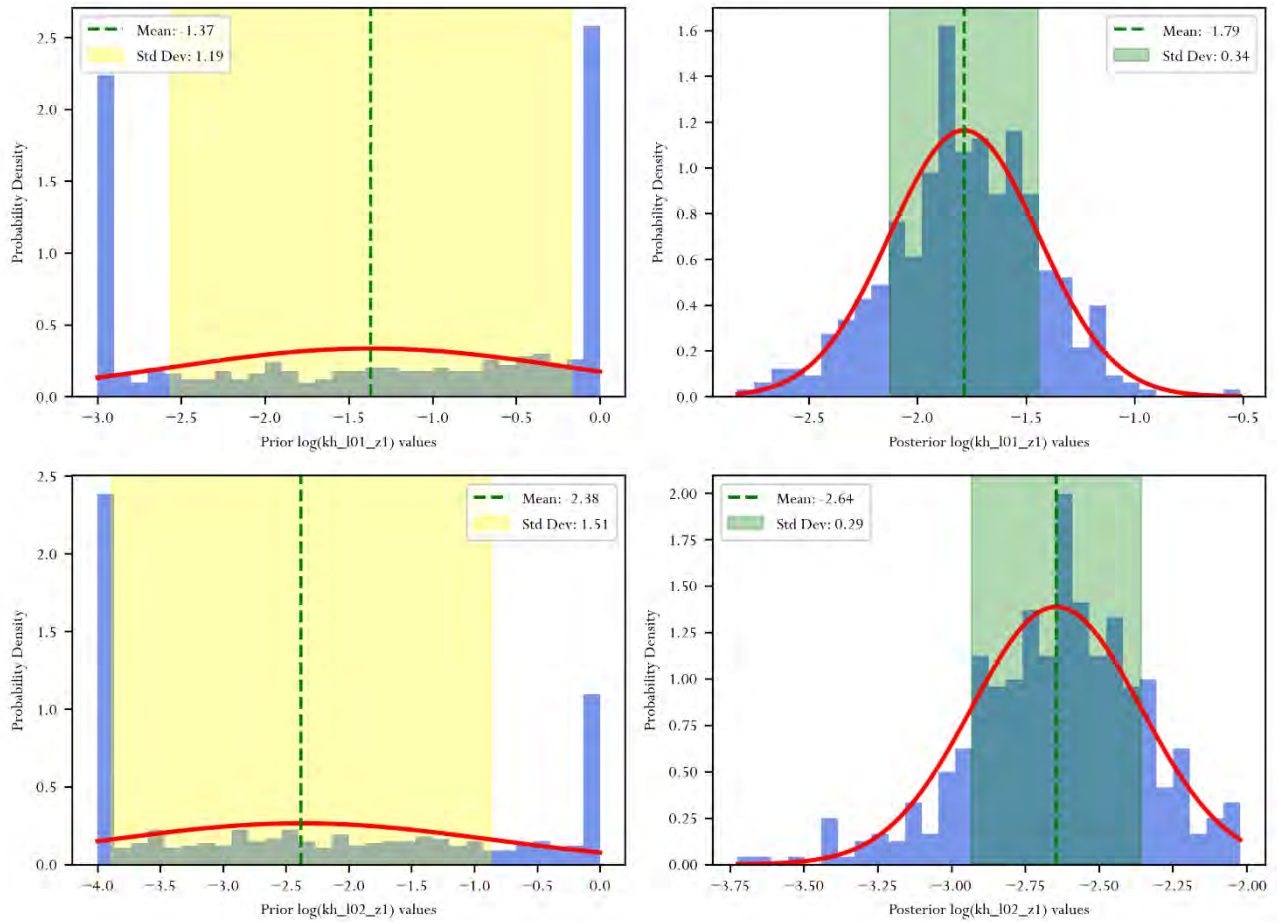
28/05/2025

8. References

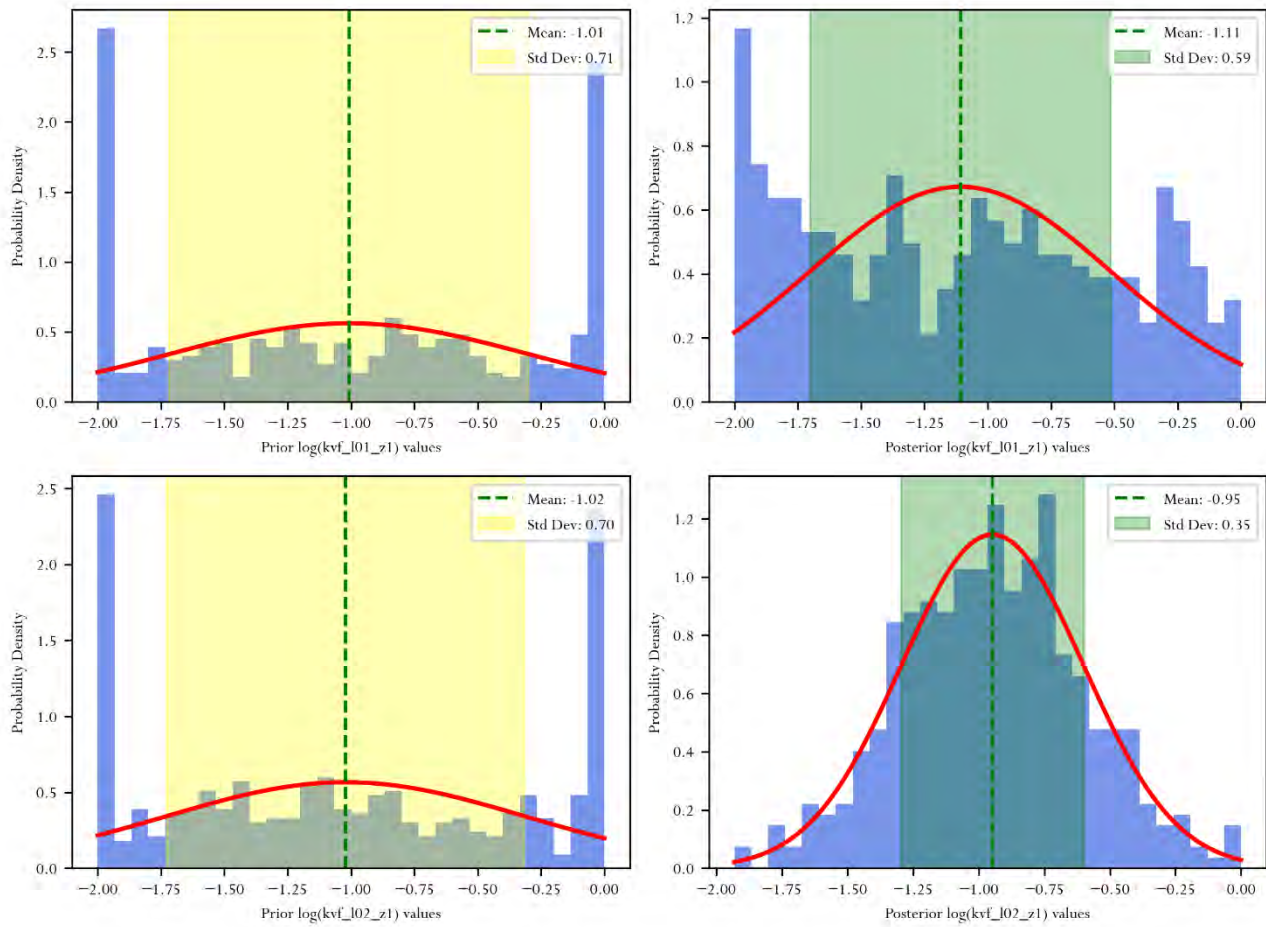
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Appendix A Parameter uncertainty

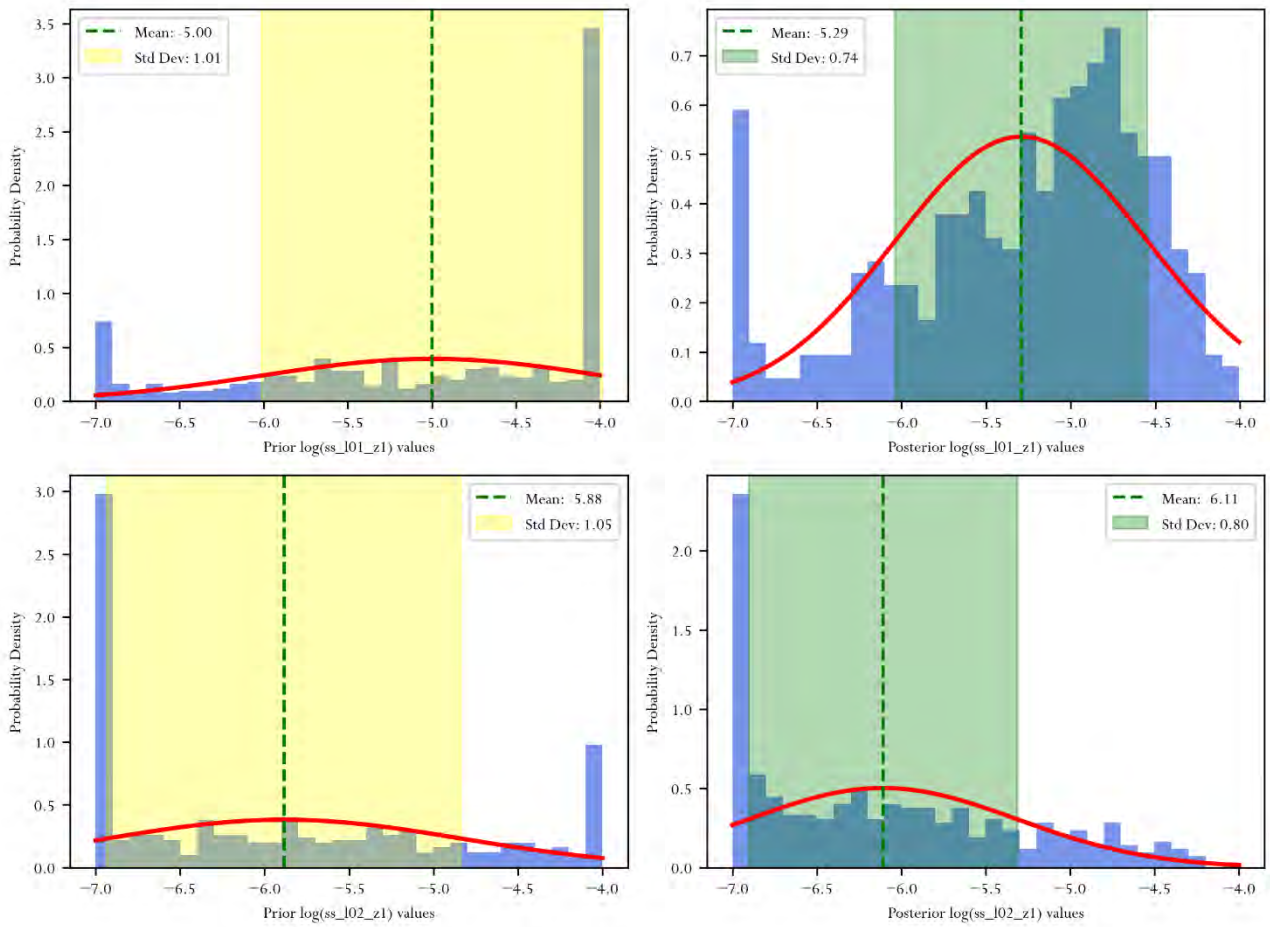
Hydraulic conductivity ensemble distribution in Layer 1 and 2



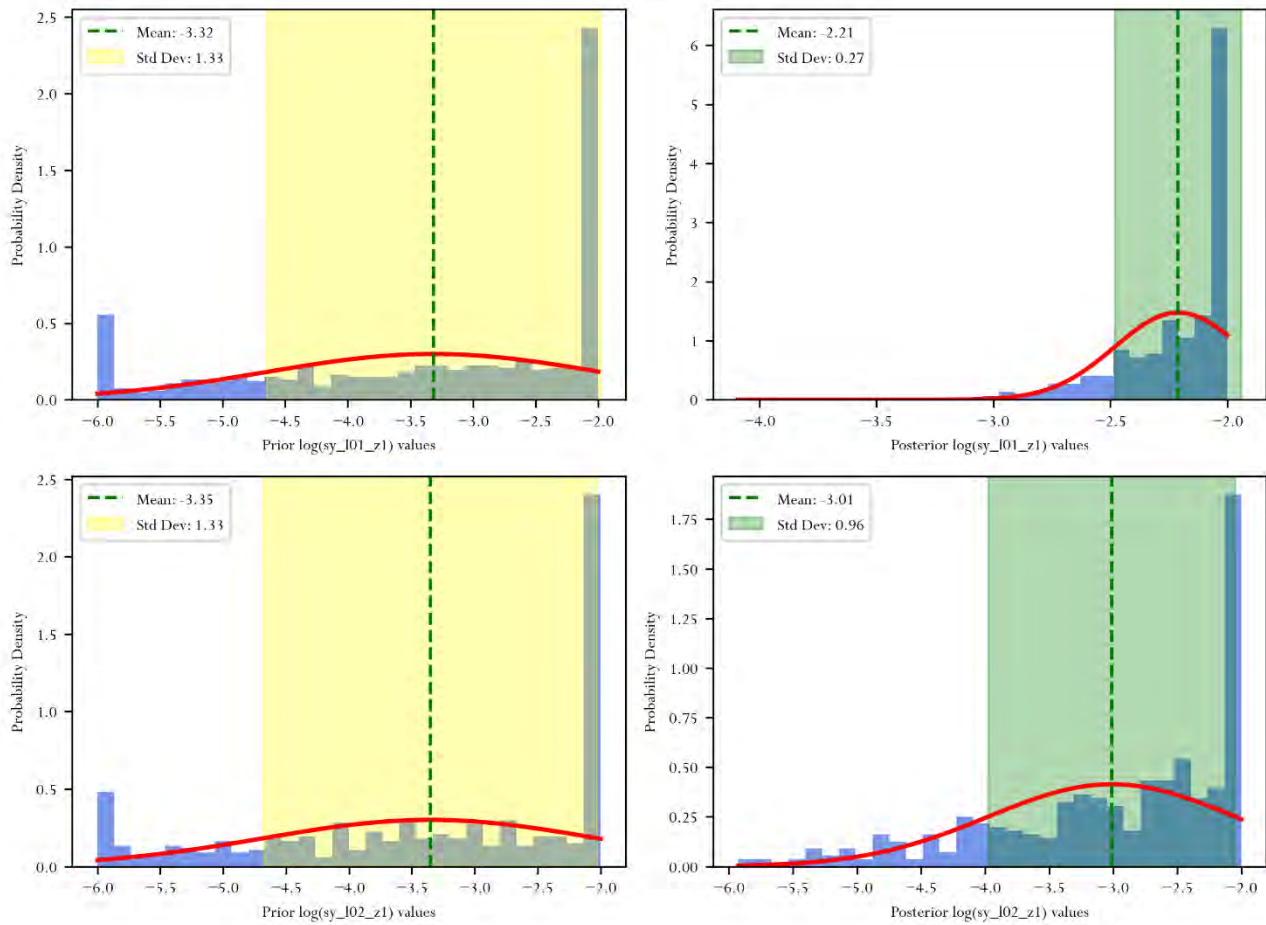
Vertical hydraulic conductivity factor ensemble distribution in Layer 1 and 2



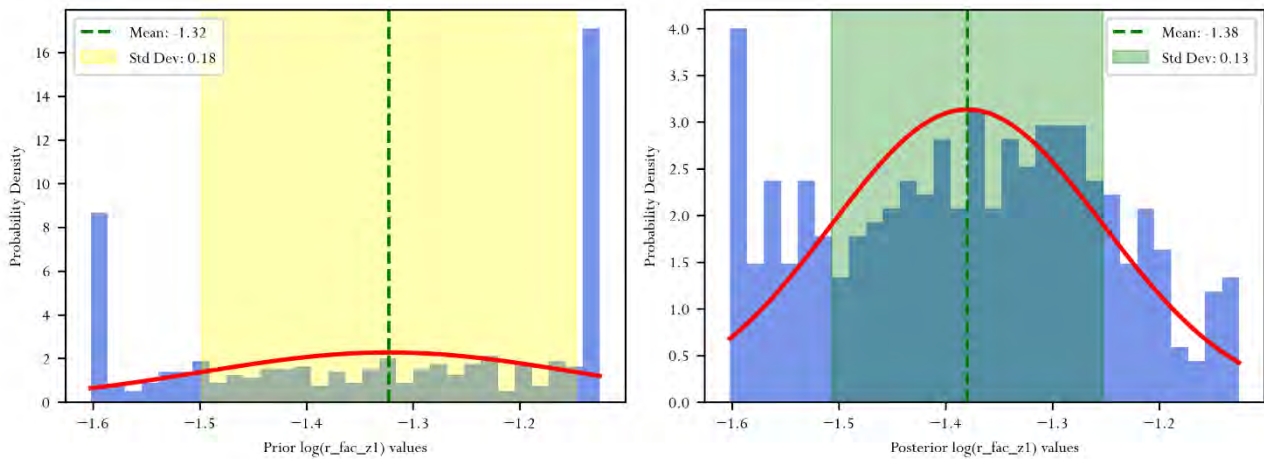
Specific storage ensemble distribution in Layer 1 and 2



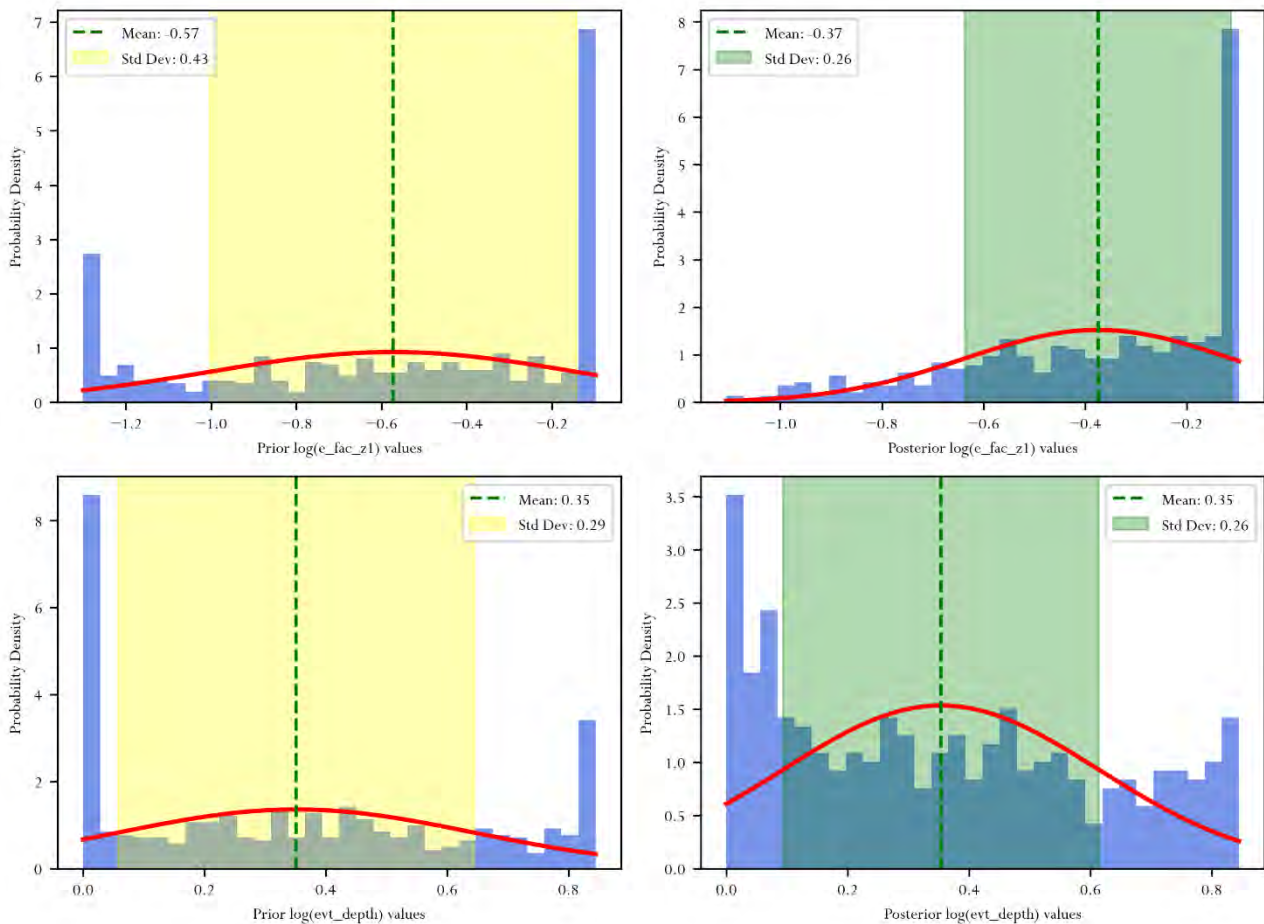
Specific yield ensemble distribution in Layer 1 and 2



Recharge rate ensemble distribution in Layer 1 and 2

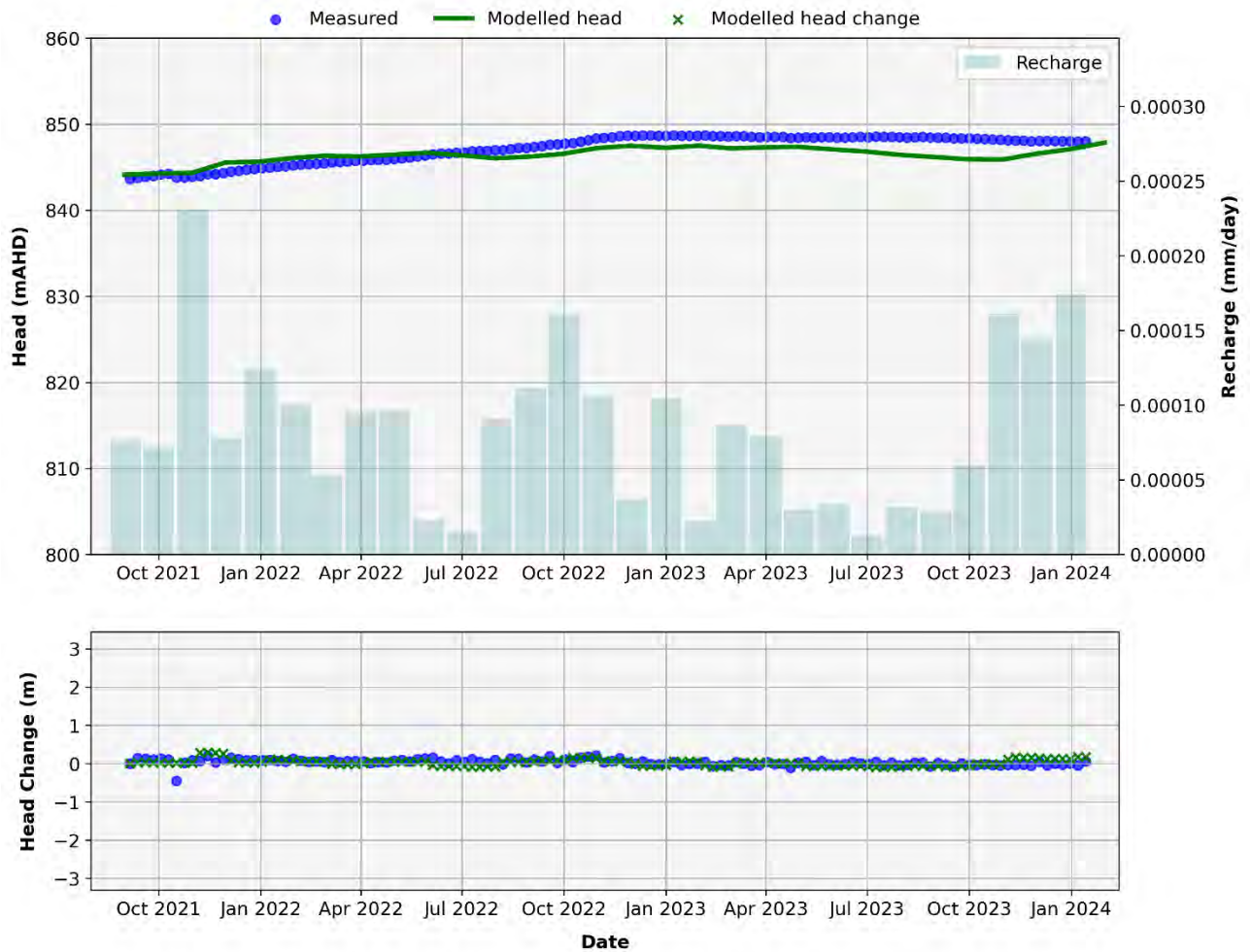


Evapotranspiration (rate and depth) ensemble distribution in Layer 1 and 2

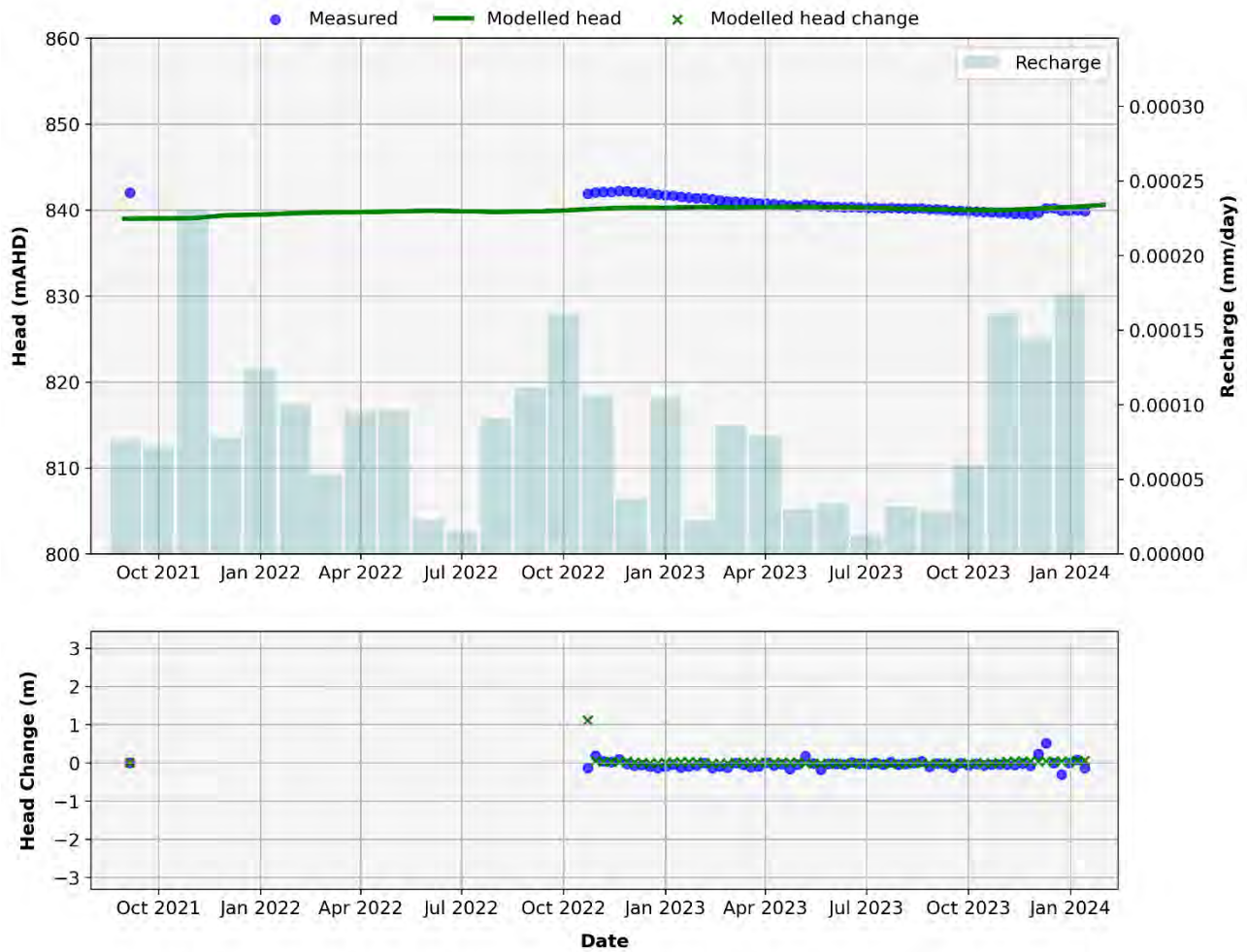


Appendix B Base model hydrographs

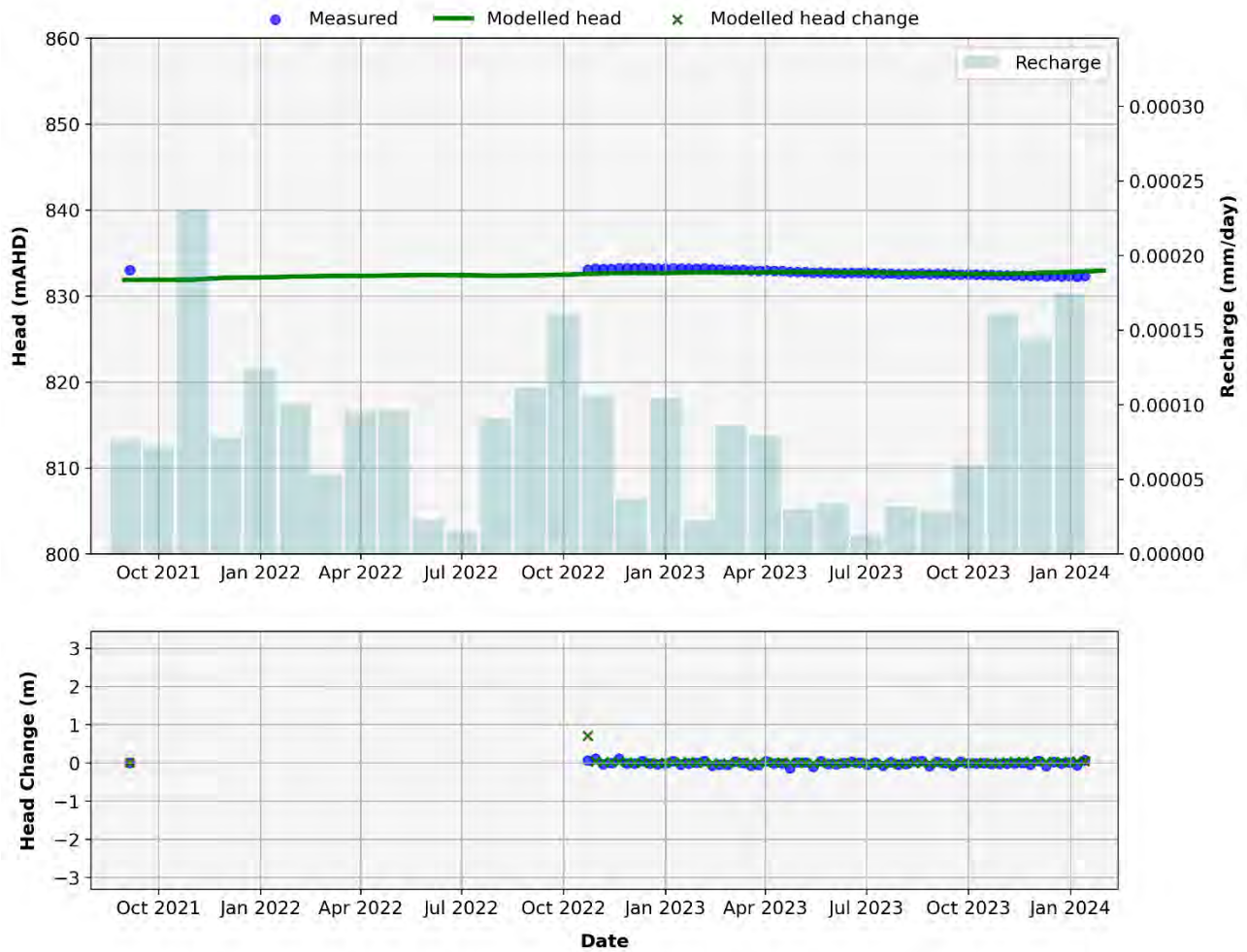
Dam Bore – Base model hydrograph



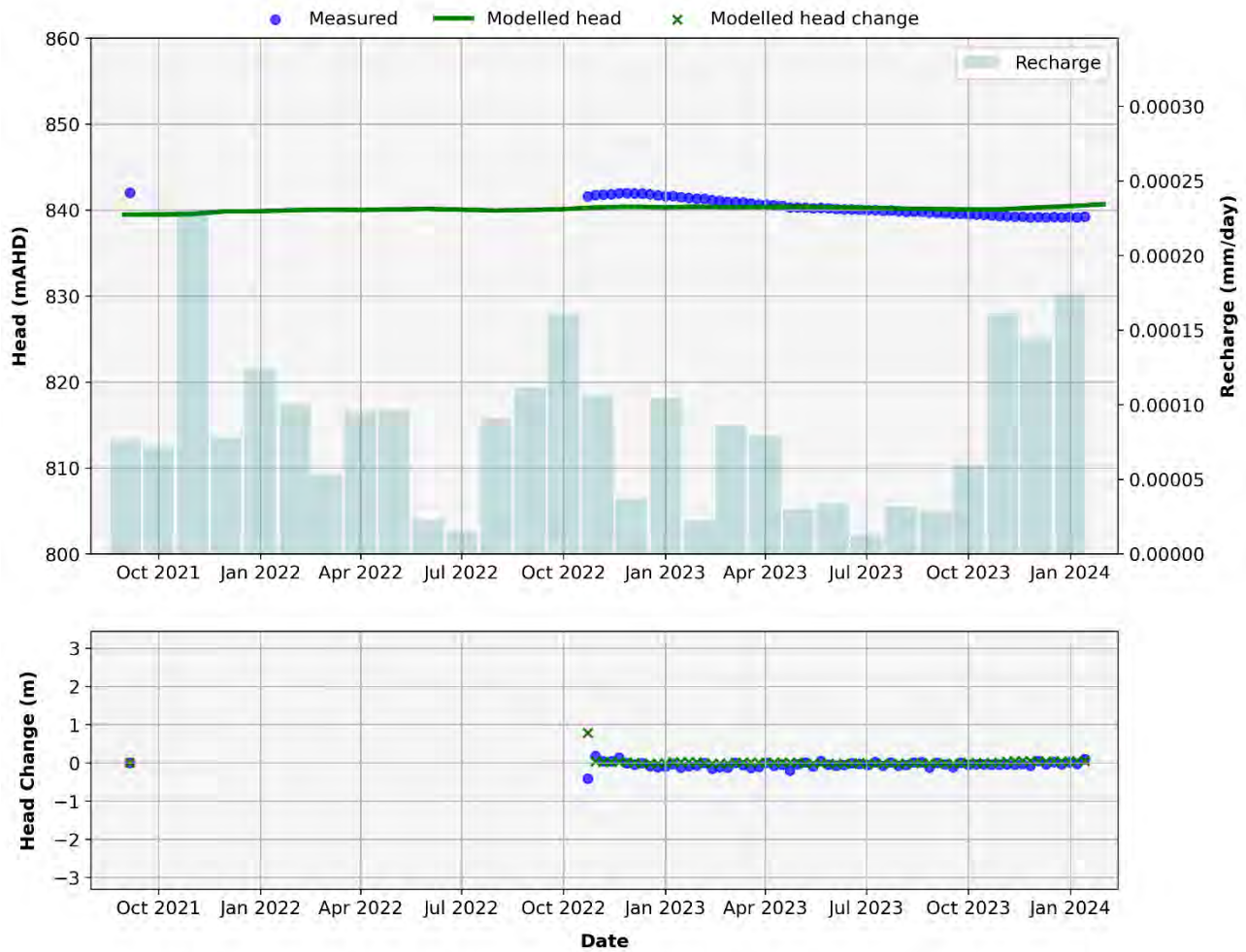
MB01 – Base model hydrograph



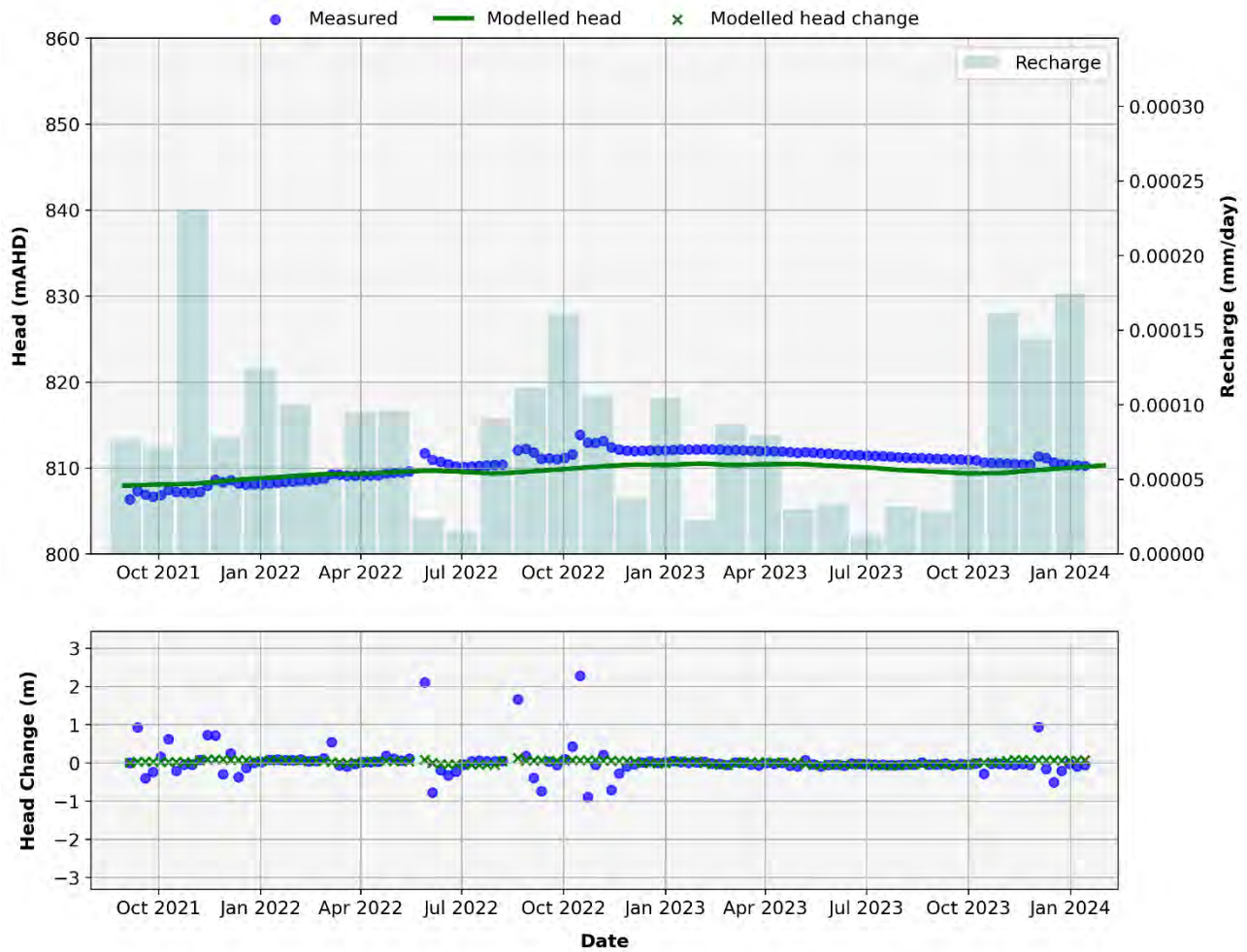
MB02 – Base model hydrograph



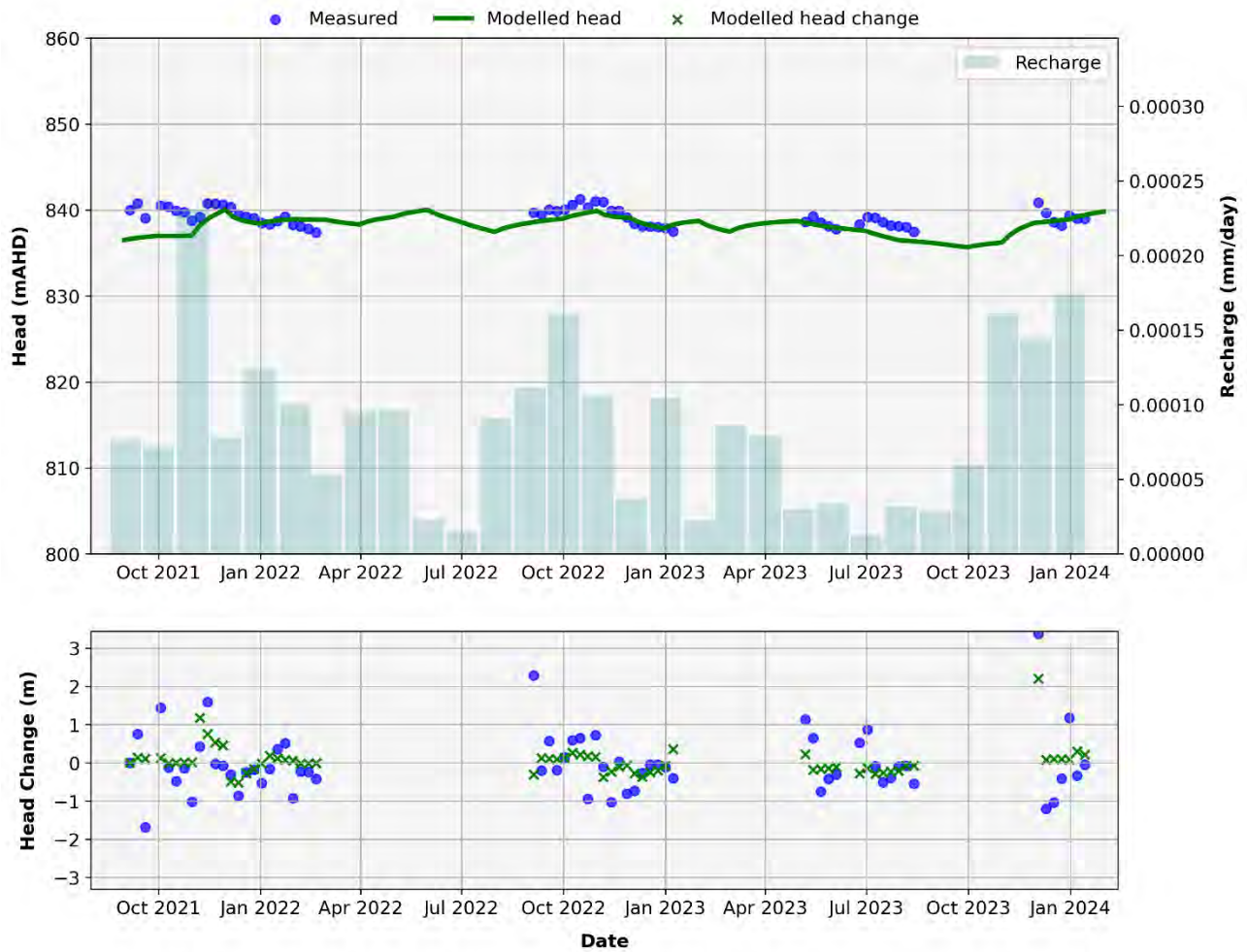
MB05 – Base model hydrograph



MRDDH08 – Base model hydrograph

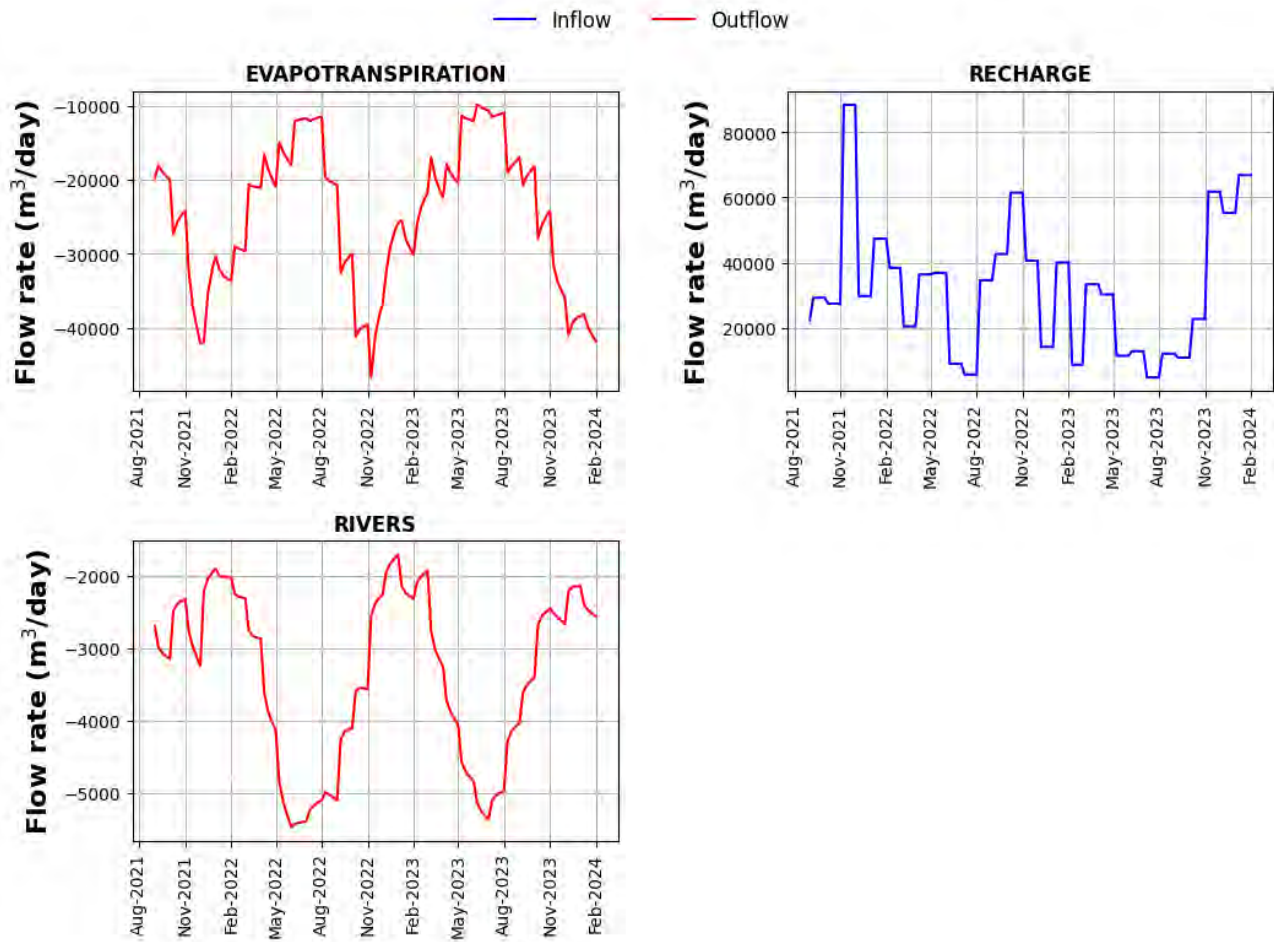


MRPDH15 – Base model hydrograph

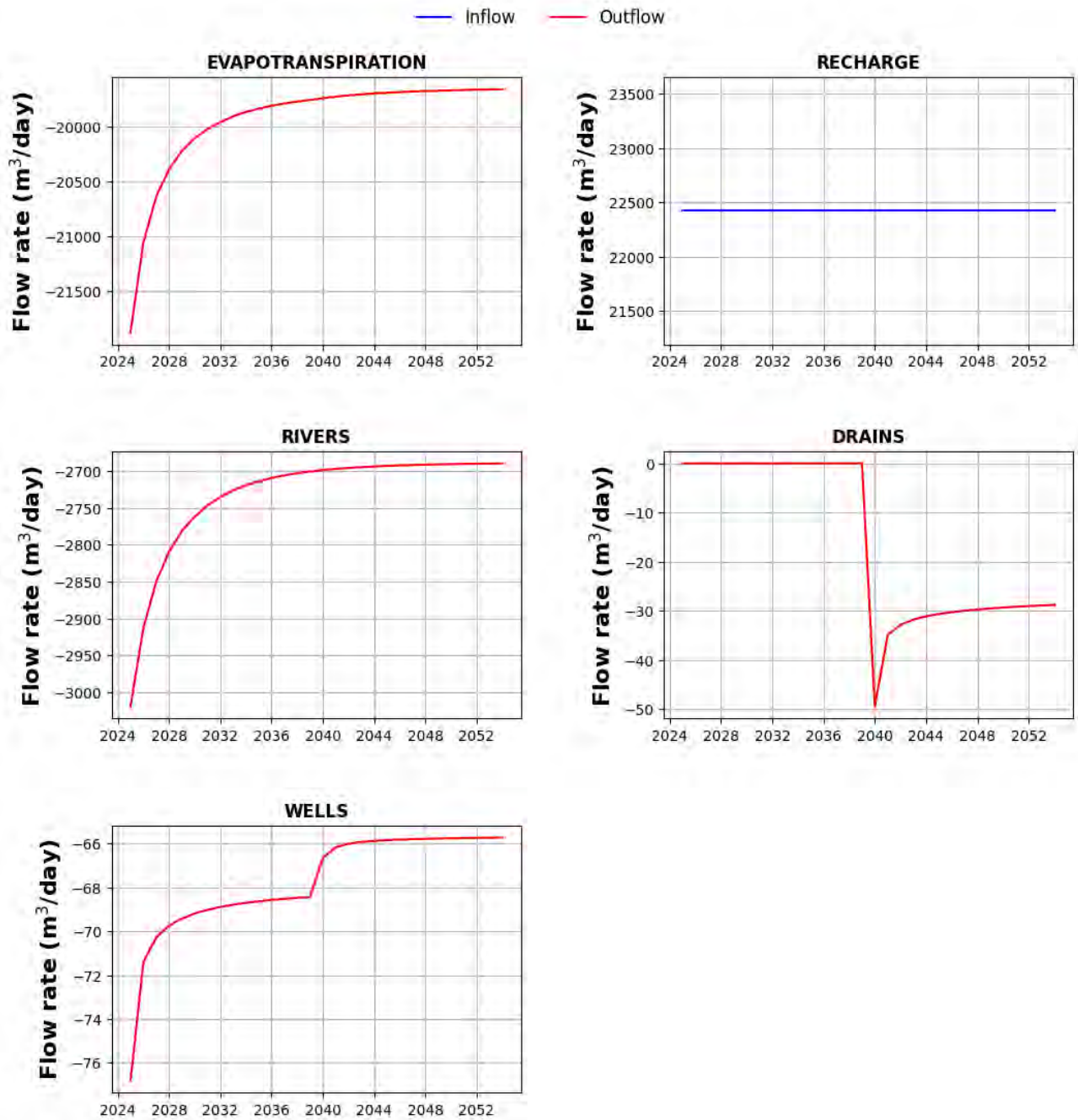


Appendix C Timeseries budgets – Base model

Model calibration period – Timeseries budgets

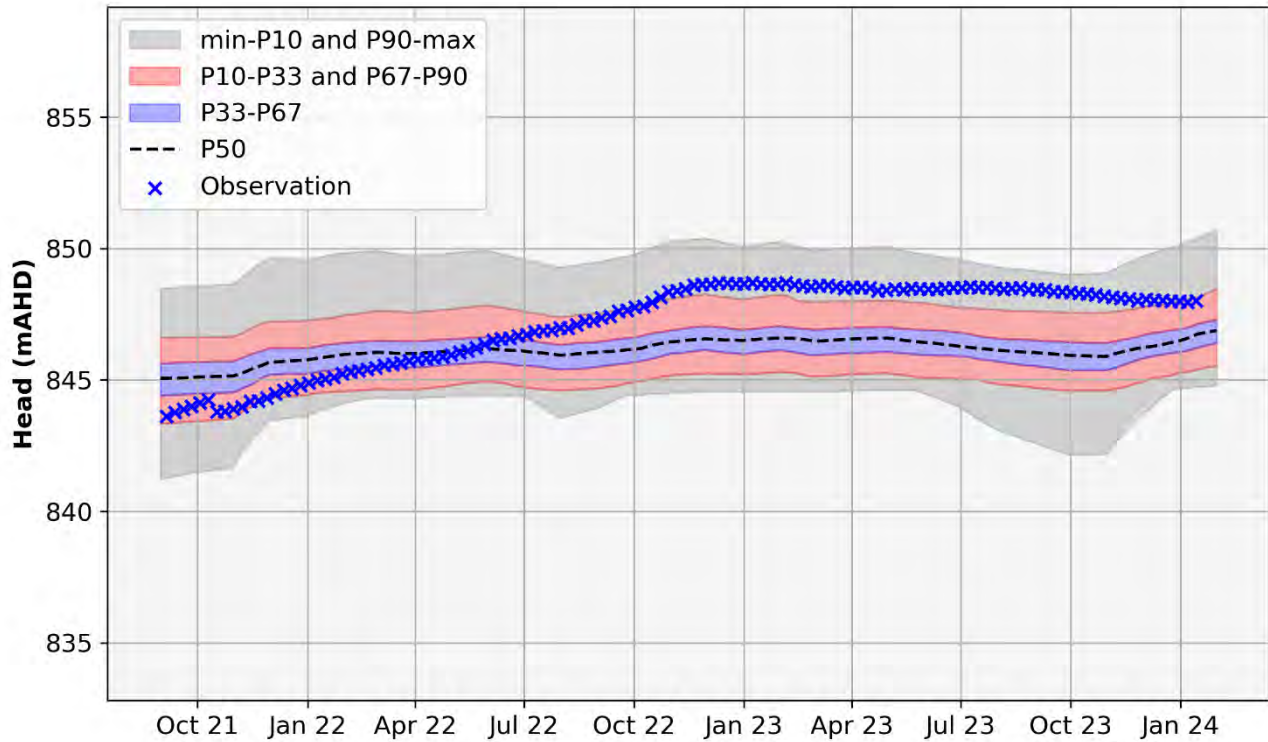


Model prediction period (Project scenario) – Timeseries budgets

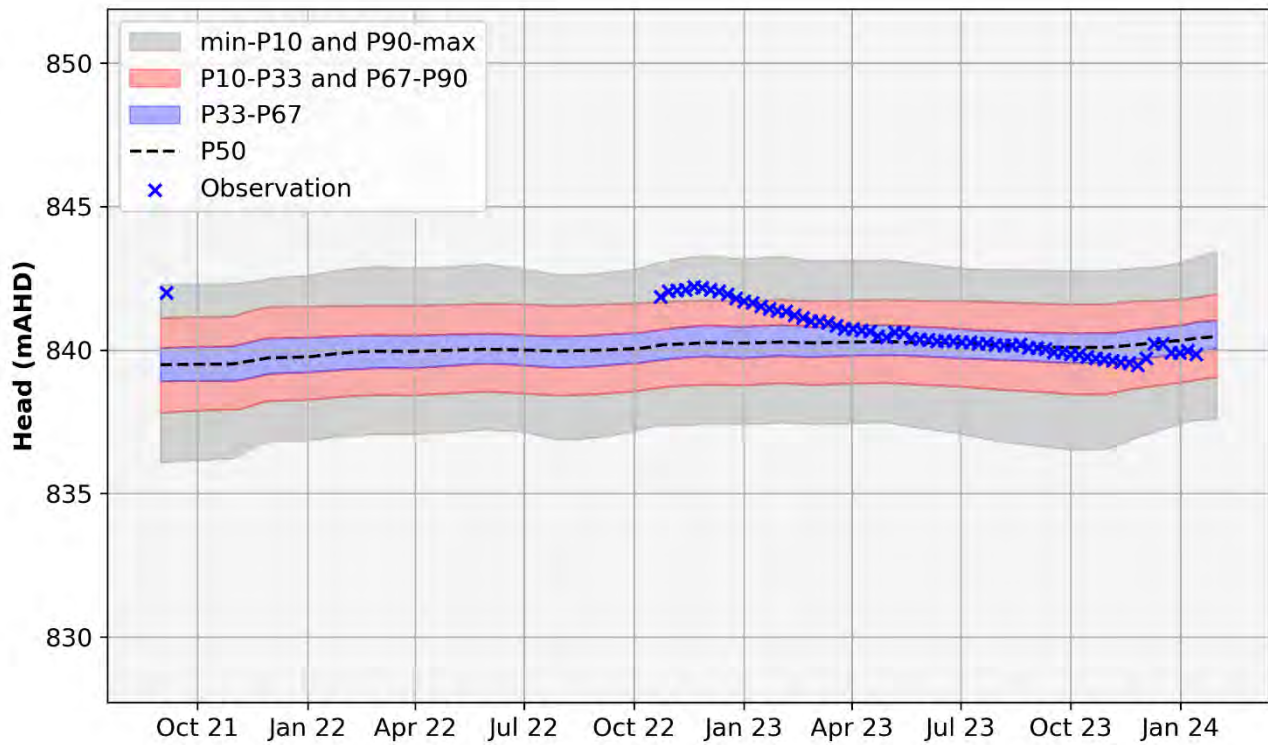


Appendix D Hydrograph uncertainty

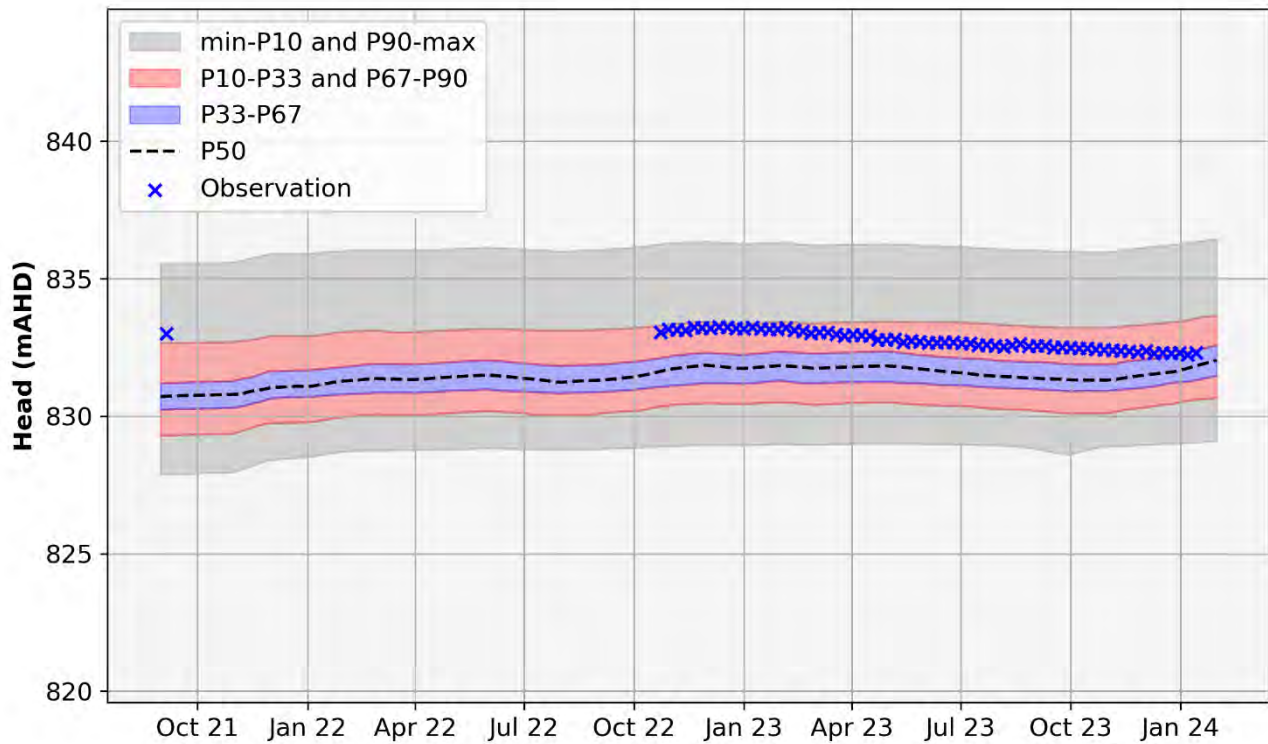
Dam Bore – Hydrograph uncertainty



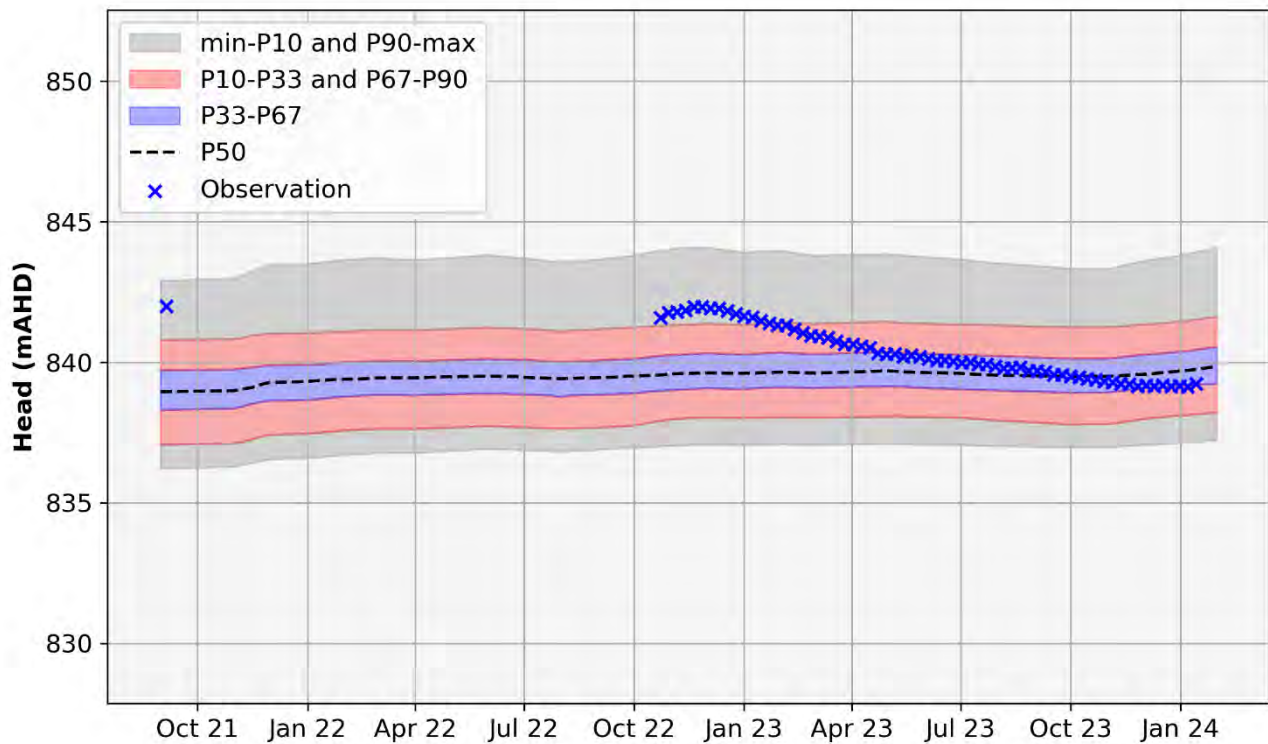
MB01 – Hydrograph uncertainty



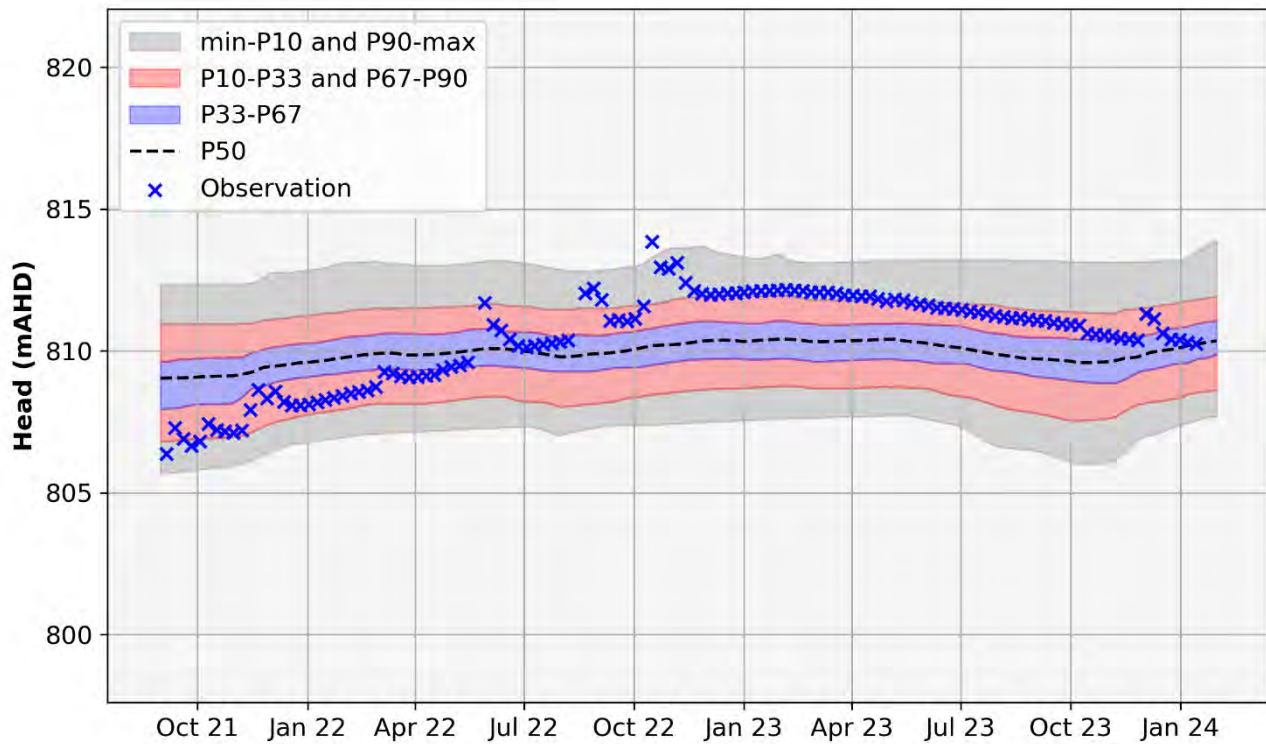
MB02 – Hydrograph uncertainty



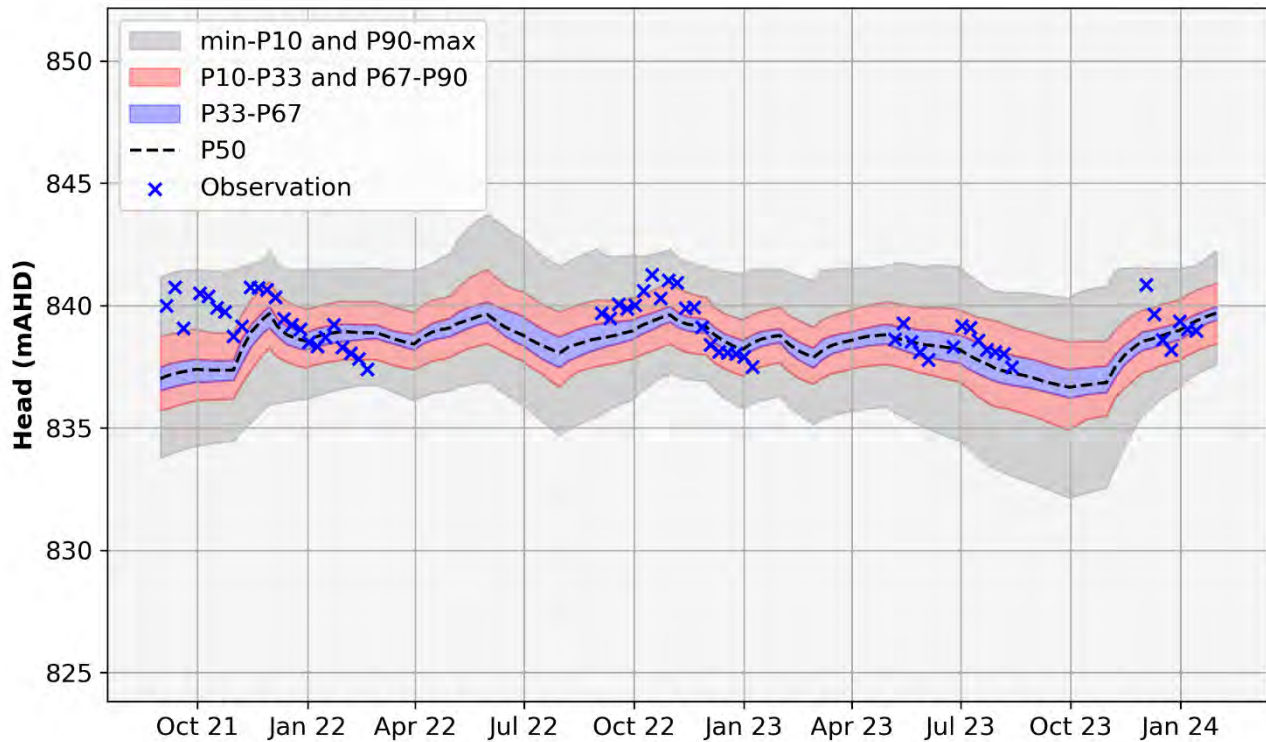
MB05 – Hydrograph uncertainty



MRDDH08 – Hydrograph uncertainty



MRPDH15 – Hydrograph uncertainty



Appendix D Third party review report



Independent peer review of the numerical groundwater modelling for the Monaro Rock Project

Prepared for R. W. Corkery & Co. Pty Ltd



Document control register

Version	Date	Amended by	Revision type
0.1	28 May 2025	Neil Manewell / Charmaine Manewell	First draft
1.0	2 June 2025	Neil Manewell	Final draft

Document details

Last saved	2 June 2025
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Project manager	Neil Manewell
Client	R. W. Corkery & Co. Pty Ltd
Document title	Independent peer review of the numerical groundwater modelling for the Monaro Rock Project
Project number	MON-2024-PEER

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Section 1: Introduction

1.1 Overview

This report presents an independent technical peer review of the Monaro Rock Project (the Project) groundwater impact assessment (GIA) and the associated numerical groundwater modelling. The aim of the review is to ensure technical competency and adherence to regulations.

Monaro Rock Pty Ltd (Monaro Rock) is proposing a hard rock quarry located in Royalla, adjacent to the border separating New South Wales (NSW) and the Australian Capital Territory (ACT). While the Project would be developed on land within NSW, access to the Project is proposed to be via a dedicated access road and intersection with the Monaro Highway within the ACT.

Monaro Rock has engaged R. W. Corkery and Co. Pty Ltd (RWC) to manage the environmental approvals for the Project. Subsequently, RWC has engaged hydrogeologist.com.au to prepare a Groundwater Impact Assessment and associated numerical groundwater model to support the Project. The Project comprises of a hard rock quarry operating over a period of 30-35 years, covering a total extraction area of 21.1 ha with a maximum depth of around 100 m below ground level (mbGL).

Numerical modelling is undertaken in support of:

- GIA for submission to DCCEEW under the EPBC Act – Monaro Rock Quarry.

The objectives of the Monaro Rock Quarry GIA is to:

- predict the extent and magnitude of maximum groundwater depressurisation (drawdown) associated with quarrying activities;
- estimate groundwater inflow rates to the quarry throughout operations;
- forecast extraction flowrates for a proposed production well; and
- simulate post-closure groundwater conditions to assess the long-term behaviour of the final void.

1.2 Documentation

Familiarisation of the project was undertaken by review of the following reports:

- hydrogeologist.com.au, Monaro Rock Project – Groundwater Conceptualisation, 18 March 2024.
- hydrogeologist.com.au, Monaro Rock Quarry Numerical Groundwater Model (presentation).
- hydrogeologist.com.au, Report on Monaro Rock Quarry Groundwater Impact Assessment, Project Number: 4110, 3 April 2025.
- hydrogeologist.com.au, Report on Monaro Rock Quarry Numerical Groundwater Modelling Report, Project Number: 4110, 2 April 2025.

The review is based on the following report:

- hydrogeologist.com.au, Report on Monaro Rock Quarry Groundwater Impact Assessment, Project Number: 4110, 29 May 2025.

Manewell Groundwater attended a progressive peer review meeting including the presentation of the initial model approach, calibration results, predictive model setup and uncertainty analysis.

Section 2: Numerical modelling review

2.1 Methodology

This review is undertaken in accordance with the principles and guidelines outlined in the Australian Groundwater Modelling Guidelines (Barnett et al, 2012). The technical review incorporates the latest guidance on best practices for uncertainty analysis methods as presented in Uncertainty analysis—Guidance for groundwater modelling within a risk management framework (Middlemis and Peeters, 2023). The technical review is also based on a combination of professional expertise and modelling methodology, together with the model appraisal checklist provided in the Australian Groundwater Modelling guidelines.

The review consults the following federal regulatory guidelines to assess the sufficiency of the GIA and confirm compliance:

- NSW State Environmental Planning Policy (Resources and Energy) 2021;
- NSW Environmental Planning and Assessment Act 1979;
- NSW Environmental Planning and Assessment Regulation 2000;
- NSW Water Management Act 2000;
- NSW Aquifer Interference Policy (State of New South Wales, 2012);
- Groundwater assessment toolbox for major projects in NSW (DPE – Water, 2022);
- Information Guidelines Explanatory Note Assessing groundwater-dependent ecosystems (IESC 2019);
- Information guidelines for proponents preparing coal seam gas and large coal mining development proposals, issued by the Independent Expert Scientific Committee of the Commonwealth of Australia (Peeters & Middlemis, 2023); and

2.2 Model commentary

2.2.1 Model conceptualisation

Conceptualisation is presented in the main Groundwater Impact Assessment (GIA) report (hydrogeologist.com.au, 2025). Sufficient rigor has been applied to the development of this conceptual site model (CSM) which represents a relatively simple hydrogeological system consisting of four major units; weathered profile, Deakin Volcanics, Royalla Fault, and Colinton Volcanics.

The weathered profile is represented simplistically as a uniform 40 m deep layer (based on the maximum depth from exploration drilling) and is often unsaturated in higher elevated areas of the Project. The fresh units indicate deeper groundwater levels with low recharge rates. The Deakin Formation is relatively impermeable, with secondary flow controlled by fractures, faults and weathering horizons. There is evidence faults act as barriers, evident in compartmentalised heads across mapped faults, while other faults may act as conduits. The Royalla Fault is the largest structural feature within the project area and likely allow to moderate aquitard according to site investigations.

There is expected to be little to no discharge to watercourse or evapotranspiration due to the deep watertable. There is uncertainty in the depth of tap roots that may extend to the watertable which has been incorporated into the conceptual and numerical model. The absence of Terrestrial groundwater dependant ecosystems (GDEs) in national and regional datasets validates this conceptualisation. The conceptual model is adequately presented and discussed in the report.

2.2.2 Model code / extent and mesh design

The model utilises industry standard MODFLOW-6 using a quadtree model grid. The extent is sufficiently large to overcome boundary condition effects on the reliability of model predictions. The grid is refined appropriately around key features, including the Royalla fault, the proposed quarry, creeks, and bores to reduce structural error. The area of refined model cells is more than adequate to reduce structural error associated with steep hydraulic gradients around the quarry. This refinement also provides adequate representation of inferred heterogeneity around the Project.

2.2.3 Model layers

A total of 2 layers are used to represent key hydrostratigraphic units. Layer 1 represents a conservative representation of the weathered profile, set to a uniform thickness of 40m. Layer 2 represents the basement rock. The base of layer 2 represents a smoothed reflection offset from the model surface, with thicknesses as high as 412m. The segregation of the units is appropriate given the expected hydraulic properties of the shallow strata and the general dry nature of the units. Detailed layering within the basement units was attempted but proved unnecessary.

2.2.4 Timing

Steady state represents pre-quarrying (2021) conditions, progressing to a transient historic monthly stress periods from 2021 to 2024. Annual stress periods commence Jan 2024 to Dec 2053 to represent the progression of the drain cells as the quarry declines and extends.

Post quarrying is using a single steady state stress period – a common and acceptable approach, given the simplicity applied to climate during recovery.

2.2.5 Boundary conditions and stresses

River cells are used to represent regional groundwater flow out of the model at the model boundaries. There are no flow cells along northern boundary as regional throughflow is assumed negligible. The no flow cells are far enough from the quarry areas to ensure the reliability of the predictions is not compromised.

Since groundwater levels do not reach the creek beds, it is reasonable to forgo explicitly simulating creek drainage with the commonly applied River package with zero stage heights. The EVT package is set up as a surrogate for surface drainage over most of the model. Potential ET is applied to 2 m depths over most of the model and is activated in lower lying areas at the extents of the project area (evident in the simulated depth to water map). It is unknown if tap roots with a deeper rooting depth exist and are sourcing deeper groundwater. Water budgets indicate a reasonable rate of outflow throughout the simulation. The interaction areas between the saturated groundwater phase and the tap roots are typically outside the potential drawdown impact area (as shown in Figure 41).

Diffuse recharge is simplistically represented using a spatially varying coefficient of monthly/annual average rainfall. Daily rainfall and potential evaporation was simulated using SILO point data. Arguably, this approach has the potential to provide perennial recharge and subdued recharge events, as rainfall is not perfectly correlated to recharge. In this instance however, the approach is acceptable because recharge rates are relatively low, resulting in subdued hydrograph responses that approximately match observation data.

2.2.6 Quarrying

The progression of the quarry is simulated using nominally high conductance rates with the base of the drain cells set to the base of the quarry. Drains do not advance at yearly rates; they are simply set to the base of the provided stage snapshots (year 1 to 5, 6 to 10, 11 to 15, and 16 to 20). Acceptably, this skews predictions on the conservative side, as the drain cells represents dewatering over a larger, deeper area for longer than is realistically proposed. The volumes of groundwater entering the drains are reasonable.

2.2.7 Water usage

Minor pumping from the proposed production bore adjacent to the Northern Dam is simulated using the WEL package with the AUTOFLOWREDUCE option for the predictive phase. The model indicates long term abstraction rates of ~65 m³/day is sustainable for the base realisation. The predictive ensemble indicates the target rate of 100 m³/day is achievable for approximately 1/3 of the model realisations, while minimum sustainable yield is as low as ~20 m³/day. The results appear reasonable.

2.2.8 History matching

The historical model was history-matched using industry standard data assimilation software PESTPP-IES (White, 2018). A sufficiently large ensemble of 500 realisations was used – current guidance is to generate an ensemble of equal size to the number of singular values present in the parameter/observation dataset. A detailed description of the calibration process is provided. Groundwater levels from moderate dataset were used to history match. The

spatial coverage of these bores suitably covers the Monaro Rock Quarry impact area. The regional groundwater monitoring bores not used in the calibration serve of validation targets. The model over-predicts heads in these areas, although their measurements are subject to significant measurement noise. A number of model realisations were rejected from the posterior ensemble; a reasonable approach.

Observation data, approach, and weighting schemes have been considered and adequately described.

Horizontal, vertical hydraulic conductivity, specific yield, specific storage, recharge, evaporation depth, rate and river conductance parameters were refined. Pilot points in all layers were added appropriately to represent heterogeneity. It is assumed spatial covariance information generated using PPCOV was added to PESTPP-IES to promote spatial correlation during the optimisation process (i.e., pilot points close to each other within the 'A range' of a semi-variogram will maintain similarity). Covariance parameters are adequately discussed in the report.

The performance metrics for the best calibrated model and the posterior ensemble is presented in section 3.6 as scatter plots and hydrographs. The SRMS from the best calibrated realisation indicate groundwater heads are adequately matched across the model domain. The results from the ensemble are presented and discussed with rigor. The ensemble generally spans the range of measured groundwater levels with expected and appropriate precision.

Simulated water level and depth to water level maps reveal levels and unsaturated extents that are consistent with model conceptualisation. Calibration hydrographs indicate the ensemble is generally well behaved.

Whole of model flows appear reasonable and consistent across steady state and transient phases. Realistic volumes of groundwater recharges the system via diffuse rainfall.

Calibrated hydraulic parameters are presented and appear reasonable and consistent with site measurements and other regional studies. Heterogeneity is broadly correlated due to the pilot point spacing and high spatial correlation distances. There are potential zones of high hydraulic conductivity that may be more connected than they are in reality, potentially leading to conservative skewing of the drawdown predictions. However, these concerns are mitigated by the presence of 164 versions with different degrees of connectivity. The recharge, evapotranspiration, and river conductance parameters for the best-calibrated parameter set appear reasonable.

2.2.9 Predictions

Predictions were made using two predictive scenario models based on the standard Cumulative and Null approach for two average climate conditions. The mass balances align with the historic phases. Climate change was not assessed.

Predicted drawdowns in the weathered formation and the bedrock are as expected. Drawdowns are presented adequately as composite maximum drawdown arrays. Long term drawdown is less than during the predictive phases and extends slightly outside the project area. Drawdown predictions for the best calibrated realisation and from the ensemble appear reasonable. Worst case drawdown extends approximately 5 km from the pit.

Absolute inflows to the Monaro Rock workings appear reasonable. Inflow peaks to a maximum of $\sim 230 \text{ m}^3/\text{day}$ ($\sim 50 \text{ m}^3/\text{day}$ for the base realisation). Well abstraction is conservatively represented in the model by assuming continuous operation, resulting in aquifer drawdown that remains within a small fraction of the available saturated thickness.

2.2.10 Calibration sensitivity analysis

PESTPP-IES does not record parameter sensitivities during the optimisation process, however, the presentation of the relative reduction of uncertainty constitutes an acceptable and informative alternative. These values are similar to parameter identifiability, except they are advantageous because they honour the prior parameter distribution.

The results indicate that the posterior ensemble maintains integrity, even at high optimization counts (10^{th} iteration). Relative reductions show most parameter uncertainty is reduced by less than 59%. This is understandable given the absence of significant stresses on groundwater levels in the measurement dataset.

2.2.11 Post quarrying recovery modelling

A final void remains once quarrying finishes in 2053. The RIV package is used to represent the final quarry lake. This is different to the industry standard "high K lake" approach, however, given the simplicity of the system and the use of data from surface water balance modelling, this is appropriate. Enhanced recharge is not applied to any spoil piles around the void.

2.2.12 Predictive uncertainty analysis

A Type 3 uncertainty analysis was undertaken to assess future impacts. As already discussed, the posterior ensemble exhibits pleasing calibration statistics and parameter distributions. Impacts from the 164 realisation ensemble are more conservative than the base realisation, i.e. they produce more drawdown and higher inflows than the base realisation. However, given the IES ensemble leans towards conservatism, their results are fit for purpose.

Confidence intervals were not tested to validate whether 164 realisations was enough to capture the likelihood of impacts. However, when considering the 95th confidence interval, generally most information of the pertinent predictions are gained using less than 100 realisations and therefore it is likely the ensemble size is adequate.

Inflow predictions into the Monaro Rock Quarry are presented adequately. Maximum inflows appear reasonable and likely conservative due to the wide posterior parameter ranges assessed.

Exceedance maps, drawdown maps and charts of drawdown during the predictions are presented according to IESC uncertainty modelling guidelines. Results suggests that it is unlikely that incremental drawdowns of 1 m or more will extend >5 km north. Given the conservatism of the impacts and the range of parameters assessed in the uncertainty analysis, combined with the conservative representation of pit lake recovery, this is likely a conservative estimate.

2.3 Model confidence

Table 2-1 presents the key indicators listed in the AGMG (Barnett et al., 2012). Generally, Manewell Groundwater agrees with evaluation presented in the modelling appendix report, with exception of a several indicators, but does not change the overall classification of a class 2 to 3 model.

Table 2-1 Model confidence class indicators

Category	Description	Confidence level
Data	Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain.	2
	No available records of metered groundwater extraction or injection.	1
	Field-testing data to define key parameters.	2
	Rainfall and evaporation data is available.	3
	Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation.	3
	Scaled RMS error or other calibration statistics are acceptable.	3
Calibration	Long-term trends are adequately replicated where these are important.	2
	Seasonal fluctuations not adequately replicated in all parts of the model domain.	2
	Transient calibration is current, i.e. uses recent data.	3
	Observations of the key modelling outcomes dataset are used in calibration.	2
	Predictive model time frame far exceeds that of calibration.	1
Prediction	Temporal discretisation used in the predictive model is different from that used in transient calibration.	2
	Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration.	2
	Validation* suggests relatively poor match to observations when calibration data is extended in time and/or space.	1
	Predictive model time frame far exceeds that of calibration.	1
Key indicator	Mass balance closure error is less than 0.5% of total.	3
	Appropriate computational methods used with appropriate spatial discretisation to model the problem.	3
	The model has been reviewed and deemed fit for purpose by an experienced, independent hydrogeologist with modelling experience.	3
	Temporal discretisation in predictive model is not the same as that used in calibration.	2
	Key calibration statistics are acceptable and meet agreed targets.	3

Category	Description	Confidence level
	Stresses in predictions are more than 5 times higher than those in calibration.	1
		2 to 3

This peer review report applies a new concept for assessing model confidence. The 2023 IESC Explanatory Note for Uncertainty Analysis defines a model is fit for purpose when results are:

- Useable – Relevant to the decision-making process, provide information on the uncertainty in conceptualisations and model simulations that allows decision-makers understand the effects of uncertainty on project objectives and potential bias.
- Reliable – Demonstrate that the range of model outcomes is consistent with system knowledge. Uncertainties affecting decision-critical predictions are not underestimated.
- Feasible - Trade-offs due to budget, time and technical constraints are reasonable and justifiable within the risk context of the project.

Table 2-2 presents this reviewers assessment of the four sources of uncertainty (structural, parameterisation, measurement error, predictions).

Overall, it is this reviewer's opinion that the model is indeed useable, reliable and feasible in accordance with the IESC uncertainty note criteria. Given the conservative assumptions applied to spatial connectivity, particularly in a groundwater system shown to exhibit significant compartmentalisation, and the simulation of abstraction as continuous use, the risk of impact is considered low. Should observed drawdown fall significantly outside the ensemble of simulated predictions, refinement of the model would be warranted to further reduce predictive uncertainty ahead of quarry dewatering and bore abstraction.

Table 2-2 Model confidence assessment

Type	Part	Status	Comment
Structural/ Conceptual	Grid and Model Extent	Fit for purpose	Model extent sufficiently large so that drawdown does not significantly interact with boundaries. MODFLOW-6 quadtree grid with more than sufficient refinement area key features. The model has a quadtree grid that includes detailed cell refinement around site, drainage features, bores.
	Layers	Fit for purpose	Top of model uses LiDAR data where available.
		Fit for purpose, improvements possible	Model layer elevation based on uniform thickness. Depth of weathering is approximate and based on maximum observable depth from extensive geological investigations.
	Conceptualisation – Geological Structure	Fit for purpose, improvements possible	Hydrostratigraphy represented as more of a connected system than the strongly compartmentalised system inferred by some dry bores on site. Additional drilling at early quarrying could inform the heterogeneous priors used in the uncertainty analysis.
	Conceptualisation – GDEs	Fit for purpose	A GDE conceptualisation is provided. Data suggests no GDEs in impact area.
	Conceptualisation – Surface Water Groundwater Interactions	Fit for purpose, improvements possible	Surface water-groundwater interaction considered minimal in the Project area. Detailed discussion in provided in the GIA report
	Conceptualisation – Fault	Fit for purpose, improvements possible	Not specifically replicated as a defined conductive or restrictive zone. To reconceptualise if more data becomes available and if determined it has connection to propagate drawdown to receptors close to its presence.
Parameterisation	Hydraulic Conductivity – Weathered formation	Fit for purpose, improvements possible	Heterogeneity represented using pilot points. Future analysis could involve more pumping tests to reduce parameter uncertainty and validate variogram used to impose spatial connectivity. Reduction in uncertainty of weathered aquifer from dewatering stress significantly reduces uncertainty of impacts.
	Hydraulic Conductivity – Fresh	Fit for purpose, improvements possible	Heterogeneity represented using pilot points. Future analysis could involve more pumping tests to reduce parameter uncertainty and validate variogram used to impose spatial connectivity. Field testing of hydraulic conductivity has been conducted in the region and at site.
	Storage	Fit for purpose, improvements possible	Field hydraulic testing of specific storage and specific yield appears limited (single pumping test). Additional pumping tests would assist.
	Vertical Hydraulic Conductivity	Fit for purpose	Given the hydrogeology and vertical layer resolution this parameter is unlikely to significantly change impact predictions.
	Rivers	Fit for purpose	Drainage lines are highly ephemeral. Flow likely occurs for a few days per year. Conservative representation of baseflow conditions appropriate. It should be noted that the presence of baseflow around the fringes of the impact area should be validated.
	Evapotranspiration	Fit for purpose, improvements possible	A simple 2m rooting depth applied. Future ecological studies could confirm rooting depth along key impact areas and the potential for Terrestrial impacts. Note that no Terrestrial GDEs are mapped in impact area, however, there are aquatic high potential GDEs on site.
	Recharge	Fit for purpose, improvements possible	Recharge is simple, although appropriate for this level of assessment. If future refinement warranted, modellers could consider more sophisticated recharge models, and spatial variability in recharge.

Type	Part	Status	Comment
Measurement Error	Observation Data Quality	Fit for purpose, improvements possible	Bore logs and construction details available for most site bores. Site bores have 3 years water level data available. Measurement noise implied by the accuracy of the measurement devices/bore construction could be incorporated more accurately into inversion exercise. Measurement noise has potential to increase parameter uncertainty (and consequently predictive uncertainty).
	Landholder Bore Data Quality	Fit for purpose	Landholder bore construction subject to more uncertainty. However, given the promotion of connectivity in units that demonstrate compartmentalization additional detail unlikely to significantly lower risk of impact. Impacts on registered landholder bores are influenced by the assumptions of the bore design, target geology and use.
	Temporal spread	Fit for purpose, improvements possible	Timeseries water level data gathered for all units over an adequate monitoring period. Transient, reliable data outside the project area would validate impacts and assist with triggers. Timeseries water level data from the site, but only unreliable measurements regionally.
Scenario Uncertainties Future stresses/conditions	Calibration	Fit for purpose, improvements possible	Steady state/Transient (2022-present) history-matching to groundwater levels undertaken using PESTPP-IES. Improvements could be made to include drawdown/flow data at early onset of stresses.
	Predictive	Fit for purpose	Predictive model simulated proposed quarrying at Monaro using annual stress periods and average climate conditions. Model captures proposed quarrying at Monaro and abstraction from well near the Northern Dam.
			No other neighbouring quarry/mines were identified within the model domain. Landholder pumping considered minor and should not significantly cumulatively change impacts.
	Sensitivity and uncertainty	Fit for purpose, improvements possible	Predictive uncertainty analysis undertaken on the 2 scenarios. Recharge and EVT parameters were varied within the ensemble that span the range of potential climate change scenarios. Uncertainty analysis covered the entire model simulation period (Pre-quarrying, during quarrying and post-quarrying). Uncertainty analysis has been conducted by stochastic modelling using an adapted Monte Carlo method with modern software packages.
			Predictive uncertainty undertaken on post quarrying recovery scenarios. The uncertainty analysis quantified the variability in predictions with changes in maximum predicted drawdowns, quarry inflows, and sustainable yield during quarrying and in post quarrying.

2.4 GMDSI decision-support modelling guiding

In a similar vein to the IESC uncertainty, the Groundwater Modelling Decision Support Initiative released ‘Monograph: Decision-Support Modelling Viewed Through the Lens of Model Complexity’ (Doherty & Moore, 2021). Manewell Groundwater has distilled the key guiding principles into checklist items to ensure the model is not overly complex, and model is a useful tool that appropriately assesses the likelihood of the “bad thing” from occurring. Table 2-3 presents pertinent guiding principles as checklist items.

Table 2-3 Decision-support guiding principles checklist

Category	Guiding Principle Item	Yes/No	Comment
Client/Regulator Concerns	Have the impacts that the client/regulator fears been clearly identified before starting the modelling process?	Yes	Second iteration of this model has been presented to peer reviewers.
Model Purpose and Uncertainty	Is the model specifically designed to make a particular prediction and quantify the uncertainty associated with that prediction?	Yes	Model designed to predict drawdown, inflow and abstraction sustainability.
Simplicity Over Complexity	Has the model avoided unnecessary complexity, opting for simpler, effective approximations?	Yes	Model is 2 layers and highly parameterised.
Conceptual Model Collaboration	Is the conceptual model developed in collaboration with relevant experts, addressing where key information resides?	Yes	Model developed with team of hydrogeologists and groundwater modellers.
Exploration of Hydrogeological Representations	Are multiple representations of specific hydrogeological details explored, acknowledging system unknowns?	Yes	Pilot points used to represent heterogeneity in all model layers.
Historical Stress Response Simulation	Can the model simulate the system's response to historical stresses effectively?	Yes	Ensemble of models replicates absolute heads and general response to climate appropriately.
Numerical Efficiency and Robustness	Does the model run reasonably fast and maintain numerical robustness for effective hypothesis testing?	Yes	Model runs at an appropriate speed to meet the model objectives.
Model-Partner Software Integration	Is there a non-intrusive interface with model-partner software, capable of running models in parallel?	Yes	History-matching and uncertainty analysis undertaken using PESTPP suite.
History Matching Approaches	Are appropriate numerical strategies, such as Tikhonov regularization and singular value decomposition, used in history matching?	Yes	Pilot point spatial covariance used as regularisation in PESTPP-IES.
Data-Driven Prediction Design	Is the primary model designed for calibration against historical field measurements?	Yes/No	Monthly stress periods used to simulate climate, but annual for predictive phase.
Parameterization in Decision-Support Modelling	Are model parameters plentiful, adjustable, and capable of stochastic representation?	Yes	Groundwater system has an appropriate number of pilot points.
Accommodation of Uncertainty in Decision-Modelling	Does decision-modelling accommodate uncertainty, exploring the pessimistic end of the uncertainty bell curve?	Yes	The posterior parameter ranges presents as wide. Given layer wide parameters in the basement are perturbed, it is assumed the predictions are at the pessimistic end of the bell curve.
Reduction of Decision-Critical Uncertainty	Is decision support modelling tuned to reduce the uncertainty of one or a few critical predictions?	Yes	Drawdown, inflow, sustainable yield predicted.
Avoiding Type 2 Statistical Error	Does the model avoid overstating the widths of decision-critical predictive uncertainty analysis?	Yes/No	Range of posterior parameter distribution enforced by expert knowledge. Some simplifications are

Category	Guiding Principle Item	Yes/No	Comment
			potentially overstating long-term drawdown impacts.
Predictive Error Accounting	Is predictive error introduced by numerical methodologies accounted for and communicated effectively?	Yes	Posterior parameter distributions presented. Posterior projection process undertaken to industry standards and well discussed. Appropriate range of predictions presented as likelihood bands.
System Component Representation	Are essential system components that impact predictions represented in the numerical model?	Yes	Key processes relevant to dewatering and the saturated groundwater phase represented.
Parameter Importance and Hosting of Information	Is the importance of parameters and their role in hosting information acknowledged?	Yes	Pilot points used to expose heterogeneity in response to groundwater level measurements.
Hypothesis Testing for Future Stresses	Is the hypothesis that future stresses will result in negative outcomes only rejected when demonstrably incompatible with known system measurements or behaviours?	Yes/No	Predictive uncertainty used historic groundwater level information to reject unrepresentative realisation. Hypothesis testing with respect to landholder drawdown not undertaken, although not usually undertaken at this phase of the study.
Prediction Spectrum Awareness	Is there an understanding of the differences between data-driven, expert-knowledge-driven, and mixed predictions?	Yes	Not explicitly addressed, although mixed prediction approach used is appropriate.

Overall, it is this reviewer's opinion that the model serves as a useful decision support tool. Generally, the model has the ability to harvest information and produce reliable estimations of Project risk.

2.5 Australian Modelling Guidelines checklists

Table 2-4 is the NWC Compliance Checklist from the Australian Groundwater Modelling Guidelines (Barnett, 2012). The results conclude that the groundwater model is "fit for purpose", where the primary purpose is to develop upon an existing model that is reasonably well calibrated to historic groundwater levels. The model is a suitable tool for decision support where the purpose is to provide predictions on potential impacts due to Monaro Rock Quarry.

Table 2-4 Compliance checklist

No.	Review Questions	Yes/No	Comment
1	Are the model objectives and model confidence level classification clearly stated?	Yes	Model objectives clearly stated, and model level classification discussed in detail.
2	Are the objectives satisfied?	Yes	The objectives of the study of assessment of effects from the quarry have been satisfied through predictions of dewatering effects on receptors. Impacts on groundwater receptors are sufficiently calculated and discussed. The effects of the voids on the post quarry groundwater system are presented and discussed.
3	Is the conceptual model consistent with objectives and confidence level classification?	Yes	The conceptual model is consistent to the geological structure and quarrying included stresses. The interaction between surface and groundwater stresses is adequately simulated given the conceptualisation, field observations, and scale of the model. The model cell count is low and proves to be useable, reliable, and feasible. The numerical model is history matched to best practice and uncertainty analysis assessed to industry standards.
4	Is the conceptual model based on all available data, present clearly and reviewed by and appropriate reviewer?	Yes	Although there a scarcity of data to inform the conceptual site model, it was developed using all available data and the key processes are adequately discussed in the GIA report.
5	Does the model design conform to best practice?	Yes	An adequate conceptual model has been generated and is reflected in the numerical model. The simplistic surface/groundwater interactions are aligned to the conceptual model. Pilot points are used to represent heterogeneity in the weathered and fresh units. Heterogeneity is represented based on a reasonable geostatistical model. Given the range of parameters tested, the analysis can be considered conservative.
6	Is the model calibration satisfactory?	Yes	The model correctly replicates absolute groundwater levels and changes to groundwater levels around the areas of importance proximal to the proposed quarry. Large mismatches remain distal to the project - however the uncertainty of those single point measurements is high. Recharge trends are generally well matched within the ensemble of models. Remaining mismatches are exposed and discussed.
7	Are the calibrated parameter values and estimated fluxes plausible?	Yes	History-matched parameter values are within plausible bounds and align to site information (limited and reliant primarily on slug testing and a pumping test). Recharge rates and hydraulic parameters of the aquifer units are consistent with studies undertaken throughout the region. Fluxes into the quarry workings appear plausible. Fluxes to surface water drains are aligned to site information.
8	Do the model predictions conform to best practice?	Yes	Model predictions include time variant pit seepage inflows and drawdown. Composite maximum drawdown maps are presented to show transient maxima. Potential Impacts on baseflow are discussed (unlikely due to depth of groundwater and observations in impacted area). Predictive hydrographs are presented. Predictions are calculated using the difference between null and cumulative scenarios at a time-step level.
9	Is the uncertainty associated with the predictions reported?	Yes	A comprehensive posterior Monte Carlo predictive parametric uncertainty analysis using 424 realisations spanning a wide range of parameters. The ensemble was further calibration constrained according to an SRMS threshold, leaving 164 model realisations used in the predictive analysis. Structural uncertainty is discussed and attempts made to reduce error. Variability in recharge across the uncertainty analysis arguably spans reduction in recharge implied by climate change. (Post quarrying uncertainty analysis not undertaken).
10	Is the model fit for purpose?	Yes	The model is built and assessed to industry standards. Given site information around the project suggesting surface-groundwater interactions are minimal, and predictive uncertainty presented is likely conservative, the model is considered fit for purpose.

Table 2-5 Review checklist (2012 National Guidelines)

No.	Review Questions	Yes/No	Comment
1	Planning		
1.1	Are the project objectives stated?	Yes	GIA and model prepared in accordance with SSD, DEO, IESC, AGMG, AIP, Water Act, Sharing Plans
1.2	Are the model objectives stated?	Yes	GIA and model prepared in accordance with SSD, DEO, IESC, AGMG, AIP, Water Act, Sharing Plans
1.3	Is it clear how the model will contribute to meeting the project objectives?	Yes	The report states that the modelling results are to assess the likely impacts of the proposed quarrying activity.
1.4	Is a groundwater model the best option to address the project and model objectives?	Yes	Measuring the effects of the propagation of drawdowns on piezometric surface through time, and possible flow changes in this case is best tested through a numerical groundwater model.
1.5	Is the target model confidence-level classification stated and justified?	Yes	Contemporary model level classification determined, discussed and presented.
1.6	Are the planned limitations and exclusions of the model stated?	Yes/No	Detailed coverage of qualitative uncertainty included in the appendix report. Limitations and exclusions not specifically reported.
2	Conceptualisation		
2.1	Has the literature review been completed, including examination of prior investigations?	Yes	Previous studies are scarce, and relevant information from publicly available studies, and historic site investigations used to develop conceptual model.
2.2	Is the aquifer system adequately described?	Yes	The hydrostratigraphic units have been described across 2 model layers. The hydrogeology and vertical gradients have been adequately described.
2.2.1	Hydrostratigraphy including aquifer type (porous, fractured rock ...)	Yes	The hydrostratigraphy describes the main components of the system related to the desired project objectives - namely weathered profile, Deakin Volcanics, Royalla Fault, and Colinton Volcanics (fractured and basement system)
2.2.2	Lateral extent, boundaries and significant internal features such as faults and regional folds.	Yes	The extent of the groundwater model is fit for purpose and well thought out. Rivers and creeks are represented as baseflow conditions only, as per site information.
2.2.3	Aquifer geometry including layer elevations and thicknesses.	Yes	Appendix report presents layer elevations of the weathered profile. Elevation presented only, however, thickness is adequately described in text.
2.2.4	Confined or unconfined flow and the variation of these conditions in space and time?	Yes	Brief discussion on nature of unconfined/confined conditions in modelling appendix report.
2.3	Have data on groundwater stresses been collected and analysed?	Yes	Pumping test undertaken at Dam bore.
2.3.1	Recharge from rainfall, irrigation, floods, lakes.	Yes	Recharge responses evident in hydrographs analysed and discussed. Recharge simply a percentage of rainfall, which is slightly simplistic, yet adequate for the purposes of this study. A dam location to the east of the workings is represented in the model. There are no other major offsite water bodies that would significantly change groundwater predictions (best to be conservative), and the effect of flooding events do not appear in the groundwater level records.
2.3.2	River or lake stage heights.	Yes	River stage heights set to river base to represent ephemeral creeks. Positive river stages used to represent adjacent dam.
2.3.3	Groundwater usage (pumping, returns etc.)	Yes	Well package used to simulate groundwater abstraction for future quarry water requirements.
2.3.4	Evapotranspiration.	Yes	EVT package used to simulate groundwater take from tree roots. In some areas this is used as a surrogate for surface drainage.

No.	Review Questions	Yes/No	Comment
2.3.5	Other?	No	
2.4	Have groundwater level observations been collected and analysed?	Yes	3+ years of groundwater level measurements recorded across the site.
2.4.1	Selection of representative bore hydrographs.	Yes	Key hydrographs presented and discussed. All other hydrographs presented in an Appendix.
2.4.2	Comparison of hydrographs.	Yes	Observed and simulated groundwater levels presented on the same chart.
2.4.3	Effect of stresses on hydrographs.	Yes	Effect of potential leakage of water through the annulus discussed. Rise in levels due to diffuse recharge presented and discussed.
2.4.4	Watertable maps/piezometric surfaces?	Yes	Historic and simulated contoured heads presented. Simulated depth to watertable presented.
2.4.5	If relevant, are density and barometric effects taken in account in the interpretation of groundwater head and flow data?	N/A	Not relevant to the scale of this study
2.5	Have flow observations been collected and analysed?	Yes/No	Site observations of baseflow discussed, although no flow gauge information on minor drainage line in the anticipated affected area. Pumping test undertaken. No available long-term stress flow information.
2.5.1	Baseflow in rivers.	Yes	The absence of measured baseflow used as a validation target.
2.5.2	Discharge in springs.	N/A	GIA report suggests no springs were mapped within the vicinity of the Project area.
2.5.3	Location of diffuse discharge areas?	N/A	Out of the scope of this study.
2.6	Is the measurement error or data uncertainty reported?	No	Briefly discussed, although measurement error assumed in the inversion exercise not presented.
2.6.1	Measurement error for directly measured quantities (e.g. piezometric level, concentration, flows).	No	Briefly discussed, although measurement error assumed in the inversion exercise not presented.
2.6.2	Spatial variability/heterogeneity of parameters.	Yes	Discussion of local heterogeneity discussed in modelling appendix report. Heterogeneity represented in hydraulic properties via pilot points. Geostatistical parameters used in the covariance matrix presented as a table.
2.6.3	Interpolation algorithm(s) and uncertainty of gridded data?	No/Yes	Uncertainty of anything other than heterogeneity not discussed. Kriging interpolation used to interpolate heterogeneity discussed and nugget presented in table (0).
2.7	Have consistent data units and geometric datum been used?	Yes	m, mAHD, m ³ /day used appropriately.
2.8	Is there a clear description of the conceptual model?	Yes	
2.8.1	Is there a graphical representation of the conceptual model?	Yes	Presented in the GIA report as a hydrostratigraphical cross section with inferred groundwater levels and key features (albeit quite simply).
2.8.2	Is the conceptual model based on all available, relevant data?	Yes	CSM based on geological information from drill-logs and geological models. Key processes are discussed (although not graphically presented). Post quarrying conditions are discussed.
2.9	Is the conceptual model consistent with the model objectives and target model confidence level classification?	Yes	The key system components have been integrated to target the project objectives, the objectives being effects of quarry development on groundwater levels, groundwater users, and river and stream baseflows (if at all). Effects on potential GDEs can be inferred from the section and presented maps.

No.	Review Questions	Yes/No	Comment
2.9.1	Are the relevant processes identified?	Yes	The main components of the hydrology, hydraulics of the system have been included and the transient stresses from quarry development. Key interactions are identified.
2.9.2	Is justification provided for omission or simplification of processes?	Yes	The report qualitative uncertainty section discusses simplification and omission of processes.
2.10	Have alternative conceptual models been investigated?	No	
3	Design and construction		
3.1	Is the design consistent with the conceptual model?	Yes	Numerical model replicates the CSM.
3.2	Is the choice of numerical method and software appropriate (Table 4-2)?	Yes	Model is simulated using MODFLOW-6 using the equivalent of upstream weighting function - details on the saturation functions not detailed in the report.
3.2.1	Are the numerical and discretisation methods appropriate?	Yes	The cell refinement is 25 to 100m around surface drainage, Royalla Fault, quarry areas, and monitoring bores, extending to 800m regionally. The total of number of cells (35,732) provides adequate spatial resolution and relatively fast model run times.
3.2.2	Is the software reputable?	Yes	MODFLOW-6 is an accepted industry standard for this type of application.
3.2.3	Is the software included in the archive or are references to the software provided?	Yes	MODFLOW-6 is referenced.
3.3	Are the spatial domain and discretisation appropriate?	Yes	Spatial domain is well thought out. The minimum cell size of 25m separates stresses, captures local heterogeneity. The resolution of drainage lines is adequate to capture potential baseflow and underlying EVT processes.
3.3.1	1D/2D/3D.	Yes	3D
3.3.2	Lateral extent.	Yes	These are well thought out and defined in the model. The lateral boundaries are located far enough from areas stressed during simulation and prediction.
3.3.3	Layer geometry?	Yes	The model uses two major model layers separating the weathered formation and the fresh units, this is thought appropriate for this level of study and the hydrogeology.
3.3.4	Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	Yes	The model could be thought of as finely discretised in the XY direction. The model is simple in the Z direction, however this doesn't diminish its ability to predict impacts.
3.3.5	Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	Yes	There are known downward gradients between the weathered and fresh units as represented by the model. There is compartmentalisation in the fresh units, however, as a conservative measure, by simplifying the connections to a single layer predictions of drawdown are likely overstated.
3.4	Are the temporal domain and discretisation appropriate?	Yes	Monthly stress periods during historic simulation to appropriately attempt to fit responses to recharge. Yearly stress periods appropriate as climate responses not significant, and baseflow impacts not expected.
3.4.1	Steady state or transient.	Yes	Steady state and transient calibration undertaken, followed by transient predictive analysis.
3.4.2	Stress periods.	Yes	Stress period information well documented. Appropriately simulated using monthly periods during historic phase, then annual for predictions. Steady state stress period for post-closure stage.

No.	Review Questions	Yes/No	Comment
3.4.3	Time steps?	Yes/No	Adaptive time-stepping used. Details of the timesteps not presented.
3.5	Are the boundary conditions plausible and sufficiently unrestrictive?	Yes	Cumulative drawdown extents do not significantly interfere with model extent boundaries. River cells used to represent water storage do not leak unrealistic flows into the groundwater system.
3.5.1	Is the implementation of boundary conditions consistent with the conceptual model?	Yes	RIV cells used to remove groundwater at the boundaries of the model. DRN and WELL cells used to represent quarry dewatering and abstraction. RIV cells used to represent post quarrying pit lake.
3.5.2	Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	Yes	Predictive impacts from the quarry do not interact with no flow boundaries and RIV cells at model extents. River cells representing drains act as baseflow only (with exception of dam, which has appropriate river conductance rates).
3.5.3	Is the calculation of diffuse recharge consistent with model objectives and confidence level?	Yes	Recharge is simply calculated as a percentage of rainfall. Although the fine-scale responses are not perfectly replicated, the longer-term responses are adequately replicated by the model.
3.5.4	Are lateral boundaries time-invariant?	Yes	RIV cells using fixed levels used for the entire simulation.
3.6	Are the initial conditions appropriate?	Yes	Steady state groundwater levels used that override any initial conditions. Pre-quarrying and steady state representative of 2021 conditions that appear representative of average climate conditions.
3.6.1	Are the initial heads based on interpolation or on groundwater modelling?	Yes	Model uses solved steady state at approx. 2021 conditions to commence historic phase. There are no fixed heads in boundaries, so this is appropriate.
3.6.2	Is the effect of initial conditions on key model outcomes assessed?	Yes	Steady state heads reformulated for every parameter combination.
3.6.3	How is the initial concentration of solutes obtained (when relevant)?	N/A	
3.7	Is the numerical solution of the model adequate?	Yes	The numerical model solver settings produces percentage discrepancies of over the guidelines of <0.0%.
3.7.1	Solution method / solver.	No	Not discussed in the report. IMS solver assumed.
3.7.2	Convergence criteria.	No	Not discussed in the report. Convergence criteria for each individual time step.
3.7.3	Numerical precision.	No	No discussion on numerical precision in the report.
4	Calibration and sensitivity		
4.1	Are all available types of observations used for calibration?	No	Only site monitoring bores used to match heads.
4.1.1	Groundwater head data.	Yes	Model history matched to site head measurements.
4.1.2	Flux observations.	No	Baseflow estimations were qualitatively checked against site information proximal to the proposed quarry area.
4.1.3	Other: environmental tracers, gradients, age, temperature, concentrations etc.	No	GIA report discusses chloride concentration, but calibrated recharge rates not related back to this.
4.2	Does the calibration methodology conform to best practice?	Yes	The reporting of the calibration process is well-documented. History matching was achieved using PESTPP-IES. Statistics, hydrographs, water budgets and adequately presented.
4.2.1	Parameterisation.	Yes	Calibrated to groundwater heads and validated to the absence of baseflow while maintaining other model parameters with pre-defined realistic bounds based on site data or literature.

No.	Review Questions	Yes/No	Comment
4.2.2	Objective function.	Yes	Briefly discussed in the observation weighting scheme, the evolution of phi during the calibration process is presented and discussed.
4.2.3	Identifiability of parameters.	Yes	Identifiability results including tables and maps are thoroughly presented and discussed (relative reduction of uncertainty is a better surrogate).
4.2.4	Which methodology is used for model calibration?	Yes	PESTPP-IES using an ensemble smoother approach.
4.3	Is a sensitivity of key model outcomes assessed against?	Yes/No	Not directly assessed in the report, however it is noted that the calibration process revealed the hydraulic parameters and recharge to be the most identifiable (or estimable) parameter.
4.3.1	Parameters.	Yes/No	As above
4.3.2	Boundary conditions.	Yes/No	Recharge, EVT and river conductance identifiability discussed.
4.3.3	Initial conditions.	No	Not discussed in the report.
4.3.4	Stresses.	Yes/No	Recharge, EVT and river conductance identifiability discussed.
4.4	Have the calibration results been adequately reported?	Yes	
4.4.1	Are there graphs showing modelled and observed hydrographs at an appropriate scale?	Yes	Ensemble and base realisation results presented in report and Appendix.
4.4.2	Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	Yes/No	The absence of specific nested observations makes vertical gradients difficult to verify. Heads discussed at length, temporary vertical gradients that form in the weathered formation discussed.
4.4.3	Are calibration statistics reported and illustrated in a reasonable manner?	Yes	Appropriate statistics, scatter, and histograms presented.
4.5	Are multiple methods of plotting calibration results used to highlight goodness or fit robustly? Is the model sufficiently calibrated?	Yes	Scatter and hydrographs presented. The model is sufficiently calibration given the scale of the model.
4.5.1	Spatially.	Yes/No	Piezometric surfaces presented, although spatial residuals are not presented.
4.5.2	Temporally.	Yes	Transient calibration hydrographs presented.
4.6	Are the calibrated parameters plausible?	Yes	Within plausible bounds from available data.
4.7	Are the water volumes and fluxes in the water balance realistic?	Yes	The most likely inflow rates are reasonable and similar to other projects in similar hydrogeological settings.
4.8	Has the model been verified?	Yes/No	The regional groundwater monitoring bores not used in the calibration serve of validation targets. The model over-predicts heads in these areas, although their measurements are subject to significant measurement noise.
5	Prediction		
5.1	Are the model predictions designed in a manner that meets the model objectives?	Yes	Progressive drain cells simulate open cut dewatering. Average climate conditions assumed. Predictions calculated as difference from Null and Approved model scenarios.
5.2	Is predictive uncertainty acknowledged and addressed?	Yes	Predictive uncertainty adequately addressed and acknowledged through demonstration.
5.3	Are the assumed climatic stresses appropriate?	Yes	Fixed annual average stresses during predictive period which are appropriate given the historic response to stress. Future modelling exercises may consider applying quarterly stress periods and associated climate stresses based on historic climate fluctuations.

No.	Review Questions	Yes/No	Comment
5.4	Is a null scenario defined?	Yes	Predictive runs are compared to a null scenario (where no quarrying occurs).
5.5	Are the scenarios defined in accordance with the model objectives and confidence level classification?	Yes	Predictive modelling undertaken throughout the entire quarrying operation and includes a steady state recovery period.
5.5.1	Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence?	Yes	Abstraction is not simulated in the calibrated model. However, uncertainty is acknowledged is explored through predictive uncertainty analysis.
5.5.2	Are well losses accounted for when estimating maximum pumping rates per well?	Yes	Losses are very simply represented via AUTOFLOWREDUCE option in the WEL package.
5.5.3	Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?	Yes	The predictive time period (~30-35 years) is greater than the transient calibration simulation duration (~2.5 years). Uncertainty of system stresses discussed.
5.5.4	Are the assumed stresses and timescale appropriate for the stated objectives?	Yes	As above. The recovery steady state stress period are adequate given the absence of significant impacts on landholders and GDEs at quarry completion.
5.6	Do the prediction results meet the stated objectives?	Yes	The predictive results measure changes in groundwater levels, potential impacts on receptors, abstraction bore sustainability, and potential inflows. This meets the stated study objectives.
5.7	Are the components of the predicted mass balance realistic?	Yes	Inflows and discharge rates going into the model are realistic and adequately reported and presented.
5.7.1	Are the pumping rates assigned in the input files equal to the modelled pumping rates?	No	Sustainable pumping rates are calculated according to the AUTOFLOWREDUCE function and the well cell water balance.
5.7.2	Does predicted seepage to or from a river exceed measured or expected river flow?	Yes	The river boundary volumes are realistic.
5.7.3	Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)?	No	RIV cells representing water storage during predictions do not significantly contribute to the groundwater flow budget.
5.7.4	Is diffuse recharge from rainfall smaller than rainfall?	Yes	Recharge rates range from 2.5 to ~7.5% of rainfall according to the uncertainty analysis histogram (3.5% on average)
5.7.5	Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?	No	
5.8	Has particle tracking been considered as an alternative to solute transport modelling?	No	Potential for pit lake salinity increases and consequential changes to the groundwater system not assessed. The author has concluded any changes to groundwater quality is negligible.
6	Uncertainty		
6.1	Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?	Yes	Posterior Monte Carlo (via PESTPP-IES) predictive analysis undertaken and presented.
6.2	Is the model with minimum prediction-error variance chosen for each prediction?	Yes	Ensemble represents the posterior distribution of model parameters that have been statistically minimised through the inversion process.
6.3	Are the sources of uncertainty discussed?	Yes	Discussed in section 7.1 and 7.2
6.3.1	Measurement of uncertainty of observations and parameters.	No	Provided measurement uncertainty assumed equal to the reciprocal of observation weights.
6.3.2	Structural or model uncertainty.	Yes	Discussed in section 7.1 and 7.2

No.	Review Questions	Yes/No	Comment
6.4	Is the approach to estimation of uncertainty described and appropriate?	Yes	Parametric uncertainty explored using relatively wide, spatially variable, hydraulic perturbations. Combination of parameters appropriately explored. Ensemble of models assessed remain calibrated. Uncertainty applied to predictive phase only. The uncertainty of the post quarrying predictions were not undertaken, but are inferred from the uncertainty of the predictive phase. Future modelling exercise could include uncertainty of the post-quarrying phase, including uncertainty in the equilibrated quarry lake.
6.5	Are there useful depictions of uncertainty?	Yes	Predictions are presented as estimates of likelihood as per the IESC uncertainty guidelines.
7	Solute transport		
		N/A	Not applicable for this Project.
8	Surface water-groundwater interaction		
8.1	Is the conceptualisation of surface water-groundwater interaction in accordance with the model objectives?	Yes	The conceptual model determined that surface water-groundwater interactions proximal to the Project area were minimal. The model validates this assumption and predictions of baseflow are assessed appropriately for the scale of the model. Future studies could validate the absence of baseflow, although accessibility may prove difficult.
8.2	Is the implementation of surface water-groundwater interaction appropriate?	Yes	Given the absence of significant baseflow in the project area the simplistic representation of surface water-groundwater interaction is appropriate.
8.3	Is the groundwater model coupled with a surface water model?	No	Surface water-groundwater interactions are minimal, so properly coupled modelling is not required.
8.3.1	Is the adopted approach appropriate?	Yes	The simulation of rivers and streams through the application of boundary conditions is appropriate.
8.3.2	Have appropriate time steps and stress periods been adopted?	Yes	Monthly stress periods used to replicate historic phase. Annual for predictive phase. Given baseflow impacts are not deemed significant these stress periods are appropriate for this stage of assessment.
8.3.3	Are the interface fluxes consistent between the groundwater and surface water models?	Yes/No	Monthly/Annual recharge averaged and applied as a factor of rainfall. Similarly, estimations on post quarrying drawdown are calculated in annual average conditions. This approach is appropriate.

Section 3: Report review

The Monaro Rock Quarry Numerical Groundwater Modelling Report is a high-quality, 70-page long document including appendices that contain base model hydrographs, parameter uncertainty and hydrograph uncertainty. The modelling report presents excellent information regarding the IES ensemble, the best calibrated base realisation, and the likelihood of drawdown impacts and flows. The Groundwater Impact Assessment report that the modelling supports is 53 pages and contains background information, the conceptual model, a summary of the model build and predictions, impact considerations, and information on the proposed groundwater monitoring program.

The reports are well-structured and well-written. The figures and maps are of high quality and easy to understand. Modelling objectives are clearly stated and adequately addressed in the reports.

Section 4: Data review

The hydrogeological model for which this model is built upon was derived from programs undertaken in 2022 and 2024. Drilling programs have been used to inform the hydrogeological conceptual model. Falling head, constant head, and pumping testing forms the basis of the hydraulic testing program. The results from these are covered in the GIA report. Given falling head tests provide a snapshot of average hydraulic properties in the area around the test site, and only a single pumping tests was undertaken, literature ranges and regional studies have been used to augment the prior hydraulic parameter distributions assessed under uncertainty. As a result, parameters ranges remain suitably wide. Posterior uncertainty could only be reduced through the acquisition of additional hydraulic testing, such as additional pumping tests or laboratory analysis. If there are concerns over the range of predictions presented, and if observed drawdown significantly differs from the range of the simulated predictions, more hydraulic information is required.

Generally, the quality of groundwater level measurements within the model domain is adequate and captures general climate variability. Long-term trends are approximated at several sites, although data is limited.

Groundwater recharge and surface water flow has been conceptualised adequately, considering the arid environment for which this quarry exists. Groundwater quality is suitably discussed in the groundwater modelling report.

The identification of potential GDEs is thorough and implications considering groundwater impacts is discussed. There are few groundwater users in the model domain. It is concluded that there is no evidence of the presence of springs, swamps, or groundwater fed baseflow to creeks on the subject land or adjacent to it.

The model was history matched to groundwater levels only. The reliability of the predictions would benefit from measured flows upon quarrying and dewatering to reduce non-uniqueness.

Section 5: Conclusion

In this reviewer's opinion, the documented groundwater modelling meets professional industry standards. The report provides valuable analysis and insights into the conceptual and numerical groundwater models. The conclusions from the review and checklists indicate that the model is fit for purpose, which is to produce a calibrated groundwater model and predict groundwater flows and drawdown. The ensemble of predictive models is suitable for use as a decision support tool to predict future impacts due to the Monaro Rock Quarry.

Stated modelling objectives have been met, the model is reasonably well calibrated, and the likelihood of future predictions appear reasonable. Expected drawdown occurs in the weathered formation and basement proximal to the quarry area. In the most likely scenario, it is unlikely that groundwater receptors will be significantly affected by dewatering and the post quarrying void at Monaro Rock Quarry.

The ensemble of models is well-calibrated, with heads and flows (including their absence) consistent with site observations. The uncertainty analysis is robust and likely overestimates the expected impacts at the higher percentiles. Therefore, clients and stakeholders can have confidence that the model is a reliable predictor of future quarrying impacts.

At the onset of quarrying and groundwater abstraction, the model ensemble should be validated against observed drawdown to confirm it remains within the range of simulated predictions. Should significant deviations be observed, the model should be revised and recalibrated to ensure it remains fit for purpose.

Section 6: References

- Barnett et al. (2012). *Australian groundwater modelling guidelines*, Waterlines report. National Water Commission, Canberra.
- Doherty, J. and Moore, C. (2021). *Decision Support Modelling Viewed through the Lens of Model Complexity. A GMDSI Monograph*. National Centre for Groundwater Research and Training, Flinders University, South Australia.
- Peeters, L.J.M. and Middlemis, H. (2023). *Information Guidelines Explanatory Note: Uncertainty analysis for groundwater modelling*. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of Climate Change, Energy, the Environment and Water, Commonwealth of Australia.