APPENDICES

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OVEN MOUNTAIN PUMPED HYDRO ENERGY STORAGE EIS

Groundwater impact assessment

OVEN MOUNTAIN PUMPED HYDRO STORAGE

EMM creating opportunities

Oven Mountain Pumped Hydro Energy Storage Project

Groundwater impact assessment

Prepared for OMPS Pty Ltd

March 2023

Oven Mountain Pumped Hydro Energy Storage Project

Groundwater impact assessment

OMPS Pty Ltd

J210465 OMPS EIS - Groundwater

March 2023

Version	Date	Prepared by	Approved by	Comments
1	10 November 2022	Henry Noakes	Sean Cassidy	
2	6 December 2022	Henry Noakes	Sean Cassidy	
3	1 March 2023	Henry Noakes	Sean Cassidy	
4	22 March 2023	Henry Noakes	Sean Cassidy	

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Executive Summary

ES1 Introduction

OMPS Pty Ltd (OMPS) is proposing to develop the Oven Mountain Pumped Hydro Energy Storage Project (the Project), an off-river pumped hydro energy storage system located approximately half-way between Kempsey and Armidale adjacent to the Macleay River in northern NSW. The Project is located within the New England Renewable Energy Zone (REZ) and the Armidale Regional Local Government Area (LGA), proximate to its border with Kempsey Shire LGA.

At a basic level, the Project will consist of upper and lower water reservoirs, an underground waterway connecting them, and a hydro-electric power station connected to the National Electricity Market (NEM) that is capable of generating or consuming electricity.

The Project has been declared by the NSW Government to be critical State significant infrastructure (CSSI) under the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). Infrastructure projects are declared to be CSSI if, in the opinion of the NSW Minister for Planning, they are essential to the State for economic, environmental, or social reasons. The Project will aid in the transition of the NEM towards cleaner, more reliable and affordable electricity by supporting - new renewable energy projects by providing up to 900 megawatts (MW) of electricity generating and load capacity, and up to twelve hours of dispatchable energy at full generation to be stored and made available to the NEM through the New England REZ.

The expected operational lifespan of the Project is in excess of 100 years.

ES2 Water resources

The surface water and groundwater sources of relevance to the Project area are subject to water sharing plans (WSPs) and therefore most aspects of Project water management are regulated under the NSW *Water Management Act 2000* (WM Act). The NSW Aquifer Interference Policy (AIP) establishes the criteria for assessment of projects that intercept groundwater and how the Project needs to be licensed. This groundwater impact assessment (GIA) has been undertaken in accordance with the WM Act and AIP.

Surface water resources (as assessed in the Surface Water Impact Assessment (EMM, 2023a)) within the Project area comprise the Macleay River Catchment. There are four surface water sources within the Project area that are managed under the Water Sharing Plan for the Macleay Unregulated and Alluvial Water Sources 2016 (Macleay WSP), including:

- Macleay Gorges Water Source
- Macleay Valley Water Source
- Dyke River Water Source
- Georges River Water Source.

The groundwater resources for the Project are managed under the Macleay WSP and the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 (Groundwater WSP), specifically the New England Fold Belt Coast Groundwater Source (NEFB Coast Groundwater Source) (DPI 2016b).

The Macleay WSP includes management measures for the water 'contained within the alluvial sediments below the surface of the ground (DPI, 2016a)', including the:

- Coastal Macleay Floodplain Alluvial Groundwater Source
- upriver alluvial sediments within the:
  - Macleay Valley Water Source
  - remaining water sources, within the Macleay WSP.

ES3 Baseline monitoring program

A water monitoring network has been designed and implemented to establish pre-construction baseline data for the Project. The water monitoring network has been designed to ensure that the Project can be adequately assessed against the AIP and has been designed and developed in accordance with the Guidelines for Groundwater Documentation for SSD/SSI Projects. Technical Guideline (DPE Water 2022).

The groundwater monitoring network includes conventional groundwater monitoring bores, third-party landholder bores and groundwater springs. The network covers 31 locations across the Project area, many of which include dual installations. The surface water monitoring network includes one streamflow gauging location and eight surface water quality monitoring locations. Surface water monitoring targets areas upstream and downstream of the Project area in major creeks and rivers intercepted by the Project. Both the groundwater and surface water monitoring networks have been developed in consultation with NSW Department of Planning and Environment (DPE) Water hydrogeologists, hydrologists and assessment officers.

A diverse range of field investigations has been undertaken to develop the conceptual model understanding, including hydraulic testing, geochemical investigations, geophysical investigations, geomorphological studies and ecological studies.

The extent, duration and frequency of baseline monitoring, for which this GIA has been based on, is considered fit-for-purpose. Additional data will continue to be gathered at key locations to further understand and monitor potential Project impacts at a more local scale and verify model predictions and provide recalibration targets over time.

ES4 Assessment and findings

Numerical modelling has been used in this assessment to predict potential changes in groundwater and surface water resources. Groundwater flow into the key subsurface Project features (i.e. the power waterway, reservoirs access tunnels and the underground power station) is expected to occur primarily as a function of secondary porosity (i.e. via fractures and along bedding planes). The model assumed a bulk conservative hydraulic conductivity for each rock type and cannot simulate individual fractures because the locations and conductivity of individual fractures are not known until the tunnel intersects them. Attempts to 'constrain' the model to simulate unknown geological occurrences (i.e. fractures interspersed with low hydraulic conductivity zones) or design elements, is not in-line with the Australian Groundwater Modelling Guidelines (Barnett et al 2012) and this has therefore not been undertaken.

The modelling results are therefore conservative for two reasons:

- Modelling does not consider actual design, management or mitigating activities (i.e. pre/post-grouting, concrete lining and steel lining). During construction the discrete fractures that yield excess water will be grouted during construction, reducing the actual overall tunnel inflow volume.

- Hydraulic parameters within the numerical model for the Macleay River floodplain alluvials are conservative and assume significant permeability and flow. However, in reality, the entire unit may not behave like this, with some parts expected to be much less permeable with storage also expected to be constrained by thickness.

Therefore, the model predictions of inflow, baseflow reduction and watertable drawdown are likely to be overestimating Project impacts. The results of this conservative model approach need to be considered within this overall context to accurately assess the Project on its true merits.

Groundwater modelling predicts localised watertable drawdown in the vicinity of the Project throughout construction and operation. Watertable drawdown, once the Project has advanced into year 5 of construction and into operations, is predicted to extend up to approximately 1.7 kilometres (km) north of the Project's pumped hydro generation works across the escarpment area and west of the Carrai Plateau. Watertable drawdown across the Carrai Plateau area is less extensive, propagating 600 m north-east of the Project and less than 350 metres (m) east and south of the Project. During operations, modelling also predicts localised raising of the watertable (i.e. "mounding").

Based on the model, watertable drawdown is predicted to have effects on terrestrial groundwater dependent ecosystems (GDEs), and groundwater available for baseflow to rivers and creeks. Impacts on GDEs are explored in greater detail in Appendix I (GDE assessment) of the Project's EIS. The modelled reduction in baseflow is predicted to have greatest effect to the upper reaches of the various perennial streams (1% of lengths are affected) across the escarpment area, and similar impacts to the affected reaches of the Macleay River (3% of lengths are affected). The predicted effects will be localised to the area directly overlying the drawdown zone and are not predicted to significantly affect downstream reaches of these watercourses. Furthermore, the Project is not predicted to impact the Carrai Waterholes, any groundwater/surface water user, or obligate GDEs identified across the plateau. Water drawdown at plant communities has been assessed as low risk.

Water quality objectives have been provided to develop a minimum standard for Project related water quality. These objectives will be monitored throughout the construction and operation of the Project to ensure discharged water is of sufficient quality to meet this standard.

ES5 Mitigation and management

If required, mitigation and management options available during construction include:

- pre-grouting (i.e. grouting through pilot holes at the excavation face if inflows are un-manageable via pumping)
- post-grouting (i.e. following excavation via drill and blast methodologies).

These mitigation and management measures will likely reduce the groundwater inflow volumes.

ES6 Water licensing and overall take

The volume of groundwater required to be licensed for the Project is defined in accordance with the AIP for interception activities, plus the direct take for construction and potable supply (if required). The licence requirements for Project inflows are separated into direct take (i.e. power waterway inflow), and the effects on overlying water sources which includes reduced availability of groundwater to provide baseflow (i.e. baseflow reduction to streams). This baseflow reduction is a stream impact, but is licensed from the source, which is groundwater. Due to the time lag, the water is removed from the water source once, but licensed twice to account for secondary impacts that occur years after the initial inflow occurs. Top-up process water and potable supply may be provided via bores into the NEFB Coast Groundwater Source, although estimates of required take for potential bores are not currently clear, nor presented in this assessment.

The peak inflow, impacts and take are considered for each groundwater source, and for each component that requires licensing in Table ES1. The overall licence peak direct take is 407 megalitres (ML) in the NEFB Coast Groundwater Source.

Table ES1 Licence take breakdown by source

Measure	*North Coast Fractured and Porous Rock Groundwater Sources 2016*		
	Direct Project inflow	**Reduced baseflow to Macleay River**	**Reduced baseflow to perennial streams**
Peak take/interception/process	407 ML in construction year 1	117 ML in construction year 5	47 ML in construction year 4

There is sufficient groundwater entitlement available within the applicable groundwater source to secure the peak predicted take for the Project.

OMPS has acquired 232 share components and successfully bid the remaining 175 unit shares within the NEFB Coast Groundwater Source, purchased through the 2021 and 2022 controlled allocation orders (CAOs). This volume covers the peak predicted direct take anticipated to be intercepted by the Project.

It is noted that the numerical groundwater model is conservative and with the inclusion of design mitigation options and a potential refinement of the hydraulic parameters, the inflow volumes required for licensing may be reduced.

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1 Introduction

1.1 The Project

OMPS Pty Ltd (OMPS) is proposing to develop the Oven Mountain Pumped Hydro Energy Storage Project (the Project), an off-river pumped hydro energy storage system (referred to as the 'pumped hydro system') located approximately half-way between Kempsey and Armidale, adjacent to the Macleay River in northern NSW. The Project is located within the New England Renewable Energy Zone (REZ) and the Armidale Regional Local Government Area (LGA), proximate to its border with Kempsey Shire LGA.

Figure 1.1 and Figure 1.2 provide the regional and local context of the Project respectively.

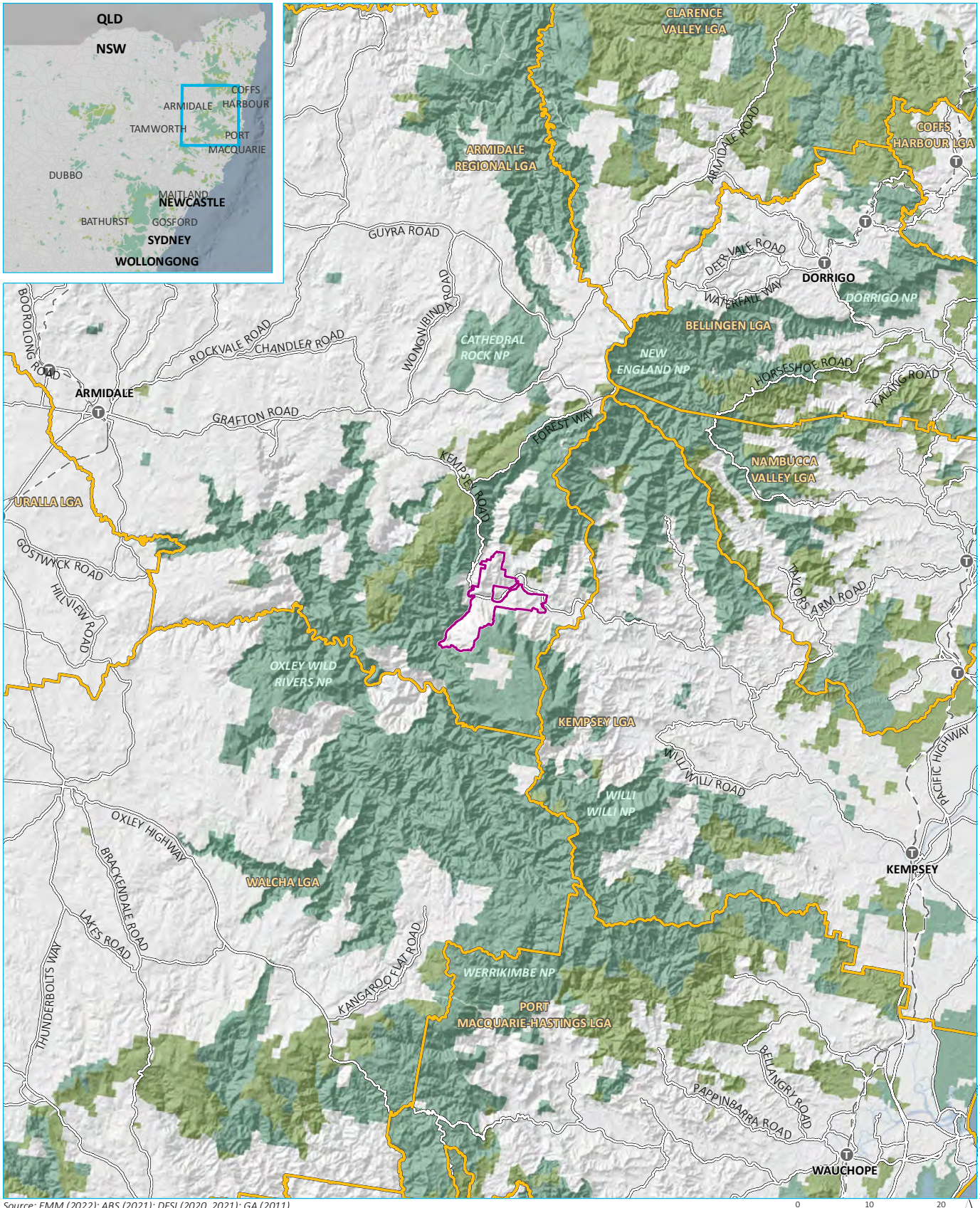
At a basic level, the Project will consist of upper and lower water reservoirs and an underground waterway connecting them via a hydro-electric power station.

The Project has been declared by the New South Wales (NSW) Government to be critical State significant infrastructure (CSSI) under the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). Infrastructure projects are declared to be CSSI if, in the opinion of the NSW Minister for Planning, they are essential to the State for economic, environmental, or social reasons. By providing up to 900 MW of electricity generating capacity, the Project will aid in the transition of the NEM towards cleaner, more reliable and affordable electricity. It will also provide up to between eight and 12 hours of dispatchable energy at full generation to be stored and made available to the National Electricity Market (NEM) through the New England REZ. The expected operational lifespan of the Project is in excess of 100 years.

The Project will utilise the highly favourable natural terrain of the site on which it sits to allow electrical energy from the main grid to be stored by pumping water from the lower reservoir to the upper reservoir. Energy can then be generated when needed by allowing water to flow back down to the lower dam and reservoir via the hydro-electric power station, effectively enabling the Project to act as a large battery.

1.2 Proponent

OMPS (ABN 22 160 259 174) is developing the Project and is located in Kempsey at 2/28 Clyde Street, Kempsey NSW 2440.



Source: EMM (2022); ABS (2021); DFSI (2020, 2021); GA (2011)

0 10 20 km

GDA 1994 MGA Zone 56

N

KEY

- Project area
- Train station
- Rail line
- Major road
- Named waterbody
- Local government area
- NPWS reserve
- State forest

INSET KEY

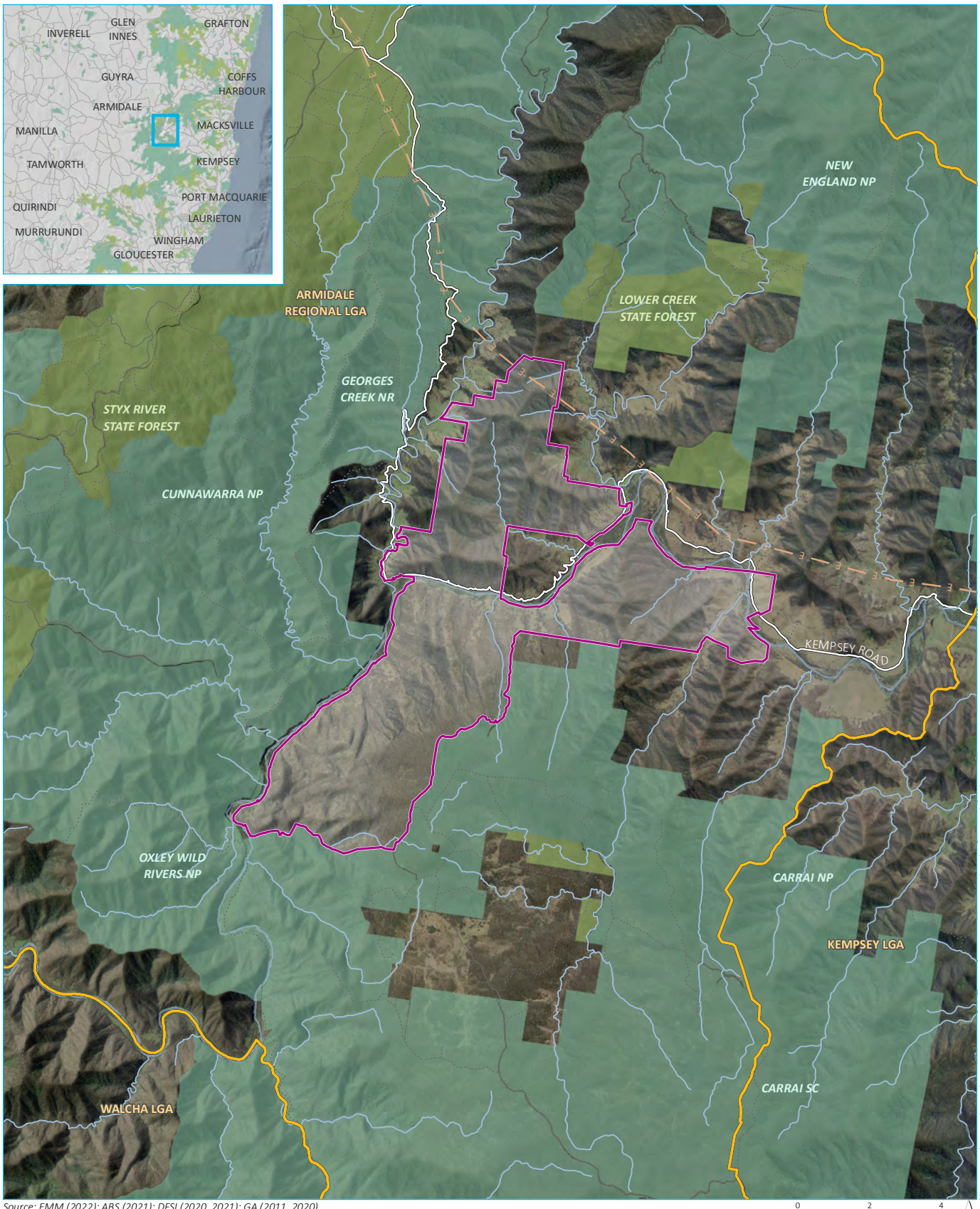
- Major road
- NPWS reserve
- State forest

Regional setting

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
OMPS Pty Ltd
Figure 1.1

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Source: EMM (2022); ABS (2021); DFSI (2020, 2021); GA (2011, 2020)

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GDA 1994 MGA Zone 56

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KEY

- Projec area
- Existing transmission line
- Major road
- Minor road
- Vehicular track
- Named watercourse
- Named waterbody
- Local government area
- NPWS reserve
- State forest

INSET KEY

- Major road
- NPWS reserve
- State forest

The Project area - local context

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
OMPS Pty Ltd
Figure 1.2

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1.3 Purpose of this report

This groundwater impact assessment (GIA) is an appendix to the Project's environmental impact statement (EIS), and should be read in conjunction with it. The key objectives of this GIA are to:

- Satisfy the Secretary's Environmental Assessment Requirements (SEARs) relevant to groundwater impacts.
- Provide the regulatory setting (regarding water management) within which the Project will operate.
- Quantify the water requirements for the Project during construction and operation, with arrangements detailed to acquire sufficient water allocations through the relevant legislative pathway.
- Assess the existing groundwater environment, baseline groundwater conditions and groundwater users within and near the Project area.
- Quantify (through predictions) the potential impacts induced by the Project on the existing groundwater environment, baseline groundwater conditions and groundwater users within and near the Project area.
- Develop management measures for implementation during construction and operation of the Project to mitigate groundwater related impacts.
- Provide commitments to continued groundwater monitoring, supporting:
    - predictions of potential groundwater impacts
    - an assessment of the efficacy of the implemented management measures
- Provide Project relevant information to the wider community, including the potential groundwater impacts at a local and regional scale.

This report consists of the following sections:

- Chapter 2 – The Project description, summarising the key Project components and definition of the Project and study area.
- Chapter 3 – Project setting, providing a groundwater relevant background for the Project area including topography, land use, climate, geology, existing surface water and groundwater conditions and regulation of water sources.
- Chapter 4 – Regulatory and policy context and assessment, outlining the relevant regulatory policies and documents considered during development of this GIA.
- Chapter 5 – Baseline monitoring program, summarising the relevant field surveys of the pre-Project environment.
- Chapter 6 – Groundwater characterisation, discussing the outcomes from the baseline monitoring program.
- Chapter 7 – Conceptual model, providing an interpretive assessment of the existing groundwater environment prior to Project construction.
- Chapter 8 – Assessment approach, providing the basis and rationale for assessing potential impacts induced by the Project.

- Chapter 9 – Groundwater flow assessment, discussing the potential impacts induced by the Project arising from reduced groundwater levels or availability.
- Chapter 10 – Water quality assessment, discussing the potential impacts induced by the Project arising from altered water quality and chemistry.
- Chapter 11 – Impact summary and risk assessment, providing a summary of the consequence of impacts associated with the Project.
- Chapter 12 – Water licences, providing the water licensing pathway for the Project and outlining commitments to navigate the appropriate water regulation and licensing.
- Chapter 13 –*NSW Aquifer Interference Policy* (AIP) assessment framework, providing a summary of the relevant requirements stipulated in the AIP and referencing the relevant section of this GIA.
- Chapter 14 – Conclusions, concluding this GIA with the key findings, management strategies and commitments.

This GIA has been collated in consideration of the Project surface water assessment (SWA), (EMM, 2023a) and biodiversity development assessment report (BDAR), (EMM, 2023b). This GIA should be read in conjunction with these reports.

1.4 Assessment guidelines and requirements

This GIA has been prepared to address the SEARs issued by NSW Department of Planning, Industry and Environment (DPIE, now the NSW Department of Planning and Environment (DPE)) on 10 June 2022. This assessment also considers relevant governmental assessment requirements, guidelines and policies, and has been developed in consultation with DPE-Water.

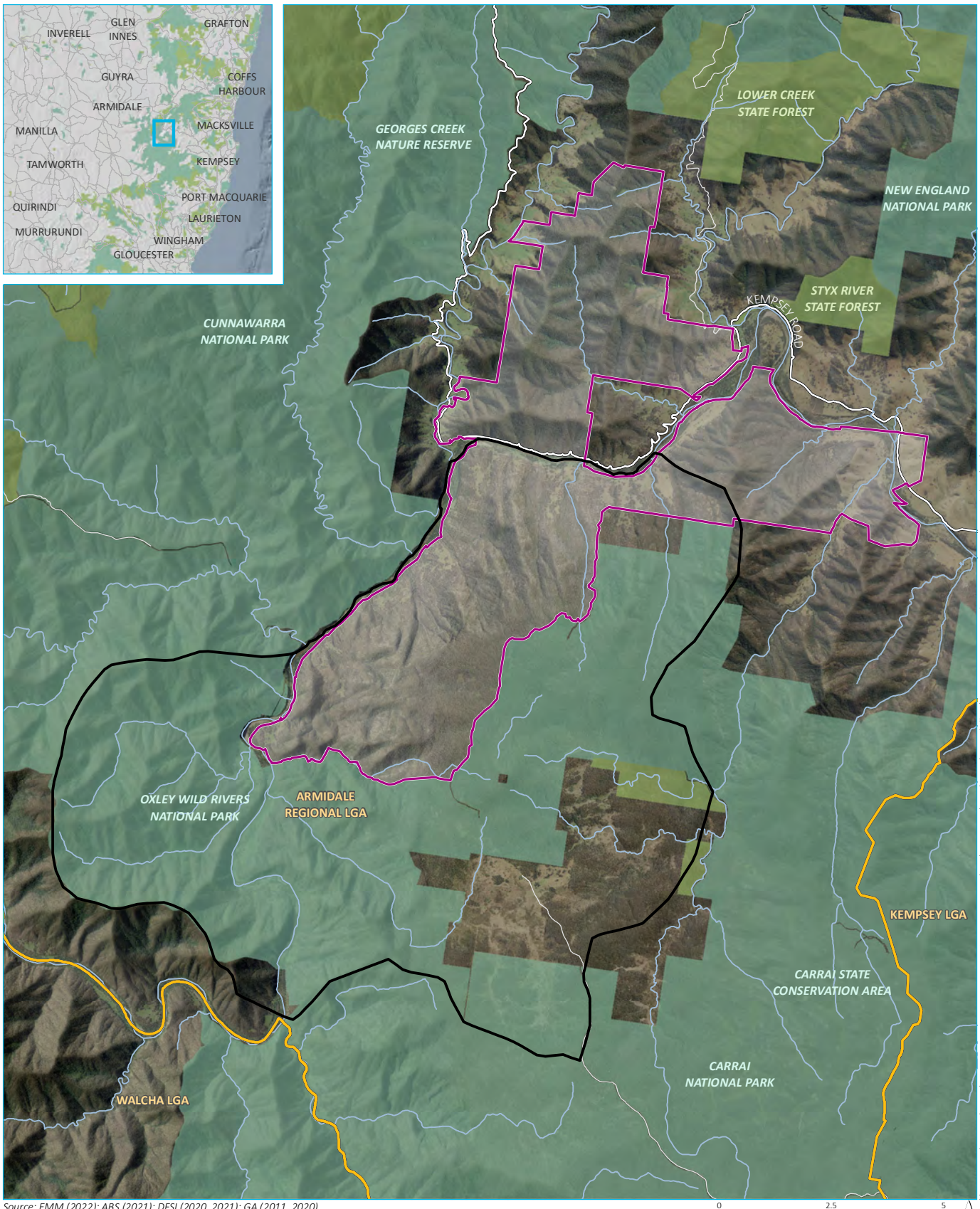
Table 1.1 lists the matters relevant to this assessment and where they are addressed in this report.

Table 1.1 Relevant matters raised in SEARs

Requirement	Section addressed
A detailed site water balance for the Project, including the water take from each surface and groundwater source, any licensing requirements, and determine whether an adequate and secure water supply is available for the development.	Section 12.2 and Section 12.3 SWA – Section 7.2 (EMM, 2023a) SWA – Chapter 9 (EMM, 2023a)
An assessment of the impacts of the Project on:	
• the quantity and quality of the region's surface and groundwater	The existing environment is discussed in Chapter 6, and an assessment of impacts to quantity and quality is presented in Chapter 9 and Chapter 10, respectively.
• resources, including Macleay River and Fingerboard Crossing Creek	Section 9.2.5v SWA – Chapter 6 (EMM, 2023a) SWA – Chapter 7 (EMM, 2023a)
• water security for local downstream receivers	Section 9.2.5vi SWA – Section 6.5 (EMM, 2023a) SWA – Section 7.5 (EMM, 2023a)

Table 1.1 Relevant matters raised in SEARs

Requirement	Section addressed
• hydrological flows on site, including any potential flooding impacts	SWA – Section 7.8 (EMM, 2023a)
• key water features on site, including potential impacts on riparian land	SWA – Section 5.9 (EMM, 2023a) SWA – Section 6.3 (EMM, 2023a) SWA – Section 7.3 (EMM, 2023a)
• type and extent of any dredging or reclamation activities within 'water land'	Not applicable
• water-related infrastructure, basic landholder rights and the entitlements of water users.	Section 9.2.5vi SWA – Section 6.7 (EMM, 2023a) SWA – Section 7.7 (EMM, 2023a)
A description of the likely changes to the hydrological regime of the Macleay River, and any associated biodiversity impacts.	Section 9.2.5v BDAR – Section 7 (EMM, 2023b)
Where the Project involves works within 40 metres of the high bank of any river, lake or wetlands (collectively waterfront land), identify likely impacts to the waterfront land, and how the activities are to be designed and implemented in accordance with the *Guidelines for Controlled Activities on Waterfront Land* (DoI, 2018) and (if necessary) *Why Do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings* (Fairfull & Witheridge, 2003); and *Policy & Guidelines for Fish Habitat Conservation & Management* (DPI, 2013).	SWA – Section 5.9 (EMM, 2023a)
A strategy to manage spoil and enhance any new landforms created.	Section 10.3.1 Rehabilitation and closure strategy – Section 8.4 (EMM, 2023c)
Specific risks: Hydrologic impacts on the Macleay River, including direct extraction and/or capture of groundwater or runoff that would have otherwise run into the river (aquatic and semi-aquatic species including frogs, fish, waterbirds, aquatic mammals, aquatic invertebrates such as crayfish). Management of runoff will be all the more important given that the referral indicates that the midstory and groundcover were burnt over much of the Project area. While it is noted that the Macleay River itself is not included in the World Heritage property where it borders the proposed Project area, its western tributaries would be.	Section 9.2.5iv Section 9.2.5v Section 6.3 (EMM, 2023a) Section 7.3 (EMM, 2023a) BDAR – Section 7 (EMM, 2023b)



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Source: EMM (2022); ABS (2021); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse
- Local government area
- NPWS reserve
- State forest

INSET KEY

- Major road
- NPWS reserve
- State forest

Project area and study area

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
OMPS Pty Ltd
Figure 1.3

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2 The Project description

2.1 Project overview

The Project involves building two 'off river' water containment structures to create an upper and a lower reservoir (referred to as 'the upper dam and reservoir' and 'the lower dam and reservoir'), on an ephemeral tributary of the Macleay River. An underground hydro-electric power station complex will be connected to the reservoirs by infrastructure including a power waterway and tunnels. During operation, the water will enable the generation of electricity as it passes through the underground power station while moving from the upper to the lower reservoir, from where it is pumped back up via the same waterway in a 'closed-loop circuit'. The pumped hydro system will be connected to the existing transmission network via new overhead high voltage transmission lines.

A detailed description of the Project and its strategic context is provided in the Project's EIS which should be read in conjunction with this report.

An overview of the key components and elements are provided below.

2.2 Key Project design elements

Broadly, the Project has been categorised into three key components, which are further broken down into the Project's key elements in Table 2.1 and shown in Figure 2.1:

- pumped hydro-electric and generation works (PHGW) – including:
  - new upper and lower water storage dams and reservoirs
  - a new underground pumped hydro-electric power station and transformer hall
  - water tunnels, access tunnels, portals and adits
  - tailrace
  - intake and outlet structures
  - associated gates, shafts and screens
- transmission connection works – including:
  - new electricity transmission lines to connect the PHGW to the existing electricity transmission network (Line 965)
  - new electricity transmission infrastructure
  - a new substation
- ancillary development – including but not limited to:
  - access roads, tracks and bridge
  - on-site quarries and related infrastructure
  - utilities and communications infrastructure
  - construction pads containing assets such as workshops, concrete batching plants (CBPs), and offices

- laydown and storage areas
- construction accommodation
- pumping infrastructure
- operational facilities such as offices, and camps for staff
- construction and operational power supply.

Table 2.1 Key Project elements

Project element	Description
PHGW	
Underground power station complex	An underground pumped hydro-electric power station located below the upstream end of the pumped hydro system to optimise the hydraulic arrangement of the Project. The power station complex consists of: • two main caverns comprising; – the machine hall – the transformer hall • interconnecting tunnels, the transformer hall tunnel and isolated phase busbar (IPB) tunnels.
Dams and reservoirs	Two concrete faced rockfill dams (CFRD) and reservoirs, referred to as the upper dam and reservoir and lower dam and reservoir, with the following specifications:
	Upper dam and reservoir: • CFRD approximately 70 metres (m) high and 780 m long • reservoir covering a total area of approximately 20 hectares (ha) and an inundation extent of approximately 16.7 ha • reservoir height of 881 m Australian Height Datum (AHD) at full supply level (FSL) and 830 m AHD at minimum operating level (MOL) • total reservoir storage capacity of around 5.1 gigalitres (GL) at FSL.
	Lower dam and reservoir: • CFRD approximately 70 m high and 280 m long • reservoir covering a total area of approximately 24.7 ha and an inundation extent of approximately 21.6 ha • reservoir height of 250 m AHD at FSL, 215 m at MOL and 205 m AHD at lowest operating level (LOL) • total reservoir storage capacity of around 6.5 GL at FSL.
Water intake structures	Two intake structures, one at each reservoir, including: • a morning glory, vertical-type intake structure situated at the upper dam and reservoir • a lateral intake structure, with head gates and stoplog slots, and an intake channel, at the lower dam and reservoir.
Spillway	Two concrete lined spillway chutes, one for each of the upper and lower dams and reservoirs. Both spillway crests will comprise of ungated ogee-shaped overflow weirs on the upstream ends of the spillway chutes.
Macleay River pump facility	A pump facility on the edge of the Macleay River, which will include an access road, duty and standby pumps for the initial fill and for ongoing top ups as required.

Table 2.1 Key Project elements

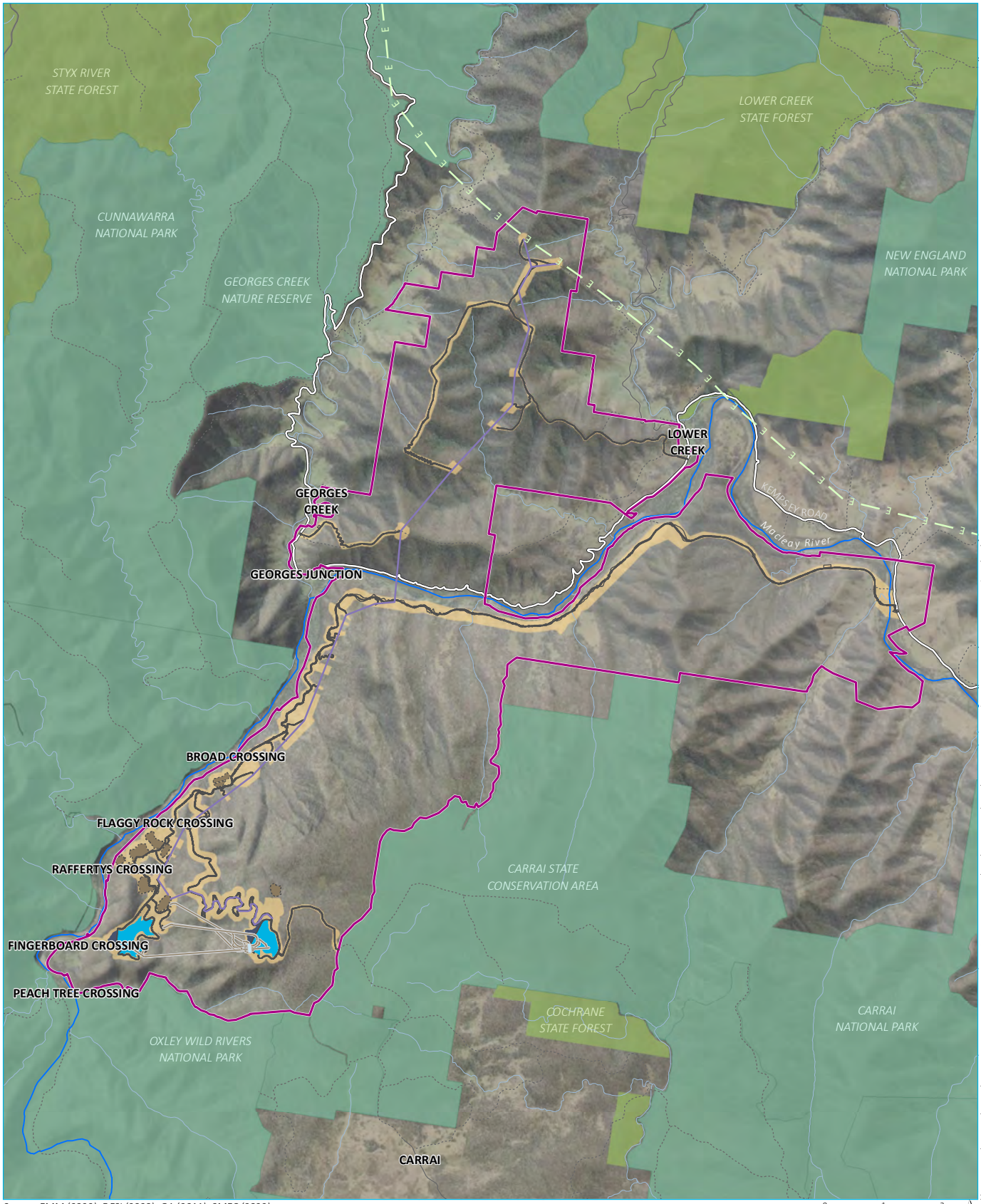
Project element	Description
Tunnels	Three main tunnels comprising of: • two main access tunnels (MAT1 and MAT2) • the emergency, cable, ventilation tunnel (ECVT). The MAT1 and MAT2 will provide loop access to the power station complex from the MAT portal. The ECVT will provide services access and egress between the switchyard portal and the transformer hall. The ECVT portal will contain the station switchyard, control rooms, ventilation and firefighting equipment, with blast walls separating important equipment.
Power waterway	The power waterway will consist of: • a 660 m deep, 5.1 m diameter vertical pressure shaft • 250 m concrete and steel lined high-pressure headrace tunnel • three or more 80 m long penstock tunnels • three or more 120 m long draft tube tunnels • an approximately 1,825 m long concrete lined tailrace tunnel.
Transmission connection works	
Connection works	The connection works will consist of: • an approximately 15km long transmission alignment comprising, at a maximum, double circuit single tower 330 kV overhead infrastructure and single circuit single tower 132 kV overhead infrastructure connecting to TransGrid Line 965 • up to 25 transmission tower sites (approximately 50 m x 50 m) containing the 132 kV and 330 kV infrastructure • a transmission easement width of a maximum of approximately 105 m. Note: The upgrade of existing Line 965 will be the subject of a separate application.
Sub-station	Construction of a substation and associated connection infrastructure of up to 330 kV rating.
Switchyard	A high voltage connection linking the connection transmission lines to the cables exiting the underground power station complex. The outdoor air insulated switchyard will likely include: • switchgear and control room • cable potheads • disconnector/earth switches • capacitive voltage transformer (VT) • lightning protection • security fencing, lighting and surveillance • surge arrestor.
Ancillary development (construction and operation)	
Access roads, access tracks and bridge	A variety of road works to improve existing access, and construction of new permanent roads to enable construction access, temporary establishment and use of construction sites, and general access to the Project area including transmission line infrastructure.
	The proposed main access will be via the construction of a new unsealed two-lane access road located to the east of the site (the Eastern Access Road (EAR)). The main access road will interface with the existing Kempsey Armidale Road and will require the construction of one new single or two lane low-level bridge crossing over the Macleay River. A temporary bridge may be utilised prior to the construction of the permanent bridge.

Table 2.1 Key Project elements

Project element	Description
	There will be approximately 40 km of permanent roads connecting the dams, surface works, portals, transmission assets and spoil sites. Some of these roads are existing roads, however approximately 25 km will be newly constructed roads. The key road components include: • Main Access Road (approximately 4.7 km) • EAR (up to approximately 11.4 km) • Lower Dam Access Road (approximately 3.6 km) • Upper Dam Access Road (approximately 7.1 km) • access to portals and underground works • Upper Dam Emergency Egress Road (approximately 2.2 km). Access to the transmission infrastructure north of the Macleay River will be via two roads accessed from the Kempsey Armidale Road. These two roads include the: • Northern Transmission Access Road (approximately 15 km) • Southern Transmission Access Road (approximately 2.3 km). To support access along the transmission line easement south of the Macleay River and to each of the tower sites, a network of interconnecting access and maintenance tracks will be constructed, to a large extent utilising existing access tracks.
Surface works pads and facilities	There are four main construction pads in addition to surface portals which will be used temporarily during construction for different services (accommodation camp, construction site offices, workshop area, and laydown storage).
	Construction works will require the establishment of the following ancillary support infrastructure and areas: • main accommodation camp(s), which will temporarily accommodate the majority of workers as required workers as required throughout the construction period • temporary or fly camps, which may be required in addition to the main accommodation camp being constructed • two works areas including Works Area 1 and Works Area 2, which will contain ancillary facilities such as CBPs, mechanical and electrical workshops, a laboratory and various water treatment and wash areas • spoil emplacement areas • staging area • stockpiling areas • temporary site offices to be used during construction.
Communications	Communication infrastructure such as fibre optic cables are required for the operation of the Project and will be located: • on an overhead line linking the upper and lower dams and reservoirs (in conjunction with the electrical line) • buried in road corridors. The communication network will also include a communications tower near the upper dam and reservoir.
Utilities during construction	• Construction water will be supplied to water storage systems either via groundwater bores, or via pumping of water from the Macleay River to support camp operations, the CBP, dust suppressions and other activities across the site. • Construction power will be supplied primarily by use of portable diesel generators and supported where possible by leveraging off existing electricity distribution infrastructure running through the generation site.
Utilities for operation	Alignment and length of utilities (electricity, water, etc.) will be combined into a single corridor (total length of about 5.4 km).

Table 2.1 Key Project elements

Project element	Description
Water diversion and water treatment facilities	• Site drainage will include a combination of cross drainage culverts, drainage pits and pipe, open channels/open drains (vegetated, rock-lined or concrete), levees/bunds, and detention basins. • Various water treatment plants will be used for construction drainage and water treatment facilities – for the main accommodation camp, temporary or fly camps, CBP, tunnel, etc. • Specific discharge locations are planned for stormwater and surface water runoff and will be determined during detailed design or construction planning.
Laydown/stockpile areas	Temporary laydown/stockpile areas will be utilised across the Project area.
Spoil emplacement areas	To accommodate spoil generated through excavation of the underground caverns and tunnels, three permanent spoil placement locations have been identified with a capacity to store around 2 million cubic metres (Mm^3) of material. Dead storage space within the reservoirs will also be used for spoil placement, with a capacity to store approximately 300,000–400,000 m^3.
Ancillary operational facilities	Primary operation of the Project can be undertaken remotely and will require minimal onsite operational staff, other than for maintenance activities. Operational facilities include maintenance housing, work area, car parking, workshop and storage, control room and switchgear, water treatment plant, office area, heating, ventilation and air conditioning (HVAC), backup generators and Macleay River pump facility.
Other	
Construction	• Construction duration of around four to five years. • Construction workforce of over 600 at construction peak.
Rehabilitation	Rehabilitation of areas disturbed during pre-construction and construction will be undertaken progressively where practical during all stages and phases of the Project. Progressive rehabilitation will occur over about 60 ha including spoil emplacement areas and areas used for construction ancillary facilities no longer needed during operation. At the end of the Project's life, 192 ha in total will be rehabilitated to native ecosystem (including native vegetation and rock landscape). Approximately 138 ha will be retained permanently for the water storages and access roads, subject to agreement with relevant landowners/land managers.
Operation	• The Project will provide up to 900 MW of electricity generating capacity and up to eight hours of energy storage at full generating capacity. • Maintenance and operational activities will include power station operations, infrastructure inspections, maintenance to assets, vegetation management, auditing and compliance and other activities. • It is expected that the operation of the new power station will require around 30–50 full-time workers, as well as additional contractors for regular and ad hoc maintenance and repairs.
Hours of operation	• Construction of the Project will be 24/7 and 365 days per year. • Operation of the Project will be 24/7 and 365 days per year.
Project timeline	The Project will involve the construction and operational stages, and numerous phases which are outlined in the Project's EIS.
CIV	Estimated to be about $1.8 billion (refer to Appendix BB).



Source: EMM (2022); DFSI (2020); GA (2011); SMEC (2022)

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KEY

- Project area
- Indicative generation component disturbance area

Project operational elements

- Power station
- Tunnels, portals, intakes, shafts
- Transmission overhead lines
- Permanent road
- Surface works
- Dam wall
- Reservoir

Existing environment

- Macleay River
- Watercourse/drainage line
- Major road
- Minor road
- Vehicular track
- Existing transmission line
- NPWS reserve
- State forest

Key Project elements

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
OMPS Pty Ltd
Figure 2.1

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2.3 Project area terminology

Approval for the Project is being sought based on feasibility designs as is common for projects of this size and scale. To accommodate minor changes and amendments to the design as it progresses, a 'Project area', 'construction envelope', 'disturbance footprint' and 'operational footprint' approach is being adopted for the Project. This approach is aimed at ensuring environmental impacts are assessed as accurately as possible, whilst accounting for the current level of design and the likelihood of design refinements occurring as the Project progresses towards construction. This approach was adopted for the assessment of Snowy Hydro Limited's Snowy 2.0 Project.

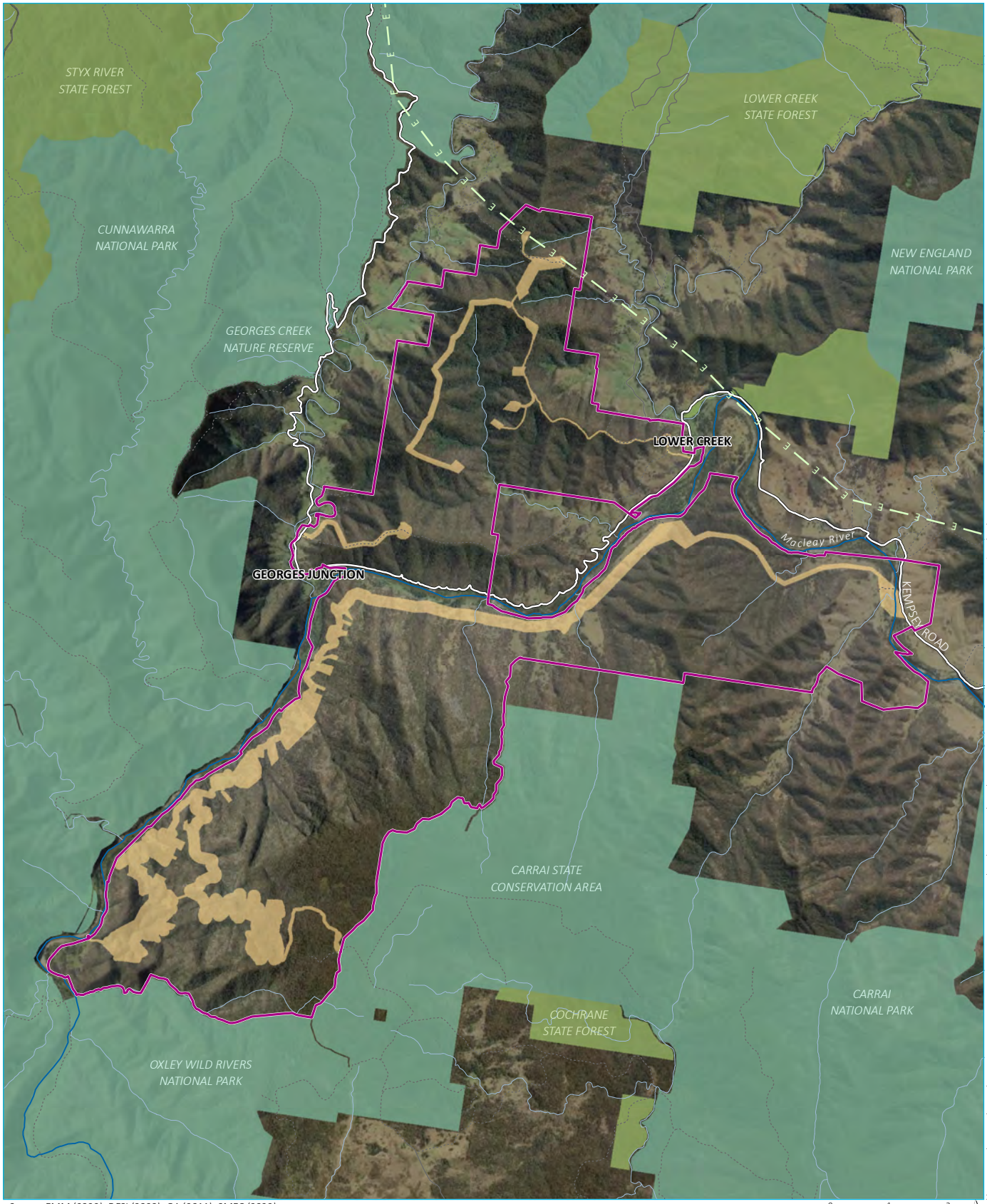
The *Project area* is the broader area within which the Project will be built and operated, and the extent within which direct impacts from the Project are anticipated. Importantly the Project area does not represent a footprint for the construction works, but rather indicates an area that was investigated during environmental assessments. The Project area has been further divided into different areas to facilitate the assessment of direct impacts from the Project.

The *construction envelope* represents the maximum extent of where disturbance may occur during the construction of the Project. In order to derive the construction envelope, buffers have been applied to key Project elements and infrastructure. The buffers used to derive the final construction envelope area reflect the confidence around the current siting of the asset or infrastructure, and the likelihood that some minor amendments may be required prior to commencing the construction works as a result of the detailed design. The construction envelope for the Project is around 780 ha.

Located entirely within the bounds of the construction envelope sits the *disturbance footprint*, a smaller area that has been derived directly from the current level of design. The disturbance footprint represents the physical disturbance that can be expected as part of the construction works. As the design is refined, the final siting of the disturbance footprint can move within the construction envelope, subject to the recommended environmental management measures, and provided it does not exceed any limits as defined by the construction envelope. It is proposed that most of the disturbance area will be rehabilitated and landformed at the completion of the Project, however other parts will be retained post construction. These components are necessary for the ongoing operation and maintenance of the new power station (operational footprint). The disturbance footprint for the Project is around 330 ha.

Progressively and at the end of construction, temporary components that are required to support the construction of the Project will be rehabilitated and returned to a state representing its previous use. The exception to this is the areas required for permanent operation of the Project, which would be retained (referred to as the *operational footprint*). The operational footprint of the Project covers an area of around 270 ha. Approximately 60 ha would be progressively rehabilitation during and following completion of construction.

The Project area, construction envelope and disturbance footprint are shown in Figure 2.2.



Source: EMM (2022); DFSI (2020); GA (2011); SMEC (2022)

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KEY

Project area
Construction envelope

Existing environment
Macleay River
Watercourse/drainage line
Kempsey-Armidale Road
Minor road
Vehicular track
Existing transmission line
NPWS reserve
State forest

Project area overview

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
OMPS Pty Ltd
Figure 2.2

EMM creating opportunities

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3 Project setting

3.1 Overview

The study area relevant to this GIA aligns with the numerical groundwater model boundary, as indicated in Figure 1.3. The study area, which is larger than the Project area (refer Section 1.1), encompasses the:

- Project related sub-surface excavations
- Project related water monitoring network
- nearby licensed groundwater bores
- nearby high potential groundwater dependent ecosystems (GDEs)
- identified sites of cultural significance.

As discussed in Section 2.2, proposed infrastructure beyond the study area comprises:

- power transmission lines and towers
- substation infrastructure
- access roads.

The aforementioned infrastructure will be designed to mitigate permanent interception of the regional groundwater table. Temporary de-watering may be required for footing or trench excavations however, potential impacts are considered minor and temporary and are not considered as part of the study area. Further discussion is provided in Section 10.2.1.

The study area has been split into four focus areas, broadly constrained by topographic relief, comprising:

- the Carrai Plateau (the plateau), in the eastern portion of the study area
- the escarpment, extending west of the plateau
- the Macleay River floodplain, a relatively narrow area bordering the Macleay River
- the western catchment, on the western side of the Macleay River.

Focus areas are presented on Figure 3.1.

3.2 Topography and land use

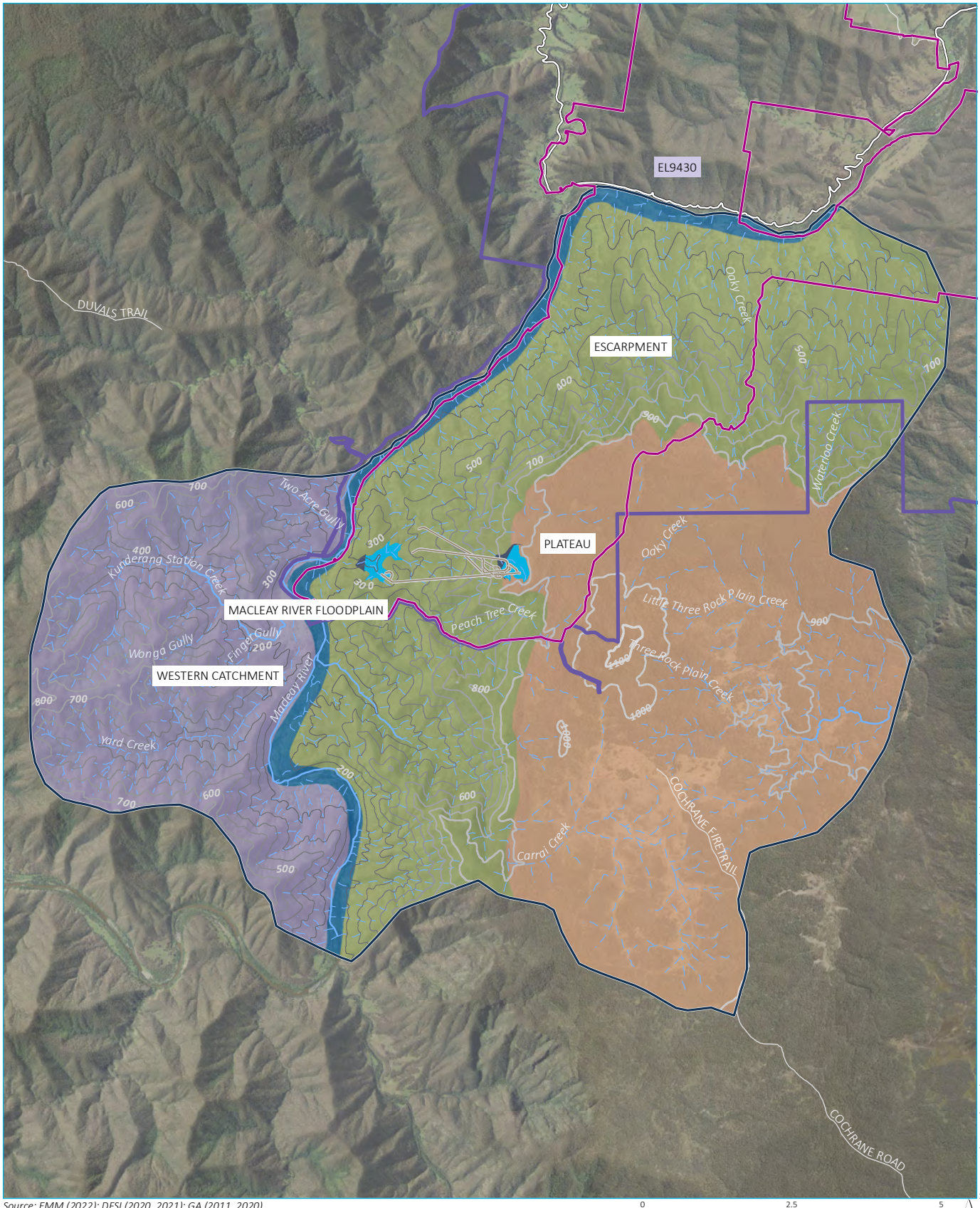
The topography of the plateau is relatively level at an average elevation of approximately 1,000 metres Australian Height Datum (mAHD). The escarpment dips down to the west and north-west from the plateau, where the relief levels out at an average elevation of 145 mAHD along the Macleay River floodplain.

The escarpment is dominated by a series of steep scarp slopes ranging between 20° and 30°. It is across this focus area where the majority of the power generation will occur, aided by an average grade of 25%. Incised valleys (generally orientated east-west) separate spurs, extending along the escarpment to the plain. The incised valleys support the majority of surface water relief, discharging via a series of watercourses to the Macleay River. Similar topography is mirrored by the Macleay River in the western catchment focus area, rising to approximately 760 mAHD, undulating over a series of north-south orientated ridgelines. Watercourses lie in the valley floors and discharge to the Macleay River.

Land use within the study area is predominantly agricultural, comprising agistment based cattle farming on privately owned land. Based on the Geological Survey of NSW (GSNSW) mining tenements database (GSNSW, 2022), Pickands Mather & Co International and BHP Minerals Limited have undertaken mineral exploratory works in 1971 and 1974 respectively. Exploratory works were generally concentrated within exploration lease EL9430 (formerly named EL664), encompassing the northern escarpment and Macleay Valley floodplain (refer Figure 3.1). Exploratory sampling and geological works were undertaken to assess the prospectivity for:

- arsenic (As)
- tin (Sn)
- molybdenum (Mo)
- copper (Cu)
- gold (Au)
- tungsten (W).

The topography and land use within the study area is illustrated in Figure 3.1.



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

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KEY

- Project area
- Study area
- Exploration lease EL9430
- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts

Focus area

- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

Existing environment

- Major road
- Minor road

Streams within study area

- Perennial
- Non-perennial

Topographic contour (100 m interval)

- 200
- 300
- 400
- 500
- 600
- 700
- 800
- 900
- 1000
- 1100

Focus areas, topography and land use

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
OMPS Pty Ltd
Figure 3.1

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3.3 Climate

3.3.1 Overview

The study area includes two climatic categories (Geiger, 1954), characterised as:

- humid-subtropical in the lower areas (near the Macleay River floodplain, lower escarpment and lower western catchment), with:
  - no dry months in summer
  - at least one-months' average temperature above 22°C
- temperate oceanic in the higher areas (near the plateau, upper escarpment and upper western catchment), with:
  - potential for dry months in summer
  - all months with average temperatures below 22°C.

3.3.2 Rainfall

Rainfall is typically higher across the Macleay River floodplain, lower escarpment and lower western catchment, with 1,136 millimetres per year (mm/yr) average rainfall at Bellbrook (representative of the Macleay River floodplain, lower escarpment and lower western catchment) and 935 mm/yr at Jeogla Station (representative of the plateau, upper escarpment and upper western catchment). Rainfall occurs year-round in both areas, with slightly increased rainfall in summer months on average (compared to winter months).

There are several Bureau of Meteorology (BoM) operated rainfall gauges that provide representative records for the study area. Key information and statistical data for five gauges near the study area are provided in Table 3.1. The rainfall gauges presented in Table 3.1 have been chosen based on their proximity, length and completeness of records.

Table 3.1 Annual rainfall statistics

Statistic	Units	Jeogla Station (BoM: 57011)[1]	Uralla (Blue Nobby) (BoM: 57091)[1]	Georges Creek (BoM: 57008)[1]	Lower Creek (Cedar Park) (BoM: 57052)[1]	Bellbrook (East Street) (BoM: 59000)[1]
Rainfall record	-	1907–present	1959–present	1918–1961	1961–2017	1889–2017
Record completeness	-	99%	97%	97%	89%	97%
Distance from study area	-	25 km north-west	33 km west	0 km	8 km north-east	30 km east
Elevation	(mAHD)[2]	950	1,067	166	130	95
Average annual rainfall	(mm/yr)[3]	935	933	912	1,069	1,136
Lowest annual rainfall	(mm/yr)	310	271	473	597	522
Highest rainfall	(mm/yr)	1,781	1,397	1,459	1,724	2,052

1. Source: BoM website (climate data online)
2. mAHD = metres Australian Height Datum
3. mm/yr = millimetres per year.

The annual rainfall totals shown in Table 3.1 indicate that annual rainfall totals are similar for the two gauges (BoM: 57011, 57091), located on the elevated tablelands and west of the study area. Annual rainfall totals are observed to increase as elevation declines (approaching the coast), with the highest annual rainfall totals observed at the Bellbrook (East Street) gauge (BoM: 59000).

The Georges Creek (BoM: 57008) gauge, located immediately north of the Project area, has an average annual rainfall of 912 mm/yr, approximately 150 mm/yr less than the Lower Creek (BoM: 57052) gauge (1,069 mm/yr), located 8 km further north. It is considered that this is indicative of a relatively short rainfall record period during drought.

The Georges Creek and Lower Creek rainfall gauges are expected to be more representative of rainfall conditions for the Macleay River floodplain and lower escarpment/western catchment. The Jeogla Station (BoM: 57011) rainfall gauge is expected to provide more representative rainfall conditions near the plateau and upper escarpment/western catchment.

Inferred rainfall records accessed from the SILO database (DES, 2022) have been used to summarise historic rainfall trends for the study area. The deviation in the average annual rainfall total at the Georges Creek (BoM: 57011) station since 1918 is shown in Figure 3.2, indicating that the Project area has experienced long-term climate cycles with distinct wet and dry periods.

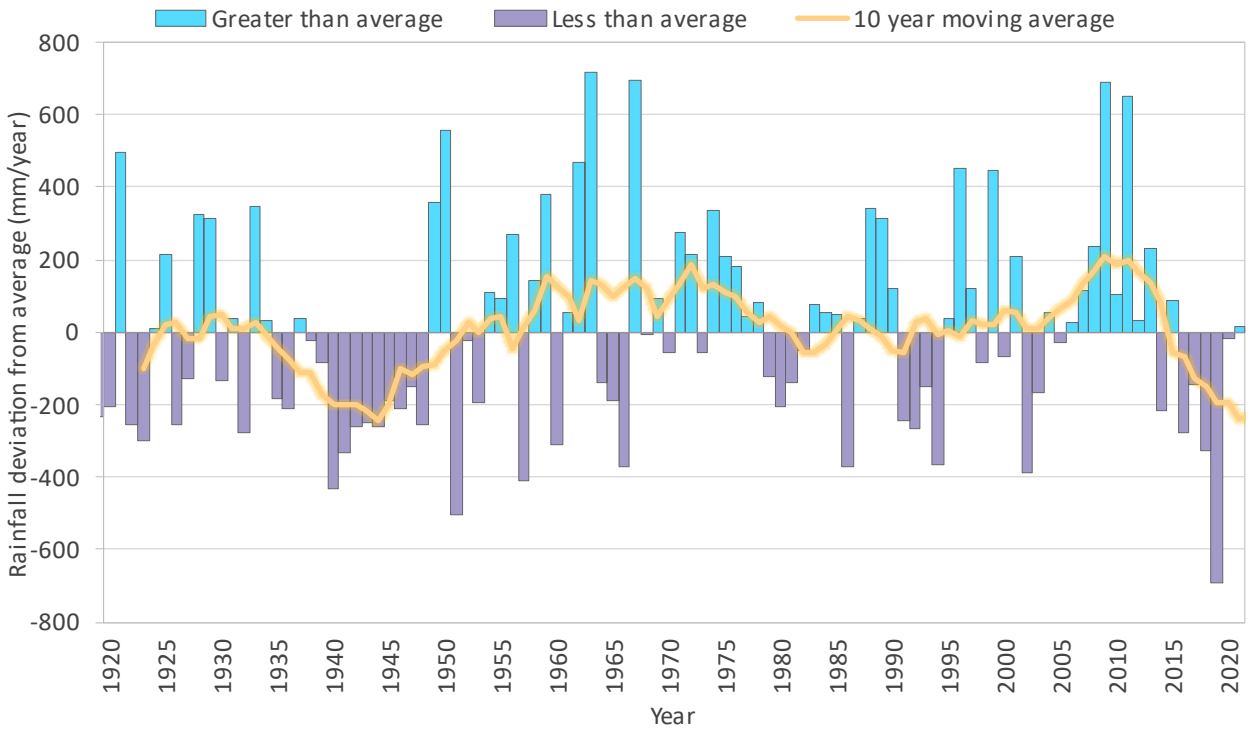


Figure 3.2 Historical rainfall trend at Jeogla Station (BoM: 57011)

3.3.3 Evaporation

The median yearly pan evaporation is approximately 1,345 mm/yr within the study area, as estimated using the SILO database (DES, 2022) at the nearby Georges Creek (BoM: 57011) station. Evaporation and rainfall data is provided in Figure 3.3, illustrating the lower than average rainfall proportional to the higher than average evaporation (drought period) until January 2020 and a distinct wetter period (higher than average rainfall and lower than average evaporation) since July 2021.

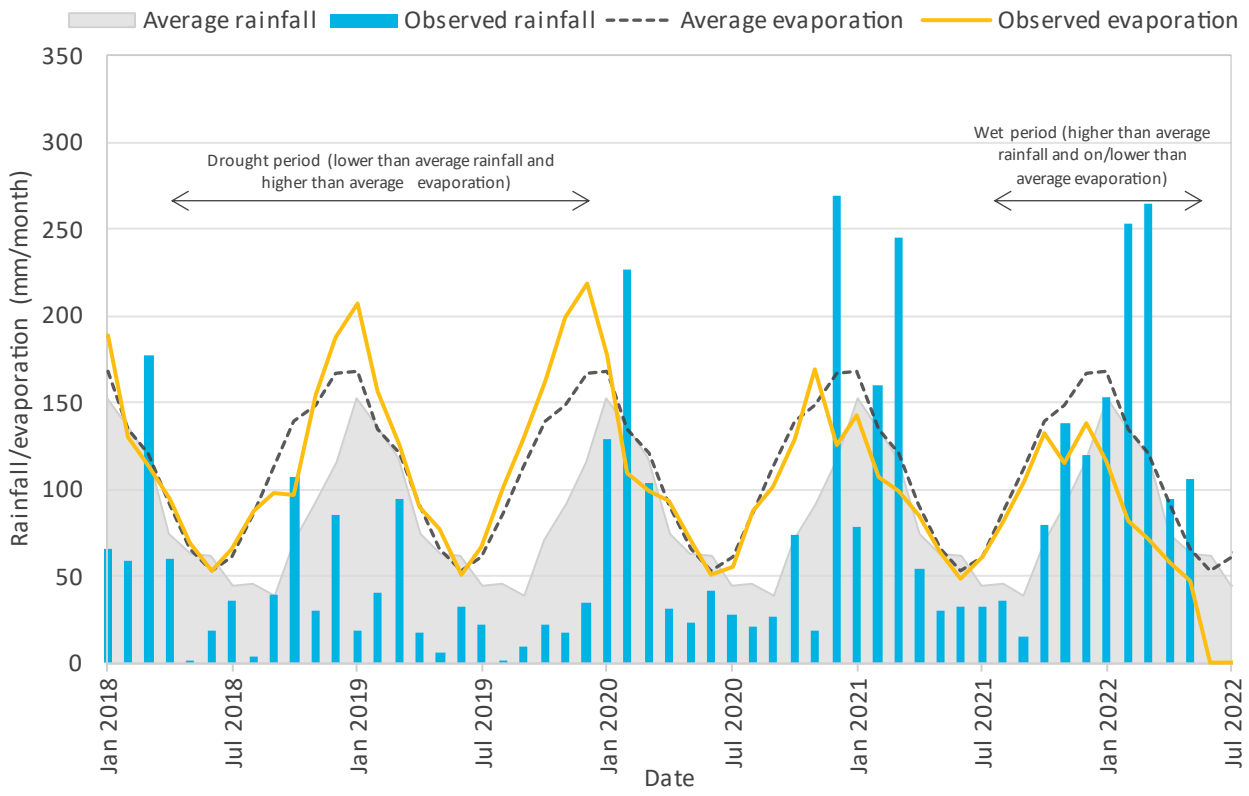


Figure 3.3 Monthly rainfall variability (Georges Creek SILO station) and mean monthly pan evaporation

3.4 Soils and geology

Based on publicly available Australian soil classification mapping data (DPIE, 2021), the soil groups mapped within the study area include Kandosols, Tenosols and Rudosols (refer Figure 3.4). In general, these soil groups are observed (DJPR, 2020):

- to be relatively shallow, with rock close to surface
- comprising minimal clay content (≤15%)
- exhibiting poor water holding capability.

Soils within the Project area are predominantly residual, with their composition influenced by the properties of the underlying rock unit. In general, residual soil overlying the:

- granitic rock (granodiorite, adamellite and monzogranite) typically comprising of pale grey, medium grained sand with minor clay inclusions
- metamorphic rock (hornfels and metasediments) typically comprising of dark grey, medium–high plasticity clay.

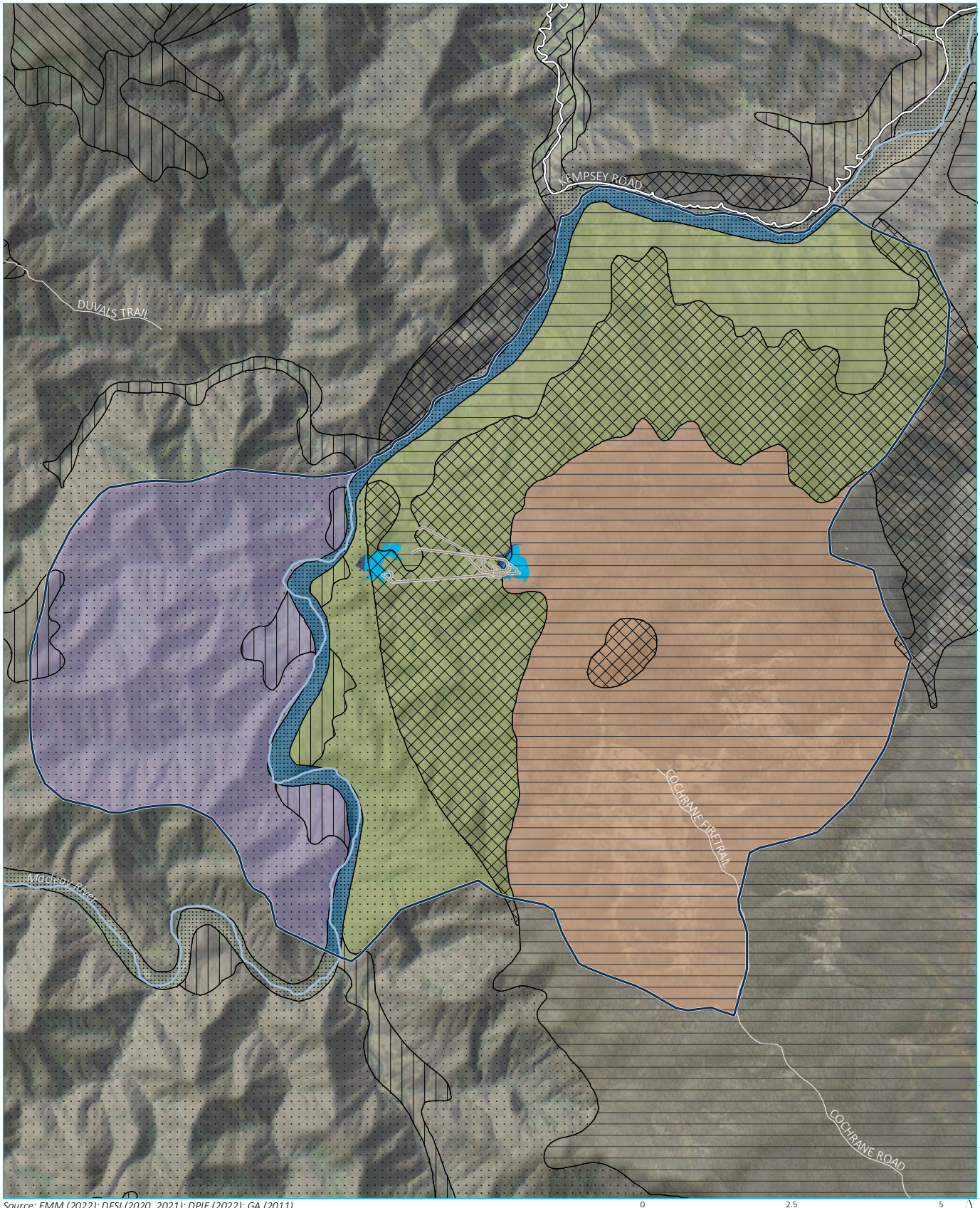
Deposits of alluvial and colluvial soils occupy the incised valleys which support the watercourses formed across the upper escarpment area (refer Section 3.2). The deposits become more substantial in the lower escarpment and plain area (further along the geomorphological profile of the streamline), reflecting the increased energy of the environment and wider catchment area, and generally comprise sub-rounded to rounded boulders, cobbles, gravel and sand. Further down the catchment, within the riparian corridor and along the fifth order Macleay River, the surficial geology is comprised of a relatively thin deposit of alluvium, comprising well rounded cobbles, gravel and sand.

The study area lies within the New England Orogen (NEO). The NEO extends approximately 2,000 km along the east coast of Australia from Townsville, QLD (north) to Newcastle, NSW (south), and is bordered by the Sydney-Gunnedah-Bowen Basin to the west (Jessop et al. 2019). Differing geodynamics in the early Permian to Triassic led to a series of linked pluton structures (known collectively as the New England Batholith) which intruded the sedimentary units of the Permian-aged Parrabel Beds and Carboniferous-aged Pee Dee Beds. The Triassic-aged Carrai Granodiorite; a plutonic structure outcropping over approximately 168 square kilometres (km^2), is the dominant geological unit occurring within the study area and a product of the New England Batholith.

A summary of the stratigraphy within the Project area is provided in Table 3.2. The distribution and extent of the relevant geological units to the study area are mapped and shown on Figure 3.5.

Table 3.2 Study area stratigraphy

Period	Formation	Typical description (Colquhoun et al. 2022)
Quaternary	Undifferentiated alluvial, colluvial sediments	Well sorted, coarse grained and oversized fractions at the base of the incised valleys and adjacent to the Macleay River. Generally, comprises localised deposits of cobbles and boulders at the base of the incised valleys, becoming more prevalent and continuous within the lower escarpment. Sands to cobbles more frequently observed within the Macleay Valley floodplain.
Triassic	Carrai Granodiorite	Coarse grained, felsic, crystalline igneous rocks including granodiorite, monzogranite and leucogranite. Relatively shallow weathering profile (≤9 m depth) and strength typically increasing with depth. Dominant geology underlying the study area.
Permian	Parrabel Beds	Fine to coarse grained sedimentary rocks including diamictite, conglomerate, sandstone, mudstone, limestone and tuff. Highly metamorphosed within the Project area by the Carrai Granodiorite intrusion, forming an aureole contact of hornfels and meta-sediments. Underlies the majority of the western catchment.
Carboniferous	Pee Dee Beds	Fine to coarse grained sedimentary rocks including slaty siltstone, lithic sandstone and minor diamictite. Likely metamorphosed near the Project area by Carrai Granodiorite intrusion, forming an aureole contact of hornfels and meta-sediments. Underlies the northern portion of the western catchment and a small component of the Macleay River floodplain.



Source: EMM (2022); DFSI (2020, 2021); DPIE (2022); GA (2011)

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KEY

- Study area
- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts

Existing environment

- Major road
- Minor road
- Macleay River

Focus area

- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

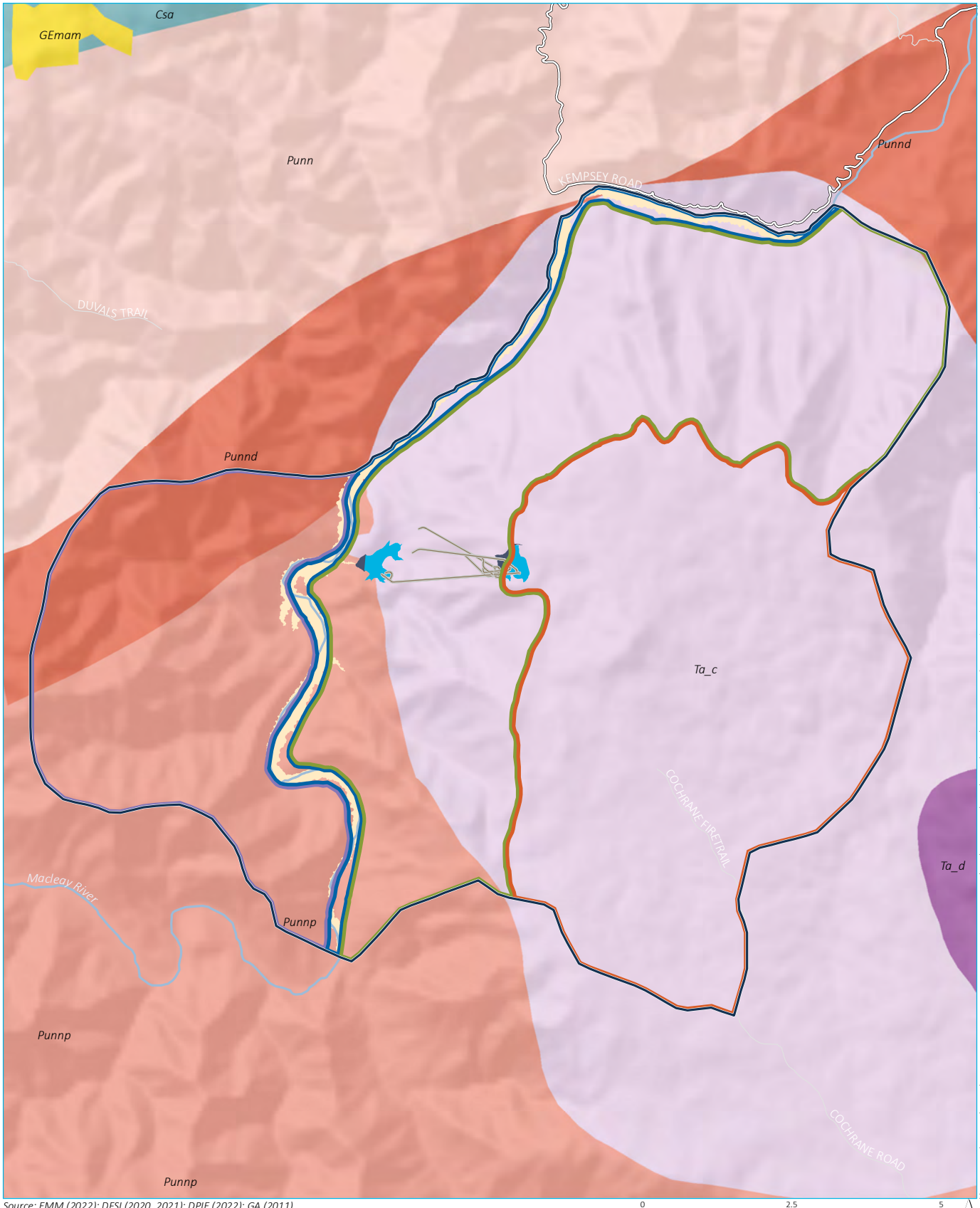
Soil type (ASC)

- Dermosols
- Ferrosols
- Kandosols
- Kurosols
- Rudosols
- Rudosols (alluvial)
- Tenosols

Soil distribution within the Carrai, NSW region

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Groundwater impact assessment
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Figure 3.4

EMM creating opportunities



Source: EMM (2022); DFSI (2020, 2021); DPIE (2022); GA (2011)

0 2.5 5 km

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KEY

Study area
Dam wall
Reservoir
Tunnels, portals, intakes, shafts
Inferred alluvium

Existing environment
Major road
Minor road
Macleay River

Focus area
Escarpment
Macleay River floodplain
Plateau
Western catchment

Surface geology (GSNSW)

Priabonian
Maybole Volcanics (GEmam)

Late Triassic
Carrai Granodiorite (Ta_c)
Daisy Plains Leucosyenogranite (Ta_d)

Permian
Nambucca beds (Punn)
Parrabel beds (Punnp)
Pee Dee beds (Punnd)

Carboniferous
Sandon Association (Csa)

Surface geology within the Carrai, NSW region

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Groundwater impact assessment
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Figure 3.5

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3.5 Surface water

The study area is located within the Macleay River catchment, covering approximately 11,400 km^2 from Armidale (on the Great Dividing Range of NSW) to Hat Head (on the east coast of NSW). The catchment generally comprises relatively impervious rock at the ground surface, leading to rapid water level and streamflow responses in the Macleay River following rainfall.

As described in Section 3.2, most of the surface water within the study area flows to the Macleay River via a series of watercourses. Based on a search of the NSW Hydrography database (DCS, 2022), the following perennial watercourses occur within the study area:

- Peach Tree Creek and Carrai Creek, originating in the upper escarpment and discharging to the Macleay River within the Macleay River floodplain
- Kunderang Station Creek, originating in the upper western catchment and discharging to the Macleay River within the Macleay River floodplain
- Three Rock Plain Creek and Little Three Rock Plain Creek, originating in the eastern plateau and discharging to the Macleay River outside (east) of the study area.

Ephemeral and intermittent streams discharge directly to the Macleay River or form upper tributaries to the perennial watercourses (refer Figure 3.1). The ephemeral streams typically flow for periods proportional to recent duration and magnitude of rainfall, with relatively high flow events evident from the transported boulders and vegetation. Intermittent streams flow for attenuated periods following rainfall, supported by groundwater discharge from localised groundwater systems across the plateau.

3.6 Groundwater

The study area largely comprises crystalline-igneous (Carrai Granodiorite) and metamorphic (metamorphosed Parrabel Beds/Pee Dee Beds) rocks associated with the NEO, forming a generally low permeability, fractured rock groundwater system, including a:

- shallow groundwater system, supporting:
  - vegetation (including eucalypts, grasses)
  - swamp areas (fens) and associated eco-systems
  - ephemeral streams, eventually discharging to the Macleay River
  - a small component of baseflow to the Macleay River
- deep groundwater system.

Localised groundwater systems are contained within the lower permeability soils associated with weathered rock across the plateau, and high permeability alluvium/colluvium within the lower escarpment, lower western catchment and Macleay River floodplain.

One groundwater bore (GW307320) is registered within the study area, located in the western catchment. The bore has intercepted a moderate yield (5 litres per second (L/s)) from within the shallow fractured rock groundwater system, providing typically fresh water for domestic use. Prospectivity for groundwater supply within the regional fracture rock groundwater system is typically low, with practical supply contingent on intercepting the infrequent fracture networks within the geology. No additional groundwater users are registered within 7 km of the study area (BoM, 2013).

3.6.1 Groundwater dependent ecosystems

Based on the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 (Groundwater WSP) (DPI, 2016b), no high priority GDEs are mapped within 12 km of the study area.

Based on the relevant high ecological value aquatic ecosystem (HEVAE) database (DPE, 2022a) and the GDE atlas (BoM, 2017), GDEs were identified within the study area. A summary of the high potential and high category (as defined by the BoM and HEVAE databases respectively) is provided in Table 3.3 and outlined on Figure 3.6.

Table 3.3 Desktop summary of high potential and high category groundwater dependent ecosystems

Category	Groundwater dependent ecosystem	Focus area	Source
Terrestrial	River Oak	Macleay River floodplain	[1]BoM GDE atlas
	Freshwater Wetland	Plateau	[1]BoM GDE atlas
	Sedgeland/rushland	Plateau	[1]BoM GDE atlas
	New England Tableland Carex Fens (PCT3944)	Plateau	[2]HEVAE database
	Eastern New England Granites Wet Heath (PCT3934)	Plateau	[2]HEVAE database
Aquatic	Macleay River	Macleay River floodplain	[1]BoM GDE atlas
	Floodplain wetland	Macleay River floodplain	[1]BoM GDE atlas
Subterranean	[3]No ecosystem analysed		[1]BoM GDE atlas

Notes: 1. (BoM, 2017)

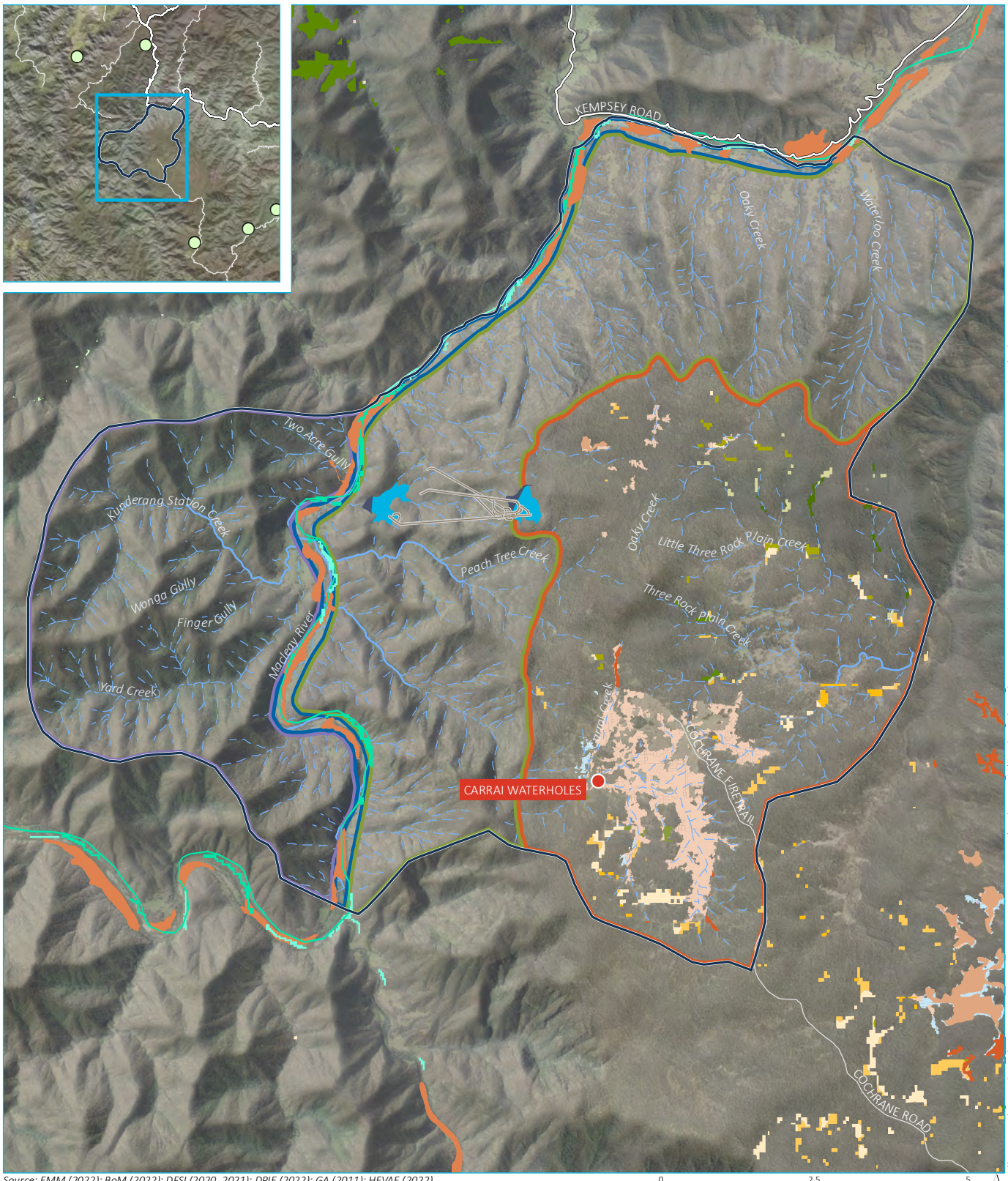
2. (DPE, 2022a)

3. Subterranean groundwater dependent ecosystem data not available within New South Wales (BoM, 2017).

Additional works were undertaken in the baseline monitoring program to further characterise GDEs within the study area, as discussed in the Project Groundwater Dependent Ecosystem assessment (EMM, 2023).

3.6.2 Groundwater relevant cultural areas

Based on a search of the NSW state heritage inventory (DPE, 2022b), the 'Carrai Waterholes' were identified as a declared area of cultural significance, with a potential for groundwater interaction. The approximate location of the Carrai Waterholes is provided on Figure 3.6.



Source: EMM (2022); BoM (2022); DFSI (2020, 2021); DPIE (2022); GA (2011); HEVAE (2022)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

- Study area
- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts

Focus area

- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

Existing environment

- Major road
- Minor road

Streams within study area

- Perennial
- Non-perennial
- Carrai Waterholes (approximately)
- High priority GDE

GDE - Terrestrial (HEVAE)

- Central Eastern Ranges Riparian Dry Rainforest
- Eastern New England Granites Wet Heath
- Far North Escarpment Granitoid Wet Heath
- New England Tableland Carex Fens
- Northern Gorges Diverse Grassy Forest
- Northern Gorges River Oak Forest
- Northern Hinterland Red Gum Grassy Forest
- Northern Hinterland Shatterwood Dry Rainforest

GDE Aquatic (BoM)

- High potential GDE - Maclaey River
- Moderate potential GDE - Macleay River

GDE Terrestrial (BoM)

Moderate potential GDE

- Alpine Gum
- Diehard Stringybark-New England Blackbutt
- Grassy New England Blackbutt-Tallowwood-Blue Gum
- Manna Gum
- Mid North Coast Wet Brushbox-Tallowwood-Blue Gum
- Moist Escarpment New England Blackbutt
- Snow Gum -Mountain/Manna Gum
- Sub-Tropical & Warm Temperate Rainforest
- Sub-Tropical Rainforest

High potential GDE

- Freshwater Wetland
- River Oak
- Sedgeland/Rushland

Groundwater dependent ecosystems and relevant cultural areas

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Figure 3.6

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3.7 Water resources

3.7.1 Surface water management and use

Surface water within the study area is managed under the Water Sharing Plan for the Macleay Unregulated and Alluvial Water Sources 2016 (Macleay WSP). The Macleay WSP covers 33 surface water sources (with connected alluvial groundwater systems, refer Section 3.7.2) and one floodplain alluvial groundwater source (DPI, 2016a), between Armidale and Hat Head. The extent of the Macleay WSP is outlined on Figure 3.8.

All streams within the Macleay WSP are classed as unregulated and users generally rely on natural flows for water supply, including Bellbrook and Willawarrin townships (located downstream of the Project).

Multiple weirs and small farm dams have been constructed throughout the Macleay WSP area including (Geoscience Australia, 2016):

- Steuart Mcintryre Dam, providing raw water supply for Kempsey, NSW
- Gara Dam, part of a former hydro-electric scheme operating 1895–1907 (Gojak, Giopoulos, & Dunnett, 1988)
- Oaky River Dam, part of a former hydro-electric scheme operating 1956–2013 (The Dam Zihni Built, 1998)
- Malpas Dam, providing raw water supply for Armidale, NSW
- Puddledock Creek Dam, providing raw water supply for Armidale, NSW.

The Project area straddles four water sources within the Macleay WSP (with further information provided in the Surface Water Impact Assessment (EMM, 2023a)), comprising the:

- Macleay Gorges Water Source, including 2 unit shares (also straddled by the study area)
- Macleay Valley Water Source, including 3,432 unit shares (also straddled by the study area)
- Dyke River Water Source, without any unit shares
- Georges River Water Source, without any unit shares.

Registered dams and Project relevant Macleay WSP water source boundaries are provided on Figure 3.7.

3.7.2 Groundwater management and use

Groundwater within the study area is managed under the Macleay WSP and the Groundwater WSP (DPI, 2016b).

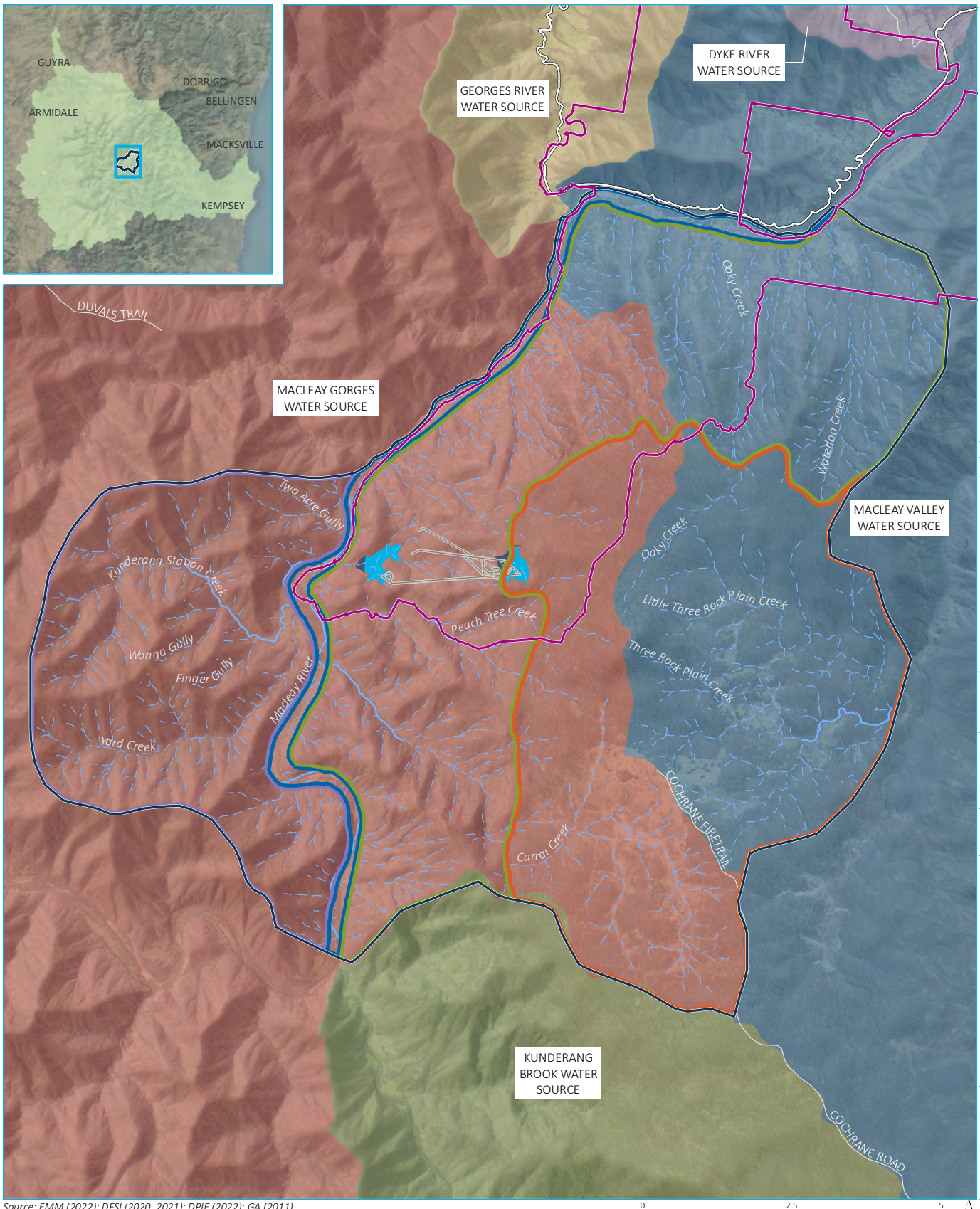
The Macleay WSP includes management measures for the water “contained within the alluvial sediments below the surface of the ground…” (DPI, 2016a), including the:

- Coastal Macleay Floodplain Alluvial Groundwater Source (135 ML of share components in the 2021/2022 water year)
- upriver alluvial sediments within the:
    - Macleay Valley Water Source (281 ML of share components in the 2021/2022 water year)
    - remaining water sources, within the Macleay WSP (0 ML of share components in the 2021/2022 water year).

Most groundwater extracted from the alluvial sediments is allocated for Kempsey Shire Council (KSC) town water supply. Groundwater is accessed via eight production bores within the Sherwood borefield, located approximately 11 km west of Kempsey, NSW (WaterNSW, 2022). Mapped upriver alluvial sediment boundaries are provided on Figure 3.8.

The Groundwater WSP covers 13 fractured and porous rock groundwater sources, located over approximately 69,400 km^2 between Gosford and the Queensland border. The study area is contained entirely within the New England Fold Belt Coast Groundwater Source (NEFB Coast Groundwater Source), with 15,899 ML of share components in the 2021/2022 water year.

The sub-surface Project infrastructure (tunnels, reservoirs, machine halls etc) will be entirely within the NEFB Coast Groundwater Source, as illustrated on Figure 3.8.



Source: EMM (2022); DFSI (2020, 2021); DPIE (2022); GA (2011)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

- Project area
- Study area
- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts

Focus area

- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

Existing environment

- Major road
- Minor road

Streams within study area

- Perennial
- Non-perennial

- Macleay WSP (see inset)

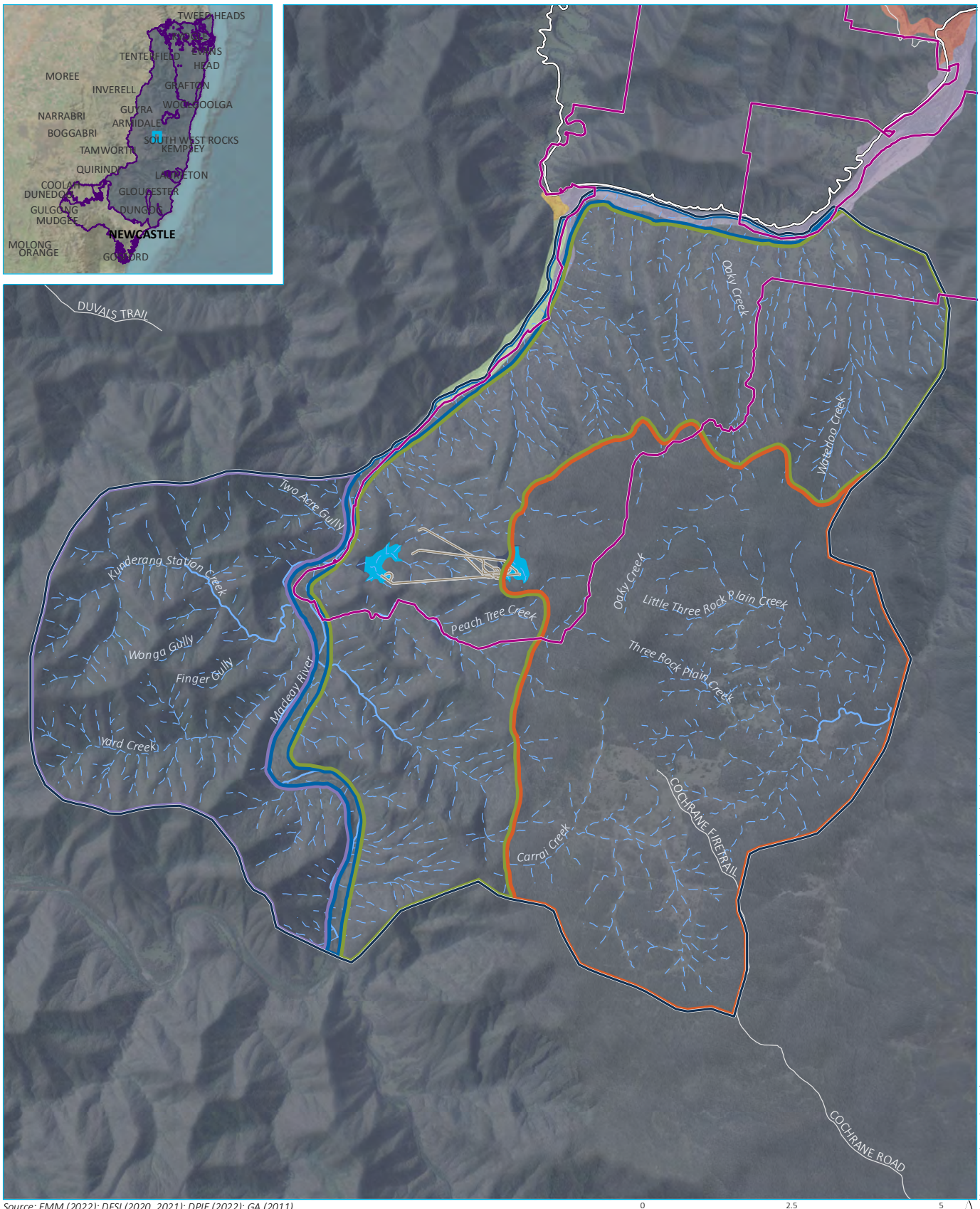
Surface water sources (Macleay WSP)

- Dyke River Water Source
- Georges River Water Source
- Kunderang Brook Water Source
- Macleay Gorges Water Source
- Macleay Valley Water Source

Surface water management and sources

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Figure 3.7

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Source: EMM (2022); DFSI (2020, 2021); DPIE (2022); GA (2011)

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KEY

- Project area
- Study area
- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts

Focus area

- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

Existing environment

- Major road
- Minor road

Streams within study area

- Perennial
- Non-perennial

Groundwater WSP

- North Coast Fractured and Porous Rock Groundwater Source 2016

Groundwater source (groundwater WSP)

- New England Fold Belt Coast Groundwater Source
- Unnamed Upriver Alluvium in WSP in the Dyke River Water Source
- Unnamed Upriver Alluvium in WSP in the Georges River Water Source
- Unnamed Upriver Alluvium in WSP in the Macleay Gorges Water Source
- Unnamed Upriver Alluvium in WSP in the Macleay Valley Water Source

Groundwater management and sources

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
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Figure 3.8

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4 Regulatory and policy context and assessment

The primary water related statutes that apply to the Project are the NSW *Water Management Act 2000* (WM Act), NSW *Water Act 1912* (Water Act), NSW *Protection of the Environment Operations Act 1997* (POEO Act), the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and their attendant regulations (including water sharing plans (WSPs) under the WM Act). Projects that intercept groundwater also need to consider the AIP (DPI, 2012), which requires the Project to hold licences that account for the volume of water intercepted and consider changes in water quality and water levels at sensitive receptors in accordance with prescribed minimal impact criteria.

4.1 NSW Water Act 1912

The Water Act is gradually being repealed and replaced by the WM Act as WSPs are developed for water sources across NSW, and as new regulations are made. Some aspects of the Water Act are still operational across all of NSW, such as the requirement to hold a licence for all monitoring bores greater than 40 m depth. OMPS is exempt under the NSW *Water Management (General) Regulation 2018* as the Project is declared CSSI.

4.2 NSW Water Management Act 2000

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

The WM Act provides for water sharing between different water users, including environmental, basic rights or existing water access licence (WAL) holders, and provides security for licence holders. The licensing provisions of the WM Act apply to those areas where a WSP has commenced.

4.3 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 [Project] 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) has been considered throughout this GIA, including during the development of:

- the baseline water monitoring network (refer Chapter 5)
- a groundwater characterisation (discussed in Chapter 6)
- the conceptual model (discussed in Chapter 7)
- an assessment approach (discussed in Chapter 8)
- the groundwater flow and quality impact assessments (discussed in Chapter 9 and 10 respectively)
- the management and mitigation measures to be implemented by the Project proponent (discussed in Chapter 11)
- the requirements for water licensing (discussed in Chapter 12).

4.3.1 Water sharing plans

WSPs are statutory documents that apply to one or more water sources. They contain the rules for sustainably sharing and managing water resources within water source areas. WSPs outline the vision, objectives and strategies for achieving sustainable water sharing, and describe the basis for water sharing. WSPs document the water available and how it is shared between environmental, extractive, and other uses. WSPs also outline the water available for extractive uses within different categories (at the time the plan commenced), such as: local water utilities, domestic and stock, basic rights, and access licences. WSPs establish trading rules and mandatory licence conditions that apply to licence holders within each water source.

The NSW Water Register is an online database that contains the most current information available on licence volumes, within different licence categories which may change over time.

The WSPs, associated water sources, available water, basic rights and licence shares as outlined in the WSPs applicable to the Project area are outlined in Table 4.1.

Table 4.1 Available water, basic rights and licence shares

WSP	Groundwater WSP[1]	Macleay WSP[2]			
Water source	**New England Fold Belt Coast groundwater source**	**Macleay Gorges water source**	**Macleay Valley water source**	**Dyke River water source**	**Georges River water source**
Long-term average annual rainfall recharge, as per the relevant WSP ([3]ML/yr)					
High environmental value areas	480,000	Not applicable			
Not high environmental value areas	1,500,000				
Total long-term average annual rainfall recharge (LTAARR)	1,980,000				
Planned environmental water, as per the relevant WSP ([3]ML/yr)					
High environmental value areas	480,000[4]	Not applicable			
Not high environmental value areas	1,440,000[5]				
Total planned environmental water	1,920,000				
Long-term average annual extraction limit, as per the relevant WSP ([3]ML/yr)					
Long term average annual extraction limit (LTAAEL)	60,000 (~3% of LTAAR)	Not applicable			
Requirements for share components, as per the relevant WSP ([3]ML/yr)					
Domestic and stock rights	9,605	14	483	8	8
Native title	0	0	0	0	0

Table 4.1 Available water, basic rights and licence shares

WSP	Groundwater WSP[1]	Macleay WSP[2]			
Water source	**New England Fold Belt Coast groundwater source**	**Macleay Gorges water source**	**Macleay Valley water source**	**Dyke River water source**	**Georges River water source**
Share components, as per the NSW Water Register at the conclusion of the 2021/2022 water year (share components/year)					
Domestic and stock	0	0	8	0	0
Aquifer	15,639	0	281	0	0
Local water utility	240	0	0	0	0
Local water utility (unregulated)	-	0	41	0	0
Local water utility (groundwater)	0	0	10,100	0	0
Unregulated river	-	2	3,379	0	0
Total requirements for share components (ML/yr[6])	**25,484**	**16**	**14,292**	**8**	**8**
Unassigned share components (LTAAEL minus total requirements for water, ML/yr[3])	**34,516**	**0**	**0**	**0**	**0**
Total registered water usage in the 2021/2022 water year	**133.1**	**0**	**2,420.3**	**0**	**0**

Notes:
1. Water Sharing Plan for the Macleay Unregulated and Alluvial Water Sources 2016.
2. Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016.
3. Megalitres per year.
4. Equivalent to 100% of the relevant LTAAR for high environmental value areas.
5. Equivalent to 96% of the relevant LTAAR for high environmental value areas.
6. Equal to one megalitre per year (ML/yr), unless a reduced available water determination is made for the water source.

The NEFB Coast Groundwater Source is approximately 43% allocated, with an additional 34,516 share components (each equivalent to 1 ML when water determinations are not reduced) of water potentially available for release (DPI, 2016b). The releases of additional share components are made available via a controlled allocation approximately every 12–18 months, where users can apply and if successful, purchase water allocations directly from the NSW Government (further discussed in Section 4.3.2).

Surface water licences required for Project construction and operation are discussed in the Surface Water Impact Assessment (EMM, 2023a).

i Environmental water

Planned environmental water is prescribed within a WSP to protect the aquifer and GDEs (planned environmental groundwater) or the river and streams systems and associated ecosystems (planned environmental surface water). For groundwater, environmental water is typically defined as 100% of the storage volume plus a proportion of the annual recharge volume.

Within the groundwater WSP, the proportion of annual recharge reserved for environmental water is categorised within (DPI, 2016b):

- 'high environmental value' areas as 100% of annual recharge (within the high environmental areas)
- 'not high environmental value' areas as 96% of annual recharge (within the not high environmental areas).

The total volume of annual recharge reserved for environmental water as per the WSPs, is reported as 1,920,000 ML/yr for the NEFB Coast Groundwater Source (~97% of average annual recharge reserved).

4.3.2 Water availability and licences

The volume of available water for licences within the relevant water sources within the Project area represent a relatively small percentage of the overall availability of water. The groundwater source is typically not highly productive and groundwater abstraction within the geological units is predominantly for stock and domestic purposes. The groundwater availability and licences for the NEFB Coast Groundwater Source are shown on Figure 4.1.

The actual measured and recorded groundwater usage for the 2021/22 water year was minimal (133.1 ML, or 0.002% of the LTAAEL). Therefore, there are large volumes of water unassigned within these water sources available to be granted.

Share components for a WAL can be granted by the NSW Government where the right to apply for the licence has been acquired in accordance with a controlled allocation order (CAO) made under Section 65 of the WM Act. Section 65 (1) provides that:

> The Minister may, by order published in the Gazette, declare that the right to apply for an access licence for a specified water management area or water source is to be acquired by auction, tender or other means specified in the order.

Under the AIP, OMPS will need to hold adequate share components to license the equivalent volumes of water intercepted each year. When submitting an EIS for a project, there needs to be a demonstrated pathway for the peak water demand to be obtained from the source to which it originates. The numerical groundwater model (Chapter 9) demonstrates that water inflow (intercepted during subsurface infrastructure construction and operation) will be sourced from the NEFB Coast Groundwater Source.

OMPS has acquired 232 share components and successfully bid the remaining 175 unit shares within the NEFB Coast Groundwater Source, purchased through the 2021 and 2022 CAOs. This volume covers the peak predicted direct take anticipated to be intercepted by the Project (refer Table ES1).

OMPS will meter actual groundwater inflow to the Project, consistent with Policy requirements, to validate that direct take remains below the peak predicted annual direct take of 407 ML. Should actual inflow exceed this then OMPS will enter the trading market to acquire additional share entitlement, noting that the NEFB Coast Groundwater Source contains a significant portion of unassigned water available for purchase.

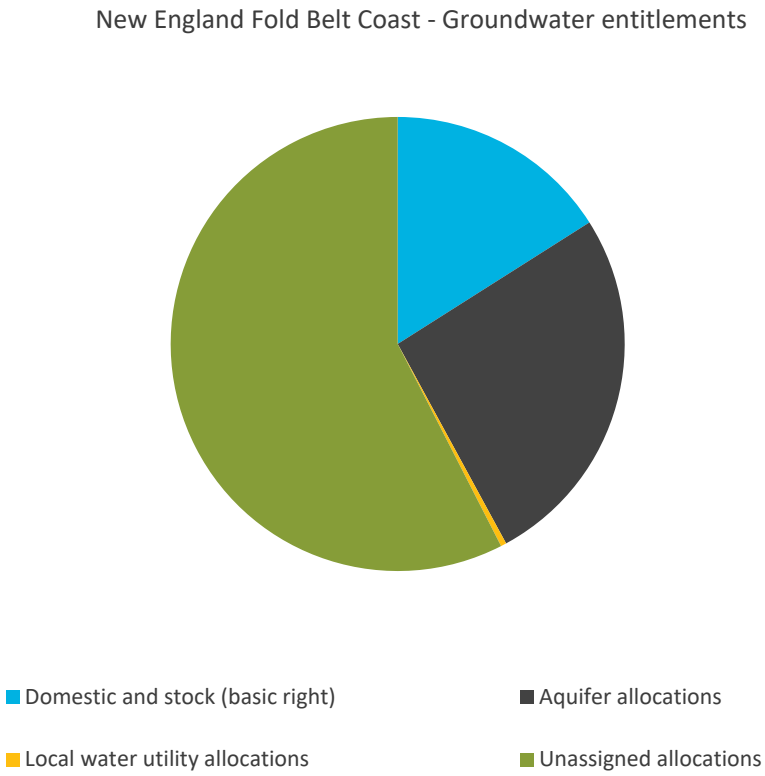


Figure 4.1 Groundwater availability – New England Fold Belt Coast groundwater source

4.3.3 NSW Aquifer Interference Policy

The dictionary to the WM Act (under Section 91) defines an 'aquifer interference activity' as an activity involving any of the following:

- penetration of an aquifer
- interference with water in an aquifer
- obstruction of the flow of water in an aquifer
- taking of water from an aquifer in the course of carrying out mining, or any other activity prescribed by the regulations
- disposal of water taken from an aquifer in the course of carrying our mining or any other activity prescribed in the regulations.

Section 91 (3) of the WM Act relates to aquifer interference approvals. The requirement to obtain an aquifer interference approval under Section 91 is triggered only when a proclamation has been made under Section 88A that the particular type of approval is required. To date, no proclamation has been made specifying that an aquifer interference approval is required in any part of NSW. This is expected to remain the case for the Project.

In the meantime, the AIP sets the policy with respect to aquifer interference. The policy explains the role and requirements of the Minister in determining applications for aquifer interference activities. The aquifer interference assessment framework is included (and completed) in Chapter 13.

The AIP specifically refers to 'take' that is 'required to allow for the effective and safe operation of an activity, for example dewatering to allow mining' (DPI, 2012) regardless of whether the take will be used. The take, use, and incidental interception of groundwater requires a licence. The AIP states that, unless specifically exempt, a WAL is required under the WM Act where any act by a person carrying out an aquifer interference activity causes:

- the removal of water from a water source
- the movement of water from one part of an aquifer to another part of an aquifer
- the movement of water from one water source to another water source, such as:
    - from an aquifer to an adjacent aquifer, or
    - from an aquifer to a river/lake, or
    - from a river/lake to an aquifer.

The AIP defines water sources as being either 'highly productive' or 'less productive', where groundwater sources are generally considered highly productive if:

- groundwater salinity is less than 1,500 milligrams per litre (mg/L)
- yield from groundwater bores are generally greater than 5 litres per second (L/s).

DPE-Water provides indicative distributions of the highly productive and less productive groundwater sources in NSW (DPI-Water, 2013). The AIP further defines water sources by their general geological composition, being one of alluvium, coastal sand, porous rock, or fractured rock.

For each category of water source, the AIP identifies thresholds for minimal impact considerations. These thresholds relate to water table impacts, water pressure and water quality, and are ranked as being either 'level 1 minimal impact' or 'level 2 exceeding minimal impact'. The definition of 'minimal impact' is outlined in a series of tables which demonstrate how the criteria are applied for different types of water sources and for different sensitive receptors (i.e. other users and ecosystems).

Based on mapped areas of groundwater productivity in NSW (DPI-Water, 2013), the Project area is considered to be within a 'less productive' fractured rock source. The applicable minimal impact considerations are shown in Table 4.2.

If the impact of an activity is assessed as being 'Level 1: minimal impact', then the Project is considered to have impacts that are acceptable. Where the predicted impacts exceed the Level 1 thresholds by no more than the accuracy of the model, then this is considered as having impacts within the range of acceptability and extra monitoring or mitigation or remediation will be required during operations.

Where the predicted impact of an activity is assessed as being 'Level 2' or 'greater than minimal impact', additional studies are required to fully understand the predicted impacts. If the assessment shows that the predicted impacts, although greater than 'minimal', do not prevent the long-term viability of the relevant water-dependent asset, then the impacts will be considered to be acceptable.

Where impacts are predicted to be 'greater than minimal impact' and the long-term viability of the water-dependent asset is compromised, the impact is subject to make good provisions.

AIP Fact Sheet 4 (NOW 2013b) outlines how a minimal impact is to be considered. It describes how the minimal impact criteria are applied to both a water supply work and a GDE defined in a WSP. This fact sheet also defines the term 'make good provisions' as the requirement to ensure that third parties with water supply works have access to an equivalent supply of water through enhanced infrastructure or other means, for example deepening an existing bore, compensation for extra pumping costs or constructing a new pipeline or bore.

Table 4.2 Minimal impact criteria for 'less productive' porous and fractured rock water sources

Watertable	Water pressure	Water quality
1. Less than or equal to 10% cumulative variation in the watertable, 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 watertable, 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.

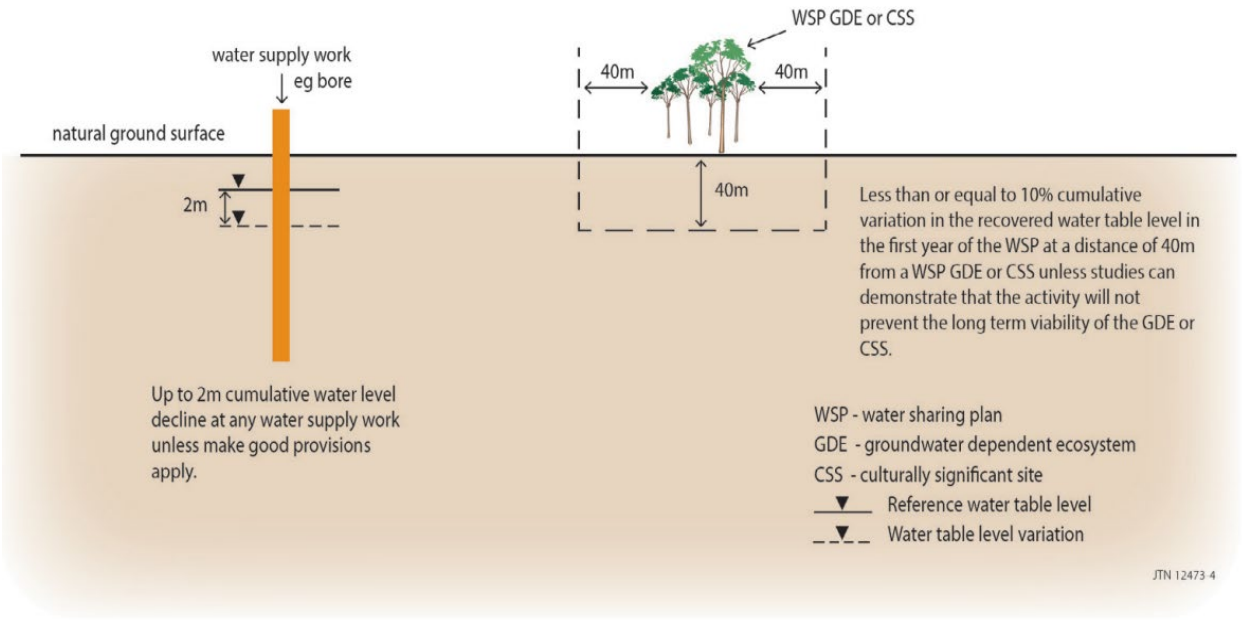


Figure 4.2 Fractured rock groundwater source minimal impact considerations

The AIP requires that two years of baseline groundwater data be collected and incorporated into an impact assessment before lodging an activity development application. An extensive groundwater monitoring network has been installed for the Project in consultation with DPE-Water, including:

- eight conventional groundwater monitoring bores
- three shallow fen monitoring bores

- one existing landholder bore.

The baseline monitoring program commenced in August 2020 (over two years prior to the submission of the EIS) and is ongoing. Further discussion on the baseline monitoring program is provided in Chapter 5.

4.4 NSW Protection of the Environment Operations Act 1997

The POEO Act is the key piece of environment protection legislation administered by the NSW Environment Protection Authority (EPA). The POEO Act enables the government to set protection of the environment policies that provide environmental standards, goals, protocols, and guidelines. It also establishes a licensing regime for pollution generating activities in NSW. Under Sections 47 and 48 of the POEO Act, an environment protection licence (EPL) is required for 'scheduled development work' and 'scheduled activities', respectively, which include electricity generation and wastewater treatment. Accordingly, an EPL for the Project will be applied for.

In accordance with Section 5.24 of the EP&A Act, an EPL cannot be refused if it is necessary for carrying out approved SSI (and CSSI, by extension) and is to be consistent with the approval, should it be granted by the NSW Minister for Planning. The POEO Act also includes a duty to notify relevant authorities of pollution incidents where material harm to the environment is caused or threatened.

4.5 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The EPBC Act provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities, and heritage places, which are defined as matters of national environmental significance.

On 27 November 2020, OMPS submitted a referral for a proposed action to the Commonwealth Department of Agriculture, Water and the Environment (DAWE, now Commonwealth Department of Climate Change, Energy, the Environment and Water (DCCEEW)) under the EPBC Act for the Project (EPBC Ref: 2020/8850). This referral considered impacts to matters of MNES and the environment generally and detailed that the Project would potentially have a significant impact on MNES, including national heritage places, listed threatened species and ecological communities and listed migratory species. The referral also identified that the Project would have a potentially significant impact on the environment, as defined under the EPBC Act.

Due to the potential impacts of the Project on MNES and the environment, an accredited assessment process was sought under Section 87(4) of the EPBC Act, where the Commonwealth accredits the assessment process under Division 5.2 of the EP&A Act. On 1 February 2021, the DAWE Assistant Secretary provided notification of its referral decision and designated proponent, determining that the Project's action was a controlled action and is to be assessed by accredited assessment process under Part 5, Division 5.2 of the EP&A Act. A variation to the Project's action was approved on 23 December 2022 to include the transmission and EAR (which did not form part of the original referral).

As part of the accredited assessment process, DAWE assessment requirements have been included in the SEARs.

4.6 Relevant NSW plans, policies and guidelines

Several other guidelines and policies relevant to the water assessment are discussed in the following sections.

4.6.1 State Groundwater Policy Framework Document

The NSW State Groundwater Policy Framework Document (DLWC, 1997) aims to manage the groundwater resources of the state so they can sustain environmental, social, and economic outcomes for the people of NSW. The policy will be considered in resource management decisions made in NSW.

The document is a framework for the following three policies:

- NSW State Groundwater Quantity Management Policy (2001 (unpublished))
- NSW State Groundwater Quality Protection Policy (DLWC, 1998)
- NSW State Groundwater Dependent Ecosystem Policy (DLWC, 2002).

This policy establishes the overarching principles for the management of groundwater in NSW, which still remains valid more than twenty years after its inception. The principles of sustainability across the three environmental, social, and economic aspects are still referenced in modern water policies released by the NSW Government.

The Project and applied mitigation strategies will considerably minimise groundwater inflow and overall groundwater impacts (see Chapter 11). The design of the Project will closely follow the NSW State Groundwater Policy Framework Document objectives of achieving beneficial environmental, social, and economic outcomes for the state of NSW.

4.6.2 Risk assessment guidelines for groundwater dependent ecosystems

The Risk assessment guidelines for groundwater dependent ecosystems (Serov, Kuginis, & Williams, Risk assessment guidelines for groundwater dependent ecosystems, 2012) (GDE Risk Assessment Guidelines) are adopted by the DPE, establishing the requirements for assessment and management of GDEs under the WM Act. The dictionary to the Groundwater WSP provides that:

> groundwater dependent ecosystems include ecosystems which have their species composition and natural ecological processes wholly or partially determined by groundwater.

The GDE Risk Assessment Guidelines provide that GDEs:

> explicitly include any ecosystem that uses groundwater at any time or for any duration in order to maintain its composition and condition.

An ecosystem's dependence on groundwater can be variable, ranging from partial and infrequent dependence, i.e. seasonal or episodic (facultative), to total continual dependence (entire/obligate) (see Figure 4.3).

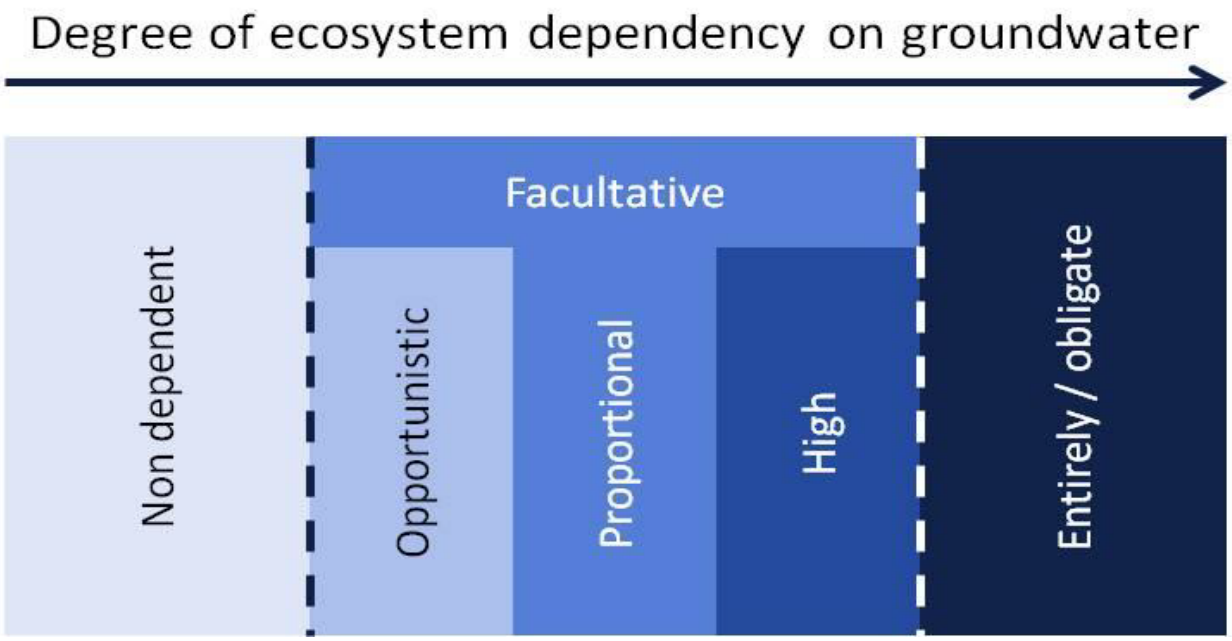


Figure 4.3 Ecosystem level of dependence on groundwater

A GDE risk assessment has been completed for the Project in accordance with the GDE Risk Assessment Guidelines. The assessment has been detailed in the Biodiversity Development Assessment Report (EMM, 2023b) and Aquatic Ecology Impact Assessment (Stantec, 2022), and is summarised in the Project Groundwater Dependent Ecosystem assessment (EMM, 2023).

The process for identification, assessment and risk mitigation (where required) has been documented in Figure 4.4.

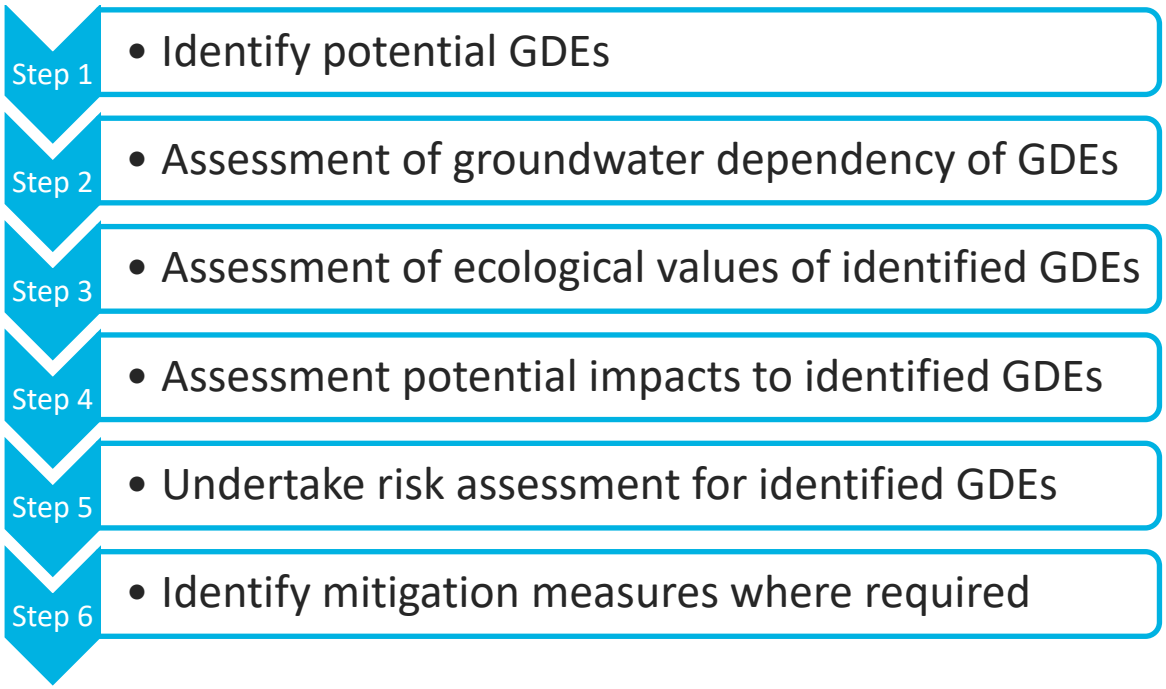


Figure 4.4 GDE risk assessment

Ecosystems that may rely on either the surface or subsurface expression of groundwater within or surrounding the Project area are those associated with:

- watercourses where groundwater is discharging and provides baseflow, including the Macleay River and ephemeral streams across the escarpment
- springs (providing flow to the ephemeral streams) across the escarpment
- terrestrial vegetation overlying shallow groundwater (within the vegetation root zone).

These ecosystems have been classified into three categories according to their dependence on groundwater:

- non-dependent
- facultative:
  - opportunistic
  - proportional
  - highly dependent
- entirely dependent/obligate.

Considerations in evaluating plant community types (PCT) and their potential dependency on groundwater included the:

- physiology of plant species that occur in the community and the likely dependence on groundwater availability
- location of PCTs in the landscape
- rooting depth of vegetation, further considering the potential for access to groundwater based on likely aquifer depth and soil characteristics.

Groundwater access is predominantly dependant on the depth to the watertable. As terrestrial vegetation communities are composed of a range of vegetation types with a range of rooting depths and strategies, there is generally a relationship between groundwater depth and the types and composition of the vegetation that is able to access it (Serov, Kuginis, & Williams, Risk assessment guidelines for groundwater dependent ecosystems, 2012).

4.6.3 NSW Wetlands Policy

The NSW Wetlands Policy (DECCW, 1996) provides for the protection, ecologically sustainable use and management of NSW wetlands.

A wetland is defined as areas of land that are wet by surface and/or groundwater for a sufficient period that plants and animals adapt to and depend on that moisture for at least part of their life cycle. Wetlands can be permanent or ephemeral. The policy contains 12 guiding principles focused on conservation, water and land management, sustainability, prioritisation of significant wetlands, recognition of wetlands' cultural significance, climate change, protection, and reporting.

As discussed in the Aquatic Ecology Impact Assessment (Stantec, 2022) and in accordance with the NSW Wetlands Policy, no wetlands have been identified within the study area, as per the:

- Directory of Important Wetlands in Australia (Environment Australia, 2001)
- Australian Ramsar Wetlands database (DAWE, 2021).

4.7 Relevant Commonwealth policy and guidelines

4.7.1 Australian Groundwater Modelling Guidelines

The Australian Groundwater Modelling Guidelines (Barnett, et al., 2012) provide a consistent and sound approach for the development of groundwater flow models in Australia. The guidelines 'propose a point of reference and not a rigid standard' and provide direction on scope and approaches while acknowledging that techniques are continually evolving, and innovation is to be encouraged. The guidelines provide a confidence-based classification system that defines three different classes of model:

- class 1 – low confidence in model predictions, suitable for use in low value resource or low risk developments
- class 2 – high confidence in model predictions, suitable for use in high value resources or projects with medium to high risk developments
- class 3 – high confidence in model predictions, suitable for use in high value resources and projects such as regional sustainable yield assessments.

The guidelines provide information on the data requirements for each model class, such as spatial distribution of bores and temporal groundwater level data. Groundwater resource assessments at major development sites generally require the use of a class 2 model. The onerous data requirements to achieve a class 3 model (i.e. reliable metered extraction and the duration of the prediction to be not more than three times the calibration data period) mean that for most projects at the planning assessment phase in NSW a full class 3 model is practically unattainable.

The numerical groundwater model developed to predict potential impacts of the Project is best described as a class 1 model, however many elements of the model meet the characteristics of a class 2 model, with further discussion provided in Section 9.1. DPE-Water were consulted during the development of the numerical groundwater model. The numerical model has been prepared in accordance with the Australian Groundwater Modelling Guidelines and peer reviewed using the structure of the 'review checklist'.

4.7.2 Australian and New Zealand Guidelines for Fresh and Marine Water Quality

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Agriculture and Resource Management Council of Australia and New Zealand and the Australian and New Zealand Environment and Conservation Council (ANZECC & ARMCANZ) describe the water quality objectives for marine and freshwater environments, aquatic ecosystems, primary industries, and recreational water (ANZECC & ARMCANZ, 2000).

The guidelines should be considered when setting water quality objectives for natural and semi-natural water resources in Australia and New Zealand sustaining current or likely future environmental values/uses (EV), as required under Section 96(3A) of the POEO Act (OEH, 1997). The ANZECC guidelines also set out a framework for the application of water quality trigger levels, relevant to maintaining ecosystem condition.

The guidelines are a generic reference and should be used accordingly, i.e. only as a default reference. It is recommended to collect and use site-specific baseline data to establish baseline conditions and develop trigger levels. Project impacts should be assessed using site-specific baseline data and not the generic guidelines, where sufficient (typically >24 months) baseline data allows.

Further revisions to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality were made in 2018 with the release of a web-based guideline (ANZECC & ARMCANZ, 2018). The revised default guideline values for chemical contaminants/toxicants that are relevant to the Project area are consistent with levels presented in the earlier water quality objectives (ANZECC & ARMCANZ, 2000). Physical and chemical stressors have not yet been released for the ecoregion that contains the Project area.

Water quality objectives and EVs have been established in accordance with the ANZECC guidelines (ANZECC & ARMCANZ, 2000) for the Project (and in accordance with Section 4.7.3).

4.7.3 Australian Drinking Water Guidelines

The Australian Drinking Water Guidelines (ADWG) (NHMRC & NRMMC, 2011) provide a framework for sustainable management of drinking water supplies that, if implemented, will assure safety at point of use. The ADWG have been developed after consideration of the best available scientific evidence and are designed to provide an authoritative reference on what defines safe, good quality water, how it can be achieved and how it can be assured.

Drinking water is defined as water intended primarily for human consumption, either directly, as supplied from the tap, or indirectly, in beverages, ice or foods prepared with water. Drinking water is also used for other domestic purposes such as bathing and showering.

The ADWG guidelines should be considered when setting water quality objectives for water receptors that may be used for potable supply and support likely future EVs, as required under Section 96(3A) of the POEO Act (OEH, 1997). The ADWG guidelines also provides a framework for the application of water quality trigger levels, relevant to maintaining water receptors potentially used for drinking water supply.

The ADWG include two categories for guideline values:

- A health-related guideline value, which is the concentration or measure of a water quality characteristic that, based on present knowledge, does not result in any significant risk to the health of the consumer over a lifetime of consumption.

- An aesthetic guideline value, which is the concentration or measure of a water quality characteristic that is associated with acceptability of water to the consumer; for example, appearance, taste and odour.

ADWG guideline values and EVs have been applied to establish water quality objectives for the Project, in-line with the methodology outlined in the ANZECC & ARMCANZ guidelines (refer Section 4.7.2), where applicable.

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

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

The guidelines EVs and water quality objectives, have been referenced in Section 10.2.

5 Baseline monitoring program

5.1 Overview

Baseline monitoring is an essential component in characterising the pre-existing groundwater conditions within the study area. Baseline water level and quality data obtained during the monitoring has facilitated the development and validation of a conceptual and numerical model, as well as supporting discussion on:

- water chemistry
- water flow mechanisms
- water recharge and discharge characteristics
- groundwater-surface water connectivity.

The water monitoring network (the network) was designed and monitored by EMM to establish a baseline dataset for the Project. The network was designed to capture data considering geological, spatial and temporal variations. The network was developed in consultation with DPE-Water, supporting a groundwater assessment in accordance with the AIP (DPI, 2012).

Groundwater and surface water monitoring commenced in August 2020 (and is currently ongoing), with increased monitoring as additional locations were identified or constructed. An overview of the baseline monitoring program is provided in Section 5.2.

5.2 Water monitoring network

5.2.1 Summary

The groundwater monitoring network included:

- eight conventional groundwater monitoring bores
- three shallow fen monitoring bores
- one existing landholder bore
- seven boreholes
- eleven springs
- one seep.

A summary of the groundwater monitoring bore and groundwater spring network is provided in Table 5.1 and Table 5.2 respectively.

The groundwater monitoring network was supplemented with surface water monitoring sites, comprising:

- six locations within the Macleay River
- one location within a second order ephemeral stream
- one location within an upper tributary of the Macleay River catchment (east of Armidale, NSW).

A summary of the supplementary surface water monitoring locations is provided in Table 5.3.

Monitoring sites were positioned to provide spatial coverage, investigate the dominant geologies and groundwater environments, and monitor potentially sensitive features. Specifically, the groundwater monitoring network was designed to:

- identify and characterise water bearing units in the study area, with focus on characterising groundwater flow and quality
- identify and characterise the different geological units in the study area, with a focus on characterising groundwater flow and quality
- establish baseline groundwater
- provide spatial representation and flux of pressure heads across the Project area to investigate potential vertical hydraulic gradients and connectivity between water bearing units
- investigate the potential for surface water–groundwater interaction
- understand and monitor potential sensitive features, including surface watercourses and water levels in potential GDEs.

The groundwater monitoring network includes both background (regional) monitoring locations and targeted monitoring locations along the alignment of the key Project infrastructure. The groundwater monitoring bore network was installed in a drilling campaign between September 2021 and July 2022). Bore completion reports are available in Attachment A.

The groundwater data collection commenced in August 2020 at certain sites. Additional locations were included in the network as they were completed.

Table 5.1 Summary of groundwater monitoring bore sites

Target formation	Bore ID	Easting (GDA20)	Northing (GDA20)	Top of casing (mAHD)[1]	Total depth (mBGL)[2]	Screen interval (mBGL)[2]		Screened lithology
						Top	Base	
Boreholes								
Carrai Granodiorite	OM1	421606.50	6591183.10	890.60	49.80	0.00	49.80	Hornfels
	OM2	421691.80	6591318.60	881.70	50.00	0.00	50.00	Hornfels
	OM3	421793.20	6591463.00	846.10	50.30	0.00	50.30	Hornfels
	OM4	421936.00	6591542.30	899.70	49.67	0.00	49.67	Granite
	OM5	421990.00	6591228.60	891.40	30.00	0.00	30.00	Leucogranite
Parrabel Beds	OM6	419231.90	6591557.20	213.00	50.00	0.00	50.00	Meta-sediment
	OM7	419232.80	6591427.10	209.20	50.10	0.00	50.10	Meta-sediment
Monitoring bores								
Carrai Granodiorite	MB01A	419853.60	6593143.50	183.90	36.50	28.50	34.50	Granodiorite
	MB02A	420108.50	6592190.80	303.50	34.50	25.60	31.60	Granodiorite
	MB02B	420094.00	6592175.20	301.50	187.00	173.50	185.50	Granodiorite
Carrai Granodiorite	MB04A	423003.90	6591263.90	972.70	10.50	6.35	9.35	Sand (residual soil)
	MB04B	422999.70	6591259.00	972.50	60.50	46.70	58.70	Granodiorite
	BH4A	421495.5	6591273.5	884.50	77.70	63.80	75.80	Hornfels
Parrabel Beds	MB03A	418650.90	6591232.30	167.30	23.00	15.00	21.00	Hornfels
	MB03B	418645.80	6591223.60	167.80	100.00	86.00	98.00	Phyllite and hornfels
Fen monitoring bores								
Carrai fen[3]	HA2201	422747.60	6592351.50	922.80	1.00	0.50	1.00	Clayey sand (residual soil)
	HA2202	422783.70	6592443.80	931.00	0.90	0.40	0.90	Sandy clay (residual soil)
	HA2203	422925.50	6592371.30	935.10	1.00	0.50	1.00	Sandy clay (residual soil)
Production bores								
Parrabel Beds	GW307320	[4]418259	[4]6590097	[4]183	58.00	30.00	58.00	Quartz shale; weathered

Notes: 1. MAHD = metres Australian Height Datum.
2. mBGL = metres Below Ground Level.
3. Interpreted surficial formation.
4. Interpreted from geographical software.

Table 5.2 Summary of groundwater spring monitoring sites

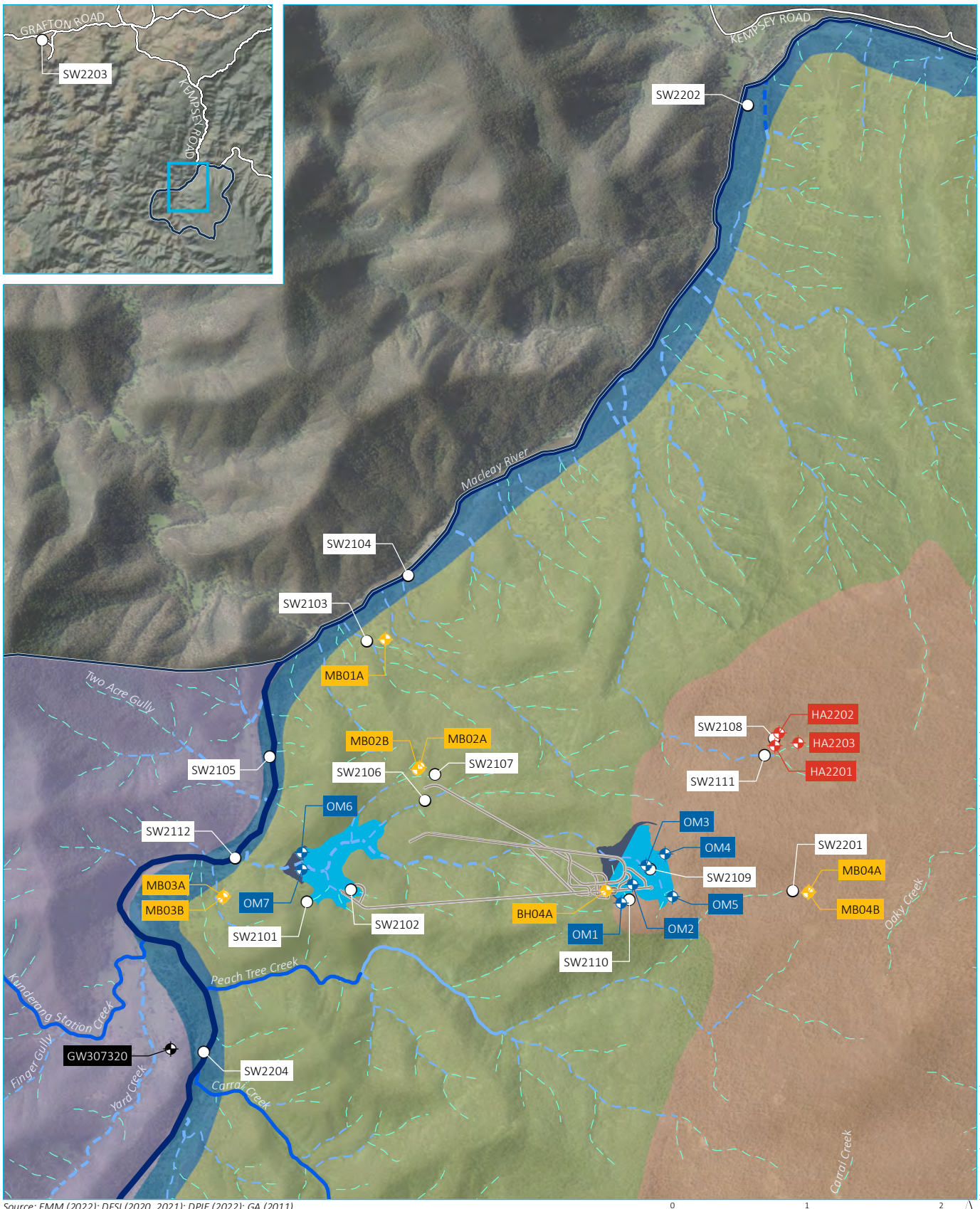
Spring ID	[1]Target	[2]Easting (GDA94)	[2]Northing (GDA94)	[2]Elevation ([3]mAHD)
SW2101	First order stream	419271	6591188	269
SW2102	First order stream	419598	6591279	244
SW2103	Second order stream	419717	6593130	172
SW2106	Second order stream	420149	6591944	311
SW2107	First order stream	420223	6592138	333
SW2108	Fen expression	422744	6592406	926
SW2109	First order stream	421823	6591434	863
SW2110	First order stream	421669	6591206	896
SW2111	Second order stream	422674	6592280	925
SW2201	First order stream	422882	6591274	971
SW2204	First order stream	418505	6590074	144

Notes: 1. As per the Strahler stream database (GSNSW, 2022) or site observations.
2. Interpreted from geographical software.
3. Metres above Australian height datum.

Table 5.3 Summary of surface water monitoring locations

Spring ID	[1]Target	[2]Easting (GDA94)	[2]Northing (GDA94)	[2]Elevation ([3]mAHD)
SW2104	Macleay River	420024	6593617	139
SW2105	Macleay River	418994	6592271	141
SW2112	Macleay River	418739	6591515	140
SW2202	Macleay River	422548	6597117	135
SW2203	Bakers Creek	393481	6620735	950
SW2206	Macleay River	418392	6591499	145
SW2207	Macleay River	418498	6590490	145
SWG2101	Third order stream	419123	6591425	191

Notes: 1. As per the Strahler stream database (GSNSW, 2022) or site observations.
2. Interpreted from geographical software.
3. Metres above Australian height datum.



Source: EMM (2022); DFSI (2020, 2021); DPIE (2022); GA (2011)

0 1 2 km

GDA 1994 MGA Zone 56

N

KEY

- Study area
- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts

Focus area

- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

Existing environment

- Major road

Streams within study area

- 1st order (non-perennial)
- 2nd order (non-perennial)
- 3rd order (perennial)
- 3rd order (non-perennial)
- 4th order (perennial)
- 4th order (non-perennial)
- 9th order (perennial)

- Landholder bore
- Surface water sampling location

Groundwater monitoring network

- Borehole
- Fen monitoring bore
- Monitoring bore

Water monitoring locations

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
OMPS Pty Ltd
Figure 5.1

EMM creating opportunities

5.2.2 Hydraulic testing

Hydraulic tests provide site-specific information on the hydraulic properties of the various groundwater systems. Hydraulic testing included:

- rising and falling head (slug) tests
- packer tests.

i Rising and falling head tests

Slug testing has been completed in the conventional groundwater monitoring bores, with results analysed to estimate the bulk hydraulic conductivity in the immediate vicinity of the screened interval.

Slug testing involves instantaneously displacing water in the bore (using compressed air) and measuring the groundwater level response (using an automated pressure transducer data logger (logger)). When the groundwater level decreases (as a result of injecting compressed air into the bore), the change in water level is captured by the data logger and the aquifer response used to calculate horizontal hydraulic conductivity.

ii Packer tests

Packer testing (also known as Lugeon testing) is an in-situ method of testing the average hydraulic conductivity of a rock mass over a selected depth interval. The formation is tested by inflating pneumatic or hydraulic packers and injecting water at a constant pressure into the isolated section of the borehole.

Packer testing is typically completed in five stages, gradually increasing then decreasing injection pressure, averaging the flow and pressure at each stage to estimate average hydraulic conductivity. Results are expressed in Lugeon units (equivalent to the conductivity required to inject 1 litre (L) of water per metre of the test interval under a constant pressure).

5.2.3 Groundwater level monitoring

Project specific groundwater level monitoring commenced in August 2020, with the installation of loggers in existing boreholes drilled in 1996 (SMEC, 1997). The groundwater level monitoring network has been progressively expanded as new monitoring bores have been installed (refer Table 5.1).

Groundwater levels are monitored via loggers submerged within the monitoring bores and boreholes. Groundwater level and temperature data was recorded at a six-hourly interval and synchronised across the network.

Total pressures recorded at the pressure transducer data loggers are compensated for atmospheric pressure changes using barometric loggers installed at OM4 and MB02A. The barometric loggers provide sufficient spatial coverage at representative elevations to capture barometric fluctuations across the study area. All data loggers are downloaded monthly, and groundwater levels are verified with manual groundwater level measurements taken during each groundwater quality sampling event. Groundwater level monitoring will continue following submission of the EIS.

A summary of groundwater level monitoring is provided in Figure 5.2.

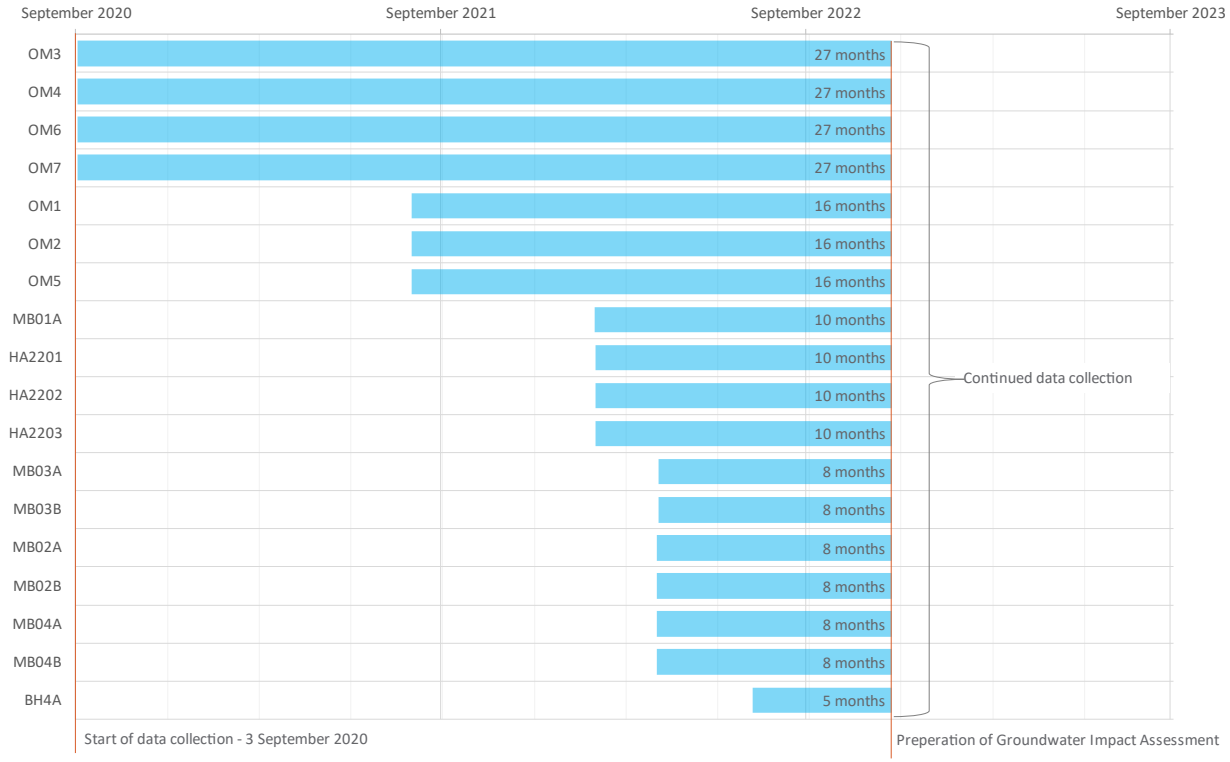


Figure 5.2 Groundwater level monitoring duration

5.2.4 Groundwater quality monitoring

Project specific groundwater chemistry monitoring commenced in August 2021, with chemistry samples obtained from existing boreholes drilled in 1996 (SMEC, 1997) and springs. The groundwater chemistry monitoring network has been progressively expanded as new monitoring bores have been installed (refer Table 5.1) and additional springs and fens were identified (typically attributed to increased rainfall and spring flow and observations from ecological surveys respectively).

Groundwater sampling is typically undertaken monthly in accordance with AS/NZS 5667.11:1998 Australian Standard for Water Quality Sampling. Dedicated sampling pumps (Solinst™ double-valve pumps) are installed in eight of the fourteen conventional groundwater monitoring bores and are used to collect groundwater samples using low-flow sampling methods. The remaining open boreholes and groundwater monitoring bores, including the three shallow fen monitoring bores, are sampled using conventional bailing techniques. Spring water samples are collected from the highest point in the ephemeral stream with visibly flowing water (best representing the groundwater expression).

The sampling and analysis methods and monitoring analytes for the groundwater monitoring program are described in Table 5.4. A record of monitoring events is shown in Table 5.5.

Field and laboratory quality control (QC) procedures are used to establish accurate, reliable and precise results. QC procedures included: analysis of unstable parameters in the field, calibration of equipment, submitting laboratory samples within holding times, collection of blind duplicate samples (to multiple laboratories), keeping samples chilled and wearing gloves during sampling.

5.2.5 Surface water quality monitoring

Surface water sampling commenced in August 2021, with chemistry samples obtained from the Macleay River. The surface water sampling network has been progressively expanded as increased flow was identified in the lower reaches of the ephemeral watercourses (typically attributed to increased rainfall) and additional areas of interest were identified in the Macleay River and Bakers Creek.

Surface water sampling is typically undertaken monthly in accordance with AS/NZS 5667.11:1998 Australian Standard for Water Quality Sampling. Samples are collected from designated locations on the respective watercourse.

The sampling and analysis methods and monitoring analytes for the groundwater monitoring program are described in Table 5.4. A record of monitoring events is shown in Table 5.5.

Field and laboratory quality control (QC) procedures are used to establish accurate, reliable and precise results. QC procedures included: analysis of unstable parameters in the field, calibration of equipment, submitting laboratory samples within holding times, collection of blind duplicate samples (to multiple laboratories), keeping samples chilled and wearing gloves during sampling.

Table 5.4 Groundwater analysis methods and parameters

Category	Monitoring analytes	Analysis method
Physico-chemical properties	pH, electrical conductivity, total dissolved solids, dissolved oxygen, temperature, redox potential	Measured in situ using a portable water quality meter
	Alkalinity (bicarbonate, carbonate, hydroxide and total as $CaCO_3$)	Analysis undertaken by a NATA certified laboratory
Major ions	Calcium, chloride, magnesium, sodium, potassium, sulphate.	
Inorganics	Fluoride	
Nutrients	Total nitrogen, ammonia, oxidised nitrogen and total kjeldahl nitrogen	
	Total phosphorus and reactive phosphorous	
Metals (field filtered)	Aluminium (Al), Arsenic (As), Antimony (Sb), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Manganese (Mn), Nickel (Ni), Lead (Pb), and Zinc (Zn)	
Hydrocarbons	Total petroleum hydrocarbons, total recoverable hydrocarbons, benzene, toluene, ethylbenzene, xylene and naphthalene	

Table 5.5 Water quality sampling overview

Location	2021					2022										Sum
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
Groundwater monitoring and spring locations																
OM1	X	X	X	X	X	X	X		X	X	X	X	X	X	X	14
OM2	X	X	X	X	X	X	X		X	X	X	X	X	X	X	14
OM3	X	X	X	X	X	X	X		X	X	X	X	X	X	X	14
OM4	X	X	X	X	X	X	X		X	X	X	X	X	X	X	14

Table 5.5 Water quality sampling overview

Location	2021						2022									Sum
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
OM5	X	X	X	X	X	X	X		X	X	X	X	X	X		13
OM6	X	X	X	X	X	X	X		X	X	X	X	X	X	X	14
OM7	X	X	X	X	X	X	X		X	X	X	X	X	X	X	14
HA2201							X		X	X	X	X	X	X	X	8
HA2202							X		X	X	X	X	X	X	X	8
HA2203							X		X	X	X	X	X	X	X	8
MB01A			X	X	X	X	X		X		X	X	X	X	X	11
MB02A					X	X	X		X	X		X	X	X	X	9
MB02B							X		X	X	X	X	X	X	X	8
MB03A									X	X	X	X	X	X	X	7
MB03B									X	X	X	X	X	X	X	7
MB04A						X	X		X	X	X	X	X			7
MB04B						X	X		X	X	X	X	X			7
BH4A												X	X			2
GW307320							X				X					2
SW2101	X											X				2
SW2102	X										X	X	X	X		5
SW2103	X				X		X		X		X	X	X	X		8
SW2106	X								X	X	X	X	X	X		7
SW2107	X								X	X	X	X	X			6
SW2108	X								X	X	X	X	X	X		7
SW2109	X								X	X	X	X	X	X		7
SW2110	X								X	X		X	X	X		6
SW2111	X								X	X	X	X	X	X		7
SW2201							X		X	X	X	X	X	X		7
SW2204										X	X	X	X	X		5
Surface water locations																
SW2104	X										X	X	X	X		5
SW2105	X															1
SW2112					X		X		X			X	X	X		6

Table 5.5 Water quality sampling overview

Location	2021						2022									Sum
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
SW2202							X		X			X	X	X		5
SW2203									X		X		X	X		4
SW2206											X	X	X	X		4
SW2207											X					1
SWG2201					X		X		X			X	X	X		6

5.3 Isotope assessment

Isotope samples were collected from seven groundwater monitoring bores, targeting the main hydrogeological units relevant to the Project (refer Section 3.6). Samples were analysed for a series of isotopes, providing an understanding of the age of groundwater in each hydrogeological unit, at the respective sample depth and location.

Samples were purged using a low-flow sampling methodology from the dedicated sampling pumps (Solinst™ double-valve pumps) using nitrogen gas, eliminating the potential for isotope contamination potentially introduced by conventional purging gas (i.e. carbon dioxide).

Samples were preserved and issued to the Australian Nuclear Science and Technology Organisation (ANSTO) under chain of custody protocols, for analysis of:

- radiocarbon (^{14}C), including stable isotope ratio analysis for dissolved inorganic carbon ($\delta^{13}C_{DIC}$)
- tritium (^{3}H).

A summary of the isotope assessment results in provided in Table 5.6.

Table 5.6 Summary of isotope assessment results

Sampled bore	Geological unit	Relative depth	Focus area	[1]Age based on ^{14}C (years prior to 1950)	Age based on ^{3}H (years prior to 1950)
HA2202	Carrai Granodiorite (Residual soil)	Surface (within fen)	Plateau	3	3
MB02A	Carrai Granodiorite	Shallow	Escarpment	-	5
MB02B	Carrai Granodiorite	Deep	Escarpment	-	7
MB03A	Parrabel Beds	Shallow	Lower escarpment	15	12
MB03B	Parrabel Beds	Deep	Lower escarpment	-	36
MB04A	Carrai Granodiorite (Residual soil)	Shallow	Plateau	10	2
MB04B	Carrai Granodiorite	Deep	Plateau	-	10

Notes: 1. As per the reporting standard set out in (Stuiver & Polach, 1977)

Results from the isotope assessment indicate residence times for groundwater increase with depth, with similar groundwater ages reported between the fen monitoring bore (HA2202) and shallow Carrai Granodiorite monitoring bore (MB04A). Residence times are also highest in the lower escarpment (MB03A and MB03B), near the Macleay River floodplain. Further information is provided in the isotope assessment report, attached as Attachment B.

5.4 Geochemistry assessment

Publicly available geochemical data was accessed from the Geological Survey of NSW (GSNSW, 2022) database to inform geochemical characterisation. Reviewed data was used to provide a basis for sample selection from the chips and core obtained during the hydrogeological and geotechnical site investigations respectively.

Fourteen samples were collected from the chips (5 in total) and core (9 in total). Samples were selected based on proximity to Project infrastructure (i.e. areas that are likely to be excavated during construction) and inferred geochemical properties (i.e. zones of hydrothermal alteration, leading to potentially entrained metal/metalloids and sulphides).

Samples were preserved and issued to ALS Pty Ltd under chain of custody protocols, in summary:

- Seven samples analysed for a waste classification suite, in accordance with the Waste Classification Guidelines (EPA, 2014), including leachable concentrations of all analytes.
- Seven samples (and separate to the above) were analysed for acid rock drainage (ARD).

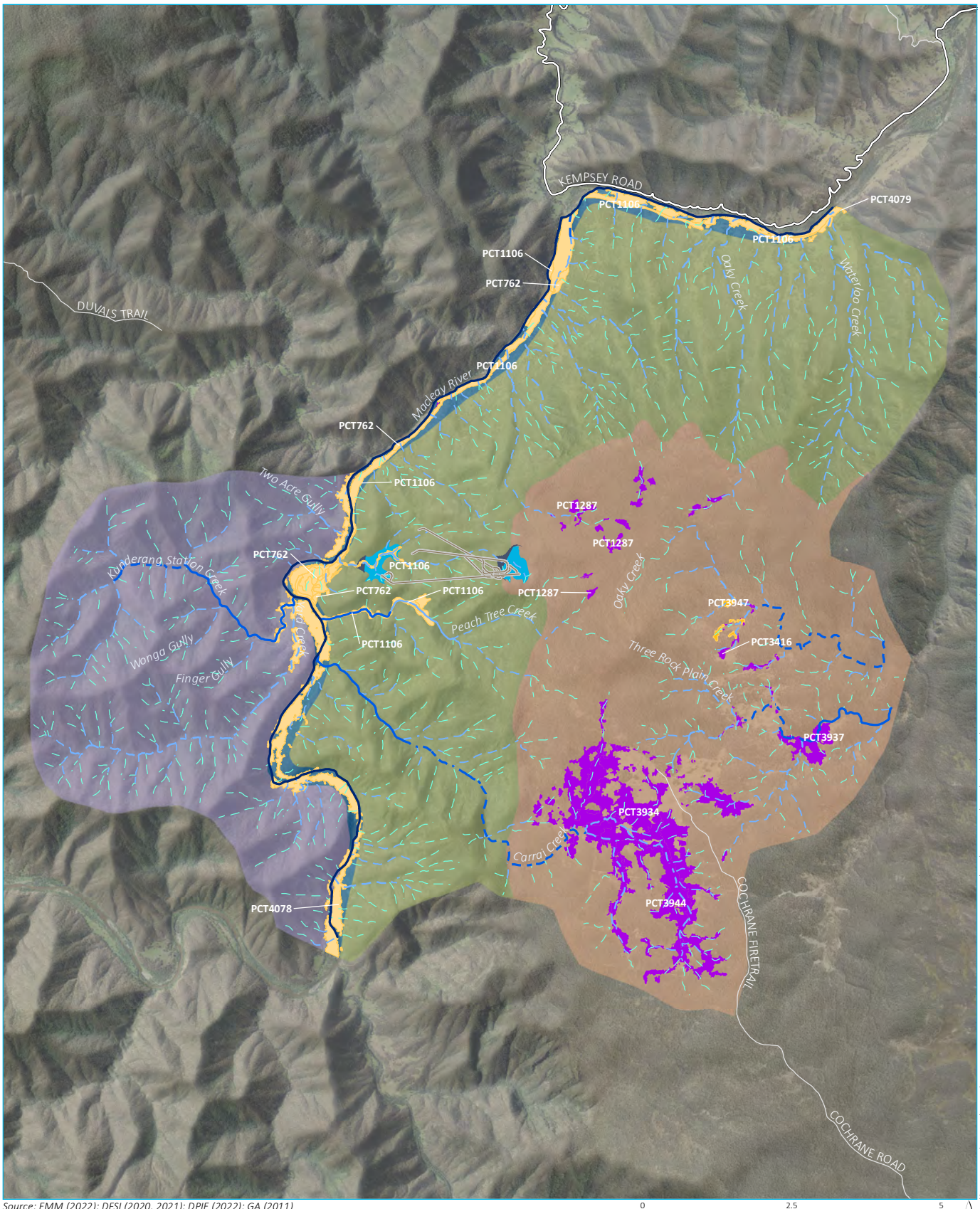
Results from the geochemistry assessment indicated leachable (i.e. transferrable to water in contact with the material) concentrations of:

- calcium carbonate at all tested depths within all identified geological units relevant to the study area (refer Section 3.4), ranging between 4 and 16 mg/L
- manganese at the limit of reporting (0.1 mg/L) in three samples, comprising:
  - BH4B (at 2.39–2.51 and 22.05–22.30 mBGL), representing the shallow undifferentiated hornfels
  - MB02B (at 0–9 mBGL), representing the weathered Carrai Granodiorite
- iron at all tested depths within all identified geological units relevant to the study area (refer Section 3.4), ranging between 1 and 5.9 mg/L
- aluminium within all identified geological units relevant to the study area (refer Section 3.4), ranging between 2.4 and 4.2 mg/L
- one of the seven samples (MB01A) analysed for antimony marginally exceeded (0.016mg/L) applicable guideline value (0.009 mg/L) for the 95th percentile protection of fresh water species
- arsenic concentrations were not detected in any of the analysed samples.

All sampled materials tested indicate that there is low potential for acid generation. Further discussion is provided in the Geochemistry Characterisation Report (EMM, 2023d).

5.5 Geological surface mapping

Geological surface mapping was undertaken as part of the geotechnical site investigations (SMEC, 2022) and was supported by field observations made by EMM during water monitoring events. Geological surface mapping provides an indication of the spatial extent of the geological units across the Project area, informing the hydrogeological conceptual model and supporting development of the numerical groundwater model.



Source: EMM (2022); DFSI (2020, 2021); DPIE (2022); GA (2011)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts

Focus area

- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

Streams within study area

- 1st order (non-perennial)
- 2nd order (non-perennial)
- 3rd order (perennial)
- 3rd order (non-perennial)
- 4th order (perennial)
- 4th order (non-perennial)
- 9th order (perennial)

GDEs within study area

- Facultative – high
- Facultative – opportunistic
- Obligate

Existing environment

- Major road
- Minor road

Groundwater dependent ecosystems

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
OMPS Pty Ltd
Figure 5.3

EMM creating opportunities

6 Groundwater characterisation

6.1 Overview

This chapter describes the local hydrogeological setting, including groundwater levels and flow, hydraulic properties, groundwater quality and interaction between surface water and groundwater associated with the groundwater systems within the study area.

Ecological values (EV) are values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health, and which require protection from the effects of contamination, waste discharges and deposits. In general accordance with the National Water Quality Management Strategy (NWQMS), EVs for groundwater include (ANZECC & ARMCANZ, 2000):

- aquatic ecosystems
- primary industries, comprising:
    - irrigation and general water users
    - stock drinking water
    - aquaculture
    - human consumption of aquatic foods
- recreation and aesthetics
- drinking water
- industrial water
- cultural and spiritual values.

As groundwater provides baseflow to watercourses (including the Macleay River, supporting ecosystems and town water supply) within the study area, the primary ecological value for groundwater is aquatic ecosystems and drinking water.

Water quality objectives (WQO) provide guideline values to mitigate potential impacts to EVs, the following WQO values have been referenced to characterise groundwater quality within the study area:

- Physical and chemical stressors – default trigger values for upland rivers in south-eastern Australia (ANZECC & ARMCANZ, 2000).
- Toxicant trigger values for the protection of 95% of freshwater aquatic species (ANZECC & ARMCANZ, 2000).
- Health based guideline values for physical and chemical characteristics in drinking water (NHMRC & NRMMC, 2011).

Baseline characterisation of water quality is provided in Section 6.3.

6.2 Local geological setting

The majority of the study area (the plateau, and generally the escarpment and part of the Macleay River floodplain, refer Figure 3.5) ultimately overlies the Triassic Carrai Granodiorite pluton (the pluton). The surrounding topography and geology have been highly influenced by the pluton.

Hornfels overlie the pluton within parts of the plateau and escarpment, particularly near the proposed upper reservoir and pressure shaft (refer Figure 3.5). It is considered the hornfels are remnant from the intrusion of the pluton into the nearby sedimentary units, with weathering processes subsequently reducing the hornfels extent and depth, exposing the underlying pluton across the majority of the escarpment and plateau.

The Permian Parrabel beds and Carboniferous Pee Dee beds (the sedimentary units) underlie the western catchment and western extent of the escarpment and Macleay River floodplain. The sedimentary units have been highly metamorphosed (to hornfels) near the contact, with the degree of metamorphosis decreasing with distance from the pluton, observed as phyllite and slate in MB03A and MB03B (between the lower reservoir and Macleay River).

The pluton and hornfels are highly durable geological units that are resistant to weathering, resulting in a generally shallow soil profile (generally less than 1 m thick) across the majority of the study area. Localised pockets of deeper weathered rock (up to 12 m) are observed underlying the saturated areas, typically near the upper reaches of the ephemeral streams. The streambed of the ephemeral streams within upper escarpment and plateau comprise relatively fresh rock.

Localised, surficial deposits of alluvium (typically comprising sand–boulders) occupy the base of the ephemeral streams within the lower escarpment, becoming less prevalent in the upper escarpment and non-existent in plateau. The Macleay River floodplain comprises a continuous deposit of alluvium (typically comprising sand-cobbles) adjacent-to and underlying Macleay River.

6.3 Hydrogeological characterisation

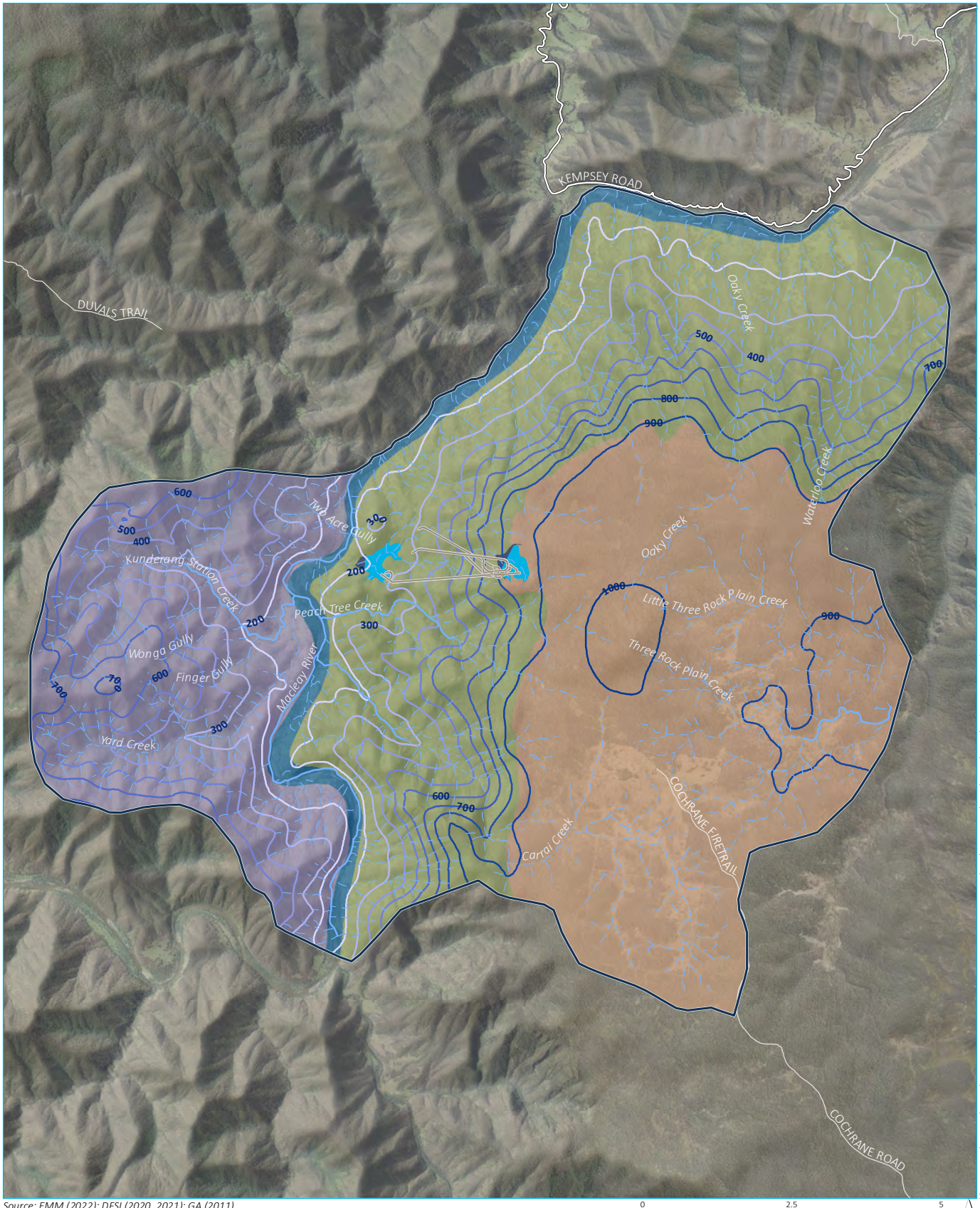
6.3.1 Groundwater levels and flow

Groundwater levels reflect the topography within the study area, with the regional groundwater table shallowest in the upper plateau (~1–2 mBGL at MB04A) and deepest near top of the escarpment and proposed pressure shaft decline (~50 mBGL at OM1). Groundwater levels within the alluvium is highly dependent on the adjacent stream, with groundwater levels rapidly responding to changes in the stream water level and becoming unsaturated in dry streamflow periods.

Rainfall induced groundwater level fluctuations have been measured across the study area within the Carrai Granodiorite. Fluctuations are typically less than 0.5 m and are more prominent in the shallow groundwater monitoring bores. The hornfels unit shows minimal rainfall response.

Groundwater levels in the localised pockets of weathered rock are above the base of the ephemeral watercourses following rainfall, providing interflow to the ephemeral streams during a period proportional to the magnitude and duration of the rainfall.

Groundwater generally flows radially from the plateau to the Macleay River. Vertical flow is predominantly downward within the plateau/upper western catchment and upward in the Macleay River floodplain. Groundwater level contours are provided in Figure 6.1.



Source: EMM (2022); DFSI (2020, 2021); GA (2011)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

\\emmsvr1\EMM3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_GIA\GIA009_GroundwaterLevelContours_20221111_02.mxd 13/12/2022

KEY

- Study area
- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts

Focus area

- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

Existing environment

- Major road
- Minor road

Streams within study area

- Perennial
- Non-perennial

Groundwater level contours (m AHD)

- 200
- 300
- 400
- 500
- 600
- 700
- 800
- 900
- 1000

Groundwater level contours

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
OMPS Pty Ltd
Figure 6.1

EMM creating opportunities

6.3.2 Hydraulic conductivity

Testing indicated that hydraulic conductivity of the hydrogeological units within the study area is:

- Generally decreasing as depth increases within the Triassic Carrai Granodiorite and Permian Parrabel beds, with the deeper fractured rock results indicating one to two orders of magnitude lower hydraulic conductivity than the shallow fractured rock (refer Table 6.1 and Figure 6.2).
- The weathered Carrai Granodiorite has a hydraulic conductivity approximately one order of magnitude higher than the underlying shallow fractured rock (refer Table 6.1).
- The hydraulic properties of the geology intercepted by the Project is generally interpreted to have a low hydraulic conductivity, consistent with lower bound values reported in literature for fracture rock geological units (Domenico & Schwartz, 1990).

A summary of hydraulic testing results is provided in Table 6.1.

Table 6.1 Hydraulic conductivity within hydrogeological units

Unit	Hydraulic conductivity ([1]m/s)		
	Minimum	Maximum	Average
Residual soil (weathered Carrai Granodiorite)	$2.8x10^{-5}$	$2.8x10^{-5}$	$2.8x10^{-5}$
Carrai Granodiorite (shallow)	$5.4x10^{-7}$	$4.3x10^{-6}$	$2.7x10^{-6}$
Carrai Granodiorite (deep)	$5.0x10^{-7}$	$5.0x10^{-7}$	$5.0x10^{-7}$
Parrabel Beds (shallow)	$2.0x10^{-5}$	$2.0x10^{-5}$	$2.0x10^{-5}$
Parrabel Beds (deep)	$1.7x10^{-7}$	$1.7x10^{-7}$	$1.7x10^{-7}$
[2]Hornfels (undifferentiated)	$<1x10^{-9}$	$\sim2.4x10^{-7}$	$\sim4.1x10^{-8}$

Notes: 1. Metres per second.

2. As interpreted from lugeon packer testing.

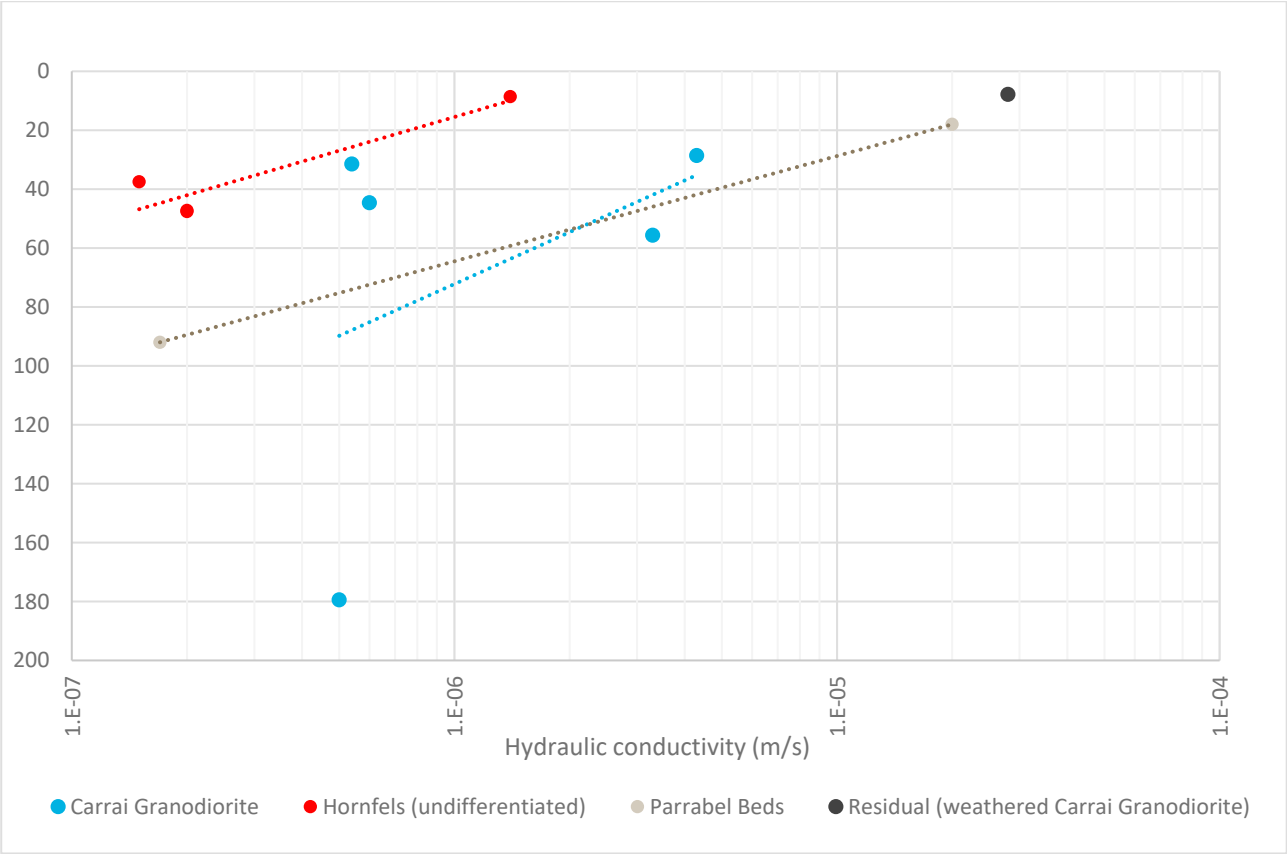


Figure 6.2 Hydraulic conductivity vs depth

6.3.3 Water chemistry

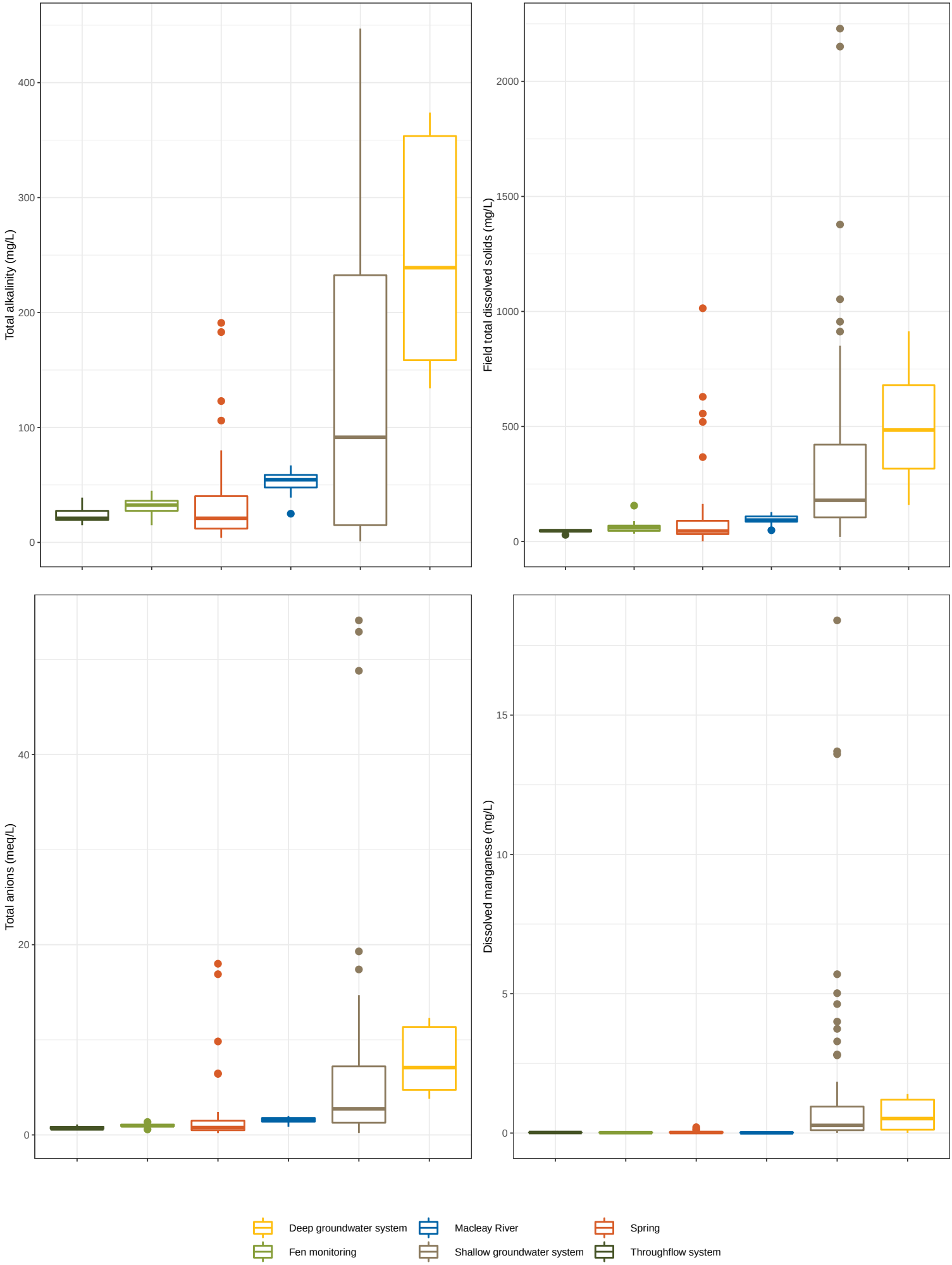
General groundwater quality within the study area is summarised below:

- pH is relatively variable across the monitoring network, ranging between 3.6 and 11.45
- average total dissolved solid concentrations range between:
  - 332 mg/L (fresh) and 492 mg/L (marginal salinity) in the shallow and deep fractured rock groundwater systems respectively
  - 44 mg/L (fresh) and 104 mg/L (fresh) in the springs, Macleay River, fen monitoring bores and localised weathered rock groundwater system
- cation and anion average concentrations range between:
  - 5.8 and 7.8 milliequivalents per lite (meq/L) in the shallow and deep fractured rock groundwater systems respectively
  - 0.6 and 1.8 meq/L in the springs, Macleay River, fen monitoring bores and localised weathered rock groundwater system.

Considering the results from the geochemistry assessment discussed in Section 5.4, leachable analytes detected as part of that assessment are summarised below:

- calcium carbonate average concentrations range between:
  - 146.4 and 252.3 mg/L in the shallow and deep fractured rock groundwater systems respectively
  - 24.1 and 52.5 mg/L in the springs, Macleay River, fen monitoring bores and localised weathered rock groundwater system
- dissolved manganese concentrations range between:
  - 0.65 and 1.17 mg/L in the shallow and deep fractured rock groundwater systems respectively
  - 0.01 and 0.02 mg/L in the springs, Macleay River, fen monitoring bores and localised weathered rock groundwater system
- relatively low (near the limit of reporting, 0.1 mg/L) and consistent concentrations of dissolved iron and dissolved aluminium have been detected across the monitoring network.

Box and whisker plots are presented in Figure 6.3 for the key chemistry indicators discussed above, including total dissolved solids, total anions (and inferred cations), total alkalinity (as calcium carbonate) and dissolved manganese.



Groundwater chemistry − box and whisker plots

Oven Mountain Pumped Hydro Energy Storage − OMPS Pty Ltd

Groundwater impact assessment

Figure 6.3

7 Conceptual model

7.1 Overview

This chapter discusses the extent of local and regional groundwater systems of relevance to the study area, including the mechanisms by which groundwater is recharged, transmitted and discharged, as well characterising the dependency of access to relevant systems.

A graphical depiction of the conceptual hydrogeological understanding for the Project is shown on Figure 7.1.

7.2 Localised groundwater systems and mechanisms

The localised groundwater units of relevance to the study area include:

- Alluvium/colluvium (refer Section 3.4), accumulating along the riparian corridor and floodplain extents of both ephemeral first and second order watercourses and the Macleay River.
- Weathered rock associated with the Triassic Carrai Granodiorite (refer Section 3.4), supporting localised groundwater systems across the plateau (noting the weathered rock is typically unsaturated within the Macleay River floodplain).

Recharge to the localised weathered rock groundwater systems occurs via rainfall (direct recharge) and a small component of basal recharge (infiltration recharge) from the shallow fractured rock groundwater system (refer Section 7.3.1). The localised alluvium/colluvium groundwater systems are supported via hydraulic connection to the adjacent surface water features, receiving in-direct recharge from the surface water and retaining short-term bank storage.

Groundwater flow occurs through pore space (primary porosity) within the saturated medium of the rock unit. Flow is relative to the particle size distribution, with increased flow typically evident in coarser mediums, such as boulders, cobbles and gravels.

Discharge occurs to the ephemeral streams, forming across the escarpment and plateau areas, eventually discharging to the Macleay River. Adjacent to the Macleay River, where the thickness of the alluvium/colluvium unit is thought to be much more developed, this unit is expected to hold temporary bank storage, contributing baseflow to the Macleay River during extended dry periods and gaining as a system during sustained wet periods.

7.3 Regional groundwater systems

7.3.1 Shallow fractured rock

The shallow fractured rock groundwater system (shallow groundwater system) is supported by the shallow, saturated rock units (refer Section 3.4), specifically the Triassic Carrai Granodiorite, Permian Parrabel beds, Carboniferous Pee Dee beds and undifferentiated hornfels. The hydrogeological properties of the shallow, saturated rock units are similar within the study area and are considered laterally connected, forming the shallow groundwater system.

The shallow fractured rock groundwater system supports the regional groundwater table and is typically unconfined, with levels fluctuating in response to rainfall. Groundwater mechanisms are further described in Section 7.4.

7.3.2 Deep fractured rock

The deep fractured rock groundwater system (deep groundwater system) underlies the shallow fractured rock groundwater system. The deep groundwater system is contained within the Carrai Granodiorite (near the plateau and upper escarpment) and the Parrabel Beds (near the lower escarpment and Macleay River floodplain). The hydrogeological properties of both rock units are similar within the study area and are considered laterally connected, forming the deep groundwater system.

The deep groundwater system is semi-confined to confined, with a varying degree of hydraulic connection to the overlying shallow groundwater system. Groundwater level fluctuations are relatively limited, with minimal response to rainfall observed. Groundwater mechanisms are further described in Section 7.4.

7.4 Regional groundwater mechanisms

7.4.1 Recharge

Recharge to the shallow groundwater system occurs predominantly across the plateau (the recharge zone), through:

- direct recharge from rainfall infiltration where the unit outcrops
- in-direct recharge from surface water infiltration where fractures extend to surface within streambeds
- localised recharge from rainfall percolating through the vadose zone or localised groundwater system.

The deeper fractured groundwater system is recharged by localised infiltration from the overlying shallow groundwater system, typically in the recharge zone and upper escarpment.

Minor groundwater recharge occurs outside the recharge zone via similar mechanisms, however rainfall on the escarpment and Macleay River floodplain typically flows down the ephemeral streams for a relatively short period following rainfall, allowing minimal opportunity for in-direct recharge to occur.

7.4.2 Flow

Groundwater flows from the recharge zone to the discharge zone, with radial flow from the plateau to the Macleay River and easterly flow from the upper western catchment to the Macleay River (refer Figure 6.1). There is a downward vertical flow gradient (shallower–deeper groundwater systems) in the recharge zone and upward vertical gradient (deeper–shallower groundwater systems) in the discharge zone. Groundwater levels oscillate between wet and dry periods, influencing the magnitude of groundwater flow seasonally.

Flow is typically supported via interconnected fractures, joints, fault gouges etc (secondary porosity). Primary porosity is limited by the tight rock matrix and considered negligible due to the crystalline, igneous composition of the rock.

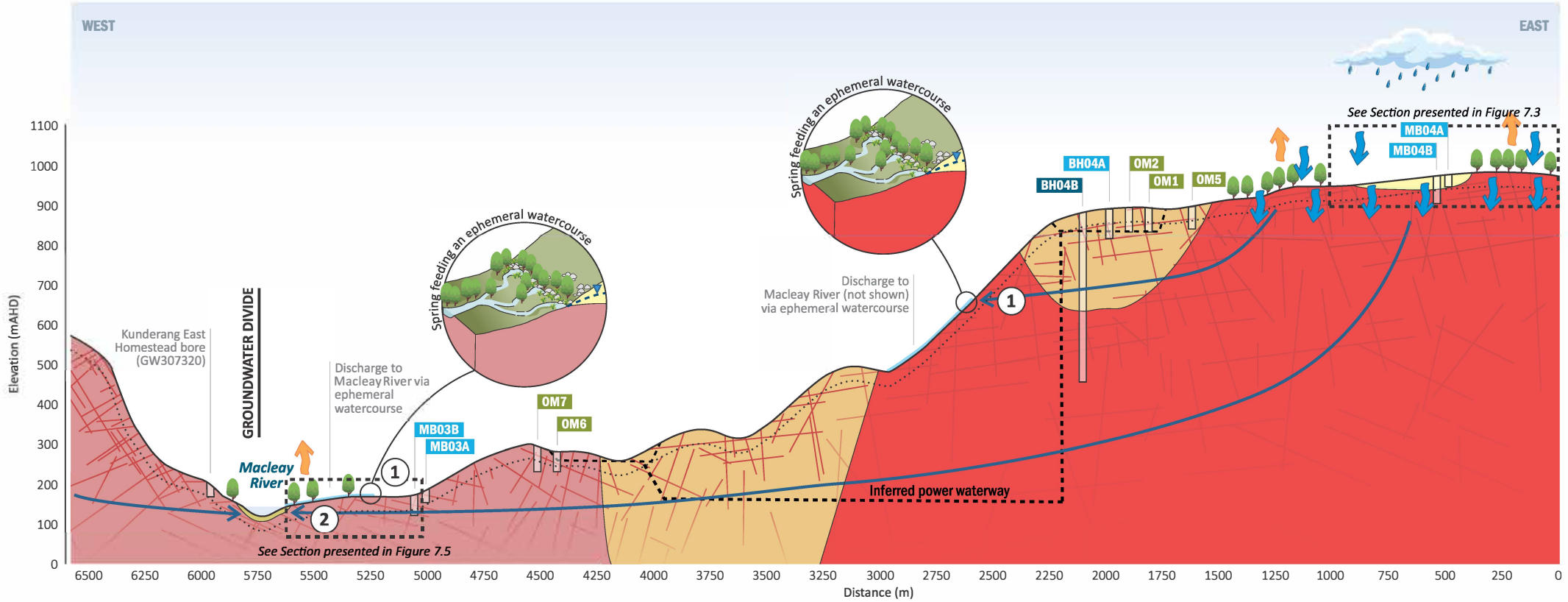
7.4.3 Discharge

The Macleay River forms the overall discharge zone within the study area, receiving groundwater from baseflow contributions, via the regional groundwater systems and ephemeral streams, supported by groundwater expressions in the upper tributaries.

While there is some uncertainty regarding the source of groundwater expressions, it is considered they may be supported by localised groundwater systems, regional groundwater systems or a combination of both. The understanding has been simplified to include (Bryan, 1919):

- Pocket springs, visible flow of groundwater from the localised groundwater systems described in Section 7.2. Typically observed in the upper escarpment and forming the headwaters of ephemeral streams.
- Inclined fracture springs, upward flow from the shallow fractured rock groundwater system through fractures connected to surface.
- Lowland seeps, similar to springs however, flow is not visible and groundwater percolates upward through soil pores. Typically observed in low-lying areas around the Macleay River floodplain, adjacent to large watercourses and tributaries creating bogs and fens.
- Fens, moist ground forming the dominant groundwater discharge feature across the plateau. Generally observed below granodiorite outcrops in the upstream sections of smaller tributaries, typically supported by the localised groundwater systems and contributing attenuated:
    - recharge to the shallow groundwater system
    - flow to the ephemeral streams following rainfall, with attenuated flow proportionate to rainfall magnitude and duration.

Given the extent and complexity of groundwater and surface water systems in the study area, there is local variability and uncertainty regarding groundwater flow, vertical connectivity and baseflow contribution to bogs, fens and watercourses.



LEGEND

- Alluvium
- Colluvium/residual soil
- Hornfels (undifferentiated)
- Parrabel Beds
- Carrai Granodiorite
- Weathering
- Fracturing
- Geotechnical bore
- Rainfall/infiltration
- Evapotranspiration
- Groundwater flow path

Groundwater monitoring

- OM7 Existing open borehole (SMEC, 1996)
- BH04B Geotechnical borehole with packers/VWP's
- MB04A Groundwater monitoring bore

1. Discharge to ephemeral stream
2. Baseflow contribution to Macleay River

(this diagram is a conceptual representation only)

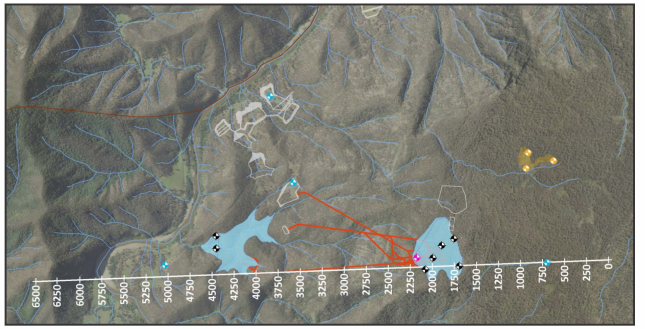


Figure 7.1 Groundwater occurrence and flow - simplified concept

EMM creating opportunities

7.5 Surface water and groundwater interaction

Surface water features that interact with groundwater include:

- The Macleay River, a perennial watercourse which:
  - receives baseflow from the shallow fractured rock groundwater system (and in-directly receiving groundwater as discharge from the ephemeral streams) during average/dry periods
  - discharges to the localised alluvial and shallow fractured rock groundwater systems during flooding events.
- Ephemeral streams, originating at springs or fens (associated with the localised groundwater systems) in the upper tributaries and alternating down the flow path between receiving and discharging groundwater from/to the shallow fractured rock groundwater system via fractures within the stream bed (refer Section 7.4.2).
- Fens, specifically located on the plateau, receiving groundwater from the localised groundwater systems and discharging to the ephemeral streams.
- Lowland seeps, supporting riparian bogs within the plain area and receiving groundwater from near surface expressions of the shallow groundwater system, typically adjacent to streamlines.

7.6 Groundwater dependent ecosystems

7.6.1 Terrestrial

Groundwater dependent PCTs have been identified as being obligate or facultative/opportunistic type GDEs, and intercept shallow and/or regional groundwater systems, further discussion is provided in the Biodiversity Development Assessment Report (EMM, 2023b) and the Groundwater Dependent Ecosystems Assessment (EMM 2023e). Other PCTs are non-dependent on groundwater.

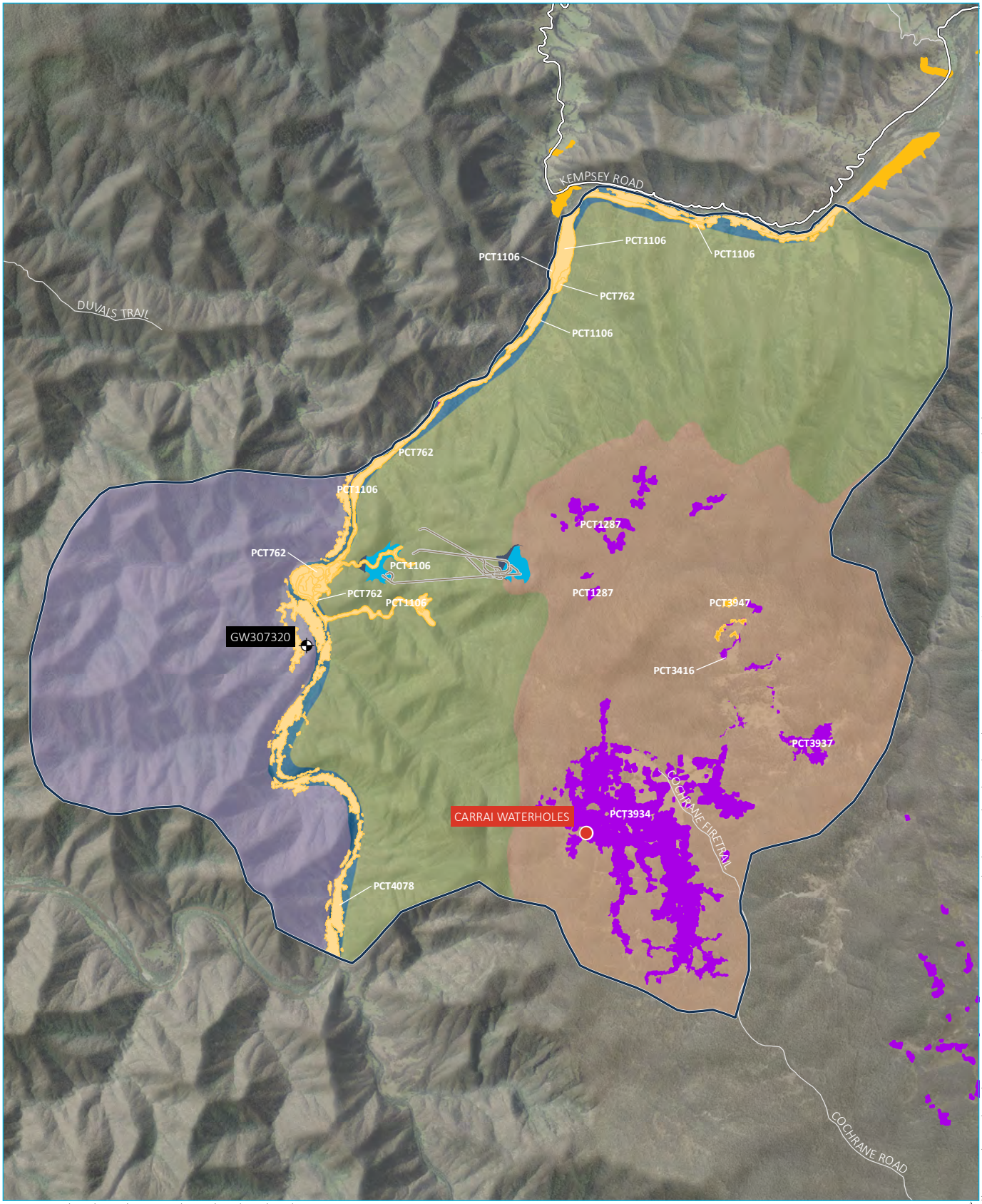
Where there is a reduction in depth to groundwater, or variability in climate, this may be reflected as a proportional change in ecosystem prevalence for facultative-opportunistic PCTs, but the ecosystem remains resilient in the absence of groundwater (Serov, Kuginis, & Williams, Risk assessment guidelines for groundwater dependent ecosystems, 2012).

7.6.2 Aquatic

The Macleay River and Floodplain Wetlands identified in Section 3.6.1 are predominantly supported by the Macleay River flow regimes and are described as non-dependent on groundwater. Further discussion is provided in the Aquatic Ecology Impact Assessment (Stantec, 2022).

7.6.3 Subterranean

Noting that stygofauna were not detected during ecological field surveys (refer to Project Groundwater Dependent Ecosystem assessment (EMM, 2023)), existing stygofauna are assumed to exist within some parts of the groundwater system and are assumed to be similar to those encountered in other fractured rock systems in NSW. Stygofauna are likely to be more common in bogs, hyporheic zones and shallow fractured rock groundwater systems due to the greater availability of dissolved oxygen and nutrients, further discussion is provided in the Aquatic Ecology Impact Assessment (Stantec, 2022).



Source: EMM (2022); DFSI (2020, 2021); DPIE (2022); GA (2011)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_GIA\GIA011_PotentialGroundwaterReceptors_20221111_02.mxd 17/03/2023

Summary of potential groundwater receptors for assessment

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
OMPS Pty Ltd
Figure 7.2

EMM creating opportunities

8 Assessment approach

8.1 Potential impacts

8.1.1 Overview

The assessment of Project-related impacts to water resources, water users and the resultant water licensing requirements considers the requirements of the WM Act, the relevant WSPs and the AIP.

The assessment methodology that has been used to characterise impact is modelled on the National Water Commission's (NWC) risk framework (NWC, 2010). The Framework uses a source-pathway analysis model that describes how water affecting activities might impact groundwater receptors, referred to as a source-pathway-receptor model in this GIA.

This GIA quantifies the risk of Project related water affecting activities which are predicted to alter baseline groundwater conditions (if left unmitigated/managed), by identifying direct impacts (discussed in Section 8.1.2) and indirect impacts at identified groundwater receptors (discussed in Section 8.1.3).

8.1.2 Direct impacts

Direct impacts refer to a disruption of the physical water system and behaviour, linked directly to a specific Project activity. Types of direct impacts may include:

- changes to surface water or groundwater quantity (e.g. water table drawdown or aquifer depressurisation, reduced baseflow to gaining watercourses)
- changes to surface water or groundwater quality (e.g. potential leaching of solutes or oxidation of acid-generating elements, uncontrolled release of contaminated water intercepting during construction)
- changes to the physical aquifer medium (e.g. aquifer impoundment generating groundwater mounding, excavation below water table resulting in depressurisation).

A summary of the relevant water affecting activities, their associated direct impacts, potential effects and the assessment criteria that have been used to quantify the significance of the impact is provided in Table 8.3.

An expansive description of the water affecting activity (i.e. construction of the power waterway) related to the Project is provided in Chapter 2.

8.1.3 Indirect impacts

i Overview

Indirect impacts represent the final link in the source-pathway-receptor chain (refer Section 8.1.1). An indirect impact is resultant of direct impact (i.e. a change in water quality, quantity or the aquifer medium, as discussed in Section 8.1.2). Types of indirect impacts may include the following:

- Altered groundwater quantity or quality available for terrestrial, aquatic or subterranean ecosystems that potentially rely on groundwater. This may be caused by a direct impact which has resulted in reduced water availability or altered water chemistry, exceeding the tolerance or limits of the groundwater supported species.

- Reduced water availability or altered water chemistry which has impacted the functioning of nearby third-party users that rely on groundwater, including landholders who rely on:
  - groundwater supply bores, and/or
  - surface water extraction from the nearby groundwater dependent watercourses.
- Reduced water availability or altered water chemistry which alters the cultural/spiritual amenity of declared culturally and/or spiritually significant sites.

The significance of an indirect impact is a function of the impact magnitude, receptor sensitivity and receptor resilience to changing groundwater conditions. The assessment of indirect impacts, and particularly the significance of the impact, requires an understanding of the relevant sensitive receptors. Principally these include:

- location within the landscape, particularly in relation to the receivers' proximity to water affecting activities
- reliance on water (e.g. depth to watertable, groundwater flux to baseflow-fed streams, water quality to meet beneficial purposes)
- capacity to adapt to altered surface water and/or groundwater regimes (resilience and resistance)
- an understanding of the scale of direct impacts
- the EV of the receptor, as discussed below.

ii Environmental values

Environmental values (EVs) establish a level of significance for groundwater receptors, providing an understanding of the importance for maintaining baseline water conditions at the groundwater receptor during Project construction and operation. EVs are dependent on the intrinsic value of an ecosystem (i.e. distribution of plant communities and category of endangerment) and the beneficial use of the source water system (i.e. water intended for drinking water supply or agricultural purposes). For the purpose of this GIA, groundwater receptors with cultural/spiritual significance (such as the Carrai Waterholes, refer Section 3.6.2) have been defined as an EV however, are assessed at the highest level of significance. Definitions of EVs relevant to the Project are provided in Table 8.1.

Table 8.1 Summary of environmental values and definitions

Environmental value	Definition
Cultural/spiritual areas	The requirement to sustain water available to features of cultural or spiritual significance (i.e. ceremonial water features such as initiation waterholes.
Aquatic ecosystems	The intrinsic value of aquatic ecosystems, habitat and species supported by perennial watercourses, waterholes and riparian areas (i.e. floodplain wetlands and fish).
Terrestrial ecosystems	The intrinsic value of terrestrial ecosystems, habitat and species supported by near surface groundwater (i.e. plant communities with a dependence on groundwater, potentially providing a habitat for animal species).
Subterranean ecosystems	The intrinsic value of subterranean ecosystems supported by subsurface groundwater (i.e. stygofauna).
Irrigation water	The suitability of water to support irrigation of crops, gardens and recreational areas.
Stock water	The suitability of water to support drinking water for livestock.

Table 8.1 Summary of environmental values and definitions

Environmental value	Definition
Domestic water	The suitability of water to support domestic supply (i.e. household use for laundry, bathing and washing).
Recreation water	The suitability of water to support recreational use (i.e. swimming and boating).
Drinking water supply	The suitability of water to support drinking water for households, requiring relatively minimal water treatment (such as water softening or disinfection).

Although the sensitivity of the EV will not change (i.e. is generally determined qualitatively by the interaction of the receptor's condition, adaptive capacity, and resilience), the magnitude of the potential impact is variable and may be categorised quantitatively (i.e. numerical modelling of groundwater drawdown) to facilitate the prediction of impact likelihood and significance.

iii Groundwater receptors within the Project area

Project-relevant EVs have been identified in Table 8.2, providing a basis for assessing the significance of impact to receptors.

Table 8.2 Environmental values and identified groundwater receptors

Environmental value	Groundwater receptor
Cultural/spiritual areas	• Carrai Waterholes.
Terrestrial ecosystems	• Plant communities with a dependence on groundwater.
Subterranean ecosystems	• Stygofauna.
Irrigation water	• Macleay River, supporting downstream unregulated river water access licenses used for irrigation.
Stock water	• Macleay River, supporting downstream landholders utilising the river for stock watering.
Domestic water	• Macleay River, supporting downstream domestic water access licenses. • East Kunderang Homestead water supply bore (GW307320).
Recreation water	• Macleay River, supporting downstream recreational water usage.
Drinking water supply	• Macleay River, supporting downstream town water supply (local water utility access licenses) for the townships of Bellbrook, Willawarrin and Kempsey.

iv Summary of Project sources, pathways and receptors

Table 8.3 presents a summary of Project water affecting activities (sources), direct impacts (pathways) and indirect impacts (receptors).

Table 8.3 Direct and indirect impacts: water affecting activities and assessment criteria

Water affecting activity (source)	Potential effects	Direct impact (pathway)	Indirect impact (receptor)	Assessment criteria
Subsurface excavation (drill and blast)	• Watertable drawdown • Aquifer depressurisation • Modified groundwater flow paths	Changes to groundwater quantity	Reduced water availability and habitat for EVs	AIP
	• Contamination of groundwater (from chemical spills or materials used in activity)	Changes to groundwater quality	Altered water chemistry for EVs	AIP WQO
	• Modified baseflow to watercourses	Changes to surface water – groundwater interaction	Reduced water availability and habitat for EVs	AIP WQO
	• Physical removal of part or whole of aquifer • Modified groundwater flow paths	Aquifer disruption	Reduced water availability and habitat for EVs	AIP
Stockpiling of generated spoil and wastewater ponds / storage	• Modified recharge • Hydraulic loading on aquifer • Project induced perched groundwater system	Changes to groundwater quantity	Altered water availability and habitat for EVs	AIP
	• Acid spoil drainage • Metalliferous spoil drainage	Changes to groundwater quality	Altered water chemistry for EVs	AIP WQO
Operation of the Project	• Watertable drawdown • Watertable mounding • Aquifer depressurisation	Changes to groundwater quantity	Altered water availability and habitat for EVs	AIP
	• Modified groundwater flow paths	Aquifer disruption	Reduced water availability and habitat for EVs	AIP
Dewatering for maintenance purposes	• Watertable drawdown • Aquifer depressurisation	Changes to groundwater quantity	Reduced water availability and habitat for EVs	AIP
	• Modified groundwater flow paths	Aquifer disruption	Reduced water availability and habitat for EVs	AIP
Groundwater supply for construction	• Watertable drawdown • Aquifer depressurisation	Changes to groundwater quantity	Reduced water availability and habitat for EVs	AIP

8.1.4 Cumulative effects

Cumulative water-related effects have been assessed for the Project within the following context:

- existing pre-Project surface water quality, considering historic mining activities and nearby agistment, farming practices within the catchment
- Project-induced drawdown, baseflow reduction and surface water quality during the construction phase of the Project
- the ongoing influence of drawdown, baseflow increase and surface water quality during the operational phase of the Project.

At the time of compiling this GIA, there are no other relevant projects within the general Project area that may induce cumulative impacts.

8.2 Risk based assessment approach

Impacts will be assessed in accordance with a risk-based approach, comprising:

- identification of relevant water effecting Project activities (during construction and operational phases)
- assessment of EVs (including location, sensitivity, resilience and resistance)
- assessment of the risk of potential impacts to EVs, including the:
  - significance of potential impacts
  - likelihood of potential impacts
- recommendation of mitigation measures, with an assessment of the effectiveness of mitigation options
- assessment of the residual impact.

Further discussion of assessed impacts is provided in Chapter 11.

9 Groundwater flow assessment

9.1 Overview

This section provides a summary of the GIA based on outcomes of numerical groundwater flow modelling. Only groundwater level and flow Project-related impacts are discussed.

The Australian Groundwater Modelling Guidelines (Barnett, et al., 2012) developed a system to classify the confidence level for groundwater models. Models are classified as Class 1, Class 2 or Class 3 in order of increasing confidence based on key indicators such as available data, calibration procedures, consistency between calibration and predictive analysis and level of stresses. The modelling conducted for the Project aligns best with the criteria for a medium confidence level (Class 2), with some criteria conforming to Class 1, and a few to Class 3. Justifications for model Class levels are provided in Table 9.1.

The modelling report was peer reviewed by Chris Nicol of Groundwater Logic and found to be fit for purpose with all modelling objectives satisfied and the model principally complies with current best practise with regards to design, calibration and prediction. Further detail (including a copy of the peer review) of the groundwater flow modelling is provided in Attachment C.

9.2 Numerical groundwater flow modelling

9.2.1 Modelling objectives

The following modelling objectives were defined to support the GIA:

- predict drawdown/mounding at nearby groundwater users
- predict drawdown/mounding at GDEs and other identified sensitive receptors
- predict groundwater inflow to the Project infrastructure during construction and operation periods
- predict changes to the water balance resulting from the Project.

9.2.2 Design

The model was built in the Groundwater Vistas version 8 Pro (ESI, 2022) graphical user interface and run using the MODFLOW-USG version 1.10 code (Panday, Langevin, Niswonger, Ibaraki, & Hughes, 2017). The model employs a spatial domain (refer Figure 9.1) sufficiently large to encompass the anticipated extent of drawdown/mounding resulting from construction and operation of the Project. It contains all groundwater-affecting components of the Project, the Macleay River, GDEs in the vicinity and the sole third-party groundwater well in area.

The use of the MODFLOW-USG code enabled the model to employ an unstructured Voronoi polygon mesh, which was built using AlgoMesh 2.0 (HydroAlgorithmics, 2020). This highly efficient meshing technique allows refinement by using small cell sizes along key model features such as below surface tunnels and above ground watercourses while letting the cell size increase in areas that are further away from features of interest. The model domain is discretised into 46,146 cells per layer, and 25 model layers. The model uses a feature of MODFLOW-USG which allows cells to be “pinched out” where a layer is not present, or is less than 0.5 m thick, and the pinched out cells are treated as inactive and are removed from all calculations while a model is running. Of the 1,153,650 total cells in the model, about half are pinched out reducing the total number of active cells to 563,404.

The model employs boundary conditions to represent the climate-driven processes of recharge from rainfall and evapotranspiration. Surface water-groundwater interaction is simulated for the Macleay River as well as the minor creeks and drainage lines.

The model is parameterised using pilot points, from which hydraulic properties are interpolated and extrapolated to all model cells. This highly parameterised approach, as opposed to a simpler "zoned" approach, was necessary to enable a Monte Carlo stochastic approach to predictive uncertainty analysis.

9.2.3 History-matching

The model was history-matched in both steady state and transient modes, combined into a single model run, to obtain a base case model parameterisation consistent with both static baseline heads and transient head fluctuations in response to climate-driven rainfall recharge and discharge processes. This approach assumes, consistent with the conceptualisation, that the groundwater system was in steady state, except for relatively small-scale, short-term responses to seasonal rainfall, prior to construction. The steady state solution provides initial heads for the transient period which begins with a transient warm-up, employing monthly stress periods, from September 2020 to August 2021. Transient history-matching data were then available from September 2021 with monthly stress periods maintained until January 2022, when they were refined to fortnightly in line with expansion of the groundwater monitoring network.

The model was history-matched to a total of 1,432 targets obtained from the monitoring network installed for the Project. These were split into a group containing individual head measurements and a group containing transient time series head difference targets. These were comprised of:

- 16 steady state head targets taken as the minimum recorded groundwater level for each of the monitoring bores.
- 13 head targets at points and times where springs were observed during site visits, weighted at 20% of the value of the bores.
- 1,403 head difference transient targets, defined as the difference between the current and previous measured hydraulic head. These behave similarly to drawdown targets but are better when the steady state head is not well known.

The parameter estimation software PEST++ version 4.2.16 (USGS, 2019) was employed to automate the history-matching process. The resulting base case parameterisation achieved scaled root mean squared (SRMS) errors of 0.52% against steady state targets and 6.81% against transient targets. These were considered to produce an overall good match to measured groundwater levels, gradients and dynamic responses to climate stresses.

9.2.4 Predictive modelling

i Approach

Given the short duration of baseline groundwater monitoring, limited spatial extent in the monitoring network and limited hydraulic testing available, the parameterisation of the model could not be as highly constrained as if additional data were available. Therefore, despite the anticipated low groundwater risk posed by the Project, a type 3 "stochastic modelling with Bayesian probability quantification" predictive uncertainty analysis approach, as defined Uncertainty analysis – guidance for groundwater modelling within a risk management framework (Middlemiss & Peeters, 2018), was implemented. In addition to the base case history-matched model parameterisation, 200 alternative realisations of parameters were sampled from parameter probability distributions. Only those realisations that achieved a history-matching objective function up to two times that of the base case were accepted. This resulted in rejection of 92 realisations and acceptance of a suite of 109 realisations, including the base case, that were adopted for predictive modelling.

For each realisation a null scenario (i.e. no Project) and Project scenario were run. Project-related changes (e.g. drawdown/mounding or change in water balance components) were calculated as the difference between the null scenario and the Project scenario for each realisation. In this way non-Project related effects (such as response to seasonal climate) were removed.

ii Scenario definition

A predictive scenario was developed, continuing on from the history-matching period, that simulated construction followed by operation of the Project. Quarterly stress periods were employed over 4.25 years of construction (representing the relevant portion of the construction program intercepting groundwater, i.e. starting with construction of the MAT in April 2023 (SMEC, 2022)) with progressive simulation of construction of Project components in line with the provided construction schedule. Boundary conditions were employed to simulate seasonal climate variation as well as construction of the Project. Immediately following the construction period, the scenario employs a 1,000 year duration stress period to simulate operation of the scheme (under average climate) and the temporal response to commencement of operation, followed by a steady state stress period to simulate long term equilibrium in the groundwater system with the Project in operation (under average climate).

During construction:

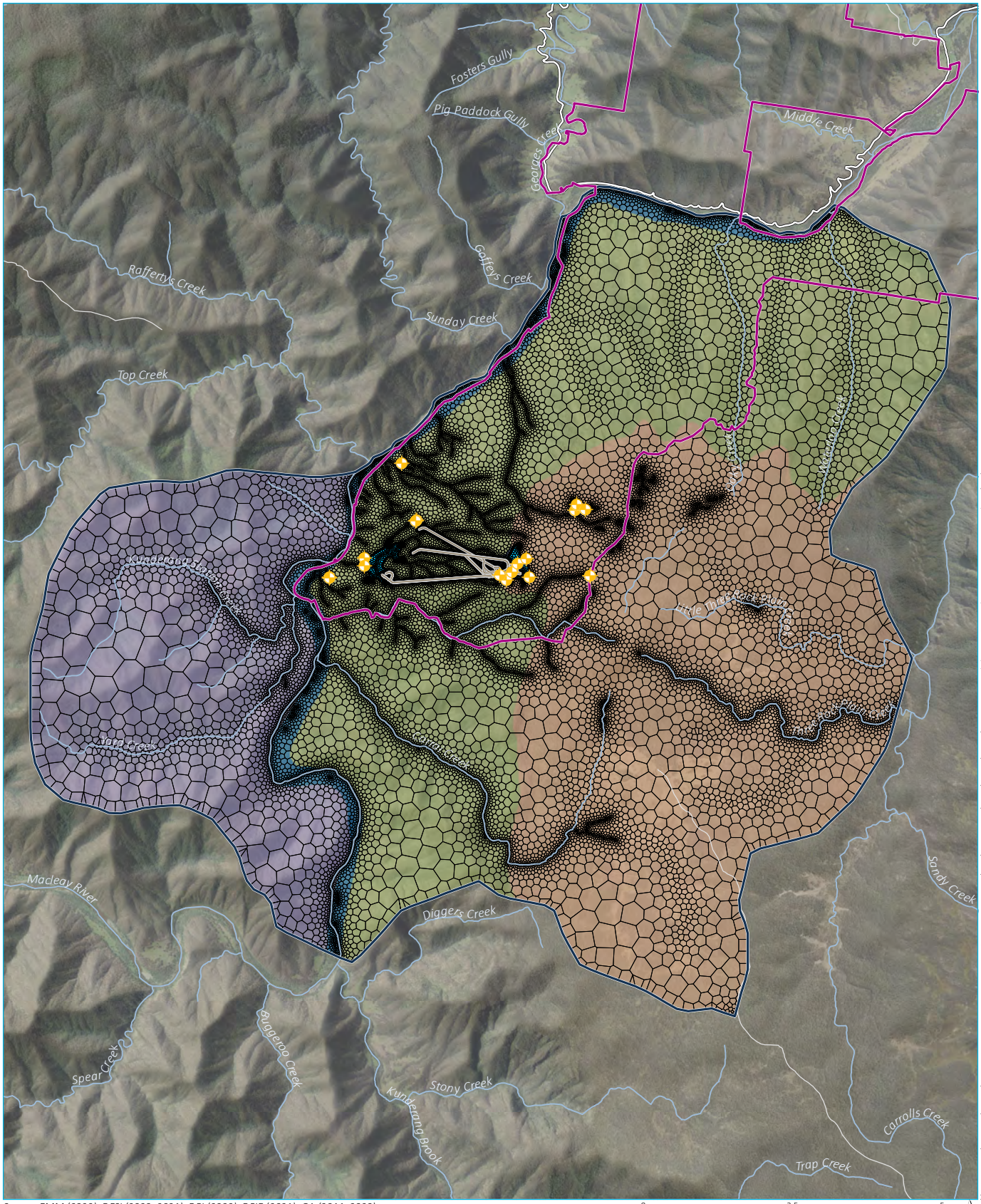
- Upper and lower reservoirs are simulated using the Drain (DRN) package with stage set to the bottom of the excavation for a given model cell and the conductance set at 10,000 metres squared per day (m^2/d) so that discharge is not limited by the boundary condition, but rather the transmissivity of the intersected HSUs.
- Dam walls are simulated using the Time-Variant Materials (TVM) package to change modelled in-situ weathered rock (model layer 1) hydraulic conductivity (~ 0.5 metres per day (m/d)) to a low permeability (0.001 m/d).
- The head race, tail race, access portals and power station are represented using the DRN package with the stage of each drain set to the base of the Project element in each cell and the conductance set to a high value of 10,000 m^2/d to ensure effective dewatering of model cells to the assigned drain stage.

During operation:

- The two reservoirs were represented by the General Head Boundary (GHB) package applied to the top model layers. As the operational head will vary significantly at sub-daily intervals, the average operating levels were adopted (855.5 mAHD at the Upper Reservoir and 227.5 mAHD at the Lower Reservoir) as the assigned heads.
- Water pressure in the headrace pressure shaft and tailrace were represented using the GHB package with heads assigned equal to those in their respective connected reservoir. Conductance was applied as per the DRN package boundary conditions used during the construction period.
- Any open access portals maintain the same DRN boundary condition configuration as adopted for the construction period.
- The penstocks and headrace tunnel are to be steel lined and impermeable and, hence, are assigned no boundary conditions during operation.
- Some tunnels that were needed during construction are plugged at entrance and exit during operation. These are assigned no boundary conditions during operation and are allowed to equilibrate with the surrounding aquifer.

Table 9.1 Evaluation of model confidence level classification (after Barnett et al. 2012)

Data	Class	Calibration	Class	Prediction	Class	Key indicator	Class
Bore logs and temporal head measurements available. Coverage is focussed around upper and lower reservoirs and within Project footprint. More temporal data would improve confidence in the future.	2	Validation not undertaken.	1	Transient discretisation is different to that of calibration.	1	Key calibration statistics are reasonable although can be poor in some parts of the domain.	2
Bore logs and stratigraphy data available. Downhole hydraulic testing improves understanding of fracture intensities with depth.	2	Calibration to steady-state and transient conditions. Overall reasonable statistics with areas for improvement.	2	Transient calibration over a short time frame compared to prediction.	1	Model predictive time frame is less than 10 times longer than calibration period.	2
No available records of groundwater extraction or injection.	1	Transient history-matching datasets are current and reflect contemporary aquifer conditions.	3	Level and type of stresses included in the predictive model are outside the range of those used in transient calibration.	2	Stresses in predictions are more than 5 times higher than those in calibration.	1
Rainfall and evaporation data based on SILO and BOM synthetic datasets.	2	Model is calibrated to heads (and changes in head) only.	2		2	Stress period or calculation interval is broadly different to that used in calibration.	1
Some aquifer testing to define aquifer properties.	2	Some of the key modelling outcomes (flow fields and hydraulic interactions) are reflected in calibration.	2			Temporal discretisation in predictive model is not the same as that used in calibration.	2
Little or no data on streamflow. Only site observations.	1					Cumulative mass balance – closure error is less than 0.5%.	3
Very good quality and spatial coverage of DEM to define ground surface – 2 m LIDAR.	3					Most but not all model parameter values consistent with conceptual model.	2
						Appropriate computational methods used with appropriate spatial discretisation to model the problem.	3
						The model has been reviewed by an independent hydrogeologist/groundwater modeller.	2



Source: EMM (2022); DFSI (2020, 2021); DPI (2003); DPIE (2021); GA (2011, 2020)

0 2.5 5 km

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KEY

- Project area
- Study area
- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts

Existing environment

- Major road
- Minor road
- Named watercourse
- Groundwater bore network
- Model mesh

Focus area

- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

Model domain and major features

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Figure 9.1

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9.2.5 Predicted water table drawdown

i Overview

Water table drawdown in the Project is caused by groundwater flow into the key subsurface Project features (i.e. the power waterway, reservoirs access tunnels and the underground power station). This is expected to occur primarily as a function of secondary porosity (i.e. via fractures and along bedding planes). The model assumed a bulk conservative hydraulic conductivity for each rock type and cannot simulate individual fractures because the locations and conductivity of individual fractures are not known until the tunnel intersects them. Attempts to 'constrain' the model to simulate unknown geological occurrences (i.e. fractures interspersed with low hydraulic conductivity zones) or design elements, is not in-line with the Australian Groundwater Modelling Guidelines (Barnett et al 2012) and this has therefore not been undertaken.

The modelling results are therefore conservative for two reasons:

- Modelling does not consider actual design, management or mitigating activities (i.e. pre/post-grouting, concrete lining and steel lining). During construction the discrete fractures that yield excess water will be grouted during construction, reducing the actual overall tunnel inflow volume.
- Hydraulic parameters within the numerical model for the Macleay River floodplain alluvials are conservative and assume significant permeability and flow. However, in reality, the entire unit may not behave like this, with some parts expected to be much less permeable with storage also expected to be constrained by thickness.

Therefore, the model predictions of inflow, baseflow reduction and watertable drawdown are likely to be overestimating Project impacts. The results of this conservative model approach need to be considered within this overall context to accurately assess the Project on its true merits.

Based on the stochastic modelling, the 67th percentile of maximum water table drawdown has been assessed at each node in the model and used for predicting potential impacts.

The groundwater model also assumes no reduction in permeability from any concrete lining or grouting, as would typically follow the drill and blast excavation method proposed in the Project 15% feasibility design report (SMEC, 2022)).

Predicted water table drawdown has been summarised for the construction (refer Section 9.2.5ia) and operational (refer Section 9.2.5ib) phase of the Project.

a Predicted water table drawdown during construction

Maximum water table drawdown is realised in the final year of construction when the reservoirs and sub-surface infrastructure have been excavated to design depth and intercepting the greatest portion of the respective groundwater system. Water table drawdown during construction is predicted to be:

- >20 m within the eastern (up-hill) portion of the lower reservoir and upper reservoir excavation footprint and near the pressure shaft entry
- 10–20 m extending:
  - radially from the lower reservoir excavation (extending approximately 140 m)
  - radially from the upper reservoir excavation (extending approximately 50 m)
  - approximately 700 m along the low-lying topography near Fingerboard Crossing Creek

- a relatively small area confined to the outlet of the tailrace tunnel, within the lower reservoir

- 2–10 m within the majority of the remaining low-lying topography supporting Fingerboard Crossing Creek
- 0.1–2 m, extending radially from the Project infrastructure and up to approximately 1.7 km north of the ECVT tunnel access.

The predicted water table drawdown during construction of the Project is presented in Figure 9.2.

b Predicted water table drawdown during operation

During operation, the Project induces water table drawdown near structural features continually intercepting the baseline groundwater table (i.e. the drained MAT, ECVT and upper reaches of the lower and upper reservoir), similar to the construction phase. However, infiltration from the water held in the reservoirs and power waterway induces water table mounding (raising of the water table) extending radially (and predominantly down-slope) of the upper and lower reservoir.

Water table drawdown during operation is predicted to be:

- 10–20 m in a relatively small area confined to the low-lying topography near Fingerboard Crossing Creek and adjacent to the drained MAT
- 2–10 m extending up to approximately 800 m along the low-lying topography near Fingerboard Crossing Creek and adjacent to the drained MAT
- 0.1–2 m extending radially from the Project infrastructure and up to approximately 1.4 km north of the ECVT tunnel access, though typically confined to the low-lying valleys.

Conversely, water table mounding was predicted to be:

- >20 m within the upper groundwater system underlying the upper and lower reservoir dams, representing the surface water level in the reservoir at mean supply level
- 10–20 m within a relatively confined area around the upper and lower reservoirs, likely due to infiltration through the reservoir walls
- 2–10 m extending radially (and predominantly downslope) from the upper and lower reservoirs, extending up to approximately 600 m north the upper reservoir
- 0.1–2 m, extending radially (and predominantly downslope) from the upper and lower reservoirs, extending up to approximately 1.3 km north the upper reservoir.

The predicted water table drawdown during operation of the Project is presented in Figure 9.3.

ii Potential impacts on terrestrial vegetation

In accordance with the minimal impact criteria presented in the AIP (DPI, 2012), water table drawdown has been assessed within 40 m of the identified terrestrial GDEs. In summary:

- no obligate GDEs are predicted to be impacted within the study area, comprising PCT 1287 (Upland heath swamps of the New England bioregion)
- water table drawdown is predicted during construction within 40 m of facultative/opportunistic GDEs, including:
  - PCT 1106 (River Oak riparian woodland of the NSW North Coast Bioregion and northern Sydney Basin Bioregion), with up to approximately:
    - 16 m of water table drawdown predicted within 40 m of the mapped GDE extent within the low-lying topography near Fingerboard Crossing Creek
    - 1.5 m of water table drawdown predicted within 40 m of the mapped GDE extent within Peach Tree Creek
  - PCT 762 (Cabbage Gum open forest or woodland on flats of the North Coast), with up to approximately 2.6 m of water table drawdown predicted within 40 m of the mapped GDE extent between the lower reservoir and Macleay River
- water table drawdown is predicted during operation within 40 m of facultative/opportunistic GDEs, including:
  - PCT 1106 (River Oak riparian woodland of the NSW North Coast Bioregion and northern Sydney Basin Bioregion), with up to approximately:
    - 8.4 m of water table drawdown predicted within 40 m of the mapped GDE extent within the low-lying topography near Fingerboard crossing creek
    - 0.2 m of water table drawdown predicted within 40 m of the mapped GDE extent within Peach Tree Creek.

As discussed in Section 7.6.1, terrestrial GDEs with a facultative and opportunistic dependence on groundwater (including PCT 1106 and PCT 762) predominantly depend on rainfall infiltration and adjacent surface watercourses to meet their water requirements, accessing groundwater opportunistically and seasonally when the water table is sufficiently close to the rooting depth of the particular PCT. Given the flow in the respective adjacent watercourse is likely to be sustained by rainfall runoff and releases from the upper reservoir during construction and operation, PCT 1106 and PCT 762 are at low risk of potential impacts. It is again noted that the drawdown predictions should be viewed as worst case based on conservative hydraulic conductivity values in the model and unmitigated tunnel and underground power station construction methods.

Extents of GDEs and water table drawdown are provided in Figure 9.2 and Figure 9.3.

iii Potential impacts on subterranean fauna

The predicted drawdown will reduce the extent of habitat available to stygofauna. Drawdown of less than 20 m is considered unlikely to affect many stygofauna species given the ability of these species to relocate within the saturated zone as groundwater level declines; e.g. drawdown of 5 m would be unlikely to have any significant effect.

Stygofauna communities are considered to be at high risk (Serov, Kuginis, & Williams, Risk assessment guidelines for groundwater dependent ecosystems, 2012). However, only a small area (approximately 270 ha) of habitat is predicted to be affected by drawdown, and species of stygofauna have not been identified during site investigations (refer Section 7.6.3). Therefore, it is anticipated that impacts to stygofauna communities will be low. It is again noted that the drawdown predictions are worst case based on conservative hydraulic conductivity values in the model and un unmitigated tunnel construction methods.

iv Potential impacts on aquatic ecosystems

As discussed in the Project Groundwater Dependent Ecosystem assessment (EMM, 2023) aquatic ecosystems have been assessed as non-dependent on groundwater and are assessed as low risk for Project induced impacts.

v Potential impacts on baseflow

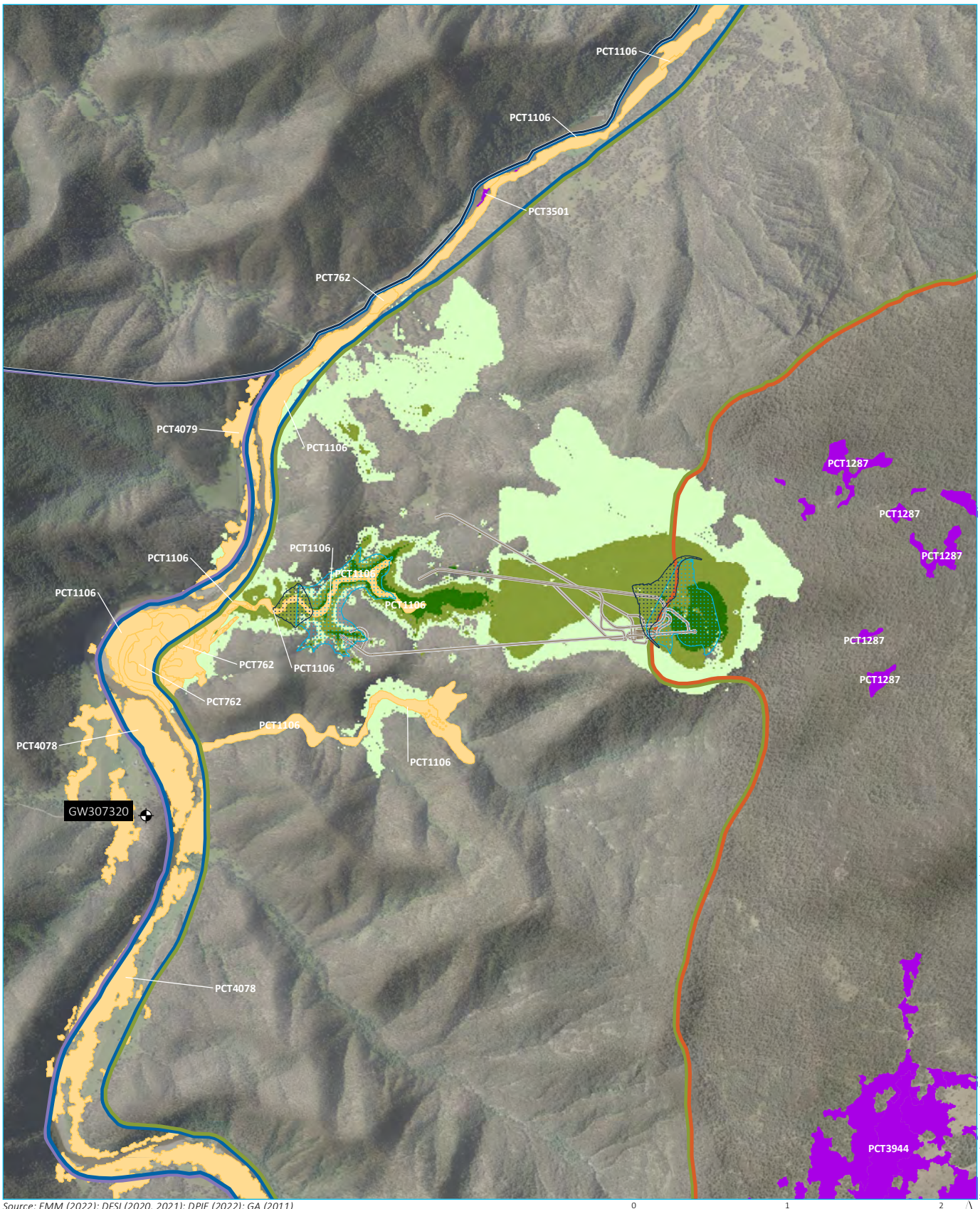
Baseflow reduction to the Macleay River and adjoining watercourses within the study area is predicted during construction of the Project, with the maximum reduction realised in the fourth year of construction at approximately 193 ML/yr, representing approximately 4% reduction from the pre-Project baseflow conditions.

Following construction of the Project, water infiltration from Project infrastructure is predicted to increase baseflow contributions by approximately 400 ML/yr, representing an increase of approximately 6% compared to the pre-Project baseflow conditions. This concept is described in Figure 9.4 and Figure 9.5.

Given the relatively low (and short-term during construction) reduction in baseflow, reduced baseflow is not anticipated to have a significant impact.

vi Predicted impacts on groundwater users

In general accordance with the minimal impact criteria presented in the AIP (DPI, 2012), a maximum of 2 m drawdown is considered minimal impact at any water supply work approval. Based on the numerical modelling, drawdown is not predicted at the East Kunderang Homestead bore (GW307320) and Project induced impacts to groundwater users is considered low risk.



Source: EMM (2022); DFSI (2020, 2021); DPIE (2022); GA (2011)

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KEY

- Study area
- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts

Focus area

- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

- Landholder bore

GDEs within study area

- Facultative – opportunistic
- Obligate

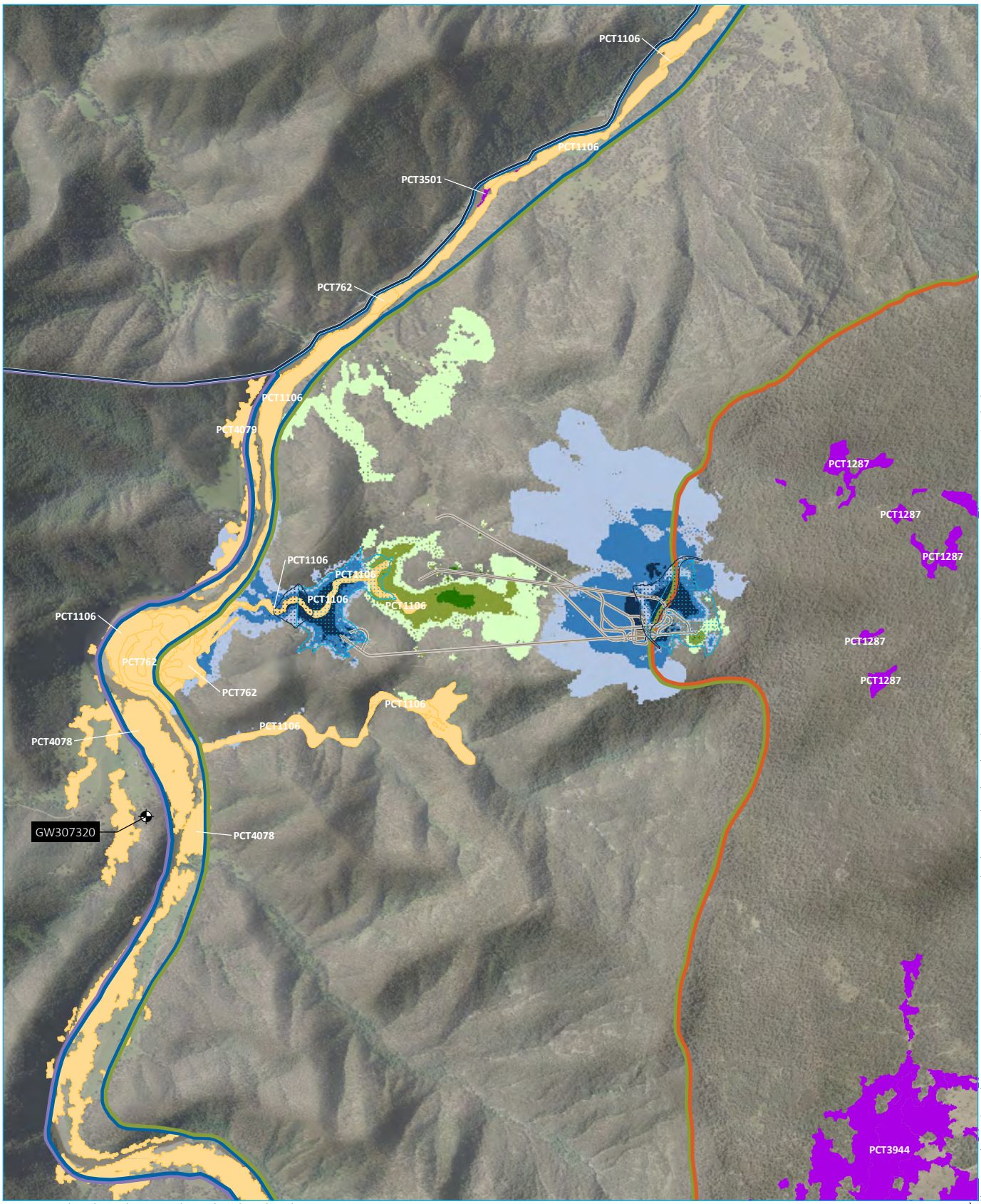
Construction probabalistic drawdown (m)

- < 0.2
- 0.2 - 2
- 2 - 10
- > 10

Predicted water table drawdown during construction of the Project (67th percentile)

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Figure 9.2

EMM creating opportunities



Source: EMM (2022); DFSI (2020, 2021); DPIE (2022); GA (2011)

0 1 2 km

GDA 1994 MGA Zone 56

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KEY

- Study area
- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts

Focus area

- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

- Landholder bore

GDEs within study area

- Facultative – opportunistic
- Obligate

Operation water table mounding (m)

- > 10
- 2 - 10
- 0.2 - 2
- < 0.2

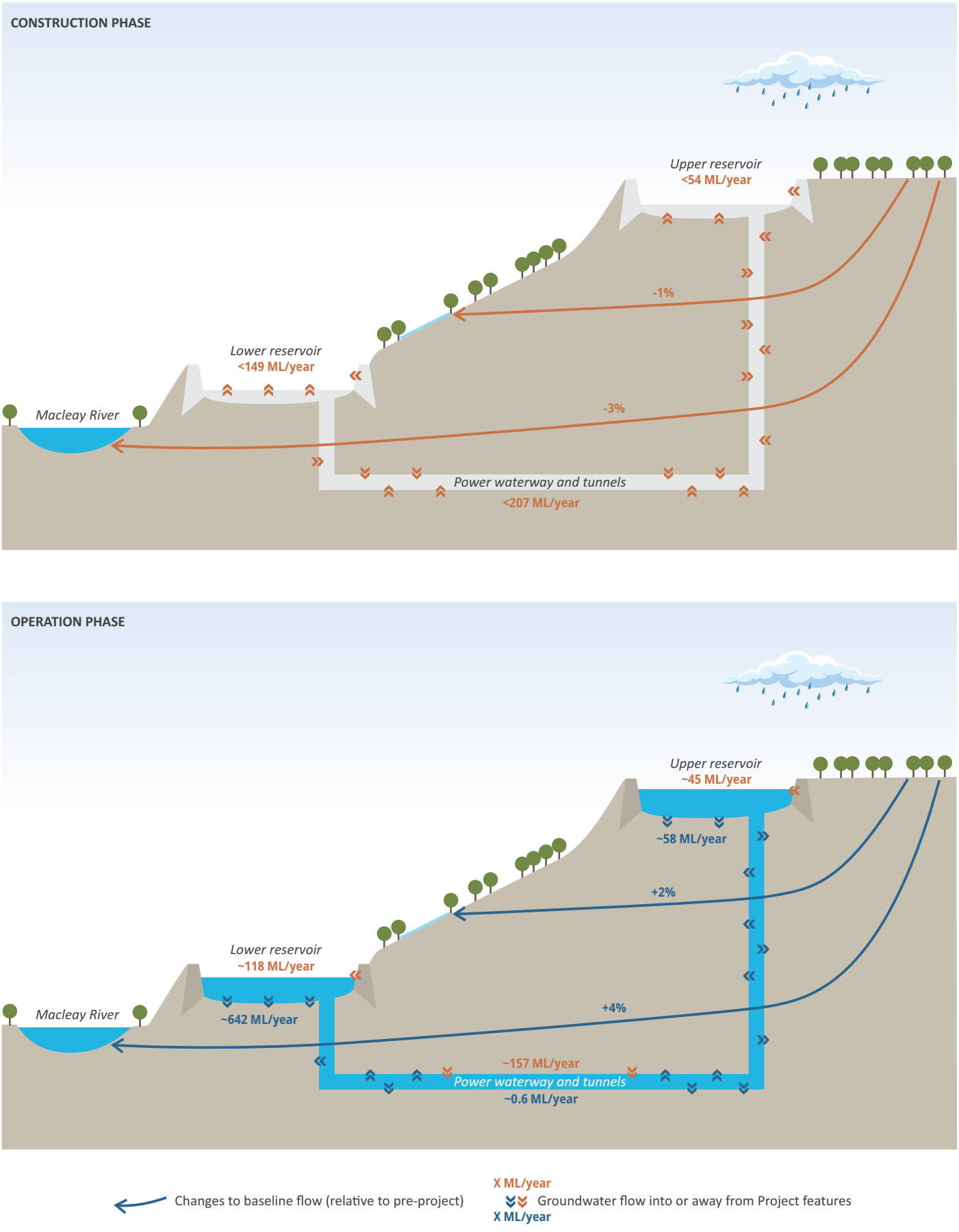
Operation probabalistic drawdown (m)

- < 0.2
- 0.2 - 2
- 2 - 10
- > 10

Predicted water table drawdown during operation of the Project (67th percentile)

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
OMPS Pty Ltd
Figure 9.3

EMM creating opportunities

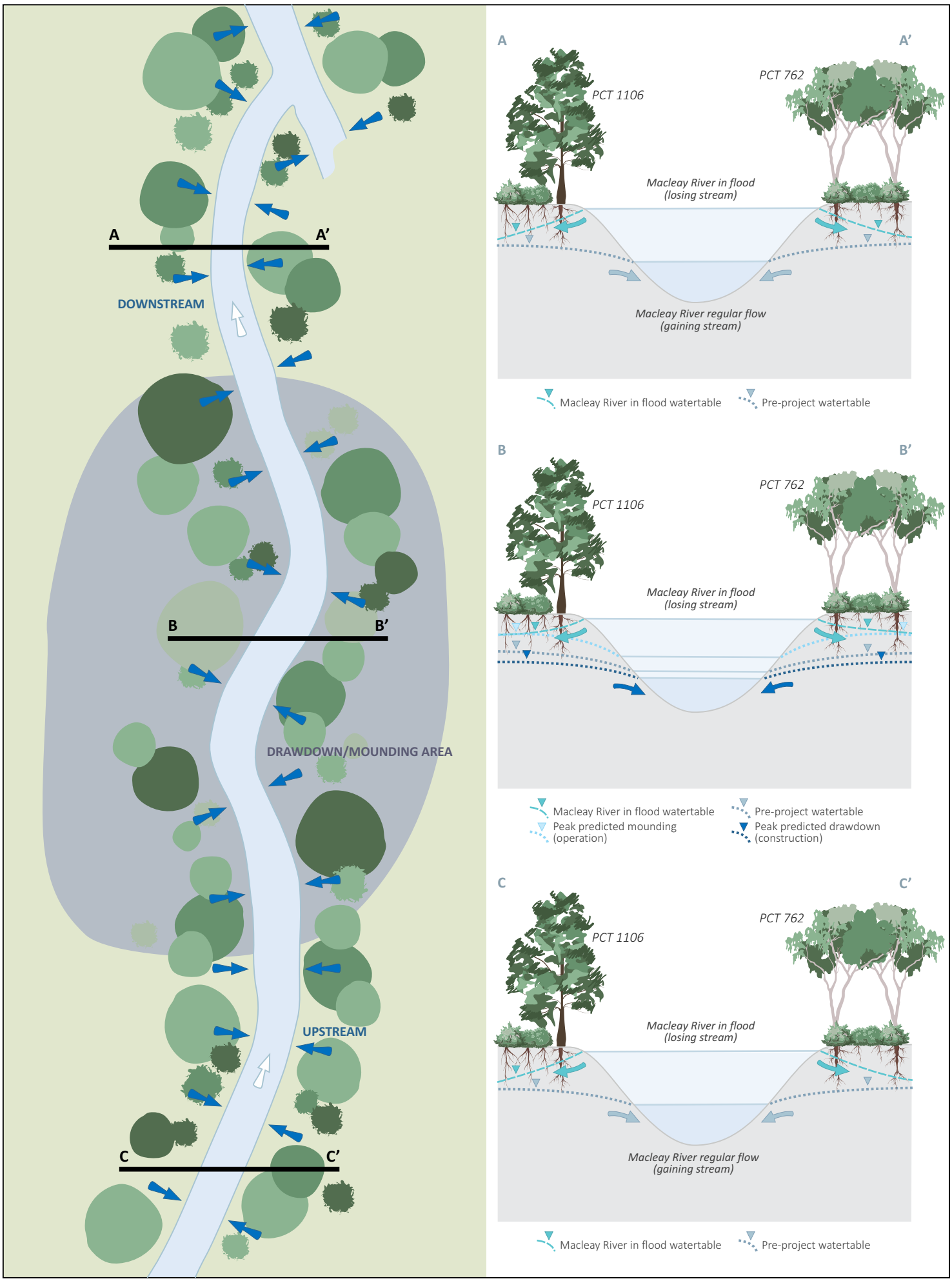


Changes to baseflow conceptualisation

OMPS Pty Ltd

Groundwater impact assessment

Figure 9.4



Baseflow impacts within the area of groundwater drawdown

OMPS Pty Ltd

Groundwater impact assessment

Figure 9.5

10 Water quality assessment

10.1 Overview of water affecting activities

As discussed in Section 8.1.3, Project activities that could be considered a potential water affecting activity include:

- Stockpiling of spoil (i.e. excavated waste rock and soils), potentially providing a source of:
  - acid drainage, potentially associated with the oxidisation of sulphides contained within the spoil
  - metals and metalloids, potentially associated with the mobilisation of metals contained within the spoil when exposed to oxygen or differing pH levels
- storage of surplus or construction water, potentially infiltrating to the groundwater system or spilling to nearby watercourses and altering water quality
- drilling and blasting for tunnel excavation, potentially introducing nutrients (typically ammonium and nitrate contained within the blasting chemicals) to the groundwater system
- machine operation, potentially introducing hydrocarbons (fuels and oils) to the groundwater system in the event of a spill.

10.2 Water quality objectives and environmental values

The NSW Water Quality and River Flow Objectives (DECCW, 2006) provides WQOs that are consistent with ANZECC/ARMCANZ water quality guidelines for the protection of the aquatic environment (ANZECC & ARMCANZ, 2018). The WQOs are "primarily aimed at maintaining and improving water quality, for the purposes of supporting aquatic ecosystems, recreation and where applicable water supply and the production of aquatic foods suitable for consumption and aquaculture activities" (DECCW, 2006).

WQOs are provided for catchments throughout NSW, with waterbodies potentially impacted by the Project contained within the Macleay River catchment.

10.2.1 Aquatic ecosystem protection

The ANZECC/ARMCANZ (2000) guidelines present default trigger values for the protection of 99%, 95%, 90%, and 80% of aquatic species. The guidelines also present default trigger values for the protection of slightly-moderately disturbed ecosystems that are based on the default trigger values for the protection of 95% of species, but which use the lower default trigger values for the protection of 99% of species for chemicals for which possible bioaccumulation and secondary poisoning effects should be considered.

10.2.2 Protection of systems supporting drinking water

The ADWG (NHMRC & NRMMC, 2011) present default trigger values for the protection of receiving waters that may be utilised for human consumption. In this regard, ADWG trigger values apply more conservative values for certain contaminants than ANZECC/ARMCANZ (2000) default guideline values. Given this, this assessment conservatively assumes that ADWG default criteria supersedes ANZECC/ARMCANZ (2000) guideline criteria for certain analytes where applicable.

10.2.3 Summary of water quality objectives

WQOs for watercourses and reservoirs are based on the NSW Water Quality and River Flow Objectives (DECCW 2006) and are presented in Table 10.1. WQOs are assigned based on the type of waterbody, the existing ecosystem condition and the potential receptors to any discharged water.

There is currently insufficient data to prepare SSTVs for all monitoring locations, streamflow conditions and operating regimes (in the case of reservoirs). Hence, the default guideline values presented in Table 10.1 and Table 10.2 have been applied to characterise and assess water quality. These values are referred to as WQO values throughout the water assessment. SSTVs can be prepared during construction phase monitoring if sufficient data is available.

Table 10.1 Summary of water quality objective values

Water component	Ecosystem condition / beneficial use	Ecosystem condition justification	Proposed WQO approach	Default WQO values
Watercourses (ephemeral and perennial streams)	• Slightly–moderately disturbed	• Upstream mining activities have impacted water quality within the Macleay River catchment (Ashley, Graham, Tighe, & Wofenden, 2007). • Agricultural land use within and near the Project area has likely impacted water quality.	• Physical and chemical stressors (some change due to natural variability acceptable).	• Default trigger values for upland rivers in south-east Australia (ANZECC & ARMCANZ, 2018).
			• Toxicant trigger values for slightly–moderately disturbed ecosystems.	• Toxicant trigger values for slightly–moderately disturbed ecosystems (ANZECC & ARMCANZ, 2018).
Reservoirs	• Slightly–moderately disturbed	• System would be considered disturbed by the construction of the Project.	• Physical and chemical stressors (some change due to natural variability acceptable).	• Default trigger values for freshwater lakes and reservoirs in south-east Australia (ANZECC & ARMCANZ, 2018).
			• Toxicant trigger values for slightly–moderately disturbed ecosystems.	• Toxicant trigger values for slightly–moderately disturbed ecosystems (ANZECC & ARMCANZ, 2018).
Discharge directly to Macleay River	• Slightly–moderately disturbed • Downstream water supply	• Upstream mining activities have impacted water quality within the Macleay River catchment (Ashley, Graham, Tighe, & Wofenden, 2007). • Agricultural land use within and near the Project area has likely impacted water quality. • Downstream towns of Willawarrin, Bellbrook and Kempsey extract water for utility supply (refer Section 3.7).	• Physical and chemical stressors (some change due to natural variability acceptable).	• Default trigger values for freshwater lakes and reservoirs in south-east Australia (ANZECC & ARMCANZ, 2018).
			• Toxicant trigger values for slightly–moderately disturbed ecosystems.	• Toxicant trigger values for slightly–moderately disturbed ecosystems (ANZECC & ARMCANZ, 2018).
			• Guideline values for physical and chemical characteristics of drinking water (where not presented in ANZECC guidelines, (ANZECC & ARMCANZ, 2018)).	• Guideline values for physical and chemical characteristics (NHMRC & NRMMC, 2011).

Table 10.2 Water quality objectives – default trigger values

Indicator	Units	Aquatic ecosystem[1]	Visual amenity	Secondary contact	Primary contact	Livestock water supply	Irrigation water supply	Aquatic foods (cooked)	ADWG (health)	ADWG (aesthetic)
Physico-chemical										
pH	-	6.5–8.5	-	-	5.0–9.0	-	6.5–8.5	-	-	6.5–8.5
Temperature	°C	-	-	-	15–35	-	-	<2 °C change over one hour	-	-
Dissolved oxygen	%	85–110	-	-	-	-	-	-	-	>85
Electrical conductivity	µS/cm	200–300[2]	-	-	-	3,582[3]	<950[4]	.	<896[3]	-
Turbidity	NTU	50	-	-	6	-	-	-	-	5
Nutrients										
Oxidised nitrogen	µg/L	40	-	-	-	-	-	-	-	-
Ammonia	µg/L	20	-	-	-	-	-	-	-	500
Total nitrogen	µg/L	350	-	-	-	-	25,000–125,000	-	-	-
Reactive phosphorus	µg/L	20	-	-	-	-	-	-	-	-
Total phosphorus	µg/L	25	-	-	-	-	800–12,000	-	-	-
Chemical contaminants/toxicants										
Aluminium	µg/L	55	-	As per ADWG aesthetic	As per ADWG health	5,000	5,000	-	-	200
Arsenic	µg/L	13[5]	-			500	100	-	10	-
Antimony	µg/L	9[6]	-			-	-	-	3	-
Cadmium	µg/L	0.2	-			10	10	-	2	-

Table 10.2 Water quality objectives – default trigger values

Indicator	Units	Aquatic ecosystem[1]	Visual amenity	Secondary contact	Primary contact	Livestock water supply	Irrigation water supply	Aquatic foods (cooked)	ADWG (health)	ADWG (aesthetic)
Chromium	µg/L	1.0[7]	-			1,000	100	-	50	-
Copper	µg/L	1.4	-			1,000	200	5	2,000	1,000
Iron	µg/L	-	-			2,000	200	-	-	300
Lead	µg/L	3.4	-			100	2,000	-	10	-
Manganese	µg/L	1900	-			-	200	-	500	100
Mercury	µg/L	0.06	-			2	2	1	1	-
Nickel	µg/L	11	-			1,000	200	-	20	-
Zinc	µg/L	8	-			20,000	2,000	5	-	3,000
Other chemical contaminants/toxicants	-	As per ANZG (2018)	-			As per Table 4.3.2 ANZECC	As per Table 4.2.10 ANZECC	-	As per ADWG (2011)	As per ADWG (2011)
Biological										
Chlorophyll-a	µg/L	5	-	-	-	-	-	-	-	-
Algae & blue-green algae	Cells/mL	-	-	<15,000	<15,000	<11,500	Not visible	-	<2,000	-
Faecal coliforms	Col./100 mL	-	-	<1,000	<150	<100	<10	2.3 MPN/g	0	0
Enterococci	Ent. /100 mL	-	-	<230	<35	-	-	-	-	-

Notes:
1. Contaminant/toxicant DGVs for slightly to moderately disturbed ecosystems as per ANZG (2018). All other indicators for lowland (<150 m AHD) rivers as per DECCW (2006).
2. Values typical of NSW low land rivers as described in Table 3.3.3 of ANZECC (2000).
3. Derived from a total dissolved solids concentration by using the following equation electrical conductivity x 0.67 = total dissolved solids (ANZEC 2000).
4. For sensitive crops as defined in Table 4.2.4 of ANZECC (2000).
5. As for Arsenic (V).
6. Unknown reliability value.
7. As for Chromium (VI).

10.3 Groundwater quality

10.3.1 Material stockpiling

Spoil material will be stockpiled within the boundaries presented in Figure 2.1. As outlined in the Geochemistry Characterisation Report (EMM, 2023d), the potential for acidic or metalliferous seepage from the excavated spoil has been assessed as low, with results indicating the tested material as:

- non-acid forming (NAF)
- low risk for metal contamination of nearby surface water courses.

Iron sulphide (or pyrite) has been observed within the Project area (refer Attachment A). Pyrite is generally considered to be the dominant indicator for potentially acid forming (PAF) materials, with oxidation potentially leading to the development of sulphuric acid. Project infrastructure may intersect pyrite and generate PAF spoil.

10.3.2 Storage and transportation of chemicals and fuels

There is the potential for the Project construction works to cause contamination to the groundwater resource. This predominately encompasses either spills of hazardous materials/chemicals and/or the generation of solid or liquid waste. Examples of this include spills of hydrocarbons while refuelling or lubricants used by machinery, and generation of solid construction waste or liquid waste during tunnelling. All scenarios have the potential to impact human and environmental health depending on the type of contaminant if not managed accordingly.

11 Impact summary and risk assessment

11.1 Risk assessment and management framework

An evaluation of Project activities and potential impacts to groundwater, surface water and GDEs associated with these activities has been completed. The Project activities are discussed in Chapter 2, with potential groundwater impacts arising from these impacts discussed in Chapter 9 and Chapter 10.

A risk assessment matrix has been used to quantify the level of environmental risk based on:

- likelihood of a potential impact occurring
- consequence of a potential impact, in line with the AIP (DPI, 2012).

The definition of likelihood and the consequences are defined in Table 11.1 and Table 11.2 respectively. Based on the likelihood and consequence of Project activity inducing impact, an overall risk score has been developed and is presented in Table 11.3.

Table 11.1 Classification of likelihood

Likelihood category	Description of qualitative likelihood (water chemistry)	Description of quantitative likelihood (based on groundwater modelling of water table drawdown)
Almost Certain (AC)	A recurring event during the lifetime of an operation or Project.	I.e. the P10 (refer Attachment C) results predict drawdown.
Likely (L)	An event that will probably occur during the lifetime of an operation or Project.	I.e. the P33 (refer Attachment C) results predict drawdown.
Possible (P)	An event that may occur during the lifetime of an operation or Project.	I.e. the P67 (refer Attachment C) results predict drawdown.
Unlikely (U)	An event that is unlikely to occur during the lifetime of an operation or Project.	I.e. the P90 (refer Attachment C) results predict drawdown.
Rare (R)	An event with a low probability to occur during the lifetime of an operation or Project.	No (refer Attachment C) predicted drawdown.

Table 11.2 Classification of significance

Significance category	Description of impact	Minimal impact considerations (DPI, 2012)
Severe (5)	• Considered critical to the decision-making process. • Permanent and irreversible impacts to EVs or areas of cultural/spiritual significance. • Occurring over a large area.	Level 2 – requires modification of Project activity
High (4)	• Considered important to decision-making process. • Long-term and reversible (>5 year recovery period) impacts to EVs or areas of cultural/spiritual significance. • Occurring over medium–large areas.	Level 2 – requires modification of Project activity

Table 11.2 Classification of significance

Significance category	Description of impact	Minimal impact considerations (DPI, 2012)
Moderate (3)	• Considered relevant to the decision-making process. • Short-term to long-term and reversible (1–4 year recovery period) impacts to EVs or areas of cultural/spiritual significance. • Highly localised to the Project area.	Level 2 – requires consideration when developing mitigation measures
Minor (2)	• Considered relatively minor in the decision-making process. • Short-term and reversible (<12 month recovery period). • Highly localised to the water affecting source.	Level 2 – requires consideration when developing mitigation measures
Negligible (1)	• Minimal change to the existing environment. • Allowable under relevant assessment criteria. • Results in a negligible change to sensitive receptors and therefore does not impact EV.	Level 1 – considered minimal impact

Table 11.3 Classification of risk

Likelihood	Significance				
	Negligible (1)	Minor (2)	Moderate (3)	High (4)	Severe (5)
Rare (R)	Low (R1)	Low (R2)	Low (R3)	Medium (R4)	High (R5)
Unlikely (U)	Low (U1)	Low (U2)	Medium (U3)	Medium (U4)	Critical (U5)
Possible (P)	Low (P1)	Medium (P2)	Medium (P3)	High (P4)	Critical (P5)
Likely (L)	Low (L1)	Medium (L2)	High (L3)	Critical (L4)	Critical (L5)
Almost Certain (AC)	Medium (AC1)	High (AC2)	Critical (AC3)	Critical (AC4)	Critical (AC5)

11.2 Unmitigated risk evaluation

This section provides a risk assessment based on the Project construction and operation without mitigation measures. As such, the risks identified within this section should be considered an initial assessment to inform the development of mitigation measures and subsequent residual risks.

The risks of potential impacts caused by Project activities, assuming no controls are in place are summarised in Table 11.4. Potential impacts identified as having a medium or above risk classification may be downgraded if appropriate controls and management measures are implemented and maintained. The commitments to the implementation of management measures and residual risk levels are provided in Table 11.4.

Table 11.4 Assessment of unmitigated potential impacts

Potential impact mechanism	Potential impact	Risk analysis (likelihood and consequence)			
		Low	Medium	High	Critical
Changes to groundwater **quantity** (flow/levels)	Localised drawdown – construction			L3	
	Localised drawdown – operation			L3	
	Regional drawdown – construction		L2		
	Regional drawdown – operation		L2		
Changes to groundwater **quality**	Localised quality impacts – construction	U2			
	Localised quality impacts – operation	U2			
	Regional quality impacts – construction	R2			
	Regional quality impacts –- operation	R2			

11.3 Environmental management measures

The objectives of environmental management measures, as they relate to water resources, are to minimise and/or mitigate the potential for environmental impacts arising from Project activities.

If required, it is proposed to implement:

- pre-grouting (i.e. grouting through pilot holes at the excavation face if inflows are un-manageable via pumping)
- post-grouting (i.e. following excavation via drill and blast methodologies).

Whilst this construction methodology hasn't been considered in the Project groundwater model, these management controls are likely to restrict groundwater inflows during construction and operation of the Project, subsequently reducing impact to water resources. Peer reviewed referenced journal articles on inflow reductions from pre-or-post-grouting in other fractured rock tunnel environments are quoted as reducing inflows to manageable levels (Wannenmacher, Entfellner, & Hauer, 2022).

The residual risk levels, which are presented in Section 11.3.1, reflect the outcomes of management and mitigation measures.

11.3.1 Residual risk levels and environmental management measures

Specific management measures to address the requirements relating to water and the unmitigated potential impacts identified in Table 11.4 have been broadly outlined in Table 11.5. In addition, the residual risk associated with each potential impact has been reassessed.

The control measure(s) focus on lowering the likelihood of an impact occurring, typically the consequence will remain unchanged, except where the risk control measure applied directly reduces the impact/consequence (e.g. pre-or-post grouting).

Table 11.5 Assessment of mitigated (residual) potential impacts

Potential impact mechanism	Potential impact	Risk analysis (likelihood and consequence)			
		Low	Medium	High	Critical
Changes to groundwater **quantity** (flow/levels)	Localised drawdown – construction	P1			
	Localised drawdown – operation	P1			
	Regional drawdown – construction	U1			
	Regional drawdown – operation	U1			
Changes to groundwater **quality**	Localised quality impacts – construction	R2			
	Localised quality impacts – operation	R2			
	Regional quality impacts – construction	R1			
	Regional quality impacts – operation	R1			

Following the implementation of control and mitigation management measures, the residual risk of the potential impacts has reduced for all impact mechanisms.

Table 11.6 lists potential risks to the Project from potential deviations from the model predictions and identified impacts. Proposed management measures are also provided.

Table 11.6 Potential risks to the Project and management measures from potential deviations

Potential impact deviation	Management measure
Groundwater drawdown (levels and extent) is significantly larger than predicted.	Groundwater monitoring to provide early indication of potential change in predicted impacts. Reconciliation of groundwater model predictions against groundwater monitoring data, e.g. increased drawdown, verified by groundwater monitoring, can be mitigated with further grouting treatments.
Groundwater inflow rates are higher than predicted to the tunnel, affecting water management system and Project licensing (compliance).	Metering and monitoring will be in place to record the volume of water removed from the tunnel. Notify regulators. Standby pumps to increase volume removed from the underground for safe operation. Review of groundwater model.
Impacts on baseflow are greater than predicted.	Monitoring during operations to provide indication of impact. Triggers and trigger action response plans (TARP), detailing potential mitigation measures, to be assigned within a water management plan (WMP). Notify relevant regulators.

11.4 Water management strategy and plans

11.4.1 Management Plan

A WMP will be developed for the Project to support construction activities. The WMP will be a sub-plan of the construction environmental management plan (CEMP). The WMP will document the proposed mitigation and management measures for the approved Project, and will include the surface and groundwater monitoring program, reporting requirements, spill management and response, water quality trigger levels, corrective actions, contingencies, and responsibilities for all management measures.

The WMP will be prepared in consultation with DPE, the EPA and key local stakeholders, and would consider concerns raised during the exhibition and approvals process for the Project.

The WMP will include details of the surface water and groundwater monitoring program, which will incorporate and update the existing monitoring network, monitoring frequencies and water quality constituents, and physical water take and pumping volumes between water storage structures. Reporting frameworks for the above will be prepared in accordance with licensing and agency requirements. Trigger levels for water quality parameters will be developed as part of the WMP to assist in early identification of water quality trends. The monitoring program will be prepared in accordance with the approved Project's EPL, once enacted.

11.4.2 Monitoring and thresholds

The baseline water monitoring network is comprehensive, allowing for quality data collection as the Project advances. The network has been developed with ongoing consultation with DPE Water. The water monitoring network is positioned to provide spatial coverage across the Project area and beyond, investigate the major hydrological and hydrogeological environments, and monitor potentially sensitive features.

Baseline data will continue to be collected from this network throughout the life of the Project. Expansion of the network may be considered once the Project starts construction and then operation, and may expand to include aspects such as:

- water metering and recording of pumped volumes to/from the Project
- monitoring quality and metering the volume of water releases to the Macleay River from the WTP (if required).

The suite of water quality analytes to be sampled and the frequency of sampling will be reviewed and updated in the WMP developed for the Project. Data loggers that currently monitor water levels will continue to operate. Any required ongoing development and expansion of the monitoring network will occur in consultation with DPE.

11.4.3 Model validation

The groundwater model predictions would be validated by installing custom-designed groundwater monitoring sites at selected virtual piezometers used in the model. Should sites be unsuitable (i.e. access restrictions), then the model will be re-run with additional virtual piezometers in accessible sites. The model can be regularly validated. Significant deviations from the predicted impacts will be investigated. Reporting on this is proposed annually. Model recalibration will be considered every two years (based on analysis of predicted versus actual impacts) and completed as required.

12 Water licences

12.1 NSW water legislation and policies for licensing water

OMPS is required to licence water that is either taken or intercepted in accordance with the WM Act and the AIP. This includes water taken for use as well as water intercepted and managed as a result of Project activities. OMPS is required to hold WALs in each affected water source to account all water extracted and intercepted.

In accordance with the AIP, the Project is required to licence both the direct and indirect take from adjacent and overlying water sources. The volume of water to be licensed for the Project is defined as:

- groundwater inflow to the Project that is physically handled by the water management system
- groundwater inflow to the Project that is evaporated and thereby lost from the system
- reduced baseflow to overlying water sources
- increases in induced leakage from overlying water sources.

The results of the groundwater modelling have been used to estimate the required groundwater licence entitlements for the Project, based on the predicted total groundwater inflow rates to the Project and baseflow changes in permanent stream flows in the vicinity of the subsurface infrastructure (primarily the headrace tunnel).

The WALs and associated shares need to be held for the water year in which the impact occurs. All shares and WALs do not need to be held prior to the Project approval, as some effects do not occur for years after construction and operation commences. However, a valid pathway needs to be demonstrated to prove the shares can be obtained. OMPS has proposed valid pathways for obtaining the required licence shares over time, allowing them to hold the required entitlements for each year of the Project lifespan.

12.2 Volumetric inflow predictions

12.2.1 Project inflow – direct take

The volumetric inflow to the tunnel from the construction of the Project will occur directly from the NEFB Coast Groundwater Source. The groundwater inflow comprises groundwater inflow to excavations and constructed subsurface features and reduced groundwater available for baseflow to streams. The predicted inflow rates directly into the excavations and subsurface features are summarised below:

- The peak predicted excavation inflow rate to (and take) occurs during construction in year one and is 407 ML.
- Indirect peak predicted take occurs during construction in year four and is 161 ML.
- The excavation inflow rate decreases following year one of construction and then plateaus as the Project construction concludes and it enters an operation phase.
- Once operation commences, the power waterway and other drained features become a throughflow system – with all water remaining within water sources (i.e. the physical take of water ceases once operation commences).
- The steady state (i.e. long-term) inflow rate is 319 ML/yr, however 700 ML/yr (641 ML of which occurs as infiltration from the Lower Reservoir) is throughflow back into the NEFB Coast Groundwater Source, and an additional 364 ML/yr flows into the Macleay River and connecting perennial tributaries.

12.2.2 Water sources for Project inflow

The groundwater model predicts effects on overlying surface water features as a result of Project inflow. The predicted reductions to baseflow are restricted to areas immediately adjacent to the Project alignment and result in reduced baseflow in localised areas to a number of creeks and the Macleay River within the Project area.

The reductions to baseflow are considered over time and the source of this water has also been considered in accordance with AIP. The AIP requires the peak baseflow reductions to be considered for licensing purposes from each source of the water. The peak Project inflow occurs in year one of construction, this volume comes initially from storage within the surrounding groundwater system. Time lags in the depressurisation of the overlying groundwater systems mean that the peak reductions to groundwater available for baseflow does not occur until year four of construction.

Reductions in groundwater available for baseflow to watercourses was considered from the ultimate source perspective, as per a legal interpretation of the AIP, and in accordance with how the AIP has been implemented for other major project assessments. Reductions in streamflow (from a licence perspective) are either:

- reduced groundwater available for baseflow contributions (i.e. less gaining stream – but ultimately still a gaining stream) – this is licensed as groundwater, and/or
- induced losses from the surface water system to the underlying groundwater system (i.e. induced leakage from the surface water source) – this is licensed as surface water.

The source of the water has been determined in the groundwater modelling to be a result of both reduced baseflow and streamflow losses. Therefore, the baseflow reduction portion will be licensed as groundwater from within the NEFB Groundwater Source and the Macleay Gorges Water Source for the induced loss component.

The peak reduction in baseflow as a result of the Project within the NEFB Coast Groundwater Source is 161 ML which occurs in year four of construction.

i New England Fold Belt Coast Groundwater Source

Baseflow to the Macleay River are expected to reduce by a peak of up to 117 ML/yr in year five of construction. Baseflow to collectively the unnamed and named perennial watercourses across the escarpment area of the Project area are expected to reduce by a peak of up to 47 ML/yr in year four of construction.

ii Macleay Gorges Water Source

Induced losses from the Macleay River to the underlying NEFB Coast Groundwater Source is expected to peak at 33 ML/yr in year four of construction.

12.2.3 Total Project licence requirements

The total Project licence requirements are presented on a yearly time-step Table 12.1 and Figure 12.1.

Table 12.1 Required licences and licence components

Date year ending	Year	NEFB Coast Groundwater Source		
		Flow to excavations (ML)[1]	Tunnel inflow (indirect) Reduced baseflow (ML)	Total (ML)
2023	C1	407	62	**469**
2024	C2	365	132	**497**
2025	C3	314	151	**465**
2026	C4	293	161	**454**
2027	C5	295	160	**455**
	Steady State (operations)	*320*	*0*	***320***
	Maximum			**497**

Notes: 1. ML = megalitres

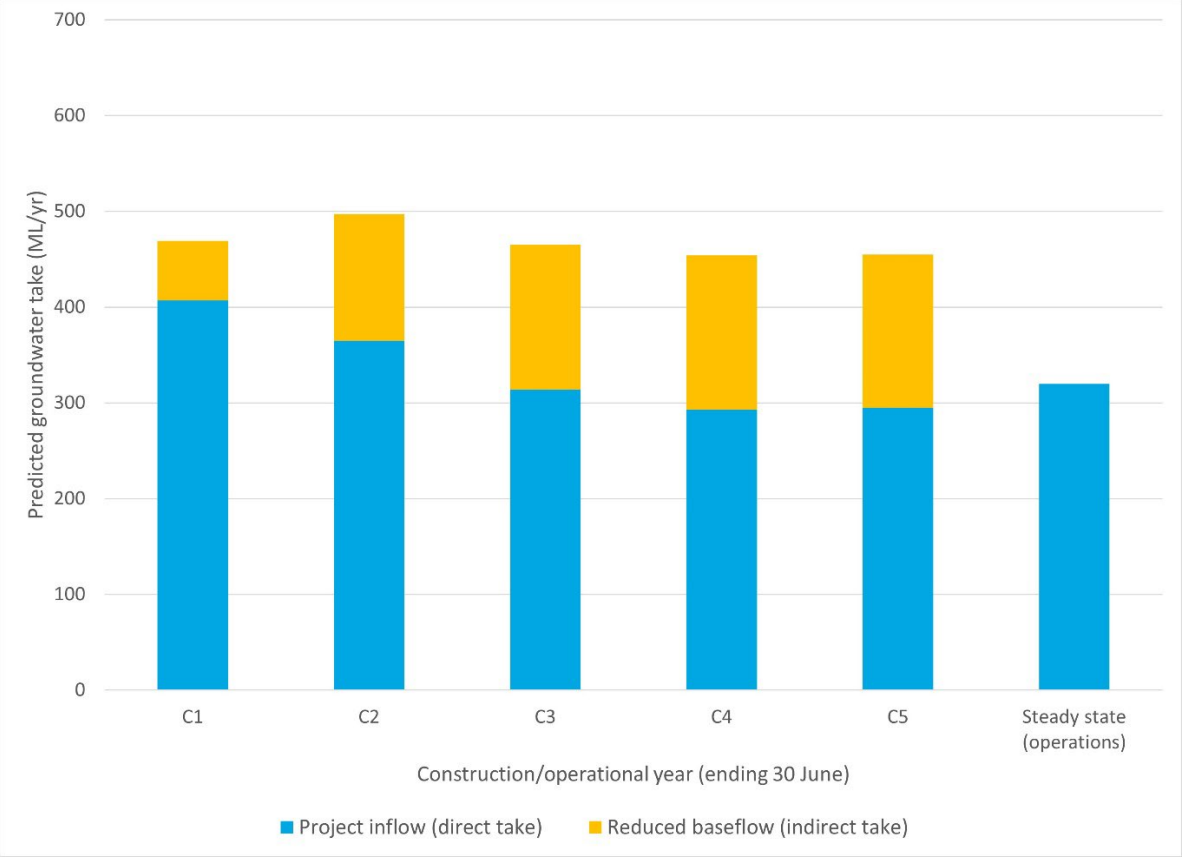


Figure 12.1 New England Fold Belt Coast Groundwater Source yearly licence requirements

12.3 Licence summary

Once operation of the scheme commences, the tunnel acts as a throughflow system, with groundwater inflow from the NEFB Coast Groundwater Source both entering the tunnel and water in the tunnel also flowing back into the source. The steady state flow back into the NEFB Coast Groundwater Source is 700 ML/yr.

It is also noted that groundwater inflow to the tunnel re-enters the downstream reservoir, which may under exceptional circumstances discharge to the Macleay River (Macleay Valley Gorges Source) and will be available and provide additional water into this source. This water would have eventually made its way into the Macleay River system and once operational, the presence of the tunnel will effectively increase the rate at which water can flow from the NEFB Coast Groundwater Source into the Macleay River in this portion of the Macleay catchment. This will manifest as an increased reliability of water in the downstream system. The net benefit of the Project from a water supply perspective is the ongoing contribution of the NEFB Coast Groundwater Source into the regulated Macleay River at an increased annual rate.

It is noted that OMPS hold a share allocation of 232 units (WAL reference number 30AL324745) and has acquired the remaining 175 units within the NEFB Coast Groundwater Source to meet the total predicted direct take. It is noted that the peak predicted indirect take, assigned to a reduction in baseflow, of 161 ML/yr is excluded from the total proposed share entitlement as OMPS have essentially already captured the Project-related impact through the licensing of the direct portion of take.

Requisite surface water licenses are discussed in the Surface Water Impact Assessment (EMM, 2023a).

The groundwater model will be reviewed and recalibrated (if necessary) in year 2 of construction. Revisions to the model predictions will be used to confirm the licensing requirements in subsequent years. This approach aligns with the approved groundwater monitoring and modelling plan for the Project commitment to periodically calibrate the groundwater model (see Chapter 11).

13 AIP assessment framework

This chapter reproduces the AIP assessment framework with commentary to assist the DPE and DPE Water with the assessment.

Table 13.1 Does the activity require detailed assessment under the AIP?

#	Consideration	Proponent response
1	Is the activity defined as an aquifer interference activity?	Yes
2	Is the activity a defined minimal impact aquifer interference activity according to Section 3.3 of the AIP?	Yes

13.1 Accounting for, or preventing the take of water

Table 13.2 Accounting for, or preventing the take of water, has the proponent:

#	AIP requirement	Proponent response
1	Described the water source(s) the activity will take water from?	Yes, this information is provided in Section 3.7.
2	Predicted the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity?	Yes, this information is provided in Section 12.2.
3	Predicted the total amount of water that will be taken from each connected groundwater or surface water source after the closure of the activity?	No, this does not apply to the Project.
4	Made these predictions in accordance with Section 3.2.3 of the AIP?	Yes, this information is provided in Chapter 9 and Section 12.2.
5	Described how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources?	Yes, this information is provided in Section 12.2.2.
6	Described how any licence exemptions might apply?	Yes, this has been described in Section 9.2.3 of the *Surface Water Impact Assessment* (EMM, 2023a)
7	Described the characteristics of the water requirements?	Yes, this has been provided in Section 3.7.
8	Determined if there are sufficient water entitlements and water allocations that are able to be obtained for the activity?	Yes, this has been provided in Section 4.3.1.
9	Considered the rules of the relevant water sharing plan and if it can meet these rules?	Yes, this has been provided in Section 4.3.1.
10	Determined how it will obtain the required water?	Yes, the approach to obtain the required water has been outlined in Section 9.4 of the *Surface Water Impact Assessment* (EMM, 2023a)
11	Considered the effect that activation of existing entitlement may have on future available water determinations?	Yes, this has been considered in Chapter 12.
12	Considered actions required both during and post-closure to minimize the risk of inflows to a mine void as a result of flooding?	Not applicable.
13	Developed a strategy to account for any water taken beyond the life of the operation of the Project?	Not applicable.

Table 13.2 Accounting for, or preventing the take of water, has the proponent:

#	AIP requirement	Proponent response
Will uncertainty in the predicted inflows have a significant impact on the environment or other authorised water users? If **yes**, items 14–16 must be addressed.		Yes.
14	Considered any potential for causing or enhancing hydraulic connections, and quantified the risk?	Yes, impacts have been discussed in Chapter 9 and Chapter 10 and are quantified in Chapter 11.
15	Quantified any other uncertainties in the groundwater or surface water impact modelling conducted for the activity?	Yes, uncertainty analysis has been documented in Attachment C.
16	Considered strategies for monitoring actual and reassessing any predicted take of water throughout the life of the Project, and how these requirements will be accounted for?	Yes, commitment is made Chapter 11 for model verification following ongoing collection of water monitoring data during construction and operation of the Project.

Table 13.3 Determining water predictions in accordance with Section 3.2.3 (complete one row only – consider both during and following completion of activity)

#	AIP requirement	Proponent response
1	For the Gateway process, is the estimate based on a simple modelling platform, using suitable baseline data, that is, fit-for-purpose?	Yes. Details of the modelling platform is provided in Attachment C and a description of available baseline data used for model calibration has been described in Chapter 5.
2	For State Significant Development or mining or coal seam gas production, is the estimate based on a complex modelling platform that is: • Calibrated against suitable baseline data, and in the case of a reliable water source, over at least two years? • Consistent with the Australian Modelling Guidelines? • Independently reviewed, robust and reliable, and deemed fit-for-purpose?	The Project is CSSI. Numerical modelling has been calibrated to a reliable baseline data record, described in detail in Attachment C. The model has been developed in accordance with the requirements of the *Australian Groundwater Modelling Guidelines* (Barnett et al 2012).
3	In all other processes, estimate based on a desk-top analysis that is: • Developed using the available baseline data that has been collected at an appropriate frequency and scale. • Fit-for-purpose?	The duration and frequency of monitoring are adequate for the assessment. Details of which have been provided in Chapter 5.

Table 13.4 Other requirements to be reported on under Section 3.2.3 of the AIP Has the proponent provided details on:

#	AIP requirement	Proponent response
1	Establishment of baseline groundwater conditions?	Yes. Details provided in Chapter 5.
2	A strategy for complying with any water access rules?	Yes. Details provided in Chapter 12.
3	Potential water level, quality or pressure drawdown impacts on nearby basic landholder rights water users?	Yes. Details provided in Chapter 9 and Chapter 10.
4	Potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources?	Yes. Details provided in Chapter 9 and Chapter 10.
5	Potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems?	Yes. Details provided in Chapter 9 and Chapter 10.
6	Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	Yes. Details provided in Chapter 10.
7	Potential to cause or enhance hydraulic connection between aquifers?	Yes. Details provided in Chapter 11
8	Potential for river bank instability, or high wall instability or failure to occur?	Not applicable.
9	Details of the method for disposing of extracted activities (for coal seam gas activities)?	Not applicable.

13.2 Addressing the minimal impact considerations

Two water sources are impacted: the LFB MDB Fractured Rock and LDB South Coast groundwater sources. Both water sources are defined as 'less productive' groundwater systems in the fractured rock sub-grouping.

Table 13.5 Minimal impact considerations

Aquifer **Category**	**Fractured rock** **Less productive**
Level 1 Minimal Impact Consideration	**Assessment**
Water table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any: • high priority groundwater dependent ecosystem; or • high priority culturally significant site. listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	No. Predicted impacts have been presented in Chapter 10.
Water pressure A cumulative pressure head decline of not more than a 2 m decline, at any water supply work.	No. Predicted impacts have been presented in Chapter 10.
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.	No. Predicted impacts have been presented in Chapter 9.

13.3 Proposed remedial actions where impacts are greater than predicted

Table 13.6 Proposed remedial actions where impacts are greater than predicted, has the proponent:

#	AIP requirement	Proponent response
1	Considered types, scale, and likelihood of unforeseen impacts *during operation*?	Impacts to water resources during Project operations have been detailed in Chapter 9, Chapter 10 and Chapter 11.
2	Considered types, scale, and likelihood of unforeseen impacts *post closure*?	Not applicable.
3	Proposed mitigation, prevention or avoidance strategies for each of these potential impacts?	Management, mitigation strategies have been recommended to address predicted impacts to water resources. These have been described in Chapter 12.
4	Proposed remedial actions should the risk minimization strategies fail?	Yes. Details provided in Chapter 11.
5	Considered what further mitigation, prevention, avoidance or remedial actions might be required?	Yes. Details provided in Chapter 11.
6	Considered what conditions might be appropriate?	Yes. Details provided in Chapter 11.

13.4 Other considerations

Table 13.7 Other considerations, has the proponent:

#	AIP requirement	Proponent response
1	Addressed how it will measure and monitor volumetric take? (Page 4 of the AIP).	Yes. Details provided in Chapter 11.
2	Outlined a reporting framework for volumetric take? (Page 4 of the AIP).	Yes. Details provided in Chapter 11.

14 Conclusions

This GIA forms part of the EIS for the Project. It has been informed by the 15% feasibility design (SMEC, 2022) for the Project. The following aspects of the Project have been addressed in this assessment:

- Assessment of environmental and human users dependent on groundwater, including:
  - terrestrial GDEs
  - subterranean GDEs
  - aquatic GDEs
  - downstream water users
  - landholder water supplies.
- Management of groundwater during construction and operation of the Project, including:
  - consideration for excavation sequencing, pre-grouting and post-grouting influence on groundwater inflow and environmental impacts
  - changes to water quality due to construction and operation.
- Assessment of the Project against the assessment requirements of the AIP, including:
  - consideration for the minimal impact criteria, as it relates to groundwater pressures, levels and quality
  - consideration for impacts to GDEs
  - consideration for Level 1 and 2 impacts.

Numerical groundwater modelling predicted groundwater drawdown within the study area during construction and operation of the Project. Groundwater flow into the tunnel is via fractures. The groundwater model assumes a relatively high permeability for the intercepted geology; however, it is expected that although parts of this unit will be fractured, the entire unit may not, and other sections of this geology will be much less permeable. Conservative hydraulic parameters were used to support the groundwater model for these units.

The model cannot simulate individual fractures because the locations and conductivity of individual fractures are not known until intersected by the Project. Because the exact locations and extent of inflow mitigation strategies are not yet known the groundwater modelling adopted a conservative approach of simulating all excavations as non-mitigated/controlled. Attempts to 'constrain' the model to simulate unknown geological occurrences or design elements are not in line with the Australian Groundwater Modelling Guidelines (Barnett, et al., 2012) and have therefore not been undertaken.

The modelling results are conservative for two reasons:

- Modelling does not consider actual design, management or mitigating activities (i.e. pre/post-grouting, concrete lining and steel lining). During construction the discrete fractures that yield excess water will be grouted during construction, reducing the actual overall tunnel inflow volume.

- Hydraulic parameters within the numerical model for the Carrai Granodiorite and Parrabel Beds are conservative and assume fracturing throughout the entire matrix however, in reality the entire unit may not behave like this, with some parts expected to be less permeable.

Therefore, the model predictions of tunnel inflow, baseflow reduction and water table drawdown are considered conservative and likely to be over estimating Project impacts.

Numerical modelling predicted a localised reduction in groundwater baseflow contributions from the NEFB Coast Groundwater Source to the Macleay River (117 ML in construction year 5) and the ephemeral streams (47 ML in construction year 4). During operation of the Project additional (i.e. greater than pre-Project) baseflow contributions are predicted to the Macleay River (212 ML/yr of operation) and the ephemeral streams (153 ML/yr of operation). There is no impact predicted for baseflow contributions to the Carrai Waterholes.

The peak inflow to the Project within the NEFB Coast Groundwater Source occurs in year 1 of construction and is 407 ML for the water year. During operation of the Project, inflow to the Project reduces to 320 ML/yr of operation. OMPS have acquired an initial 232 share components within the NEFB Coast Groundwater Source, purchased through the 2021 COA and a further 175 through the 2022 COA to fully meet the Project's needs.

Watertable drawdown is predicted during construction and operation of the Project, with drawdown propagating approximately 1.7 km and 1.4 km north of the PHGW respectively. There is no impact predicted to the Carrai Waterholes or obligate GDEs identified across the plateau, additionally there are no identified high priority GDEs within the study area. Water table drawdown is predicted at plant communities with a facultative/opportunistic dependence on groundwater however, this has been assessed as low risk due to the communities' reliance on surface water for sustainment.

It is noted that the numerical model is conservative and predicts that impacts are localised to the study area. Regionally, there is little change predicted. Also, with the inclusion of design mitigation options and a potential refinement of the hydraulic parameters adopted for the hydrogeological units, the watertable drawdown and inflow volumes required for licensing may be reduced and these localised impacts will also be reduced.

Water supply for construction may be accessed from groundwater supply bores. Potential groundwater supply bores will access water from NEFB Coast Groundwater Source and as such, will require allocation. Noting the conservatism of the numerical model inflow predictions and reducing water take over subsequent construction years, this will likely be captured under the peak construction groundwater take allocation.

Management controls have been proposed to mitigate environmental impacts to water resources. An overarching and adaptive WMP will be prepared for the Project in consultation with NSW government agencies.

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Units

Unit	Description
$	Australian dollar
%	percent
°C	degrees Celsius
µm	micrometre
µS/cm	microsiemens per centimetre
ha	hectare
kg/yr	kilograms per year
L/s	litres per second
km	kilometre
km^2	square kilometres
m	metres
m/d	metres per day
m/yr	metres per year
m^3/d	cubic metres per day
mAHD	metres Australian Height Datum
mBGL	metres below ground level
mbtoc	metres below top of casing
meq/L	milliequivalents per litre
mg/L	milligrams per litre
ML	megalitres
ML/d	megalitres per day
ML/yr	megalitres per year
mm/d	millimetres per day
mm/hr	millimetres per hour
Mt	million tonnes
Mtpa	million tonnes per annum
pH	pH, unit of acidity and alkalinity

Abbreviations

Abbreviation	Description
ADWG	Australian Drinking Water Guidelines
AHD	Australian height datum
AIP	Aquifer Interference Policy 2012
ALS	Australian Laboratory Services
ANZECC and ARMCANZ	Australian and New Zealand guidelines for fresh and marine water quality
AR	Agency recommendation
ARI	Average recurrence interval
AWBM	Australian Water Balance Model
BOD	Biochemical oxygen demand
BoM	Bureau of Meteorology
BTEX	Benzene, toluene, ethyl-benzene, and xylene
BTEXN	benzene, toluene, ethyl-benzene, xylene and naphthalene
CDFM	Cumulative deviation from the mean
CWMP	Construction water management plan
DEC	Department of Environment and Conservation
DECC	Department of Environment and Climate Change NSW
DECCW	Department of Environment, Climate Change, and Water NSW
DEHP	Department of Environment and Heritage Protection (QLD)
DIPNR	Department of Infrastructure, Planning and Natural Resources NSW
DLWC	Department of Land and Water Conservation NSW
DNR	Natural Resources Department NSW
DO	Dissolved oxygen
DPI	Department of Primary Industries
DSITAI	Department of Science, Information Technology, Innovation and the Arts QLD
DTIRIS	Department of Trade and Investment, Regional Infrastructure and Services NSW
DWE	Department of Water and Energy NSW
EC	Electrical conductivity
EIS	Environmental Impact Statement
EP&A Act	*Environmental Planning and Assessment Act*
EPA	Environment Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act*

Abbreviation	Description
EPL	Environment protection licence
EV	Environmental value
GDE	Groundwater dependent ecosystem
GMMP	Groundwater monitoring and modelling plan
IBRA	Interim Biogeographic Regionalisation for Australia
K	Hydraulic conductivity
Kh	Horizontal hydraulic conductivity
Kv	Vertical hydraulic conductivity
LGA	Local government area
LPI	Land and Property Information NSW
LTAAEL	Long-term average annual extraction limit
N	Nitrogen
NATA	National Association of Testing Authorities
NHMRC	National Health and Medical Research Council
NorBE	Neutral or beneficial effect
NOW	NSW Office of Water, now DPIE Water
NSW	New South Wales
NUDLC	National Uniform Drillers Licensing Committee
NWC	National Water Commission
NWQMS	National Water Quality Management Strategy
OEH	Office of Environment and Heritage
PRM	Probabilistic rational method
OWMP	Operation water management plan
PAH	Polycyclic aromatic hydrocarbons
PMF	Predicted maximum flood
PMP	Probable maximum precipitation
POEO Act	*Protection of the Environment Operations Act 1997*
QA/QC	Quality assurance/quality control
RC	Riparian corridors
REF	Review of Environmental Factors
SD	Standard deviation
SEARs	Secretary's environmental assessment requirements
SEPP	State Environmental Planning Policy

Abbreviation	Description
SST	Sandstone
TDS	Total dissolved solids
TN	Total nitrogen
TP	Total phosphorus
TRH	Total recoverable hydrocarbons
TSS	Total suspended solids
VRC	Vegetated riparian corridors
VWP	Vibrating wire piezometer
WA 1912	*Water Act 1912*
WAL	Water access licence
WMA 2000	*Water Management Act 2000*
WMP	Water management plan
WSP	Water sharing plan
WTP	Water treatment plant

Glossary

Term	Definition
Abstraction	The removal of water from a water store.
Allocation	The specific volume of water allocated to water access entitlements in a given water year or allocated as specified within a water resource plan.
Alluvium	Loose, unconsolidated (not cemented together into a solid rock), soil or sediments (including clay, silt, sand, gravel, cobbles and boulders), eroded, deposited and reshaped by water in some form in a non-marine setting.
Announced allocation	A number, expressed as a percentage, which is used to determine the maximum volume of water that may be accessed from a water source in a water year.
Antecedent soil moisture	Water present in the soil profile prior to a rainfall event.
Aquifer	A geological formation or group of formations; able to receive, store and transmit significant quantities of water. Means a geological structure or formation, or an artificial landfill, that is permeated with water or is capable of being permeated with water (NSW *Water Management Act 2000* definition).
Aquifer, confined	An aquifer overlain by a confining bed. The confining bed has a significantly lower hydraulic conductivity than the aquifer. Typically, groundwater in a confined aquifer is under pressure significantly greater than atmospheric pressure.
Aquifer, fractured rock	An aquifer that occurs in sedimentary, igneous and metamorphosed rocks which have been subjected to disturbance, deformation, or weathering, and which allow water to move through joints, bedding planes, fractures and faults.
Aquifer interference activity	Means an activity involving any of the following: (a) the penetration of an aquifer, (b) the interference with water in an aquifer, (c) the obstruction of the flow of water in an aquifer, (d) the taking of water from an aquifer in the course of carrying out mining, or any other activity prescribed by the regulations, (e) the disposal of water taken from an aquifer as referred to in paragraph (d). (NSW Water Management Act 2000 definition).
Aquifer, unconfined	An aquifer in which there is no confining bed between the zone of saturation and the surface. The watertable is the upper boundary of an unconfined aquifer and is at atmospheric pressure.
Aquitard	A geological formation that may contain groundwater but is not capable of transmitting significant quantities of it under normal hydraulic gradients. May function as a confining bed.
Available water determination	The water made available from time to time to water access licence holders in NSW. Expressed as ML/unit share (but still publicised to users as percentage allocations).
Bank storage	Bank storage generally refers to water held in weathered rock and sediments along the bank of a stream during and immediately after a flood event. It is released back into the stream as a flood event recedes.
Baseflow	The component of streamflow supplied by groundwater discharge. Baseflow is characterised by an exponential decay curve following the cessation of surface runoff.
Baseflow separation	The process of dividing a hydrograph into baseflow and quickflow (or surface flow) components.
Bathymetry	The topography or the shape of the land below the water surface.

Term	Definition
Bed conductance	As a property of a physical unit, conductance is equal to the hydraulic conductivity in the direction of flow (usually considered to be vertical distance) divided by the thickness of the unit. Conductance is the inverse of Hydraulic resistance. As a parameter applied in a numerical model to represent the bed of surface water body, Bed conductance is the product of Conductance (see above) and the length and width of a reach of river or of a cell or element beneath a surface water body. Bed conductance as a model parameter cannot be measured directly. It is a surrogate for the combination of hydraulic conductivities and geometries that occur in the near field of the water body. A number of analytical solutions give guidance for this kind of conductance, but values are generally either assumed or chosen during model calibration.
Bogs	Collective term for endangered ecological communities (EECs) listed under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and NSW Biodiversity Conservation Act 2016 (BC Act).
Bore	A hole drilled in the ground, a well or any other excavation used to access groundwater. May be used for observation of groundwater (including water level, pressure or quality).
Calibration	Process of adjusting the values of model parameters within physically defensible ranges until the model performance adequately matches observed historical data from one or more locations represented by the model (ie a match is obtained that is robust and fit for purpose).
Catchment	The land area draining to a point of interest, such as a water storage or monitoring site on a watercourse.
Colluvium	Unconsolidated sediments that have been deposited at the base of hillslopes or depressions in the landscape by either runoff, sheet wash, slow continuous downslope creep, or a variable combination of these processes.
Conceptual model	Documentation or schematic of the conceptual understanding of groundwater recharge and discharge processes, flow within a groundwater system, and the interaction of groundwater with surface water and GDEs.
Consumptive use	Use of water for private benefit consumptive purposes including irrigation, industry, urban and stock and domestic use.
Dead storage	In a water storage, the volume of water stored below the level of the lowest outlet (the minimum supply level). This water cannot be accessed under normal operating conditions.
Dewatering	Removal of water from an aquifer as part of the construction phase of a development or part of ongoing activities to maintain access, serviceability and/or safe operating conditions. (NSW AIP).
Drawdown	The lowering of water levels in a surface water or groundwater storage resulting from the loss or take of water from the storage.
Eco-hydrogeological zone	A region where similar processes determine the interaction between groundwater and ecosystems, due to similar ecology, geology, climate, and groundwater/surface water connections.
Ecological water requirement	Description of the water regimes needed to sustain the ecological values of water-dependent ecosystems at a low level of risk.
Ecosystem	A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.
Electrical conductivity (EC)	Electrical conductivity (EC) measures dissolved salt in water. The standard EC unit is microSiemens per centimetre (µS/cm) at 25 °C.
Elevated wetland	A terrestrial ecosystem that occurs high in the KNP landscape with little or no catchment area. They are maintained by rainfall, snowmelt and perched groundwater and are not considered bogs or fens.
Environmental flow	The streamflow required to maintain appropriate environmental conditions in a waterway or water body.

Term	Definition
Ephemeral	Something which only lasts for a short time. Typically used to describe rivers, lakes and wetlands that are intermittently dry.
Evaporation	A process that occurs at a liquid surface, resulting in a change of state from liquid to vapour. In relation to water resource assessment and water accounting, evaporation refers to the movement of water from the land surface (predominantly liquid) to the atmosphere (water vapour). The liquid water at the land surface that may be available for evaporation includes surface water, soil water, shallow groundwater, water within vegetation, and water on vegetation and paved surfaces.
Evapotranspiration	The combined loss of water from a given area during a specified period of time by evaporation from the soil or water surface and by transpiration from plants.
Extraction	Synonymous with abstraction in the case where water is removed from a groundwater store.
Floodplain	Flat or nearly flat land adjacent to a stream or river that experiences occasional or periodic flooding.
Full supply level	The normal maximum operating water level of a surface water storage when not affected by floods. This water level corresponds to 100% capacity.
Gaining stream	A stream where groundwater discharge contributes to streamflow.
Groundwater	Water contained within rocks and sediments below the ground surface in the saturated zone, including perched systems above the regional watertable.
Groundwater access entitlement	Water access entitlement granted on the groundwater resource. In NSW, equivalent to an aquifer access licence.
Groundwater allocation	Volume of water resulting from an allocation announcement made on a groundwater access entitlement.
Groundwater, artesian	Groundwater that is under pressure when tapped by a bore and rises above the level at which it is first encountered. It may or may not flow out at ground level.
Groundwater Dependent Ecosystem (GDE)	Natural ecosystems that require access to groundwater to meet all or some of their water requirements on a permanent or intermittent basis, so as to maintain their communities of plants and animals, ecosystem processes and ecosystem services.
Groundwater, deep	Groundwater below the regional watertable in the fractured rock groundwater system that has a long circulation flowpath and discharges to regional features (generally low in the landscape) such as incised gorges and permanent creeks and rivers.
Groundwater discharge	The process by which groundwater is released into the environment usually either via baseflow or evapotranspiration.
Groundwater flow	Water that flows in aquifers and aquitards.
Groundwater level	The level of groundwater in an aquifer, typically measured in a groundwater bore. In the case of an unconfined aquifer, the groundwater level is equal to the watertable level.
Groundwater, perched	A region in the unsaturated zone where the soil or rock may be locally saturated because it overlies a low-permeability unit. In the KNP, perched groundwater is very shallow groundwater above the regional watertable that is derived from rainfall and is retained in the elevated wetlands and some mid-slope bogs/fens, and potentially some basalt caps.
Groundwater, regional	A collective term for shallow and deep groundwater.
Groundwater recharge	The process which replenishes groundwater, usually by rainfall infiltrating from the ground surface to the watertable and/or by surface water infiltrating to the watertable from a stream. Other forms of recharge include flooding and irrigation, and artificial recharge can also occur through various means, including bore injection.

Term	Definition
Groundwater, shallow	Groundwater below the regional watertable in the weathered fractured rock groundwater system that has a short circulation flowpath and discharges to local features (generally in upper and mid catchment landscape areas) such as springs and permanent creeks.
Groundwater system	Multiple aquifers that are overlying or adjacent but not necessarily connected, and are hydrogeologically similar regarding geological province, hydraulic characteristics and water quality. A system may consist of groundwater in one or more geological formations.
Hydraulic conductivity	A property of soil or rock, which describes the ease with which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the material and on the degree of saturation. Saturated hydraulic conductivity describes water movement through saturated media.
Hydraulic gradient	Calculated as the difference between two hydraulic head measurements divided by the distance between the two measurements. Hydraulic gradient is used in the calculation of water flow.
Hydraulic resistance (vertical)	The resistance against flow experienced by water moving vertically through or between hydrostratigraphic units. It is mostly used in the description of vertical flow between aquifers, through aquitards. Hydraulic resistance increases with aquitard thickness and decreases with aquitard hydraulic conductivity. The inverse of hydraulic resistance is the hydraulic conductance.
Hydrogeologic unit	One or more geologic units which have similar hydrogeological characteristics and behaviour.
Hydrograph	A graph showing the surface level, discharge, velocity, or some other feature of water, with respect to time.
Hydrostratigraphic unit	The subsurface is divided into hydrostratigraphic units that have similar properties from the point of view of storage and transmission of groundwater. Units that store significant amounts of water and transmit this water relatively easily are called aquifers. Units that offer a high resistance to flow are called aquitards, or confining layers. See also Hydrogeologic unit.
Incidental water	Water that is taken by an aquifer interference activity that is incidental to the activity; including water that is encountered within and extracted from mine workings, tunnels, basements or other aquifer interference structures that must be dewatered to maintain access, serviceability and/or safe operating conditions. (NSW AIP).
Infiltration	The process by which water on the ground surface enters the soil profile.
Interflow	Water that infiltrates the soil surface and then moves laterally through the upper soil horizons toward stream channels, either as unsaturated flow, or more usually, as shallow perched saturated flow above the regional watertable.
Karst	Terrain characterised by sinkholes, caves and springs, developed most commonly in carbonate rocks, where significant dissolution of the rock has occurred due to flowing water.
Losing stream	A stream from which water is lost to the surrounding and underlying substrate via infiltration through the streambed and banks.
Mid-slope bog/fen	A terrestrial ecosystem that occurs on mid-slopes in the KNP landscape and in gullies and occasionally adjacent to an ephemeral stream.
Monitoring site	A place where observations of the environment are made; typically a physical location where sensors are used to measure the properties of one or more features of the environment (eg depth of a river, water level in a bore, surface or groundwater quality).
Nested bore	A bore with more than one pipe or a group of nearby bores, open at different levels in aquifers/aquitards, used to evaluate the vertical variation in groundwater pressure head or chemistry.
Non-consumptive use	Non-consumptive use is when there is no diversion from or diminishment of resource, for example water used to generate hydroelectricity. Held and planned environmental water is a non-consumptive water use.
Observed river height (or 'stage')	The depth of water at a river height measuring gauge located along the river. In most cases a zero reading is the lowest water-level that is reached during dry conditions.

Term	Definition
Overland flow	Surface runoff, which is caused when either, the ground surface is impervious, the underlying soil is saturated and cannot accommodate any more water, or because the intensity of rainfall is greater than the soil's capacity to infiltrate it.
Parameter	A measurable characteristic of a physical entity (feature); for example, the temperature of water in a river.
Peak river height	The highest river height observed during a flood event at the specified site on the river.
Permeability	The measure of the ability of a rock, soil or sediment to transmit a fluid. The magnitude of the permeability depends largely on the porosity and the connectedness of pores spaces. Synonymous with hydraulic conductivity when water is the fluid involved.
pH	Value that represents the acidity or alkalinity of an aqueous solution. It is defined as the negative logarithm of the hydrogen ion concentration of the solution.
Piezometer	A non-pumping bore, generally of small diameter, that is used to measure the elevation of the watertable or potentiometric surface.
Potentiometric surface	A surface representing the hydraulic head of groundwater; represented by the watertable altitude in an unconfined aquifer or by the altitude to which water will rise in a properly constructed bore in a confined aquifer.
Precipitation	All forms in which water falls on the land surface and open water bodies as rain, sleet, snow, hail, or drizzle.
Quickflow	The component of streamflow that has travelled through the catchment as interflow or across the surface as overland flow or is released from bank storage during the recession from a flood peak.
Regulated river	River on which a licensed entitlement regime exists with centralised allocation, and from which orders may be placed for upstream release of a licensed allocation. A necessary, but not sufficient condition for a river to be regulated is that it is located downstream of a surface water storage.
Riparian	An area or zone within or along the banks of a stream or adjacent to a watercourse or wetland; relating to a riverbank and its environment, particularly to the vegetation.
Riparian bog/fen	A terrestrial ecosystem that occurs low in the KNP landscape and adjacent to a permanent stream.
Saturated zone	The soil and geological layers below the land surface where all spaces between soil/sediment/rock particles are filled with water. It encompasses all the soil and geological layers below the watertable.
Soil moisture	The water content in the unsaturated zone of a soil profile.
Seepage	The infiltration of water from streams, irrigation channels, water storages, farm dams, natural surface water features and septic tanks into the groundwater system. It is a form of surface water–groundwater interaction and groundwater recharge. The term can also apply to low volumes of groundwater discharge.
Sensitivity	The degree to which numerical model outputs are affected by changes in selected input parameters.
Specific yield	The storage property for an unconfined aquifer that defines the quantity of water that can be drained from an aquifer under the influence of gravity or extracted by pumping.
Standing water level	Depth to groundwater below a datum point or reference point, usually from the top of casing or natural surface.
Storage	A pond, lake or basin, whether natural or artificial, for the storage, regulation and control of water.
Storage level	The elevation of the water surface in a water storage at a particular time and date, measured relative to a specified datum, typically the Australian Height Datum (AHD).

Term	Definition
Storativity	The volume of water a confined aquifer will release when the water-level is lowered due to pumping or natural discharge. Upon the lowering of potentiometric water levels in such aquifers, they remain fully saturated so that no dewatering occurs (ie the potentiometric surface remains above the top of the confined aquifer formation). The water released is volumetrically equivalent to the volumetric expansion of the water and contraction of the pore space.
Stratification	The formation of layers in a water body that show differences in temperature, turbidity, pH, nutrients, salinity, dissolved oxygen or light penetration at various depths.
Stream	A watercourse and its tributaries. A stream can be permanent or ephemeral.
Streamflow	The flow of water in streams, rivers and other channels.
Stygofauna	Aquatic animals found in groundwater; sometimes used as a synonym of stygobite.
Surface runoff	Water from precipitation or other sources that flows over the land surface.
Surface water	Water that flows over or is stored on the surface of the earth that includes: (a) water in a watercourse, lake or wetland and (b) any water flowing over or lying on land: (i) after having precipitated naturally or (ii) after having risen to the surface naturally from underground.
Take	Take water from a water resource means to remove water from, or to reduce the flow of water in or into, the water resource including by any of the following means: (a) pumping or siphoning water from the water resource (b) stopping, impeding or diverting the flow of water in or into the water resource (c) releasing water from the water resource if the water resource is a wetland or lake (d) permitting water to flow from the water resource if the water resource is a well or watercourse and includes storing water as part of, or in a way that is ancillary to, any of the processes or activities referred to in paragraphs (a) to (d). (Commonwealth Water Act 2007 definition).
Total dissolved solids (TDS)	The sum of all particulate material dissolved in water. Usually expressed in terms of milligrams per litre (mg/L).
Total suspended solids (TSS)	In relation to a water sample, the measure of the particles mixed in the water sample.
Transmissivity	The rate at which water moves through a unit width of aquifer or aquitard under a unit hydraulic gradient. It is the product of aquifer thickness and hydraulic conductivity.
Turbidity	Means the measure of the light scattering properties of water and is an indicator of the presence of suspended solids.
Uncertainty	A state of lack of confidence to exactly describe the current or future condition of a system when limited knowledge of that system is available. Uncertainty is often categorised into two main types (AGMG; Barnett et al. 2012): • deficiency in our knowledge of the natural world (including the effects of error in measurements) • failure to capture the complexity of the natural world (or what we know about it) in a model. Formal definition from AS/NZS ISO 310000:2009: Uncertainty is the state, even partial, of deficiency of information related to the understanding or knowledge of an event, its consequence, or its likelihood.
Unregulated river	A river where there is no entitlement system at all or where there is an entitlement system that does not allow orders to be placed for upstream release of a licensed allocation.
Unsaturated zone	The soil between the land surface and the regional watertable in which the pore space contains both air and water.
Validation	Where observations and model simulations are compared using data that were not part of the model calibration.

Term	Definition
Verification	Verification involves comparing the predictions of the calibrated model to a set of measurements that were not used to calibrate the model, in order to confirm that the model is suitable for use as a predictive tool.
Water access entitlement	A perpetual or ongoing entitlement to exclusive access to a share of water from a specified consumptive pool as defined in the relevant water plan. In NSW, equivalent to a water access licence (ie an access licence referred to in section 56 of the Water Management Act 2000).
Water balance	The flow of water into and out of, and changes in the storage volume of, a surface water system, groundwater system, catchment or specified area over a defined period of time.
Water quality	The physical, chemical and biological characteristics of water. Water-quality compliance is usually assessed by comparing these characteristics with a set of reference standards. Common standards used are those for drinking water, safety of human contact and the health of ecosystems.
Water resource	All natural water (surface water or groundwater) and alternative water sources, such as recycled or desalinated water, that has not yet been abstracted or used.
Water sharing plan	A legislated plan that establishes rules for managing and sharing water between ecological processes and environmental needs of the respective water source (river/aquifer). It manages water access licences, water allocation and trading, water extraction, operation of dams, management of water flows, and use and rights of different water users.
Water source	In NSW, water source means the whole or any part of: (a) one or more rivers, lakes or estuaries, or (b) one or more places where water occurs on or below the surface of the ground (including overland flow water flowing over or lying there for the time being), and includes the coastal waters of the State. (NSW Water Management Act 2000 definition).
Watertable	The top of an unconfined aquifer which can be either perched or regional. It is at atmospheric pressure and, in a regional context, indicates the level below which soil and rock are saturated with water.
Water year	A continuous twelve-month period starting from a specified month for water accounting purposes. In NSW this is 1 July to 30 June each year.
Wetland	An area of land whose soil is saturated with moisture either permanently or intermittently. Wetlands are typically highly productive ecosystems. They include areas of marsh, fen, parkland and open water. Open water can be natural or artificial; permanent or temporary; static or flowing; and fresh, brackish or salty.

Attachment A

Hydrogeological investigation program

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Oven Mountain pumped energy storage

Stage one hydrogeological drilling and testing report

Prepared for SMEC Australia Pty Limited

August 2022

Oven Mountain pumped energy storage

Stage one hydrogeological drilling and testing report

SMEC Australia Pty Limited

E210769 RP1

August 2022

Version	Date	Prepared by	Approved by	Comments
1	11 April 2022	Alex Bayer	Sean Cassidy	Draft
2	3 August 2022	Alex Bayer	Sean Cassidy	Final

Approved by



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

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1 Introduction

1.1 Project overview and background

EMM Consulting Pty Limited (EMM) was engaged on behalf of SMEC Australia Pty Limited (SMEC) to undertake a hydrogeological investigation program (HIP) for the proposed Oven Mountain Pumped Hydro Energy Storage project (the project), located near Carrai, NSW (the site, as outlined in Figure 1.1).

The HIP was designed by EMM to establish a groundwater monitoring network, facilitating the collection of baseline data in accordance with the project Secretary's Environmental Assessment Requirements (SEARs) issued on the 19 February 2021 to inform the proposed Environmental Impact Statement (EIS).

In accordance with the proposal (EMM 2021), EMM provided the client with the scope of works outlined in Section 1.2. This report provides a factual summary of the subsequent monitoring bore installation and testing program.

1.2 Scope of Works

The following agreed scope of works was undertaken:

1. installation of eight monitoring bores:
    a) one monitoring bore installed to assess groundwater within the Permian Nambucca Beds;
    b) two monitoring bores installed to assess groundwater within the Permian Parabell Beds; and
    c) five monitoring bores installed to assess groundwater within the Triassic Carrai Granodiorite;
2. bore development at each newly installed monitoring bore, in general accordance with Minimum Construction Requirements for Water Bores in Australia (NUDLC 2020);
3. collection of one groundwater chemistry sample, at each newly installed monitoring bores; noting the groundwater quality sample results from BH4A are not presented in this report, as we are awaiting laboratory analysis;
4. installation of one water level data logger at each newly installed monitoring bores, with one barometric data logger installed in the headspace of one monitoring bore;
5. installation of dedicated low flow pumps at each of the newly installed monitoring bores, noting that a dedicated pump is not currently installed in BH4A as installation is scheduled for late August;
6. *in-situ* hydraulic testing at each of the newly installed monitoring bores using a rising head test methodology, with the exception of BH4A where packer testing was undertaken by SMEC; and
7. provision of a hydrogeological drilling and testing report.





KEY

- Project area

Existing environment

- Major road
- Watercourse/drainage line
- Transmission line
- NPWS reserve
- State forest

Source: EMM (2022); DFSI (2017); GA (2011); ASGC (2006)

0 10 20 km

GDA 1994 MGA Zone 56

N

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Site setting

Oven Mountain Pumped Hydro Storage Project
Stage one hydrogeological drilling and testing report

Figure 1.1

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2 Site description

2.1 Topography and drainage

Topography within the site generally dips down from the Carrai Plateau (east) to the Macleay River (west). Elevation changes by approximately 900 m over a series of steep escarpments and slopes of up to 60°.

A series of incised valleys, trending east-west (along the axis) represent the dominant drainage feature, supporting ephemeral streams that discharge to the Macleay River. The ephemeral streams typically flow during periods of high rainfall with some attenuated flow following prolonged rainfall events.

2.2 Climate and river data

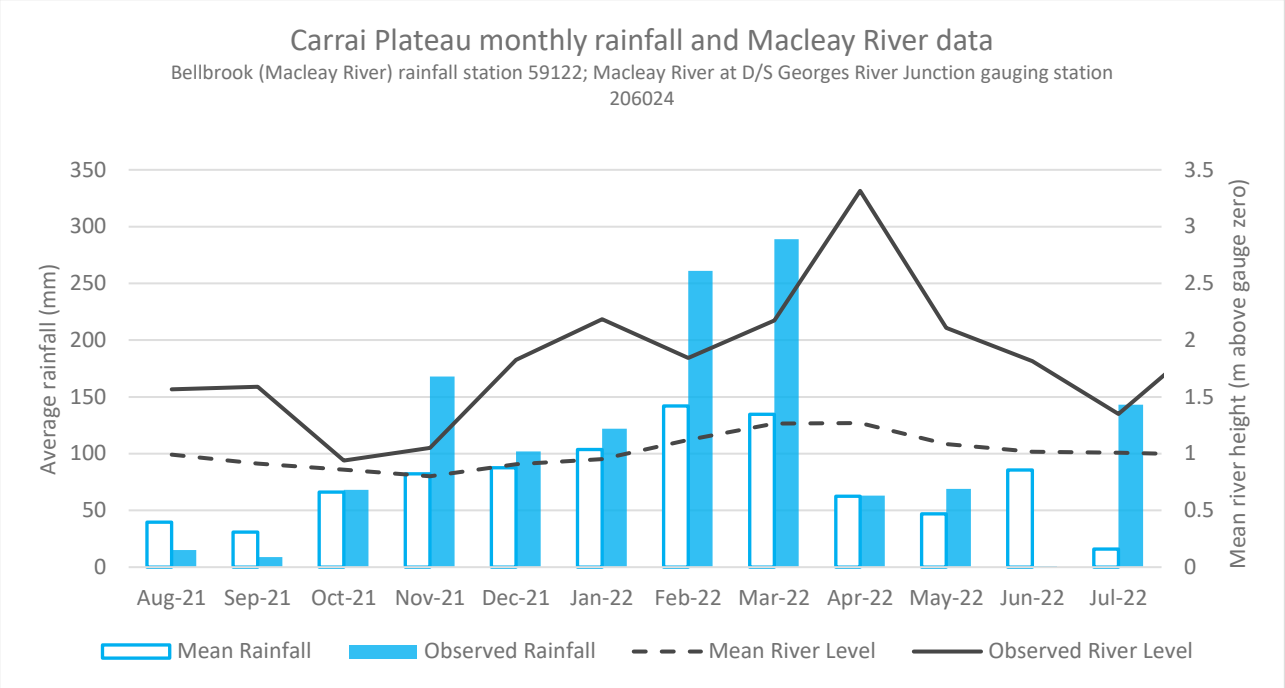
Rainfall data obtained from the Bureau of Meteorology (BoM) Bellbrook (Macleay River) rainfall station (BoM: 59122, located approximately 30 km east of the project area) indicates 52% of the yearly rainfall is typically received between December and March (BoM, 2022).

A summary of historical mean monthly rainfall and river height data compared to observed data from August 2021 to June 2022 is provided in Figure 2.1.

Macleay River height data obtained from the Macleay River D/S Georges River Junction gauging station (WaterNSW: 206024), located approximately 300 m north of the northern boundary of the project area, indicates river levels are typically higher between December and March, correlating with the periods of higher expected rainfall.

The observed monthly rainfall was typically equal to or greater than the historical mean monthly rainfall values. The largest falls were observed in February and March 2022. Observed mean monthly river levels were greater than the historical monthly mean for all months from August 2021 to July 2022. The highest river levels occurring in April 2022 as a response to the significant observed rainfall throughout February and March 2022.

Due to the steep and complex topography of the site, orographic microclimate effects may affect the overall reliability of rainfall and climate data.



Source: Rainfall data; Averaged monthly data August 2001-present at BOM station 59122 Bellbrook (BOM, 2022)
River height data; Averaged monthly data June 1969-present at NSW DPIE station 206024 Macleay D/S Georges (WaterNSW 2022)

Figure 2.1 Carrai Plateau monthly rainfall and Macleay River data

2.3 Geology

The project area lies within the southcentral portion of the Palaeozoic to early Mesozoic New England Orogeny. (Buckman and Bevin 2010). The New England Orogeny extends approximately 2,000 km along the east coast of Australia from Townsville, QLD (north) to Newcastle, NSW (south), and is bounded by the Sydney-Gunnedah--Bowen Basin system to the west (Jessop et al. 2019).

The New England Orogeny is characterised by volcanic arc and fore-arc regions (Day et al. 1978), typically comprising complex suites of:

- Devonian–Carboniferous sedimentary formations (conglomerate, sandstone and mudstone) (Leitch 1974); and
- Carboniferous ashfall tuffs and ignimbrites (Leitch 1974).

Differing geodynamics in the early Permian to Triassic led to the formation of the New England Batholith (O'Neil et al. 1977; Shaw and Flood 1981), a series of linked pluton structures within the southern portion of the New England Orogeny, including the Triassic Carrai Granodiorite pluton (the dominant geology within the site, refer Figure 2.1).

The Carrai Granodiorite typically comprises Hornblende-biotite granodiorite, monzogranite, and minor biotite leucogranite (Leitch & McDougall, 1979). Aplitic and porphyritic dykes are observed irregularly throughout the granodiorite (Leitch 1976).

The elevated margins of the Carrai Granodiorite are steeply dipping into the lower lying contact metamorphic boundaries with the surrounding sedimentary units. These include the late Permian metasedimentary strata and country rock of the Nambucca Beds and the Permian Parrabel Beds (intercepted by the project's proposed lower reservoir, refer Figure 2.2), which comprises conglomerates, sandstones, siltstone, and limestones (Kinny et al. 1985).

Colluvial and alluvial deposits occupy the valley floor, distributed by the floodwaters of the Macleay River and its tributaries.

The surface geology of the project area is shown on Figure 2.2.

2.4 Hydrogeology

2.4.1 Overview

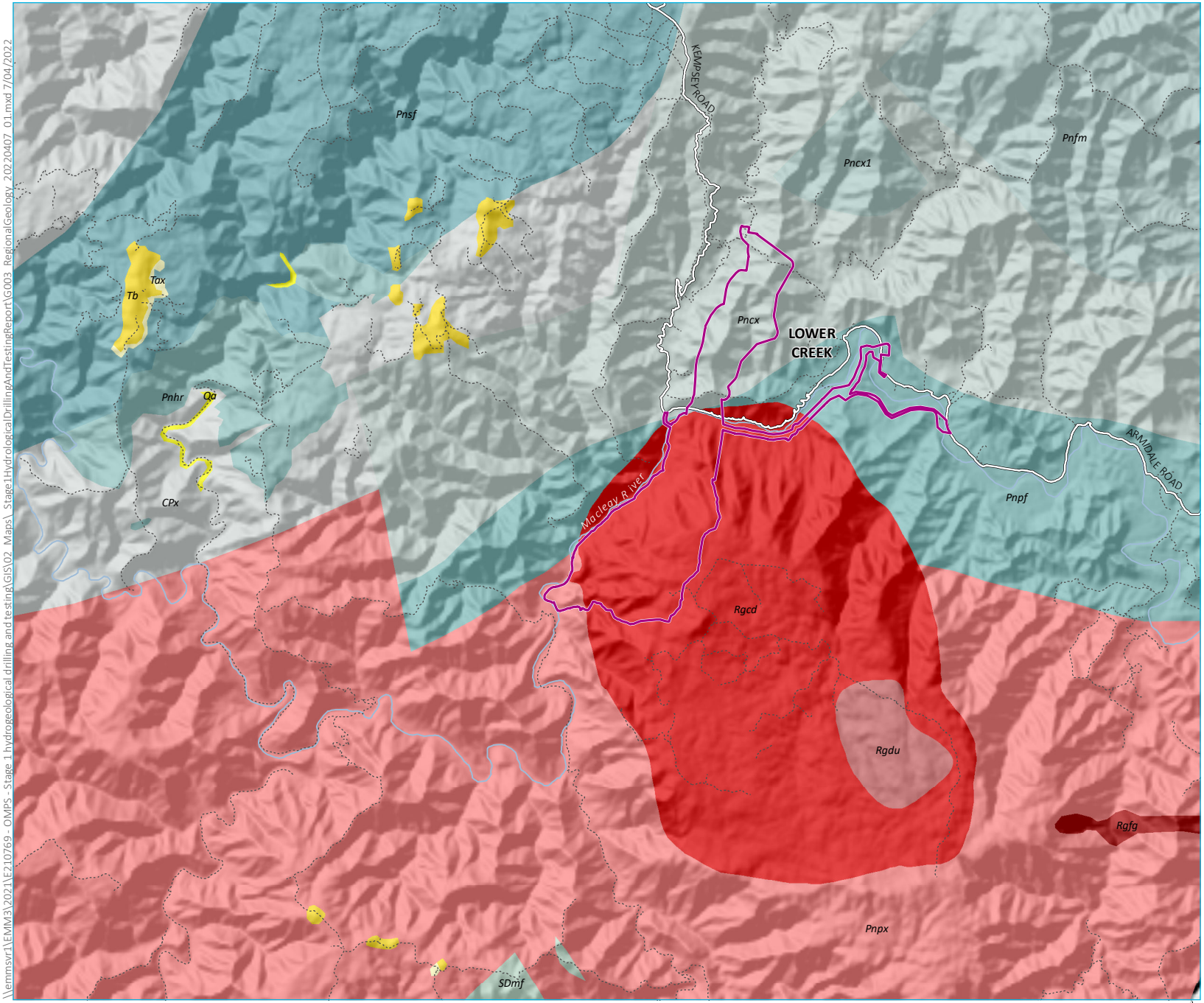
Hydrogeology across the site comprises two systems:

- a surficial localised groundwater system, within the unconsolidated colluvial and alluvial materials deposited within the incised valleys, and adjacent to the Macleay River; and
- a deeper fractured rock groundwater system, within the Triassic Carrai Granodiorite and Permian Parrabel Beds.

Groundwater recharge is predominantly via rainfall across the Carrai Plateau, infiltrating into the outcrops of the fractured rock groundwater system. Longer-term seepage from localised weathered geology likely contributes to attenuated infiltration.

Groundwater flow is dominant within the fractured rock groundwater system via interconnected fracture networks, with negligible flow through the rock matrix pore-space. Groundwater within the fractured rock system discharges to the Macleay River via:

- ephemeral streams, connected through surface expressions at discontinuities in the rock dominated stream bed;
- pore spaces within the surficial localised colluvial/alluvial groundwater systems (which are highly dependent on flow within the ephemeral streams); and
- direct baseflow contribution.



KEY

- Project area
- Major road
- Vehicular track
- Macleay River

Geology 250k period and formation

Quaternary
- Qa - Quaternary, unnamed

Tertiary
- Tax - Tertiary
- Tb - Tertiary

Permian
- Pnpx - Permian, Parrabel bed
- Rgcd - Permian, Carrai Granodiorite
- Rgdu - Permian, Daisy Plains Leucoadamellite
- Rgfg - Permian, Fife Adamellite

Carboniferous
- CPx - Carboniferous, Coffs Harbour association
- Pncx - Carboniferous
- Pncx1 - Carboniferous
- Pnfm - Carboniferous
- Pnhr - Carboniferous
- Pnpf - Carboniferous, Pee Dee bed
- Pnsf - Carboniferous

Silurian
- SDmf - Silurian - Myra bed

Source: EMM (2020); DFSI (2017); GA (2011); OMPS (2020); DPI (2003)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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Regional geology

Oven Mountain Pumped Hydro Storage Project
Stage one hydrogeological drilling and testing report
Figure 2.2

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3 Methodology

3.1 Overview

All drilling, bore construction and testing works were completed in accordance with the Drilling and Testing Plan (EMM 2021a).

3.2 Drilling

Numac Drilling Services Australia Pty Ltd (Numac), Terratest Pty Ltd (Terratest), and Mulligan Geotechnical Pty Ltd (Mulligan) were engaged by SMEC to complete the drilling, bore construction, and bore development activities for the HIP.

Boreholes were typically progressed through the surficial, unconsolidated strata using an 8" blade-bit with air circulation. Following installation of 8" PVC casing (to stabilise the unconsolidated strata), all boreholes, with the exception of BH4A, were continued to the designated target depth using a 5" or 6" pneumatic hammer with air/water circulation. BH4A was progressed using a 125 mm PQ coring methodology. Further drilling information is provided in the geological logs (Appendix A). It is noted that the geological log for BH4A will be included in the Geotechnical investigation report (GIR).

It is noted that due to adverse drilling conditions encountered during the drilling of MB02B that drilling had to be abandoned at this location, with activities shifted approximately 10 m south-east of the original location where more favourable drilling conditions were encountered.

An EMM hydrogeologist was onsite to collect. log and photograph geology samples and measure water quality and yields. Samples were typically collected at 1 m intervals and logged in general accordance with AS1726—2017 Geotechnical Site Investigation (Standards Australia, 2017). Water physico-chemical field parameters and indicative yields were typically measured with a calibrated water quality meter at the end of every drill rod. Sample photographs are included in Appendix B.

3.3 Monitoring bore construction

Monitoring bores were constructed from Class 18, 50 mm nominal diameter (ND) threaded uPVC with 0.4mm horizontal machine slotted slots for the screen sections. The bores typically comprised:

- sump (~1 m), with end cap;
- screen section (ranging from 3–12 m) above the sump, and
- blank casing to surface.

Bentonite was placed in the base of the monitoring bore beneath the sump. The annular space within the borehole around the casing/screen typically comprised:

- filter pack (nominal diameter 2–3 mm sand);
- slow-release bentonite chips;
- backfill (when required); and
- cement based grout to ground level.

Monitoring bores were completed with a ~0.6 m standpipe monument was installed within a 0.5 m x 0.5 m concrete plinth.

3.4 Monitoring bore development

Following drilling completion, boreholes were developed by circulating air throughout the full borehole profile until physico-chemical parameters stabilised and water clarity improved.

3.5 Water quality sampling

Representative groundwater samples were collected from each bore by an EMM hydrogeologist at the conclusion of development. Samples were collected using a submersible bailer and submitted to a NATA accredited laboratory for analysis of the following suite of analytes:

- general water suite (pH, electrical conductivity, total dissolved solids, alkalinity, sulfate, chloride, fluoride, major cations, major anions and ionic balance);
- twelve dissolved metals (aluminium, antimony, arsenic, cadmium, chromium, copper, manganese, mercury, nickel, lead, zinc and iron); and
- hydrocarbons (TRH(C6-C40) and BTEXN).

Water quality sampling is summarised in Table 4.3to Table 4.5 and certificates of analysis are attached as Appendix C. It is noted that water chemistry results from BH4A were not available at the time of reporting. These data will be summarised, incorporated into this report, and reissued once results are made available.

3.5.1 Quality control

In general accordance with the National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPC, 1999), quality control measures were adopted to improve confidence in the analytical data set. The following quality control samples were submitted to NATA accredited laboratories for analysis:

- one duplicate sample (intra-lab duplicate, referenced as QC01) submitted for analysis to the primary laboratory, providing an indication of the field sampling and primary laboratory consistency;
- one triplicate sample (inter-lab duplicate, referred to as QC02) submitted for similar analysis to a secondary laboratory, providing an indication of the primary laboratory's precision and reliability;
- one rinsate blank sample (referred to as Rinsate) taken from de-ionised water poured over the water level meter, providing an indication that the sampling equipment is appropriately de-contaminated;
- one trip blank sample (a vial of de-ionised water, referred to as TB) pre-organised by the primary laboratory and transported with the groundwater samples, providing an indicator if extraneous contamination (TRH and BTEXN) has entered the groundwater samples during transport; and
- one trip spike sample (a vial of de-ionised water 'spiked' with a known concentration of BTEXN, referred to as TS) pre-organised by the primary laboratory and transported with the groundwater samples, providing indication of appropriate TRH and BTEXN sample preservation.

The relative percentage difference (RPD) was calculated for duplicate and triplicate samples to provide a quantitative assessment of dataset reliability, as demonstrated in equation 1:

Equation 1; $$RPD\ (\%) = \frac{|C_1 - C_2|}{\frac{C_1 + C_2}{2}} \times 100$$

Where: RPD is relative percentage difference;

C_1 is the concentration of analyte from sample 1; and

C_2 is the concentration of analyte from sample 2.

In the absence of project site specific data quality objectives, EMM adopted the following acceptance criteria for quality control assessment:

- if primary sample analyte concentration is:
  - less than or equal to five (5) times the limit of reporting, RPD should be less than 100%; or
  - greater than five (5) times the limit of reporting, RPD should be less than 50%;
- trip spikes analyte concentrations are greater than or equal to 90% of known spiked concentrations; and
- rinsate and trip blank concentrations are less than the limit of reporting.

Results are provided in Section 4.4 and attached as Appendix C.

3.6 Hydraulic conductivity testing

Rising head tests were undertaken at all monitoring bores to infer the hydraulic conductivity of the respective lithology. Whilst BH4A also underwent hydraulic conductivity testing through the use of inflatable packers, this scope was undertaken by SMEC and as such results are not summarised in this report.

The testing undertaken by EMM was performed using a pneumatic slug testing apparatus (PST) as follows:

1. The PST was fitted at the top of the PVC stickup and a logger was temporarily installed to allow for automated data collection (nominally set to a 1 to 5 second interval).
2. A manual water level measurement was taken for logger depth calibration and to infer a representative static water level.
3. Air was pumped into the bore with a hand pump (for approximately 3 min) to pressurise the bore and cause a displacement in the static water level.
4. The pressurised seal was removed, and the monitoring bore was allowed to recover until the water level was close to the initial standing water level. Manual water level measurements were periodically taken to assess recovery.
5. The logger was removed, and data was downloaded.

Data was analysed using Aqtesolv software. A summary of processed results is provided in Table 4.2 and analytical models are attached as Appendix D.

3.7 Monitoring bore equipment installation and ongoing monitoring

3.7.1 Equipment installation

Loggers were installed in all monitoring bores to measure water levels at six-hour intervals. The initial water level was manually measured following installation for logger depth calibration. A barometric logger was installed in the headspace of MB02A to allow for atmospheric compensation. Water level hydrographs are presented in Appendix E.

Dedicated double valve pumps (DVP) and tubing were installed in all monitoring bores to collect reliable and representative water quality samples.

4 Results

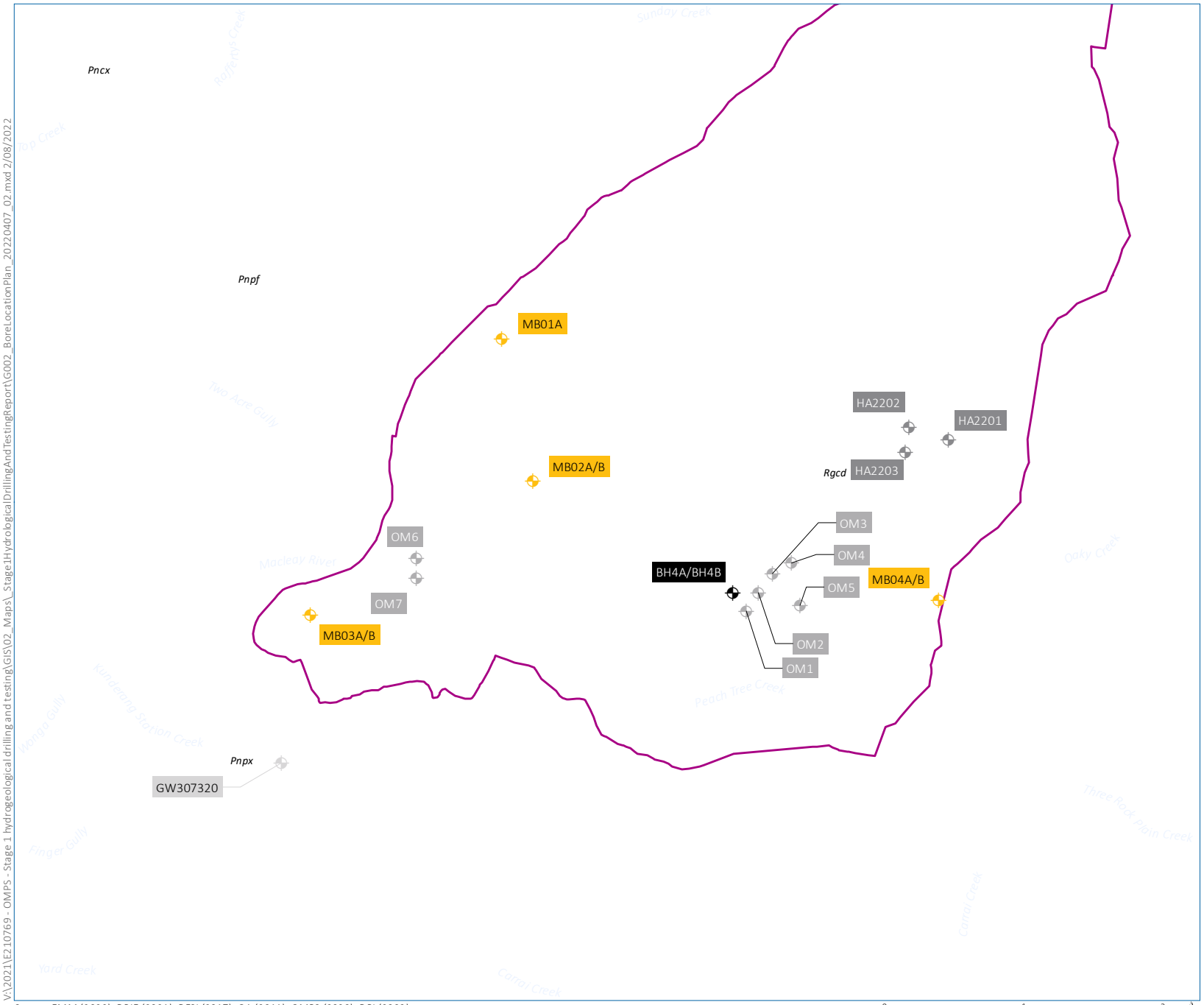
4.1 Monitoring bore summary

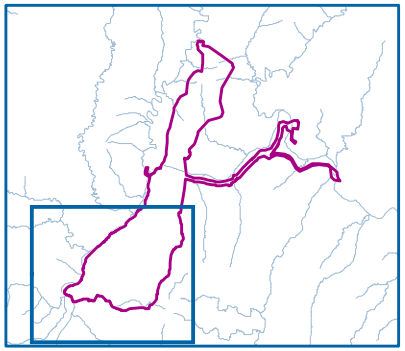
A summary of monitoring bore installations is provided in Table 4.1 and monitoring bore locations are shown in Figure 4.1. Further details regarding drilling and monitoring bore installations are provided in the geological logs attached as Appendix A, with the exception of BH4A, whereby further information is provided in the GIR.

Table 4.1 Installation and water data summary

Site	Bore	[1]Coordinate		Elevation		Drilling		Construction					Equipment Installation			
										Screen				Logger		
		Easting[1]	Northing	Top of casing (mAHD)[2]	Ground level (mAHD)	Depth (mbgl)[3]	Diameter (mm)	Material	Diameter (mm)	Top (mbgl)	Bottom (mbgl)	Formation	Water level (mbgl)	Depth (mAHD)	Serial number	DVP intake (mbgl)
1	MB01A	419853.6	6593143.5	183.9	182.8	36.5	125	PVC	50	28.5	34.5	Carrai Granodiorite	9.93	166.9	2143291	32
2	MB02A	420108.5	6592190.8	303.5	302.4	34.5	200	PVC	50	25.6	31.6	Carrai Granodiorite	19.27	275.5	2143293	29
	MB02B	420094.0	6592175.2	301.5	300.6	187	200	PVC	50	173.5	185.5	Carrai Granodiorite	19.05	261.5	2142820	183
3	MB03A	418650.9	6591232.3	167.3	166.5	23	200	PVC	50	15	21	Parrabel Beds	9.68	149.3	2143294	19
	MB03B	418645.8	6591223.6	167.8	167.0	100	200	PVC	50	86	98	Parrabel Beds	10.63	137.8	2142822	96
9	MB04A	423003.9	6591263.9	972.7	972.1	10.5	125	PVC	50	6.35	9.35	Carrai Granodiorite	0.25	962.2	2150410	8.5
	MB04B	422999.7	6591259.0	972.5	971.9	60.5	125	PVC	50	46.7	58.7	Carrai Granodiorite	1.01	942.5	2142821	56
8	BH4A	421495.5	6591273.5	884.5	883.8	77.8	125	PVC	50	63.8	75.8	Nambucca Beds	44.3	834.6	[4]—	—

Notes: 1. co-ordinates are provided in GDA1994/MGA zone 56. 2. mAHD = metres Australian Height Datum. 3. mbgl = metres below ground level. 4. Logger serial number not available





KEY

- Project area
- Access track
- Named watercourse
- Proposed reservoir footprint
- Proposed subsurface infrastructure
- High potential GDE

Stage one hydrogeological program bores

- Hydrogeological (nested bore)

Bore/boreholes additional to Stage one HIP

- Geotechnical / hydrogeological bore
- Fen monitoring bore
- Existing monitoring borehole (SMEC 1996)
- Registered bore (NGIS 2022)

Geology 250k period and formation

Permian

- Pnpx - Permian, Parrabel bed
- Rgcd - Permian, Carrai Granodiorite

Carboniferous

- Pncx - Carboniferous
- Pnpf - Carboniferous, Pee Dee bed

Bore location plan

Oven Mountain Pumped Hydro Storage Project
Stage one hydrogeological drilling and testing report
Figure 4.1

[redacted]

Source: EMM (2022); DPIE (2021); DFSI (2017); GA (2011); OMPS (2020); DPI (2003)

V:\2021\E210769 - OMPS - Stage 1 hydrogeological drilling and testing\GIS\02_Maps_Stage1HydrologicalDrillingAndTestingReport\G002_BoreLocationPlan_20220407_02.mxd 2/08/2022

4.2 Hydraulic conductivity testing

A summary of hydraulic conductivity results is provided in Table 4.2, with Aqtesolv analysis provided in Appendix D.

Table 4.2 Hydraulic conductivity testing results

Site	Bore	Formation	Lithology	Screen details (mbgl)[1]	Hydraulic conductivity (m/s)[2]	Assumptions		Analytical method Confinement
						Confinement	Penetration	
1	MB01A	Carrai Granodiorite	Granodiorite, fresh to slightly weathered	28.5 – 34.5	5.4×10^{-7}	Unconfined	Partial	KGS
2	MB02A	Carrai Granodiorite	Granodiorite, fresh to slightly weathered	25.6 – 31.6	4.3×10^{-6}	Unconfined	Partial	KGS
	MB02B	Carrai Granodiorite	Granodiorite, fresh to slightly weathered	173.5 – 185.5	5.0×10^{-7}	Unconfined	Partial	KGS
3	MB03A	Parrabel Beds	Hornfels, fresh	15 –21	2.0×10^{-5}	Unconfined	Partial	KGS (w/skin)
	MB03B	Parrabel Beds	Phyllite and hornfels, fresh	86– 98	1.7×10^{-7}	Unconfined	Partial	KGS
9	MB04A	Residual Carrai Granodiorite	Sand and extremely weathered granodiorite	6.35 – 9.35	2.8×10^{-5}	Unconfined	Partial	KGS
	MB04B	Carrai Granodiorite	Granodiorite, fresh to slightly weathered	46.7 – 58.7	3.3×10^{-6}	Unconfined	Partial	Springer and Gelhar
8	BH4A	Nambucca Beds	Hornfels, fresh	63.8—75.8	—	—	—	—

Notes: 1. mbgl = metres below ground level. 2. m/s = metres per second
Source: KGS analytical method sourced via AQTESOLV software (Hyder et al. 1994); and Springer and Gelhar analytical method sourced via AQTESOLV software (Springer and Gelhar 1991).

4.3 Water quality

A summary of field and laboratory water quality results are provided in Table 4.3 to Table 4.5 and laboratory certificate of analysis are attached as Appendix C.

Table 4.3 General water quality summary

Site	Bore	Stratigraphy	Temperature (°C)	pH		Electrical conductivity (µg/L)[2]		Hardness (mg/L)[1]
			Field	Field	Laboratory	Field	Laboratory	Field
1	MB01A	Carrai Granodiorite	20.8	7.23	7.40	647	698	163
2	MB02A	Carrai Granodiorite	21.6	6.96	7.38	620	825	257
	MB02B	Carrai Granodiorite	20.7	8.14	7.36	495	694	208
3	MB03A	Parrabel Beds	24.2	8.39	6.78	1,166	986	366
	MB03B	Parrabel Beds	22.1	8.43	7.36	636	966	319
9	MB04A	Residual Carrai Granodiorite	21.6	5.93	6.02	75.7	120	2
	MB04B	Carrai Granodiorite	18.8	6.35	6.34	171.2	157	38
8	BH4A[2]	Nambucca Beds	13.4	9.50	—	179.3	—	—

Notes: 1. Milligrams per litre. 2. Microsiemens per litre 2. Water chemistry results from BH4A were not available at the time of reporting.

Table 4.4 Water chemistry results—metals summary

Site	Bore	Stratigraphy	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Alkalinity (as CaCO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (Fl)	Total Anions	Total Cations	Ionic Balance
			[1]mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	[2]meq/L	meq/L	%
1	MB01A	Carrai Granodiorite	47	11	98	5	305	26	43	0.8	7.85	7.64	1.34
2	MB02A	Carrai Granodiorite	80	14	71	6	132	254	39	0.5	9.02	8.39	3.67
	MB02B	Carrai Granodiorite	62	13	80	4	228	99	35	1.2	7.60	7.74	0.92
3	MB03A	Parrabel Beds	112	21	82	8	285	176	75	ND	ND	ND	ND
	MB03B	Parrabel Beds	90	23	108	11	358	122	56	ND	ND	ND	ND
9	MB04A	Residual Carrai Granodiorite	1	<1	12	2	39	2	10	<0.1	1.10	1.04	[3]—
	MB04B	Carrai Granodiorite	12	2	23	2	98	2	7	<0.1	2.20	1.94	—
8	[4]BH4A	Nambucca Beds	—	—	—	—	—	—	—	—	—	—	—

Notes: 1. Milligrams per litre. 2. Milliequivalents per litre. 3. — indicates limited cation/anion concentrations cannot be differentiated. 4. Water chemistry results from BH4A were not available at the time of reporting.

Table 4.5 Water chemistry results—metals summary

Site	Bore	Stratigraphy	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Lead (Pb)	Nickel (Ni)	Zinc (Zn)	Iron (Fe)
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	MB01A	Carrai Granodiorite	0.04	[1]<0.005	<0.01	<0.01	<0.01	<0.01	0.05	<0.05
2	MB02A	Carrai Granodiorite	0.001	<0.0001	<0.001	0.001	<0.001	0.009	0.024	<0.05
	MB02B	Carrai Granodiorite	<0.01	<0.005	<0.01	<0.01	<0.01	<0.01	0.04	0.05
3	MB03A	Parrabel Beds	<0.01	<0.005	<0.01	<0.01	<0.01	<0.01	0.02	0.40
	MB03B	Parrabel Beds	<0.01	<0.005	<0.01	<0.01	<0.01	<0.01	<0.01	1.14
9	MB04A	Residual Carrai Granodiorite	<0.01	<0.005	<0.01	<0.01	<0.01	<0.01	0.03	0.38
	MB04B	Carrai Granodiorite	<0.01	<0.005	<0.01	<0.01	<0.01	0.01	0.07	1.54
8	[2]BH4A	Nambucca Beds	—	—	—	—	—	—	—	—

Notes: 1. < indicates analytes were not detected above the limit of reporting for the respective analysis method. 2. Water sampling results from BH4A were not available at the time of reporting.

4.4 Quality control

Duplicate and triplicate samples were all within the acceptable criteria limits presented in Section 3.5.1, with the exception of Ionic balance concentrations between the primary/inter-lab samples (Appendix C). A summary is provided in Table 4.6.

Trip spike analyte concentrations were within the acceptable criteria limits presented in Section 3.5.1, a summary is provided in Table 4.7 and certificates of analysis are attached as Appendix C

Rinsate blanks and the trip blank analyte concentrations were all below the limit of reporting. A summary is provided in Table 4.8 and certificates of analysis are attached as Appendix C.

Table 4.6 Quality control exceedance summary

Analytes	Units	[1]LOR	Concentrations			Relative percentage differences (%)	
			Primary (MB01A)	Intra-lab (QC01)	Primary (MB01A)	Intra-lab (QC01)	Primary (MB01A)
			14/12/2021	14/12/2021	14/12/2021		
Ionic balance	%	0.01	5.58	4.56	-4.0	20	213

Notes: 1. Limit of reporting.

Table 4.7 Trip spike concentrations

Analyte	Unit	Result	Initial concentration	Retained (%)
Benzene	µg/L[1]	23.30	25	93.1
Toluene	µg/L	23.50	25	94.0
Ethylbenzene	µg/L	26.75	25	107.0
meta- & para-Xylene	µg/L	26.75	25	107.0
ortho-Xylene	µg/L	27.50	25	110.0
Naphthalene	µg/L	24.60	25	98.5

Notes: 1. Micrograms per litre.

Table 4.8 Rinsate and trip blank concentrations

Analyte	Unit	[1]LOR	Results	
			Trip blank	Rinsate
			14/12/2021	14/12/2021
Aluminium (filtered)	[3]mg/L	0.1	0.01	[2]—
Arsenic (filtered)	mg/L	0.01	<0.001	—
Antimony (filtered)	mg/L	0.01	<0.001	—
Cadmium (filtered)	mg/L	0.005	<0.0001	—
Chromium (III+VI) (filtered)	mg/L	0.01	<0.001	—
Copper (filtered)	mg/L	0.01	<0.001	—
Iron (filtered)	mg/L	0.05	<0.05	—
Lead (filtered)	mg/L	0.01	<0.001	—
Manganese (filtered)	mg/L	0.01	<0.001	—
Mercury (filtered)	mg/L	0.0001	<0.0001	—
Nickel (filtered)	mg/L	0.01	<0.001	—
Zinc (filtered)	mg/L	0.01	<0.005	—
Benzene	µg/L	1	<1	<1
Toluene	µg/L	2	<2	<2
Ethylbenzene	µg/L	2	<2	<2
meta- & para-Xylene	µg/L	2	<2	<2
ortho-Xylene	µg/L	2	<2	<2
Total Xylenes	[4]µg/L	2	<2	<2
Sum of BTEX	µg/L	1	<1	<1
Naphthalene	µg/L	5	<5	<5
C10-C16	µg/L	100	<100	—
C10-C16 (F2 minus Naphthalene)	µg/L	100	<100	—
C10-C40 (Sum of total)	µg/L	100	<100	—
C16-C34	µg/L	100	<100	—
C34-C40	µg/L	100	<100	—
C6-C10	µg/L	20	<20	<20
C6-C10 (F1 minus BTEX)	µg/L	20	<20	<20
+C10-C36 (Sum of total)	µg/L	50	<50	—
C15-C28	µg/L	100	<100	—

Table 4.8 Rinsate and trip blank concentrations

Analyte	Unit	[1]LOR	Results	
			Trip blank	Rinsate
			14/12/2021	14/12/2021
C10-C14	µg/L	50	<50	—
C29-C36	µg/L	50	<50	—
C6-C9	µg/L	20	<20	<20

Notes: 1. Limit of reporting. 2. — indicates analyte was not tested by the lab. 3. milligram per litre.
4. microgram per litre.

5 Summary and recommendations

A monitoring bore network was installed to facilitate the collection of baseline data in accordance with the Secretary's Environmental Assessment Requirements (SEARs) issued on the 19 February 2021 to inform the proposed Environmental Impact Statement (EIS).

In order to increase confidence in hydrogeological conceptualisation, EMM recommends further monitoring to obtain additional groundwater level data and water quality data to facilitate background data collection for the EIS.

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Appendix A
Geological logs

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St Leonards NSW 2065
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Hydrogeological notes and symbols

In general accordance with AS1726-2017

Groundwater observations

Yield test | Water strike | Water dip | Water level

Soil

Components	Division	Size (mm)	Fraction
Boulder		>200	Oversize
Cobble		63-200	
Gravel	Coarse Medium Fine	19.00-63.00 6.70-19.00 2.36-6.70	Coarse grained
Sand	Coarse Medium Fine	0.60-2.36 0.21-0.60 0.075-0.21	

Components	Size (mm)	Fraction
Silt	0.002-0.075	Fine grained
Clay	<0.002	
Peat	Soil comprising >25% organic content	
Fill	Anthropogenic or collapsed material	

Rock

Sedimentary	Metamorphic	Igneous	Duricrust
Limestone	Gneiss	Gabbro	Ferricrete
Conglomerate	Schist	Dolerite	Gypcrete
Breccia	Phyllite	Basalt	Calcrete
Sandstone	Slate	Diorite	Silicrete
Siltstone	Marble	Microdiorite	
Claystone	Serpentinite	Andesite	
Coal	Hornfel	Granite	
Tuff	Quartzite	Microgranite	
Gypsum/Rocksalt etc.		Rhyolite	

Well construction

Bentonite	Gravel pack	Grout	Pipe	Screen
Mudex, TR30, 1/4" coated bentonite chips	Blue Circle specialised sand, 2 mm, washed	Cement based grout, approximately 1:1 mix	PVC, 50 mm diameter, class 18, threaded with O-ring	PVC, 50 mm diameter, class 18, horizontal slots, 0.4 mm aperture, threaded with O-ring

mbgl = metres below ground level

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Monitoring bore

ID: MB01A

Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	HJN
Date:	17–21 October 2021

Easting:	419853.6
Northing:	6593143.5
Spatial reference:	MGA Zone 56
Elevation (collar):	183.9 mAHD
Elevation (ground):	182.8 mAHD
Nominal diameter:	125 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 9.93 mbgl

Screened depth: 28.5–34.5 mbgl **Total depth:** 36.5 mbgl **Level date; time:** 21 October 2021, 12:12

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes	Bore design	RL (mAHD)
0	125 mm pneumatic hammer			Residual	SAND: Medium toCoarse, brown, angular with clay, brown, trace organics, roots ~1-3 mm, dry, residual.				
				Carrai Granodiorite	SAND: Extremely weathered monzogranite; Coarse grained, pale brown, 50% quartz, 50% mixed feldspar, dry.				180
					SYENOGRANITE: Coarse grained, pale pinkish brown, ~60% quartz, 30% biotite, 10% plagioclase, dry, moderately weathered.				
					SAND: Extremely weathered monzogranite; Coarse grained, pale brown, 50% quartz, 50% plagioclase, dry.				
					GRANODIORITE: Coarse grained, pale pinkish brown, ~60% quartz, 30% biotite, 10% plagioclase, dry, highly weathered.				
10						▼	9.93 m: Recovered water level		
					GRANODIORITE: Coarse grained, reddish brown, 5% quartz, 80% plagioclase, 15% horneblende, highly weathered, moist.	K	12.35 m: Very low yield, depleting		170
					GRANODIORITE: Coarse grained, pale greyish red, 40% quartz, 40% plagioclase, 15% biotite, 5% pyrite, fresh, dry.				
					GRANODIORITE: Coarse grained, white and dark grey, 60% quartz, 10% biotite, 10% plagioclase, 20% horneblende, fresh, dry.				

Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 7.23; SPC = 647 µs/cm; Temp = 20.8°C; ORP = 95.1 mV

Driller: Justin Collyer **Termination details:** Borehole terminated at target depth of 36.5 m

File path: MB01A.ldat8

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Monitoring bore

ID: MB01A

Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	HJN
Date:	17–21 October 2021

Easting:	419853.6
Northing:	6593143.5
Spatial reference:	MGA Zone 56
Elevation (collar):	183.9 mAHD
Elevation (ground):	182.8 mAHD
Nominal diameter:	125 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 9.93 mbgl

Screened depth: 28.5–34.5 mbgl **Total depth:** 36.5 mbgl **Level date; time:** 21 October 2021, 12:12

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes	Bore design	RL (mAHD)
20	125 mm pneumatic hammer			Carrai Granodiorite			21 m: 0.5 L/sec, pH 7.86, SPC 630 µS/cm, Temp 17.5°C, Eh 152.8 mV		160
					GRANODIORITE: As above, pale grey, pale green and dark grey, trace slightly weathered chips in return, likely aplite instrusions throughout granodiorite.				
					GRANODIORITE: As above, 50% quartz, 10% plagioclase, 20% horneblende, 10% biotite, 10% pyrite.				
30							32.8 m: 0.2 L/sec, pH 8.27, SPC 401 µS/cm, Temp 21.0°C, Eh 94.1 mV		150
							34 m: 0.2 L/sec, pH 8.71, SPC 361 µS/cm, Temp 22.9°C, Eh 86.0 mV		

Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 7.23; SPC = 647 µs/cm; Temp = 20.8°C; ORP = 95.1 mV

Driller: Justin Collyer **Termination details:** Borehole terminated at target depth of 36.5 m

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Monitoring bore

ID: MB02A

Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	HJN
Date:	10–11 December 2021

Easting:	420108.5
Northing:	6592190.8
Spatial reference:	MGA Zone 56
Elevation (collar):	303.5 mAHD
Elevation (ground):	302.4 mAHD
Nominal diameter:	150 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 19.27 mbgl

Screened depth: 25.6–31.6 mbgl **Total depth:** 34.5 m **Level date; time:** 25 January 2022, 09:44

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes	Bore design	RL (mAHD)
0	150 mm pneaumatic hammer			Residual	Silty SAND: Medium grained, pale reddish brown, angular, moist, quartzose. Residual				
					Sandy GRAVEL: Fine grained, pale brown, angular, Sand is medium grained, angular, quartzose. With pyrite, moist. Residual				300
				Carrai Granodiorite	Sandy GRAVEL: Extremely weathered granodiorite, fine grained, pale brown, angular, sand is medium grained, angular, quartzose. Trace pyrite. Dry		4 m: Depleting, potential perched surface contact		
					GRANODIORITE: Coarse grained, pale yellowish red, moderately weathered, dry. 40% quartz, 10% biotite, 50% plagioclase		6.8–7 m: Highly weathered section		
10					GRANODIORITE: As above, pale grey, slightly weathered		11.2–12 m: Moderately weathered section		
					GRANODIORITE: As above, 40% quartz, 10% biotite, 20% horneblende, 30% plagioclase				290
					GRANODIORITE: As above, fresh				

Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 6.96; SPC = 620 µs/cm; Temp = 21.6°C; ORP = 71.7 mV

Driller: Steffan Colls **Termination details:** Borehole terminated at target depth of 34.5 m.

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Monitoring bore

ID: MB02A

Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	HJN
Date:	10–11 December 2021

Easting:	420108.5
Northing:	6592190.8
Spatial reference:	MGA Zone 56
Elevation (collar):	303.5 mAHD
Elevation (ground):	302.4 mAHD
Nominal diameter:	150 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 19.27 mbgl

Screened depth: 25.6–31.6 mbgl **Total depth:** 34.5 m **Level date; time:** 25 January 2022, 09:44

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes	Bore design	RL (mAHD)
20	150 mm pneaumatic hammer			Carrai Granodiorite			17.9 m: No yield, colour change in rock and slightly damp 19.27 m: Recovered water level		280
30							28 m: <0.01L/sec 29–34.5 m: Moderately weathered chip samples 31 m: 0.02 L/sec, pH 8.30, SPC 1110 µS/cm, Temp 18.8°C, Eh 36.0 mV		270

Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 6.96; SPC = 620 µs/cm; Temp = 21.6°C; ORP = 71.7 mV

Driller: Steffan Colls **Termination details:** Borehole terminated at target depth of 34.5 m.

File path: MB02A.ldat8

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Monitoring bore

ID: MB02B

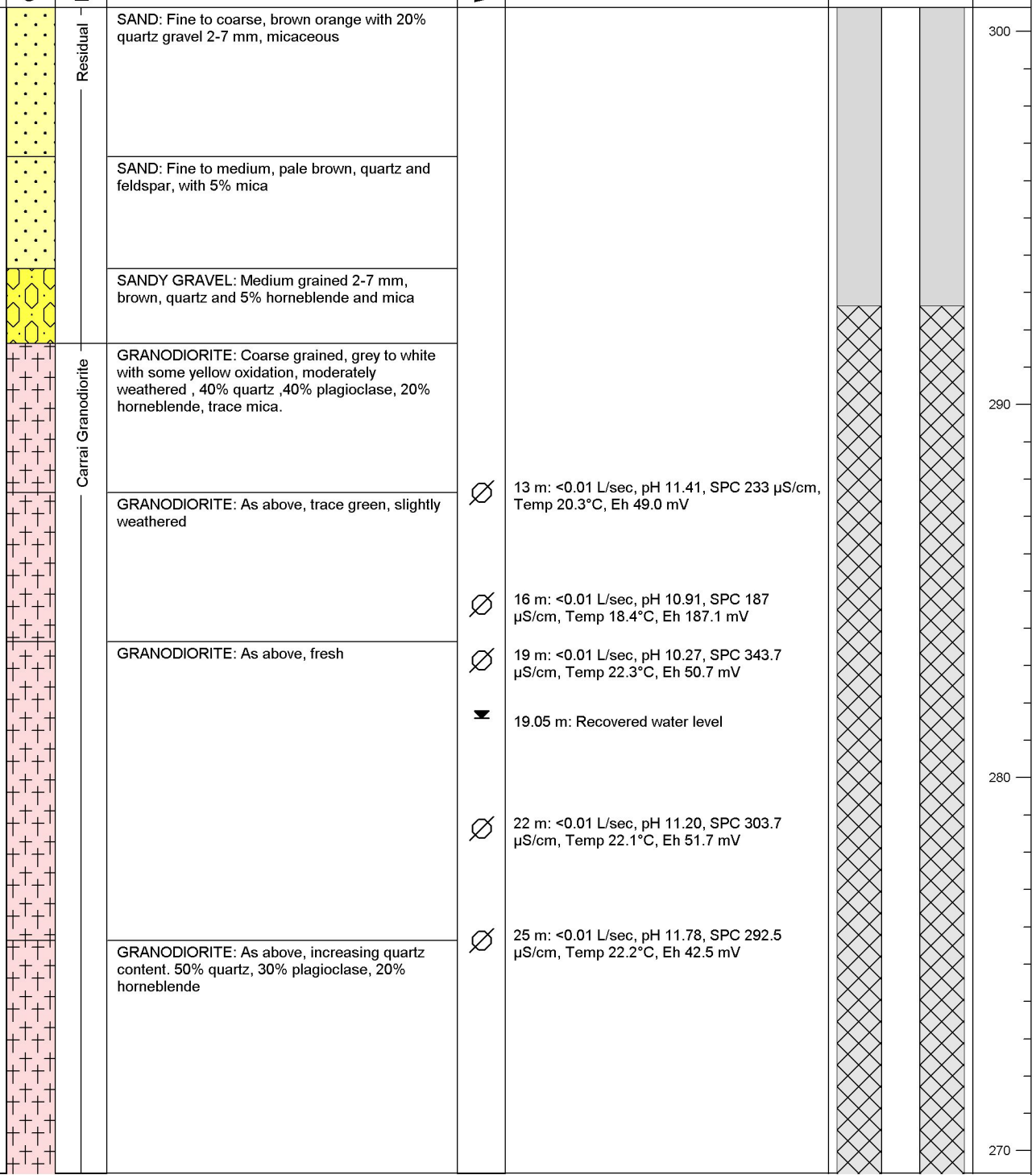
Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	QB AB
Date:	15 January–9 February 2022

Easting:	420094
Northing:	6592175.2
Spatial reference:	MGA Zone 56
Elevation (collar):	301.5 mAHD
Elevation (ground):	300.6 mAHD
Nominal diameter:	200 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 19.05 mbgl

Screened depth: 173.5–185.5 mbgl **Total depth:** 187 mbgl **Level date; time:** 10 February 2022; 12:00

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes
0	200 mm pneumatic hammer			Residual	SAND: Fine to coarse, brown orange with 20% quartz gravel 2-7 mm, micaceous		
					SAND: Fine to medium, pale brown, quartz and feldspar, with 5% mica		
					SANDY GRAVEL: Medium grained 2-7 mm, brown, quartz and 5% horneblende and mica		
10				Carrai Granodiorite	GRANODIORITE: Coarse grained, grey to white with some yellow oxidation, moderately weathered , 40% quartz ,40% plagioclase, 20% horneblende, trace mica.		
					GRANODIORITE: As above, trace green, slightly weathered	∅	13 m: <0.01 L/sec, pH 11.41, SPC 233 µS/cm, Temp 20.3°C, Eh 49.0 mV
						∅	16 m: <0.01 L/sec, pH 10.91, SPC 187 µS/cm, Temp 18.4°C, Eh 187.1 mV
					GRANODIORITE: As above, fresh	∅	19 m: <0.01 L/sec, pH 10.27, SPC 343.7 µS/cm, Temp 22.3°C, Eh 50.7 mV
						▼	19.05 m: Recovered water level
20						∅	22 m: <0.01 L/sec, pH 11.20, SPC 303.7 µS/cm, Temp 22.1°C, Eh 51.7 mV
						∅	25 m: <0.01 L/sec, pH 11.78, SPC 292.5 µS/cm, Temp 22.2°C, Eh 42.5 mV
					GRANODIORITE: As above, increasing quartz content. 50% quartz, 30% plagioclase, 20% horneblende		
30							



Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 8.14; SPC = 495 µs/cm; Temp = 20.7°C; ORP = 82.9 mV

Driller: Steffan Colls **Termination details:** Borehole terminated at target depth of 187 m.

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Monitoring bore

ID: MB02B

Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	QB AB
Date:	15 January–9 February 2022

Easting:	420094
Northing:	6592175.2
Spatial reference:	MGA Zone 56
Elevation (collar):	301.5 mAHD
Elevation (ground):	300.6 mAHD
Nominal diameter:	200 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 19.05 mbgl

Screened depth: 173.5–185.5 mbgl **Total depth:** 187 mbgl **Level date; time:** 10 February 2022; 12:00

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes	Bore design	RL (mAHD)
40	200 mm pneumatic hammer			Carrai Granodiorite	GRANODIORITE: As above, slightly weathered GRANODIORITE: As above, fresh	∅	34 m: <0.02 L/sec, pH 10.66, SPC 335.1 µS/cm, Temp 19.3°C, Eh 122.3 mV		260
						∅	37 m: <0.02 L/sec, pH 10.56, SPC 373.6 µS/cm, Temp 18.6°C, Eh 128.7 mV		
						∅	40 m: <0.02 L/sec, pH 5.50, SPC 381.8 µS/cm, Temp 19.8°C, Eh 120.1 mV		
50						∅	43 m: no WQ, too much foam		250
					GRANODIORITE: As above, slightly weathered GRANODIORITE: As above, fresh	∅	52 m: <0.02 L/sec, pH 11.3, SPC 325.9 µS/cm, Temp 21.4°C, Eh 105.2 mV		
						∅	55 m: <0.02 L/sec		
60						∅	58 m: <0.02 L/sec, pH 11.93, SPC 335.6 µS/cm, Temp 21.7°C, Eh 68.8 mV		240

Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 8.14; SPC = 495 µs/cm; Temp = 20.7°C; ORP = 82.9 mV

Driller: Steffan Colls **Termination details:** Borehole terminated at target depth of 187 m.

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Site:	Oven Mountain, Carrai, NSW
Logged by:	QB AB
Date:	15 January–9 February 2022

Easting:	420094
Northing:	6592175.2
Spatial reference:	MGA Zone 56
Elevation (collar):	301.5 mAHD
Elevation (ground):	300.6 mAHD
Nominal diameter:	200 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 19.05 mbgl

Screened depth: 173.5–185.5 mbgl **Total depth:** 187 mbgl **Level date; time:** 10 February 2022; 12:00

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes	Bore design	RL (mAHD)
	200 mm pneumatic hammer			Carrai Granodiorite	GRANODIORITE: As above , trace clay in return, potential weathered seam.		65.5 m: <1 L/sec, pH 11.83, SPC 543.0 µS/cm, Temp 21.4°C, Eh -21.4 mV		
					GRANODIORITE: As above, fresh				
70					GRANODIORITE: As above, trace low durability chips in return, slightly weathered		70 m: <1 L/sec, pH 11.80, SPC 532.6 µS/cm, Temp 20.9°C, Eh -24.9 mV		230
					GRANODIORITE: As above, 70% horneblende 30% quartz		76 m: <1 L/sec		
					GRANODIORITE: As above, fresh		79 m: <1 L/sec, pH 10.61, SPC 494.1 µS/cm, Temp 20.3°C, Eh 31.3 mV		
80									220
							82 m: <1 L/sec, pH 11.48, SPC 518.4 µS/cm, Temp 20.6°C, Eh 121.6 mV		
							85 m: <1 L/sec, pH 11.01, SPC 528.0 µS/cm, Temp 20.1°C, Eh 4.3 mV		
							88 m: <1 L/sec, pH 10.92, SPC 529.0 µS/cm, Temp 20.0°C, Eh 6.4 mV		
90									
							91 m: <1 L/sec, pH 10.60, SPC 536.0 µS/cm, Temp 20.0°C, Eh -0.3 mV		210

Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 8.14; SPC = 495 µs/cm; Temp = 20.7°C; ORP = 82.9 mV

Driller: Steffan Colls **Termination details:** Borehole terminated at target depth of 187 m.

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Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	QB AB
Date:	15 January–9 February 2022

Easting:	420094
Northing:	6592175.2
Spatial reference:	MGA Zone 56
Elevation (collar):	301.5 mAHD
Elevation (ground):	300.6 mAHD
Nominal diameter:	200 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 19.05 mbgl

Screened depth: 173.5–185.5 mbgl **Total depth:** 187 mbgl **Level date; time:** 10 February 2022; 12:00

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes	Bore design	RL (mAHD)
100	200 mm pneumatic hammer			Carrai Granodiorite	GRANODIORITE: Coarse grained, pale grey and dark grey, fresh, dry, 60% quartz, 25% biotite	∅	94 m: <1 L/sec, pH 11.18, SPC 547.5 µS/cm, Temp 19.9°C, Eh -8.7 mV		200
						∅	97 m: <0.5 L/sec, pH 8.17, SPC 472.2 µS/cm, Temp 20.4°C, Eh 127.9 mV		
					GRANODIORITE: Grey, pale orange and dark grey, ferruginous colouring, moderately to slightly weathered		100.5m: Potential fracture		
							103 m: Minor Potential fracture		
						∅	103 m: <0.7 L/sec, pH 9.27, SPC 451 µS/cm, Temp 21.3°C, Eh 90.7 mV		
					GRANODIORITE: Pale grey, dark grey, fresh				
					GRANODIORITE: Grey and dark grey, minor ferruginous colouring, slightly weathered				
						∅	109 m: <0.5 L/sec, pH 8.17, SPC 492 µS/cm, Temp 20.1°C, Eh 121.3 mV		
110					GRANODIORITE: Increasing feldspar, 60% quartz, 25% biotite, 15% feldspar				190
					GRANODIORITE: Grey, pale orange, dark grey, ferruginous colouring, slight to moderately weathered		112–113 m: Potential fracture		
							115 m: Potential fracture		
					GRANODIORITE: Grey and dark grey, minor ferruginous colouring, slightly weathered	∅	115 m: <0.5 L/sec, pH 8.28, SPC 489.6 µS/cm, Temp 20.3°C		
						∅	118–123 m: Potential fracture		
120						∅	121 m: <0.5 L/sec, pH 8.36, SPC 503.3 µS/cm, Temp 21.7°C		180
					GRANODIORITE: Grey to pale orange and dark grey, ferruginous colouring observed, slightly to		124–127 m: Potential fracture		

Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 8.14; SPC = 495 µs/cm; Temp = 20.7°C; ORP = 82.9 mV

Driller: Steffan Colls **Termination details:** Borehole terminated at target depth of 187 m.

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Monitoring bore

ID: MB02B

Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	QB AB
Date:	15 January–9 February 2022

Easting:	420094
Northing:	6592175.2
Spatial reference:	MGA Zone 56
Elevation (collar):	301.5 mAHD
Elevation (ground):	300.6 mAHD
Nominal diameter:	200 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 19.05 mbgl

Screened depth: 173.5–185.5 mbgl **Total depth:** 187 mbgl **Level date; time:** 10 February 2022; 12:00

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes	Bore design	RL (mAHD)
130	200 mm pneumatic hammer			Carrai Granodiorite	moderately weathered	∅	127 m: <0.6 L/sec, pH 8.32, SPC 498.2 µS/cm, Temp 21.8°C, Eh 108.9 mV		170
					GRANODIORITE: Pale grey and dark grey, very minor ferruginous staining, slightly weathered				
					GRANODIORITE: Pale grey and dark grey, fresh	∅	133 m: <0.9 L/sec, pH 8.20, SPC 500.5 µS/cm, Temp 22.3°C, Eh 102.2 mV		
					GRANODIORITE: Grey, pale orange, and dark grey, slightly to moderately weathered		135 m: Potential fracture		
140					GRANODIORITE: Grey and dark grey, minor ferruginous colouring, slightly weathered	∅	139 m: <0.7 L/sec, pH 8.38, SPC 502 µS/cm, Temp 22.1°C, Eh 67.0 mV		160
					GRANODIORITE: Pale grey and dark grey, fresh	∅	145 m: <0.7 L/sec, pH 8.39, SPC 511.2 µS/cm, Temp 23.0°C, Eh 96.2 mV		
150						∅	151 m: <0.7 L/sec, pH 8.47, SPC 526 µS/cm, Temp 23.0°C, Eh 68.5 mV		150
					GRANODIORITE: Grey and dark grey, minor ferruginous colouring, slightly weathered				
					GRANODIORITE: Pale grey and dark grey, fresh				

Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 8.14; SPC = 495 µs/cm; Temp = 20.7°C; ORP = 82.9 mV

Driller: Steffan Colls **Termination details:** Borehole terminated at target depth of 187 m.

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Monitoring bore

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Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	QB AB
Date:	15 January–9 February 2022

Easting:	420094
Northing:	6592175.2
Spatial reference:	MGA Zone 56
Elevation (collar):	301.5 mAHD
Elevation (ground):	300.6 mAHD
Nominal diameter:	200 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 19.05 mbgl

Screened depth: 173.5–185.5 mbgl **Total depth:** 187 mbgl **Level date; time:** 10 February 2022; 12:00

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes
	200 mm pneumatic hammer			Carrai Granodiorite		∅	157 m: <0.6 L/sec, pH 8.40, SPC 520 µS/cm, Temp 22.3°C, Eh 97.5 mV
						∅	163 m: <0.6 L/sec, pH 8.45, SPC 525 µS/cm, Temp 22.9°C, Eh 73.6 mV
					GRANODIORITE: Grey and dark grey, trace ferruginous colouring, slightly weathered	∅	169 m: <0.6 L/sec, pH 8.40, SPC 523 µS/cm, Temp 23.5°C, Eh 57.9 mV
					GRANODIORITE: Pale grey and dark grey, fresh	∅	175 m: <0.7 L/sec, pH 8.32, SPC 528 µS/cm, Temp 23.3°C, Eh 102.2 mV
					GRANODIORITE: Grey and dark grey, trace ferruginous colouring, slightly weathered	∅	181 m: <0.6 L/sec, pH 8.26, SPC 524 µS/cm, Temp 23.3°C, Eh 78.2 mV
					GRANODIORITE: Pale grey and dark grey, fresh		
					GRANODIORITE: Grey and dark grey, trace ferruginous colouring, slightly weathered		
					GRANODIORITE: Pale grey and dark grey, fresh	∅	187 m: <0.6 L/sec, pH 8.30, SPC 541 µS/cm, Temp 23.5°C, Eh 69.7 mV

Bore design

RL (mAHD): 160, 170, 180 (depth); 140, 130, 120 (RL)

Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 8.14; SPC = 495 µs/cm; Temp = 20.7°C; ORP = 82.9 mV

Driller: Steffan Colls **Termination details:** Borehole terminated at target depth of 187 m.

File path: MB02B.ldat8

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Monitoring bore

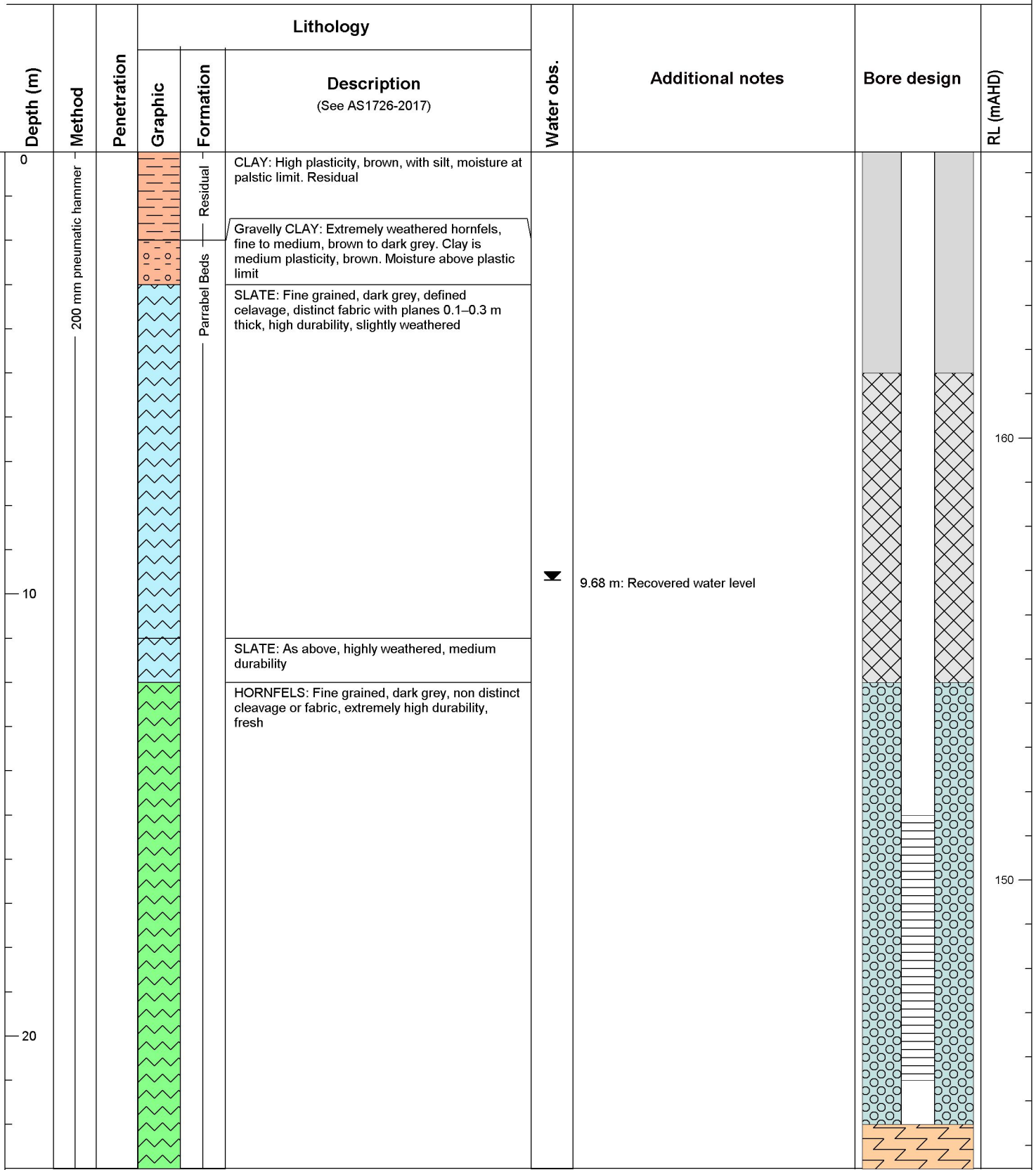
ID: MB03A

Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	JdB
Date:	20–21 March 2022

Easting:	418650.9
Northing:	6591232.3
Spatial reference:	MGA Zone 56
Elevation (collar):	167.3 mAHD
Elevation (ground):	166.5 mAHD
Nominal diameter:	200 mm

Screened lithology: Parrabel beds **Drilling method/s:** Pneumatic hammer **Water level depth:** 9.68 mbgl

Screened depth: 15–21 mbgl **Total depth:** 23 mbgl **Level date; time:** 20/3/2022



Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 8.39; SPC = 1166 µs/cm; Temp = 24.2°C; ORP = 70.4 mV

Driller: John Burns-Hind **Termination details:** Borehole termianted at target depth of 23 mbgl

File path: MB03A.ldat8

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Monitoring bore

ID: MB03B

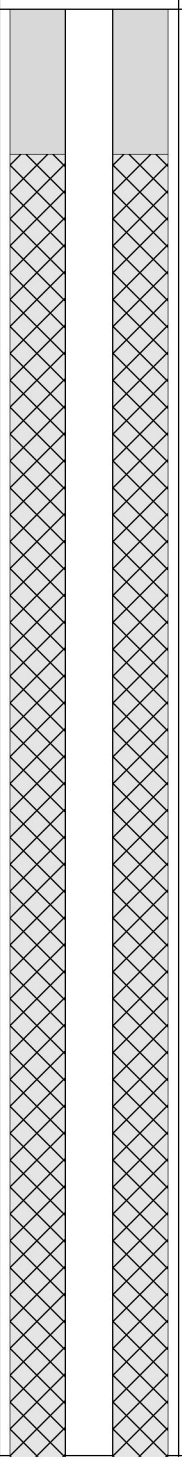
Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	JdB
Date:	22 February–20 March 2022

Easting:	418645.8
Northing:	6591223.6
Spatial reference:	MGA Zone 56
Elevation (collar):	167.8 mAHD
Elevation (ground):	167 mAHD
Nominal diameter:	200 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 10.63 mbgl

Screened depth: 86–98 mbgl **Total depth:** 100 mbgl **Level date; time:** 19/3/2022: 09:30

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes	Bore design	RL (mAHD)
0	200 mm pneumatic hammer			Parrabel Beds	CLAY: High plasticity, brown, with silt, moisture at palstic limit. Residual				
					Gravelly CLAY: Extremely weathered hornfels, fine to medium, brown to dark grey. Clay is medium plasticity, brown. Moisture above plastic limit				
					SLATE: Fine grained, dark grey, defined celavage, distinct fabric with planes 0.1–0.3 m thick, high durability, slightly weathered				
10					HORNFELS: Fine grained, dark grey, non distinct cleavage or fabric, extremely high durability, fresh	▼	10.63 m: Recovered water level		
							16–17 m: Potential quartz sill		
20					SLATE: Fine grained, dark grey, defined celavage, distinct fabric with planes 0.1–0.3 m thick, extremely high durability,fresh				
30					HORNFELS: Fine grained, dark grey, non distinct cleavage or fabric, extremely high durability, fresh		36–37 m: Aplitic intrusion, with pyrite, likely sill from nearby pluton		
40					SLATE: Fine grained, dark grey, defined celavage, distinct fabric with planes 0.1–0.3 m thick, extremely high durability,fresh				
50									



Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 8.43; SPC = 636 µs/cm; Temp = 22.1°C; ORP = 116.3 mV

Driller: John Burns-Hind **Termination details:** Borehole terminated at target depth of 100 m

File path: MB03B.ldat8

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St Leonards NSW 2065
(02) 9493 9589

Monitoring bore

ID: MB03B

Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	JdB
Date:	22 February–20 March 2022

Easting:	418645.8
Northing:	6591223.6
Spatial reference:	MGA Zone 56
Elevation (collar):	167.8 mAHD
Elevation (ground):	167 mAHD
Nominal diameter:	200 mm

Screened lithology: Carrai Granodiorite
Screened depth: 86–98 mbgl
Drilling method/s: Pneumatic hammer
Total depth: 100 mbgl
Water level depth: 10.63 mbgl
Level date; time: 19/3/2022: 09:30

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes	Bore design	RL (mAHD)
60	200 mm pneumatic hammer			Parrabel Beds	PHYLLITE: Fine grained, pale grey, banded foliation ~0.3 mm thick, extremely high durability, fresh				110
					PHYLLITE: As above, brownish dark grey, moderately weathered				
					PHYLLITE: As above , pale grey				
70					PHYLLITE: As above, brownish dark grey, moderately weathered				100
					PHYLLITE: As above , pale grey				
					HORNFELS: Fine grained, dark grey, non distinct cleavage or fabric, extremely high durability, fresh		74–78 m: Potential quartz sill, with pyrite		
80							83–85 m: Potential quartz sill, with pyrite		90
					PHYLLITE: Fine grained, pale grey, banded foliation ~0.3 mm thick, extremely high durability, fresh				
					HORNFELS: Fine grained, dark grey, non distinct cleavage or fabric, extremely high durability, fresh		88–89m: Potential quartz sill, with pyrite		80
90							93–97 m: Aplitic intrusion, with pyrite, likely sill from nearby pluton		
100									70

Company: Numac Drilling Services Pty Ltd
Driller: John Burns-Hind
Water quality: pH = 8.43; SPC = 636 µs/cm; Temp = 22.1°C; ORP = 116.3 mV
Termination details: Borehole terminated at target depth of 100 m

File path: MB03B.ldat8

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Monitoring bore

ID: MB04A

Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	HJN
Date:	29–31 January 2022

Easting:	423003.9
Northing:	6591263.9
Spatial reference:	MGA Zone 56
Elevation (collar):	972.7 mAHD
Elevation (ground):	972.1 mAHD
Nominal diameter:	125 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Tri cone **Water level depth:** 0.25 mbgl

Screened depth: 6.35 - 9.35 mbgl **Total depth:** 10.5 m **Level date; time:** 31 January 2022; 17:21

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes	Bore design	RL (mAHD)
0	Tri-cone with HWT string			Colluvium	SILTY SAND: Fine to medium grained, dark grey, subrounded, trace clay, wet. Colluvium		0.25 m: Recovered water level		
							1.4 m: 0.5 L/sec		970
				Residual	SAND: Medium to coarse grained, grey, angular, quartzose, with clay, pale grey, dry. Residual				
				Carrai Granodiorite	SAND: As above, wet				
	Shoe bit on PWT casing						6 m: 4 L/sec Casing method doesnt allow sampling		
10					SAND: Extremely weathered granodiorite; Sand, medium to coarse grained, pale grey, angular, 80% quartz, wet				

Company: Terratest Pty Ltd **Water quality:** pH = 5.93; SPC = 75.7 µs/cm; Temp = 21.6°C; ORP = 101.4 mV

Driller: Toby Osborne **Termination details:** Borehole terminated on competent rock at 10.5 m

File path: MB04A.ldat8

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Monitoring bore

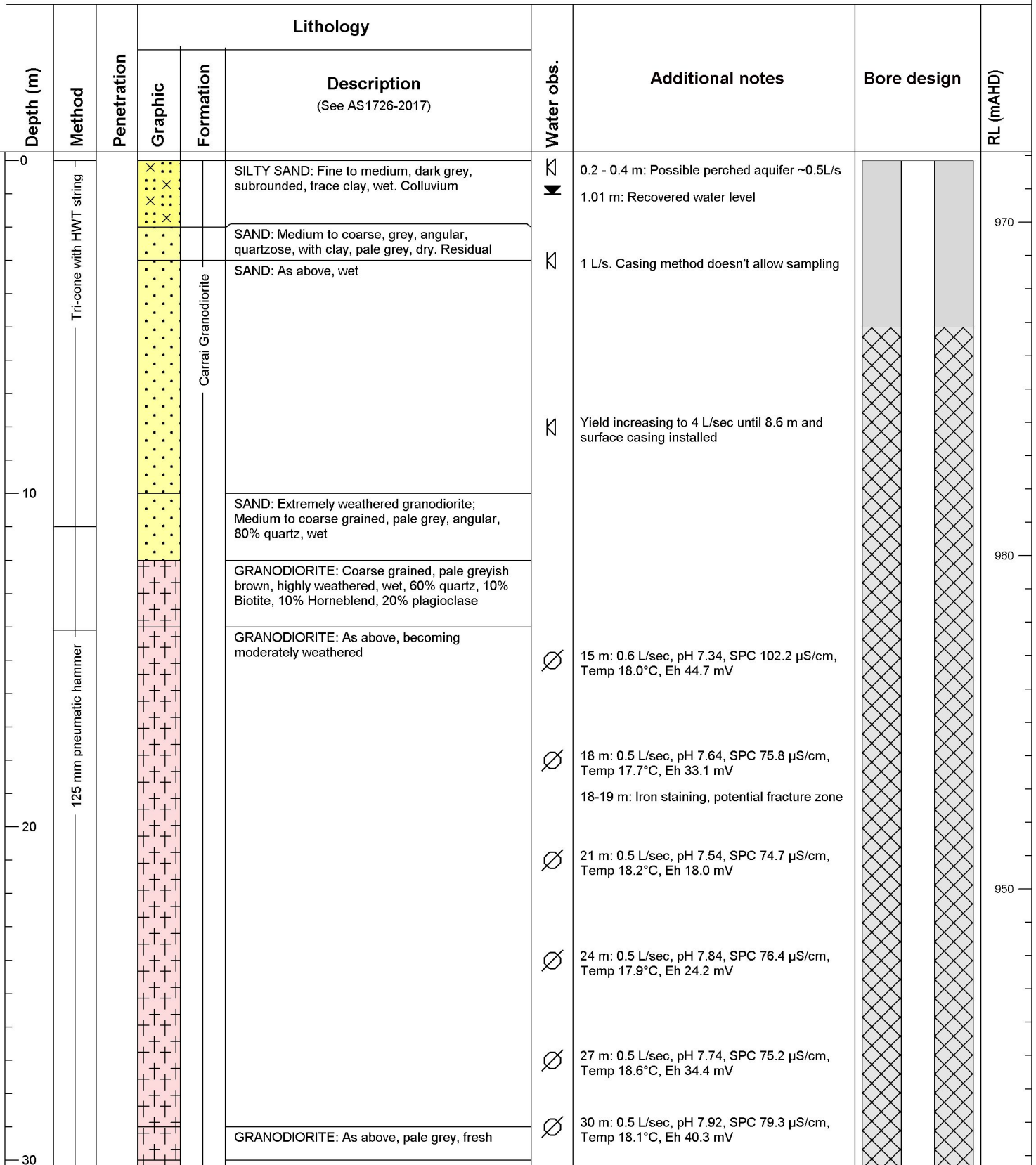
ID: MB04B

Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	HJN
Date:	29–31 January 2022

Easting:	422999.7
Northing:	6591259
Spatial reference:	MGA Zone 56
Elevation (collar):	972.5 mAHD
Elevation (ground):	971.9 mAHD
Nominal diameter:	125 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 1.01 mbgl

Screened depth: 46.7–58.7 mbgl **Total depth:** 60.5 mbgl **Level date; time:** 31 January 2022



Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 6.35; SPC = 171.2 µs/cm; Temp = 18.8°C; ORP = 17.2 mV

Driller: Toby Osborne **Termination details:** Borehole terminated at target depth of 60.5 m.

File path: MB04B.ldat8

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Monitoring bore

ID: MB04B

Project:	OMPS-Stage 1 hydrogeological drilling
Project ID:	E210769
Client:	SMEC Australia Pty Limited
Site:	Oven Mountain, Carrai, NSW
Logged by:	HJN
Date:	29–31 January 2022

Easting:	422999.7
Northing:	6591259
Spatial reference:	MGA Zone 56
Elevation (collar):	972.5 mAHD
Elevation (ground):	971.9 mAHD
Nominal diameter:	125 mm

Screened lithology: Carrai Granodiorite **Drilling method/s:** Pneumatic hammer **Water level depth:** 1.01 mbgl

Screened depth: 46.7–58.7 mbgl **Total depth:** 60.5 mbgl **Level date; time:** 31 January 2022

Depth (m)	Method	Penetration	Lithology: Graphic	Lithology: Formation	Lithology: Description (See AS1726-2017)	Water obs.	Additional notes	Bore design	RL (mAHD)
	125 mm pneumatic hammer			Carrai Granodiorite	GRANODIORITE: As above, slightly weathered	∅	33 m: 0.4 L/sec, pH 7.78, SPC 72.1 µS/cm, Temp 19.1°C, Eh 39.5 mV		940
						∅	36 m: 0.4 L/sec, pH 7.78, SPC 72.1 µS/cm, Temp 19.1°C, Eh 39.5 mV		
						∅	39 m: 2 L/sec, pH 7.46, SPC 110.8 µS/cm, Temp 18.8°C, Eh 44.4 mV		
40									
					GRANODIORITE: As above, fresh, pale green and pale grey	∅	42 m: 0.04 L/sec, pH 8.73, SPC 177.0 µS/cm, Temp 22.9°C, Eh 70.0 mV 42 m: Likely extremely high strength rock		930
					GRANODIORITE: As above, slightly weathered, pale orangey grey	∅	45 m: 0.03 L/sec, pH 8.63, SPC 112.6 µS/cm, Temp 23.7°C, Eh 67.0 mV 45-47 m: Iron staining, potential fracture zone		
					GRANODIORITE: As above	∅	48 m: 0.04 L/sec, pH 8.86, SPC 106.5 µS/cm, Temp 24.6°C, Eh 68.0 mV 49-50 m: Iron staining, potential fracture zone		
50						∅	51 m: 0.04 L/sec, pH 9.03, SPC 149.6 µS/cm, Temp 24.3°C, Eh 54.4 mV 51-54 m: easier drlling, iron staining, potential fracture zone		920
						∅	54 m: 0.05 L/sec, pH 8.73, SPC 148.6 µS/cm, Temp 25.5°C, Eh 31.5 mV		
						∅	57 m: 0.04 L/sec, pH 8.62, SPC 160.1 µS/cm, Temp 25.8°C, Eh 35.3 mV		
60									

Company: Numac Drilling Services Pty Ltd **Water quality:** pH = 6.35; SPC = 171.2 µs/cm; Temp = 18.8°C; ORP = 17.2 mV

Driller: Toby Osborne **Termination details:** Borehole terminated at target depth of 60.5 m.

File path: MB04B.ldat8

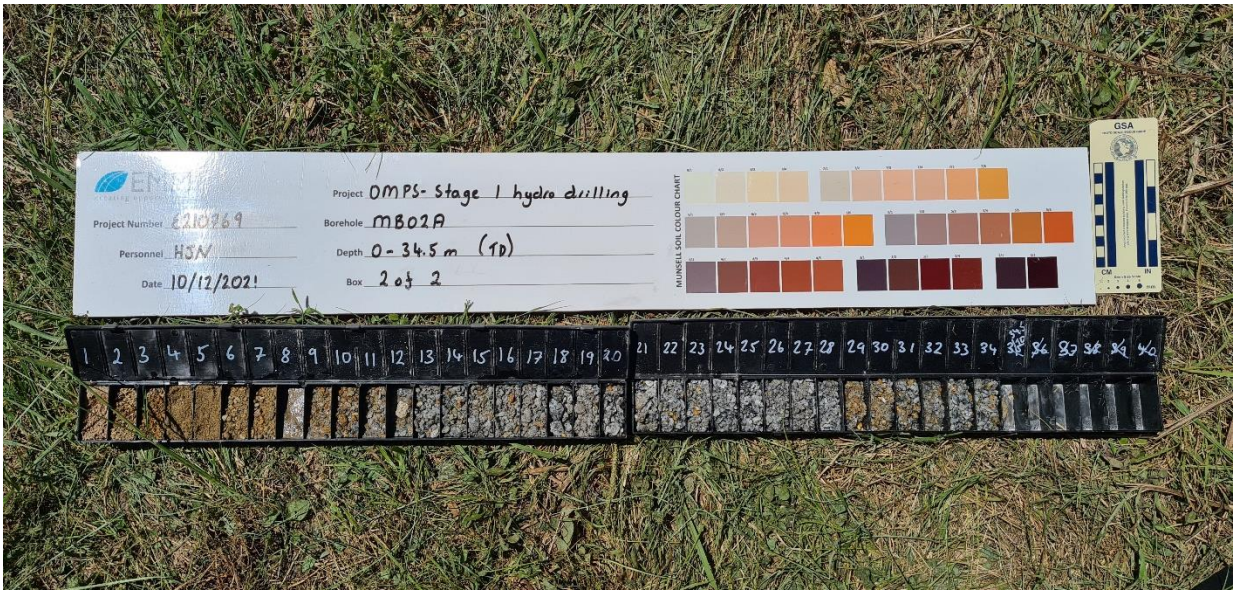
Appendix B
Photographic plates

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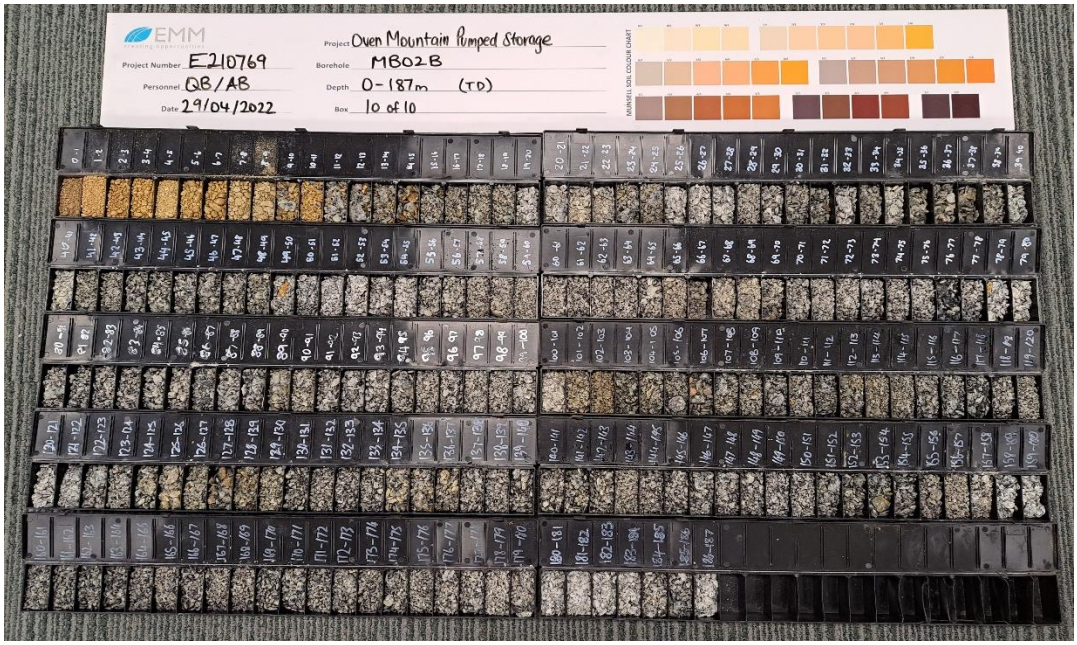
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MB01A chip trays from 0—36 m below ground level
21 October 2021
Oven Mountain Pumped Storage Project
Photograph B.1



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MB02A complete chip trays from 0—34 m below ground level
10 December 2021
Oven Mountain Pumped Storage Project
Photograph B.2



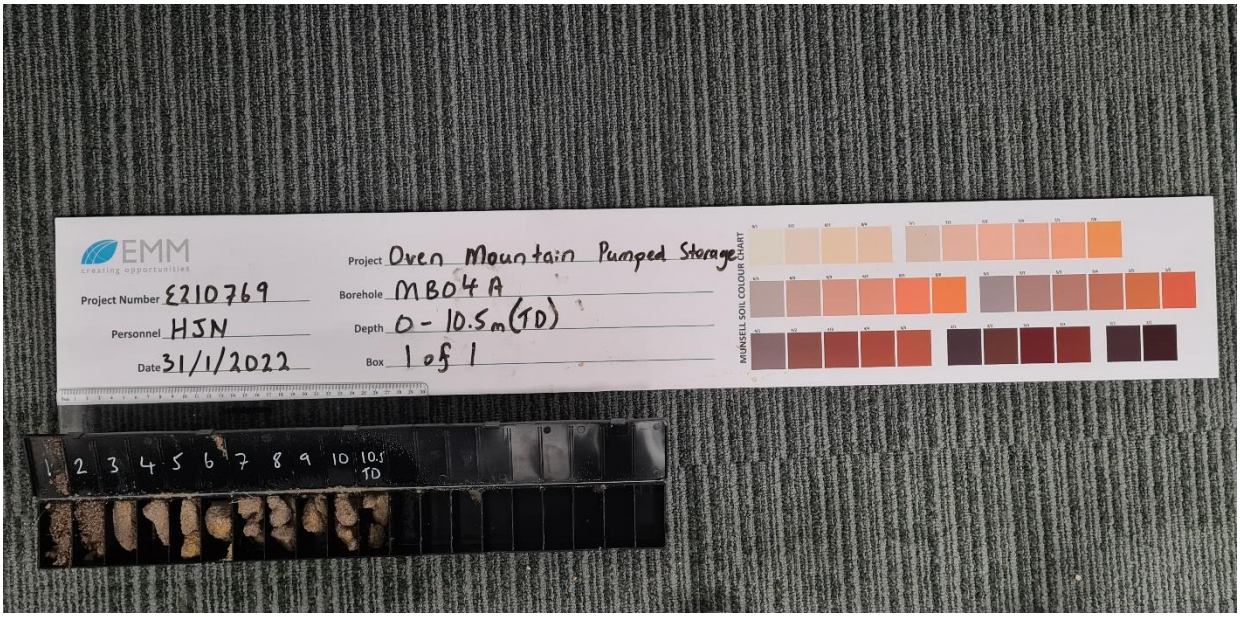
MB02B chip trays from 0—187 m below ground level
29 April 2022
Oven Mountain Pumped Storage Project
Photograph B.3



MB03A chip trays from 0—23 m below ground level
6 April 2022
Oven Mountain Pumped Storage Project
Photograph B.4



MB03B chip trays from 0—100 m below ground level
6 April 2022
Oven Mountain Pumped Storage Project
Photograph B.5



MB04A chip trays from 0—10 m below ground level
6 April 2022
Oven Mountain Pumped Storage Project
Photograph B.6



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MB04B chip trays from 0—60 m below ground level
6 April 2022
Oven Mountain Pumped Storage Project
Photograph B.7

Appendix C
Laboratory certificates of analysis

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ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **ES2138245**	Page	: 1 of 6
Client	: **EMM CONSULTING PTY LTD**	Laboratory	: Environmental Division Sydney
Contact	: HENRY NOAKES	Contact	: Sepan Mahamad
Address	: Ground Floor Suite 1 20 Chandos Street St Leonards NSW NSW 2065	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: ----	Telephone	: +61 2 8784 8555
Project	: E210769 OMPS-Stage 1 Hydrogeological drilling/Testing	Date Samples Received	: 22-Oct-2021 14:00
Order number	: E210769	Date Analysis Commenced	: 23-Oct-2021
C-O-C number	: ----	Issue Date	: 28-Oct-2021 13:56
Sampler	: HENRY NOAKES		
Site	: ----		
Quote number	: EN/112/20 Primary work		
No. of samples received	: 1		
No. of samples analysed	: 1		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted, unless the sampling was conducted by ALS. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ashesh Patel	Senior Chemist	Sydney Inorganics, Smithfield, NSW
Edwandy Fadjar	Organic Coordinator	Sydney Organics, Smithfield, NSW
Ivan Taylor	Analyst	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EP080: Where reported, Total Xylenes is the sum of the reported concentrations of m&p-Xylene and o-Xylene at or above the LOR.
- EA016: Calculated TDS is determined from Electrical conductivity using a conversion factor of 0.65.
- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	MB01A	----	----	----	----
			Sampling date / time	21-Oct-2021 00:00	----	----	----	----
Compound	CAS Number	LOR	Unit	ES2138245-001	--------	--------	--------	--------
				Result	----	----	----	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**7.40**	----	----	----	----
EA006: Sodium Adsorption Ratio (SAR)								
^ Sodium Adsorption Ratio	----	0.01	-	**3.34**	----	----	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**698**	----	----	----	----
EA016: Calculated TDS (from Electrical Conductivity)								
Total Dissolved Solids (Calc.)	----	1	mg/L	**454**	----	----	----	----
EA065: Total Hardness as CaCO3								
Total Hardness as CaCO3	----	1	mg/L	**163**	----	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	----	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	----	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**305**	----	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**305**	----	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**26**	----	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**43**	----	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**47**	----	----	----	----
Magnesium	7439-95-4	1	mg/L	**11**	----	----	----	----
Sodium	7440-23-5	1	mg/L	**98**	----	----	----	----
Potassium	7440-09-7	1	mg/L	**5**	----	----	----	----
EG005(ED093)F: Dissolved Metals by ICP-AES								
Aluminium	7429-90-5	0.10	mg/L	<0.10	----	----	----	----
Antimony	7440-36-0	0.01	mg/L	**0.02**	----	----	----	----
Arsenic	7440-38-2	0.01	mg/L	**0.04**	----	----	----	----
Cadmium	7440-43-9	0.005	mg/L	<0.005	----	----	----	----
Chromium	7440-47-3	0.01	mg/L	<0.01	----	----	----	----
Copper	7440-50-8	0.01	mg/L	<0.01	----	----	----	----
Iron	7439-89-6	0.05	mg/L	<0.05	----	----	----	----
Lead	7439-92-1	0.01	mg/L	<0.01	----	----	----	----
Manganese	7439-96-5	0.01	mg/L	**0.13**	----	----	----	----
Nickel	7440-02-0	0.01	mg/L	<0.01	----	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Sample ID	MB01A	----	----	----	----
				Sampling date / time	21-Oct-2021 00:00	----	----	----	----
Compound	CAS Number	LOR	Unit		ES2138245-001	--------	--------	--------	--------
					Result	----	----	----	----
EG005(ED093)F: Dissolved Metals by ICP-AES - Continued									
Zinc	7440-66-6	0.01	mg/L		**0.05**	----	----	----	----
EG035F: Dissolved Mercury by FIMS									
Mercury	7439-97-6	0.0001	mg/L		<0.0001	----	----	----	----
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.8**	----	----	----	----
EK055G: Ammonia as N by Discrete Analyser									
Ammonia as N	7664-41-7	0.01	mg/L		**0.02**	----	----	----	----
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N	14797-65-0	0.01	mg/L		<0.01	----	----	----	----
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N	14797-55-8	0.01	mg/L		**0.30**	----	----	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N	----	0.01	mg/L		**0.30**	----	----	----	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	0.1	mg/L		**0.4**	----	----	----	----
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser									
^ **Total Nitrogen as N**	----	0.1	mg/L		**0.7**	----	----	----	----
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	0.01	mg/L		**0.06**	----	----	----	----
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.01	mg/L		<0.01	----	----	----	----
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**7.85**	----	----	----	----
ø **Total Cations**	----	0.01	meq/L		**7.64**	----	----	----	----
ø **Ionic Balance**	----	0.01	%		**1.34**	----	----	----	----
EP080/071: Total Petroleum Hydrocarbons									
C6 - C9 Fraction	----	20	µg/L		<20	----	----	----	----
C10 - C14 Fraction	----	50	µg/L		<50	----	----	----	----
C15 - C28 Fraction	----	100	µg/L		**190**	----	----	----	----
C29 - C36 Fraction	----	50	µg/L		**80**	----	----	----	----
^ **C10 - C36 Fraction (sum)**	----	50	µg/L		**270**	----	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions									
C6 - C10 Fraction	C6_C10	20	µg/L		<20	----	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	MB01A	----	----	----	----
			Sampling date / time	21-Oct-2021 00:00	----	----	----	----
Compound	CAS Number	LOR	Unit	ES2138245-001	--------	--------	--------	--------
				Result	----	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions - Continued								
^ **C6 - C10 Fraction minus BTEX (F1)**	C6_C10-BTEX	20	µg/L	<20	----	----	----	----
>C10 - C16 Fraction	----	100	µg/L	<100	----	----	----	----
>C16 - C34 Fraction	----	100	µg/L	**230**	----	----	----	----
>C34 - C40 Fraction	----	100	µg/L	<100	----	----	----	----
^ **>C10 - C40 Fraction (sum)**	----	100	µg/L	**230**	----	----	----	----
^ **>C10 - C16 Fraction minus Naphthalene (F2)**	----	100	µg/L	<100	----	----	----	----
EP080: BTEXN								
Benzene	71-43-2	1	µg/L	<1	----	----	----	----
Toluene	108-88-3	2	µg/L	<2	----	----	----	----
Ethylbenzene	100-41-4	2	µg/L	<2	----	----	----	----
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	----	----	----	----
ortho-Xylene	95-47-6	2	µg/L	<2	----	----	----	----
^ **Total Xylenes**	----	2	µg/L	<2	----	----	----	----
^ **Sum of BTEX**	----	1	µg/L	<1	----	----	----	----
Naphthalene	91-20-3	5	µg/L	<5	----	----	----	----
EP080S: TPH(V)/BTEX Surrogates								
1.2-Dichloroethane-D4	17060-07-0	2	%	**98.0**	----	----	----	----
Toluene-D8	2037-26-5	2	%	**97.5**	----	----	----	----
4-Bromofluorobenzene	460-00-4	2	%	**96.2**	----	----	----	----

Surrogate Control Limits

Sub-Matrix: **WATER**		Recovery Limits (%)	
Compound	*CAS Number*	*Low*	*High*
EP080S: TPH(V)/BTEX Surrogates			
1.2-Dichloroethane-D4	17060-07-0	71	137
Toluene-D8	2037-26-5	79	131
4-Bromofluorobenzene	460-00-4	70	128

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **ES2146435**	Page	: 1 of 6
Client	: **EMM CONSULTING PTY LTD**	Laboratory	: Environmental Division Sydney
Contact	: HENRY NOAKES	Contact	: Sepan Mahamad
Address	: Ground Floor Suite 1 20 Chandos Street St Leonards NSW NSW 2065	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: ----	Telephone	: +61 2 8784 8555
Project	: J200096 Oven Mountain Pumped Storage Project	Date Samples Received	: 17-Dec-2021 17:00
Order number	: J200096	Date Analysis Commenced	: 17-Dec-2021
C-O-C number	: ----	Issue Date	: 24-Dec-2021 15:22
Sampler	: ----		
Site	: ----		
Quote number	: EN/112/21		
No. of samples received	: 4		
No. of samples analysed	: 4		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

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This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW
Edwandy Fadjar	Organic Coordinator	Sydney Organics, Smithfield, NSW
Ivan Taylor	Analyst	Sydney Inorganics, Smithfield, NSW
Wisam Marassa	Inorganics Coordinator	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EP080: Where reported, Total Xylenes is the sum of the reported concentrations of m&p-Xylene and o-Xylene at or above the LOR.
- EK040: Poor spike recovery for Fluoride, however insuffiicent sample amount for reanalysis.
- EA016: Calculated TDS is determined from Electrical conductivity using a conversion factor of 0.65.
- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	MB02A				
			Sampling date / time	15-Dec-2021 00:00				
Compound	CAS Number	LOR	Unit	ES2146435-001				
				Result				
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**7.38**				
EA006: Sodium Adsorption Ratio (SAR)								
^ **Sodium Adsorption Ratio**	----	0.01	-	**1.92**				
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**825**				
EA016: Calculated TDS (from Electrical Conductivity)								
Total Dissolved Solids (Calc.)	----	1	mg/L	**536**				
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**----**				
EA045: Turbidity								
Turbidity	----	0.1	NTU	**----**				
EA065: Total Hardness as CaCO3								
Total Hardness as CaCO3	----	1	mg/L	**257**				
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1				
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1				
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**132**				
Total Alkalinity as CaCO3	----	1	mg/L	**132**				
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**254**				
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**39**				
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**80**				
Magnesium	7439-95-4	1	mg/L	**14**				
Sodium	7440-23-5	1	mg/L	**71**				
Potassium	7440-09-7	1	mg/L	**6**				
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	**0.02**				
Antimony	7440-36-0	0.001	mg/L	**0.008**				
Arsenic	7440-38-2	0.001	mg/L	**0.001**				
Cadmium	7440-43-9	0.0001	mg/L	<0.0001				
Chromium	7440-47-3	0.001	mg/L	<0.001				

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	MB02A				
			Sampling date / time	15-Dec-2021 00:00				
Compound	CAS Number	LOR	Unit	ES2146435-001				
				Result				
EG020F: Dissolved Metals by ICP-MS - Continued								
Copper	7440-50-8	0.001	mg/L	**0.001**				
Nickel	7440-02-0	0.001	mg/L	**0.009**				
Lead	7439-92-1	0.001	mg/L	<0.001				
Zinc	7440-66-6	0.005	mg/L	**0.024**				
Manganese	7439-96-5	0.001	mg/L	**0.248**				
Iron	7439-89-6	0.05	mg/L	<0.05				
EG035F: Dissolved Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001				
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	0.1	mg/L	**0.5**				
EK055G: Ammonia as N by Discrete Analyser								
Ammonia as N	7664-41-7	0.01	mg/L	<0.01				
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N	14797-65-0	0.01	mg/L	<0.01				
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N	14797-55-8	0.01	mg/L	**0.03**				
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.03**				
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**0.8**				
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser								
^ **Total Nitrogen as N**	----	0.1	mg/L	**0.8**				
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.08**				
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	14265-44-2	0.01	mg/L	<0.01				
EN055: Ionic Balance								
ø **Total Anions**	----	0.01	meq/L	**9.02**				
ø **Total Cations**	----	0.01	meq/L	**8.39**				
ø **Ionic Balance**	----	0.01	%	**3.67**				
EP080/071: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	20	µg/L	<20				
C10 - C14 Fraction	----	50	µg/L	<50				

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Sample ID	MB02A				
				Sampling date / time	15-Dec-2021 00:00				
Compound	CAS Number	LOR	Unit	ES2146435-001					
				Result					
EP080/071: Total Petroleum Hydrocarbons - Continued									
C15 - C28 Fraction	----	100	µg/L	<100					
C29 - C36 Fraction	----	50	µg/L	<50					
^ C10 - C36 Fraction (sum)	----	50	µg/L	<50					
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions									
C6 - C10 Fraction	C6_C10	20	µg/L	<20					
^ C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	20	µg/L	<20					
>C10 - C16 Fraction	----	100	µg/L	<100					
>C16 - C34 Fraction	----	100	µg/L	<100					
>C34 - C40 Fraction	----	100	µg/L	<100					
^ >C10 - C40 Fraction (sum)	----	100	µg/L	<100					
^ >C10 - C16 Fraction minus Naphthalene (F2)	----	100	µg/L	<100					
EP080: BTEXN									
Benzene	71-43-2	1	µg/L	<1					
Toluene	108-88-3	2	µg/L	<2					
Ethylbenzene	100-41-4	2	µg/L	<2					
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2					
ortho-Xylene	95-47-6	2	µg/L	<2					
^ Total Xylenes	----	2	µg/L	<2					
^ Sum of BTEX	----	1	µg/L	<1					
Naphthalene	91-20-3	5	µg/L	<5					
EP080S: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	2	%	**83.9**					
Toluene-D8	2037-26-5	2	%	**116**					
4-Bromofluorobenzene	460-00-4	2	%	**114**					

Surrogate Control Limits

Sub-Matrix: **WATER**		Recovery Limits (%)	
Compound	*CAS Number*	*Low*	*High*
EP080S: TPH(V)/BTEX Surrogates			
1.2-Dichloroethane-D4	17060-07-0	71	137
Toluene-D8	2037-26-5	79	131
4-Bromofluorobenzene	460-00-4	70	128

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **ES2205754**	Page	: 1 of 19
Client	: **EMM CONSULTING PTY LTD**	Laboratory	: Environmental Division Sydney
Contact	: HENRY NOAKES	Contact	: Sepan Mahamad
Address	: Ground Floor Suite 1 20 Chandos Street St Leonards NSW NSW 2065	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: ----	Telephone	: +61 2 8784 8555
Project	: J200096 Oven Mountain pumpe Storage Project	Date Samples Received	: 18-Feb-2022 12:30
Order number	: J200096	Date Analysis Commenced	: 19-Feb-2022
C-O-C number	: ----	Issue Date	: 25-Feb-2022 19:21
Sampler	: AB/JT		
Site	: ----		
Quote number	: EN/112/21		
No. of samples received	: 23		
No. of samples analysed	: 23		

Accreditation No. 825
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Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW
Edwandy Fadjar	Organic Coordinator	Sydney Organics, Smithfield, NSW
Ivan Taylor	Analyst	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EG035: LOR raised for Mercury due to sample matrix (High TSS).
- EP080: Where reported, Total Xylenes is the sum of the reported concentrations of m&p-Xylene and o-Xylene at or above the LOR.
- EK057G:LOR raised due to sample matrix.
- ED041G:LOR raised due to sample matrix.
- EK059G:LOR rasised due to sample matrix.
- EN055: Ionic Balance out of acceptable limits for sample ES2205754-#021 due to analytes not quantified in this report.
- EP080: Sample TRIP SPIKE contains volatile compounds spiked into the sample containers prior to dispatch from the laboratory. BTEXN compounds spiked at 20 ug/L.
- EA016: Calculated TDS is determined from Electrical conductivity using a conversion factor of 0.65.
- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	MB02B				
			Sampling date / time	16-Feb-2022 00:00				
Compound	CAS Number	LOR	Unit	ES2205754-010				
				Result				
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**7.36**				
EA006: Sodium Adsorption Ratio (SAR)								
^ **Sodium Adsorption Ratio**	----	0.01	-	**2.41**				
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**694**				
EA016: Calculated TDS (from Electrical Conductivity)								
Total Dissolved Solids (Calc.)	----	1	mg/L	**451**				
EA065: Total Hardness as CaCO3								
Total Hardness as CaCO3	----	1	mg/L	**208**				
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1				
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1				
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**228**				
Total Alkalinity as CaCO3	----	1	mg/L	**228**				
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**99**				
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**35**				
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**62**				
Magnesium	7439-95-4	1	mg/L	**13**				
Sodium	7440-23-5	1	mg/L	**80**				
Potassium	7440-09-7	1	mg/L	**4**				
EG005(ED093)F: Dissolved Metals by ICP-AES								
Aluminium	7429-90-5	0.10	mg/L	<0.10				
Antimony	7440-36-0	0.01	mg/L	<0.01				
Arsenic	7440-38-2	0.01	mg/L	<0.01				
Cadmium	7440-43-9	0.005	mg/L	<0.005				
Chromium	7440-47-3	0.01	mg/L	<0.01				
Copper	7440-50-8	0.01	mg/L	<0.01				
Iron	7439-89-6	0.05	mg/L	**0.05**				
Lead	7439-92-1	0.01	mg/L	<0.01				
Manganese	7439-96-5	0.01	mg/L	**0.16**				
Nickel	7440-02-0	0.01	mg/L	<0.01				

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Sample ID	MB02B				
				Sampling date / time	16-Feb-2022 00:00				
Compound	CAS Number	LOR	Unit		ES2205754-010				
					Result				
EG005(ED093)F: Dissolved Metals by ICP-AES - Continued									
Zinc	7440-66-6	0.01	mg/L		**0.04**				
EG035F: Dissolved Mercury by FIMS									
Mercury	7439-97-6	0.0001	mg/L		<0.0001				
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**1.2**				
EK055G: Ammonia as N by Discrete Analyser									
Ammonia as N	7664-41-7	0.01	mg/L		<0.01				
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N	14797-65-0	0.01	mg/L		<0.01				
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N	14797-55-8	0.01	mg/L		<0.01				
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N	----	0.01	mg/L		<0.01				
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	0.1	mg/L		**0.6**				
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser									
^ **Total Nitrogen as N**	----	0.1	mg/L		**0.6**				
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	0.01	mg/L		**0.12**				
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.01	mg/L		<0.01				
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**7.60**				
ø **Total Cations**	----	0.01	meq/L		**7.74**				
ø **Ionic Balance**	----	0.01	%		**0.92**				
EP080/071: Total Petroleum Hydrocarbons									
C6 - C9 Fraction	----	20	µg/L		<20				
C10 - C14 Fraction	----	50	µg/L		<50				
C15 - C28 Fraction	----	100	µg/L		<100				
C29 - C36 Fraction	----	50	µg/L		<50				
^ **C10 - C36 Fraction (sum)**	----	50	µg/L		<50				
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions									
C6 - C10 Fraction	C6_C10	20	µg/L		<20				

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Sample ID	MB02B				
				Sampling date / time	16-Feb-2022 00:00				
Compound	CAS Number	LOR	Unit	ES2205754-010					
				Result					
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions - Continued									
^ **C6 - C10 Fraction minus BTEX (F1)**	C6_C10-BTEX	20	µg/L	<20					
>C10 - C16 Fraction	----	100	µg/L	<100					
>C16 - C34 Fraction	----	100	µg/L	<100					
>C34 - C40 Fraction	----	100	µg/L	<100					
^ **>C10 - C40 Fraction (sum)**	----	100	µg/L	<100					
^ **>C10 - C16 Fraction minus Naphthalene (F2)**	----	100	µg/L	<100					
EP080: BTEXN									
Benzene	71-43-2	1	µg/L	<1					
Toluene	108-88-3	2	µg/L	<2					
Ethylbenzene	100-41-4	2	µg/L	<2					
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2					
ortho-Xylene	95-47-6	2	µg/L	<2					
^ **Total Xylenes**	----	2	µg/L	<2					
^ **Sum of BTEX**	----	1	µg/L	<1					
Naphthalene	91-20-3	5	µg/L	<5					
EP080S: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	2	%	**133**					
Toluene-D8	2037-26-5	2	%	**129**					
4-Bromofluorobenzene	460-00-4	2	%	**116**					

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **ES2203887**	Page	: 1 of 6
Client	: **EMM CONSULTING PTY LTD**	Laboratory	: Environmental Division Sydney
Contact	: HENRY NOAKES	Contact	: Sepan Mahamad
Address	: Ground Floor Suite 1 20 Chandos Street St Leonards NSW NSW 2065	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: ----	Telephone	: +61 2 8784 8555
Project	: E210769 OMPS-Stage 1 Hydrogeological drilling/Testing	Date Samples Received	: 04-Feb-2022 14:50
Order number	: E210769	Date Analysis Commenced	: 07-Feb-2022
C-O-C number	: ----	Issue Date	: 10-Feb-2022 16:32
Sampler	: ----		
Site	: ----		
Quote number	: EN/112/21		
No. of samples received	: 2		
No. of samples analysed	: 2		

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Edwandy Fadjar	Organic Coordinator	Sydney Organics, Smithfield, NSW
Wisam Marassa	Inorganics Coordinator	Sydney Inorganics, Smithfield, NSW

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^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EP080: Where reported, Total Xylenes is the sum of the reported concentrations of m&p-Xylene and o-Xylene at or above the LOR.
- EP080: Positive result for ES2203887-02 has been confirmed by re-analysis.
- LOR raised due to sample matrix.
- EA016: Calculated TDS is determined from Electrical conductivity using a conversion factor of 0.65.
- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	MB04A	MB04B	----	----	----
			Sampling date / time	31-Jan-2022 18:00	31-Jan-2022 17:30	----	----	----
Compound	CAS Number	LOR	Unit	ES2203887-001	ES2203887-002	--------	--------	--------
				Result	Result	----	----	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**6.02**	**6.34**	----	----	----
EA006: Sodium Adsorption Ratio (SAR)								
^ Sodium Adsorption Ratio	----	0.01	-	**2.44**	**1.62**	----	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**120**	**157**	----	----	----
EA016: Calculated TDS (from Electrical Conductivity)								
Total Dissolved Solids (Calc.)	----	1	mg/L	**78**	**102**	----	----	----
EA065: Total Hardness as CaCO3								
Total Hardness as CaCO3	----	1	mg/L	**2**	**38**	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**39**	**98**	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**39**	**98**	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**2**	**2**	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**10**	**7**	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**1**	**12**	----	----	----
Magnesium	7439-95-4	1	mg/L	<1	**2**	----	----	----
Sodium	7440-23-5	1	mg/L	**12**	**23**	----	----	----
Potassium	7440-09-7	1	mg/L	**2**	**2**	----	----	----
EG005(ED093)F: Dissolved Metals by ICP-AES								
Aluminium	7429-90-5	0.10	mg/L	**2.45**	<0.10	----	----	----
Antimony	7440-36-0	0.01	mg/L	<0.01	<0.01	----	----	----
Arsenic	7440-38-2	0.01	mg/L	<0.01	<0.01	----	----	----
Cadmium	7440-43-9	0.005	mg/L	<0.005	<0.005	----	----	----
Chromium	7440-47-3	0.01	mg/L	<0.01	<0.01	----	----	----
Copper	7440-50-8	0.01	mg/L	<0.01	<0.01	----	----	----
Iron	7439-89-6	0.05	mg/L	**0.38**	**1.54**	----	----	----
Lead	7439-92-1	0.01	mg/L	<0.01	<0.01	----	----	----
Manganese	7439-96-5	0.01	mg/L	<0.01	**0.10**	----	----	----
Nickel	7440-02-0	0.01	mg/L	<0.01	**0.01**	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	MB04A	MB04B	----	----	----
			Sampling date / time	31-Jan-2022 18:00	31-Jan-2022 17:30	----	----	----
Compound	CAS Number	LOR	Unit	ES2203887-001	ES2203887-002	--------	--------	--------
				Result	Result	----	----	----
EG005(ED093)F: Dissolved Metals by ICP-AES - Continued								
Zinc	7440-66-6	0.01	mg/L	**0.03**	**0.07**	----	----	----
EG035F: Dissolved Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	----	----	----
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	0.1	mg/L	<0.1	<0.1	----	----	----
EK055G: Ammonia as N by Discrete Analyser								
Ammonia as N	7664-41-7	0.01	mg/L	<0.01	**0.02**	----	----	----
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N	14797-65-0	0.01	mg/L	<0.01	<0.01	----	----	----
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N	14797-55-8	0.01	mg/L	**0.25**	**0.55**	----	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.25**	**0.55**	----	----	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**1.7**	<0.2	----	----	----
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser								
^ **Total Nitrogen as N**	----	0.1	mg/L	**2.0**	**0.6**	----	----	----
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.65**	**0.23**	----	----	----
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	14265-44-2	0.01	mg/L	<0.01	<0.01	----	----	----
EN055: Ionic Balance								
ø **Total Anions**	----	0.01	meq/L	**1.10**	**2.20**	----	----	----
ø **Total Cations**	----	0.01	meq/L	**1.04**	**1.94**	----	----	----
EP080/071: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	20	µg/L	<20	<20	----	----	----
C10 - C14 Fraction	----	50	µg/L	----	<50	----	----	----
C15 - C28 Fraction	----	100	µg/L	----	<100	----	----	----
C29 - C36 Fraction	----	50	µg/L	----	<50	----	----	----
^ **C10 - C36 Fraction (sum)**	----	50	µg/L	----	<50	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
C6 - C10 Fraction	C6_C10	20	µg/L	<20	<20	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	MB04A	MB04B	----	----	----
			Sampling date / time	31-Jan-2022 18:00	31-Jan-2022 17:30	----	----	----
Compound	CAS Number	LOR	Unit	ES2203887-001	ES2203887-002	--------	--------	--------
				Result	Result	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions - Continued								
^ **C6 - C10 Fraction minus BTEX (F1)**	C6_C10-BTEX	20	µg/L	<20	<20	----	----	----
>C10 - C16 Fraction	----	100	µg/L	----	<100	----	----	----
>C16 - C34 Fraction	----	100	µg/L	----	<100	----	----	----
>C34 - C40 Fraction	----	100	µg/L	----	<100	----	----	----
^ **>C10 - C40 Fraction (sum)**	----	100	µg/L	----	<100	----	----	----
^ **>C10 - C16 Fraction minus Naphthalene (F2)**	----	100	µg/L	----	<100	----	----	----
EP080: BTEXN								
Benzene	71-43-2	1	µg/L	<1	<1	----	----	----
Toluene	108-88-3	2	µg/L	<2	**2**	----	----	----
Ethylbenzene	100-41-4	2	µg/L	<2	<2	----	----	----
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	<2	----	----	----
ortho-Xylene	95-47-6	2	µg/L	<2	<2	----	----	----
^ **Total Xylenes**	----	2	µg/L	<2	<2	----	----	----
^ **Sum of BTEX**	----	1	µg/L	<1	**2**	----	----	----
Naphthalene	91-20-3	5	µg/L	<5	<5	----	----	----
EP080S: TPH(V)/BTEX Surrogates								
1.2-Dichloroethane-D4	17060-07-0	2	%	**109**	**113**	----	----	----
Toluene-D8	2037-26-5	2	%	**105**	**105**	----	----	----
4-Bromofluorobenzene	460-00-4	2	%	**98.2**	**96.7**	----	----	----

Surrogate Control Limits

Sub-Matrix: **WATER**		Recovery Limits (%)	
Compound	*CAS Number*	*Low*	*High*
EP080S: TPH(V)/BTEX Surrogates			
1.2-Dichloroethane-D4	17060-07-0	71	137
Toluene-D8	2037-26-5	79	131
4-Bromofluorobenzene	460-00-4	70	128

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **ES2146443**	Page	: 1 of 10
Client	: **EMM CONSULTING PTY LTD**	Laboratory	: Environmental Division Sydney
Contact	: HENRY NOAKES	Contact	: Sepan Mahamad
Address	: Ground Floor Suite 1 20 Chandos Street St Leonards NSW NSW 2065	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: ----	Telephone	: +61 2 8784 8555
Project	: J200096 Oven Mountain Pumped Storage Project	Date Samples Received	: 17-Dec-2021 17:00
Order number	: J200096	Date Analysis Commenced	: 18-Dec-2021
C-O-C number	: ----	Issue Date	: 30-Dec-2021 12:12
Sampler	: ----		
Site	: ----		
Quote number	: EN/112/21		
No. of samples received	: 12		
No. of samples analysed	: 12		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted, unless the sampling was conducted by ALS. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW
Edwandy Fadjar	Organic Coordinator	Sydney Organics, Smithfield, NSW
Ivan Taylor	Analyst	Sydney Inorganics, Smithfield, NSW
Wisam Marassa	Inorganics Coordinator	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EK055G: LOR raised for Ammonia 9 due to sample matrix.
- EP080: Where reported, Total Xylenes is the sum of the reported concentrations of m&p-Xylene and o-Xylene at or above the LOR.
- EG020A-F: Positive results for sample ES2146443-011 have been confirmed by re-analysis.
- EK057G:LOR raised due to sample matrix.
- ED041G: LOR raised for Sulfate due to sample matrix
- EP080: Sample TRIP SPIKE contains volatile compounds spiked into the sample containers prior to dispatch from the laboratory. BTEXN compounds spiked at 20 ug/L.
- EA016: Calculated TDS is determined from Electrical conductivity using a conversion factor of 0.65.
- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	---- OM1	---- OM2	---- OM3	---- OM4	---- OM5
			Sampling date / time	16-Dec-2021 00:00	16-Dec-2021 00:00	16-Dec-2021 00:00	16-Dec-2021 00:00	16-Dec-2021 00:00
Compound	CAS Number	LOR	Unit	ES2146443-001	ES2146443-002	ES2146443-003	ES2146443-004	ES2146443-005
				Result	Result	Result	Result	Result
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	5.23	5.49	6.57	6.01	5.59
EA006: Sodium Adsorption Ratio (SAR)								
^ Sodium Adsorption Ratio	----	0.01	-	1.00	0.90	0.84	1.44	1.44
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	386	158	266	77	38
EA016: Calculated TDS (from Electrical Conductivity)								
Total Dissolved Solids (Calc.)	----	1	mg/L	251	103	173	50	25
EA065: Total Hardness as CaCO3								
Total Hardness as CaCO3	----	1	mg/L	101	40	96	9	<1
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	3	9	102	14	4
Total Alkalinity as CaCO3	----	1	mg/L	3	9	102	14	4
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	156	54	20	2	3
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	20	6	13	11	5
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	14	6	32	2	<1
Magnesium	7439-95-4	1	mg/L	16	6	4	1	<1
Sodium	7440-23-5	1	mg/L	23	13	19	10	6
Potassium	7440-09-7	1	mg/L	13	3	3	2	1
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	1.16	0.11	<0.01	0.12	0.12
Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	0.007	0.001	0.001
Arsenic	7440-38-2	0.001	mg/L	0.004	0.003	0.008	0.008	<0.001
Cadmium	7440-43-9	0.0001	mg/L	0.0004	0.0010	0.0009	<0.0001	<0.0001
Chromium	7440-47-3	0.001	mg/L	0.005	<0.001	<0.001	0.001	0.001
Copper	7440-50-8	0.001	mg/L	0.006	0.007	0.004	0.001	0.013
Nickel	7440-02-0	0.001	mg/L	0.049	0.027	0.013	0.018	0.140
Lead	7439-92-1	0.001	mg/L	0.002	<0.001	<0.001	0.002	<0.001
Zinc	7440-66-6	0.005	mg/L	0.252	0.314	0.403	0.064	0.092

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Sample ID	---- OM1	---- OM2	---- OM3	---- OM4	---- OM5
				Sampling date / time	16-Dec-2021 00:00	16-Dec-2021 00:00	16-Dec-2021 00:00	16-Dec-2021 00:00	16-Dec-2021 00:00
Compound	CAS Number	LOR	Unit		ES2146443-001	ES2146443-002	ES2146443-003	ES2146443-004	ES2146443-005
					Result	Result	Result	Result	Result
EG020F: Dissolved Metals by ICP-MS - Continued									
Manganese	7439-96-5	0.001	mg/L		0.799	0.320	0.323	0.200	0.094
Iron	7439-89-6	0.05	mg/L		3.58	0.06	0.06	1.75	0.18
EG035F: Dissolved Mercury by FIMS									
Mercury	7439-97-6	0.0001	mg/L		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		0.4	0.1	1.1	0.2	0.2
EK055G: Ammonia as N by Discrete Analyser									
Ammonia as N	7664-41-7	0.01	mg/L		0.04	<0.01	0.04	0.12	0.02
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N	14797-65-0	0.01	mg/L		<0.01	<0.01	0.02	<0.01	<0.01
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N	14797-55-8	0.01	mg/L		<0.01	<0.01	0.14	0.04	0.03
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N	----	0.01	mg/L		<0.01	<0.01	0.16	0.04	0.03
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	0.1	mg/L		2.0	0.6	0.2	0.4	0.4
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser									
^ Total Nitrogen as N	----	0.1	mg/L		2.0	0.6	0.4	0.4	0.4
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	0.01	mg/L		0.18	0.10	0.19	0.03	0.02
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	<0.01
EN055: Ionic Balance									
ø Total Anions	----	0.01	meq/L		3.87	1.47	2.82	0.63	0.28
ø Total Cations	----	0.01	meq/L		3.67	----	----	----	----
ø Total Cations	----	0.01	meq/L		----	1.44	2.83	0.67	0.29
ø Ionic Balance	----	0.01	%		2.69	----	----	----	----
EP080/071: Total Petroleum Hydrocarbons									
C6 - C9 Fraction	----	20	µg/L		<20	<20	<20	<20	<20
C10 - C14 Fraction	----	50	µg/L		<50	----	<50	<50	<50
C15 - C28 Fraction	----	100	µg/L		<100	----	<100	<100	<100
C29 - C36 Fraction	----	50	µg/L		<50	----	<50	<50	<50
^ C10 - C36 Fraction (sum)	----	50	µg/L		<50	----	<50	<50	<50

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER**)

Compound	CAS Number	LOR	Unit	Sample ID	---- OM1	---- OM2	---- OM3	---- OM4	---- OM5
				Sampling date / time	16-Dec-2021 00:00	16-Dec-2021 00:00	16-Dec-2021 00:00	16-Dec-2021 00:00	16-Dec-2021 00:00
					ES2146443-001	ES2146443-002	ES2146443-003	ES2146443-004	ES2146443-005
					Result	Result	Result	Result	Result
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions									
C6 - C10 Fraction	C6_C10	20	µg/L		<20	<20	<20	<20	<20
^ **C6 - C10 Fraction minus BTEX (F1)**	C6_C10-BTEX	20	µg/L		<20	<20	<20	<20	<20
>C10 - C16 Fraction	----	100	µg/L		<100	----	<100	<100	<100
>C16 - C34 Fraction	----	100	µg/L		<100	----	<100	<100	<100
>C34 - C40 Fraction	----	100	µg/L		<100	----	<100	<100	<100
^ **>C10 - C40 Fraction (sum)**	----	100	µg/L		<100	----	<100	<100	<100
^ **>C10 - C16 Fraction minus Naphthalene (F2)**	----	100	µg/L		<100	----	<100	<100	<100
EP080: BTEXN									
Benzene	71-43-2	1	µg/L		<1	<1	<1	<1	<1
Toluene	108-88-3	2	µg/L		<2	<2	<2	<2	<2
Ethylbenzene	100-41-4	2	µg/L		<2	<2	<2	<2	<2
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L		<2	<2	<2	<2	<2
ortho-Xylene	95-47-6	2	µg/L		<2	<2	<2	<2	<2
^ **Total Xylenes**	----	2	µg/L		<2	<2	<2	<2	<2
^ **Sum of BTEX**	----	1	µg/L		<1	<1	<1	<1	<1
Naphthalene	91-20-3	5	µg/L		<5	<5	<5	<5	<5
EP080S: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	2	%		**98.8**	**98.5**	**99.3**	**97.3**	**97.4**
Toluene-D8	2037-26-5	2	%		**105**	**105**	**101**	**102**	**101**
4-Bromofluorobenzene	460-00-4	2	%		**102**	**102**	**100**	**98.5**	**101**

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	---- OM6	---- OM7	---- MB01A	---- QC01	---- Rinsate
			Sampling date / time	15-Dec-2021 00:00	15-Dec-2021 00:00	15-Dec-2021 00:00	15-Dec-2021 00:00	17-Dec-2021 00:00
Compound	CAS Number	LOR	Unit	ES2146443-006	ES2146443-007	ES2146443-008	ES2146443-009	ES2146443-011
				Result	Result	Result	Result	Result
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	6.26	7.95	8.00	7.96	----
EA006: Sodium Adsorption Ratio (SAR)								
^ Sodium Adsorption Ratio	----	0.01	-	1.47	4.00	0.94	0.90	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	255	1540	532	512	----
EA016: Calculated TDS (from Electrical Conductivity)								
Total Dissolved Solids (Calc.)	----	1	mg/L	166	1000	346	333	----
EA065: Total Hardness as CaCO3								
Total Hardness as CaCO3	----	1	mg/L	64	388	209	211	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	<1	<1	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	<1	<1	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	96	447	266	260	----
Total Alkalinity as CaCO3	----	1	mg/L	96	447	266	260	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	4	186	9	9	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	25	165	28	28	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	19	83	54	55	----
Magnesium	7439-95-4	1	mg/L	4	44	18	18	----
Sodium	7440-23-5	1	mg/L	27	181	31	30	----
Potassium	7440-09-7	1	mg/L	4	60	4	4	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	0.13	0.64	<0.01	<0.01	0.01
Antimony	7440-36-0	0.001	mg/L	0.005	0.001	0.004	0.005	<0.001
Arsenic	7440-38-2	0.001	mg/L	<0.001	0.003	0.014	0.014	<0.001
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	7440-47-3	0.001	mg/L	0.004	0.007	<0.001	<0.001	<0.001
Copper	7440-50-8	0.001	mg/L	0.001	0.001	<0.001	<0.001	<0.001
Nickel	7440-02-0	0.001	mg/L	0.014	0.015	<0.001	<0.001	<0.001
Lead	7439-92-1	0.001	mg/L	0.001	0.002	<0.001	<0.001	<0.001
Zinc	7440-66-6	0.005	mg/L	0.053	0.234	0.009	0.008	<0.005

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER**)

Compound	CAS Number	LOR	Unit	Sample ID	---- OM6	---- OM7	---- MB01A	---- QC01	---- Rinsate
				Sampling date / time	15-Dec-2021 00:00	15-Dec-2021 00:00	15-Dec-2021 00:00	15-Dec-2021 00:00	17-Dec-2021 00:00
					ES2146443-006	ES2146443-007	ES2146443-008	ES2146443-009	ES2146443-011
					Result	Result	Result	Result	Result
EG020F: Dissolved Metals by ICP-MS - Continued									
Manganese	7439-96-5	0.001	mg/L		**0.222**	**0.925**	**0.100**	**0.100**	<0.001
Iron	7439-89-6	0.05	mg/L		**2.78**	**5.98**	<0.05	<0.05	<0.05
EG035F: Dissolved Mercury by FIMS									
Mercury	7439-97-6	0.0001	mg/L		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.1**	**0.5**	**0.8**	**0.8**	----
EK055G: Ammonia as N by Discrete Analyser									
Ammonia as N	7664-41-7	0.01	mg/L		**0.14**	**1.06**	<0.01	<0.10	----
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N	14797-65-0	0.01	mg/L		<0.01	<0.10	<0.01	<0.01	----
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N	14797-55-8	0.01	mg/L		**0.03**	<0.10	**0.02**	**0.01**	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N	----	0.01	mg/L		**0.03**	<0.10	**0.02**	**0.01**	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	0.1	mg/L		**1.6**	**5.0**	<0.1	**0.1**	----
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser									
^ **Total Nitrogen as N**	----	0.1	mg/L		**1.6**	**5.0**	<0.1	**0.1**	----
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	0.01	mg/L		**0.11**	**1.09**	**0.03**	**0.03**	----
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.01	mg/L		<0.01	**0.70**	<0.01	<0.01	----
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**2.71**	**17.4**	**6.29**	**6.17**	----
ø **Total Cations**	----	0.01	meq/L		**2.55**	**17.2**	**5.63**	**5.63**	----
ø **Ionic Balance**	----	0.01	%		----	**0.83**	**5.58**	**4.56**	----
EP080/071: Total Petroleum Hydrocarbons									
C6 - C9 Fraction	----	20	µg/L		<20	<20	<20	<20	<20
C10 - C14 Fraction	----	50	µg/L		<50	<50	<50	<50	<50
C15 - C28 Fraction	----	100	µg/L		<100	<100	<100	<100	<100
C29 - C36 Fraction	----	50	µg/L		<50	<50	<50	<50	<50
^ **C10 - C36 Fraction (sum)**	----	50	µg/L		<50	<50	<50	<50	<50
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions									

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Sample ID	---- OM6	---- OM7	---- MB01A	---- QC01	---- Rinsate
				Sampling date / time	15-Dec-2021 00:00	15-Dec-2021 00:00	15-Dec-2021 00:00	15-Dec-2021 00:00	17-Dec-2021 00:00
Compound	CAS Number	LOR	Unit		ES2146443-006	ES2146443-007	ES2146443-008	ES2146443-009	ES2146443-011
					Result	Result	Result	Result	Result
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions - Continued									
C6 - C10 Fraction	C6_C10	20	µg/L		<20	<20	<20	<20	<20
^ C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	20	µg/L		<20	<20	<20	<20	<20
>C10 - C16 Fraction	----	100	µg/L		<100	<100	<100	<100	<100
>C16 - C34 Fraction	----	100	µg/L		<100	<100	<100	<100	<100
>C34 - C40 Fraction	----	100	µg/L		<100	<100	<100	<100	<100
^ >C10 - C40 Fraction (sum)	----	100	µg/L		<100	<100	<100	<100	<100
^ >C10 - C16 Fraction minus Naphthalene (F2)	----	100	µg/L		<100	<100	<100	<100	<100
EP080: BTEXN									
Benzene	71-43-2	1	µg/L		<1	<1	<1	<1	<1
Toluene	108-88-3	2	µg/L		<2	<2	<2	<2	<2
Ethylbenzene	100-41-4	2	µg/L		<2	<2	<2	<2	<2
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L		<2	<2	<2	<2	<2
ortho-Xylene	95-47-6	2	µg/L		<2	<2	<2	<2	<2
^ Total Xylenes	----	2	µg/L		<2	<2	<2	<2	<2
^ Sum of BTEX	----	1	µg/L		<1	<1	<1	<1	<1
Naphthalene	91-20-3	5	µg/L		<5	<5	<5	<5	<5
EP080S: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	2	%		**98.2**	**99.2**	**97.7**	**99.6**	**101**
Toluene-D8	2037-26-5	2	%		**102**	**105**	**99.1**	**102**	**101**
4-Bromofluorobenzene	460-00-4	2	%		**100**	**103**	**98.6**	**99.3**	**99.2**

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	---- TS	---- TB	----	----	----
			Sampling date / time	06-Dec-2021 00:00	07-Dec-2021 00:00	----	----	----
Compound	CAS Number	LOR	Unit	ES2146443-012	ES2146443-013	--------	--------	--------
				Result	Result	----	----	----
EP080/071: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	20	µg/L	**----**	<20	**----**	**----**	**----**
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
C6 - C10 Fraction	C6_C10	20	µg/L	**----**	<20	**----**	**----**	**----**
^ **C6 - C10 Fraction minus BTEX (F1)**	C6_C10-BTEX	20	µg/L	**----**	<20	**----**	**----**	**----**
EP080: BTEXN								
Benzene	71-43-2	1	µg/L	**16**	<1	**----**	**----**	**----**
Toluene	108-88-3	2	µg/L	**18**	<2	**----**	**----**	**----**
Ethylbenzene	100-41-4	2	µg/L	**18**	<2	**----**	**----**	**----**
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	**18**	<2	**----**	**----**	**----**
ortho-Xylene	95-47-6	2	µg/L	**19**	<2	**----**	**----**	**----**
^ **Total Xylenes**	----	2	µg/L	**37**	<2	**----**	**----**	**----**
^ **Sum of BTEX**	----	1	µg/L	**89**	<1	**----**	**----**	**----**
Naphthalene	91-20-3	5	µg/L	**19**	<5	**----**	**----**	**----**
EP080S: TPH(V)/BTEX Surrogates								
1.2-Dichloroethane-D4	17060-07-0	2	%	**94.9**	**93.5**	**----**	**----**	**----**
Toluene-D8	2037-26-5	2	%	**114**	**119**	**----**	**----**	**----**
4-Bromofluorobenzene	460-00-4	2	%	**127**	**125**	**----**	**----**	**----**

Surrogate Control Limits

Sub-Matrix: **WATER**		Recovery Limits (%)	
Compound	*CAS Number*	*Low*	*High*
EP080S: TPH(V)/BTEX Surrogates			
1.2-Dichloroethane-D4	17060-07-0	71	137
Toluene-D8	2037-26-5	79	131
4-Bromofluorobenzene	460-00-4	70	128

ALS Environmental

QUALITY CONTROL REPORT

Work Order	: **ES2146443**	Page	: 1 of 12
Client	: **EMM CONSULTING PTY LTD**	Laboratory	: Environmental Division Sydney
Contact	: HENRY NOAKES	Contact	: Sepan Mahamad
Address	: Ground Floor Suite 1 20 Chandos Street St Leonards NSW NSW 2065	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: ----	Telephone	: +61 2 8784 8555
Project	: J200096 Oven Mountain Pumped Storage Project	Date Samples Received	: 17-Dec-2021
Order number	: J200096	Date Analysis Commenced	: 18-Dec-2021
C-O-C number	: ----	Issue Date	: 30-Dec-2021
Sampler	: ----		
Site	: ----		
Quote number	: EN/112/21		
No. of samples received	: 12		
No. of samples analysed	: 12		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted, unless the sampling was conducted by ALS. This document shall not be reproduced, except in full.

This Quality Control Report contains the following information:

- Laboratory Duplicate (DUP) Report; Relative Percentage Difference (RPD) and Acceptance Limits
- Method Blank (MB) and Laboratory Control Spike (LCS) Report; Recovery and Acceptance Limits
- Matrix Spike (MS) Report; Recovery and Acceptance Limits

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW
Edwandy Fadjar	Organic Coordinator	Sydney Organics, Smithfield, NSW
Ivan Taylor	Analyst	Sydney Inorganics, Smithfield, NSW
Wisam Marassa	Inorganics Coordinator	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis. Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

Key : Anonymous = Refers to samples which are not specifically part of this work order but formed part of the QC process lot
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
RPD = Relative Percentage Difference
= Indicates failed QC

Laboratory Duplicate (DUP) Report

The quality control term Laboratory Duplicate refers to a randomly selected intralaboratory split. Laboratory duplicates provide information regarding method precision and sample heterogeneity. The permitted ranges for the Relative Percent Deviation (RPD) of Laboratory Duplicates are specified in ALS Method QWI-EN/38 and are dependent on the magnitude of results in comparison to the level of reporting: Result < 10 times LOR: No Limit; Result between 10 and 20 times LOR: 0% - 50%; Result > 20 times LOR: 0% - 20%.

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	Sample ID	Method: Compound	CAS Number	LOR	Unit	Original Result	Duplicate Result	RPD (%)	Acceptable RPD (%)
EA005P: pH by PC Titrator (QC Lot: 4086065)									
ES2146042-001	Anonymous	EA005-P: pH Value	----	0.01	pH Unit	6.27	6.40	2.1	0% - 20%
ES2146384-006	Anonymous	EA005-P: pH Value	----	0.01	pH Unit	8.47	8.48	0.1	0% - 20%
EA010P: Conductivity by PC Titrator (QC Lot: 4086071)									
ES2146405-010	Anonymous	EA010-P: Electrical Conductivity @ 25°C	----	1	µS/cm	2950	2940	0.4	0% - 20%
ES2146407-008	Anonymous	EA010-P: Electrical Conductivity @ 25°C	----	1	µS/cm	123	123	0.0	0% - 20%
ES2146407-018	Anonymous	EA010-P: Electrical Conductivity @ 25°C	----	1	µS/cm	315	300	5.2	0% - 20%
ES2146450-009	Anonymous	EA010-P: Electrical Conductivity @ 25°C	----	1	µS/cm	10200	10200	0.4	0% - 20%
ES2146443-009	QC01	EA010-P: Electrical Conductivity @ 25°C	----	1	µS/cm	512	518	1.3	0% - 20%
ED037P: Alkalinity by PC Titrator (QC Lot: 4086070)									
ES2146441-007	Anonymous	ED037-P: Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	0.0	No Limit
		ED037-P: Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	0.0	No Limit
		ED037-P: Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	3	2	0.0	No Limit
		ED037-P: Total Alkalinity as CaCO3	----	1	mg/L	3	2	0.0	No Limit
ES2146384-006	Anonymous	ED037-P: Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	0.0	No Limit
		ED037-P: Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	67	71	5.1	0% - 20%
		ED037-P: Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	681	673	1.2	0% - 20%
		ED037-P: Total Alkalinity as CaCO3	----	1	mg/L	748	744	0.6	0% - 20%
ED037P: Alkalinity by PC Titrator (QC Lot: 4086073)									
ES2146443-009	QC01	ED037-P: Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	0.0	No Limit
		ED037-P: Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	0.0	No Limit
		ED037-P: Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	260	265	1.8	0% - 20%
		ED037-P: Total Alkalinity as CaCO3	----	1	mg/L	260	265	1.8	0% - 20%
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA (QC Lot: 4085492)									

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	Sample ID	Method: Compound	CAS Number	LOR	Unit	Original Result	Duplicate Result	RPD (%)	Acceptable RPD (%)
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA (QC Lot: 4085492) - continued									
ES2146335-001	Anonymous	ED041G: Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	516	509	1.2	0% - 20%
ES2146443-006	OM6	ED041G: Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	4	4	0.0	No Limit
ED045G: Chloride by Discrete Analyser (QC Lot: 4085493)									
ES2146335-001	Anonymous	ED045G: Chloride	16887-00-6	1	mg/L	2410	2450	1.9	0% - 20%
ES2146443-006	OM6	ED045G: Chloride	16887-00-6	1	mg/L	25	25	0.0	0% - 20%
ED093F: Dissolved Major Cations (QC Lot: 4092045)									
ES2146428-001	Anonymous	ED093F: Calcium	7440-70-2	1	mg/L	16	16	0.0	0% - 50%
		ED093F: Magnesium	7439-95-4	1	mg/L	9	9	0.0	No Limit
		ED093F: Sodium	7440-23-5	1	mg/L	49	49	0.0	0% - 20%
		ED093F: Potassium	7440-09-7	1	mg/L	3	3	0.0	No Limit
ES2146442-002	Anonymous	ED093F: Calcium	7440-70-2	1	mg/L	14	14	0.0	0% - 50%
		ED093F: Magnesium	7439-95-4	1	mg/L	2	2	0.0	No Limit
		ED093F: Sodium	7440-23-5	1	mg/L	10	10	0.0	0% - 50%
		ED093F: Potassium	7440-09-7	1	mg/L	1	1	0.0	No Limit
EG020F: Dissolved Metals by ICP-MS (QC Lot: 4092043)									
ES2146428-001	Anonymous	EG020A-F: Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	0.0	No Limit
		EG020A-F: Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Arsenic	7440-38-2	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Copper	7440-50-8	0.001	mg/L	0.539	0.522	3.2	0% - 20%
		EG020A-F: Lead	7439-92-1	0.001	mg/L	0.004	0.004	0.0	No Limit
		EG020A-F: Manganese	7439-96-5	0.001	mg/L	0.006	0.006	0.0	No Limit
		EG020A-F: Nickel	7440-02-0	0.001	mg/L	0.003	0.003	0.0	No Limit
		EG020A-F: Zinc	7440-66-6	0.005	mg/L	0.183	0.182	0.8	0% - 20%
		EG020A-F: Aluminium	7429-90-5	0.01	mg/L	<0.01	<0.01	0.0	No Limit
		EG020A-F: Iron	7439-89-6	0.05	mg/L	<0.05	<0.05	0.0	No Limit
ES2146442-002	Anonymous	EG020A-F: Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	0.0	No Limit
		EG020A-F: Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Arsenic	7440-38-2	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Copper	7440-50-8	0.001	mg/L	0.001	0.001	0.0	No Limit
		EG020A-F: Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Manganese	7439-96-5	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Nickel	7440-02-0	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Zinc	7440-66-6	0.005	mg/L	0.005	<0.005	0.0	No Limit
		EG020A-F: Aluminium	7429-90-5	0.01	mg/L	0.03	0.03	0.0	No Limit
		EG020A-F: Iron	7439-89-6	0.05	mg/L	<0.05	<0.05	0.0	No Limit
EG020F: Dissolved Metals by ICP-MS (QC Lot: 4092046)									
ES2146473-004	Anonymous	EG020A-F: Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	0.0	No Limit

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	*Sample ID*	*Method: Compound*	*CAS Number*	*LOR*	*Unit*	*Original Result*	*Duplicate Result*	*RPD (%)*	*Acceptable RPD (%)*
EG020F: Dissolved Metals by ICP-MS (QC Lot: 4092046) - continued									
ES2146473-004	Anonymous	EG020A-F: Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Arsenic	7440-38-2	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Copper	7440-50-8	0.001	mg/L	0.003	0.002	0.0	No Limit
		EG020A-F: Lead	7439-92-1	0.001	mg/L	0.001	0.002	0.0	No Limit
		EG020A-F: Manganese	7439-96-5	0.001	mg/L	0.032	0.032	0.0	0% - 20%
		EG020A-F: Nickel	7440-02-0	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Zinc	7440-66-6	0.005	mg/L	0.012	0.011	0.0	No Limit
		EG020A-F: Aluminium	7429-90-5	0.01	mg/L	0.55	0.57	3.6	0% - 20%
		EG020A-F: Iron	7439-89-6	0.05	mg/L	0.92	0.94	2.3	0% - 50%
ES2146444-001	Anonymous	EG020A-F: Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	0.0	No Limit
		EG020A-F: Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Arsenic	7440-38-2	0.001	mg/L	0.007	0.005	33.3	No Limit
		EG020A-F: Chromium	7440-47-3	0.001	mg/L	0.002	0.002	0.0	No Limit
		EG020A-F: Copper	7440-50-8	0.001	mg/L	0.004	0.004	0.0	No Limit
		EG020A-F: Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	0.0	No Limit
		EG020A-F: Manganese	7439-96-5	0.001	mg/L	0.313	0.313	0.0	0% - 20%
		EG020A-F: Nickel	7440-02-0	0.001	mg/L	0.004	0.004	0.0	No Limit
		EG020A-F: Zinc	7440-66-6	0.005	mg/L	0.008	0.008	0.0	No Limit
		EG020A-F: Aluminium	7429-90-5	0.01	mg/L	<0.01	<0.01	0.0	No Limit
		EG020A-F: Iron	7439-89-6	0.05	mg/L	0.07	0.07	0.0	No Limit
EG035F: Dissolved Mercury by FIMS (QC Lot: 4092044)									
ES2146441-001	Anonymous	EG035F: Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	0.0	No Limit
ES2146443-002	OM2	EG035F: Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	0.0	No Limit
EK040P: Fluoride by PC Titrator (QC Lot: 4086072)									
ES2146441-007	Anonymous	EK040P: Fluoride	16984-48-8	0.1	mg/L	<0.1	<0.1	0.0	No Limit
ES2146443-009	QC01	EK040P: Fluoride	16984-48-8	0.1	mg/L	0.8	0.8	0.0	No Limit
EK055G: Ammonia as N by Discrete Analyser (QC Lot: 4089353)									
ES2146377-001	Anonymous	EK055G: Ammonia as N	7664-41-7	0.01	mg/L	39.3	38.9	1.1	0% - 20%
ES2146443-002	OM2	EK055G: Ammonia as N	7664-41-7	0.01	mg/L	<0.01	<0.01	0.0	No Limit
EK057G: Nitrite as N by Discrete Analyser (QC Lot: 4085490)									
ES2146136-001	Anonymous	EK057G: Nitrite as N	14797-65-0	0.01	mg/L	<0.01	<0.01	0.0	No Limit
ES2146135-001	Anonymous	EK057G: Nitrite as N	14797-65-0	0.01	mg/L	<0.01	<0.01	0.0	No Limit
EK057G: Nitrite as N by Discrete Analyser (QC Lot: 4085495)									
ES2146443-006	OM6	EK057G: Nitrite as N	14797-65-0	0.01	mg/L	<0.01	<0.01	0.0	No Limit
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser (QC Lot: 4089354)									
ES2146383-001	Anonymous	EK059G: Nitrite + Nitrate as N	----	0.01	mg/L	12.5	12.7	2.1	0% - 20%
ES2146443-002	OM2	EK059G: Nitrite + Nitrate as N	----	0.01	mg/L	<0.01	<0.01	0.0	No Limit
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QC Lot: 4089352)									

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	*Sample ID*	*Method: Compound*	*CAS Number*	*LOR*	*Unit*	*Original Result*	*Duplicate Result*	*RPD (%)*	*Acceptable RPD (%)*
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QC Lot: 4089352) - continued									
ES2146443-001	OM1	EK061G: Total Kjeldahl Nitrogen as N	----	0.1	mg/L	2.0	1.8	11.7	0% - 20%
EK067G: Total Phosphorus as P by Discrete Analyser (QC Lot: 4089351)									
ES2146349-001	Anonymous	EK067G: Total Phosphorus as P	----	0.01	mg/L	0.36	0.37	0.0	0% - 20%
ES2146443-001	OM1	EK067G: Total Phosphorus as P	----	0.01	mg/L	0.18	0.18	0.0	0% - 50%
EK071G: Reactive Phosphorus as P by discrete analyser (QC Lot: 4085491)									
ES2146136-001	Anonymous	EK071G: Reactive Phosphorus as P	14265-44-2	0.01	mg/L	<0.01	<0.01	0.0	No Limit
ES2146443-006	OM6	EK071G: Reactive Phosphorus as P	14265-44-2	0.01	mg/L	<0.01	<0.01	0.0	No Limit
EP080/071: Total Petroleum Hydrocarbons (QC Lot: 4088979)									
ES2146492-002	Anonymous	EP080: C6 - C9 Fraction	----	20	µg/L	<20	<20	0.0	No Limit
EP080/071: Total Petroleum Hydrocarbons (QC Lot: 4096811)									
ES2146408-001	Anonymous	EP080: C6 - C9 Fraction	----	20	µg/L	<20	<20	0.0	No Limit
ES2146443-001	OM1	EP080: C6 - C9 Fraction	----	20	µg/L	<20	<20	0.0	No Limit
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions (QC Lot: 4088979)									
ES2146492-002	Anonymous	EP080: C6 - C10 Fraction	C6_C10	20	µg/L	<20	<20	0.0	No Limit
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions (QC Lot: 4096811)									
ES2146408-001	Anonymous	EP080: C6 - C10 Fraction	C6_C10	20	µg/L	<20	<20	0.0	No Limit
ES2146443-001	OM1	EP080: C6 - C10 Fraction	C6_C10	20	µg/L	<20	<20	0.0	No Limit
EP080: BTEXN (QC Lot: 4088979)									
ES2146492-002	Anonymous	EP080: Benzene	71-43-2	1	µg/L	<1	<1	0.0	No Limit
		EP080: Toluene	108-88-3	2	µg/L	<2	<2	0.0	No Limit
		EP080: Ethylbenzene	100-41-4	2	µg/L	<2	<2	0.0	No Limit
		EP080: meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	<2	0.0	No Limit
		EP080: ortho-Xylene	95-47-6	2	µg/L	<2	<2	0.0	No Limit
		EP080: Naphthalene	91-20-3	5	µg/L	<5	<5	0.0	No Limit
EP080: BTEXN (QC Lot: 4096811)									
ES2146408-001	Anonymous	EP080: Benzene	71-43-2	1	µg/L	<1	<1	0.0	No Limit
		EP080: Toluene	108-88-3	2	µg/L	<2	<2	0.0	No Limit
		EP080: Ethylbenzene	100-41-4	2	µg/L	<2	<2	0.0	No Limit
		EP080: meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	<2	0.0	No Limit
		EP080: ortho-Xylene	95-47-6	2	µg/L	<2	<2	0.0	No Limit
		EP080: Naphthalene	91-20-3	5	µg/L	<5	<5	0.0	No Limit
ES2146443-001	OM1	EP080: Benzene	71-43-2	1	µg/L	<1	<1	0.0	No Limit
		EP080: Toluene	108-88-3	2	µg/L	<2	<2	0.0	No Limit
		EP080: Ethylbenzene	100-41-4	2	µg/L	<2	<2	0.0	No Limit
		EP080: meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	<2	0.0	No Limit
		EP080: ortho-Xylene	95-47-6	2	µg/L	<2	<2	0.0	No Limit

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	*Sample ID*	*Method: Compound*	*CAS Number*	*LOR*	*Unit*	*Original Result*	*Duplicate Result*	*RPD (%)*	*Acceptable RPD (%)*
EP080: BTEXN (QC Lot: 4096811) - continued									
ES2146443-001	OM1	EP080: Naphthalene	91-20-3	5	µg/L	<5	<5	0.0	No Limit

Method Blank (MB) and Laboratory Control Sample (LCS) Report

The quality control term Method / Laboratory Blank refers to an analyte free matrix to which all reagents are added in the same volumes or proportions as used in standard sample preparation. The purpose of this QC parameter is to monitor potential laboratory contamination. The quality control term Laboratory Control Sample (LCS) refers to a certified reference material, or a known interference free matrix spiked with target analytes. The purpose of this QC parameter is to monitor method precision and accuracy independent of sample matrix. Dynamic Recovery Limits are based on statistical evaluation of processed LCS.

Sub-Matrix: **WATER**

				Method Blank (MB) Report	Laboratory Control Spike (LCS) Report			
					Spike	Spike Recovery (%)	Acceptable Limits (%)	
Method: Compound	CAS Number	LOR	Unit	Result	Concentration	LCS	Low	High
EA005P: pH by PC Titrator (QCLot: 4086065)								
EA005-P: pH Value	----	----	pH Unit	----	4 pH Unit	100	98.8	101
				----	7 pH Unit	99.8	99.2	101
EA010P: Conductivity by PC Titrator (QCLot: 4086071)								
EA010-P: Electrical Conductivity @ 25°C	----	1	µS/cm	<1	220 µS/cm	95.7	91.1	107
				<1	2100 µS/cm	97.6	93.2	108
ED037P: Alkalinity by PC Titrator (QCLot: 4086070)								
ED037-P: Total Alkalinity as CaCO3	----	----	mg/L	----	200 mg/L	107	81.0	111
				----	50 mg/L	80.0	80.0	120
ED037P: Alkalinity by PC Titrator (QCLot: 4086073)								
ED037-P: Total Alkalinity as CaCO3	----	----	mg/L	----	200 mg/L	106	81.0	111
				----	50 mg/L	105	80.0	120
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA (QCLot: 4085492)								
ED041G: Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	<1	25 mg/L	108	82.0	122
				<1	500 mg/L	101	82.0	122
ED045G: Chloride by Discrete Analyser (QCLot: 4085493)								
ED045G: Chloride	16887-00-6	1	mg/L	<1	50 mg/L	100	80.9	127
				<1	1000 mg/L	94.3	80.9	127
ED093F: Dissolved Major Cations (QCLot: 4092045)								
ED093F: Calcium	7440-70-2	1	mg/L	<1	50 mg/L	98.1	80.0	114
ED093F: Magnesium	7439-95-4	1	mg/L	<1	50 mg/L	96.4	90.0	116
ED093F: Sodium	7440-23-5	1	mg/L	<1	50 mg/L	96.2	82.0	120
ED093F: Potassium	7440-09-7	1	mg/L	<1	50 mg/L	94.1	85.0	113
EG020F: Dissolved Metals by ICP-MS (QCLot: 4092043)								
EG020A-F: Aluminium	7429-90-5	0.01	mg/L	<0.01	0.5 mg/L	89.8	80.0	116
EG020A-F: Antimony	7440-36-0	0.001	mg/L	<0.001	0.02 mg/L	89.7	70.0	130
EG020A-F: Arsenic	7440-38-2	0.001	mg/L	<0.001	0.1 mg/L	93.6	85.0	114
EG020A-F: Cadmium	7440-43-9	0.0001	mg/L	<0.0001	0.1 mg/L	94.2	84.0	110
EG020A-F: Chromium	7440-47-3	0.001	mg/L	<0.001	0.1 mg/L	93.4	85.0	111
EG020A-F: Copper	7440-50-8	0.001	mg/L	<0.001	0.1 mg/L	91.4	81.0	111
EG020A-F: Lead	7439-92-1	0.001	mg/L	<0.001	0.1 mg/L	93.1	83.0	111
EG020A-F: Manganese	7439-96-5	0.001	mg/L	<0.001	0.1 mg/L	91.6	82.0	110
EG020A-F: Nickel	7440-02-0	0.001	mg/L	<0.001	0.1 mg/L	90.7	82.0	112
EG020A-F: Zinc	7440-66-6	0.005	mg/L	<0.005	0.1 mg/L	92.9	81.0	117
EG020A-F: Iron	7439-89-6	0.05	mg/L	<0.05	0.5 mg/L	95.4	82.0	112

Sub-Matrix: **WATER**

Method: Compound	CAS Number	LOR	Unit	Method Blank (MB) Report	Laboratory Control Spike (LCS) Report			
					Spike	Spike Recovery (%)	Acceptable Limits (%)	
				Result	Concentration	LCS	Low	High
EG020F: Dissolved Metals by ICP-MS (QCLot: 4092046)								
EG020A-F: Aluminium	7429-90-5	0.01	mg/L	<0.01	0.5 mg/L	89.8	80.0	116
EG020A-F: Antimony	7440-36-0	0.001	mg/L	<0.001	0.02 mg/L	83.8	70.0	130
EG020A-F: Arsenic	7440-38-2	0.001	mg/L	<0.001	0.1 mg/L	90.4	85.0	114
EG020A-F: Cadmium	7440-43-9	0.0001	mg/L	<0.0001	0.1 mg/L	94.0	84.0	110
EG020A-F: Chromium	7440-47-3	0.001	mg/L	<0.001	0.1 mg/L	96.2	85.0	111
EG020A-F: Copper	7440-50-8	0.001	mg/L	<0.001	0.1 mg/L	89.0	81.0	111
EG020A-F: Lead	7439-92-1	0.001	mg/L	<0.001	0.1 mg/L	94.3	83.0	111
EG020A-F: Manganese	7439-96-5	0.001	mg/L	<0.001	0.1 mg/L	94.1	82.0	110
EG020A-F: Nickel	7440-02-0	0.001	mg/L	<0.001	0.1 mg/L	90.3	82.0	112
EG020A-F: Zinc	7440-66-6	0.005	mg/L	<0.005	0.1 mg/L	90.4	81.0	117
EG020A-F: Iron	7439-89-6	0.05	mg/L	<0.05	0.5 mg/L	99.2	82.0	112
EG035F: Dissolved Mercury by FIMS (QCLot: 4092044)								
EG035F: Mercury	7439-97-6	0.0001	mg/L	<0.0001	0.01 mg/L	97.4	83.0	105
EK040P: Fluoride by PC Titrator (QCLot: 4086072)								
EK040P: Fluoride	16984-48-8	0.1	mg/L	<0.1	5 mg/L	106	82.0	116
EK055G: Ammonia as N by Discrete Analyser (QCLot: 4089353)								
EK055G: Ammonia as N	7664-41-7	0.01	mg/L	<0.01	1 mg/L	107	90.0	114
EK057G: Nitrite as N by Discrete Analyser (QCLot: 4085490)								
EK057G: Nitrite as N	14797-65-0	0.01	mg/L	<0.01	0.5 mg/L	106	82.0	114
EK057G: Nitrite as N by Discrete Analyser (QCLot: 4085495)								
EK057G: Nitrite as N	14797-65-0	0.01	mg/L	<0.01	0.5 mg/L	108	82.0	114
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser (QCLot: 4089354)								
EK059G: Nitrite + Nitrate as N	----	0.01	mg/L	<0.01	0.5 mg/L	96.2	91.0	113
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QCLot: 4089352)								
EK061G: Total Kjeldahl Nitrogen as N	----	0.1	mg/L	<0.1	10 mg/L	89.8	69.0	101
				<0.1	1 mg/L	104	70.0	118
				<0.1	5 mg/L	101	70.0	130
EK067G: Total Phosphorus as P by Discrete Analyser (QCLot: 4089351)								
EK067G: Total Phosphorus as P	----	0.01	mg/L	<0.01	4.42 mg/L	94.0	71.0	101
				<0.01	0.442 mg/L	106	72.0	108
				<0.01	1 mg/L	104	70.0	130
EK071G: Reactive Phosphorus as P by discrete analyser (QCLot: 4085491)								
EK071G: Reactive Phosphorus as P	14265-44-2	0.01	mg/L	<0.01	0.5 mg/L	96.2	85.0	117
EP080/071: Total Petroleum Hydrocarbons (QCLot: 4086077)								
EP071: C10 - C14 Fraction	----	50	µg/L	<50	400 µg/L	70.0	55.8	112
EP071: C15 - C28 Fraction	----	100	µg/L	<100	600 µg/L	89.6	71.6	113
EP071: C29 - C36 Fraction	----	50	µg/L	<50	400 µg/L	78.2	56.0	121

Sub-Matrix: **WATER**

Method: Compound	CAS Number	LOR	Unit	Method Blank (MB) Report	Laboratory Control Spike (LCS) Report			
					Spike	Spike Recovery (%)	Acceptable Limits (%)	
				Result	Concentration	LCS	Low	High
EP080/071: Total Petroleum Hydrocarbons (QCLot: 4087140)								
EP071: C10 - C14 Fraction	----	50	µg/L	<50	400 µg/L	69.0	55.8	112
EP071: C15 - C28 Fraction	----	100	µg/L	<100	600 µg/L	90.9	71.6	113
EP071: C29 - C36 Fraction	----	50	µg/L	<50	400 µg/L	89.1	56.0	121
EP080/071: Total Petroleum Hydrocarbons (QCLot: 4087219)								
EP071: C10 - C14 Fraction	----	50	µg/L	<50	400 µg/L	79.0	55.8	112
EP071: C15 - C28 Fraction	----	100	µg/L	<100	600 µg/L	83.3	71.6	113
EP071: C29 - C36 Fraction	----	50	µg/L	<50	400 µg/L	79.6	56.0	121
EP080/071: Total Petroleum Hydrocarbons (QCLot: 4088979)								
EP080: C6 - C9 Fraction	----	20	µg/L	<20	260 µg/L	90.4	75.0	127
EP080/071: Total Petroleum Hydrocarbons (QCLot: 4096811)								
EP080: C6 - C9 Fraction	----	20	µg/L	<20	260 µg/L	89.4	75.0	127
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions (QCLot: 4086077)								
EP071: >C10 - C16 Fraction	----	100	µg/L	<100	500 µg/L	71.0	57.9	119
EP071: >C16 - C34 Fraction	----	100	µg/L	<100	700 µg/L	96.7	62.5	110
EP071: >C34 - C40 Fraction	----	100	µg/L	<100	300 µg/L	103	61.5	121
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions (QCLot: 4087140)								
EP071: >C10 - C16 Fraction	----	100	µg/L	<100	500 µg/L	73.5	57.9	119
EP071: >C16 - C34 Fraction	----	100	µg/L	<100	700 µg/L	93.5	62.5	110
EP071: >C34 - C40 Fraction	----	100	µg/L	<100	300 µg/L	82.3	61.5	121
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions (QCLot: 4087219)								
EP071: >C10 - C16 Fraction	----	100	µg/L	<100	500 µg/L	68.0	57.9	119
EP071: >C16 - C34 Fraction	----	100	µg/L	<100	700 µg/L	80.4	62.5	110
EP071: >C34 - C40 Fraction	----	100	µg/L	<100	300 µg/L	67.0	61.5	121
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions (QCLot: 4088979)								
EP080: C6 - C10 Fraction	C6_C10	20	µg/L	<20	310 µg/L	92.6	75.0	127
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions (QCLot: 4096811)								
EP080: C6 - C10 Fraction	C6_C10	20	µg/L	<20	310 µg/L	98.2	75.0	127
EP080: BTEXN (QCLot: 4088979)								
EP080: Benzene	71-43-2	1	µg/L	<1	10 µg/L	85.2	70.0	122
EP080: Toluene	108-88-3	2	µg/L	<2	10 µg/L	95.0	69.0	123
EP080: Ethylbenzene	100-41-4	2	µg/L	<2	10 µg/L	99.3	70.0	120
EP080: meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	10 µg/L	98.3	69.0	121
EP080: ortho-Xylene	95-47-6	2	µg/L	<2	10 µg/L	98.5	72.0	122
EP080: Naphthalene	91-20-3	5	µg/L	<5	10 µg/L	106	70.0	120
EP080: BTEXN (QCLot: 4096811)								
EP080: Benzene	71-43-2	1	µg/L	<1	10 µg/L	85.3	70.0	122

Sub-Matrix: **WATER**

Method: Compound	CAS Number	LOR	Unit	Method Blank (MB) Report: Result	Laboratory Control Spike (LCS) Report: Spike Concentration	Spike Recovery (%): LCS	Acceptable Limits (%): Low	Acceptable Limits (%): High
EP080: BTEXN (QCLot: 4096811) - continued								
EP080: Toluene	108-88-3	2	µg/L	<2	10 µg/L	85.6	69.0	123
EP080: Ethylbenzene	100-41-4	2	µg/L	<2	10 µg/L	93.1	70.0	120
EP080: meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	10 µg/L	91.7	69.0	121
EP080: ortho-Xylene	95-47-6	2	µg/L	<2	10 µg/L	93.6	72.0	122
EP080: Naphthalene	91-20-3	5	µg/L	<5	10 µg/L	96.6	70.0	120

Matrix Spike (MS) Report

The quality control term Matrix Spike (MS) refers to an intralaboratory split sample spiked with a representative set of target analytes. The purpose of this QC parameter is to monitor potential matrix effects on analyte recoveries. Static Recovery Limits as per laboratory Data Quality Objectives (DQOs). Ideal recovery ranges stated may be waived in the event of sample matrix interference.

Sub-Matrix: **WATER**

Laboratory sample ID	Sample ID	Method: Compound	CAS Number	Matrix Spike (MS) Report: Spike Concentration	SpikeRecovery(%): MS	Acceptable Limits (%): Low	Acceptable Limits (%): High
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA (QCLot: 4085492)							
ES2146335-001	Anonymous	ED041G: Sulfate as SO4 - Turbidimetric	14808-79-8	10 mg/L	# Not Determined	70.0	130
ED045G: Chloride by Discrete Analyser (QCLot: 4085493)							
ES2146335-001	Anonymous	ED045G: Chloride	16887-00-6	50 mg/L	# Not Determined	70.0	130
EG020F: Dissolved Metals by ICP-MS (QCLot: 4092043)							
ES2146428-002	Anonymous	EG020A-F: Arsenic	7440-38-2	1 mg/L	95.9	70.0	130
		EG020A-F: Cadmium	7440-43-9	0.25 mg/L	101	70.0	130
		EG020A-F: Chromium	7440-47-3	1 mg/L	99.9	70.0	130
		EG020A-F: Copper	7440-50-8	1 mg/L	99.2	70.0	130
		EG020A-F: Lead	7439-92-1	1 mg/L	94.6	70.0	130
		EG020A-F: Manganese	7439-96-5	1 mg/L	102	70.0	130
		EG020A-F: Nickel	7440-02-0	1 mg/L	97.6	70.0	130
		EG020A-F: Zinc	7440-66-6	1 mg/L	102	70.0	130
EG020F: Dissolved Metals by ICP-MS (QCLot: 4092046)							
ES2146443-011	Rinsate	EG020A-F: Arsenic	7440-38-2	1 mg/L	73.6	70.0	130
		EG020A-F: Cadmium	7440-43-9	0.25 mg/L	82.2	70.0	130
		EG020A-F: Chromium	7440-47-3	1 mg/L	86.2	70.0	130
		EG020A-F: Copper	7440-50-8	1 mg/L	78.7	70.0	130
		EG020A-F: Lead	7439-92-1	1 mg/L	80.0	70.0	130
		EG020A-F: Manganese	7439-96-5	1 mg/L	84.2	70.0	130
		EG020A-F: Nickel	7440-02-0	1 mg/L	77.6	70.0	130
		EG020A-F: Zinc	7440-66-6	1 mg/L	78.8	70.0	130

Sub-Matrix: **WATER**

				Matrix Spike (MS) Report			
				Spike	SpikeRecovery(%)	Acceptable Limits (%)	
Laboratory sample ID	Sample ID	Method: Compound	CAS Number	Concentration	MS	Low	High
EG035F: Dissolved Mercury by FIMS (QCLot: 4092044)							
ES2146398-001	Anonymous	EG035F: Mercury	7439-97-6	0.01 mg/L	93.4	70.0	130
EK040P: Fluoride by PC Titrator (QCLot: 4086072)							
ES2146441-007	Anonymous	EK040P: Fluoride	16984-48-8	5 mg/L	102	70.0	130
EK055G: Ammonia as N by Discrete Analyser (QCLot: 4089353)							
ES2146377-001	Anonymous	EK055G: Ammonia as N	7664-41-7	1 mg/L	# Not Determined	70.0	130
EK057G: Nitrite as N by Discrete Analyser (QCLot: 4085490)							
ES2146135-001	Anonymous	EK057G: Nitrite as N	14797-65-0	0.5 mg/L	130	70.0	130
EK057G: Nitrite as N by Discrete Analyser (QCLot: 4085495)							
ES2146443-006	OM6	EK057G: Nitrite as N	14797-65-0	0.5 mg/L	130	70.0	130
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser (QCLot: 4089354)							
ES2146383-001	Anonymous	EK059G: Nitrite + Nitrate as N	----	0.5 mg/L	# Not Determined	70.0	130
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QCLot: 4089352)							
ES2146443-001	OM1	EK061G: Total Kjeldahl Nitrogen as N	----	5 mg/L	86.2	70.0	130
EK067G: Total Phosphorus as P by Discrete Analyser (QCLot: 4089351)							
ES2146377-001	Anonymous	EK067G: Total Phosphorus as P	----	1 mg/L	# Not Determined	70.0	130
EK071G: Reactive Phosphorus as P by discrete analyser (QCLot: 4085491)							
ES2146136-001	Anonymous	EK071G: Reactive Phosphorus as P	14265-44-2	0.5 mg/L	118	70.0	130
EP080/071: Total Petroleum Hydrocarbons (QCLot: 4088979)							
ES2146492-002	Anonymous	EP080: C6 - C9 Fraction	----	325 µg/L	99.7	70.0	130
EP080/071: Total Petroleum Hydrocarbons (QCLot: 4096811)							
ES2146408-001	Anonymous	EP080: C6 - C9 Fraction	----	325 µg/L	111	70.0	130
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions (QCLot: 4088979)							
ES2146492-002	Anonymous	EP080: C6 - C10 Fraction	C6_C10	375 µg/L	100	70.0	130
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions (QCLot: 4096811)							
ES2146408-001	Anonymous	EP080: C6 - C10 Fraction	C6_C10	375 µg/L	116	70.0	130
EP080: BTEXN (QCLot: 4088979)							
ES2146492-002	Anonymous	EP080: Benzene	71-43-2	25 µg/L	93.1	70.0	130
		EP080: Toluene	108-88-3	25 µg/L	94.0	70.0	130
		EP080: Ethylbenzene	100-41-4	25 µg/L	107	70.0	130
		EP080: meta- & para-Xylene	108-38-3 106-42-3	25 µg/L	107	70.0	130

Sub-Matrix: **WATER**

				Matrix Spike (MS) Report			
				Spike	SpikeRecovery(%)	Acceptable Limits (%)	
Laboratory sample ID	Sample ID	Method: Compound	CAS Number	Concentration	MS	Low	High
EP080: BTEXN (QCLot: 4088979) - continued							
ES2146492-002	Anonymous	EP080: ortho-Xylene	95-47-6	25 µg/L	110	70.0	130
		EP080: Naphthalene	91-20-3	25 µg/L	98.5	70.0	130
EP080: BTEXN (QCLot: 4096811)							
ES2146408-001	Anonymous	EP080: Benzene	71-43-2	25 µg/L	80.8	70.0	130
		EP080: Toluene	108-88-3	25 µg/L	79.8	70.0	130
		EP080: Ethylbenzene	100-41-4	25 µg/L	82.1	70.0	130
		EP080: meta- & para-Xylene	108-38-3 106-42-3	25 µg/L	81.7	70.0	130
		EP080: ortho-Xylene	95-47-6	25 µg/L	84.4	70.0	130
		EP080: Naphthalene	91-20-3	25 µg/L	91.3	70.0	130

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **ES2213920**	Page	: 1 of 9
Client	: **EMM CONSULTING PTY LTD**	Laboratory	: Environmental Division Sydney
Contact	: HENRY NOAKES	Contact	: Sepan Mahamad
Address	: Ground Floor Suite 1 20 Chandos Street St Leonards NSW NSW 2065	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: ----	Telephone	: +61 2 8784 8555
Project	: J200096 Oven Mountain Pumped Storage Project	Date Samples Received	: 22-Apr-2022 15:00
Order number	: J200096	Date Analysis Commenced	: 23-Apr-2022
C-O-C number	: ----	Issue Date	: 29-Apr-2022 17:36
Sampler	: KB		
Site	: ----		
Quote number	: EN/112/21		
No. of samples received	: 10		
No. of samples analysed	: 10		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted, unless the sampling was conducted by ALS. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Senior Chemist - Inorganics	Sydney Inorganics, Smithfield, NSW
Edwandy Fadjar	Organic Coordinator	Sydney Organics, Smithfield, NSW

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EP080: Where reported, Total Xylenes is the sum of the reported concentrations of m&p-Xylene and o-Xylene at or above the LOR.
- EK040: Poor spike recovery for Fluoride, however insufficent sample amount remaining for confirmation analysis.
- EP080: Batch ES2213920-7 Result has been confirmed by re-analysis.
- EK055G:LOR raised due to sample matrix.
- EK057G:LOR raised due to sample matrix.
- ED041G:LOR raised due to sample matrix.
- It has been noted that Reactive P is greater than Total P, however this difference is within the limits of experimental variation.
- EP080: Sample TRIP SPIKE contains volatile compounds spiked into the sample containers prior to dispatch from the laboratory. BTEXN compounds spiked at 20 ug/L.
- EA016: Calculated TDS is determined from Electrical conductivity using a conversion factor of 0.65.
- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	TS	TB	RIN	OM6	OM7
			Sampling date / time	15-Mar-2022 00:00	15-Mar-2022 00:00	21-Apr-2022 00:00	21-Apr-2022 00:00	20-Apr-2022 00:00
Compound	CAS Number	LOR	Unit	ES2213920-001	ES2213920-002	ES2213920-003	ES2213920-004	ES2213920-005
				Result	Result	Result	Result	Result
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	----	----	6.37	6.93	7.10
EA006: Sodium Adsorption Ratio (SAR)								
^ Sodium Adsorption Ratio	----	0.01	-	----	----	0.12	1.13	3.94
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	----	----	<1	209	1160
EA016: Calculated TDS (from Electrical Conductivity)								
Total Dissolved Solids (Calc.)	----	1	mg/L	----	----	<1	136	754
EA065: Total Hardness as CaCO3								
Total Hardness as CaCO3	----	1	mg/L	----	----	<1	59	286
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	----	----	<1	<1	<1
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	----	----	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	----	----	<1	86	379
Total Alkalinity as CaCO3	----	1	mg/L	----	----	<1	86	379
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	----	----	<1	<1	<10
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	----	----	<1	19	142
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	----	----	<1	17	60
Magnesium	7439-95-4	1	mg/L	----	----	<1	4	33
Sodium	7440-23-5	1	mg/L	----	----	<1	20	153
Potassium	7440-09-7	1	mg/L	----	----	<1	4	59
EG005(ED093)F: Dissolved Metals by ICP-AES								
Aluminium	7429-90-5	0.10	mg/L	----	----	----	<0.10	1.03
Antimony	7440-36-0	0.01	mg/L	----	----	----	<0.01	<0.01
Arsenic	7440-38-2	0.01	mg/L	----	----	----	<0.01	<0.01
Cadmium	7440-43-9	0.005	mg/L	----	----	----	<0.005	<0.005
Chromium	7440-47-3	0.01	mg/L	----	----	----	<0.01	0.01
Copper	7440-50-8	0.01	mg/L	----	----	----	<0.01	<0.01
Iron	7439-89-6	0.05	mg/L	----	----	----	2.26	2.31
Lead	7439-92-1	0.01	mg/L	----	----	----	<0.01	<0.01
Manganese	7439-96-5	0.01	mg/L	----	----	----	0.18	0.86
Nickel	7440-02-0	0.01	mg/L	----	----	----	0.01	0.02

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	TS	TB	RIN	OM6	OM7
			Sampling date / time	15-Mar-2022 00:00	15-Mar-2022 00:00	21-Apr-2022 00:00	21-Apr-2022 00:00	20-Apr-2022 00:00
Compound	CAS Number	LOR	Unit	ES2213920-001	ES2213920-002	ES2213920-003	ES2213920-004	ES2213920-005
				Result	Result	Result	Result	Result
EG005(ED093)F: Dissolved Metals by ICP-AES - Continued								
Zinc	7440-66-6	0.01	mg/L	----	----	----	**0.19**	**0.04**
EG035F: Dissolved Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	----	----	----	<0.0001	<0.0001
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	0.1	mg/L	----	----	<0.1	<0.1	**0.4**
EK055G: Ammonia as N by Discrete Analyser								
Ammonia as N	7664-41-7	0.01	mg/L	----	----	<0.01	**0.13**	**1.91**
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N	14797-65-0	0.01	mg/L	----	----	<0.01	<0.01	<0.10
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N	14797-55-8	0.01	mg/L	----	----	<0.01	<0.01	<0.10
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	----	----	<0.01	<0.01	<0.10
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	----	----	<0.1	**1.2**	**3.7**
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser								
^ Total Nitrogen as N	----	0.1	mg/L	----	----	<0.1	**1.2**	**3.7**
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	----	----	<0.01	**0.07**	**1.11**
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	14265-44-2	0.01	mg/L	----	----	<0.01	<0.01	**1.19**
EN055: Ionic Balance								
ø Total Anions	----	0.01	meq/L	----	----	<0.01	**2.25**	**11.6**
ø Total Cations	----	0.01	meq/L	----	----	<0.01	**2.15**	**13.9**
ø Ionic Balance	----	0.01	%	----	----	----	----	**9.02**
EP080/071: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	20	µg/L	----	<20	<20	<20	<20
C10 - C14 Fraction	----	50	µg/L	----	----	<50	<50	<50
C15 - C28 Fraction	----	100	µg/L	----	----	<100	<100	<100
C29 - C36 Fraction	----	50	µg/L	----	----	<50	<50	<50
^ C10 - C36 Fraction (sum)	----	50	µg/L	----	----	<50	<50	<50
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
C6 - C10 Fraction	C6_C10	20	µg/L	----	<20	<20	<20	<20

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	TS	TB	RIN	OM6	OM7
			Sampling date / time	15-Mar-2022 00:00	15-Mar-2022 00:00	21-Apr-2022 00:00	21-Apr-2022 00:00	20-Apr-2022 00:00
Compound	CAS Number	LOR	Unit	ES2213920-001	ES2213920-002	ES2213920-003	ES2213920-004	ES2213920-005
				Result	Result	Result	Result	Result
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions - Continued								
^ **C6 - C10 Fraction minus BTEX (F1)**	C6_C10-BTEX	20	µg/L	----	<20	<20	<20	<20
>C10 - C16 Fraction	----	100	µg/L	----	----	<100	<100	<100
>C16 - C34 Fraction	----	100	µg/L	----	----	<100	<100	<100
>C34 - C40 Fraction	----	100	µg/L	----	----	<100	<100	<100
^ **>C10 - C40 Fraction (sum)**	----	100	µg/L	----	----	<100	<100	<100
^ **>C10 - C16 Fraction minus Naphthalene (F2)**	----	100	µg/L	----	----	<100	<100	<100
EP080: BTEXN								
Benzene	71-43-2	1	µg/L	**14**	<1	<1	<1	<1
Toluene	108-88-3	2	µg/L	**14**	<2	<2	<2	<2
Ethylbenzene	100-41-4	2	µg/L	**14**	<2	<2	<2	<2
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	**15**	<2	<2	<2	<2
ortho-Xylene	95-47-6	2	µg/L	**16**	<2	<2	<2	<2
^ **Total Xylenes**	----	2	µg/L	**31**	<2	<2	<2	<2
^ **Sum of BTEX**	----	1	µg/L	**73**	<1	<1	<1	<1
Naphthalene	91-20-3	5	µg/L	**18**	<5	<5	<5	<5
EP080S: TPH(V)/BTEX Surrogates								
1.2-Dichloroethane-D4	17060-07-0	2	%	**106**	**108**	**105**	**107**	**124**
Toluene-D8	2037-26-5	2	%	**102**	**101**	**97.9**	**102**	**123**
4-Bromofluorobenzene	460-00-4	2	%	**107**	**108**	**107**	**110**	**127**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER**)

Compound	CAS Number	LOR	Unit	Sample ID	MB01A	MB02A	MB02B	MB03A	MB03B
				Sampling date / time	20-Apr-2022 00:00	20-Apr-2022 00:00	20-Apr-2022 00:00	21-Apr-2022 00:00	21-Apr-2022 00:00
					ES2213920-006	ES2213920-007	ES2213920-008	ES2213920-009	ES2213920-010
					Result	Result	Result	Result	Result
EA005P: pH by PC Titrator									
pH Value	----	0.01	pH Unit		**7.06**	**6.77**	**6.69**	**6.78**	**7.36**
EA006: Sodium Adsorption Ratio (SAR)									
^ Sodium Adsorption Ratio	----	0.01	-		**0.88**	**1.57**	**1.32**	**1.86**	**2.63**
EA010P: Conductivity by PC Titrator									
Electrical Conductivity @ 25°C	----	1	µS/cm		**509**	**685**	**520**	**986**	**966**
EA016: Calculated TDS (from Electrical Conductivity)									
Total Dissolved Solids (Calc.)	----	1	mg/L		**331**	**445**	**338**	**641**	**628**
EA065: Total Hardness as CaCO3									
Total Hardness as CaCO3	----	1	mg/L		**232**	**249**	**172**	**366**	**319**
ED037P: Alkalinity by PC Titrator									
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L		<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L		<1	<1	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L		**241**	**280**	**157**	**285**	**358**
Total Alkalinity as CaCO3	----	1	mg/L		**241**	**280**	**157**	**285**	**358**
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA									
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L		**12**	**86**	**88**	**176**	**122**
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	1	mg/L		**27**	**20**	**25**	**75**	**56**
ED093F: Dissolved Major Cations									
Calcium	7440-70-2	1	mg/L		**55**	**80**	**36**	**112**	**90**
Magnesium	7439-95-4	1	mg/L		**23**	**12**	**20**	**21**	**23**
Sodium	7440-23-5	1	mg/L		**31**	**57**	**40**	**82**	**108**
Potassium	7440-09-7	1	mg/L		**4**	**10**	**4**	**8**	**11**
EG005(ED093)F: Dissolved Metals by ICP-AES									
Aluminium	7429-90-5	0.10	mg/L		<0.10	<0.10	<0.10	<0.10	<0.10
Antimony	7440-36-0	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	<0.01
Arsenic	7440-38-2	0.01	mg/L		**0.06**	**0.01**	<0.01	<0.01	<0.01
Cadmium	7440-43-9	0.005	mg/L		<0.005	<0.005	<0.005	<0.005	<0.005
Chromium	7440-47-3	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	<0.01
Copper	7440-50-8	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	<0.01
Iron	7439-89-6	0.05	mg/L		**1.32**	**0.54**	**0.23**	**0.40**	**1.14**
Lead	7439-92-1	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	<0.01
Manganese	7439-96-5	0.01	mg/L		**0.14**	**3.74**	**0.10**	**0.10**	**0.52**
Nickel	7440-02-0	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	<0.01

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Sample ID	MB01A	MB02A	MB02B	MB03A	MB03B
				Sampling date / time	20-Apr-2022 00:00	20-Apr-2022 00:00	20-Apr-2022 00:00	21-Apr-2022 00:00	21-Apr-2022 00:00
Compound	CAS Number	LOR	Unit		ES2213920-006	ES2213920-007	ES2213920-008	ES2213920-009	ES2213920-010
					Result	Result	Result	Result	Result
EG005(ED093)F: Dissolved Metals by ICP-AES - Continued									
Zinc	7440-66-6	0.01	mg/L		<0.01	**0.01**	<0.01	**0.02**	<0.01
EG035F: Dissolved Mercury by FIMS									
Mercury	7439-97-6	0.0001	mg/L		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.7**	**0.7**	**1.1**	**0.2**	**0.6**
EK055G: Ammonia as N by Discrete Analyser									
Ammonia as N	7664-41-7	0.01	mg/L		**0.02**	**0.30**	<0.01	<0.01	**0.04**
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N	14797-65-0	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	<0.01
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N	14797-55-8	0.01	mg/L		<0.01	<0.01	**0.03**	**0.18**	<0.01
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N	----	0.01	mg/L		<0.01	<0.01	**0.03**	**0.18**	<0.01
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser									
Total Kjeldahl Nitrogen as N	----	0.1	mg/L		<0.1	**0.8**	<0.1	**0.1**	<0.1
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser									
^ **Total Nitrogen as N**	----	0.1	mg/L		<0.1	**0.8**	<0.1	**0.3**	<0.1
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	0.01	mg/L		**0.15**	**0.58**	**0.05**	**0.45**	**0.08**
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	<0.01
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**5.83**	**7.95**	**5.67**	**11.5**	**11.3**
ø **Total Cations**	----	0.01	meq/L		**6.09**	**7.71**	**5.28**	**11.1**	**11.4**
ø **Ionic Balance**	----	0.01	%		**2.20**	**1.50**	**3.55**	**1.71**	**0.40**
EP080/071: Total Petroleum Hydrocarbons									
C6 - C9 Fraction	----	20	µg/L		<20	<20	<20	<20	<20
C10 - C14 Fraction	----	50	µg/L		<50	<50	<50	<50	<50
C15 - C28 Fraction	----	100	µg/L		<100	<100	<100	<100	<100
C29 - C36 Fraction	----	50	µg/L		<50	<50	<50	<50	<50
^ **C10 - C36 Fraction (sum)**	----	50	µg/L		<50	<50	<50	<50	<50
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions									
C6 - C10 Fraction	C6_C10	20	µg/L		<20	<20	<20	<20	<20

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Sample ID	MB01A	MB02A	MB02B	MB03A	MB03B
				Sampling date / time	20-Apr-2022 00:00	20-Apr-2022 00:00	20-Apr-2022 00:00	21-Apr-2022 00:00	21-Apr-2022 00:00
Compound	CAS Number	LOR	Unit		ES2213920-006	ES2213920-007	ES2213920-008	ES2213920-009	ES2213920-010
					Result	Result	Result	Result	Result
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions - Continued									
^ **C6 - C10 Fraction minus BTEX (F1)**	C6_C10-BTEX	20	µg/L		<20	<20	<20	<20	<20
>C10 - C16 Fraction	----	100	µg/L		<100	<100	<100	<100	<100
>C16 - C34 Fraction	----	100	µg/L		<100	<100	<100	<100	<100
>C34 - C40 Fraction	----	100	µg/L		<100	<100	<100	<100	<100
^ **>C10 - C40 Fraction (sum)**	----	100	µg/L		<100	<100	<100	<100	<100
^ **>C10 - C16 Fraction minus Naphthalene (F2)**	----	100	µg/L		<100	<100	<100	<100	<100
EP080: BTEXN									
Benzene	71-43-2	1	µg/L		<1	<1	<1	<1	<1
Toluene	108-88-3	2	µg/L		<2	<2	<2	<2	<2
Ethylbenzene	100-41-4	2	µg/L		<2	<2	<2	<2	<2
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L		<2	**2**	<2	<2	<2
ortho-Xylene	95-47-6	2	µg/L		<2	**4**	<2	<2	<2
^ **Total Xylenes**	----	2	µg/L		<2	**6**	<2	<2	<2
^ **Sum of BTEX**	----	1	µg/L		<1	**6**	<1	<1	<1
Naphthalene	91-20-3	5	µg/L		<5	<5	<5	<5	<5
EP080S: TPH(V)/BTEX Surrogates									
1.2-Dichloroethane-D4	17060-07-0	2	%		**108**	**111**	**113**	**102**	**109**
Toluene-D8	2037-26-5	2	%		**106**	**108**	**107**	**99.0**	**107**
4-Bromofluorobenzene	460-00-4	2	%		**112**	**114**	**115**	**105**	**111**

Surrogate Control Limits

Sub-Matrix: **WATER**		Recovery Limits (%)	
Compound	*CAS Number*	*Low*	*High*
EP080S: TPH(V)/BTEX Surrogates			
1.2-Dichloroethane-D4	17060-07-0	71	137
Toluene-D8	2037-26-5	79	131
4-Bromofluorobenzene	460-00-4	70	128

Appendix D

Hydraulic conductivity analytical outputs

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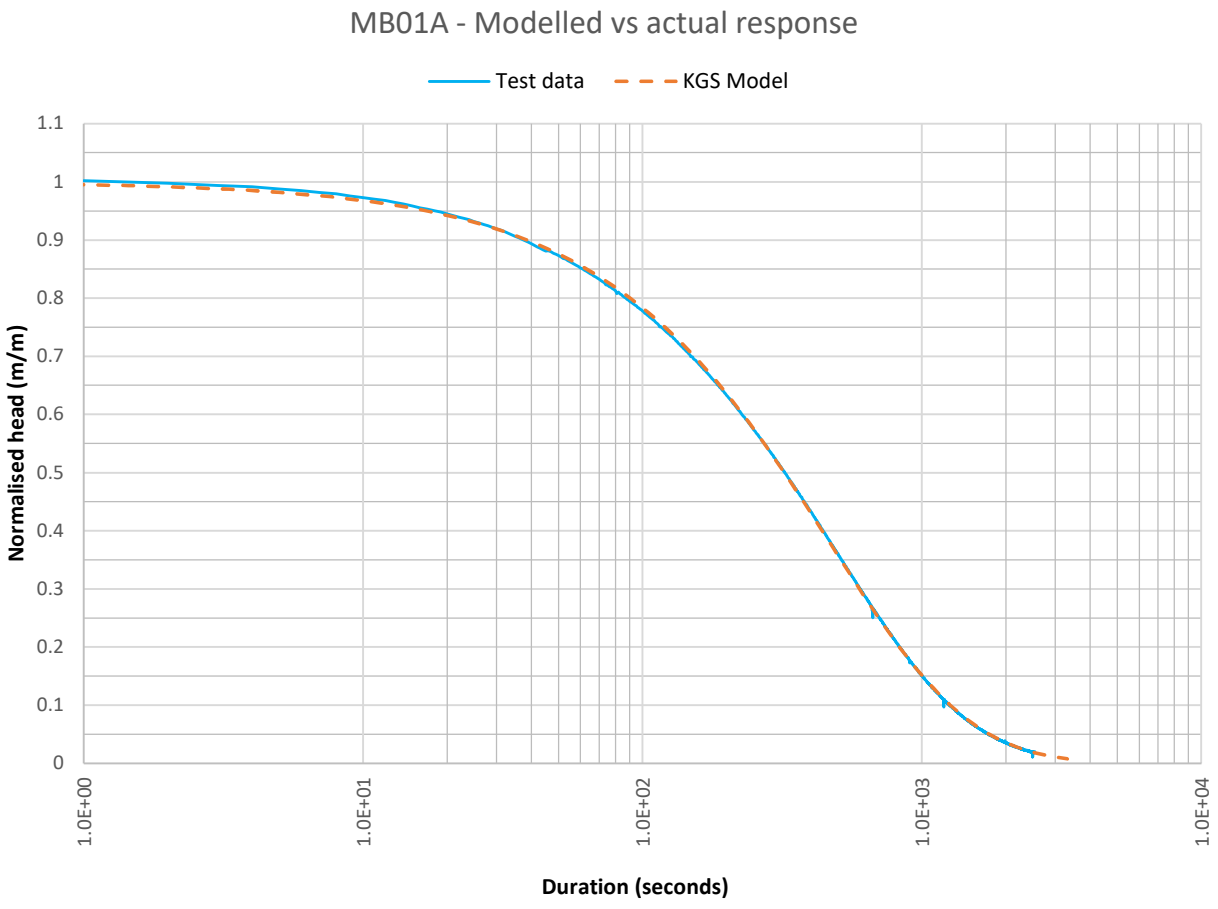
Permeability assessment

ID: MB01A

Client:	SMEC Australia Pty Limited	**Test type:**	Rising head test
Site:	Oven Mountain, Carrai NSW	**Equipment:**	Pneumatic apparatus
Project:	Oven Mountain Pumped Hydro	**Test start:**	15 February 2022; 14:16
Reference:	E210769	**Test finish:**	15 February 2022; 14:58
Field personnel:	AB	**Duration:**	42 minutes
Analysed by:	HJN	**Data method:**	Automated (transducer)

Testing stratigraphy:	Triassic Carrai Granodiorite	**Aquifer type:**	Unconfined
General description:	Granodiorite, fresh to slightly weathered	**Bore construction:**	Partial penetration
Drill method:	125 mm diameter air hammer	**Analytical model:**	KGS (Hyder et al. 1994)

Well type:	PVC monitoring bore	**Logger depth:**	15.03 m
Screen top depth:	28.5 m	**Initial water depth:**	8.43 m
Screen bottom depth:	34.5 m	**Final water depth:**	8.43 m
Screen length:	6 m	**Approximate recovery:**	100%
Casing radius:	25 mm	**Induced displacement:**	1.48 m
Well radius:	62.5 mm	**Water column height:**	26.08 m
Well skin radius:	- Note 1	**Saturated thickness:**	26.08 m Note 2



K = 5.4 x 10^{-7} m/s

Notes;

Note 1 well skin radius considered negligible the referenced analytical model;

Note 2 saturated thickness assumed to be equal to water column height for partially penetrating wells;

Reference (as accessed through Hydrosolve Inc - Aqtesolv software)

Hyder, Z, Butler, J, McElwee, C & Liu, W 1994. Slug tests in partially penetrating wells, *Water Resources Research* , vol. 30, no. 11, pp. 2945-2957.

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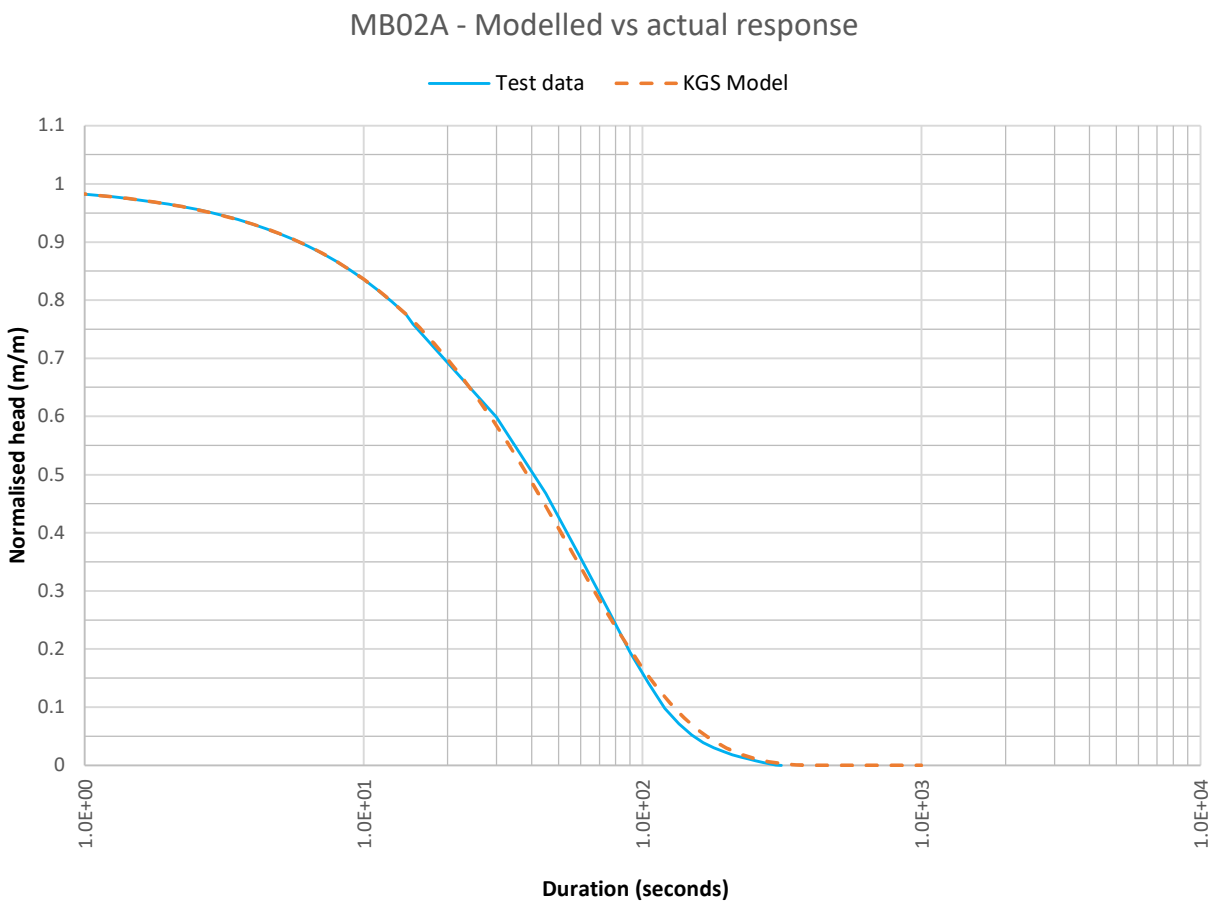
Permeability assessment

ID: MB02A

Client:	SMEC Australia Pty Limited	**Test type:**	Rising head test
Site:	Oven Mountain, Carrai NSW	**Equipment:**	Pneumatic apparatus
Project:	Oven Mountain Pumped Hydro	**Test start:**	15 February 2022; 09:45
Reference:	E210769	**Test finish:**	15 February 2022; 09:50
Field personnel:	HJN	**Duration:**	5 minutes
Analysed by:	HJN	**Data method:**	Automated (transducer)

Testing stratigraphy:	Triassic Carrai Granodiorite	**Aquifer type:**	Unconfined
General description:	Granodiorite, fresh to slightly weathered	**Bore construction:**	Partial penetration
Drill method:	125 mm diameter air hammer	**Analytical model:**	KGS (Hyder et al. 1994)

Well type:	PVC monitoring well	**Logger depth:**	23.73 m
Screen top depth:	25.6 m	**Initial water depth:**	19.42 m
Screen bottom depth:	31.6 m	**Final water depth:**	19.42 m
Screen length:	3.1 m	**Approximate recovery:**	100%
Casing radius:	25 mm	**Induced displacement:**	1.08 m
Well radius:	62.5 mm	**Water column height:**	12.18 m
Well skin radius:	- Note 1	**Saturated thickness:**	12.18 m Note 2



K = 4.3 x 10^{-6} m/s

Notes;

Note 1 well skin radius not accounted for in the referenced analytical model;

Note 2 saturated thickness assumed to be equal to water column height for partially penetrating wells;

Reference (as accessed through Hydrosolve Inc - Aqtesolv software)

Hyder, Z, Butler, J, McElwee, C & Liu, W 1994. Slug tests in partially penetrating wells, *Water Resources Research* , vol. 30, no. 11, pp. 2945-2957.

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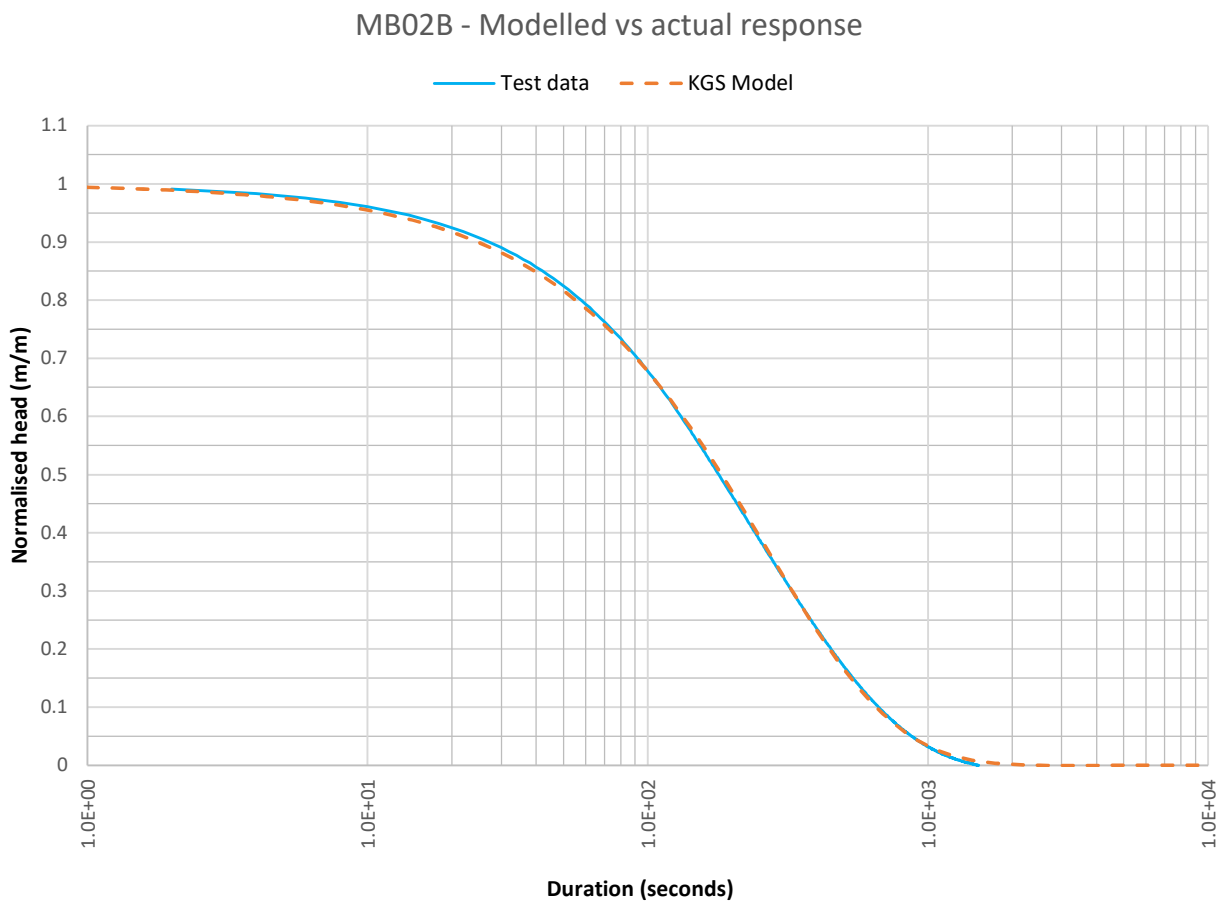
Permeability assessment

ID: MB02B

Client:	SMEC Australia Pty Limited	**Test type:**	Rising head test
Site:	Oven Mountain, Carrai NSW	**Equipment:**	Pneumatic apparatus
Project:	Oven Mountain Pumped Hydro	**Test start:**	20 April 2022; 12:57
Reference:	E210769	**Test finish:**	20 April 2022; 13:22
Field personnel:	AB	**Duration:**	24 minutes
Analysed by:	AB	**Data method:**	Automated (transducer)

Testing stratigraphy:	Triassic Carrai Granodiorite	**Aquifer type:**	Unconfined
General description:	Granodiorite, fresh to slightly weathered	**Bore construction:**	Partial penetration
Drill method:	152.4 mm diameter air hammer	**Analytical model:**	KGS (Hyder et al. 1994)

Well type:	PVC monitoring well	**Logger depth:**	43.13 m
Screen top depth:	173.5 m	**Initial water depth:**	18.57 m
Screen bottom depth:	185.5 m	**Final water depth:**	18.57 m
Screen length:	12 m	**Approximate recovery:**	100%
Casing radius:	25 mm	**Induced displacement:**	2.38 m
Well radius:	76.2 mm	**Water column height:**	166.93 m
Well skin radius:	- Note 1	**Saturated thickness:**	166.93 m Note 2



K = 5.0 x 10^{-7} m/s

Notes;

Note 1 well skin radius not accounted for in the referenced analytical model;

Note 2 saturated thickness assumed to be equal to water column height for partially penetrating wells;

Reference (as accessed through Hydrosolve Inc - Aqtesolv software)

Springer, R.K. and L.W. Gelhar, 1991. Characterization of large-scale aquifer heterogeneity in glacial outwash by analysis of slug tests with oscillatory response, Cape Cod, Massachusetts, U.S. Geol. Surv. Water Res. Invest. Rep. 91-4034, pp. 36-40

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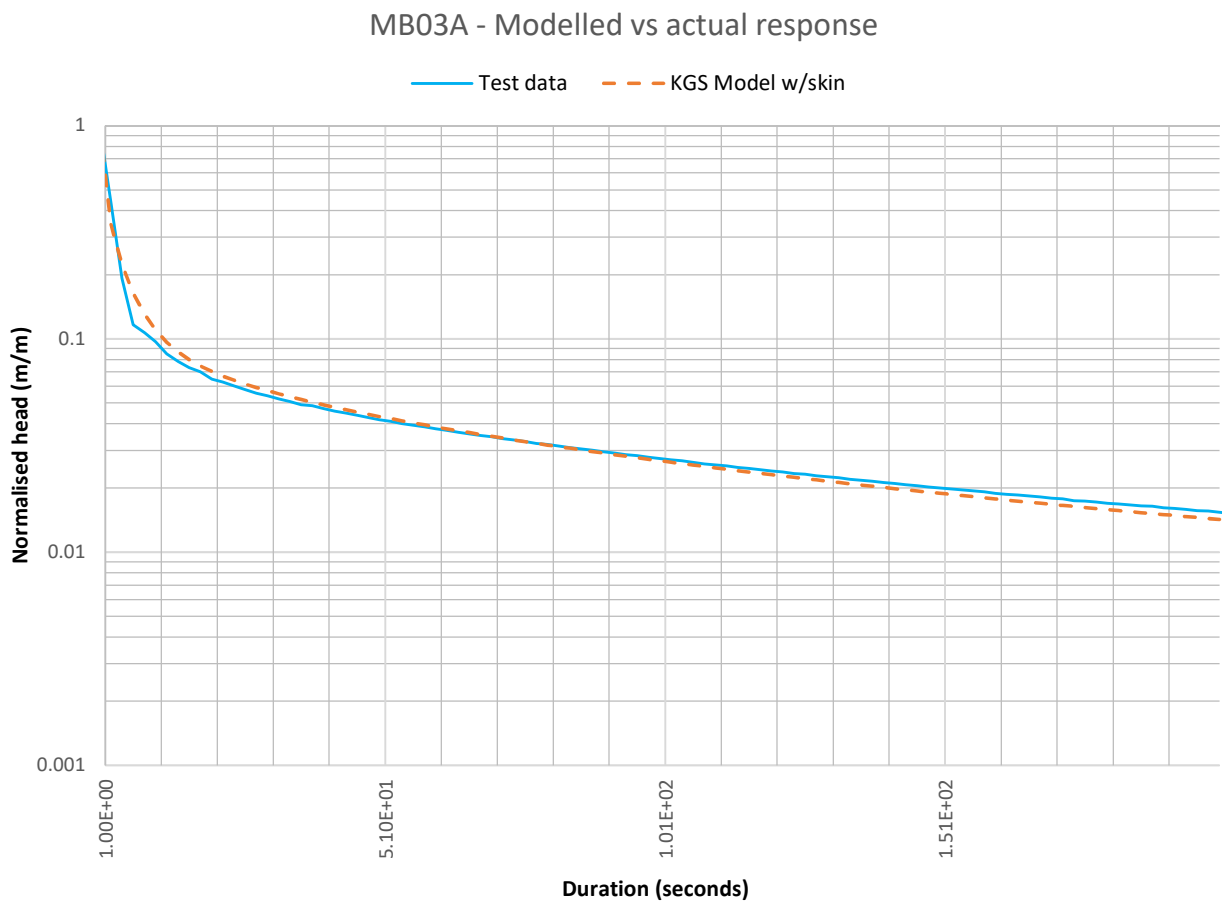
Permeability assessment

ID: MB03A

Client:	SMEC Australia Pty Limited	**Test type:**	Rising head test
Site:	Oven Mountain, Carrai NSW	**Equipment:**	Pneumatic apparatus
Project:	Oven Mountain Pumped Hydro	**Test start:**	21 April 2022; 09:12
Reference:	E210769	**Test finish:**	21 April 2022; 09:35
Field personnel:	AB	**Duration:**	22 minutes
Analysed by:	AB	**Data method:**	Automated (transducer)

Testing stratigraphy:	Triassic Carrai Granodiorite	**Aquifer type:**	Unconfined
General description:	Granodiorite, fresh to slightly weathered	**Bore construction:**	Partial penetration
Drill method:	152.4 mm diameter air hammer	**Analytical model:**	KGS (Hyder et al. 1994) w/skin

Well type:	PVC monitoring well	**Logger depth:**	11.72 m
Screen top depth:	15 m	**Initial water depth:**	3.127 m
Screen bottom depth:	21 m	**Final water depth:**	3.127 m
Screen length:	6 m	**Approximate recovery:**	100%
Casing radius:	25 mm	**Induced displacement:**	2.71 m
Well radius:	76.2 mm	**Water column height:**	17.873 m
Well skin radius:	0.4 m	**Saturated thickness:**	17.873 m Note 1



K = 2.0 x 10^{-5} m/s

Notes;

Note 1 saturated thickness assumed to be equal to water column height for partially penetrating wells;

Reference (as accessed through Hydrosolve Inc - Aqtesolv software)

Hyder, Z, Butler, J, McElwee, C & Liu, W 1994. Slug tests in partially penetrating wells, *Water Resources Research* , vol. 30, no. 11, pp. 2945-2957.

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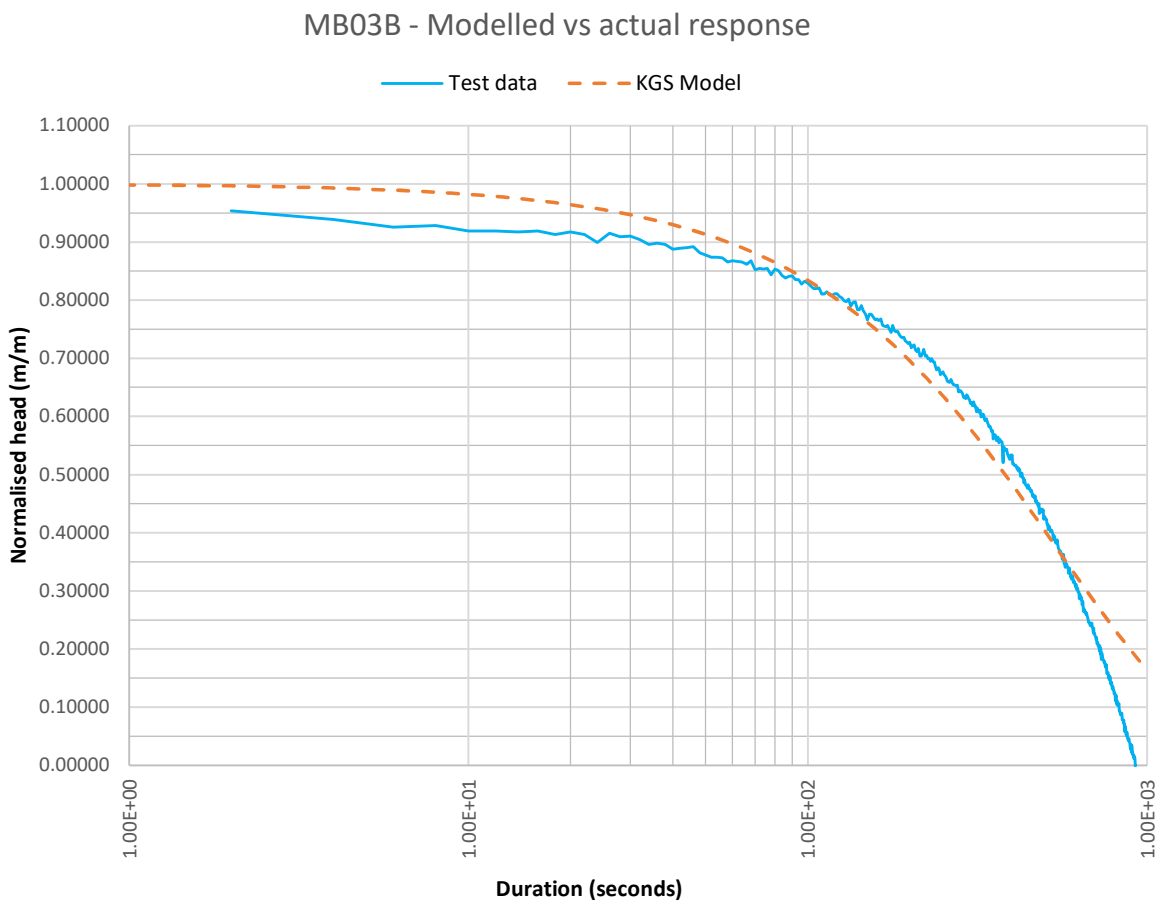
Permeability assessment

ID: MB03B

Client:	SMEC Australia Pty Limited	**Test type:**	Rising head test
Site:	Oven Mountain, Carrai NSW	**Equipment:**	Pneumatic apparatus
Project:	Oven Mountain Pumped Hydro	**Test start:**	21 April 2022; 10:10
Reference:	E210769	**Test finish:**	21 April 2022; 10:25
Field personnel:	AB	**Duration:**	15 minutes
Analysed by:	AB	**Data method:**	Automated (transducer)

Testing stratigraphy:	Triassic Carrai Granodiorite	**Aquifer type:**	Unconfined
General description:	Granodiorite, fresh to slightly weathered	**Bore construction:**	Partial penetration
Drill method:	152.4 mm diameter air hammer	**Analytical model:**	KGS (Hyder et al. 1994)

Well type:	PVC monitoring well	**Logger depth:**	29.61 m
Screen top depth:	86 m	**Initial water depth:**	1.85 m
Screen bottom depth:	98 m	**Final water depth:**	1.85 m
Screen length:	12 m	**Approximate recovery:**	100%
Casing radius:	25 mm	**Induced displacement:**	0.1 m
Well radius:	67.2 mm	**Water column height:**	96.15 m
Well skin radius:	- Note 1	**Saturated thickness:**	96.15 m Note 2



K = 1.7 x 10^{-7} m/s

Notes;

Note 1 well skin radius not accounted for in the referenced analytical model;

Note 2 saturated thickness assumed to be from base of alluvium observed to measured water depth;

Reference (as accessed through Hydrosolve Inc - Aqtesolv software)

Hyder, Z, Butler, J, McElwee, C & Liu, W 1994. Slug tests in partially penetrating wells, *Water Resources Research* , vol. 30, no. 11, pp. 2945-2957.

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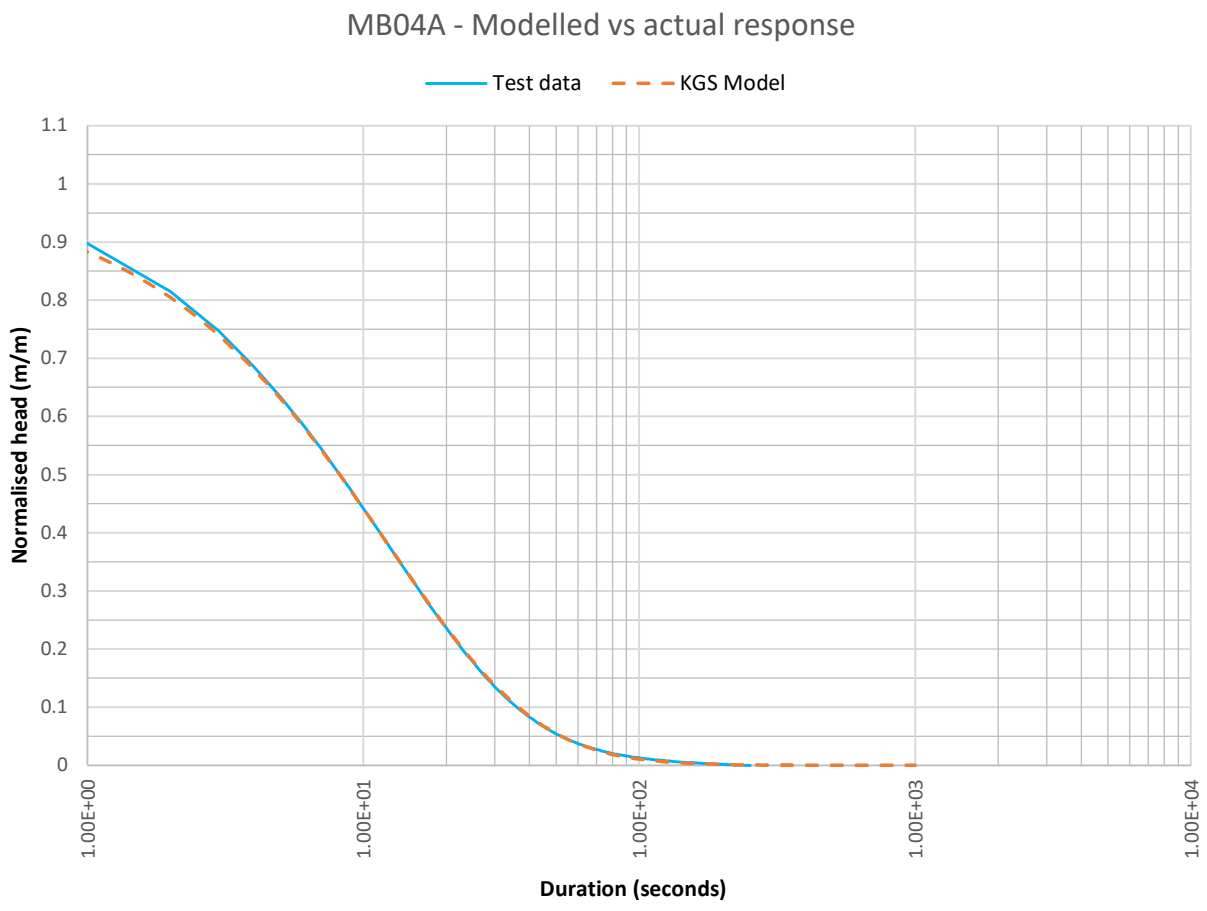
Permeability assessment

ID: MB04A

Client:	SMEC Australia Pty Limited	**Test type:**	Rising head test
Site:	Oven Mountain, Carrai NSW	**Equipment:**	Pneumatic apparatus
Project:	Oven Mountain Pumped Hydro	**Test start:**	17 February 2022; 10:25
Reference:	E210769	**Test finish:**	17 February 2022; 10:29
Field personnel:	AB	**Duration:**	4 minutes
Analysed by:	HJN	**Data method:**	Automated (transducer)

Testing stratigraphy:	Triassic Carrai Granodiorite	**Aquifer type:**	Unconfined
General description:	Granodiorite, fresh to slightly weathered	**Bore construction:**	Partial penetration
Drill method:	125 mm diameter air hammer	**Analytical model:**	KGS (Hyder et al. 1994)

Well type:	PVC monitoring well	**Logger depth:**	5.15 m
Screen top depth:	6.35 m	**Initial water depth:**	0.34 m
Screen bottom depth:	9.35 m	**Final water depth:**	0.34 m
Screen length:	3 m	**Approximate recovery:**	100%
Casing radius:	25 mm	**Induced displacement:**	2.83 m
Well radius:	62.5 mm	**Water column height:**	9.01 m
Well skin radius:	- Note 1	**Saturated thickness:**	9.01 m Note 2



K = 2.8 x 10^{-5} m/s

Notes;

Note 1 well skin radius not accounted for in the referenced analytical model;

Note 2 saturated thickness assumed to be from base of alluvium observed to measured water depth;

Reference (as accessed through Hydrosolve Inc - Aqtesolv software)

Hyder, Z, Butler, J, McElwee, C & Liu, W 1994. Slug tests in partially penetrating wells, *Water Resources Research* , vol. 30, no. 11, pp. 2945-2957.

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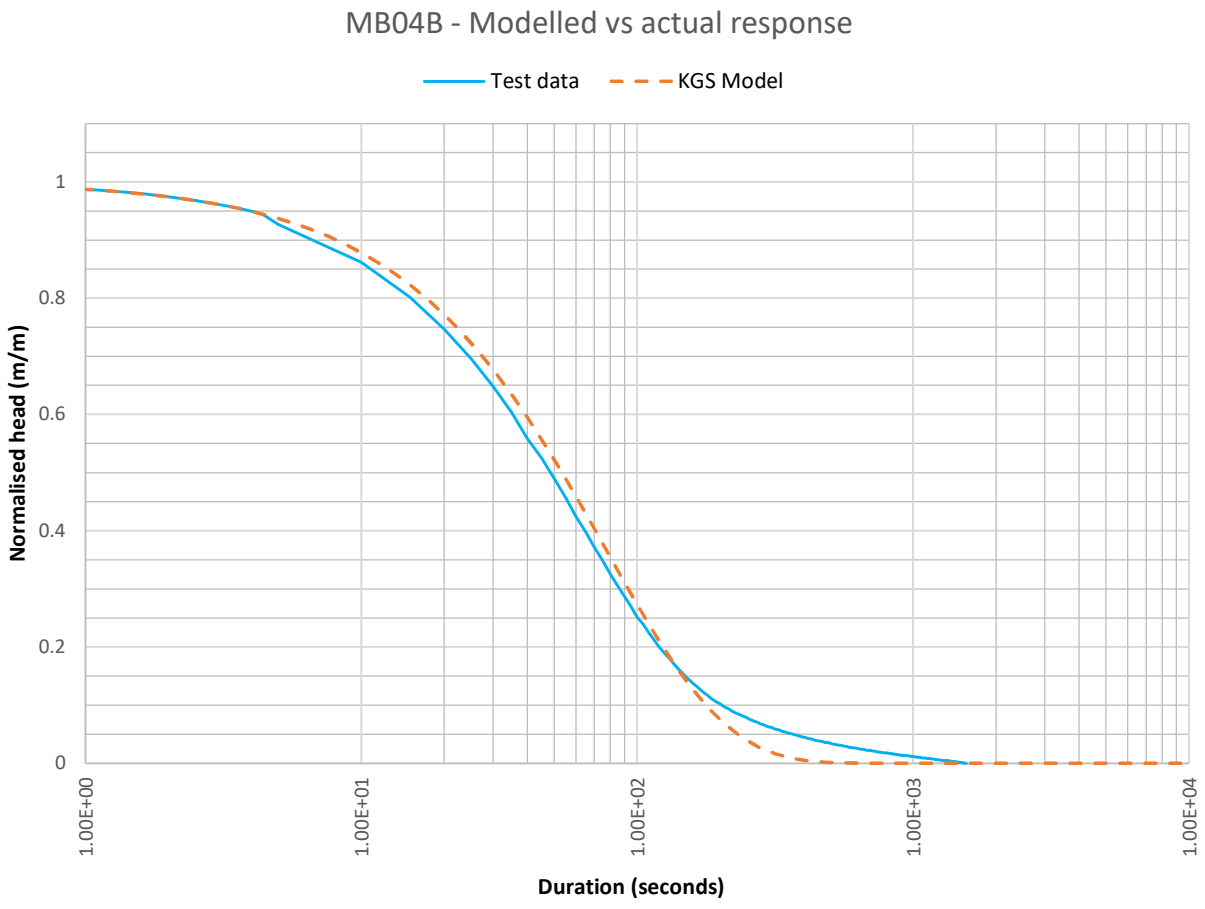
Permeability assessment

ID: MB04B

Client:	SMEC Australia Pty Limited	**Test type:**	Rising head test
Site:	Oven Mountain, Carrai NSW	**Equipment:**	Pneumatic apparatus
Project:	Oven Mountain Pumped Hydro	**Test start:**	17 February 2022; 09:05
Reference:	E210769	**Test finish:**	17 February 2022; 09:31
Field personnel:	AB	**Duration:**	26 minutes
Analysed by:	HJN	**Data method:**	Automated (transducer)

Testing stratigraphy:	Triassic Carrai Granodiorite	**Aquifer type:**	Unconfined
General description:	Granodiorite, fresh to slightly weathered	**Bore construction:**	Partial penetration
Drill method:	125 mm diameter air hammer	**Analytical model:**	Springer and Gehlar (1991)

Well type:	PVC monitoring well	**Logger depth:**	22.16 m
Screen top depth:	52.7 m	**Initial water depth:**	2.09 m
Screen bottom depth:	58.7 m	**Final water depth:**	2.11 m
Screen length:	6 m	**Approximate recovery:**	98%
Casing radius:	25 mm	**Induced displacement:**	2.87 m
Well radius:	62.5 mm	**Water column height:**	56.61 m
Well skin radius:	- Note 1	**Saturated thickness:**	56.61 m Note 2



K = 3.3 x 10^{-6} m/s

Notes;

Note 1 well skin radius not accounted for in the referenced analytical model;

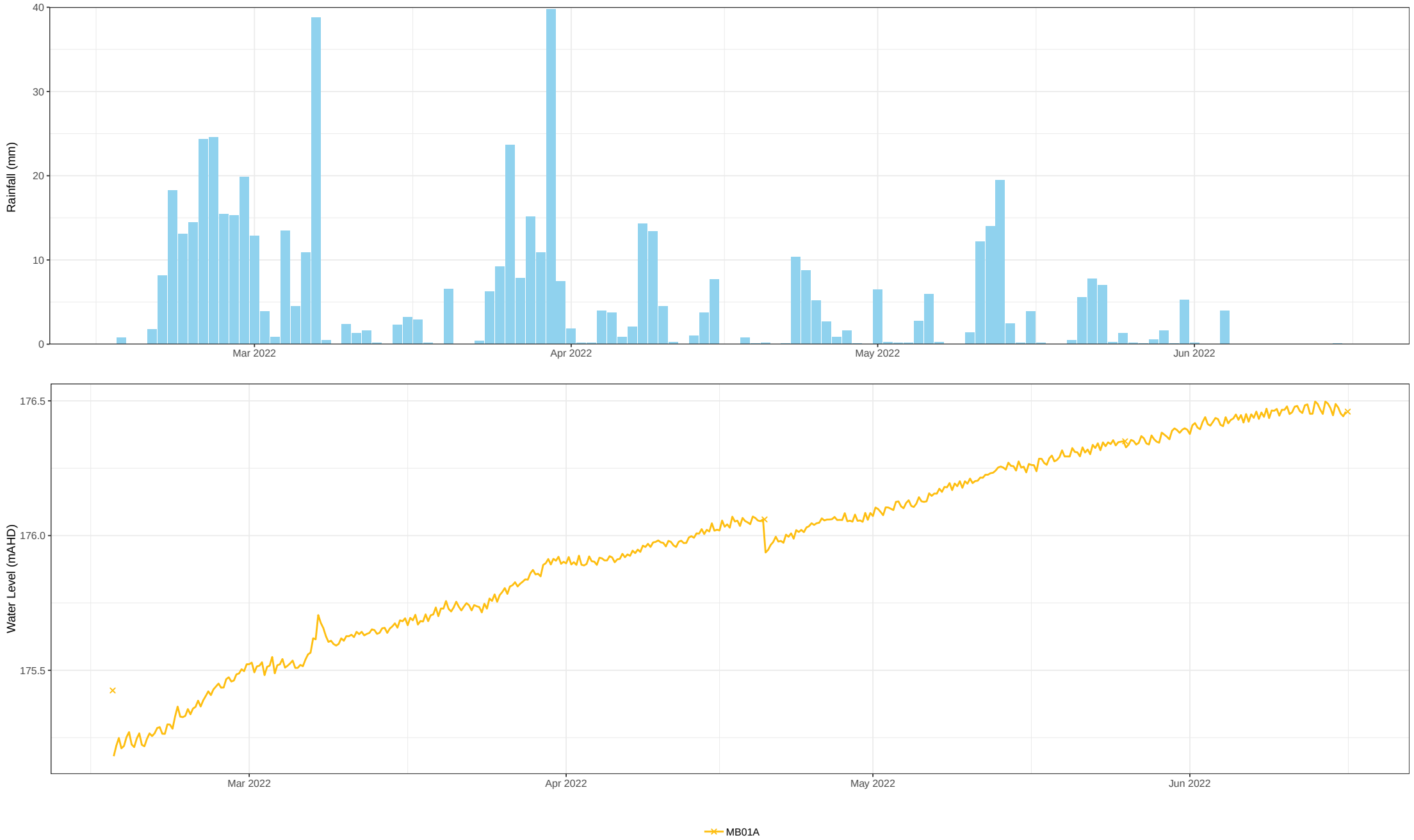
Note 2 saturated thickness assumed to be from base of alluvium observed to measured water depth;

Reference (as accessed through Hydrosolve Inc - Aqtesolv software)

Springer, R.K. and L.W. Gelhar, 1991. Characterization of large-scale aquifer heterogeneity in glacial outwash by analysis of slug tests with oscillatory response, Cape Cod, Massachusetts, U.S. Geol. Surv. Water Res. Invest. Rep. 91-4034, pp. 36-40

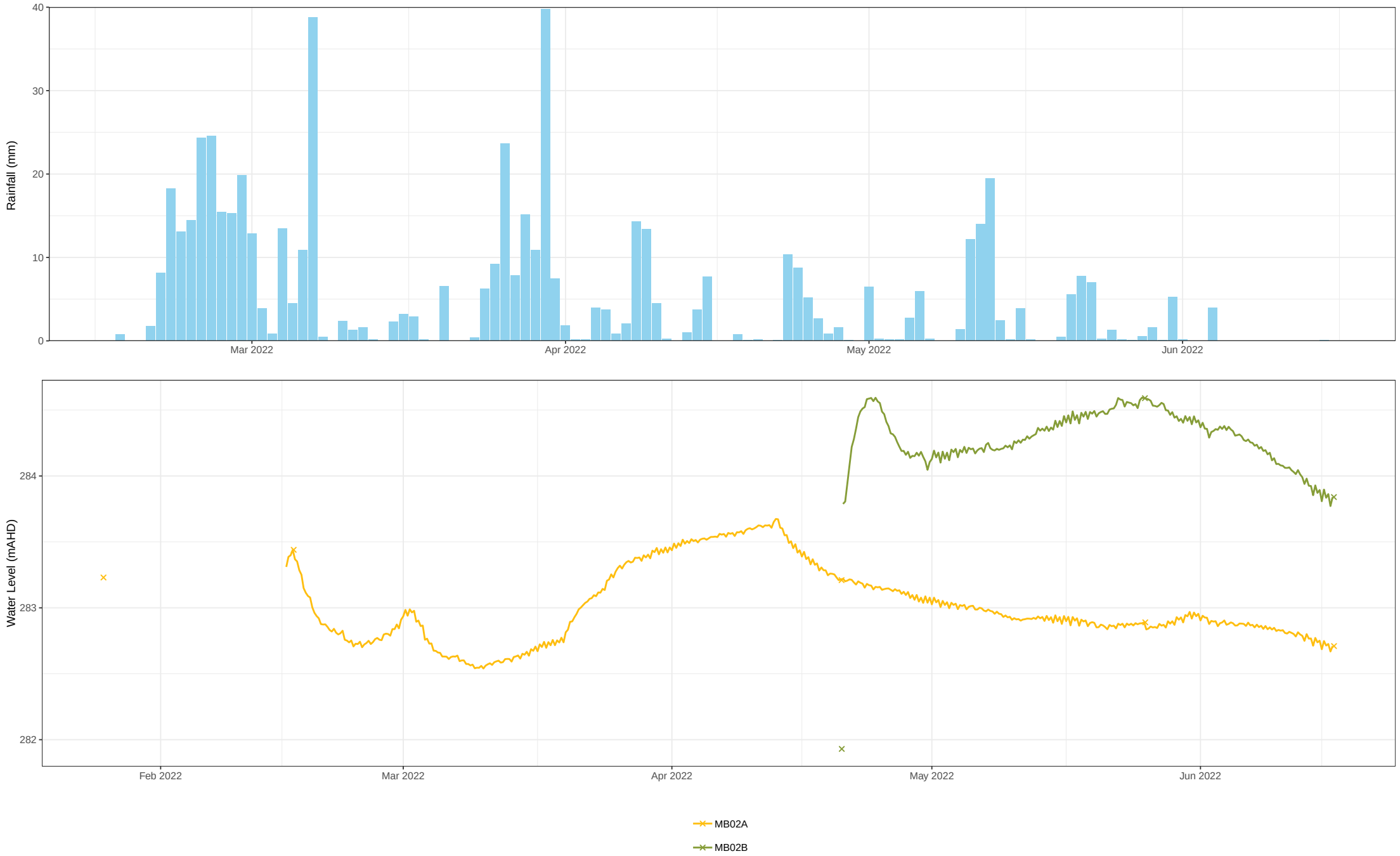
Appendix E
Groundwater level hydrographs

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Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
http://www.longpaddock.qld.gov.au/silo

Groundwater level times series data − MB01A
Oven Mountain Pumped Hydro Energy Storage − SMEC Australia Pty Limited
Stage one hydrogeological drilling and testing
Appendix E.1



Groundwater level times series data − MB02A/B

Oven Mountain Pumped Hydro Energy Storage − SMEC Australia Pty Limited

Stage one hydrogeological drilling and testing

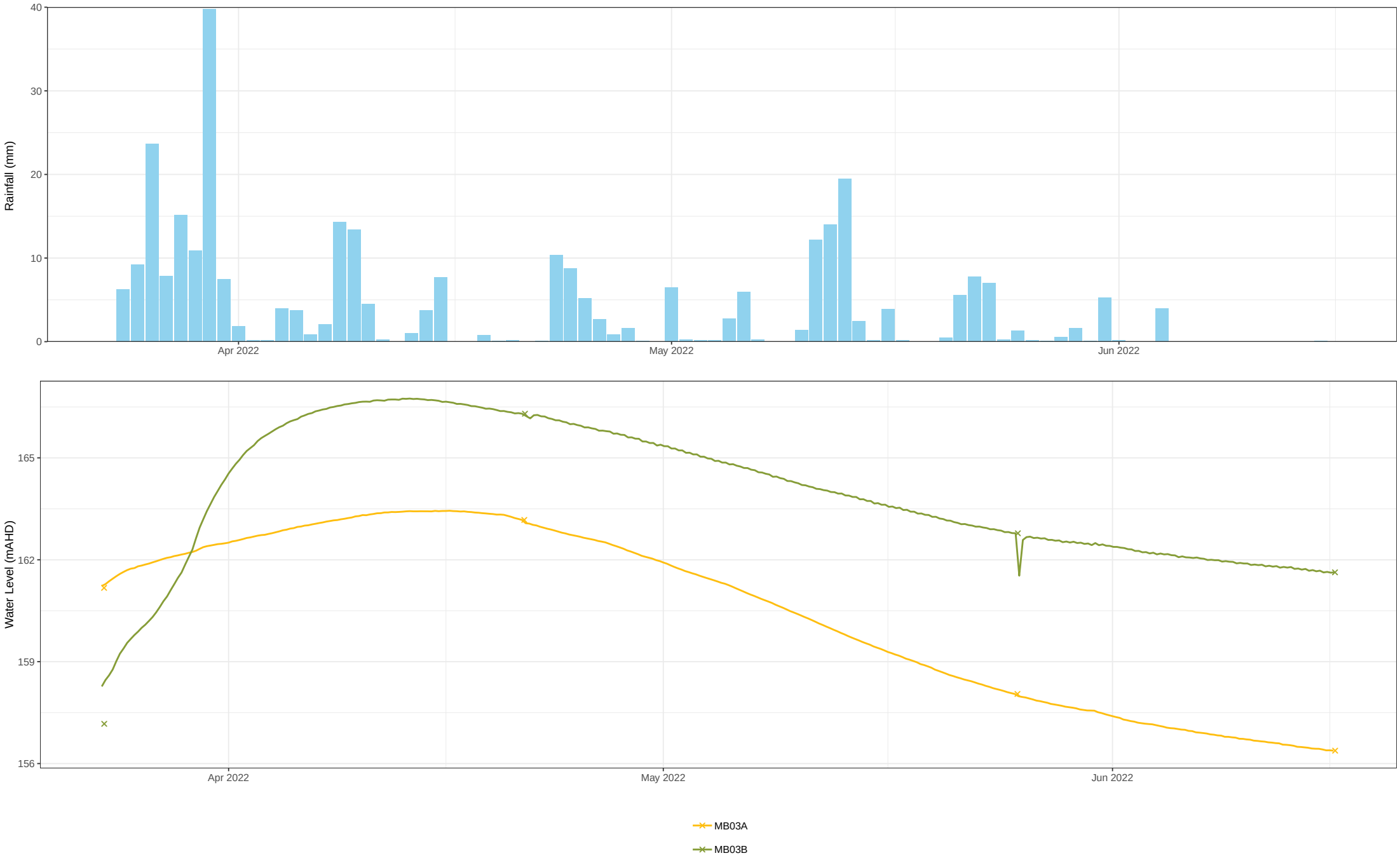
Appendix E.2

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Notes

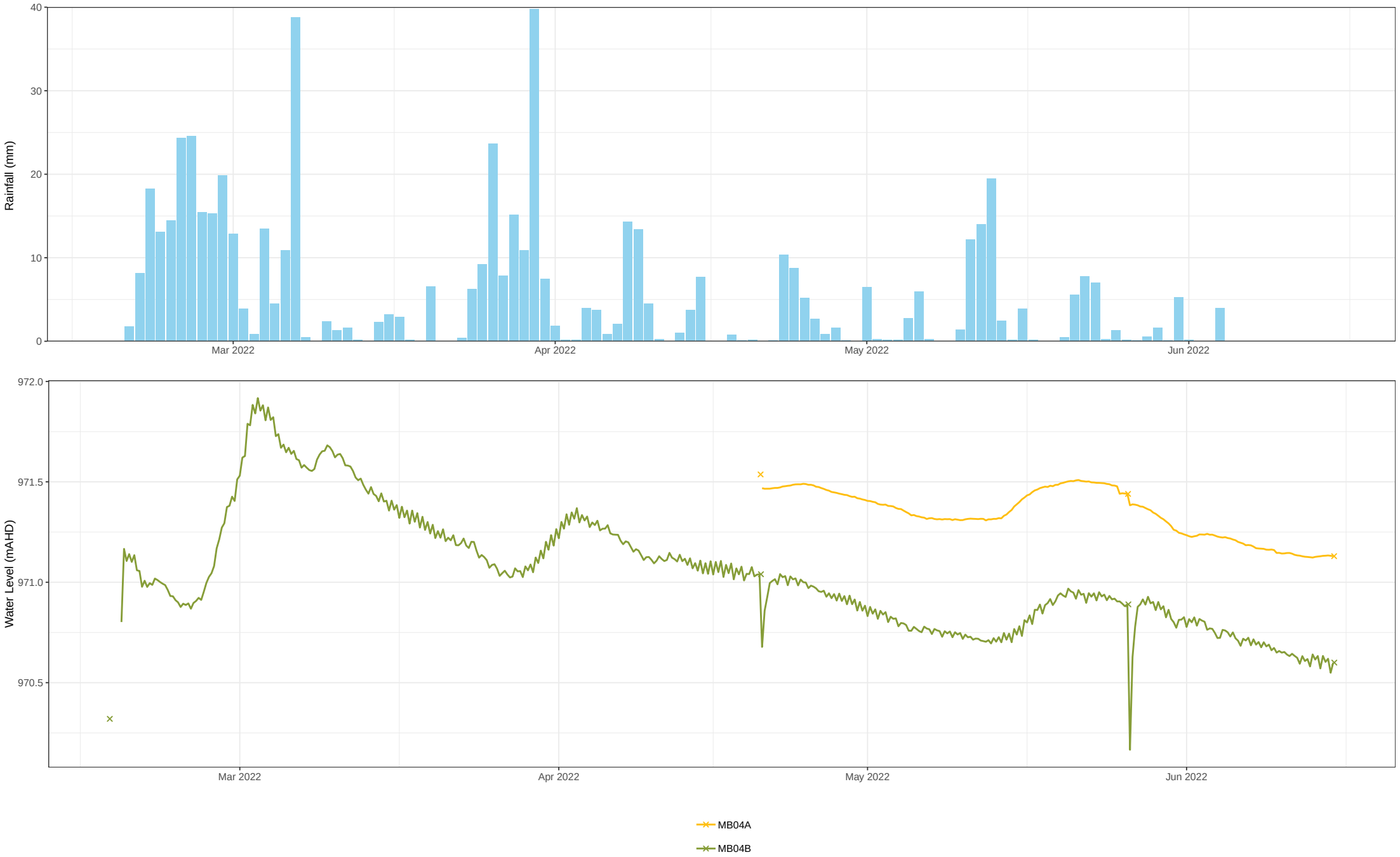
Rainfall measured at East Kunderang, Kenebree (station 57013)

http://www.longpaddock.qld.gov.au/silo



Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
http://www.longpaddock.qld.gov.au/silo

Groundwater level times series data − MB03A/B
Oven Mountain Pumped Hydro Energy Storage − SMEC Australia Pty Limited
Stage one hydrogeological drilling and testing
Appendix E.3



Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
http://www.longpaddock.qld.gov.au/silo

Groundwater level times series data − MB04A/B
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Stage one hydrogeological drilling and testing
Appendix E.4

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Attachment B

Isotope assessment

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Report

To	Henry Noakes, Senior Hydrogeologist, EMM Consulting	Date	26/11/2022
From	Dr Dioni I Cendón – ANSTO	Ref/File No. ANSTO C-1834	
Subject	Groundwater residence time assessment at the Carrai Granodiorite (NSW)		

Introduction

This report has been prepared by Dr Dioni I. Cendón from the Australian Nuclear Science and Technology Organisation (ANSTO) for EMM Consulting. The quotation for the project was prepared and delivered on 24th of May 2022 according to requests provided by Henry Noakes (Senior Hydrogeologist) from EMM Consulting. Additional advice on sample collection and protocols was provided together with the quote. Sampling was carried out by EMM Consulting personnel following their own field-parameter stabilisation protocols. Ancillary analysis needed for groundwater age interpretation (major ions) was conducted by EMM Consulting and analysed by an external laboratory. The final document was reviewed by Dr Liza McDonough from ANSTO on 29th of November 2022.

Seven groundwater samples were collected between the 24th and 26th of May 2022 and sent to ANSTO for analysis. Upon arrival, tritium (^{3}H) and radiocarbon ($^{14}C_{DIC}$) samples were sent to the respective laboratories for processing with samples logged and analytical codes assigned (Table 1). Results for ^{14}C of dissolved inorganic carbon $^{14}C_{DIC}$ were reported on the 25th of October 2022, with ^{3}Hresults reported on the 25th of November 2022 for available samples (Appendix 1).

Table 1 Samples received, and codes assigned by the respective laboratories.

Bore ID	Sample Date	Aquifer	$^{14}C_{DIC}$	^{3}H (tritium)
MB02A	25/05/2022	Carrai Granodiorite	OZAT93	2022/0147T-2
MB02B	25/05/2022	Carrai Granodiorite	OZAT94	2022/0147T-3
MB03A	25/05/2022	Parrabel Beds	OZAT95	2022/0147T-4
MB03B	25/05/2022	Parrabel Beds	OZAT96	2022/0147T-5
MB04A	26/05/2022	Carrai Granodiorite	OZAT97	2022/0147T-6
MB04B	26/05/2022	Carrai Granodiorite	OZAT98	2022/0147T-7
HA2202	24/05/2022	Carrai Granodiorite	OZAT92	2022/0147T-1

We assume these set of groundwater samples to be representative of the formations sampled. If the monitoring wells sampled were of new construction, we assume they were appropriately developed, eliminating the possibility of modern drilling fluids. Similarly, we assume no modern surface water was reinjected during development that could interfere with isotopic results.

Deliverables

As per ANSTO 24th of May quote (20002544), *"ANSTO will provide analytical isotopic expertise to enable assessment of groundwater residence times (groundwater dating) based on tritium and radiocarbon results from the Carrai Granodiorite (NSW). ANSTO will perform analysis of up to 8 radiocarbon samples in groundwater samples provided by EMM Consulting. Necessary information for analysis and interpretation of radiocarbon groundwater residence times include: Physico-chemical parameters (T, pH, SC, Eh), major ion analysis including alkalinity of groundwater sample".*

All wells for sampling have been selected by EMM Consulting, based on their local knowledge. It was recommended that EMM Consulting's hydrogeologist discuss sampling protocols with ANSTO prior to sample collection. ANSTO provided details of our field protocols for sampling of ^{3}H and $^{14}C_{DIC}$.

As part of the groundwater residence time interpretation, carbonate saturation indices were calculated using the WATEQ4F thermodynamic database in the PHREEQC interactive program (version

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3.62). The ^{14}C corrections and inverse modelling calculations were performed in NETPATH-XL (Plummer et al., 1994; Parkhurst and Charlton, 2008). Single well correction analysis was performed.

Location and Geology

The Carrai Granodiorite is located some 66 km northwest of Kempsey in the New England region of New South Wales (NSW). The area is bordered by the Macleay River in its northern side and forms an elevated plateau about 940 m asl. No other data has been provided regarding location of monitoring wells sampled or their topographic relationship to each other. The Carrai outcropping igneous materials cover an area of approximately 150 km^2 in the south-eastern part of the New England Fold Belt (Leitch, 1976). Succinct descriptions of the lithologies intersected during drilling of wells were provided. All wells are screened within two main units the Triassic Carrai Granodorite and the Permian Parrabel Beds or their weathering and/or alteration products. The Carrai Granodiorite is described by EMM Consulting as a coarse grained, felsic, crystalline igneous rocks including granodiorite, monzogranite and leucogranite. The granodiorite shows a shallow weathering profile (≤9 m depth) with strength typically increasing with depth. This material constitutes the dominant geology underlying the study area. The Parrabel Beds are described as fine to coarse grained sedimentary rocks including diamictite, conglomerate, sandstone, mudstone, limestone and tuff. Highly metamorphosed within the project area by the Carrai Granodiorite intrusion, forming an aureole contact of hornfels and meta-sediments. The contacts between the granodiorite and country rock are sharp and the metamorphism extends to about 200 m from the contact (Leitch, 1976). The Permian unit underlies most of the western catchment. Considering the available data, we expect fracture flow and/or near vertical slaty cleavage in rocks surrounding the granodiorite to be an important mechanism for groundwater movement below the weathered surface materials.

Sample details, as provided by EMM Consulting are available in Table 2.

Table 2 Monitoring bores, sampling date, assigned aquifer units and screen details. (m bgl= meters below ground level).

Bore ID	Sample Date	Aquifer/Lithology/Age	Screen from (m bgl)	Screened To (m bgl)	Screen Mid-point (m)
MB02A	25/05/2022	Carrai Granodiorite (Triassic)	25.6	31.6	28.6
MB02B	25/05/2022	Carrai Granodiorite (Triassic)	173.5	185.5	179.5
MB03A	25/05/2022	Parrabel Beds (Permian)	15	21	18
MB03B	25/05/2022	Parrabel Beds (Permian)	86	98	92
MB04A	26/05/2022	Carrai Granodiorite (Triassic)	6.35	9.35	7.85
MB04B	26/05/2022	Carrai Granodiorite (Triassic)	46.7	58.7	52.7
HA2202	24/05/2022	Carrai Granodiorite (Triassic)	0.4	0.9	0.65

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Methodology

Physicochemical parameters and major ions

Physicochemical parameters and major ion results were facilitated by EMM Consulting. Calculations necessary to assess electrical neutrality, dissolved element speciation and saturation indices for common mineral phases were undertaken using the PHREEQC interactive program (version 3.62) and the WATEQ4F thermodynamic database (Parkhurst & Appelo 1999). Major ion results for the seven samples analysed for natural radioactive traces were complemented with an additional ten samples recovered from the same area. Results have been used as provided.

Tritium and radiocarbon

Samples for ^{3}H were analysed at ANSTO following methods outlined in Cendón et al. (2014). Tritium was measured by counting beta decay events in liquid scintillation counters (LSC) using Perkin Elmer Quantulus™ instruments. Each of the samples and standards is counted for 2000 minutes over a period of 4+ weeks in 70-minute cycles to reduce bias created by fluctuations in cosmic radiation. A narrow counting window between 2 – 20 keV is selected to ensure sample & standard data has the lowest possible contribution from background radiation, thus further reducing the lower limit of detection. A 10 mL sample aliquot was mixed with the scintillation compound that releases a photon when struck by a beta particle. Photomultiplier tubes in the counter convert the photons to electrical pulses that are counted over 51 cycles, each of 20 minutes duration. The ^{3}H concentrations were expressed in tritium units (TU) with a combined standard uncertainty for the data set of ± 0.09 TU and quantification limit of 0.07 TU.

The ^{14}C samples were processed and analysed at ANSTO where the dissolved inorganic carbon (DIC) was converted into CO_2 by acidifying the samples with H_3PO_4 and extracting the liberated CO_2 gas using a cryogenic custom-built extraction line. The CO_2 sample was then heated in a sealed glass tube, containing baked CuO, Ag wire and Cu wire, at 600 °C for 2 hours to remove any sulfur compounds that may have been liberated from the groundwater sample during CO_2 extraction. The CO_2 sample was then converted into graphite by reducing it with excess hydrogen gas in the presence of an iron catalyst at 600 °C.

The ^{14}C contents (Cartwright et al., 2020; Meredith et al., 2018) were measured by accelerator mass spectrometry (AMS) using the ANSTO 1MV accelerator, VEGA. The ^{14}C results were reported as normalised percent Modern Carbon (pMC) with an average 1 σ error of 0.35 pMC. Radiocarbon reporting calculations followed the protocols outlined in Stuiver and Polach (1977). The uncorrected ages quoted in the laboratory report (Appendix 1) are 'conventional radiocarbon ages' (years BP) and not calendar ages. This method assumes that atmospheric ^{14}C levels have been constant in the past and uses a half-life of 5568 years. All ^{14}C measurements were normalised against the oxalic acid international standard (HOxI). Isotopic fractionation normalisation of all sample activities is to the base of $\delta^{13}C = -25‰$, relative to PDB. The $\delta^{13}C$ isotopic composition of the graphite target was determined by AMS with an average precision of 0.66‰. The $\delta^{13}C$ is used in the correction of radiocarbon data. In general, direct water $\delta^{13}C_{DIC}$ is preferred for radiocarbon assessments as it better represents aquifer conditions. However, these were not available and graphite target $\delta^{13}C$ are used instead.

Geochemical modelling

Geochemical models have further been applied to assess dilution of ^{14}C in the aquifer matrix. The code NETPATH-XL (Plummer et al., 1994; Parkhurst and Charlton, 2008) has been used to calculate

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final groundwater residence times on a *"one well"* approach without mass transfer along a flow path. Further details on this are provided in the Results and Discussion.

Results and Discussion

Specific conductance and major ions

In general, samples have a wide range of specific conductance (SC), varying from 38 µS/cm in OM5 to 1240 µS/cm in OM7 (Figure 1, Table 3). Higher values coincide with samples recovered in the Permian Parrabel Beds. Samples from the Carrai Granodiorite tend to increase in SC with depth. Groundwater samples, excluding those with unacceptable charge balance errors (CBEs), vary in water type from Ca-HCO_3 to Na-HCO_3 and NaCl. High CBEs are observed in all low EC samples (<100 µS/cm), except for sample OM1 that displays the highest CBE while having an SC of 1050 µS/cm. High SO_4, Ca and Mg detection levels in the major ion analysis contribute to unacceptable CBEs (>10%) (MB04A, HA2201, OM1, OM4, OM5) and poor CBEs (>5%) (MB04B, HA2203, OM5a).

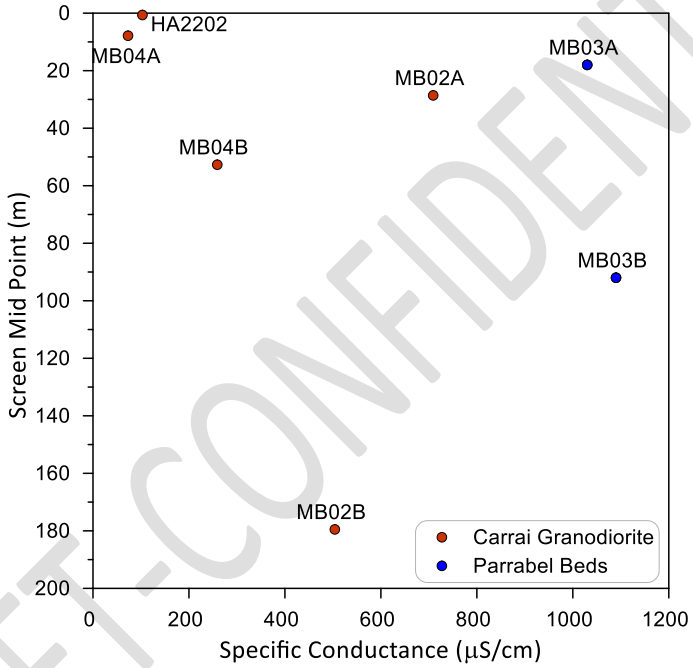


Figure 1 Relationship between depth to mid-screen point and observed specific conductance.

Table 3 Specific Conductance (SC) and major ion results (mmol/L) as provided by EMM Consulting with calculated charge balance error (CBE %). NP = not provided; bdl= below detection limits; na= not applicable.

Bore ID	Sample Date	Aquifer	SC= Electrical Conductivity @ 25°C	pH - Lab	HCO_3	Cl	SO_4	Na	K	Ca	Mg	Ca/Mg	Charge Balance	Water type
			µS/cm	pH Unit	mmol/L	mmol/L	mmol/L	mmol/L	mmol/L	mmol/L	mmol/L		(CBE % error)	
MB02A	25/05/2022	Carrai Granodiorite	709	7.19	5.5	0.9	0.36	2.5	0.1	1.65	0.41	4.0	-4.2	Ca-HCO_3
MB02B	25/05/2022	Carrai Granodiorite	504	7.3	3.5	0.8	0.26	1.8	0.1	1.17	0.49	2.4	3.0	Ca-HCO_3
MB03A	25/05/2022	Parrabel Beds	1030	7.29	4.7	2.0	1.80	3.4	0.1	2.37	0.78	3.0	-3.2	Ca-HCO_3
MB03B	25/05/2022	Parrabel Beds	1090	7.79	6.6	1.5	1.36	5.3	0.2	1.75	0.66	2.7	-3.3	Na-HCO_3
MB04A	26/05/2022	Carrai Granodiorite	73	6.18	0.7	0.2	bdl	0.5	0.0	0.02	bdl	na	-21.2	Na-HCO_3
MB04B	26/05/2022	Carrai Granodiorite	259	9.46	0.1	0.2	0.09	1.2	0.3	0.52	bdl	na	6.5	Na-Cl
HA2202	24/05/2022	Carrai Granodiorite	103	6.22	0.7	0.4	bdl	0.8	0.1	bdl	bdl	na	-11.7	Na-HCO_3
HA2201	24/05/2022	NP	77	6.26	0.9	0.1	0.11	0.7	0.1	0.05	0.04	1.2	-16.8	Na-HCO_3
HA2203	24/05/2022	NP	116	6.07	0.8	0.4	0.08	0.7	0.1	0.25	0.21	1.2	9.4	Na-HCO_3
OM1	24/05/2022	NP	1050	3.93	na	0.4	5.33	0.9	0.3	0.65	2.18	0.3	-27.5	Mg-SO_4
OM2	24/05/2022	NP	128	4.94	0.1	0.1	0.39	0.4	0.1	0.10	0.16	0.6	-0.3	Na-SO_4
OM3	24/05/2022	NP	265	6.44	1.7	0.3	0.15	0.7	0.1	0.67	0.12	5.5	-0.8	Ca-HCO_3
OM4	24/05/2022	NP	80	5.76	0.4	0.4	0.01	0.5	0.1	bdl	bdl	na	-20.0	Na-HCO_3
OM5	24/05/2022	NP	38	5.51	0.1	0.2	0.03	0.2	0.0	bdl	bdl	na	-13.8	Na-Cl
OM5a	25/05/2022	NP	41	5.58	0.1	0.2	0.03	0.3	0.0	bdl	bdl	na	-8.8	Na-Cl
OM6	25/05/2022	NP	247	6.48	1.7	0.6	bdl	1.0	0.1	0.42	0.16	2.6	-1.6	Na-HCO_3
OM7	25/05/2022	NP	1240	7.45	7.5	3.7	1.04	6.5	1.5	1.32	1.32	1.0	-1.2	Na-HCO_3

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Major ion data (Table 3) and the relationships between these ions can be observed in Figure 2 and Figure 3. These relationships are briefly mentioned because geochemical processes are used to inform ^{14}C modelling approaches (Clark and Fritz, 1997). The Na and Cl plot suggests an enrichment in Na compared to that expected in rainfall derived from seawater evaporation. This points to silicate weathering, as expected by water-rock interaction with the granodiorite. Similarly, the Ca vs Cl plot suggests a Ca-rich nature for the igneous material with which the groundwater has interacted. This is validated by the calcalkaline nature of the Carrai Granodiorite (Leitch, 1976).

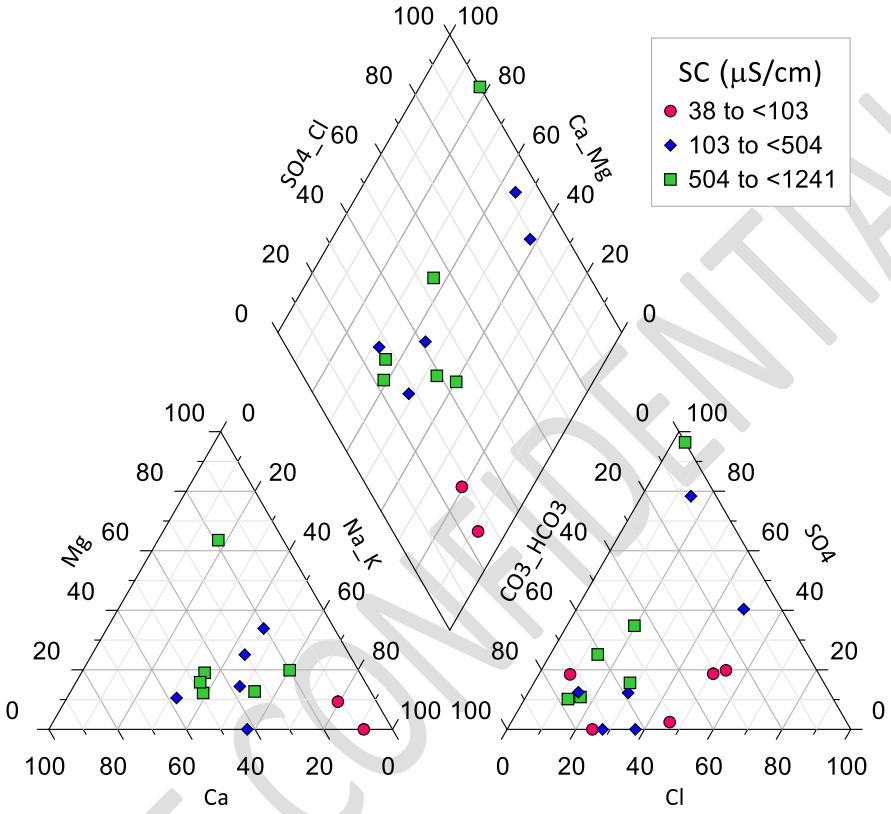


Figure 2 Piper plot for available groundwater major ion samples (meq/L). Colours and shapes represent samples containing low (red circle), medium (blue diamond) and high (green square) specific conductance (SC) values.

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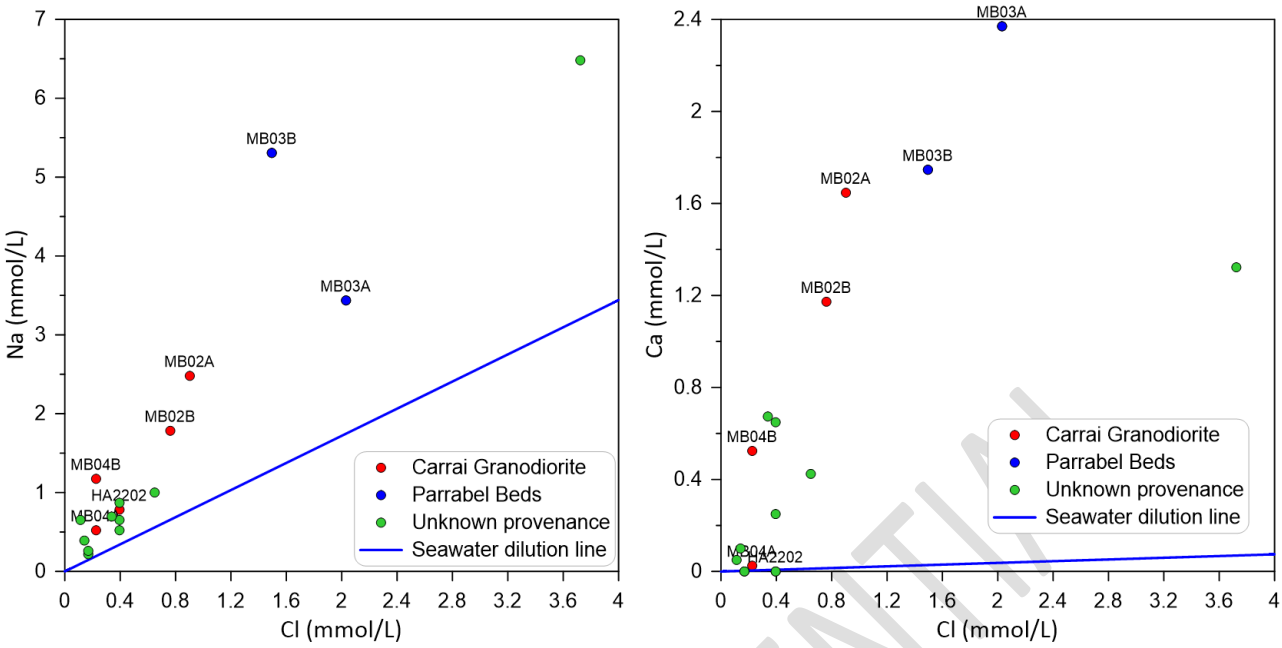


Figure 3 Na and Ca versus chloride plots. The seawater dilution line is depicted in blue for reference. Samples labelled as "unknown provenance" correspond to major ion results from other regional samples provided by EMM Consulting.

Radioactive tracers

Isotopic results for ^{3}H and $^{14}C_{DIC}$ are presented in Table 4 with interpretative plots in Figure 4. A strong trend with depth can be observed for ^{3}H in Figure 4(A). The very young nature of all groundwaters analysed inhibits an observable depth-decay relationship in the case of $^{14}C_{DIC}$. One sample, MB02B, clearly does not fit the trend observed and discarding any other potential sampling and/or well integrity issues, could represent an area of fast preferential flow for recharge.

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Table 4 Results and uncertainties associated for ^{3}H, $^{14}C_{DIC}$ and $\delta^{13}C$ in graphite-AMS

Bore ID	Sample Date	Aquifer/Lithology/Age	^{3}H (Tritium)	uncertainty	$\delta^{13}C$ graphite (AMS)	uncertainty	$^{14}C_{DIC}$	uncertainty
			(TU)	(TU)	‰	‰	pMC	pMC
MB02A	25/05/2022	Carrai Granodiorite (Triassic)	1.82	0.10	-18.9	1	85.40	0.34
MB02B	25/05/2022	Carrai Granodiorite (Triassic)	1.63	0.09	-13.7	0.5	97.67	0.38
MB03A	25/05/2022	Parrabel Beds (Permian)	1.22	0.07	-10.7	0.3	107.42	0.33
MB03B	25/05/2022	Parrabel Beds (Permian)	0.33	0.04	-11.3	1	85.30	0.28
MB04A	26/05/2022	Carrai Granodiorite (Triassic)	2.18	0.12	-21.1	0.6	105.41	0.35
MB04B	26/05/2022	Carrai Granodiorite (Triassic)	1.37	0.08	-20.5	1.2	85.89	0.4
HA2202	24/05/2022	Carrai Granodiorite (Triassic)	2.01	0.11	-18.6	0.04	103.63	0.37

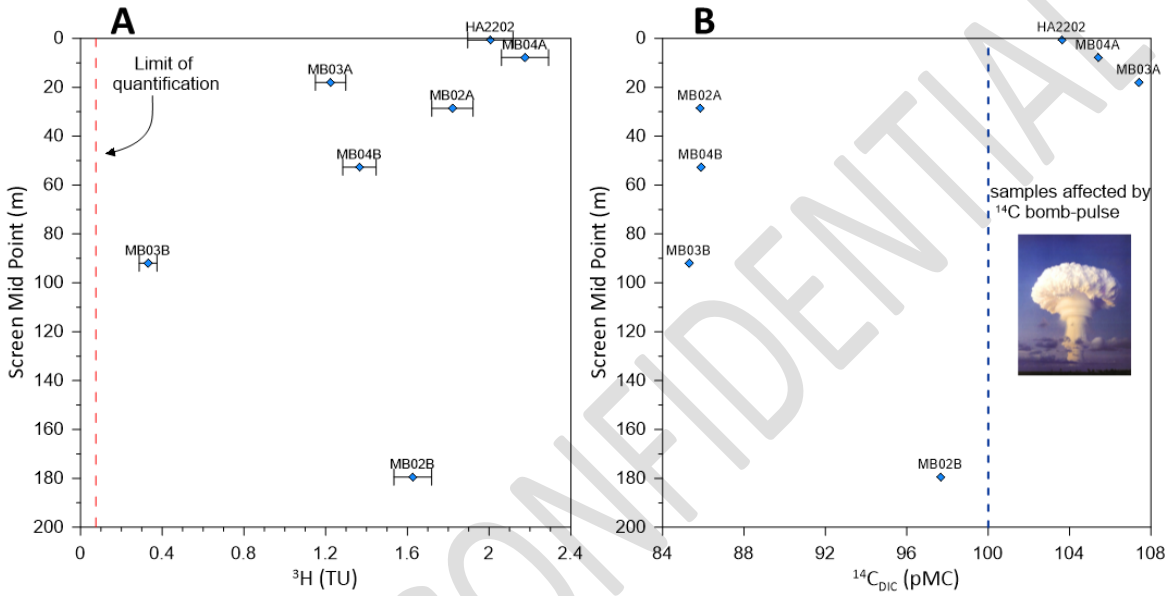


Figure 4 (A) ^{3}H as TU; (B) $^{14}C_{DIC}$ as pMC; for Carrai Granodiorite and Parrabel Beds. All isotopic results are plotted against depth expressed as screen mid-point. Samples affected by ^{14}C released into the atmosphere in the 1940's-1960's through nuclear bomb testing (^{14}C bomb-pulse) are shown to the right of the blue dashed line in B.

Geochemical modelling for ^{14}C age correction

Geochemical modelling tools are generally used to adjust and interpret measured $^{14}C_{DIC}$ contents. This is because aquifers can have many different carbon sources. As groundwater flows through the aquifer, 'radiocarbon dead' or old carbon can be diluted in the groundwater making the water appear older. However, in the case of available samples, three (HA2202, MB04A and MB03A) have ^{14}C contents above 100 pMC therefore represent very recent groundwater affected by ^{14}C bomb-pulse contributions. The modern source for analysed groundwaters is further supported by the relatively high ^{3}H activities, similar to those expected for regional rainfall (Tadros et al. 2014). We have attempted correction for samples with ^{14}C contents below 100 pMC, with all results providing a modern signature for the groundwater. Multiple correction schemes are available to account for ^{14}C sinks and sources. Often a combination of several calculations with supporting geochemical information derived from the studied systems (e.g.: major ions, $\delta^{13}C_{DIC}$, regional carbonates $\delta^{13}C$, etc.) are used to refine the ^{14}C interpretations. Additional approaches could be considered for this study area in the future to further refine ^{3}H and ^{14}C calculations, and recharge mechanisms (e.g. through the addition of isotopic tracers such water stable isotope analysis). For further understanding of the strengths and limitations of ^{14}C, we refer to Cartwright et al. (2020). Additionally, Plummer and Glynn (2013) offer an extensive analysis of different approaches and general radiocarbon systematics for groundwater applications.

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Charge balances, saturation indices, the partial pressure of CO_2 (pCO_2), HCO_3^- and CO_3^{2-} concentrations were calculated or assessed using the WATEQ4F thermodynamic database in the PHREEQC interactive 3.62 programme (Parkhurst and Appelo, 1999). Geochemical models have been applied to account for dilution of ^{14}C in the aquifer matrix. The code NETPATH-XL (Plummer et al., 1994; Parkhurst and Charlton, 2008) has been used to apply specific ^{14}C correction methods to single bore groundwater samples (*"one well"*). Numerous correction models are included in NETPATH-XL: Vogel (Vogel, 1970), Tamers (Tamers, 1975), Pearson (Pearson, 1965), and Fontes-Garnier (Fontes and Garnier, 1979). These correction models use either a statistical approach (Vogel), a hydrochemical correction (Tamers), an isotopic correction (Pearson), or a combination of the hydrochemical and isotopic data (Fontes-Garnier, Mook, Eichinger) to calculate a correction value (q) based on the groundwater chemistry of the sample. A corrected radiocarbon 'age' is then calculated as:

$$t = -\frac{1}{\lambda} ln\left(\frac{A}{A_0 \times q}\right)$$

where *t* is the groundwater age or time since recharge (in years), A is the measured ^{14}C activity of the sample, A_0 is the natural background activity of carbon in equilibrium with the atmosphere prior to radioactive decay (100 pMC was used in these calculations) and q is the calculated ^{14}C dilution factor.

Individual modelling assumptions varied according to calculations. In general, soil $CO_{2\,(g)}$ were assigned a value of $\delta^{13}C$ = -25‰ (Cendón et al. 2014), and a ^{14}C activity of 100 pMC. The $\delta^{13}C$ of dispersed pedogenic carbonates in the regolith is not known so a generic value like those found in marine derived carbonates was applied (Table 5). A ^{14}C activity of 0 pMC was assigned to potential carbonates in deep monitoring wells. This is an assumption, which in the case of interactions with shallow/recent pedogenic carbonates may not be accurate (Meredith et al. 2016). All groundwater samples were sub-saturated with respect to calcite, so if carbonates are present, those would tend to be dissolved by recharge waters.

Table 5 shows all ^{14}C corrected values yielded a modern age. Generally, we would not be able to refine that result further, however, the bomb-pulse contents in ^{14}C combined with ^{3}H results can help to provide residence-time assessment for all samples.

Table 5 Summary of ^{14}C correction and ^{3}H calculations. The green column "proposed approximate ages" shows the best groundwater residence time based on ^{14}C and ^{14}C bomb pulse. The blue shaded column shows groundwater ages based on ^{3}H decay.

			^{14}C					^{14}C bomb pulse	^{3}H
Bore ID	**Sample Date**	**Aquifer**	**uncorrected**	**Vogel (15%)**	**Tamers**	**Ingerson and Pearson**	**Revised F-G (solid exch)**	**Proposed approximate ages**	**Proposed approximate ages**
			years BP	years BP	years BP	years BP	years BP	years BP	years BP
MB02A	25/05/2022	Carrai Granodiorite	1225	Modern	Modern	Modern	Modern	Modern	5
MB02B	25/05/2022	Carrai Granodiorite	190	Modern	Modern	Modern	Modern	Modern	7
MB03A	25/05/2022	Parrabel Beds	Modern	Modern	Modern	Modern	Modern	15	12
MB03B	25/05/2022	Parrabel Beds	1280	Modern	Modern	Modern	Modern	Modern	36
MB04A	26/05/2022	Carrai Granodiorite	Modern	Modern	Modern	Modern	Modern	10	2
MB04B	26/05/2022	Carrai Granodiorite	1220	Modern	Modern	Modern	Modern	Modern	10
HA2202	24/05/2022	Carrai Granodiorite	Modern	Modern	Modern	Modern	Modern	3	3
$\delta^{13}C_{carb}$= 0‰, A=0 pMC									
A_0=100 pMC		open system							
$\delta^{13}C_{soilCO2}$= -25‰									

Radiocarbon results in the groundwater were compared to atmospheric ^{14}C values which are inherited from rain and vegetation (Hua et al. 2021) (Figure 5). Considering the shallow nature of the three groundwater samples impacted by the ^{14}C bomb-pulse (samples with ^{14}C pMC values >100), and assuming no further sinks or sources of carbon, a direct comparison with atmospheric ^{14}C can be

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explored. The three groundwater samples appear to be consistent with recharge in 2007, 2011 and 2016 respectively for MB03A, MB04A and HA2202. Further assessment of these samples could be explored by comparing groundwater pMC values to regional trends in rainfall amounts in the region (Cendón et al. 2014).

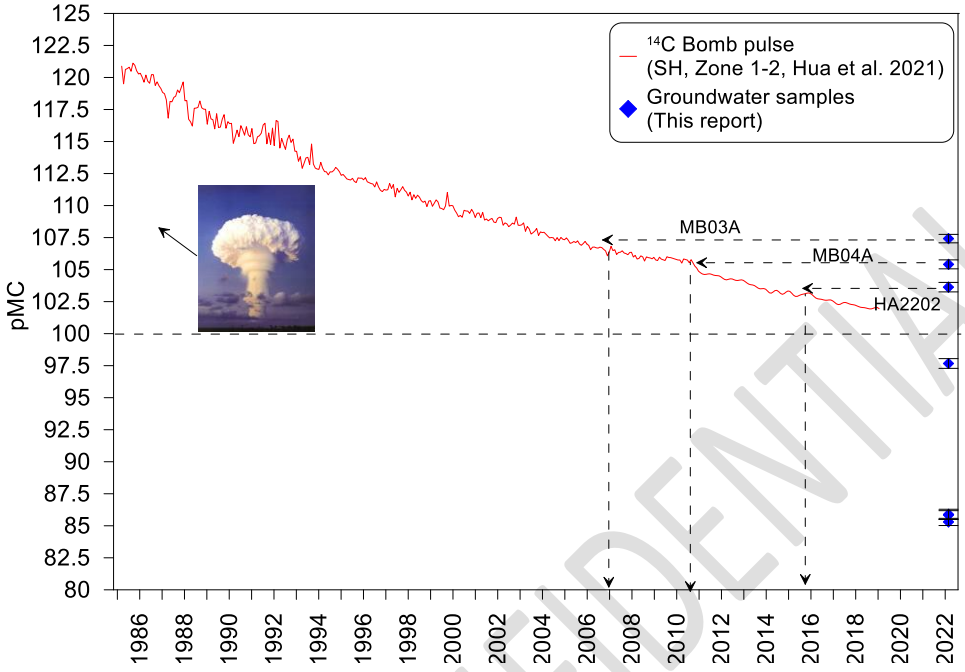


Figure 5. Evolution of ^{14}C in the atmosphere since 1986 following progressive decline of bomb-pulse derived ^{14}C since cessation of major above ground nuclear testing.

Tritium decay and groundwater age

Tritium results can be further interrogated considering: a) tritium bomb pulse in the Southern Hemisphere rainfall has returned to base-levels, similar to those prior to nuclear bomb testing (Morgenstern et al. 2010; Tadros et al. 2014) and b) the tritium initial concentration in rainfall can be estimated to values of 2-2.4 TU (Tadros et al. 2014). Using a ^{3}H half-life (12.43 yr) and assuming the activity in the samples corresponds to the residual activity after radioactive decay (no mixing), a tritium 'age' is then calculated as:

$$t = -17.93\ ln \frac{a_t\ {}^{3}H}{a_o\ {}^{3}H}$$

where t is the groundwater age or time since recharge (in years), a_t is the measured ^{3}H activity in the groundwater sample and a_0 is the natural background activity of tritium in the regional rainfall. Resulting ages can be seen in Table 5. The ^{14}C bomb-pulse and ^{3}H show similar or equal results except for sample MB04A that shows a discrepancy of 8 yr. Refinement of these modern groundwater ages would require of a regional specific ^{3}H-rainfall dataset, triangulation with existing long-term sites like Brisbane (Harris et al. 2022) and application of lump parameter models, all outside the scope of this report.

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Conclusion of groundwater residence times

Based on the results in Table 5, Figure 5Figure *6* and the available information, we differentiate three groups of groundwater samples that coincide with the specific sites and the respective shallow and deep monitoring wells. Recharge appears influenced by localised conditions with most samples following a trend from HA2202 (representative of recharge) to sample MB03B which constitutes the modern sample with the longest residence time (~40 yr). A distinctive group of samples is formed by MB02A and MB02B, showing very little increase in mean residence time (MRT) with increasing screen mid-point. Precluding any other potential causes (well development, mixing with drilling fluids), this could indicate a preferential flow path along a granodiorite lineament (Figure 6(B)). Overall groundwater samples are modern with tritium half-life and ^{14}C bomb-pulse suggesting mean residence times of up to 40 years (MB03B).

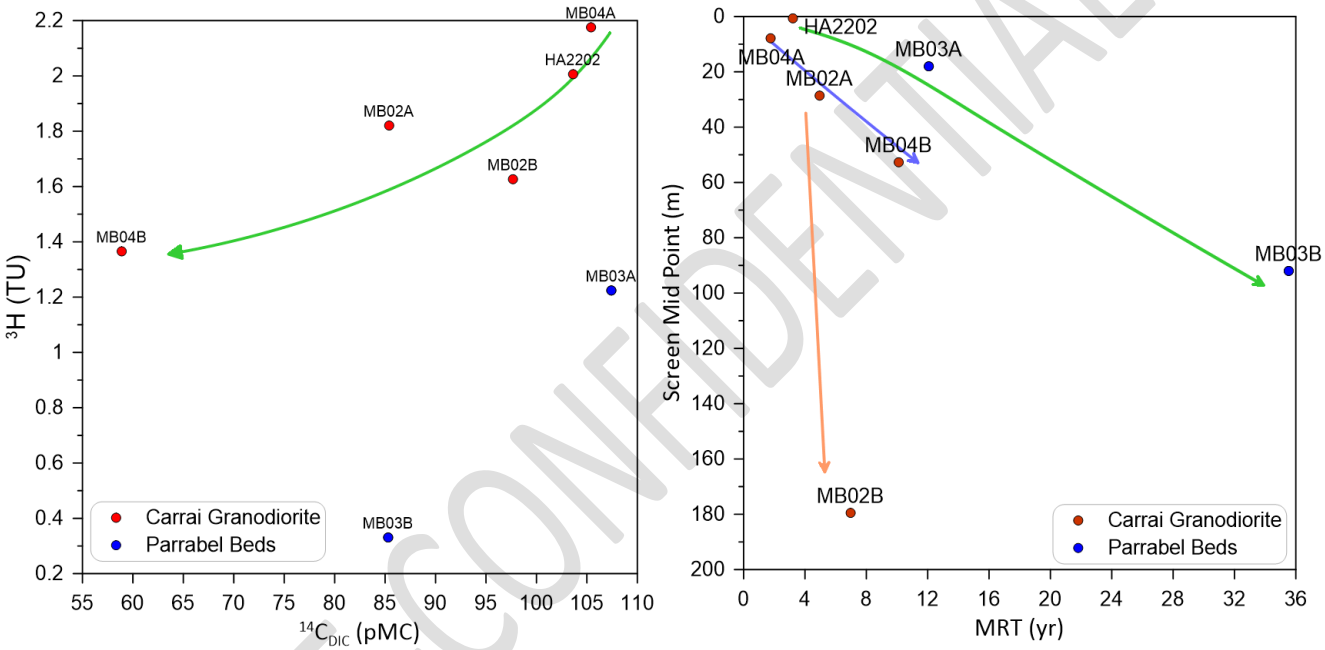


Figure 6 (A) ^{14}C groundwater (pMC) against ^{3}H (TU); (B) Screen mid-point (m) against mean residence time (MRT).

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Isotope Tracing in Natural Systems
Analytical Report

Report Number: 2022/0147T

Tritium Concentration at Sampling Date

Sample ID	Client Identification	Date Sample Collected	Tritium Activity	Uncertainty[1]	LLoQ[2]	Tritium Ratio	Uncertainty[1]	LLoQ[2]
			Bq/kg	Bq/kg	Bq/kg	TU	TU	TU
2022/0147T-1	**HA2202**	24-May-2022	0.239	0.013	0.008	2.01	0.11	0.07
2022/0147T-2	**MB2A**	25-May-2022	0.217	0.012	0.009	1.82	0.10	0.07
2022/0147T-3	**MB2B**	25-May-2022	0.194	0.011	0.009	1.63	0.09	0.07
2022/0147T-4	**MB3A**	25-May-2022	0.146	0.009	0.009	1.22	0.07	0.07
2022/0147T-5	**MB3B**	25-May-2022	0.034	0.005	0.009	0.29	0.04	0.07
2022/0147T-6	**MB4A**	26-May-2022	0.247	0.015	0.009	2.07	0.12	0.07
2022/0147-7	**MB4B**	26-May-2022	0.157	0.010	0.009	1.32	0.084	0.07

Notes:

1. Values reported are combined standard uncertainty, calculated to 1 sigma. A Coverage factor, *k*, of 2 may be used to calculate Expanded Uncertainty to 95% confidence.
2. The lower limit of quantification (LLoQ) corresponds to the fractional measurement standard uncertainty (σ(C)/C) of 0.5 [4].

Signature: Date: 25-Nov-2022

REPORT ON AMS ANALYSIS
(ANSTO Portal 14826; RUN 558)

25 October 2022

Dr Dioni Cendon
Research environment

Email: dce@ansto.gov.au

Portal 14826 - EMM consulting Henry Noakes

RADIOCARBON RESULTS

	ANSTO code	Sample Type	Submitter ID	δ(^{13}C) per mil	percent Modern Carbon pMC	1σ error	Conventional Radiocarbon age yrs BP	1σ error
1	OZAT92	Water (DIC)	HA2202	-18.6$ +/- 0.7	103.63	+/- 0.37	Modern	
2	OZAT93	Water (DIC)	MB2A	-18.9$ +/- 1.0	85.84	+/- 0.34	1,225	+/- 35
3	OZAT94	Water (DIC)	MB2B	-13.7$ +/- 0.5	97.67	+/- 0.38	190	+/- 35
4	OZAT95	Water (DIC)	MB3A	-10.7$ +/- 0.3	107.42	+/- 0.33	Modern	
5	OZAT96	Water (DIC)	MB3B	-11.3$ +/- 1.0	85.30	+/- 0.28	1,280	+/- 30
6	OZAT97	Water (DIC)	MB4A	-21.1$ +/- 0.6	105.41	+/- 0.35	Modern	
7	OZAT98‡	Water (DIC)	MB4B	-20.5$ +/- 1.2	85.89	+/- 0.40	1,220	+/- 40

‡ = A small mass correction has been applied to this sample (refer note 3)

Notes:

1. δ(^{13}C) values relate solely to the graphite derived from the fraction that was used for the radiocarbon measurement. It is sometimes the case that the δ(^{13}C) of this fraction is not the same as that of the bulk material. Measurements are determined using EA-IRMS (except for those, if present, marked with '$' which are accelerator based). Some δ(^{13}C) values may not have an associated uncertainty due to the limited number of determinations.
2. The ages quoted are radiocarbon ages, not calendar ages.
3. For some samples, the relatively large error is due to the small sample size.
4. The ages have been rounded according to M. Stuiver and A. Polach (1977). The definition of percent Modern Carbon and Conventional Radiocarbon age can also be found in this publication.
5. Please use the ANSTO Code number in publications. The AMS facility should be referenced as Fink *et al.* (2004).
6. When publishing results please acknowledge the financial support for the Centre for Accelerator Science at ANSTO through the Australian National Collaborative Research Infrastructure Strategy (NCRIS).

Attachment C

Numerical groundwater modelling report

EMM
creating opportunities

Oven Mountain Pumped Storage

Groundwater Modelling

Prepared for OMPS Pty Limited

November 2022

Oven Mountain Pumped Storage

Groundwater Modelling

OMPS Pty Limited

J210465 RP8

November 2022

Version	Date	Prepared by	Approved by	Comments
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Dr Doug Weatherill
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3 November 2022

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

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Executive Summary

The Oven Mountain Pumped Hydro Energy Storage Project (the Project) is an off-river pumped hydro energy storage system located approximately half-way between Kempsey and Armidale adjacent to the Macleay River in northern NSW. At a basic level, the Project will consist of upper and lower water reservoirs, a pipeline connecting them, and a hydro-electric power station, connected to the national energy market (NEM), that is capable of generating or consuming electricity.

The construction and operation of the Project will potentially impact on groundwater levels due to tunnelling and dam construction activities and associated works. To support a groundwater impact assessment (GIA) for the Project, a three-dimensional numerical groundwater flow model has been developed to quantify groundwater level and flow impacts due to construction and throughout the operation phase. The model was built to:

- evaluate drawdown/mounding at nearby water users and environmental receptors;
- predict groundwater inflow to the Project infrastructure during the construction and operation periods; and
- predict changes to the water balance.

Three groundwater flow systems were identified across the Project area, including:

- local perched or shallow water-bearing zones/aquifers in weathered rock and alluvium;
- an intermediate flow system within fractured bedrock to a depth of ~100 metres (m); and
- a deep groundwater flow system associated with competent bedrock with less intense fracturing at depth.

A highly parameterised regional-scale groundwater flow model has been built using MODFLOW-USG and generally aligns with the attributes of a Class 2 model as per the *Australian Groundwater Modelling Guidelines* (Barnett et al. 2012). The model has been independently reviewed by Chris Nicol of Groundwater Logic and is deemed fit for the purpose of predicting groundwater level and flow changes associated with the Project.

A Bayesian stochastic modelling approach was deployed to quantify the uncertainty associated with Project groundwater impacts. Both a null scenario and project scenario were simulated for a suite of 109 stochastic parameter realisations to allow for a range of drawdowns, mounding and water balance impacts to be predicted. The Project scenario includes separate boundary condition representation for construction dewatering activities and operation activities including filling of the reservoirs and pressuring the waterways. For this modelling project the 109 realisations (from a pool of 200 that were generated) that best matched the historical monitoring dataset, in terms of groundwater levels and groundwater level differences, were adopted.

The groundwater flow model predictions include:

- The sitewide drawdown extents are greatest during construction when the upper and lower reservoirs and portals and tunnels are excavated and passively dewatered. There is far less drawdown during operation of the scheme when the reservoirs are filled with water to design levels, the waterways are pressurised and some excavations are steel lined or backfilled and, therefore, no longer dewatered.
- The sitewide construction drawdown is mainly centred around the upper and lower reservoir footprints and along the access portal and waterways. There is elongated west-east drawdown that largely connects the impact area to between the two reservoirs. The watertable drawdown propagates radially outward from the upper reservoir across the flat-lying plateau. In contrast, the much steeper terrain and incised topography associated with the escarpment leads to elongated west-east drawdown.

- Mounding during operation is largely restricted to areas down-gradient of the two reservoirs. This mounding occurs once those reservoirs are filled with water at an elevation that exceeds the natural pre-project groundwater levels at those locations. Similar to drawdown, the mounding pattern is more radially outward from the upper reservoir due to the flatter plateau hydraulic gradients and more linear along the steep escarpment river valleys down-gradient of the lower reservoir.

- Across the 31 environmental receptor nodes there is negligible (< 0.1 m change in total drawdown/mounding) change in groundwater levels at 22 of 34 sites, there is up to 5 m of drawdown/mounding at six sites, and there is greater than 5 m of drawdown/mounding at six sites.

- There is negligible change (< 0.1 m in total drawdown/mounding) in groundwater levels predicted at the one landholder bore within the potential area of influence of the Project, being the East Kunderang Homestead bore (GW307320).

- The base case generally sits towards the centre of the suite of 109 stochastic models with respect to water balance and drawdown.

- It is very unlikely that the groundwater take due to construction will be more than 489 megalitres (ML) in any water year, and it its very unlikely that the take during operation will be more than 377 megalitres per year (ML/yr).

- Under pre-construction steady-state conditions the water balance reflects the conceptual model with most water entering the model as rainfall recharge and most water exiting the model as evapotranspiration and baseflow discharge to Macleay River and other ancillary rivers and creeks.

- During construction the project components that extract the most groundwater are the excavated reservoirs and the access tunnels. This water comes directly out of aquifer storage while maintaining a similar rate of recharge and baseflow discharge. This has led to drawdown of the aquifer system.

- During steady state operations the reservoirs are filled with water, which provides a net inflow to the aquifer and translates to localised mounding down-gradient of the reservoirs. This localised mounding translates to enhanced hydraulic gradients towards the Macleay River and other creeks and causes enhanced aquifer to river discharge operations in the order of 400 ML/yr.

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1 Introduction

1.1 Project background and context

OMPS Pty Ltd (OMPS) is proposing to develop the Oven Mountain Pumped Hydro Energy Storage Project (the Project), an off-river pumped hydro energy storage system (referred to as the 'pumped hydro system') located approximately half-way between Kempsey and Armidale adjacent to the Macleay River in northern NSW. The Project is located within the New England Renewable Energy Zone (REZ) and the Armidale Regional Local Government Area (LGA), proximate to its border with Kempsey Shire LGA.

At a basic level, the Project will consist of upper and lower water reservoirs, a pipeline connecting them, and a hydro-electric power station, connected to the national energy market (NEM), that is capable of generating or consuming electricity (Figure 1.1). The Project will utilise the highly favourable natural terrain of the site on which it sits to allow electrical energy from the main grid to be stored by pumping water from the lower reservoir to the upper reservoir. Energy can then be generated when needed by allowing water to flow back down to the lower reservoir via the hydro-electric power station, effectively enabling the Project to act as a large battery.

Construction and operation of the Project will potentially impact groundwater levels and flows due to tunnelling and dam construction activities and associated works. A groundwater impact assessment (GIA) has been undertaken by EMM Consulting Pty Ltd (EMM) to outline the predicted impacts of the Project. As part of this assessment a three-dimensional numerical groundwater flow model has been developed to quantify changes to groundwater levels and flows due to construction and operation of the Project. The GIA will form a component of the environmental impact statement (EIS) to be lodged in accordance with the requirements of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act).

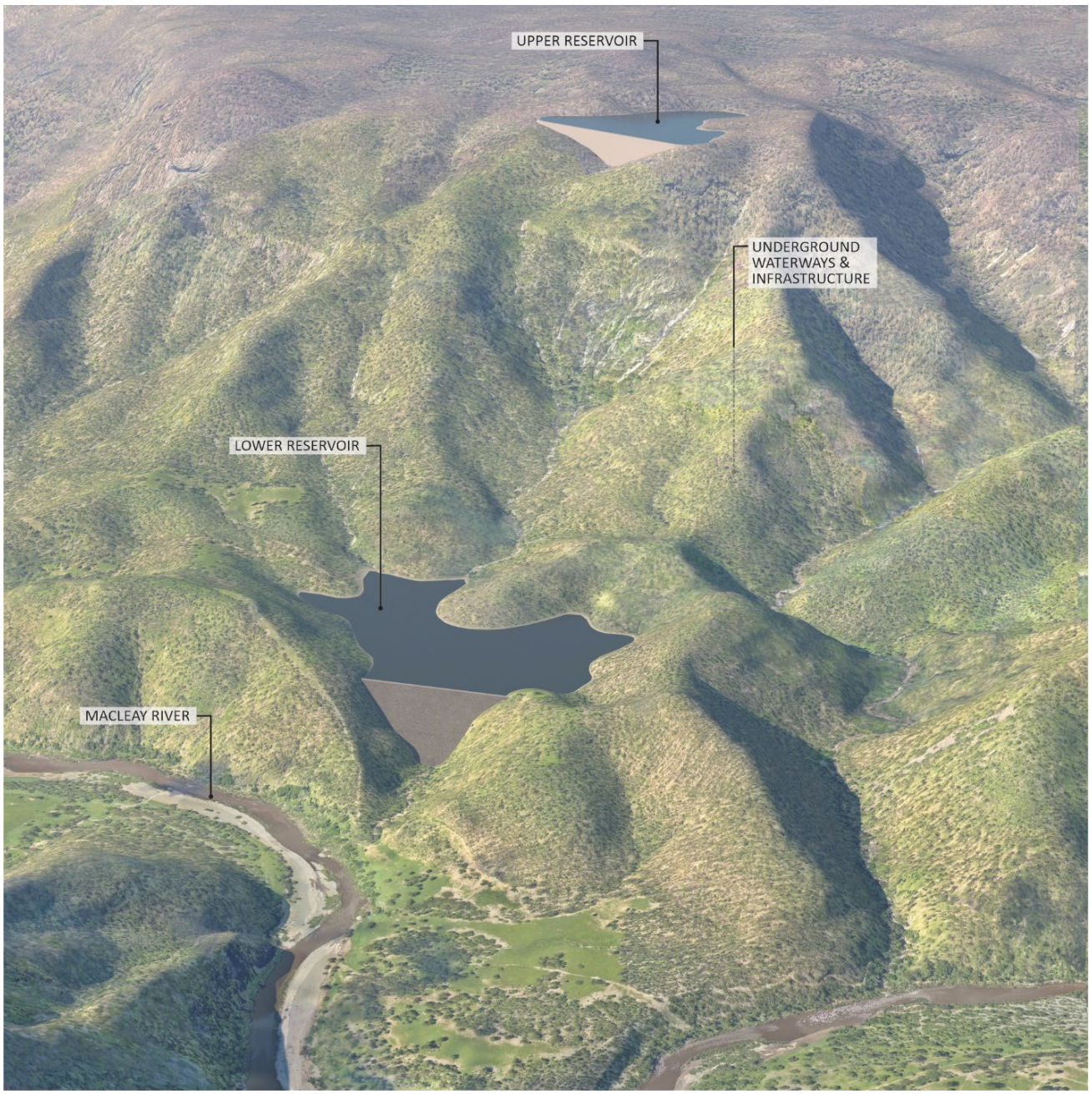


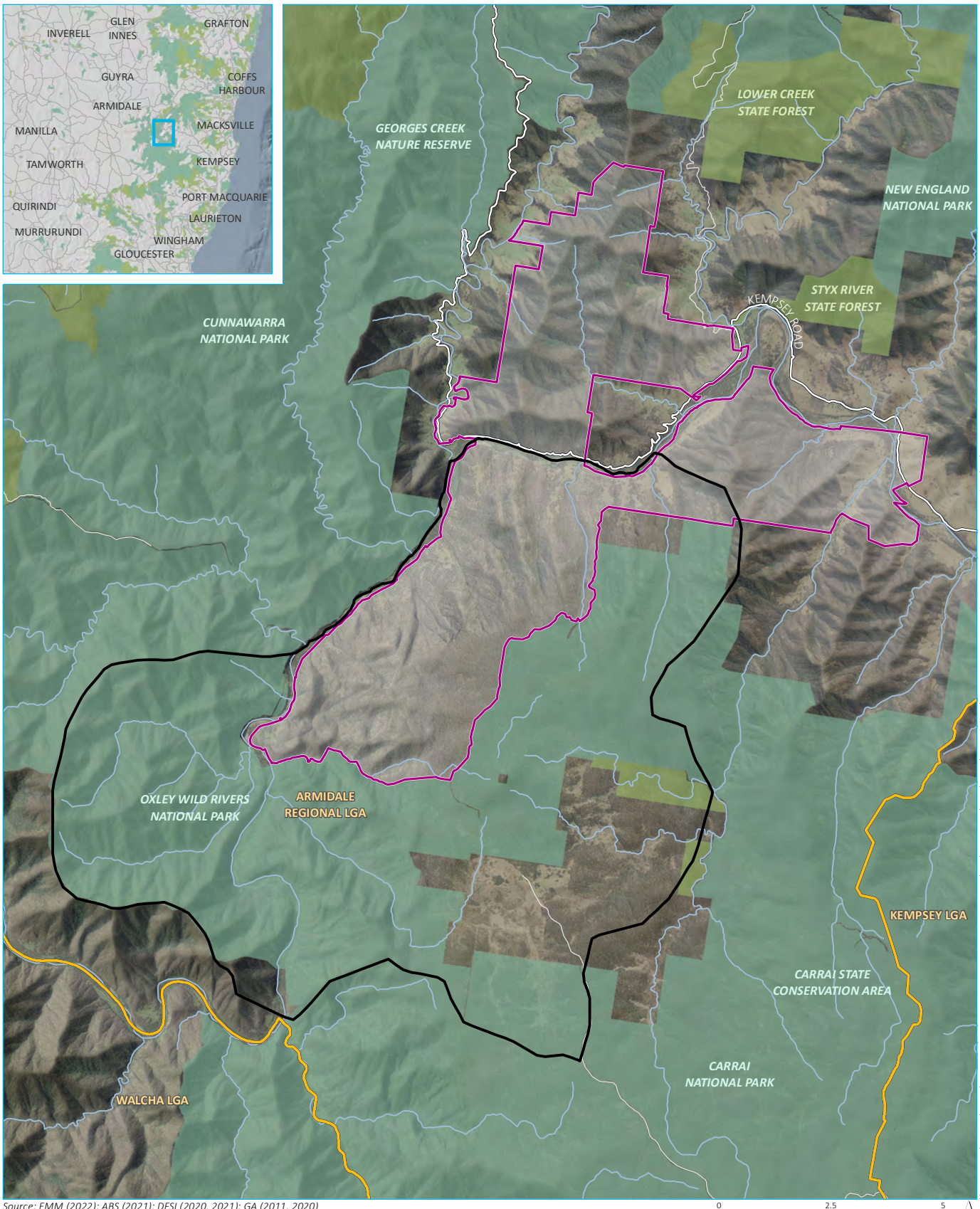
Figure 1.1 Concept visualisation of the upper and lower reservoirs at the Project site

1.2 Study area

The study area relevant to the GIA aligns with the numerical groundwater model boundary, as illustrated in Figure 1.2. The study area, which is larger than the Project area, encompasses the:

- Project-related sub-surface excavations;
- Project-related water monitoring network;
- nearby licensed groundwater bores;
- nearby high potential groundwater dependant ecosystems (GDEs); and
- identified sites of cultural significance.

The Project area boundary reflects the private land boundary and is generally bound to the west by the Macleay River and Oxley Wild Rivers National Park, to the south by Oxley Wild Rivers National Park, to the south-east by Carrai National Park and to the east by Carrai State Conservation Area. Much of the Project area contains undulating and steep terrain ranging from approximately 150 metres above Australian Height Datum (mAHD) to 1,000 mAHD with vegetation ranging from heavy to cleared.



\\emmsvr1\emm3\2021\210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW001_ProjectStudyArea_20221021_01.mxd 14/12/2022

Source: EMM (2022); ABS (2021); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse
- Local government area
- NPWS reserve
- State forest

INSET KEY

- Major road
- NPWS reserve
- State forest

Project area and study area

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd
Figure 1.2

EMM creating opportunities

1.3 Groundwater-affecting activities

The Project involves groundwater-affecting activities which are described in detail in Section 2.14. A summary of these activities is provided here for initial context while reading this report:

- Construction activities:
  - Excavation of rock and sediments at the upper and lower reservoirs to increase the supply volume of the reservoirs. Excavation of these materials has potential to occur below the watertable and lead to groundwater inflows and lowering of the watertable locally.
  - Excavation and digging of the access portals will occur through fractured and unfractured bedrock and has potential to lead to local inflows of groundwater during the construction period. This will lead to localised drawdown in those bedrock units and have potential to drain overlying sediments and waterways if vertical hydraulic gradients and material properties allow.
  - Excavation and digging of the low-pressure headrace, the deep vertical pressure shaft, the power station and the tailrace all have potential to occur through both fractured and unfractured bedrock during the construction period. This will lead to localised drawdown in those bedrock units and have potential to drain overlying sediments and waterways if vertical hydraulic gradients and material properties allow.
- Operation of the pumped hydro system:
  - Filling the reservoirs with water to operate the system will introduce an elevated body of water that will be in hydraulic connection with the local, shallow geological layers including sediments, weathered and fractured bedrock and unfractured bedrock. This raised hydraulic head has potential to induce inflows to the groundwater system and lead to localised mounding and radial flow away from these structures.
  - During operation the vertical pressure shaft and headrace will operate at equivalent pressure to the upper reservoir, while the tailrace will operate at equivalent pressure to the lower reservoir. Enforcing these pressures at depth within the bedrock may lead to altered groundwater flow paths and changes in groundwater levels surrounding and away from these structures.
  - During operation the power station and penstocks will either be concrete-sealed or steel-lined to minimise interactions with the deeper bedrock groundwater system.

1.4 Purpose of this report

This report is a technical appendix that documents a detailed account of the numerical groundwater modelling that was conducted to inform the GIA. The groundwater modelling workflow has been developed to meet the *Minimum Groundwater Modelling Requirements for SSD/SSI projects* (DPE, 2022) and this report is presented in a sequential manner that is consistent with those minimum guidelines.

1.5 Modelling objectives

The modelling objectives were developed in consultation with the GIA team to quantify potential local-scale and/or regional-scale changes to the groundwater system resulting from construction and operation of the Project. The modelling objectives are outlined in Table 1.1.

Table 1.1 Modelling objectives

Objective	Rationale
Predict drawdown/mounding at nearby water users	Determine if the Project will have minimal impacts or greater than minimal impacts to designated water users.
Predict potential impacts on GDEs	Assess magnitude and duration of potential groundwater level changes at designated GDEs and other identified sensitive receptors.
Predict groundwater inflow to the Project infrastructure during construction and operation	Predict inflows to underground project features such as access portals and waterways to inform groundwater licensing requirements.
Predict changes to the water balance as a result of the Project	Compare the Project case water balance with the null case to assess water balance changes to support groundwater licensing and/or surface water licensing.

1.6 Model complexity and confidence

Groundwater modelling has been conducted in accordance with the *Australian Groundwater Modelling Guidelines* (Barnett et al. 2012). As described in DPE (2022), the level of complexity for an individual model must be commensurate with the modelling objectives (outlined in section above) and the potential impacts on water sources. In this regard, the modelling objectives outlined in Table 1.1 require prediction of impacts at distal features many kilometres from the Project, as well as predictions of groundwater level change and groundwater inflows locally as a result of construction activities and operation of the system. To achieve this outcome, the following technical aspects related to model complexity have been considered:

- Regional simplicity of the main hydrostratigraphic units with simplified mesh discretisation. Sufficient spatial coverage of the domain to allow for meaningful predictions to be assessed at key locations without being overly influenced by boundary conditions or model settings. Simpler model layering in those areas to capture main hydrostratigraphic units only.
- Local detail in and around Project features such as access portals, waterways, and the power station. This is accommodated with both finer mesh discretisation and more detailed model layering.
- Because of the remote nature of the site and significant challenges with drilling rig access, the groundwater modelling workflow has embraced probabilistic predictive uncertainty analysis (PUA) to accommodate some of the limitations in the spatial and temporal baseline data and conceptual understanding. The PUA has been implemented to explore the potential uncertainty envelope of predictions of drawdown/mounding at receptors, water balance changes, and inflows to project components such as access portals.
- The groundwater flow model was not designed to explicitly simulate soil water, surface water or perched groundwater nor water quality/solute transport.

Under the earlier *Murray-Darling Basin Commission Groundwater Flow Modelling Guideline* (MDBC, 2001), the model is best categorised as an Impact Assessment Model of medium complexity. That earlier guide (MDBC, 2001) describes this model type as follows:

> Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies.

The *Australian Groundwater Modelling Guidelines* (Barnett et al. 2012) developed a system to classify the confidence level for groundwater models. Models are classified as Class 1, Class 2 or Class 3 in order of increasing confidence based on key indicators such as available data, calibration procedures, consistency between calibration and predictive analysis and level of stresses. The three classes of model are defined as:

- Class 1 – low confidence in model predictions, suitable for use in low value resource or low risk developments;
- Class 2 – medium confidence in model predictions, suitable for use in projects with medium to high risk developments; and
- Class 3 – high confidence in model predictions, suitable for use in high value resources and projects such as regional sustainable yield assessments.

The modelling conducted for the Project aligns best with the criteria for a medium confidence level (Class 2), with some attributes conforming to Class 1, and a few to Class 3. The following key indicators (based on Table 2-1 of Barnett et al. (2012) are summarised in Table 1.2. The suggested specific use of "prediction of impacts of proposed developments in medium value aquifers" is also aligned with a Class 2 model.

Table 1.2 Evaluation of model confidence level classification (after Barnett et al. 2012)

Data	Class	Calibration	Class	Prediction	Class	Key Indicator	Class
Bore logs and temporal head measurements available. Coverage is focussed around upper and lower reservoirs and within Project footprint. More temporal data would improve confidence in the future.	2	Validation not undertaken.	1	Transient discretisation is different to that of calibration.		Key calibration statistics are reasonable although can be poor in some parts of the domain.	2
Bore logs and stratigraphy data available. Downhole hydraulic testing improves understanding of fracture intensities with depth.	2	Calibration to steady-state and transient conditions. Overall reasonable statistics with areas for improvement.	2	Transient calibration over a short time frame compared to prediction.	1	Model predictive time frame is less than 10 times longer than calibration period	2
No available records of groundwater extraction or injection.	1	Transient history-matching datasets are current and reflect contemporary aquifer conditions.	3	Level and type of stresses included in the predictive model are outside the range of those used in transient calibration.	2	Stresses in predictions are more than 5 times higher than those in calibration.	1
Rainfall and evaporation data based on SILO and BOM synthetic datasets.	2	Model is calibrated to heads (and changes in head) only.	2		2	Stress period or calculation interval is broadly different to that used in calibration.	1

Table 1.2 Evaluation of model confidence level classification (after Barnett et al. 2012)

Data	Class	Calibration	Class	Prediction	Class	Key Indicator	Class
Some aquifer testing to define aquifer properties.	2	Some of the key modelling outcomes (flow fields and hydraulic interactions) are reflected in calibration.	2			Temporal discretisation in predictive model is not the same as that used in calibration.	2
Little or no data on streamflow. Only site observations.	1					Cumulative mass balance – closure error is less than 0.5%.	3
Very good quality and spatial coverage of DEM to define ground surface – 2 m LIDAR.	3					Most but not all model parameter values consistent with conceptual model.	2
						Appropriate computational methods used with appropriate spatial discretisation to model the problem.	3
						The model has been reviewed by an independent hydrogeologist/groundwater modeller.	2

2 Conceptual model overview

2.1 Overview

This section provides a summary of the main features of the hydrogeological conceptual model (HCM) that relate to the design, construction and history-matching of the numerical groundwater flow model. A more detailed account of the HCM is provided in the main body of the GIA report.

2.2 Site setting

2.2.1 Climate

Average annual rainfall for the Project area is estimated to range from 1,050 millimetres (mm) at lower elevations to 1,150 mm at higher elevations (Bureau of Meteorology (BoM 2021a)). Most of the annual rainfall typically occurs during summer and early autumn. However, large rainfall events may occur at any time of the year. Daily rainfall data for the Project area was obtained as SILO grid point data from the Queensland Climate Change Centre of Excellence. SILO grid point data are based on historical data from the BoM rainfall stations, where rainfall totals are interpolated at the point of interest (or grid location) from nearby station records. The daily rainfall data were obtained for the 1918 to 2022 period to coincide with available records for nearby BoM operated stations.

Monthly rainfall statistics for the Project area were calculated using the SILO grid point data and are presented in Figure 2.1. Average pan evaporation rates were sourced from the BoM climate data maps (BoM 2021a) and are also shown in Figure 2.1.

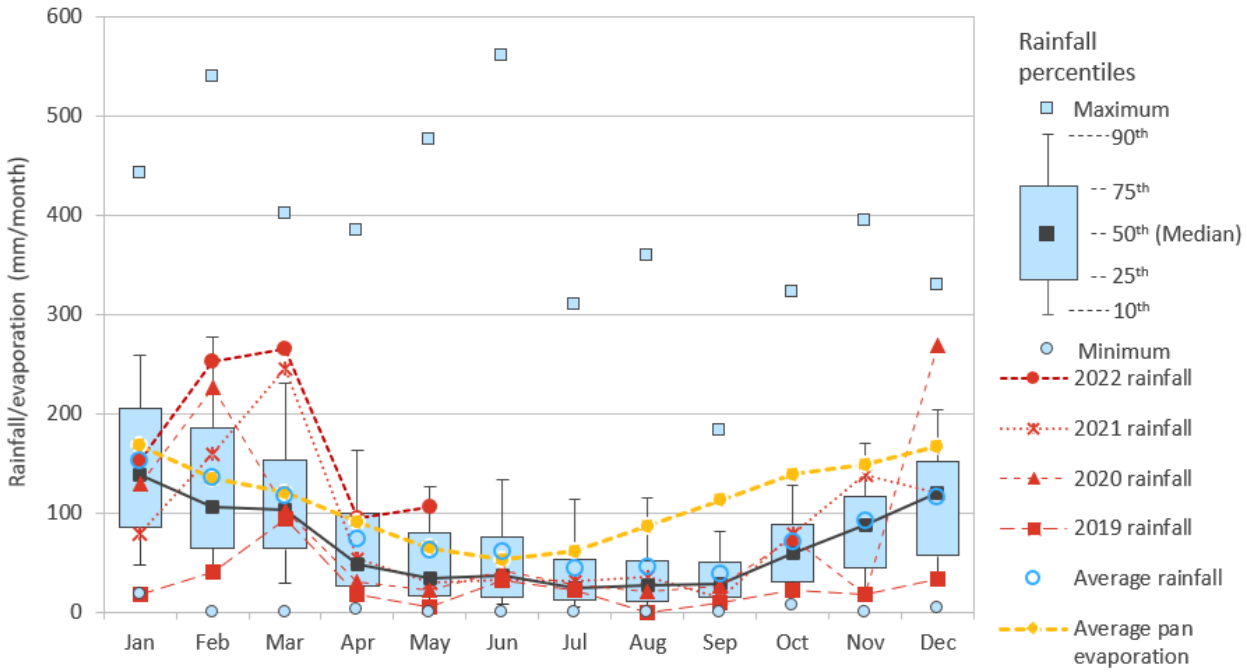


Figure 2.1 Monthly rainfall statistics (1918–2021) for the Project area (-30.75, 152.20)

The data presented in Figure 2.1 indicate greater rainfall is experienced in summer and early autumn. The larger differences between the 25th and 75th percentile values indicate greater rainfall variation also occurs during summer and early autumn. Less variation in rainfall totals occur from May to September, however large rainfall events may still occur during this period.

Average monthly pan evaporation totals are shown to be similar, although slightly higher, to median monthly rainfall totals from January to July. Average pan evaporation totals are shown to substantially exceed median rainfall totals from August to December. This is expected to be a result of low rainfall and higher temperatures (and subsequently increased evaporation) that are experienced from August to December.

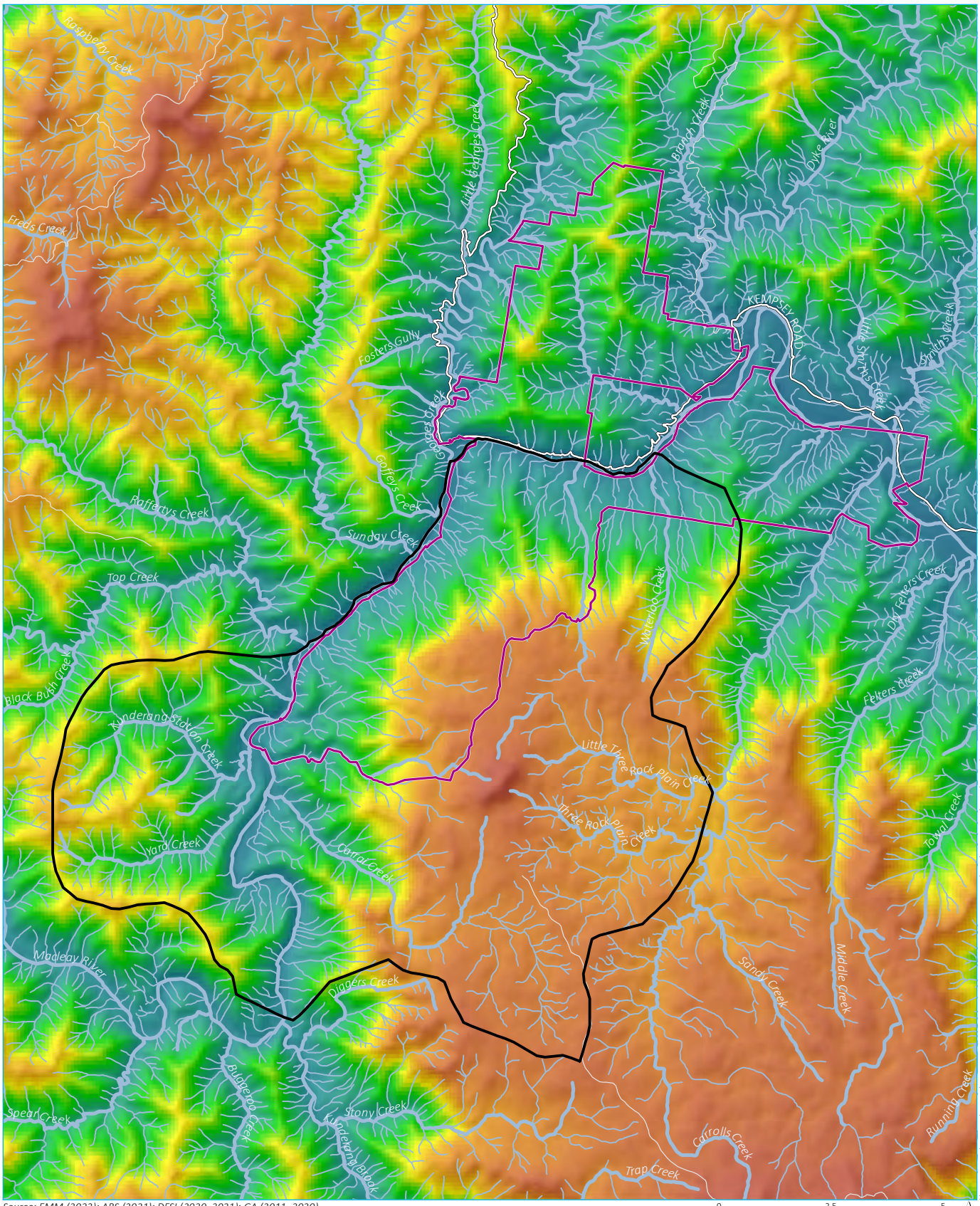
2.2.2 Topography

Topography is relatively level across the plateau, before sloping down the escarpment to the west and north-west. The plateau is approximately 1,000 mAHD and the Macleay River plain lies at approximately 145 mAHD. The elevation decline of ~855 m (vertical) over 4,000 m (horizontal) is largely represented by a series of scarps (up to 60°) and steep slopes (20–30°).

Incised valleys generally orientated east-west separate spurs (namely 'Stringybark Spur'). The spurs typically extend along the entirety of the escarpment to the Macleay River. The incised valleys support the majority of surface water relief, discharging via a series of ephemeral streams to the Macleay River and generally at a perpendicular confluence.

The study area has been split into four focus areas, broadly constrained by the topographic relief described above, comprising:

- the Carrai Plateau (the plateau), in the eastern portion of the study area;
- the escarpment, extending west of the plateau;
- the Macleay River floodplain, a relatively narrow area bordering the Macleay River; and
- the western catchment, on the western side of the Macleay River.



Source: EMM (2022); ABS (2021); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

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KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse
- Watercourse/drainage line

Elevation (m AHD)

High : 1100

Low : 0

Topographic and drainage map of the study area

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Figure 2.2

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2.2.3 Hydrological setting

The study area is located within the Macleay River catchment, covering approximately 11,400 square kilometres (km^2) from Armidale (on the Great Dividing Range of NSW) to Hat Head (on the east coast of NSW). The catchment generally comprises relatively impervious rock at ground surface, leading to rapid water level and streamflow responses in the Macleay River following rainfall.

Most of the surface water within the study area flows to the Macleay River via a series of streams, including:

- Peach Tree Creek and Carrai Creek, originating in the upper escarpment and discharging to the Macleay River within the Macleay River floodplain;
- Kunderang Station Creek, originating in the upper western catchment and discharging to the Macleay River within the Macleay River floodplain; and
- Three Rock Plain Creek and Little Three Rock Plain Creek, originating in the eastern plateau and discharging to the Macleay River outside (east) of the study area.

Ephemeral streams discharge directly to the Macleay River or form upper tributaries to the perennial watercourses (refer Figure 2.2). The ephemeral streams typically flow for periods proportional to recent duration and magnitude of rainfall, with relatively high flow events evident from the transported boulders and vegetation.

Streamflow within the Macleay River catchment (based on data from Macleay River at D/S Georges River gauge – 206024) generally rises steeply following a rainfall event (see Figure 2.3). Runoff contributions from the upper catchment (ie tablelands), and the spatial and temporal variation of rainfall across the catchment, can result in streamflow continuing to rise for several days following a rainfall event. The falling limb of the streamflow hydrograph recedes more gradually due to the slower release of water from the catchment via interflow and other slow-release processes. The slower runoff response from the upper catchment means it can take several days to weeks for streamflow to return to a predominantly baseflow fed regime following rainfall events.

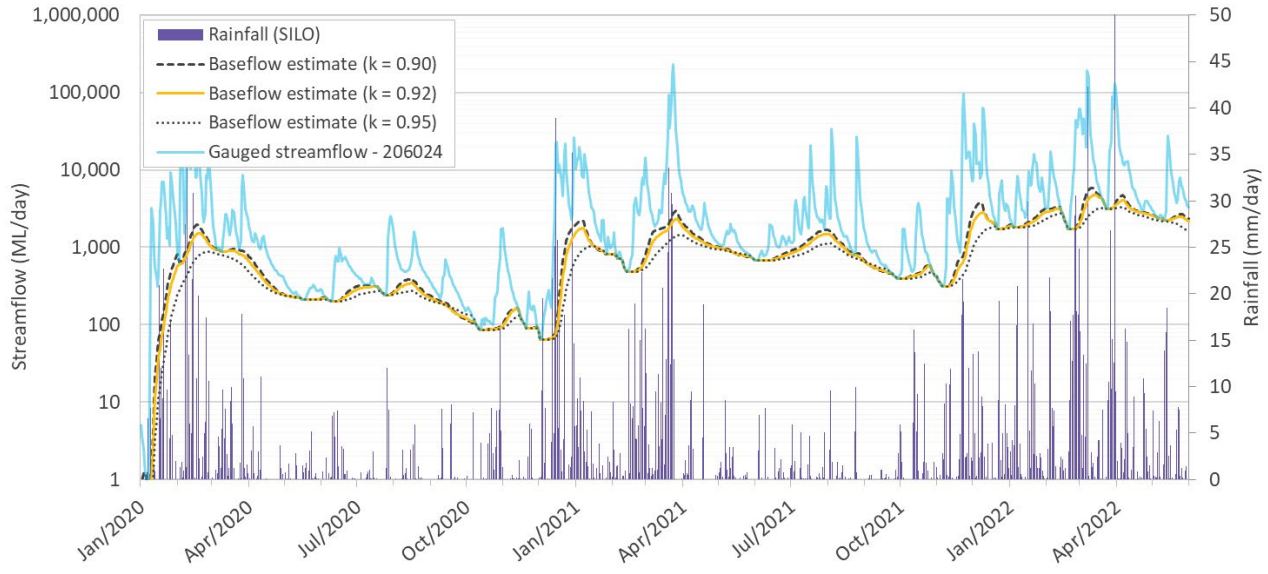


Figure 2.3 Streamflow, rainfall and calculated baseflow at gauge station 206024

2.3 Geological setting

Deposits of alluvial and colluvial soils occupy the incised valleys which support the ephemeral streams formed across the upper escarpment area. The deposits become more substantial in the lower escarpment and plain area (further along the geomorphological profile of the streamline), reflecting the increased energy of the environment and wider catchment area, and generally comprise sub-rounded to rounded boulders, cobbles, gravel and sand. Further down the catchment, within the riparian corridor and along the fifth order Macleay River, the surficial geology is comprised of a relatively thin deposit of alluvium, comprising well rounded cobbles, gravel and sand.

Soils within the Project area are predominantly residual, with their composition influenced by the properties of the underlying rock unit. In general, residual soil overlies the:

- granitic rock (granodiorite, adamellite and monzogranite) typically comprising of pale grey, medium grained sand with minor clay inclusions; and
- metamorphic rock (hornfels and metasediments) typically comprising of dark grey, medium–high plasticity clay.

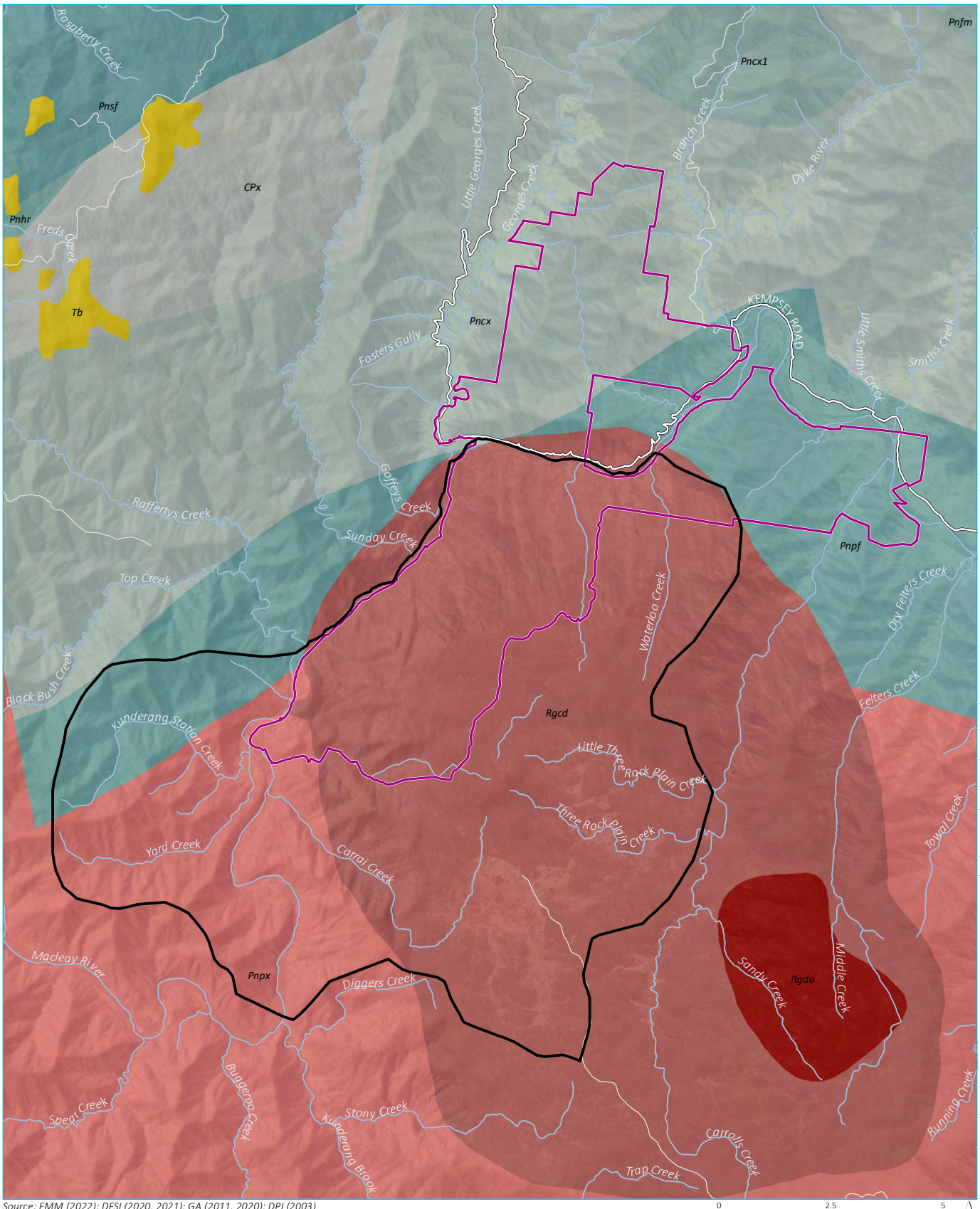
The study area lies within the New England Orogen. Differing geodynamics in the early Permian to Triassic led to a series of linked pluton structures (known collectively as the New England Batholith) which intruded the sedimentary units of the Permian-aged Parrabel Beds and Carboniferous-aged Pee Dee Beds. The Triassic-aged Carrai Granodiorite; a plutonic structure outcropping over approximately 168 km^2, is the dominant geological unit occurring within the study area and a product of the New England Batholith.

Across a large part of the proposed tunnel alignment, the Parrabel Beds were hornfelised into the crystalline Hornfels group. There are no major faults or lineaments mapped within the Project area (Gilligan et al. 1992). All three of the subsurface units: the Parrabel beds, Granodiorite, and Hornfels are comprised of tight rock unless local fracturing has created secondary porosity.

A summary of the stratigraphy within the Project area is provided in Table 2.1. The distribution and extent of the relevant geological units to the study area are mapped and shown on Figure 2.4.

Table 2.1 Study area stratigraphy

Period	Formation	Typical description (Colquhoun, et al., 2022)
Quaternary	Undifferentiated alluvial, colluvial sediments	Well sorted, coarse grained and oversized fractions at the base of the incised valleys and adjacent to the Macleay River. Generally, comprises localised deposits of cobbles and boulders at the base of the incised valleys, becoming more prevalent and continuous within the lower escarpment. Sands to cobbles more frequently observed within the Macleay Valley floodplain.
Triassic	Carrai Granodiorite	Coarse grained, felsic, crystalline igneous rocks including granodiorite, monzogranite and leucogranite. Relatively shallow weathering profile (≤9 m depth) and strength typically increasing with depth. Dominant geology underlying the study area.
Permian	Parrabel Beds	Fine to coarse grained sedimentary rocks including diamictite, conglomerate, sandstone, mudstone, limestone, and tuff. Highly metamorphosed within the Project area by the Carrai Granodiorite intrusion, forming an aureole contact of hornfels and meta-sediments. Underlies most of the western catchment.
Carboniferous	Pee Dee Beds	Fine to coarse grained sedimentary rocks including slaty siltstone, lithic sandstone and minor diamictite. Likely metamorphosed near the Project area by Carrai Granodiorite intrusion, forming an aureole contact of hornfels and meta-sediments. Underlies the northern portion of the western catchment and a small component of the Macleay River floodplain.



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020); DPI (2003)

0 2.5 5 km

GDA 1994 MGA Zone 56

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KEY

Project area
Model domain
Existing environment
Major road
Minor road
Named watercourse

Geology 250k period and formation

Tertiary
Tb - Tertiary

Permian
Pnpx - Permian, Parrabel bed
Rgcd - Permian, Carrai Granodiorite
Rgdu - Permian, Daisy Plains Leucoadamellite

Carboniferous
CPx - Carboniferous, Coffs Harbour association
Pncx - Carboniferous
Pncx1 - Carboniferous
Pnfm - Carboniferous
Pnhr - Carboniferous
Pnpf - Carboniferous, Pee Dee bed
Pnsf - Carboniferous

Surface geology

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Figure 2.4

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2.4 Summary of groundwater systems

There are three main groundwater systems within the study area:

- local perched or shallow water-bearing zones/aquifers in weathered rock and alluvium;
- an intermediate flow system within fractured bedrock to a depth of ~100 m; and
- a deep groundwater flow system associated with competent bedrock with less intense fracturing at depth.

The characteristics of the three main groundwater flow systems (which also comprise the three main hydrostratigraphic units (HSUs) for the study area) are summarised in Table 2.2 to provide an initial overview. The key aspects of these groundwater systems are then detailed in the following sub-sections and within the main body of the GIA report.

The local shallow groundwater resource includes alluvium upriver from the Macleay River, which consists of medium to coarse grained sand, silts, and gravel deposits. Groundwater from the shallow aquifer is typically highly connected to the surface water and coupled with the coarser sediments, water quality is typically good with high yields potentially obtainable in some areas.

Springs (bogs) are present on the plateau, with groundwater preferentially discharging at the contact between the soil profile and low permeability granodiorite. These springs will generally be at the head of ephemeral creeks that carry water and alluvium from the plateau down to the Macleay River during significant rainfall events, and this erosion means where a streambed cuts through, the granodiorite or hornfels units are present at the surface.

Table 2.2 Summary of groundwater systems in the study area

System/HSU	Depth	Type	Recharge	Flow paths	Discharge
Local flow system in alluvium and weathered rock	< 10 m deep	Unconfined – shows rapid groundwater level (GWL) response to rainfall.	Direct rainfall recharge	Short residence times and short flow paths	Discharge to creeks and rivers as baseflow, discharge to GDEs
Intermediate flow system in fractured rock	<100 m deep	Unconfined – shows rapid GWL response to rainfall.	Diffuse rainfall recharge preferentially through cracks and via downward leakage from overlying shallow flow system	Moderately rapid flow system	Discharge to creeks and rivers as baseflow. Groundwater yields from bores typically low (~1 litres per second (L/s)) with occasional higher yields (~10 L/s from highly fractured areas
Deep groundwater flow system in competent bedrock	>100 m deep	Confined – shows little to no response to rainfall and buried by thick expanse of rock.	Diffuse rainfall recharge and downward leakage from intermediate flow system	Very long residence times	Discharge to creeks and rivers as baseflow

2.5 Hydraulic properties

There are 42 individual hydraulic tests completed within the Project bores. Of those, 31 tests were downhole packer tests at intervals from 5 to 50 m depth. An additional 11 slug tests were completed at depths varying from 0 to 186 m depth. Seventeen tests were completed in each of the hornfels bedrock unit and the Parrabel Beds, seven tests were completed in the Carrai Granodiorite unit, and one test was completed in residual sand. Table 2.4 presents details of the hydraulic testing. Figure 2.5 presents a box plot diagram of hydraulic conductivity statistics per geological formation and by varying depth below ground. Figure 2.6 presents a similar boxplot diagram, but now organised by test type. Table 2.3 presents some basic statistics for key HSUs.

Overall, testing has indicated the following regarding hydraulic conductivity (K) of the hydrogeological units within the study area is:

- Relatively high K for geological units in the upper 10 m of the profile with values typically ranging from 1 to 0.1 metres per day (m/d) across all units tested.
- Moderate to low K for all geological units between 10 and 100 m depth. This shows the inconsistent nature of fracturing at these depths. Where no fracturing is encountered the bedrock K across all geological units is typically < $1x10^{-3}$ m/d, and where localised fractures are encountered the K can vary from 0.1 to $1x10^{-3}$ m/d.
- There is little at depth, but given the limited fractures seen in drilling below 100 m depth, it is expected that the lithostatic pressures at these greater depths would limit K to < $1x10^{-3}$ m/d.
- The difference in K observed by very local-scale slug testing and packer testing over thicker intervals suggests that locally fractures in the bedrock are permeable, but that the degree of fracturing is not pervasive and could be described as moderate to low fracture intensity.

Table 2.3 Hydraulic conductivity within the hydrogeological units

Unit	K (m/d)		
	Minimum	Maximum	Average
Weathered Carrai Granodiorite	2.42	2.42	2.42
Carrai Granodiorite	$4.32x10^{-02}$	$3.72 x10^{-01}$	$1.64 x10^{-01}$
Parrabel Beds	$1.30 x10^{-02}$	1.73	$3.20 x10^{-01}$

Table 2.4 Hydraulic properties

Bore	Depth from (metres below ground level (mbgl))	Depth to (mbgl)	K (m/d)	Test type	Geology	Saturated interval
OM1	6.47	21.16	0.004	Packer	Hornfels	No
OM1	21.16	26.14	0.03	Packer	Hornfels	No
OM1	26.14	29.83	0.17	Packer	Hornfels	No
OM1	29.83	49.8	0.4	Packer	Hornfels	Yes
OM2	5.92	10.82	0.4	Packer	Hornfels	No
OM2	10.82	14.79	0.07	Packer	Hornfels	No
OM2	14.79	38	0.0009	Packer	Hornfels	No
OM2	38	44.45	0.06	Packer	Hornfels	Yes
OM2	44.45	50	0.02	Packer	Hornfels	Yes
OM3	5.85	8.85	0.4	Packer	Hornfels	Yes
OM3	8.85	11.3	0.12	Packer	Hornfels	Yes
OM3	11.3	14.15	0.004	Packer	Hornfels	Yes
OM3	14.15	50.3	0.00009	Packer	Hornfels	Yes
OM4	5.8	8.8	0.00009	Packer	Carrai Granodiorite	No
OM4	11.68	39.65	0.00009	Packer	Carrai Granodiorite	No
OM4	39.65	49.67	0.05	Packer	Carrai Granodiorite	Yes
OM6	1.6	9.4	0.86	Packer	Parrabel Beds	No
OM6	9.4	12.25	0.2	Packer	Parrabel Beds	No
OM6	12.25	16.85	0.00009	Packer	Parrabel Beds	Yes
OM6	16.85	22.35	0.004	Packer	Parrabel Beds	Yes
OM6	22.35	34	0.009	Packer	Parrabel Beds	Yes
OM6	34	41	0.01	Packer	Parrabel Beds	Yes
OM6	41	49.51	0.004	Packer	Parrabel Beds	Yes
OM7	5.7	8.35	1.03	Packer	Parrabel Beds	No
OM7	8.35	14.39	0.6	Packer	Parrabel Beds	No
OM7	14.38	20.07	0.4	Packer	Parrabel Beds	No
OM7	20.07	27.4	0.00009	Packer	Parrabel Beds	No
OM7	27.4	32.1	0.0006	Packer	Parrabel Beds	No
OM7	32.1	39.63	0.00009	Packer	Parrabel Beds	Yes
OM7	39.63	45.13	0.02	Packer	Parrabel Beds	Yes

Table 2.4 Hydraulic properties

Bore	Depth from (metres below ground level (mbgl))	Depth to (mbgl)	K (m/d)	Test type	Geology	Saturated interval
OM7	45.13	50.1	0.02	Packer	Parrabel Beds	Yes
OM2	0	50	0.0003	Pseudo falling head	Hornfels	Yes
OM2	0	50	0.0002	Pseudo falling head	Hornfels	Yes
OM2	0	50	0.0004	Pseudo falling head	Hornfels	Yes
OM2	0	50	0.0003	Pseudo falling head	Hornfels	Yes
MB01A	28.5	34.5	0.05	Rising head	Carrai Granodiorite	Yes
MB02A	25.6	31.6	0.4	Rising head	Carrai Granodiorite	Yes
MB02B	173.5	185.5	0.04	Rising head	Carrai Granodiorite	Yes
MB03A	15	21	1.7	Rising head	Parrabel Beds	Yes
MB03B	86	98	0.01	Rising head	Parrabel Beds	Yes
MB04A	6.35	9.35	2.4	Rising head	Residual Sand	Yes
MB04B	52.7	58.7	0.3	Rising head	Carrai Granodiorite	Yes

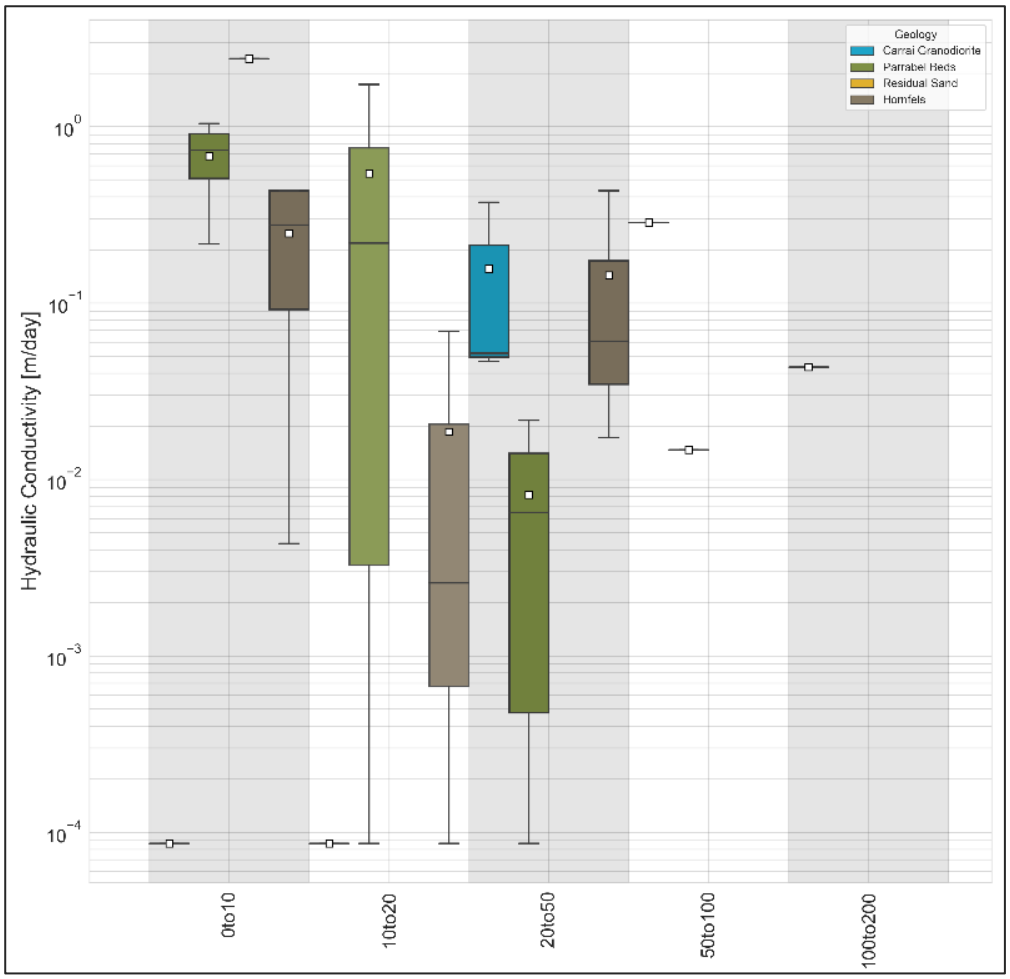


Figure 2.5 **Hydraulic conductivity versus depth grouped by geological formation**

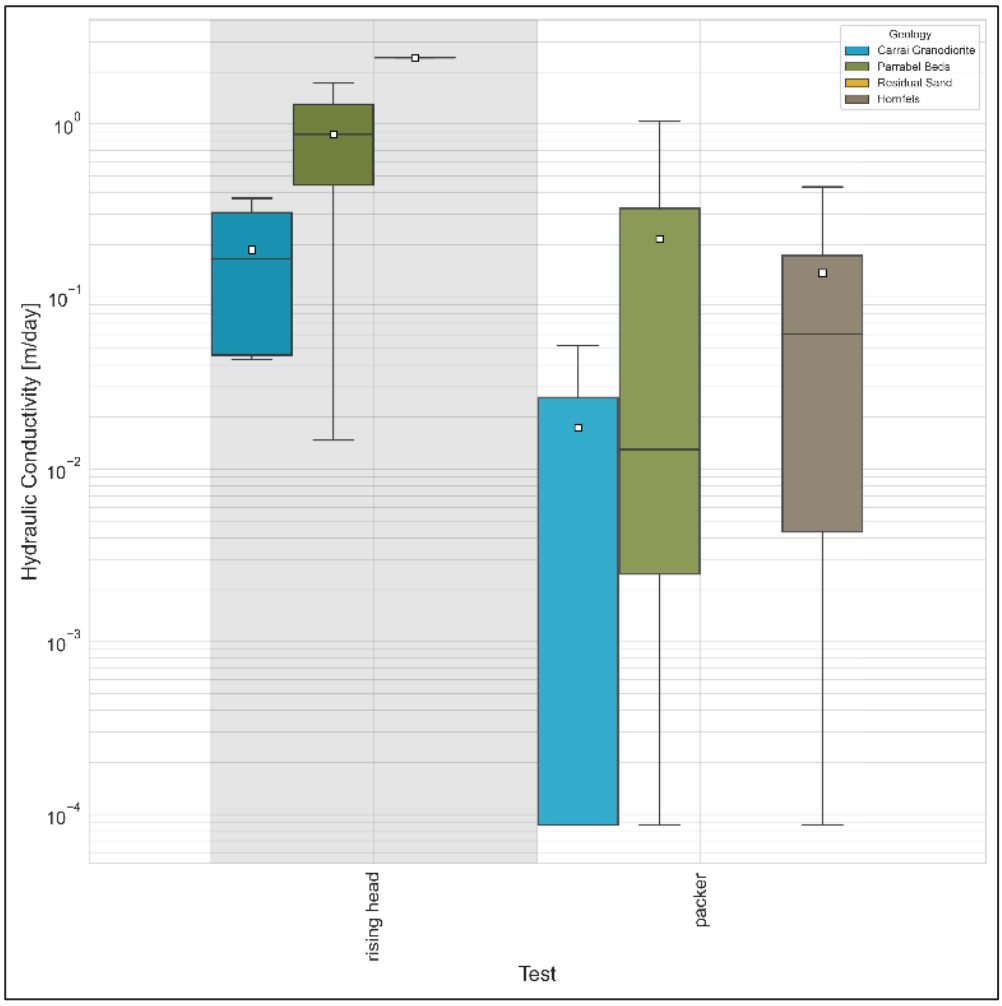


Figure 2.6 Hydraulic conductivity versus test type, grouped by geological formation

2.6 Natural boundary conditions and flow within the groundwater system

The natural boundary conditions and flow processes within the groundwater systems are summarised below. The translation of these natural boundaries to mathematical boundary conditions in the numerical model is described later in Section 3.6. The natural boundaries and flow processes include:

- A groundwater divide at the peak elevation of the plateau. Rainfall recharge will drive flow from this point towards the escarpments.
- Radial outward flow from the plateau. Groundwater flows from the recharge zone (Section 2.7.1) to the discharge zone (Section 2.7.2), with radial flow from the plateau to the Macleay River and eastward flow from the upper western catchment to the Macleay River. There is a downward vertical head gradient (shallower–deeper groundwater systems) in the recharge zone and upward vertical gradient (deeper–shallower groundwater systems) in the discharge zone. Groundwater levels oscillate between wet and dry periods, influencing the magnitude of groundwater flow seasonally.
- Flow is typically supported via interconnected fractures, joints and fault gouges (secondary porosity). Primary porosity is limited by the tight rock matrix and considered negligible due to the crystalline, igneous composition of the rock.
- Groundwater discharge along creeks and rivers along the lower floodplain areas.

- There are no mapped regional faults that may act as flow barriers or conduits within the Project area.

2.7 Recharge and discharge processes

2.7.1 Recharge

Recharge to the shallow (unconsolidated and weathered bedrock) and intermediate (fractured bedrock) groundwater systems occurs predominantly across the plateau (the recharge zone), through:

- direct recharge from rainfall infiltration where the units outcrop;
- indirect recharge from surface water infiltration where fractures extend to surface within streambeds; and
- localised recharge from rainfall percolating through the vadose zone or localised groundwater system.

The deeper groundwater system is recharged by localised infiltration from the overlying shallow and intermediate groundwater systems, typically in the recharge zone and upper escarpment.

Minor groundwater recharge occurs outside the recharge zone via similar mechanisms, however rainfall on the escarpment and Macleay River floodplain typically flows down the ephemeral streams for a relatively short period following rainfall, allowing minimal opportunity for indirect recharge to occur.

2.7.2 Discharge

i Natural discharge

The Macleay River forms the overall discharge zone within the study area, receiving groundwater from baseflow contributions, via the regional groundwater systems and ephemeral streams, supported by groundwater expressions in the upper tributaries.

There is some uncertainty regarding the source of groundwater expressions, it is considered they may be supported by localised groundwater systems, regional groundwater systems or a combination of both. The understanding has been simplified to include (Bryan, 1919):

- Pocket springs, visible flow of groundwater from the localised groundwater systems. Typically observed in the upper escarpment and forming the headwaters of ephemeral streams.
- Inclined fracture springs, upward flow from the shallow fractured rock groundwater system through fractures connected to surface.
- Lowland seeps, similar to springs however, flow is not visible and groundwater percolates upward through soil pores. Typically observed in low-lying areas around the Macleay River floodplain, adjacent to large watercourses and tributaries creating bogs and fens.
- Fens, moist ground forming the dominant groundwater discharge feature across the plateau. Generally observed below granodiorite outcrops in the upstream sections of smaller tributaries, typically supported by the localised groundwater systems and contributing attenuated:
    - recharge to the shallow groundwater system; and
    - flow to the ephemeral streams following rainfall, with attenuated flow proportionate to rainfall magnitude and duration.

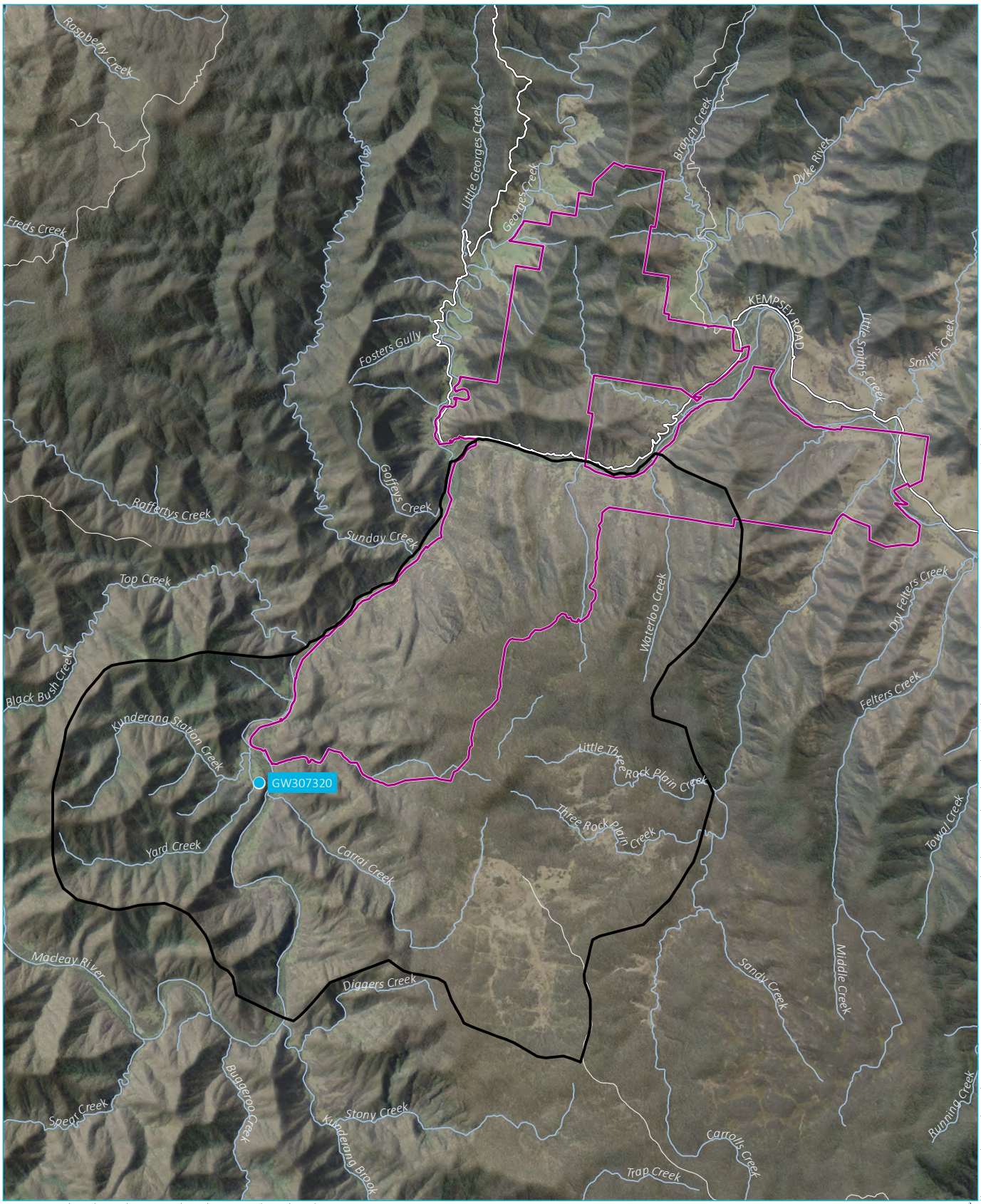
There is local variability and uncertainty regarding groundwater flow, vertical connectivity and baseflow contribution to bogs, fens and watercourses.

ii Registered bores

There are three registered landholder water supply bores located within 20 kilometres (km) of the Project area (Table 2.5 and Figure 2.7). Of these bores, the only one within the potential area of influence of the Project is the East Kunderang Homestead bore (GW307320), located 1 km south-west of the proposed lower reservoir. The bore is licenced for stock and domestic use however, to date, it has only been used intermittently to fill a small water tank. The bore is 60 m deep and screened in fractured shale of the Parabel Beds. The bore is near the Macleay River on the opposite side from the Project, and is likely to have a high degree of hydraulic connection to the river which would significantly reduce the magnitude of any impacts that may occur due to the Project (eg if the Macleay River became locally losing). An exception to this may be in periods of low to no stream flow, as in early 2020, when reductions in groundwater level would not be replenished by seepage from the river.

Table 2.5 Registered landholder water supply bores within 20 km of the Project area

Number	Licence number	Location	Installation date	Bore depth (m)
GW307320	Licence 30WA307847	Lot 3, Deposited Plan (DP) 751444 Located 1 km south-west of proposed lower reservoir	November 2013	60
GW303314	Licence 30WA312972	Lot 18, DP 751451 Located approximately 17 km north-east and downstream of proposed lower reservoir	July 2002	30.5
GW063924	Licence 30WA311261	Within the Macleay Valley, approximately 18.5 km north-west and upstream of the proposed lower reservoir	January 1988	6.7



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020); DPI (2003)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

- Project area
- Groundwater extraction
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse

Existing groundwater extraction location

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Groundwater modelling report
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Figure 2.7

EMM creating opportunities

2.8 Groundwater levels and flow

2.8.1 Monitoring network

The groundwater level monitoring network for the project is summarised in Table 2.6, including the stratigraphic unit that is screened by each bore. The locations of each bore are shown in Figure 2.9. Project specific groundwater level monitoring commenced in August 2020, with the installation of loggers in existing boreholes drilled in 1996 (SMEC, 1997). The groundwater level monitoring network has been progressively expanded as new monitoring bores have been installed. Groundwater levels are monitored via loggers submerged within the monitoring bores and boreholes. Groundwater level and temperature data were recorded at a six-hourly interval and synchronised across the network. A summary of the temporal distribution of groundwater level monitoring is provided in Figure 2.8.

Table 2.6 Groundwater monitoring bores

Target formation	Bore ID	Easting (GDA20)	Northing (GDA20)	Top of casing (mAHD)[1]	Total depth (mbgl)[2]	Screen interval (mbgl)[2]		Screened lithology
						Top	Base	
Boreholes								
Carrai Granodiorite	OM1	421606.50	6591183.10	890.60	49.80	0.00	49.80	Hornfels
	OM2	421691.80	6591318.60	881.70	50.00	0.00	50.00	Hornfels
	OM3	421793.20	6591463.00	846.10	50.30	0.00	50.30	Hornfels
	OM4	421936.00	6591542.30	899.70	49.67	0.00	49.67	Granite
	OM5	421990.00	6591228.60	891.40	30.00	0.00	30.00	Leucogranite
Parrabel Beds	OM6	419231.90	6591557.20	213.00	50.00	0.00	50.00	Meta-sediment
	OM7	419232.80	6591427.10	209.20	50.10	0.00	50.10	Meta-sediment
Monitoring bores								
Carrai Granodiorite	MB01A	419853.60	6593143.50	183.90	36.50	28.5.00	34.50	Granodiorite
	MB02A	420108.50	6592190.80	303.50	34.50	25.6.00	31.60	Granodiorite
	MB02B	420094.00	6592175.20	301.50	187.00	173.50	185.50	Granodiorite
	MB04A	423003.90	6591263.90	972.70	10.50	6.35	9.35	Sand (residual soil)
	MB04B	422999.70	6591259.00	972.50	60.50	46.70	58.70	Granodiorite
	BH4A	421495.5	6591273.5	884.5	77.70	63.80	75.80	Hornfels
Parrabel Beds	MB03A	418650.90	6591232.30	167.30	23.00	15.00	21.00	Hornfels
	MB03B	418645.80	6591223.60	167.80	100.00	86.00	98.00	Phyllite and hornfels
Fen monitoring bores								
Carrai fen[3]	HA2201	422747.60	6592351.50	922.80	1.00	0.50	1.00	Clayey sand (residual soil)

Table 2.6 Groundwater monitoring bores

Target formation	Bore ID	Easting (GDA20)	Northing (GDA20)	Top of casing (mAHD)[1]	Total depth (mbgl)[2]	Screen interval (mbgl)[2]		Screened lithology
						Top	Base	
	HA2202	422783.70	6592443.80	931.00	0.90	0.40	0.90	Sandy clay (residual soil)
	HA2203	422925.50	6592371.30	935.10	1.00	0.50	1.00	Sandy clay (residual soil)
Production bores								
Parrabel Beds	GW307320	[4]418259	[4]6590097	[4]183	58.00	30.00	58.00	Quartz shale; weathered

Notes: 1. mAHD = metres Australian Height Datum
2. mbgl = metres below ground level
3. interpreted surficial formation
4. Interpreted from geographical software

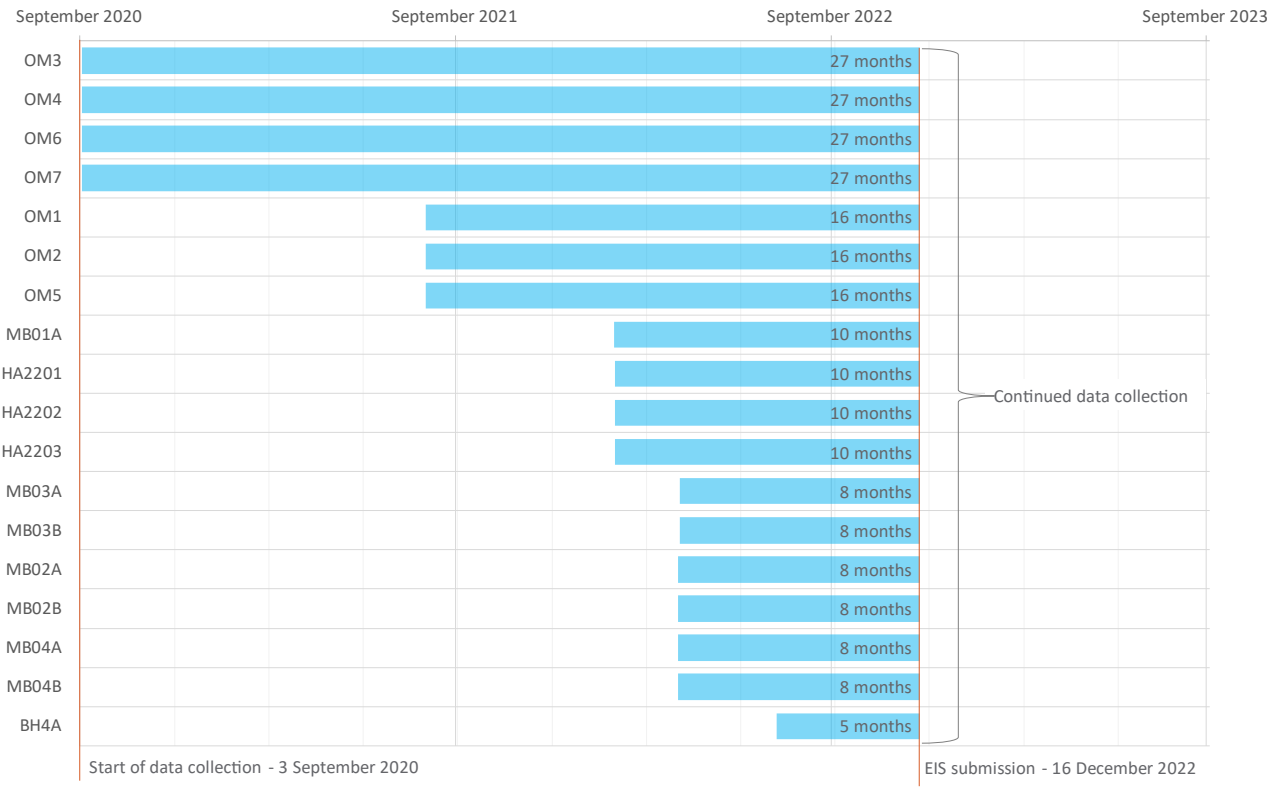
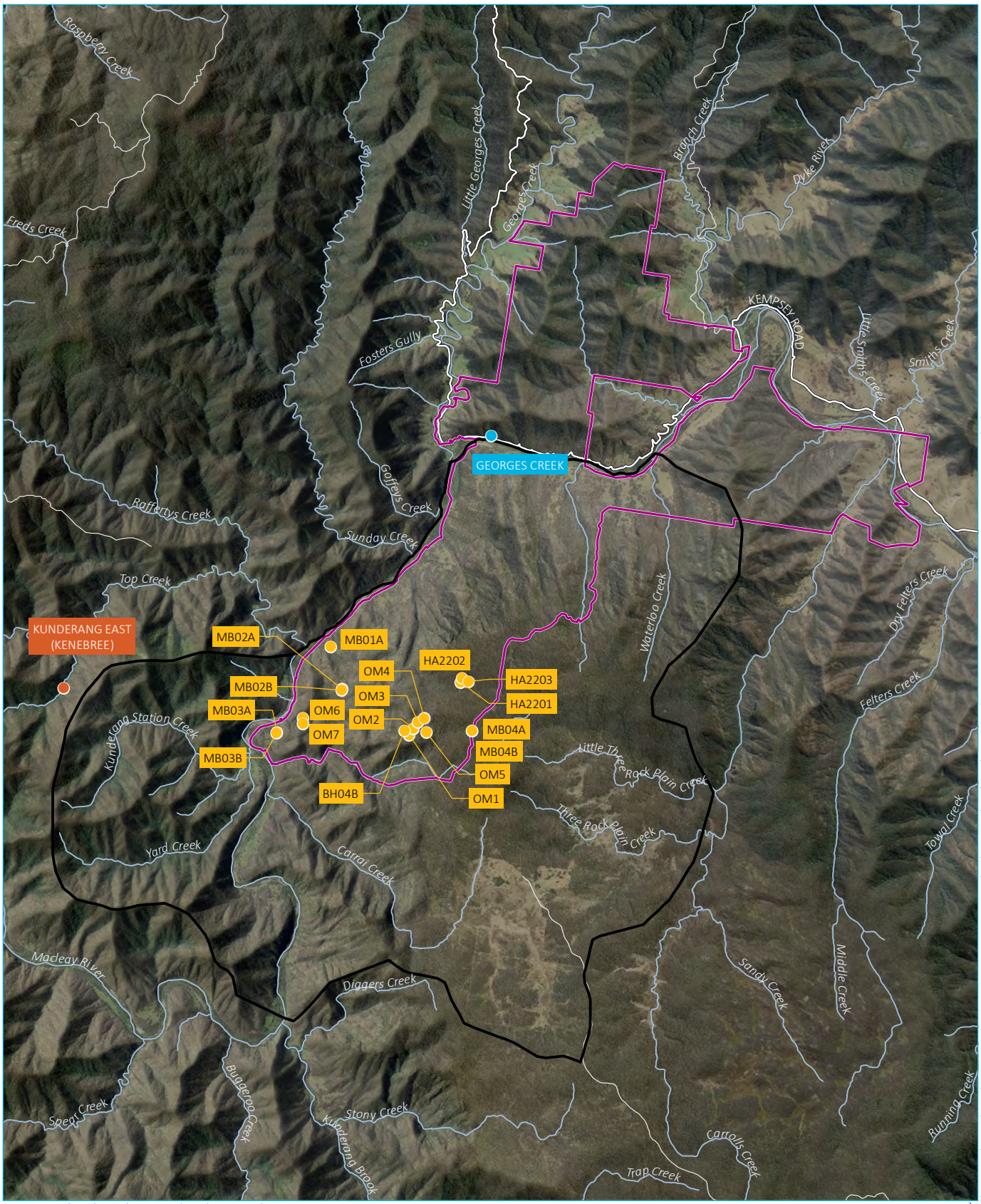


Figure 2.8 Groundwater level monitoring duration



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

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KEY

Project area

Model domain

Monitoring location

Climate station

Stream gauge

Groundwater

Existing environment

Major road

Minor road

Named watercourse

Groundwater, climate and surface water monitoring locations

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Figure 2.9

EMM creating opportunities

2.8.2 Groundwater flow processes and level trends

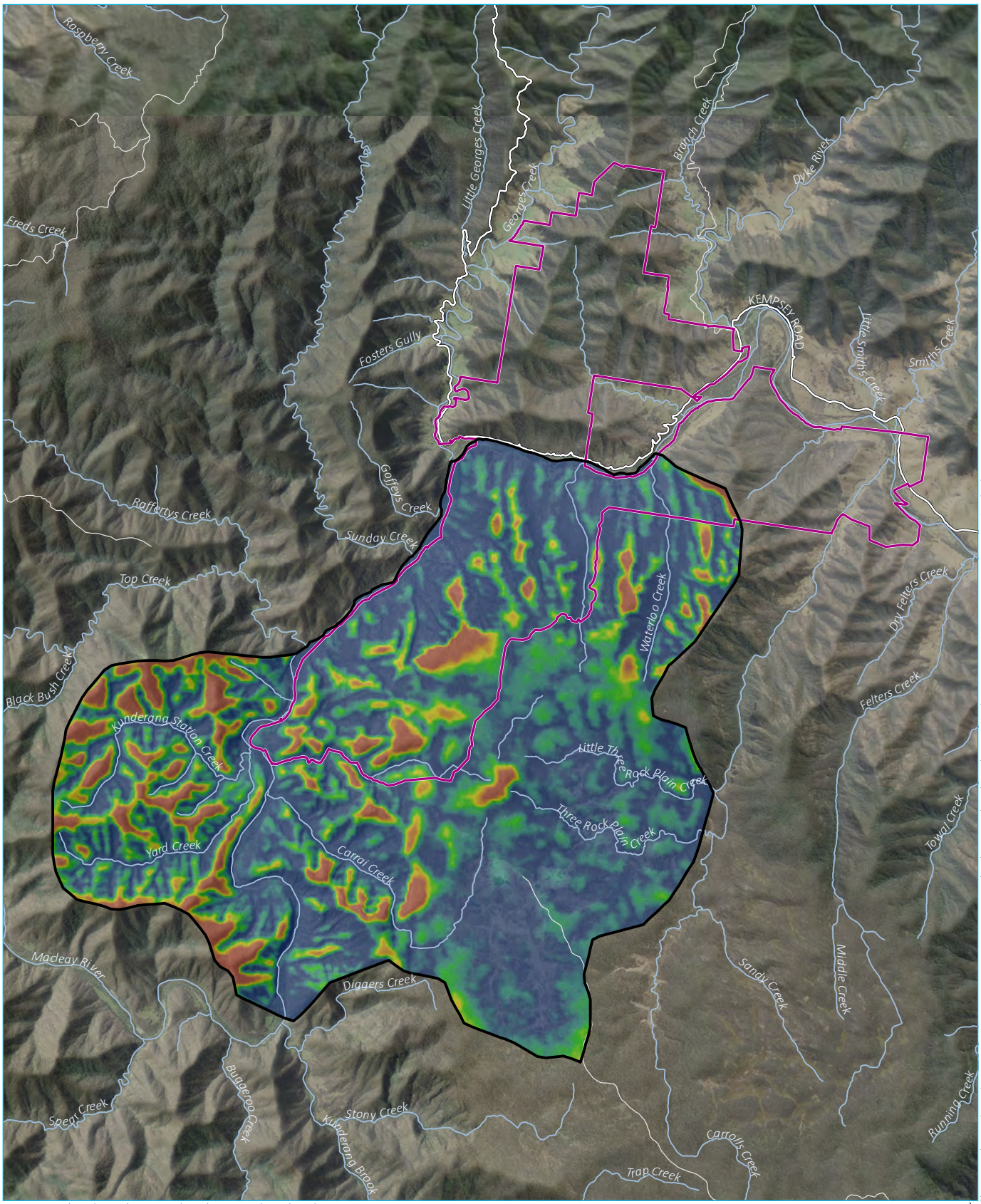
Depth to watertable and watertable elevation maps are provided as Figure 2.10 and Figure 2.11. Selected groundwater level versus rainfall hydrographs are shown in Figure 2.12 to Figure 2.14 and a complete set is given in Appendix A.

Within the study area groundwater generally flows radially from the plateau through the escarpment and toward the Macleay River where it discharges. Monitoring at nested bore sites shows predominantly downward flow within the plateau/upper western catchment and upward flow in the Macleay River floodplain. This is consistent with these areas reflecting recharge and discharge zones, respectively.

Groundwater levels tend to be a subdued reflection of the topography within the study area, with the sitewide watertable shallowest in the upper plateau (~1–2 mbgl at MB04A) and deepest near the top of the escarpment and proposed pressure shaft decline (~50 mbgl at OM2). Groundwater levels within the alluvium are highly dependent on the adjacent stream, with groundwater levels rapidly responding to changes in the stream water level and becoming unsaturated in periods of no streamflow.

Rainfall induced groundwater level fluctuations have been measured across the study area within the Carrai Granodiorite. Fluctuations are typically less than 0.5 m and are more prominent in the shallow monitoring bores. The hornfels unit shows minimal rainfall response.

Groundwater levels in the localised pockets of weathered rock are above the base of the ephemeral watercourses following rainfall, providing interflow to the ephemeral streams during a period proportional to the magnitude and duration of the rainfall.



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020); DPI (2003)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse

Depth to groundwater (m)

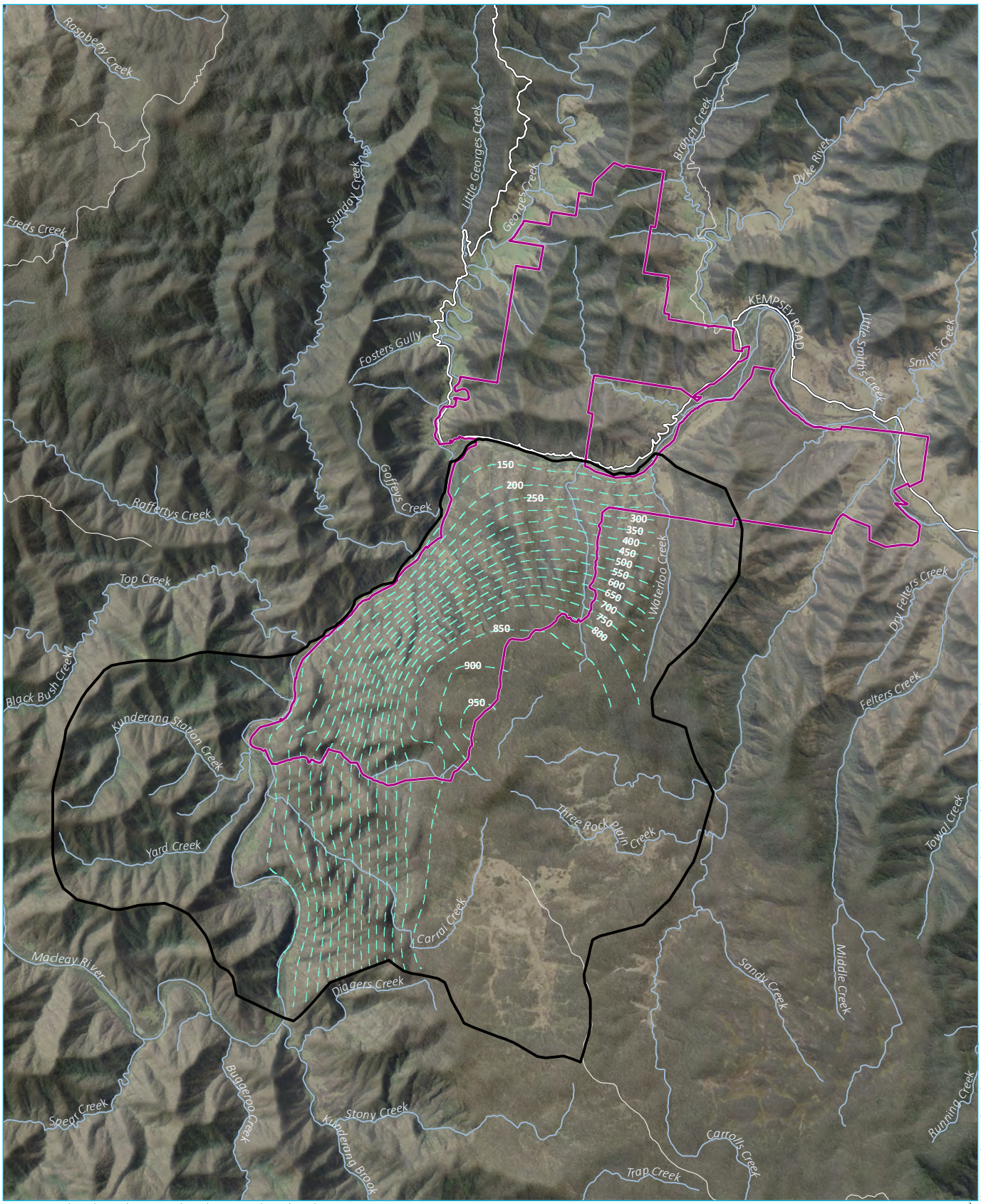
155.6

0

Depth to water table

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Groundwater modelling report
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Figure 2.10

EMM creating opportunities



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020); DPI (2003)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

- Project area
- Model domain
- Inferred groundwater contours (m AHD)

Existing environment

- Major road
- Minor road
- Named watercourse

Water table elevation

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
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Figure 2.11

EMM creating opportunities

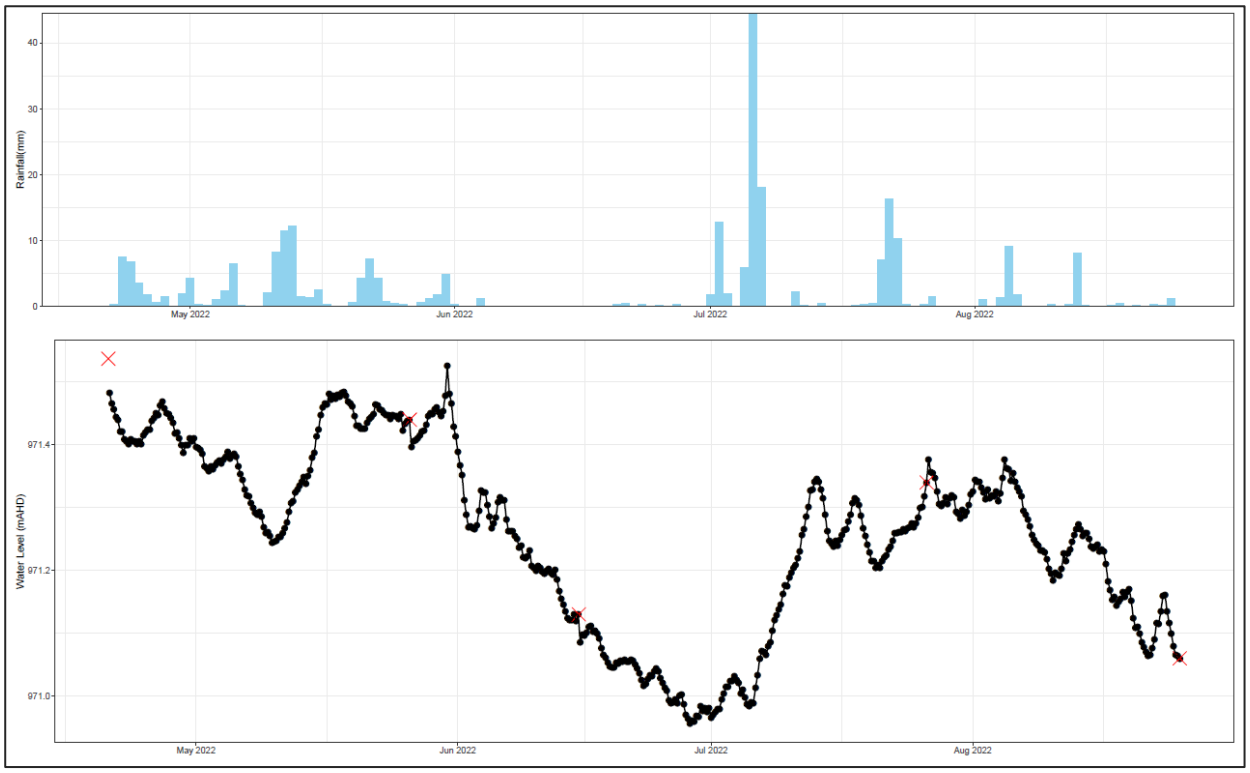


Figure 2.12 Hydrograph for bore MB04A and daily rainfall at East Kunderang, Kenebree (station 57013)

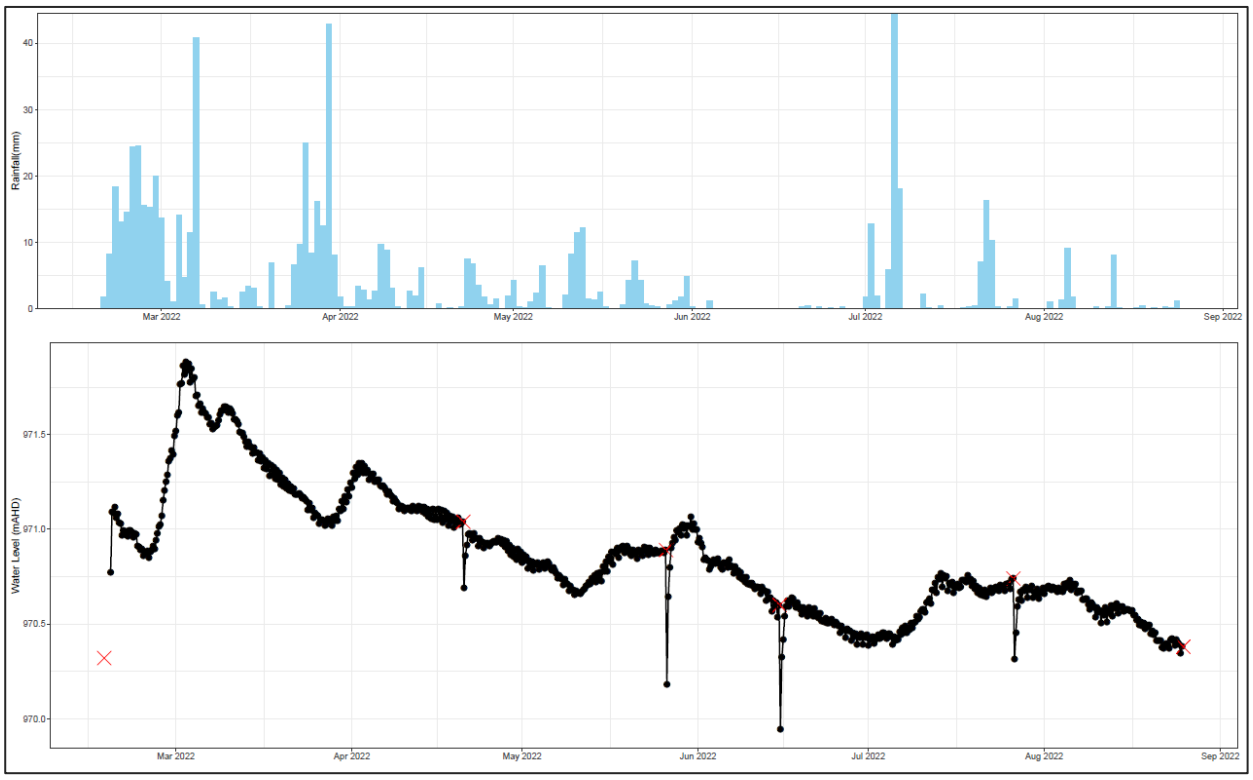


Figure 2.13 Hydrograph for bore MB04B and daily rainfall at East Kunderang, Kenebree (station 57013)

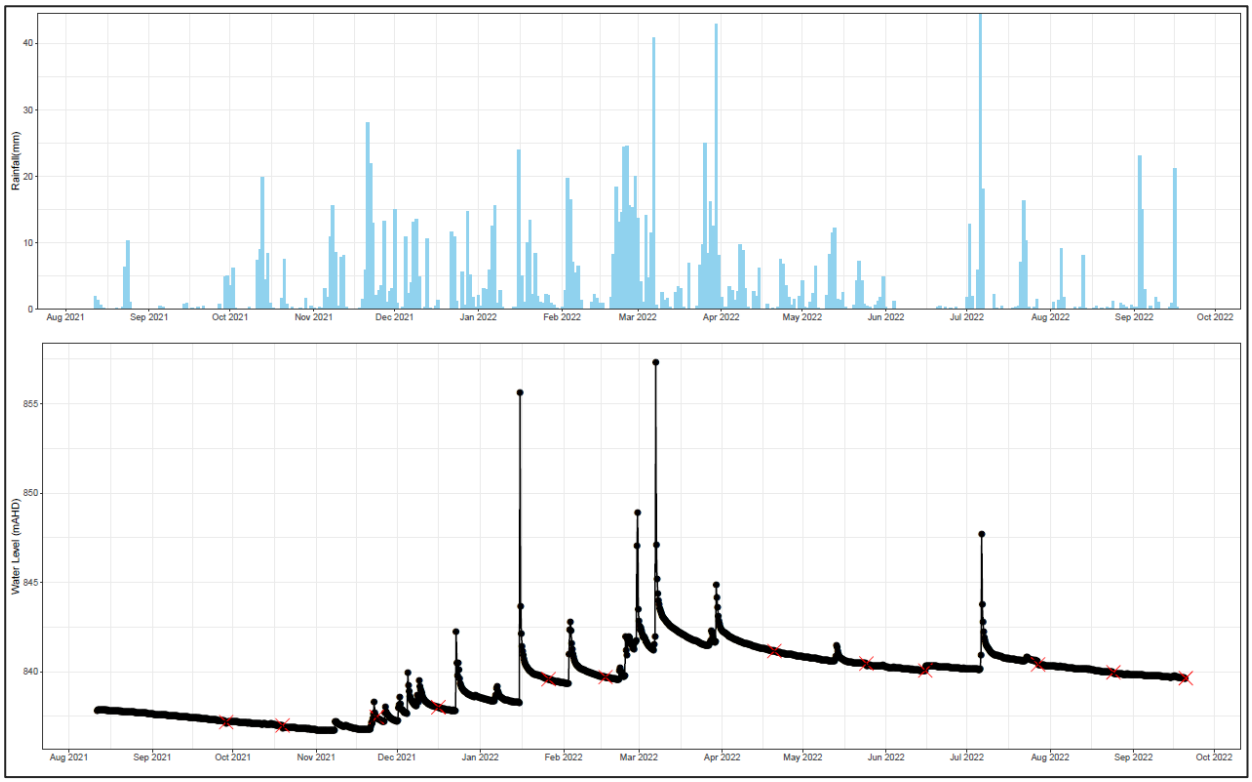


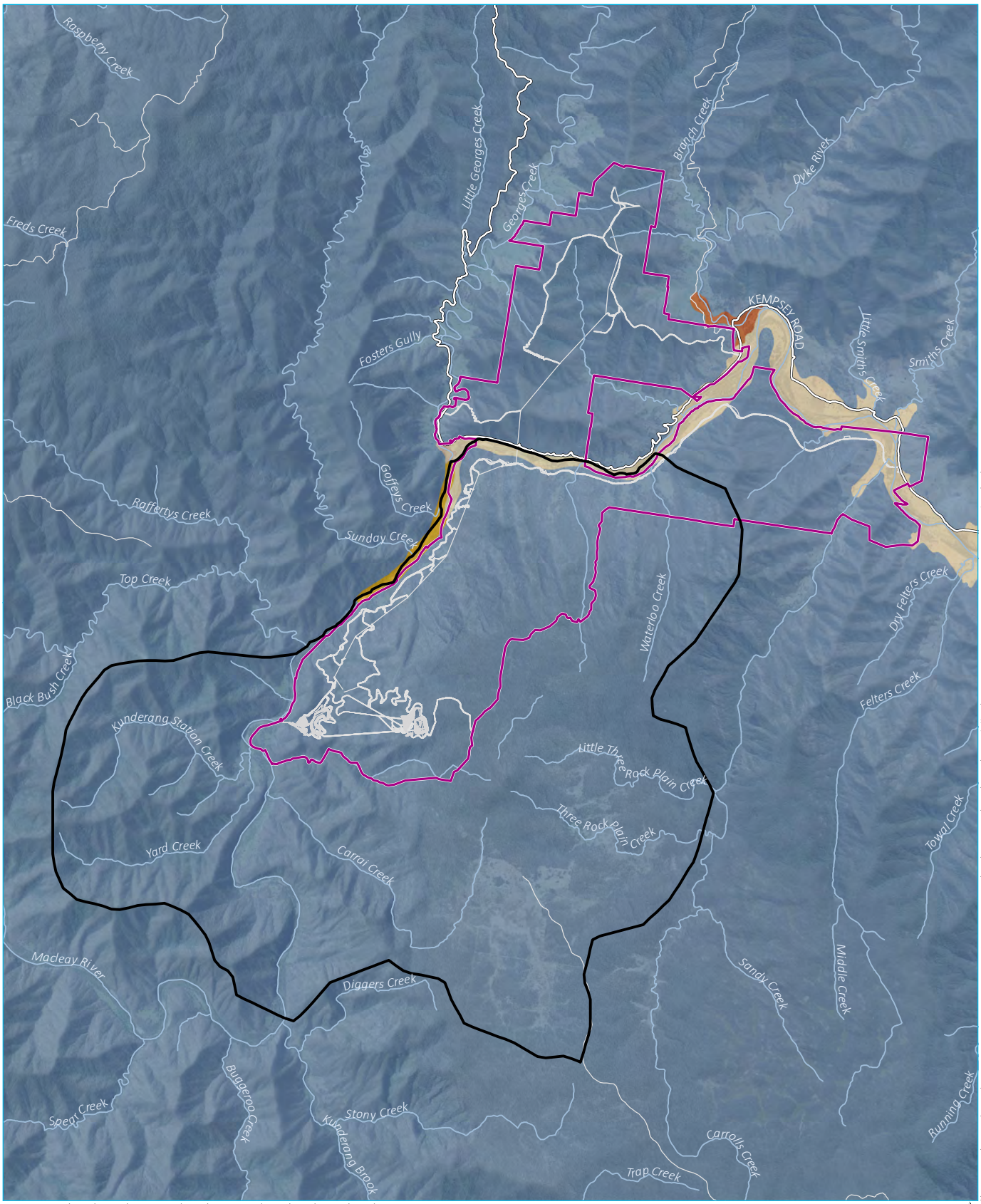
Figure 2.14 Hydrograph for bore OM2 and daily rainfall at East Kunderang, Kenebree (station 57013)

2.9 Water sources

The Project area straddles four water sources within the *Water Sharing Plan for the Macleay Unregulated and Alluvial Water Sources 2016* (Macleay unregulated WSP), comprising the:

- Macleay Gorges Water Source, including 2 unit shares (also straddled by the study area);
- Macleay Valley Water Source, including 3,432 unit shares (also straddled by the study area);
- Dyke River Water Source, without any unit shares; and
- Georges River Water Source, without any unit shares.

All rivers and creeks in the Macleay Unregulated WSP area are unregulated, and there are no defined groundwater management areas (GMAs) in the plan. Registered dams and project relevant Macleay unregulated WSP water source boundaries are illustrated on Figure 2.15.



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020); DPI (2003); DPIE (2021)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse
- Site infrastructure

- North Coast Fractured and Porous Rock Groundwater Source 2016
- New England Fold Belt Coast Groundwater Source
- Macleay Unregulated and Alluvial Water Source 2016
- Unnamed Upriver Alluvium in WSP in the Dyke River Water Source
- Unnamed Upriver Alluvium in WSP in the Georges River Water Source
- Unnamed Upriver Alluvium in WSP in the Macleay Gorges Water Source
- Unnamed Upriver Alluvium in WSP in the Macleay Valley Water Source

Map of water sources relative to the project area

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Figure 2.15

EMM creating opportunities

2.10 Groundwater-surface water connectivity

Surface water features that interact with groundwater include:

- the Macleay River, a perennial river which:
  - receives baseflow from the shallow fractured rock groundwater system (and in-directly receiving groundwater as discharge from the ephemeral streams) during average/dry periods; and
  - discharges to the localised alluvial and shallow fractured rock groundwater systems during flooding events;
- ephemeral streams, originating at springs or fens (associated with the localised groundwater systems) in the upper tributaries and alternating down the flow path between receiving and discharging groundwater from/to the shallow fractured rock groundwater system via fractures within the stream bed;
- fens, specifically located on the plateau, receiving groundwater from the localised groundwater systems, and discharging to the ephemeral streams; and
- lowland seeps, supporting riparian bogs within the plain area and receiving groundwater from near surface expressions of the shallow groundwater system, typically adjacent to streamlines.

2.11 Sensitive receptors

2.11.1 Groundwater Dependent Ecosystems

Based on the *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* (groundwater WSP) (DPI, 2016b), no high priority GDEs are mapped within 12 km of the study area.

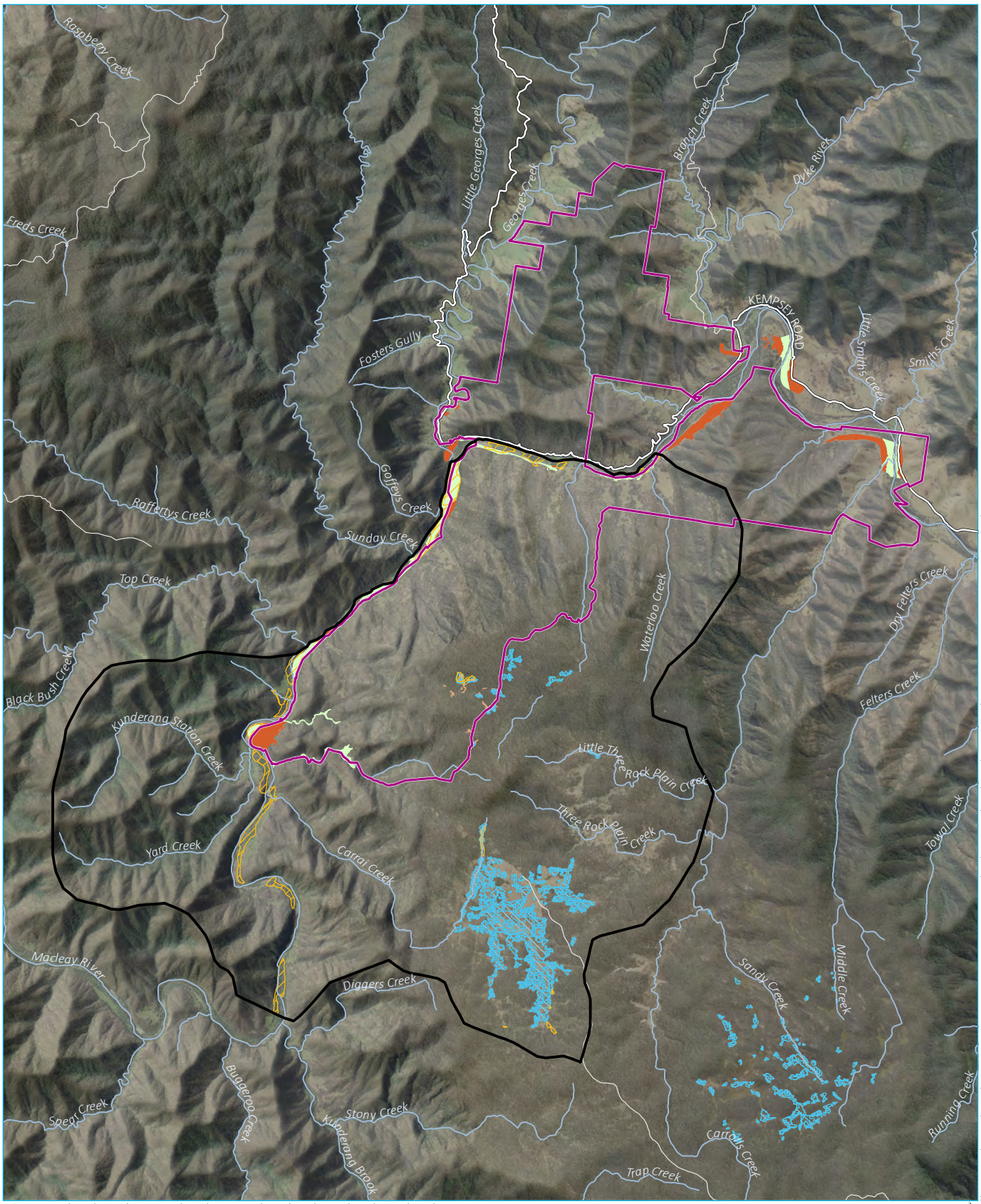
Based on the relevant high ecological value aquatic ecosystem (HEVAE) database (DPE, 2022a) and the GDE atlas (BoM, 2017), GDEs were identified within the study area. A summary of the high potential and high category GDEs (as defined by the BOM and HEVAE databases respectively) is provided in Table 2.7 and outlined on Figure 2.16. Additional works were undertaken in the baseline monitoring program to further characterise GDEs within the study area (see main body of the GIA report).

Table 2.7 Desktop summary of high potential and high category GDEs

Category	Groundwater dependent ecosystem	Focus area	Source
Terrestrial	River Oak	Macleay River floodplain	[1]BoM GDE atlas
	Freshwater Wetland	Plateau	[1]BoM GDE atlas
	Sedgeland/rushland	Plateau	[1]BoM GDE atlas
	New England Tableland Carex Fens (PCT3944)	Plateau	[2]HEVAE database
	Eastern New England Granites Wet Heath (PCT3934)	Plateau	[2]HEVAE database
Aquatic	Macleay River	Macleay River floodplain	[1]BoM GDE atlas
	Floodplain wetland	Macleay River floodplain	[1]BoM GDE atlas
Subterranean	[3]No ecosystem analysed		[1]BoM GDE atlas

Notes: 1. (BoM, 2017)
2. (DPE, 2022a)
3. Subterranean groundwater dependent ecosystem data not available within New South Wales (BoM, 2017)

GDEs have been identified as being entirely/obligate or facultative-opportunistic types, and intercept shallow and/or regional groundwater systems (refer to biodiversity assessment report for further discussion). Where there is a reduction in depth to groundwater, or variability in climate, this may be reflected as a proportional change in ecosystem prevalence for facultative-opportunistic sites, but the ecosystem remains resilient in the absence of groundwater (Serov et al 2012).



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020); DPI (2003); DPIE (2021); BoM (2022)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse

Groundwater dependent ecosystems

- High potential GDE - from regional studies
- High ecological value aquatic ecosystem - GDE

GDEs - PCT mapping

- 1106
- 1287
- 762

Mapped GDEs

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd
Figure 2.16

EMM creating opportunities

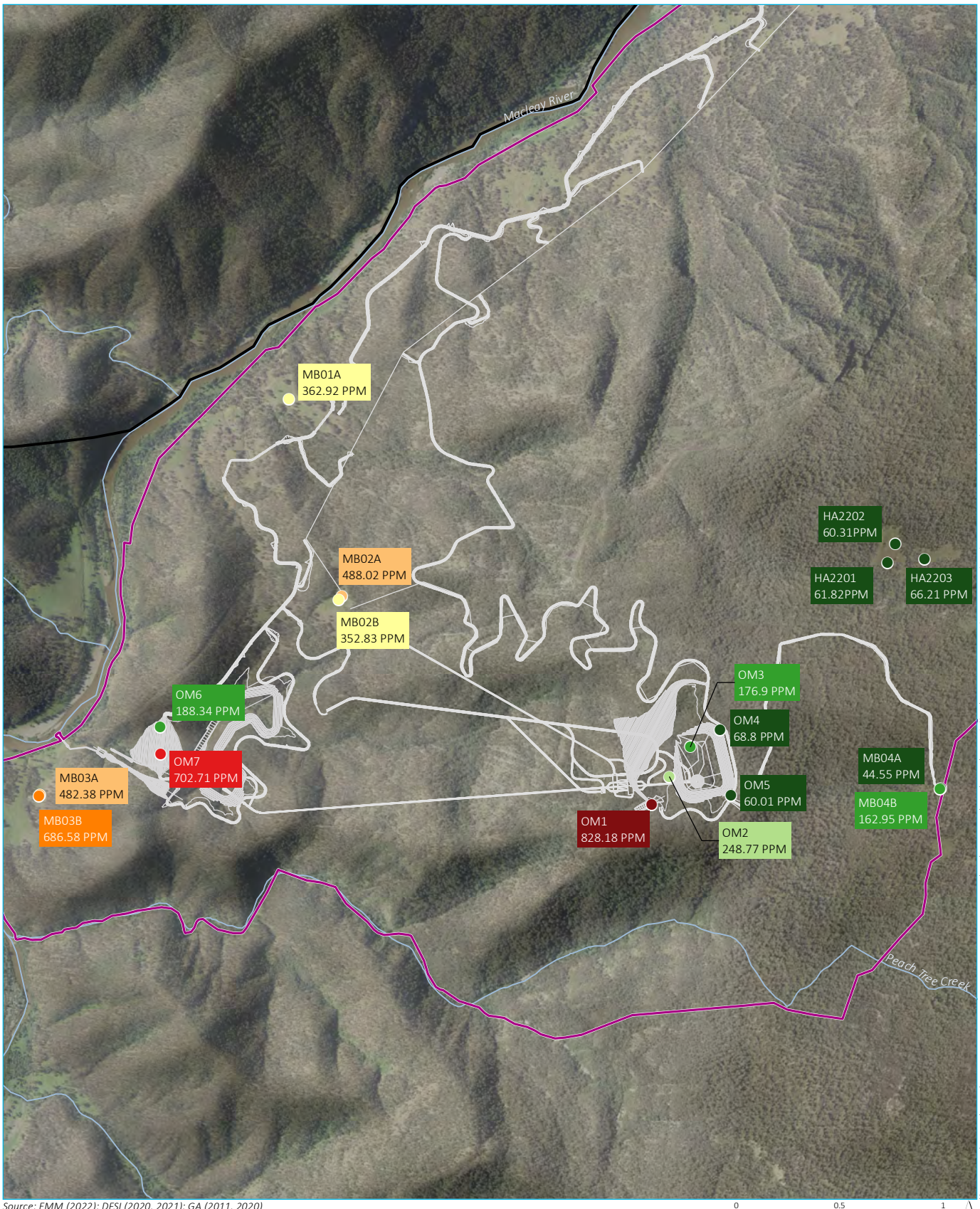
2.11.2 Groundwater relevant cultural areas

Based on a search of the NSW state heritage inventory (DPE, 2022b), the 'Carrai Waterholes' were identified as a declared area of cultural significance, with a potential for groundwater interaction. The approximate location of the Carrai Waterholes is provided on Figure 2.16.

2.12 Groundwater quality

Groundwater quality within the study area is summarised below:

- pH generally ranges between 5.0 and 11.2 within the Carrai Granodiorite groundwater system, with elevated pH typically recorded in the weathered rock. pH is more consistent in the Parrabel beds groundwater system, ranging between 5.76 and 7.24.
- Specific conductivity is relatively consistent within the study area, ranging between 47.1 microsiemens per centimetre (µs/cm) (fresh) and 1,625 µs/cm (brackish).
- Occasional elevated dissolved iron and manganese concentrations within the study area, recording up to 12 milligrams per litre (mg/L) and 3.74 mg/L respectively.
- Total dissolved solids (TDS) (see Figure 2.17) range are very low on the plateau, and low around the lower reservoir. Overall, most sites have recorded a TDS of around 200 parts per million (ppm), with none higher than 1,000 ppm.



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Source: EMM (2022); DFSI (2020, 2021); GA (2011, 0 0.5 1 km GDA 1994 MGA Zone 56 N

KEY

- Project area
- Model domain
- Named watercourse
- Site infrastructure

Total dissolved solids (ppm)

- < 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 600 - 700
- 700 - 800
- > 800

Spatial variation of groundwater quality in fractured rock water source

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Figure 2.17

EMM creating opportunities

2.13 Summary of baseline conceptual model

A schematic of the baseline HCM is presented in Figure 2.18. Key features of the HCM include:

- Shallow unconfined groundwater flow systems occur within alluvium and, colluvium and residual soil are highly localised to areas in the plateau and floodplain and are not site-wide systems. They contain shallow groundwater that provides throughflow recharge to the springs and watercourses following periods of higher rainfall.
- The Parrabel Beds, hornfels and Carrai Granodiorite are naturally tight rock formations that mainly host groundwater within joints, fractures and rock defects. In the upper 100 m of the bedrock profile, hydraulic testing has indicated that there is moderate to low intensity fracturing that provides for K ranging from 0.1 to 0.001 m/d. This limited permeability in the rock allows for unconfined conditions and this is reflected in monitoring bores that respond to higher periods of rainfall.
- At depths of > 100 m within the bedrock profile K estimates drop to < 0.001 m/d which reflects compression of defects associated with higher lithostatic pressures and less pervasive and intense fracturing at depth. This is a common phenomenon in fractured rock environments.
- Within the study area groundwater generally flows radially from the plateau to the Macleay River. Monitoring data at nested bore sites show predominantly downward flow within the plateau/upper western catchment and upward flow in the Macleay River floodplain. This is consistent with these areas reflecting recharge and discharge zones, respectively.
- Recharge to the shallow (unconsolidated and weathered bedrock) and intermediate (fractured bedrock) groundwater systems occurs predominantly across the plateau (the recharge zone) mainly through direct recharge from rainfall infiltration where the units outcrop. The deeper groundwater system is recharged by localised infiltration from the overlying shallow and intermediate groundwater systems, typically in the recharge zone and upper escarpment.
- The Macleay River forms the overall discharge zone within the study area, receiving groundwater from baseflow contributions, via the regional groundwater systems and ephemeral streams, supported by groundwater expressions in the upper tributaries.
- GDEs have been identified as being entirely/obligate or facultative-opportunistic types, and intercept shallow and/or regional groundwater systems (refer to biodiversity assessment report for further discussion). Where there is a reduction in depth to groundwater, or variability in climate, this may be reflected as a proportional change in ecosystem prevalence for facultative-opportunistic sites, but the ecosystem remains resilient in the absence of groundwater.

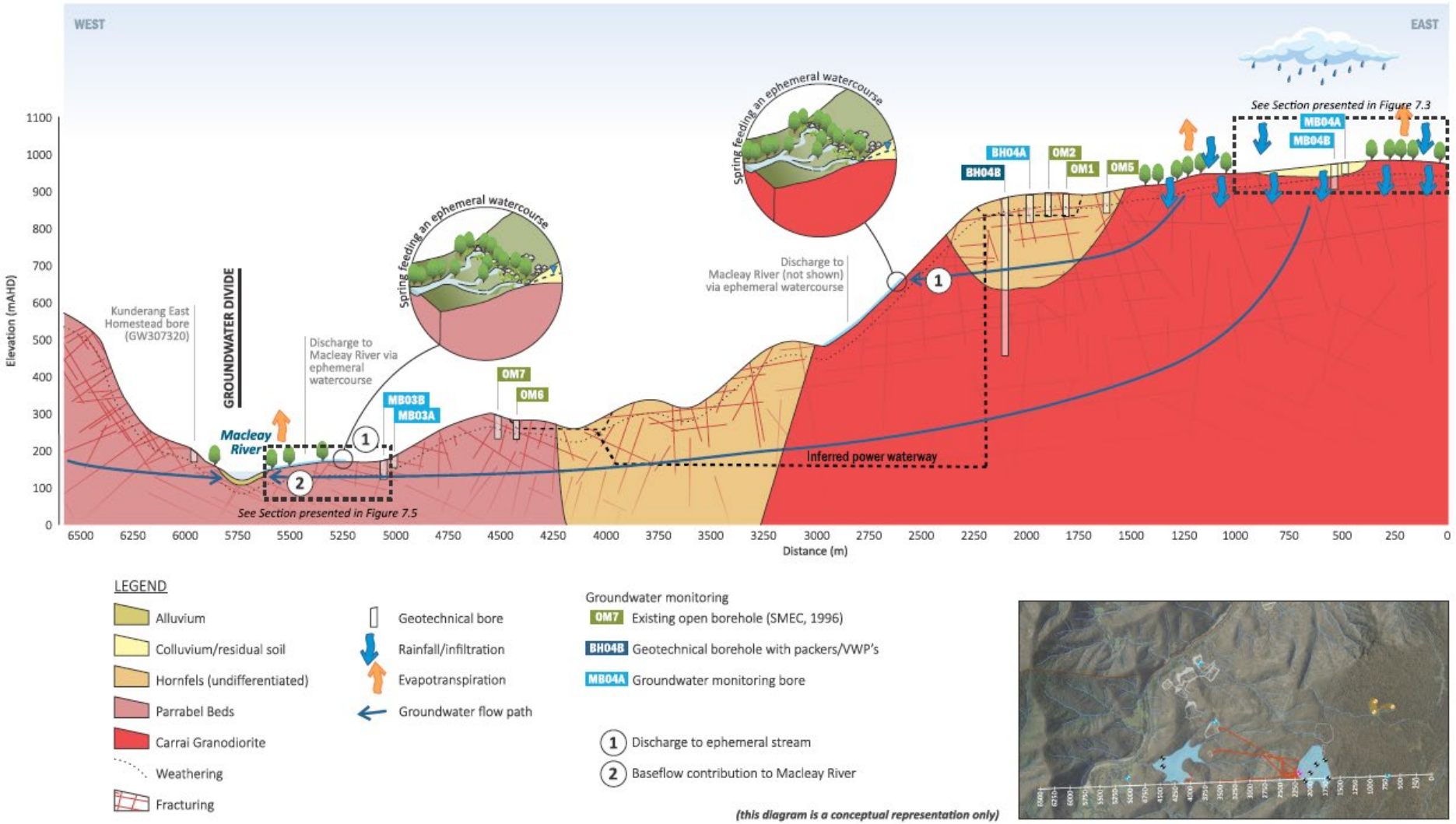


Figure 2.18 Conceptual model schematic

2.14 Conceptualisation of Project impacts

The Project involves groundwater-affecting activities that were originally outlined in Section 1.3. This section of the report details how those groundwater-affecting activities may impact the baseline groundwater systems (illustrated in Figure 2.18 above) in context of the conceptual dynamics and characteristics of those flow systems.

2.14.1 Construction phase

Construction activities with potential to impact the groundwater systems and receptors include:

- Excavation of rock and sediments at the upper and lower reservoirs to increase the storage volume of the reservoirs. Excavation of these materials will occur below the watertable and should lead to groundwater inflows and lowering of local watertables. The localised shallow groundwater systems are not physically present at either reservoir and are therefore unlikely to be impacted. The intermediate groundwater flow system (fractured bedrock) will be most affected, and the moderate permeability of those systems should lead to localised drawdowns in this unconfined groundwater system at both reservoirs. The base of excavations does not extend into the deep groundwater system (competent, tight bedrock) and negligible drawdown impacts are expected in that hydrostratigraphic unit during construction. Water management may be required to handle any groundwater inflows to the reservoirs during construction.

- Excavation and digging of the access portals will occur through fractured and unfractured bedrock and has potential to lead to local inflows of groundwater during construction. This will lead to localised drawdown in those fractured bedrock units and negligible drawdown in the deeper tight bedrock. As there are no immediately overlying sediments or water courses, there is not expected to be impact to the shallow groundwater system or connected receptors. Water management may be required to handle any groundwater inflows to the access portals during construction.

- Excavation and digging of the low-pressure headrace, the deep vertical pressure shaft, the power station, and the tailrace all have potential to occur through both fractured and unfractured bedrock during the construction period. This will lead to localised drawdown in the fractured bedrock unit and negligible drawdown in the deeper tight bedrock. Water management may be required to handle any groundwater inflows to the headrace and tailrace during construction.

- There is an anticipated very low likelihood of loss of yield in the East Kunderang Homestead bore due to regional drawdown. The bore is located west of the Macleay River and is part of a separate groundwater flow system on the other side of the groundwater divide. Additionally, most construction-related drawdown will occur within the unconfined fractured bedrock and those drawdown extents are conceptually envisaged to be localised

- It is not expected conceptually that the above construction activities will lead to loss of spring flows that may be sustaining creeks, rivers and GDEs or loss of baseflow in the Macleay River.

2.14.2 Operation phase

Operation of the pumped hydro system has potential to impact the groundwater systems and receptors including:

- Filling the reservoirs with water to operate the scheme will introduce an elevated body of water that will be in hydraulic connection with the local, shallow geological layers including sediments, weathered and fractured bedrock and unfractured bedrock. This raised hydraulic head has potential to induce inflows to the intermediate fractured bedrock groundwater flow system and lead to localised mounding in that moderately permeable unit and radial flow away from these structures towards sensitive receptors. Given the GDEs are conceptualised to be supported by local shallow groundwater flow systems within unconsolidated sediments and residual soils, there may be a slight head changes at GDEs if there is upward flow from the fractured rock and head changes in the shallow groundwater flow system.
- During operation the headrace will operate at equivalent pressure to the upper reservoir, while the tailrace will operate at equivalent pressure to the lower reservoir. Enforcing these pressures at depth within the bedrock may lead to altered groundwater flow paths and changes in groundwater levels in the fractured bedrock groundwater system immediately surrounding and within a few kilometres of these structures.
- During operation the power station and penstocks will either be concrete-sealed or steel-lined to minimise interactions with the deeper bedrock groundwater system.

3 Model design

3.1 Equivalent porous media approach

Given the scale and complexity of the model (Section 1.6) and the modelling objectives (Section 1.5) the numerical groundwater flow model was designed using an equivalent porous medium (EPM) approach for the fractured and weathered bedrock HSUs. This approach is commonly used in larger-scale groundwater models of fractured rock environments. The EPM method assigns bulk hydraulic properties for a HSU and treats the rock matrix and any fracture associated networks as if they were a single porosity medium such as a granular aquifer (Anderson and Woessner 1991). This approach was adopted for the following reasons:

- It is environmentally conservative to assume that the intermediate fractured rock groundwater system is interconnected at the site-wide scale and is also permeable. This assumption allows for drawdown/mounding to propagate radially outwards from the project components and, therefore, assessment of impacts to receptors (including baseflow reduction) is skewed towards over-emphasising potential impacts.

- From a Project water balance perspective, assuming interconnected and permeable fractured rock conditions is also conservative in that it may tend to over-predict groundwater inflow rates during construction and operation, which will reduce the risk of under-estimating groundwater and surface water licensing requirements.

- Dual porosity and discrete fracture network models require significant detail on fracture/joint orientations, spacings, lengths and apertures, which were not available for the geology in the model domain.

It is noted that the EPM approach is appropriate for a larger scale groundwater model, though one of the limitations is small-scale accuracy induced by not capturing the detail in local fracture network properties. The adopted approach to overcome that limitation was to explore predictive uncertainty through probabilistic uncertainty analysis.

3.2 Model complexity

The *Minimum Groundwater Modelling Requirements for SSD/SSI Projects* (DPE 2022) states that:

> An effective model achieves an acceptable level of parsimony, in which the model is simple enough to be manageable, yet complex enough to represent the system at the desired level of detail.

Table 3.1 provides a summary of the model complexity with respect to the environmental complexity and sensitivity (as per Figure 3 on page 19 of the DPE guidelines). Based on this assessment using DPE's criteria, the model complexity is pitched at medium to high complexity with an environmental complexity and sensitivity that is mainly low to medium complexity. The scale of the development and the importance of receptors necessitates a model complexity of medium to high ranking. This provides confidence that the overall model complexity is appropriate for the risk to the environment.

Table 3.1 Summary of model and environmental complexity

Factor	Comment	Model complexity	Environmental complexity and sensitivity (E)
Model scale	Local-scale and site-wide scale (not regional scale)	Medium complexity	
Layering	Numerical model > 5 layers	High complexity	
Model type	Numerical model with multiple aquifer units	High complexity	
Model requirements	No density issues, no coupled SW-GW requirements, no solute transport	Medium complexity	
Temporal scale	Transient model capable of simulating construction and operation of the system	Medium complexity	
Productive aquifers	Medium to low productivity aquifers		Low to medium environmental complexity
Issues	No cumulative effects, no irrigation use, no other nearby developments in same HSU		Low environmental complexity
Receptors	Receptors partially connected with exploited aquifer and GDEs present		Medium to high environmental complexity
Scale of development	Large scale development		Medium to high environmental complexity
Water supply risks	No large town water supplies nearby		Low environmental complexity
Cumulative impacts	No nearby developments in same or other aquifers		Low environmental complexity

3.3 Software

The model was run using the MODFLOW-USG code (Panday et al. 2013) through the Groundwater Vistas V8 Pro graphical user interface (Rumbaugh 2020). MODFLOW-USG represents a major revision of the standard MODFLOW code, in that it uses a different underlying numerical scheme: control volume finite difference (CVFD), rather than traditional MODFLOW's finite difference (FD) scheme. 'USG' is an acronym for Un-Structured Grid, meaning that MODFLOW-USG supports a variety of structured and unstructured model grids, including those based on cell shapes (Panday et al. 2013). The CVFD method also means that a model cell can be connected to an arbitrary number of adjacent cells, which is not the case with a standard FD scheme.

In contrast with structured rectangular finite-difference grids, flexible meshes have several advantages. Firstly, they allow finer mesh resolution to be focused solely in areas of a model that require it (eg along the tunnel alignments), as opposed to refinement over the entire mesh, significantly decreasing cell count and consequently model run times and file sizes. Secondly, spatial areas not required in the model may be omitted rather than deactivating cells or retaining "dummy" layers (ie layer pinch-outs). Thirdly, flexible meshes allow cell boundaries to follow important geographical or geological features, such as watercourses or outcrop traces, more accurately modelling the geometry of the physical system. Finally, the orientation of the flow interfaces between cells may vary, allowing preferential flow directions to be modelled with higher accuracy.

Additionally, MODFLOW-USG can simulate variably-saturated flow and can handle desaturation and re-saturation of multiple hydrogeological layers without the “dry cell” problems of traditional MODFLOW. This is pertinent to models which simulate layers, such as surficial regolith, which frequently alternate between unsaturated and saturated, as well as the depressurisation and desaturation that occurs due to tunnel excavation. Traditional versions of MODFLOW can handle depressurisation and desaturation to some extent, but model cells that are dewatered (reduced below atmospheric pressure) are replaced by “dry” cells, which can interfere with the simulation of various flow processes and cause model instability.

3.4 Domain and spatial discretisation

3.4.1 Model extent

The full extent of the groundwater model for the project is shown in Figure 3.1. The model area is irregularly shaped to follow hydrogeological features, with a maximum north-south distance of 14 km and east-west distance of 15 km. Most of the model boundary follows topographic highs that correspond to groundwater catchment divides, except for the north-western part of the boundary that instead follows the Macleay River. To the west of the Macleay River, the model boundary was extended past the river to allow for representation of the groundwater system at the private groundwater abstraction bore GW307320 at East Kunderang Homestead, which was identified as a potentially impacted third party bore. This model extent was chosen to allow the model edges to consist of either no-flow or river boundaries.

3.4.2 Mesh

The use of MODFLOW-USG (Section 3.3) allows the use of an unstructured or irregular mesh. For this project, a Voronoi polygon mesh was created (Amenta and Bern, 1998), which has the advantage of being not only irregular but maintaining the property that a line connecting adjacent cell-centres is perpendicular to the shared cell boundary. Use of the unstructured mesh allows refinement by using small cell sizes along key model features such as below surface tunnels and above ground watercourses while letting the cell size increase in areas that are further away from features of interest.

The model domain is discretised into 46,146 cells per each layer, and 25 model layers. The model uses a feature of MODFLOW-USG which allows cells to be “pinched out” where a layer is not present, or is less than 0.5 m thick, and the pinched out cells are treated as inactive and are removed from all calculations. Of the 1,153,650 total cells in the model, about half are pinched out resulting in a total of 563,404 active cells.

The Voronoi mesh was generated using AlgoMesh 2.0 (HydroAlgorithmics 2020), which provides significant control over the mesh generation process. The mesh was then imported into Groundwater Vistas to build and operate the remainder of the groundwater model.

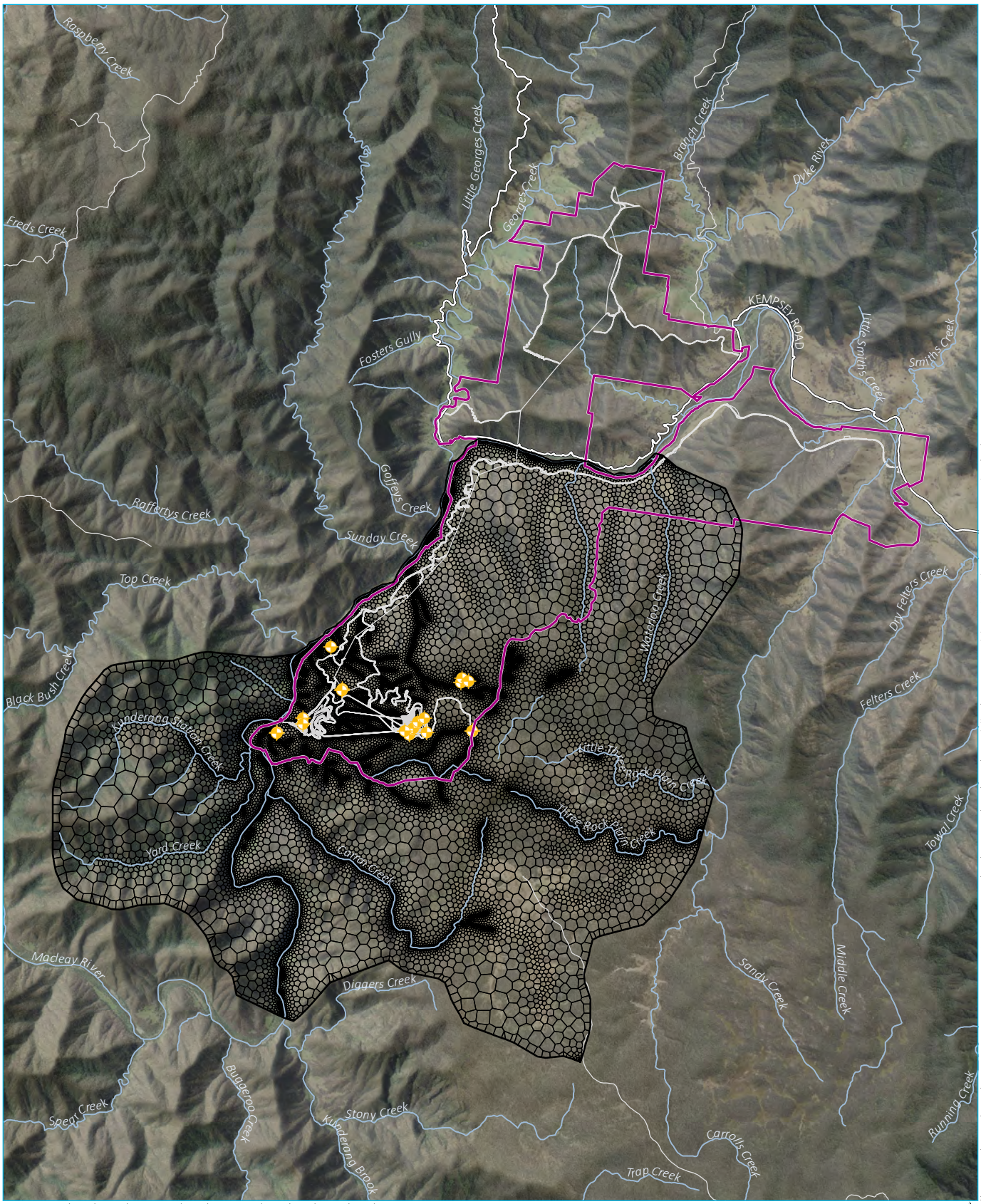
The following general approach was taken when creating the mesh:

- A buffer around the proposed tunnel alignments was used to define the access portals, water races and reservoirs.
- Polylines along mapped rivers and creeks were point sampled at regular intervals to make sure the mesh conformed to mapped drainage networks, and to enforce variable degrees of spatial detail along streams (eg greater detail along streams closest to the Project that have higher potential of being impacted).
- Monitoring bore locations were included in the mesh generation process to enforce sufficient spatial detail in areas with observations located close to one another and centralisation within the model cell to minimise interpolation errors.

In a Voronoi mesh, the maximum 'cell size' in an area is used as a constraint in the creation process, and it is defined as the distance between the centroids of two adjacent cells. The adopted maximum cell sizes in key areas of interest are as follows:

- 5 m at tunnels;
- 25 m at reservoirs;
- 25 m at GDEs, springs and streams close to the Project;
- 25 m at perennial rivers;
- 100 m along primary stream lines not in the Project vicinity; and
- 500 m maximum over the remainder of the model domain.

Cells are allowed step out to the larger size grading progressively away from tunnels and watercourses. Figure 3.1 illustrates the model domain and the Voronoi mesh adopted and a zoomed in view of the mesh in the vicinity of reservoirs, access portals and waterways is presented in Figure 3.2. Figure 3.3 illustrates some of the point features used to generate the mesh including bores, GDEs and receptors such as the Macleay River.



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020); DPI (2003); DPIE (2021)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW011_ModelDomainMesh_20221028_01.mxd 14/12/2022

KEY

- Project area
- Groundwater bore network
- Model domain
- Model mesh

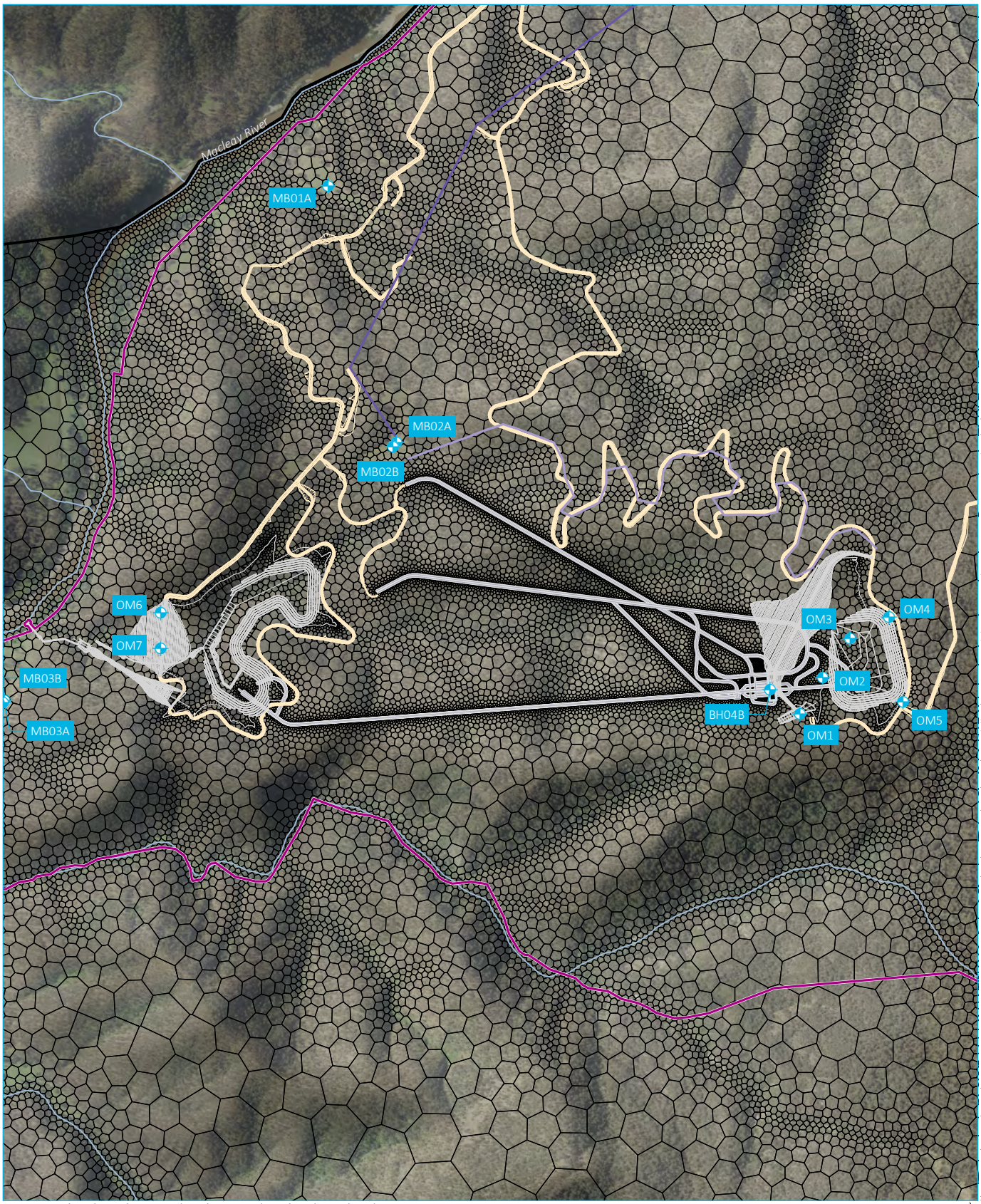
Existing environment

- Major road
- Minor road
- Named watercourse
- Site infrastructure

Model domain and Voronoi mesh

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Groundwater modelling report
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Figure 3.1

EMM creating opportunities



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020); DPI (2003); DPIE (2021)

0 0.5 1 km

GDA 1994 MGA Zone 56

N

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KEY

- Project area
- Groundwater bore network
- Model domain
- Model mesh

Existing environment

- Named watercourse

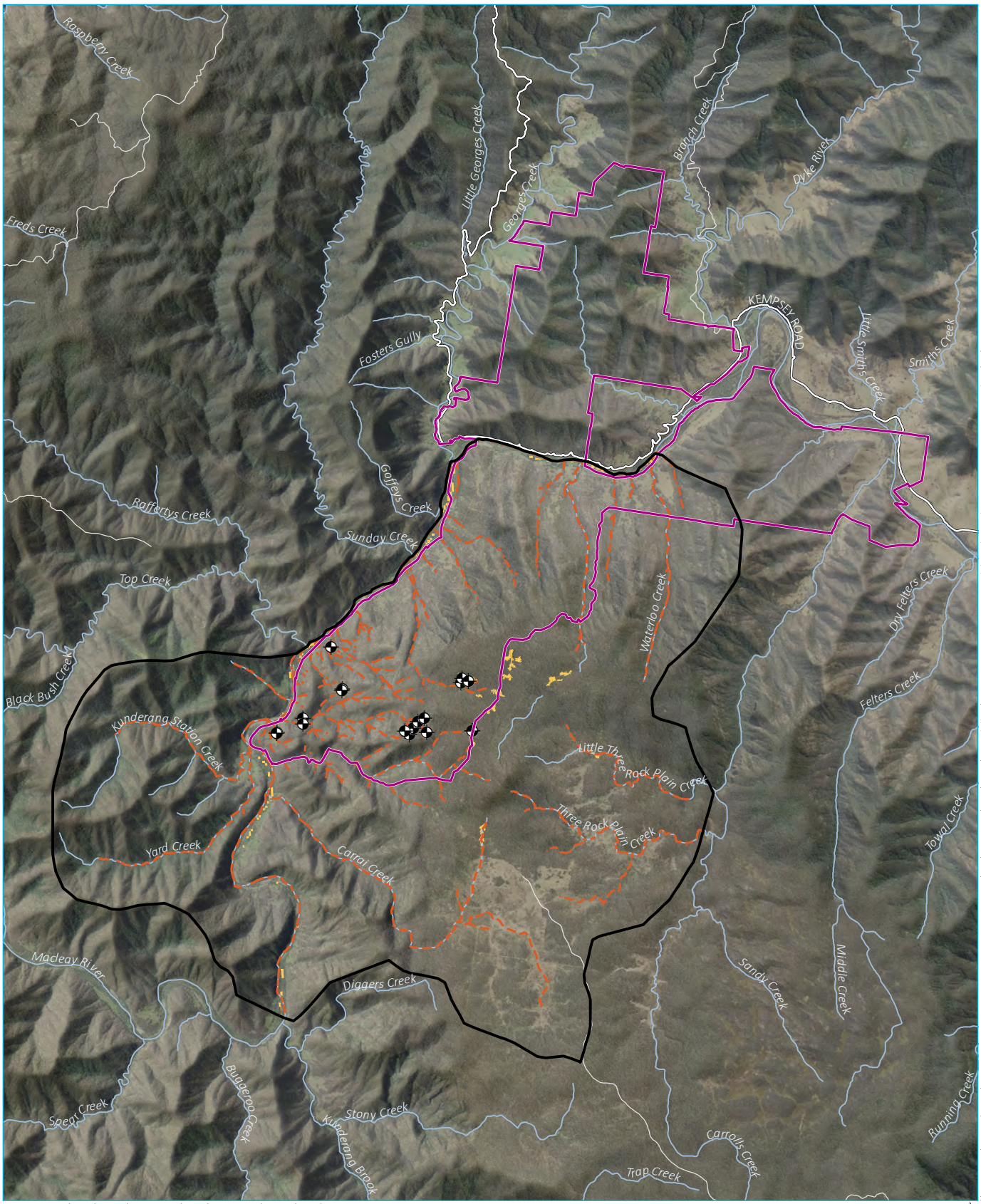
Operational elements

- Power and communications lines
- Transmission overhead lines
- Dam and reservoir design
- Permanent road
- Underground power station complex
- Tunnels, portals, intakes, shafts

Voronoi mesh in the vicinity of reservoirs, access portals and waterways

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd
Figure 3.2

EMM creating opportunities



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020); BoM (2022)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

Project area

Model domain

Existing environment

Major road

Minor road

Named watercourse

Features used in model mesh development

Bores

Surface water features

GDEs

Bore, GDEs and surface water features used in the model mesh development

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd
Figure 3.3

EMM
creating opportunities

3.4.3 Layers

Several competing demands influenced the final model layer configuration. These factors included:

- the three main groundwater flow systems are largely depth-based systems;
- there is a significant elevation difference (>800 m) between the plateau and the Macleay River floodplain;
- the reservoirs are cutting into fresh rock to enable greater supply capacity which leads to more detailed vertical resolution to both groundwater inflow and drawdown/mounding predictions;
- access portals and the headrace and tailrace intersect both the intermediate (fractured rock) and deep (tighter rock) groundwater flow systems and require more detailed vertical resolution to allow for accurate groundwater inflow and drawdown predictions; and
- the deep vertical pressure shaft, power station and penstocks mainly intersect very thick expanses of the deep groundwater flow system.

To best manage model complexity and address the key factors outlined above, the model adopted a hybrid layer configuration that is summarised in Table 3.2 with Figure 3.4 showing a cross section along the project alignment from the Macleay River in the west to beyond the top reservoir in the east. The hybrid layer structure includes:

- The uppermost layer represents the more permeable weathered geology and residual soils, alluvium and colluvium. A 2 m gridded LiDAR-derived digital elevation model (NSW DFSI, 2022) was used to define the top of the model. The layer was given a thickness of 5 m across the model domain except local to bores where logs indicated a slightly different thickness.
- Layer 2 geometry follows the base of Layer 1 with a uniform thickness of 100 m outside of the Project area. This layer represents the intermediate groundwater flow system (fractured bedrock).
- Beneath layer 2, all layers are set horizontal with bottom elevation increments of 100 m, with the base of the model at -200 mAHD.
- Within a 1 km buffer of the convex hull of tunnels and reservoirs (see from distance 1,000 to 5,800 on Figure 3.4), vertical refinement of the horizontal layers is set at 20 m between 100 mAHD and 360 mAHD, which encompasses all underground works with the exception of the upper limits of the vertical pressure shaft. This was applied to minimise the influence of cell size on inflow predictions as well as to appropriately capture the vertical hydraulic gradients resulting from groundwater inflows to the excavated components during construction and outwards pressure from the waterway during operation.
- When these 20 m thick horizontal layers are close to the surface and would be within the 100 m thickness of fractured bedrock represented by layer 2, the thickness of layer 2 is reduced down to a minimum of 20 m and those areas are also assigned fractured bedrock properties down to 100 m depth.
- Where the model elevation at the base of layer 2 is less than the bottom of a horizontal layer, or it would have a thickness of less than 0.5 m, it is pinched out. This results in only layers 1, 2 and the bottom layer 25 being fully active (continuous) across the whole model domain.

Table 3.2 Model layer summary

Layer	HSU	Project components	Active or pinched
1	Alluvium, colluvium, residual soil Weathered bedrock	Upper and lower reservoirs, access portals	Fully active
2	Fractured bedrock	Upper and lower reservoirs, access portals	Fully active
4–24	Tight bedrock	Access portals, headrace and tailrace, penstocks, vertical pressure shaft, power station	Pinched out as required
25	Tight bedrock	None	Fully active

Modelled topography is presented in Figure 3.5, while the base of model layer 2 (base of the fractured rock groundwater system) is presented in Figure 3.6.

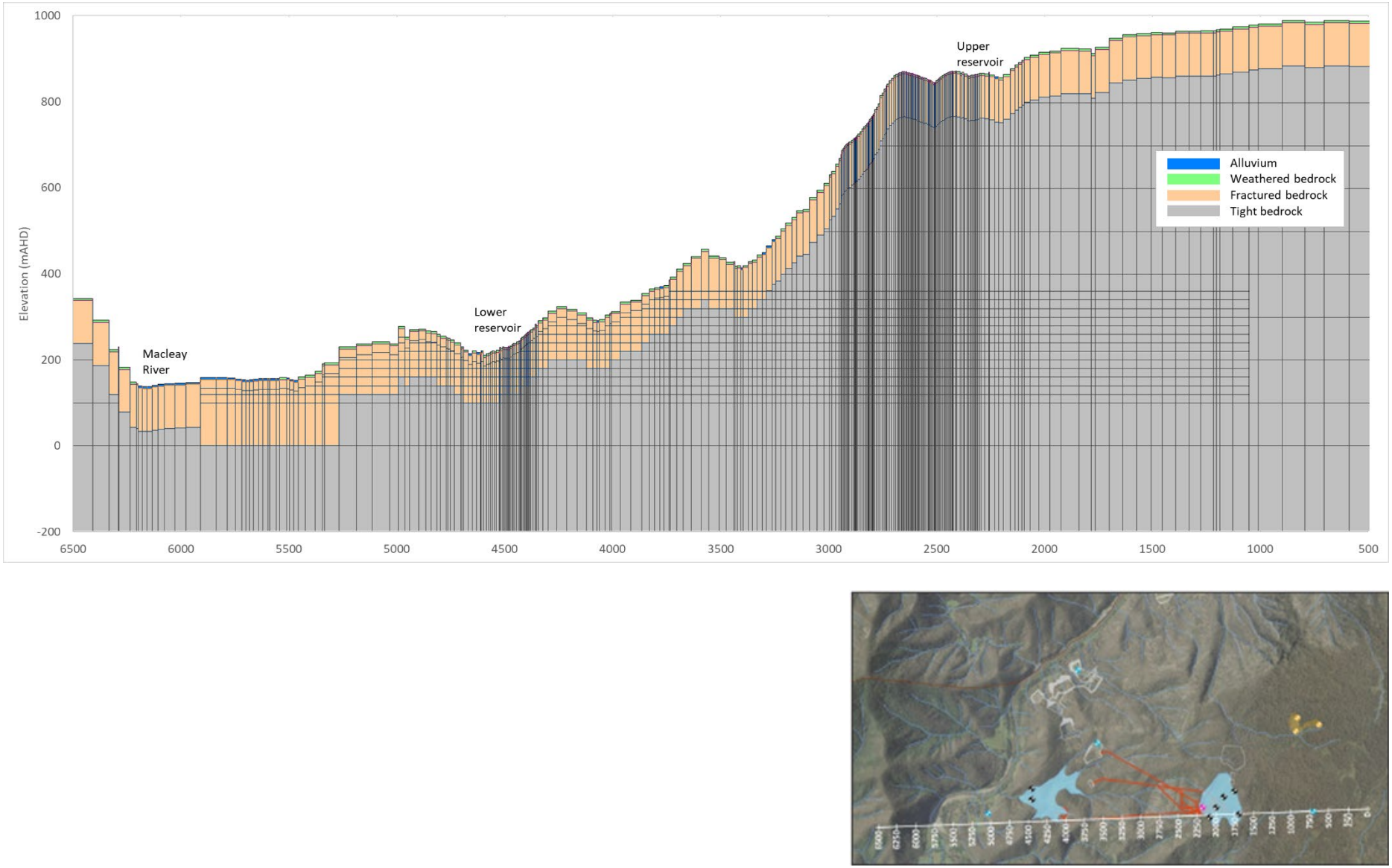
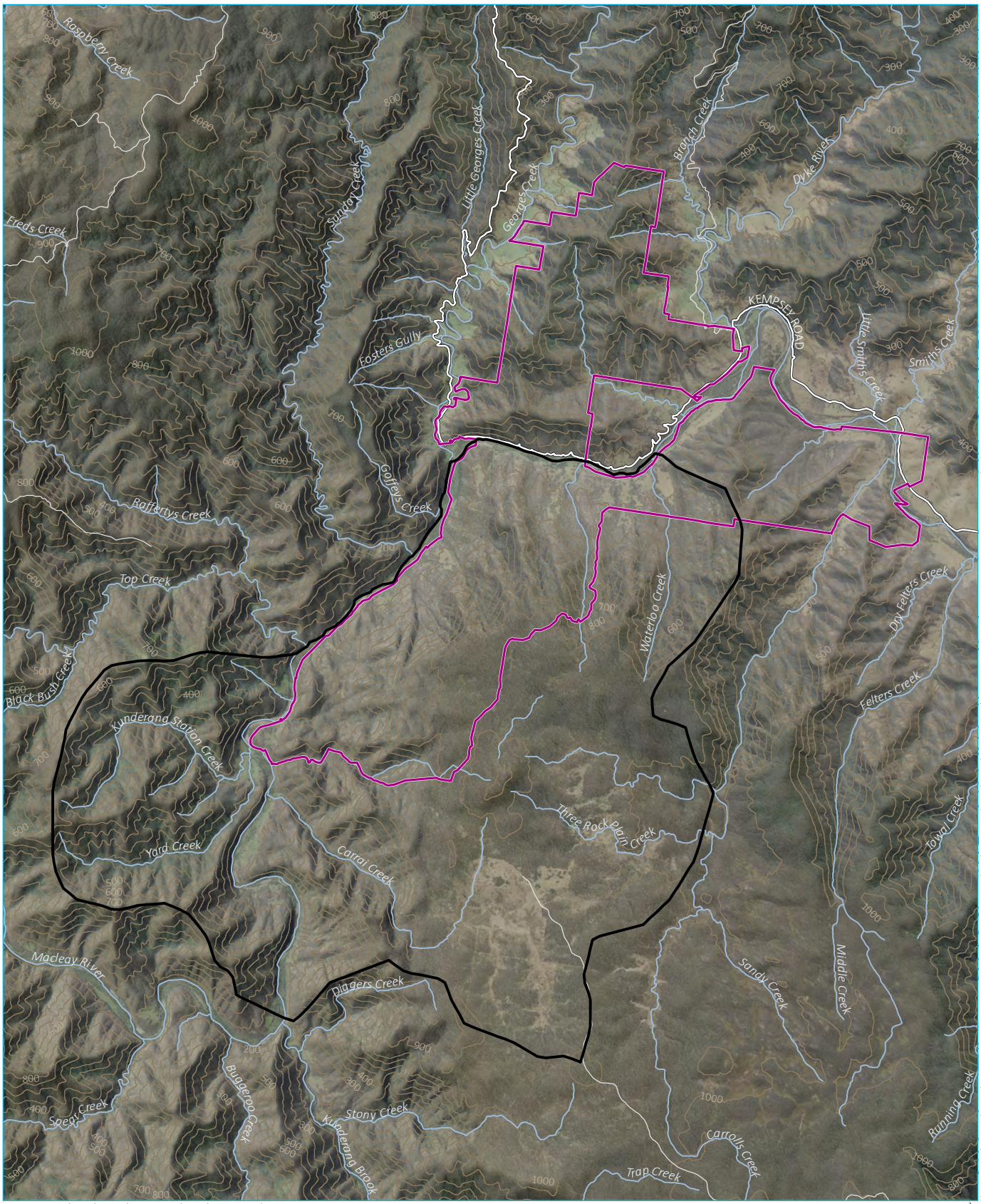


Figure 3.4 **Cross section along project alignment showing model layers**



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

- Project area
- Model domain
- Topographic contour (50 m interval)

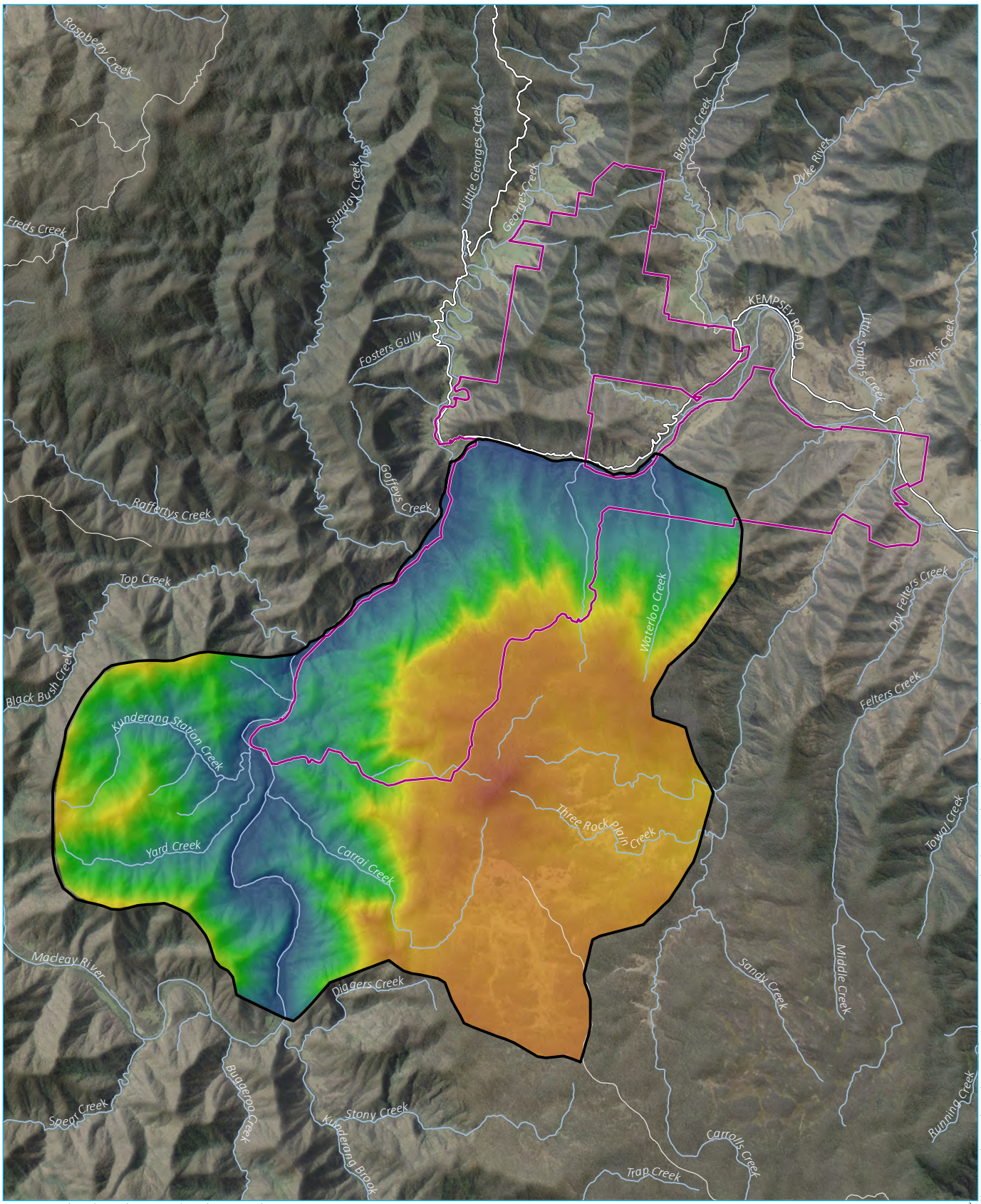
Existing environment

- Major road
- Minor road
- Named watercourse

Model topography

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Figure 3.5

EMM creating opportunities



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse

Base of fractured rock (m)

1022.3

13.5

Base of upper fractured rock unit

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
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Figure 3.6

EMM creating opportunities

\\emmsvr1\EMM3\2021\210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW015_BaseUpperFracturedRock_20221101_01.mxd 1/03/2023

3.5 Temporal discretisation and numerical solution

The stress periods implemented in the model are summarised in Table 3.3. The history-matching period employs two initial stress periods; one transient stress period run to pseudo-steady state for numerical stability, and one steady state stress period to establish stable long-term groundwater conditions. Following the steady state stress period, 16 monthly stress periods are employed over the initial history-matching period from September 2020 to December 2021 followed by 14 fortnightly stress periods until August 2022 to allow a better dynamic representation of measured responses to climatic stresses when additional bores were installed in early 2022. This is followed by a two-month stress period in order to align with the NSW water year (1 July to 30 June) and quarterly stress periods thereafter. Five quarterly stress periods continue to simulate average seasonal climate until construction is scheduled to begin in October 2023. Seventeen quarterly stress periods were required for predictive simulation of construction through to December 2027. Operation was simulated with one long transient stress period followed by a true steady state stress period with average climate stresses to allow for long-term system equilibration to the permanent operation of the system. The adaptive time stepping feature of MODFLOW-USG was employed to efficiently discretise stress periods into timesteps such that a numerically stable solution was obtained. The SMS solver was employed to solve the differential equations with a head closure criterion (HCLOSE) of 0.001 m.

Transient groundwater level data at the site is available from September 2020 (from open geotechnical holes). While the data collected at these locations are not considered to be reliable representations of short-term groundwater level fluctuations, due to likely rainfall ingress into the holes, they do allow for useful approximations to steady state conditions and general seasonal trends. Additionally, climate conditions and baseflow conditions from mid to late 2020 approximate the long-term average, so are reliable starting points to initialise the transient model from the steady state baseline. The collection of reliable groundwater level data from correctly installed piezometers commenced in September 2021 and continues through 2022, when rainfall conditions have been above average and approaching historical monthly maximums.

Due to the moderate model run times of around 2 hours, simulations were designed to include the steady state initialisation, through transient history-matching, construction and operation within a single run.

Table 3.3 Model stress periods

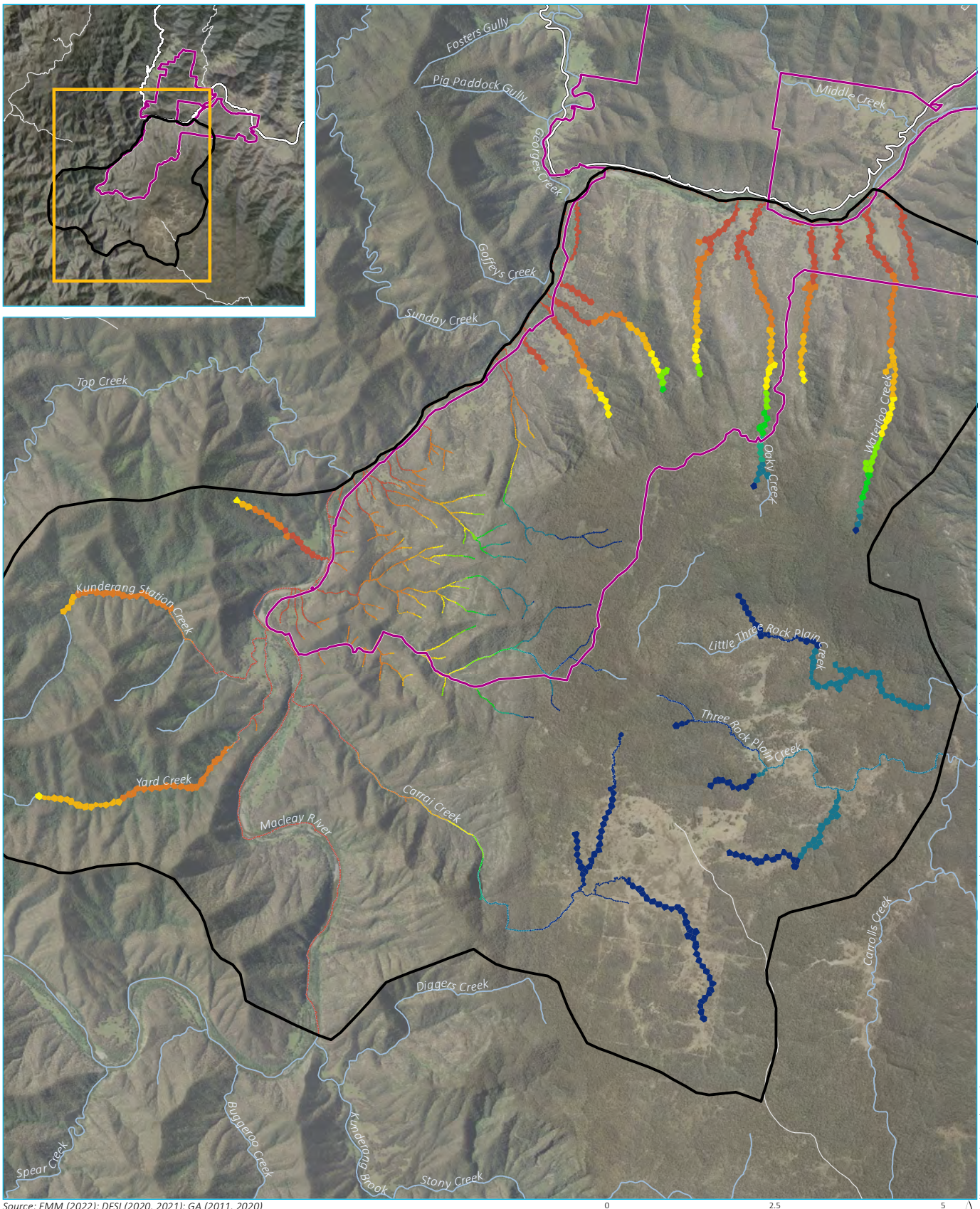
Stress period	Duration	Description
1	274 years	Pseudo steady state stress period run in transient mode to provide numerical stability when varying parameter values during the history-matching process.
2	Steady state	Develops baseline steady state conditions in response to modelled hydraulic properties and boundary conditions.
3 to 14	Monthly	Transient warm up period, from September 2020 to August 2021.
15 to 18	Monthly	History-matching period, from September 2021 to December 2021.
19 to 32	Fortnightly	History-matching period, from January 2022 to August 2022.
33 to 37	quarterly (33 is 2 months for date alignment)	Bridging period between history-matching and construction, with average seasonal climate.
38 to 54	Quarterly	Represents Project construction over a period of 4.25 years.
55	1,000 years	Transient simulation of dynamic response to commencement of Project operation.
56	Steady state	Simulates long-term equilibration to operation of the Project.

3.6 Boundary conditions

3.6.1 Regional groundwater flow

As described in Section 2.8.2, within the study area groundwater generally flows radially from the plateau to the Macleay River. Monitoring at nested bore sites shows predominantly downward flow within the plateau/upper western catchment and upward flow in the Macleay River floodplain. This is consistent with these areas reflecting recharge and discharge zones, respectively.

To replicate this flow system water enters the model as recharge (mainly in the plateau zone) and exits the model along surface water features such as the Macleay River. The model perimeter follows topographic (and groundwater) divides and is set as a 'no-flow' boundary by default, except where regional groundwater flow is likely to enter or leave the active model area via surface water features, in which case a river boundary condition is specified, as discussed in Section 3.6.4. The river boundary conditions are illustrated in Figure 3.7.



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse

River boundary conditions (m AHD)

- < 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 900
- > 900

River boundary conditions used in model domain

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Figure 3.7

EMM creating opportunities

3.6.2 Recharge

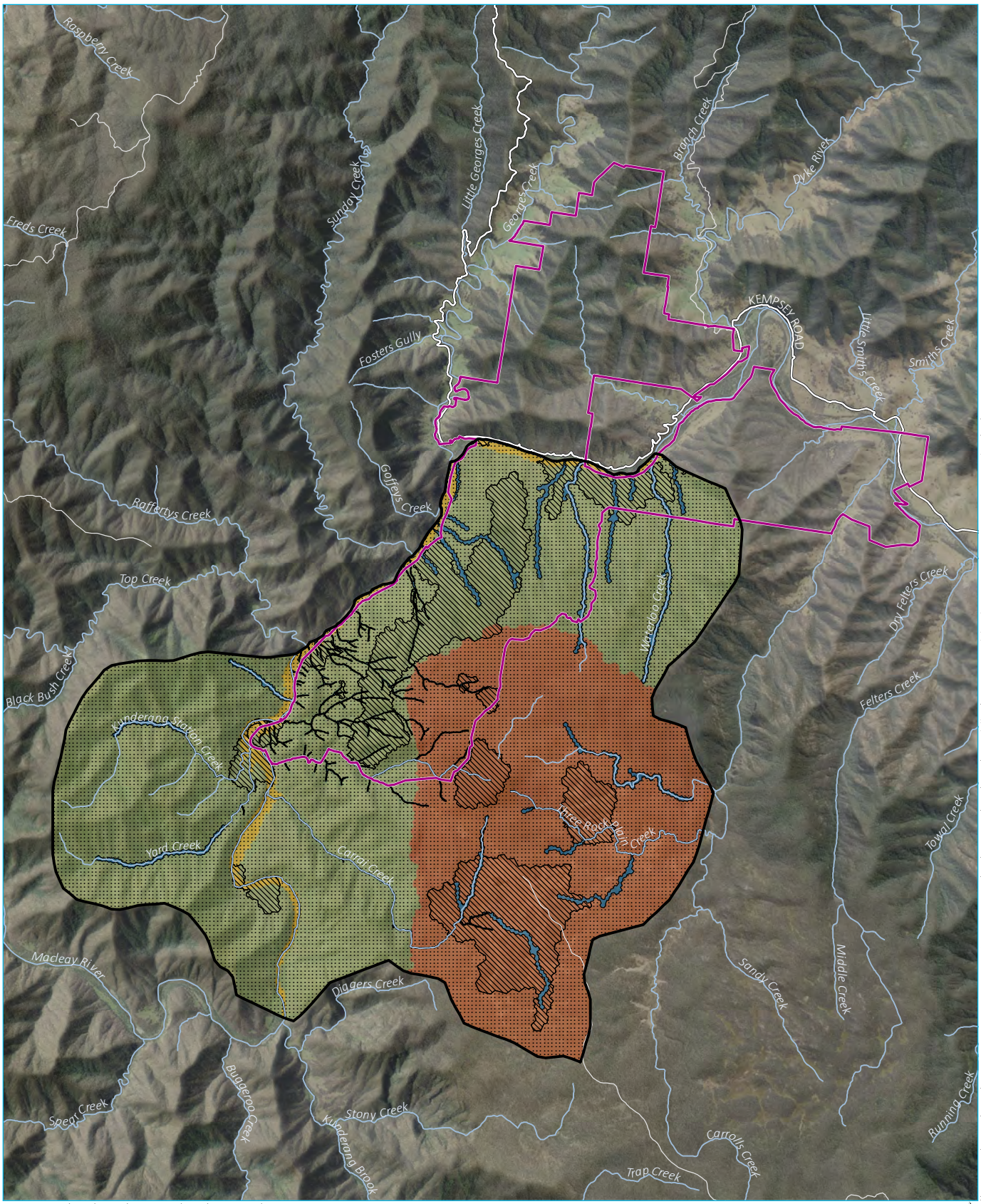
The MODFLOW Recharge (RCH) package is used to simulate diffuse rainfall recharge. Rainfall recharge was imposed as a percentage of actual rainfall (for transient history-matching) or long-term average rainfall (for steady-state history-matching and prediction). Spatially and temporally variable groundwater recharge rates were applied to the groundwater model (Figure 3.8). Spatial variations are based on the geography, with greater recharge occurring at the plateau (where rainfall will collect on flatter morphology) than on the slopes (which will have more runoff due to steeper topography).

Temporal variation to recharge for during transient simulation periods was calculated using the ratio between actual observed monthly rainfall data and the long term monthly/annual averages, with resulting multipliers applied to the steady-state recharge, assuming a long-term annual rainfall of 1,006 millimetres per year (mm/yr). The quarterly predictive stress periods are assigned periodic seasonal rainfall.

Three variable recharge zones were defined for the plateau, the escarpment, and the alluvium (see Figure 3.8), with conceptual estimates of 5%, 2% and 25% of rainfall applied across them respectively and these recharge zones were included in the history-matching process. A zero-recharge zone was applied in cells where a river boundary condition was defined.

3.6.3 Evapotranspiration

The MODFLOW Evapotranspiration (EVT) package was used to simulate evapotranspiration from the groundwater system. Two evapotranspiration zones were defined (see Figure 3.8) with extinction depths of 5 m in the primarily forested areas and 1 m in scrubland (based upon average rooting depths reported in Canadell (1996)). Maximum potential rates were set using potential evapotranspiration values and transient multipliers in the same manner as described above for recharge, assuming an average maximum evapotranspiration rate of 1,343 mm/yr.



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse
- River - no modelled recharge or EVT

Evapotranspiration (EVT) zone

- 1 | Scrubland
- 2 | Forested area

Recharge zone

- 1 | Escarpment
- 2 | Plateau
- 3 | Alluvium

Model recharge and EVT zones

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Figure 3.8

EMM creating opportunities

3.6.4 Surface water

The major water course within the model domain, the Macleay River, was simulated with the MODFLOW River (RIV) package, with the stream level applied as a transient stage above the modelled topography along the river as indicated in Figure 3.9 for the history matching period and Figure 3.10 for predictions, with a historic median stream level used. To calculate the stream levels in Figure 3.9 and Figure 3.10, a methodology (REF) was applied to the raw gauge data to average out the quickflow elements into a more long term average baseflow value for each stress period.

All other streams and creeks within key drainage lines (incised topography) were also simulated using river boundary conditions, with river stage equal to the river bed elevation (both set at topography). This allows water to flow unrestricted into the creek from the aquifer if/when the groundwater level reaches the ground surface but prevents leakage out of the channels into the groundwater system, causing the creeks to effectively act as "drains". This is considered appropriate as the creeks at higher elevations often traverse fresh rock so, while there may be some pooling where water captured in streams may locally recharge, the majority of stream flow is expected to be rapidly conveyed downslope and into the Macleay River. The downstream transfer of water is not simulated explicitly in the model, however the volumes captured in the ephemeral streams are included in the estimated baseflow volumes captured in the model domain.

All river boundaries are assigned to layer 1, which represents the weathered and alluvium units.

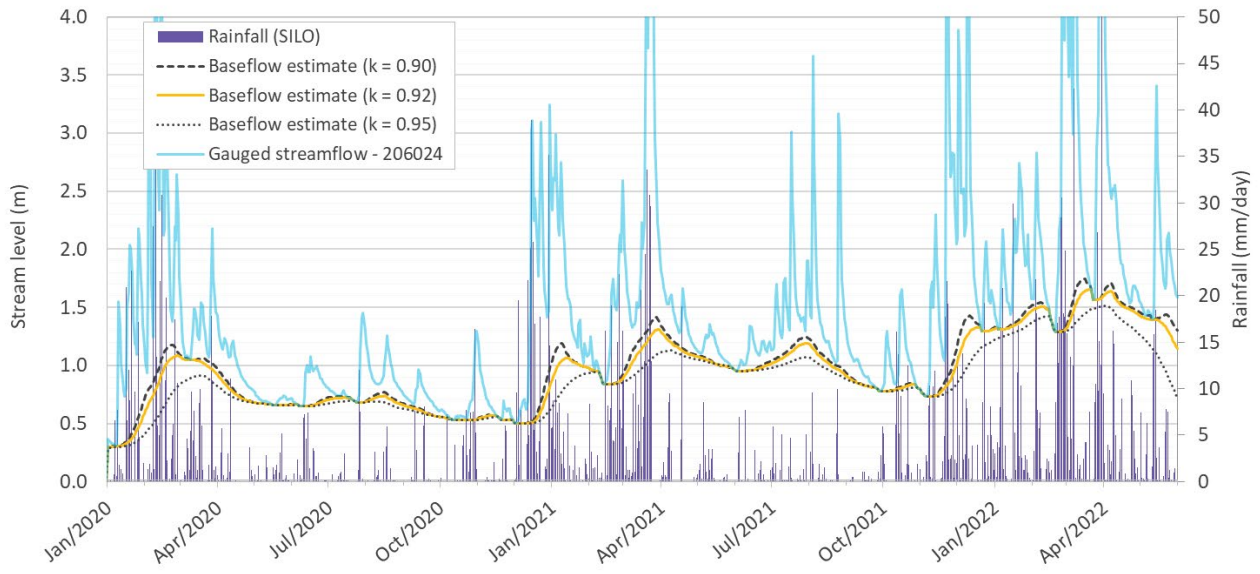


Figure 3.9 Interpreted Macleay River stream level based on baseflow separation

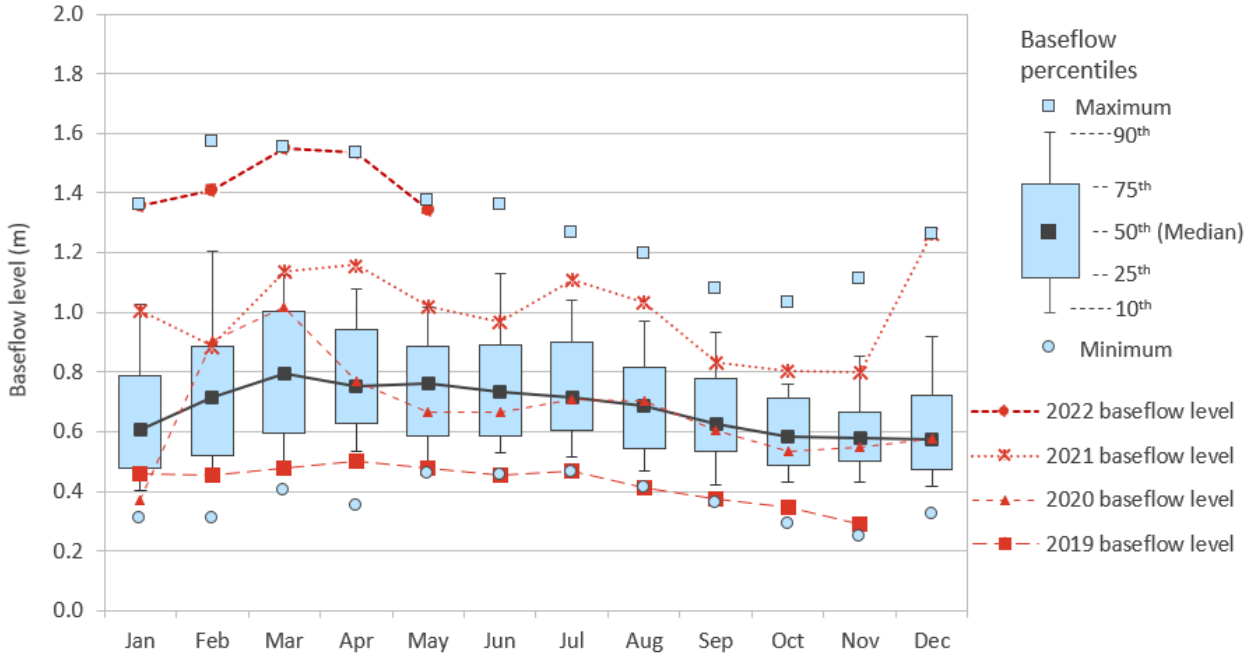


Figure 3.10 Monthly variability in baseflow levels

3.6.5 Other groundwater users

There are no other major projects that may cause interference to the natural groundwater flow regime within close proximity to the Project area (within 25 km).

Groundwater abstraction from the East Kunderang bore (GW307320) is intermittent and minimal and therefore has not been included in the model (refer Table 3.4).

Table 3.4 Groundwater extraction estimate from East Kunderang bore

Bore ID	Easting	Northing	Depth (m)	SWL (mbgl)	Yield (L/s)	Lithology
GW307320	418259	6590098	60	27	5	Fractured shale

3.6.6 GDEs

Eighteen potential GDEs have been identified near the Project. Changes to groundwater conditions at each of these GDEs were predicted and are presented as hydrographs in Appendix C.

3.6.7 Project groundwater-affecting activities

i Activities simulated

The Project will include upper and lower water reservoirs constructed on an ephemeral tributary of the Macleay River, near Georges Junction, and will operate as a closed-loop circuit. An underground power station will be connected to the reservoirs by power waterways or tunnels. Water access from the Macleay River will be required for an initial, one-off fill of the reservoirs and minimal top-up will be required thereafter. The initial fill will occur during high flow periods only and in a manner which does not compete against downstream water uses and is not anticipated to have any impact to local groundwater at the river. Once constructed, operation of the Project will involve the generation of hydro-electricity when water is transferred through underground tunnels from the upper reservoir, through turbines in the proposed underground power station, and on to the lower reservoir. The Project will allow water to be pumped back to the upper reservoir so it can be used again. Being 'off river' or a 'closed loop' scheme means that, once filled, the Project will have little annual water needs over an operational life of more than 60 years.

The power waterway is the component connecting the upper and lower reservoirs and concept designs are for an average of approximately 5 m in diameter. This diameter will change upstream and downstream of the power station complex as the waterway bifurcates to the machines. The low-pressure headrace is connected to the upper intake and is approximately 250 m long. The headrace would be followed by an approximate 640 m deep vertical pressure shaft. Penstocks, potentially steel-lined, which are approximately 300 m long would interface with the bottom of the pressure shaft to the power station complex. A tailrace surge shaft indicatively of a nominal 5 m diameter and 130 m height may be required to help regulate the hydraulic transients (water hammer). The relatively flat tailrace is approximately 1,450 m long and, to ensure the tailrace is pressured, the last section is more steeply inclined to the lower intake. Overall, the waterway length is approximately 2,700 m. A longitudinal section showing these elements is provided in Figure 3.11**.** Access tunnels (the Main Access Tunnel (MAT) and the Emergency, Cable and Ventilation Tunnel (ECVT)) are needed to provide efficient and safe access to permanent infrastructure during both construction and operation. They serve multiple purposes including provision of access for personnel, electrical connection to the electricity grid, emergency egress, and ventilation.

The construction methods for key project elements are summarised in Table 3.5.

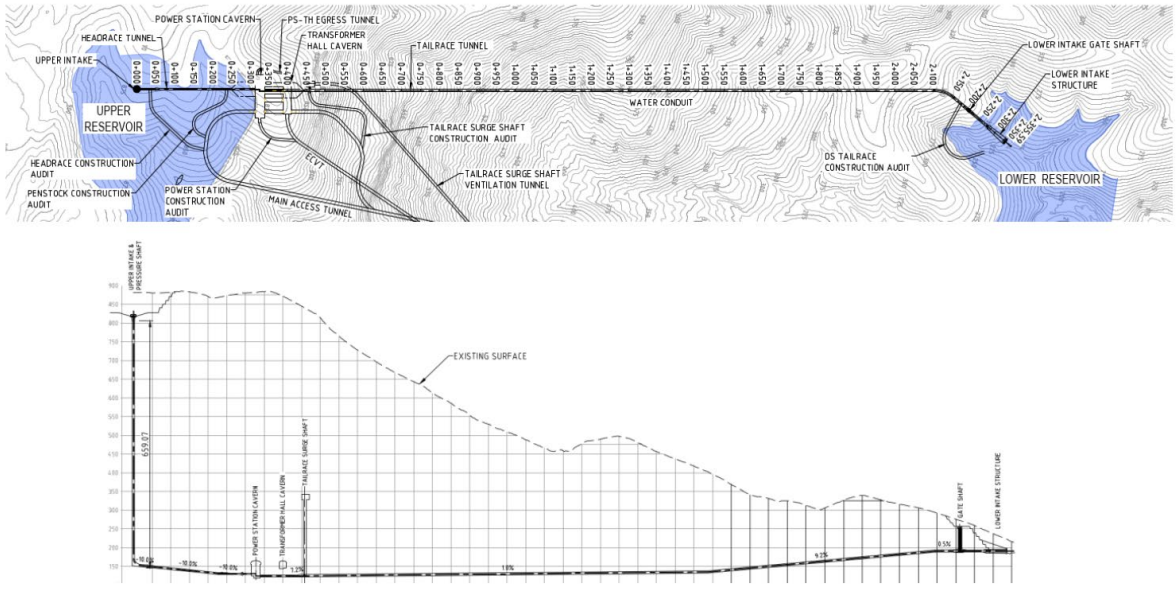


Figure 3.11 Cross sectional view through project infrastructure

Table 3.5 Construction methods for key project elements

Project element	Construction method
Access tunnels	Likely construction method will be drill and blast, however this method will be confirmed during detailed design for the MAT, ECVT and adits (where required).
Underground power station	Likely construction method will be drill and blast, however this method will be confirmed during detailed design for the underground power station.
Lower reservoir and intake	Likely construction method will include the lower reservoir floor being stripped to a suitable depth using conventional civil engineering methods with intake excavation occurring in conjunction with the power waterway tunnel. This method will be confirmed during detailed design.
Upper reservoir and intake	Likely construction method will include the upper reservoir floor being stripped to a suitable depth using conventional civil engineering methods with intake excavation occurring in conjunction with the power waterway tunnel. This method will be confirmed during detailed design.
Power waterway tunnel, chambers and shafts	Likely construction method will be drill and blast with associated road headers as a suitable method for the near horizontal components and raise bore associated with down reaming for the vertical components. This method will be confirmed during detailed design for power waterway tunnels.

ii Construction boundary conditions

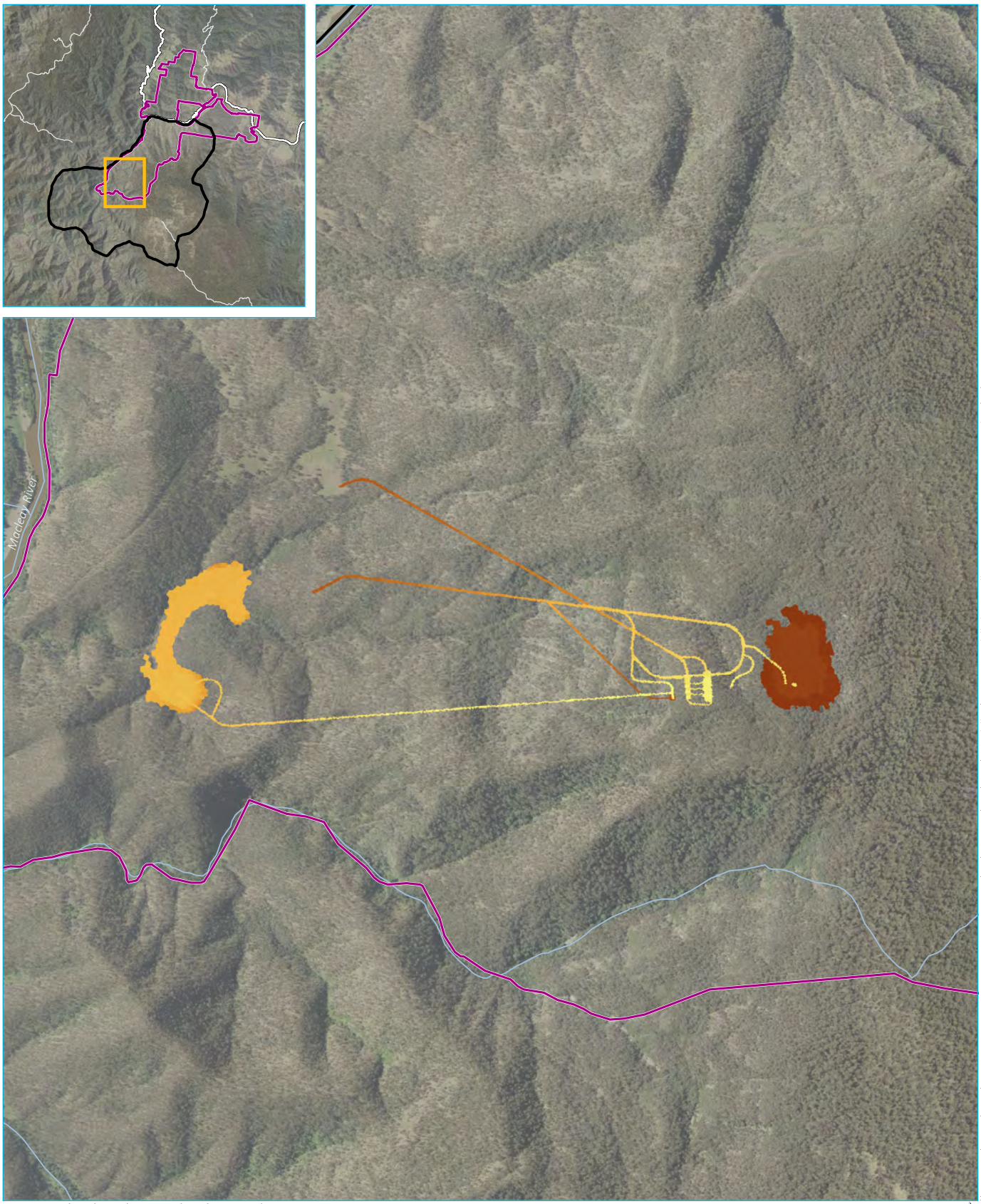
Construction of the Project was represented using the following changes to boundary conditions:

- The upper and lower reservoirs both require substantial excavation of bedrock material to accommodate the necessary supply volumes of water to operate the system (see general arrangement diagrams in Figure 3.13 and Figure 3.14). The upper reservoir is excavated down through bedrock to an elevation of 830 mAHD and the lower reservoir is excavated down through bedrock to an elevation of 190 mAHD. During construction both excavation areas will remove groundwater from the shallow and intermediate groundwater flow systems. This removal of groundwater was represented using the MODFLOW Drain (DRN) package. The stage of the drains was set to the bottom of the excavation for a given cell and the conductance set at 10,000 metres squared per day (m^2/d) so that drain discharge is not limited by the boundary condition but, rather, the transmissivity of the intersected HSUs. The locations of modelled drain boundary conditions at the end of construction are illustrated in Figure 3.12.

- The dam wall was simulated as a low permeability material (0.001 m/d) in model layer 1 across the footprint of the dam structure. This was implemented by use of the MODFLOW Time-Variant Materials (TVM) package with a 0.002 multiplier to the hydraulic conductivity of the in-situ weathered rock of 0.5 m/d.

- The tailrace, access portals and power station were represented with drain boundary conditions with the stage of each drain set to the base of the project element in each cell and the conductance set to a high value of 10,000 m^2/d to ensure effective dewatering of model cells to the assigned drain stage.

- The headrace, penstocks and draft tubes are simulated with a drain boundary condition during initial excavation and are steel lined very soon after. Steel lined components are simulated with no boundary condition at the end of construction.



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 0.5 1 km

GDA 1994 MGA Zone 56

N

KEY

Project area

Model domain

Named watercourse

Modelled drain cells

892.45

0

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW018_ModelledDrainCellsConstruction_20221102_01.mxd 14/12/2022

Modelled drain cells during construction period

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Figure 3.12

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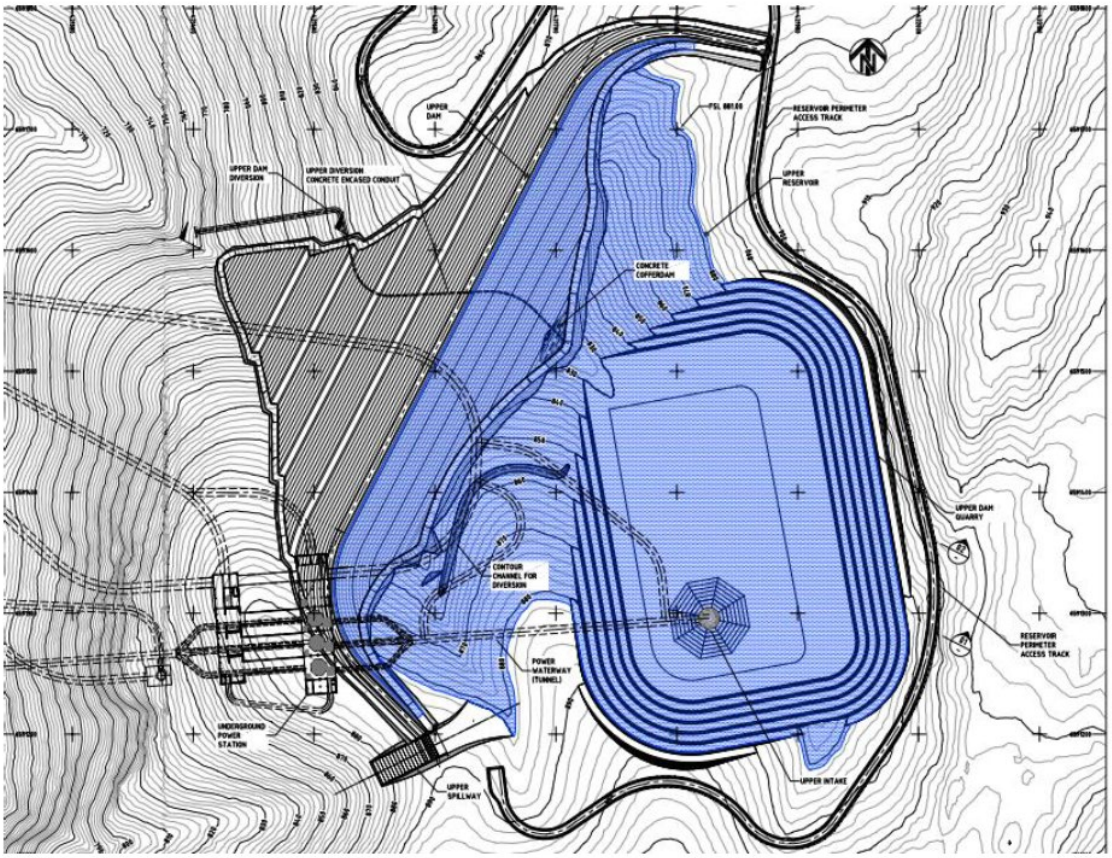


Figure 9–1: OMPS Upper Reservoir General Arrangement

Figure 3.13 Plan view of upper reservoir and project infrastructure

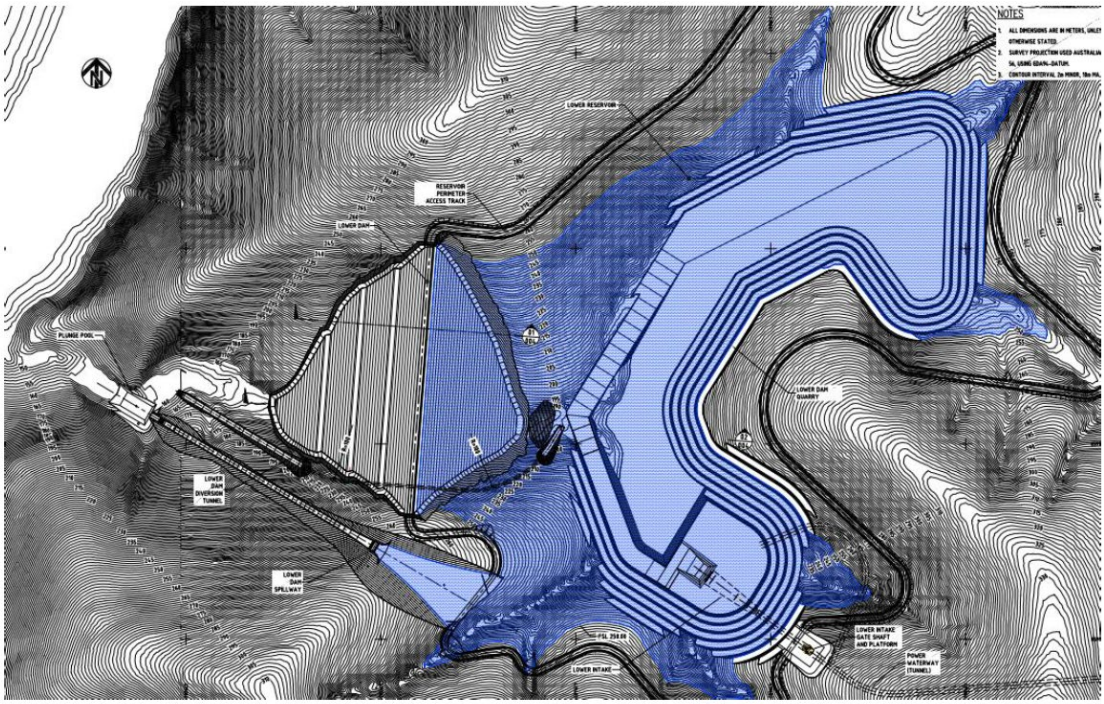


Figure 9–2: OMPS Lower Reservoir General Arrangement

Figure 3.14 Plan view of lower reservoir and project infrastructure

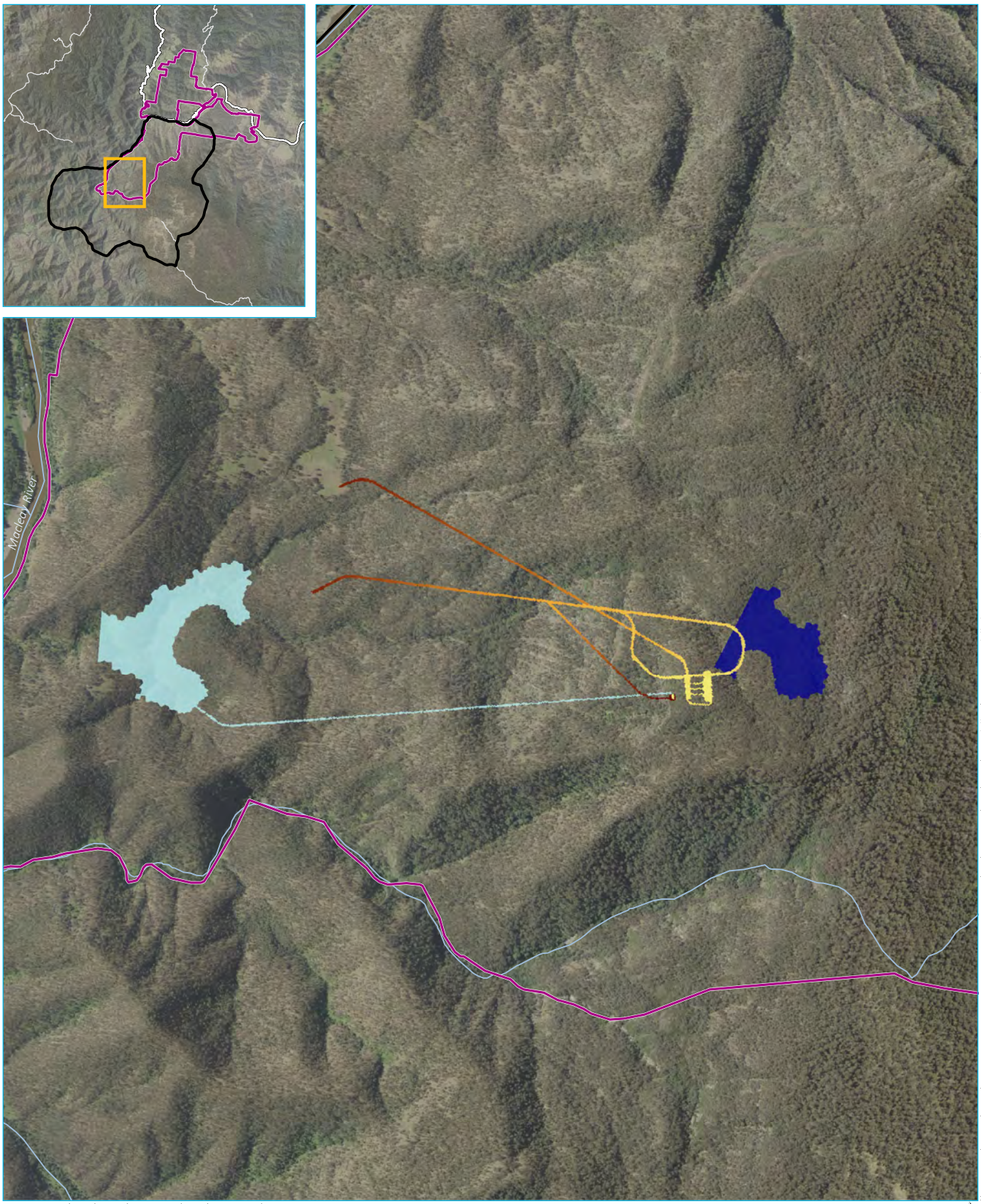
iii Operation boundary conditions

The head in the two reservoirs is represented by the General Head Boundary (GHB) package applied to the top model layers. As the operational head will vary significantly at sub-daily intervals, the average operating level was adopted (855.5 mAHD at the upper reservoir and 227.5 mAHD at the lower reservoir, see Table 3.6). Water pressure in the headrace pressure shaft and tailrace (with associated elevated pressure head) is also represented using the GHB package with the same level as the connected reservoir. GHBs were assigned the same conductance parameters applied to the drain boundary conditions during construction. Any open access portals maintain the same drain boundary condition configuration adopted for the construction period. The final boundary condition configuration used during operation is shown on Figure 3.15.

The design for the penstocks and headrace tunnel is that they will be steel lined and impermeable and, therefore, they are not assigned boundary conditions during operation. Some tunnels that were needed during construction are plugged at entrance and exit during operation; these also have no boundary conditions assigned during operation and are allowed to equilibrate with the surrounding aquifer.

Table 3.6 Water levels and volumes for upper and lower reservoirs

Parameter	Unit	Upper reservoir	Lower reservoir
Full supply level (FSL)	mAHD	881	250
Minimum operating level (MOL)	mAHD	830	205
Mid operating level	mAHD	855.5	227.5
Total volume	Gigalitres (GL)	5.06	6.47
Drought reserve	GL	-	0.9
Dead storage	GL	0.08	0.39
Reservoir area at FSL	Hectares (Ha)	16.7	21.6
Reservoir area at MOL	Ha	4.8	10.1



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 0.5 1 km

GDA 1994 MGA Zone 56

N

KEY

- Project area
- Model domain
- Named watercourse

Modelled drain cells
328.30
0

Modelled reservoir cells
855.5
227.5

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW019_ModelledDrainReservoirCellsOperation_20221102_01.mxd 14/12/2022

Modelled drain and reservoir cells during operation period

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Figure 3.15

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4 History-matching

4.1 Approach

A combination of manual and automated (using PEST++ version 4.2.16) approaches were employed during the history-matching process. PESTPP-GLM was used from the PEST++ suite for this project, and the optimised model from the PEST run is referred to as the base case in this report. History-matching was undertaken using temporal hydraulic head data, from the baseline monitoring network, which are considered representative of pre-construction conditions (see Section 2.8) across the various project elements and topographic domains. Initially, the model was history-matched manually to steady state targets only, using a single value for each hydraulic property per HSU. This approach was aimed at providing an efficient means to arrive at starting parameters that provided a reasonable model-wide fit to long term average hydraulic head data, to use as initial parameter value estimates for subsequent, more computationally demanding, transient history-matching.

4.1.1 Temporal modes

The model was history-matched in both steady state and transient modes, combined into a single model run, to obtain model parameterisation consistent with both static baseline heads and transient head fluctuations in response to climate-driven rainfall recharge and discharge processes. This approach assumes, consistent with the conceptualisation, that the groundwater system was in steady state, except for relatively small-scale, short-term responses to seasonal rainfall, prior to construction. The steady state solution then provides initial heads for the transient history-matching period.

4.1.2 History-matching targets

A total of 1,432 history-matching targets were employed, split into a group containing individual head measurements and a group containing transient time series head difference targets. The locations of these targets are shown on Figure 4.1. These were comprised of:

- 16 steady state head targets taken as the minimum recorded groundwater level for each of the monitoring bores described in Table 2.6 except for OM6, which was removed due to untrusted measured data, and BH4A, which does not have any measurements;
- 13 head targets at points and times where springs were observed during site visits, weighted at 20% of the value of the bores; and
- 1,403 head difference transient targets, defined as the difference between the current and previous measured hydraulic head. These behave similarly to drawdown targets but are better when the steady state head is not well known.

The short monitoring period for many of the bores has been during a time of very high rainfall relative to the historic average in the project area so, to reduce the impact from this, the minimum recorded head levels were defined as the steady state targets, and head change rather than drawdown was used.

PESTPP-GLM operates with the goal of minimising a least-squares objective function, defined as the sum of squared weighted differences between measurements and corresponding model outputs (known as residuals). Doherty (2016) defines the objective function as:

$$\varphi = \sum (w_i r_i)^2$$

Where *r* is the calculated residual, and *w* is the statistical weighting between 0 and 1.

A weighting scheme was adopted such that:

- both the steady state and transient data effectively contributed to the objective function;
- monitoring bores with highest reliability with respect to proper monitoring bore construction (MB01A, MB02A, MB02B, MB04A, MB04B, MB03A, HA2201, HA2201 and HA2203) were given the highest weighting during both steady state and transient periods; and
- monitoring bores with the lowest reliability with respect to proper monitoring bore construction (OM1 to OM7) were given a lower weighting during both steady state and transient periods.

The desired contributions to the objective function and resultant weightings assigned to head targets were as follows:

- steady state head targets: a high contribution to objective function was desired and the monitoring bores were given an initial weighting of 1 with the springs given a weighting of 0.2; and
- transient head difference targets: a lower contribution to objective function was desired, to guide PEST to reach a reasonable head match before targeting transient properties. A weighting of 1 for each transient point resulted in an initial objective function with a contribution of 96% from the head targets and 4% from the head change targets.

A lower contribution from the low reliability bores OM1-7 was achieved by assigning fewer transient targets – not using less trusted automated logger data and instead only using monthly manual dip data as targets.

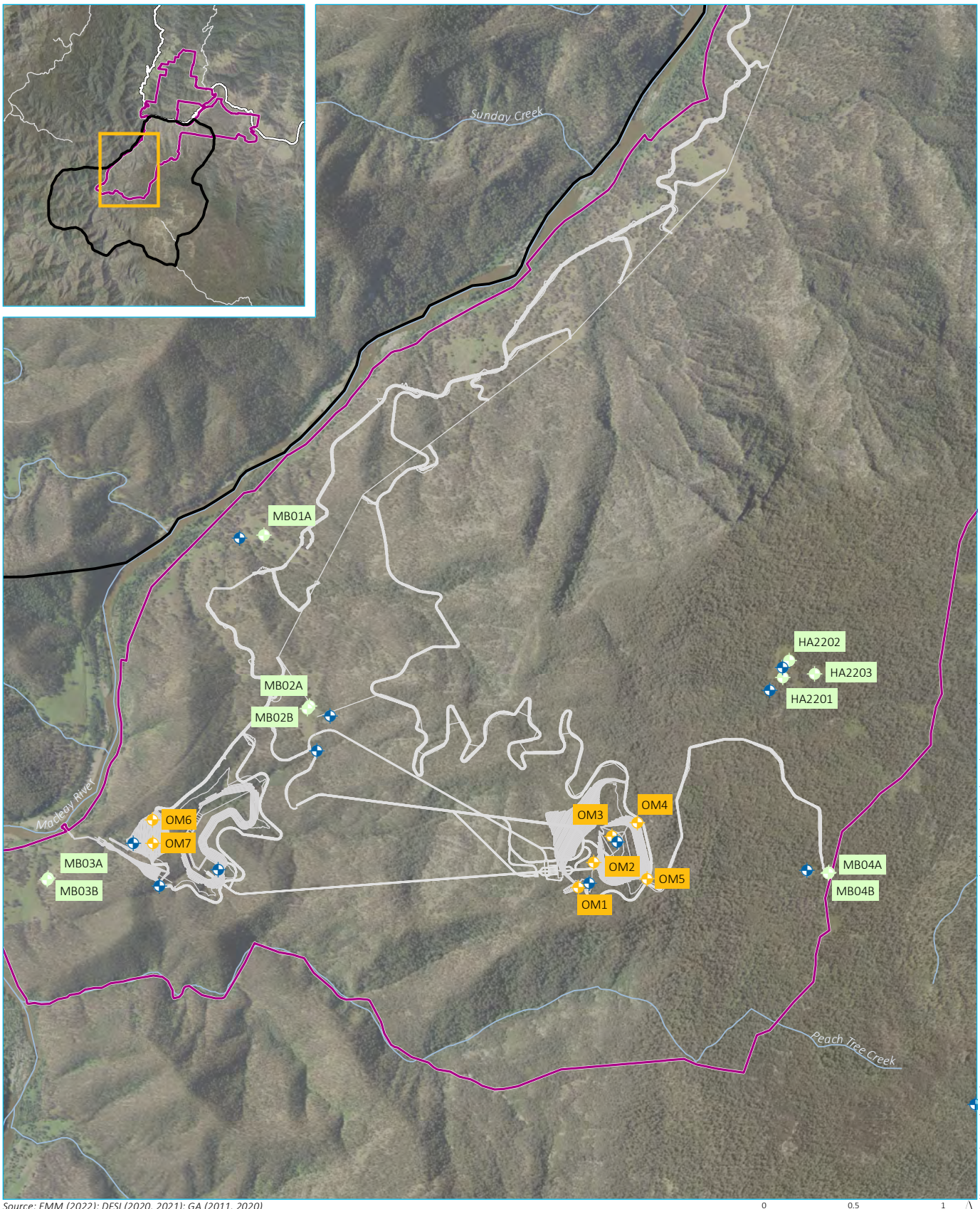
The adopted criteria for evaluation of history-matching performance are summarised in Table 4.1.

Table 4.1 Minimum history-matching criteria

Objective	Rationale
Qualitative: Simulated versus interpreted watertable potentiometric surfaces	Comparison of simulated and inferred watertable in the main HSU (fractured rock aquifer in Layer 3) taking account of field measurements and hydrogeologic interpretation. Other HSUs have insufficient spatial data for sitewide contouring. Spot checks in those HSUs done instead.
Quantitative: History-matching statistics for each HSU	Measure of fit statistics including: • Scaled RMS error separately for the steady state and transient targets; – overall, for all data points; and – separated into 'upper' and 'lower' groups to reduce the scaling factor between bores at elevations that are more than 600 m apart. • Minimum and maximum residuals. • Visual inspection of scatter plots.
Quantitative: Model water balance	Description of the steady state and transient water balance components with a target for the cumulative water balance to have a closure error of < 0.5%.
Semi-quantitative: Graphics of history-matching performance	Key graphs and figures include: • scatter plots of modelled versus measured heads for both steady state and transient targets; • a map of residuals to show spatial distribution of error; and • hydrographs comparing measured and modelled heads at individual bores

Table 4.1 Minimum history-matching criteria

Objective	Rationale
Qualitative: Conceptual Check	A review of the history-matched model to check: • final modelled hydraulic parameters are consistent with field measurements; • recharge and discharge processes obey the conceptual water balance; • modelled watertable and equipotentials make sense in terms of conceptual flow paths; • vertical head gradients in recharge and discharge zones are consistent with field data; and • boundary condition fluxes are plausible in terms of field observations.



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 0.5 1 km

GDA 1994 MGA Zone 56

N

\\emmsvr1\emm3\2021\210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW020_SpatialDistributionHistoryMatchingTarget_20221102_01.mxd 14/12/2022

KEY

- Project area
- Model domain

Existing environment

- Named watercourse
- Site infrastructure

Bore

- High reliability
- Low reliability
- Spring

Spatial distribution of history-matching targets

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Figure 4.01

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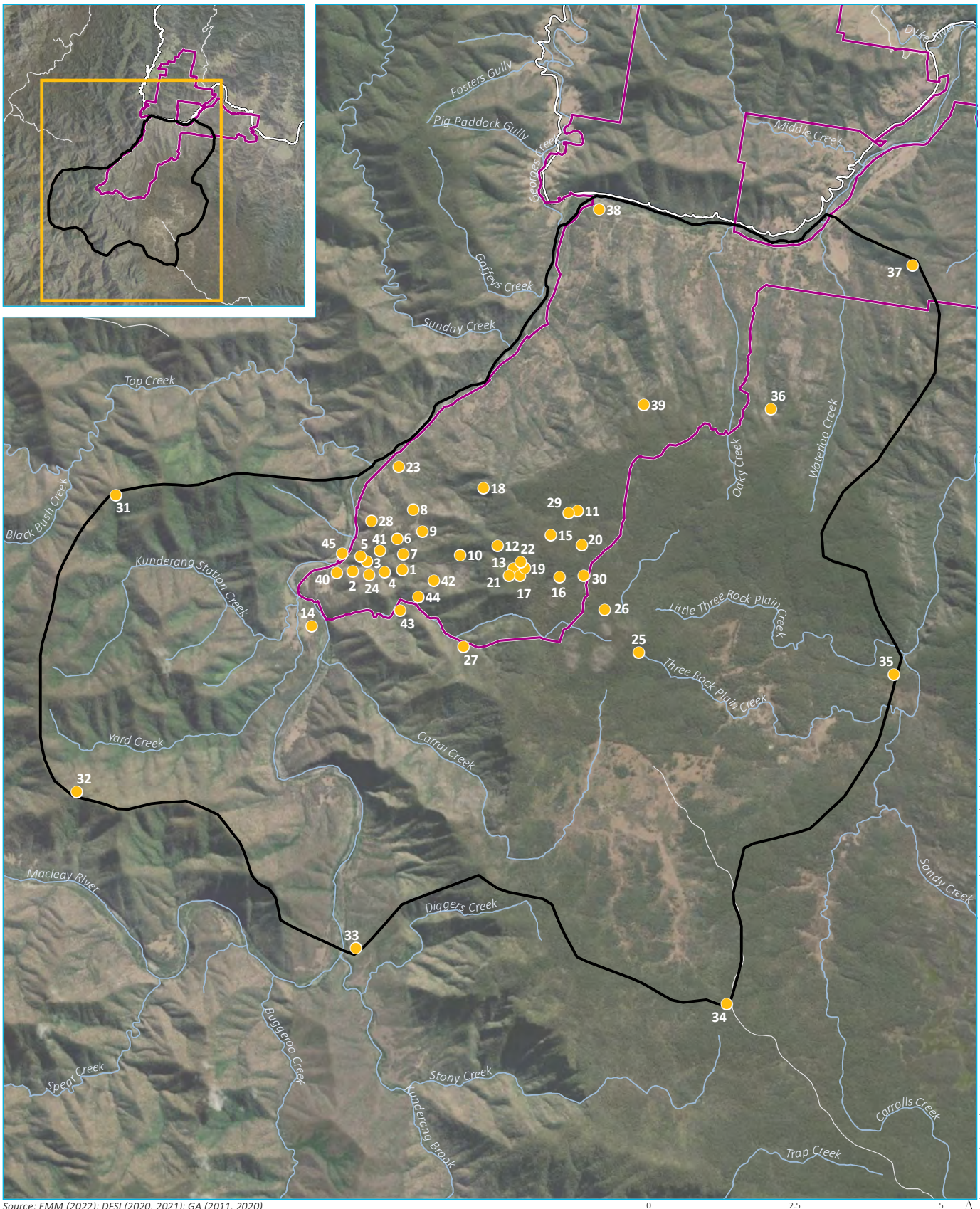
4.1.3 Parameterisation

To overcome issues of the EPM approach, of conceptual uncertainty, of parameter uncertainty and to allow for spatial variability in hydraulic properties, a highly parameterised approach to model history-matching was undertaken via the use of pilot points. This approach is consistent with best practice guidelines and provides a numerically sound basis for representing site-wide scale heterogeneities (Barnett et al. 2012).

The number and location of pilot points used in the history-matching process were carefully chosen based on available monitoring data, and in accordance with prioritising parsimony where reasonable and limiting computational burden. The following pilot point and zone configurations were established:

- three variable recharge zones representing the plateau, escarpment and alluvium zones (see Figure 3.8). As described in Section 3.6.2, the recharge zones are calibrated to a steady state value, with the transient stress periods linked to this steady state value with a static multiplier so they are calibrated together;
- 44 pilot points were established in the weathered bedrock (model layer 1). These pilot points were used for horizontal and vertical hydraulic conductivity and specific yield. A single point was used for specific storage since this property is not relevant to the surface layer. These pilot points were not tied to any others;
- one pilot point, numbered pp 45, was established in the localised alluvium in model layer 1. This pilot point was used for horizontal and vertical hydraulic conductivity, specific storage and specific yield for the alluvium only and was not duplicated on any other layer. This pilot point was not tied to any others;
- 44 pilot points were established in the fractured bedrock (model layer 2) directly underlying the ones in the weathered bedrock. These pilot points were used for horizontal and vertical hydraulic conductivity, specific storage and specific yield;
- 44 pilot points were established in tight bedrock in layer 25 directly underlying the ones in the fractured bedrock. These pilot points were used for horizontal and vertical hydraulic conductivity, specific storage and specific yield; and
- In the other layers 3–24, 44 pilot points were assigned to each and were tied to either the fractured bedrock points in layer 2 or the tight bedrock points in layer 25 based on which HSU they are present in (see Section 3.4.3). This was done so that the tight bedrock and fractured bedrock both act as one consistent unit across layers.

The locations of assigned pilot points and relevant monitoring bores are presented in Figure 4.2.



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW021_PilotPointsAlluvium_20221102_01.mxd 14/12/2022

KEY

- Project area
- Pilot point
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse

Pilot points used in the alluvium

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Figure 4.2

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4.2 Performance

4.2.1 Statistical performance

History-match performance was statistically quantified using SRMS error for hydraulic head, given as a percentage:

$$SRMS = \frac{100}{\Delta H}\sqrt{\frac{1}{n}\sum_{i=1}^{n}[W_i(z_{hi} - h_i]^2}$$

where:

- ΔH is the range of measured hydraulic heads across the model domain;
- *n* is the number of measurements used in the history-matching dataset;
- W_i is the statistical weighting between 0 and 1 applied to measurement *i*;
- z_{hi} is the modelled hydraulic head at location/time *I*; and
- h_i is the measured hydraulic head at location/time *i*.

SRMS errors were calculated for both steady state and transient hydraulic head targets. The resultant values are presented in Table 4.2. The overall statistical performance of the model is considered acceptable for the base case model, given that probabilistic uncertainty analysis was subsequently used to explore how uncertain the model parameter values might be and how that relates to predictions of Project impacts.

Table 4.2 Model statistics summary

History-matching mode	Entire model	Upper bores (measured head 837–1033 mAHD)	Lower bores (measured head 155–321 mAHD)
Steady state SRMS	0.52%	0.89%	4.11%
Steady state RMS	4.58 m	1.75 m	6.80 m
Steady state minimum residual	0.01 m	0.03 m	0.01 m
Steady state maximum residual	22.0 m	3.56 m	22.0 m
Transient SRMS	6.81%	4.23%	10.11%
Transient RMS	0.37 m	0.39 m	0.34 m
Transient minimum residual	0.00 m	0.00 m	0.00 m
Transient maximum residual	3.00 m	3.00 m	2.33 m

4.2.2 Hydraulic head

i Steady state

Data from 18 monitoring bores and piezometers were used to evaluate modelled steady state groundwater levels. A scatter plot of modelled against measured steady state hydraulic head is presented in Figure 4.3 and Figure 4.4. The data show:

- minimum bias for either over-predicted or under-predicted heads;
- reasonable correlation across the dataset;
- generally clustered close to a 1:1 line of ideal fit;
- there are few data points where the residual exceeds 5 m; and
- the overall fit to measured data indicates a generally good match to sitewide groundwater levels and across the various HSUs that are currently monitored.

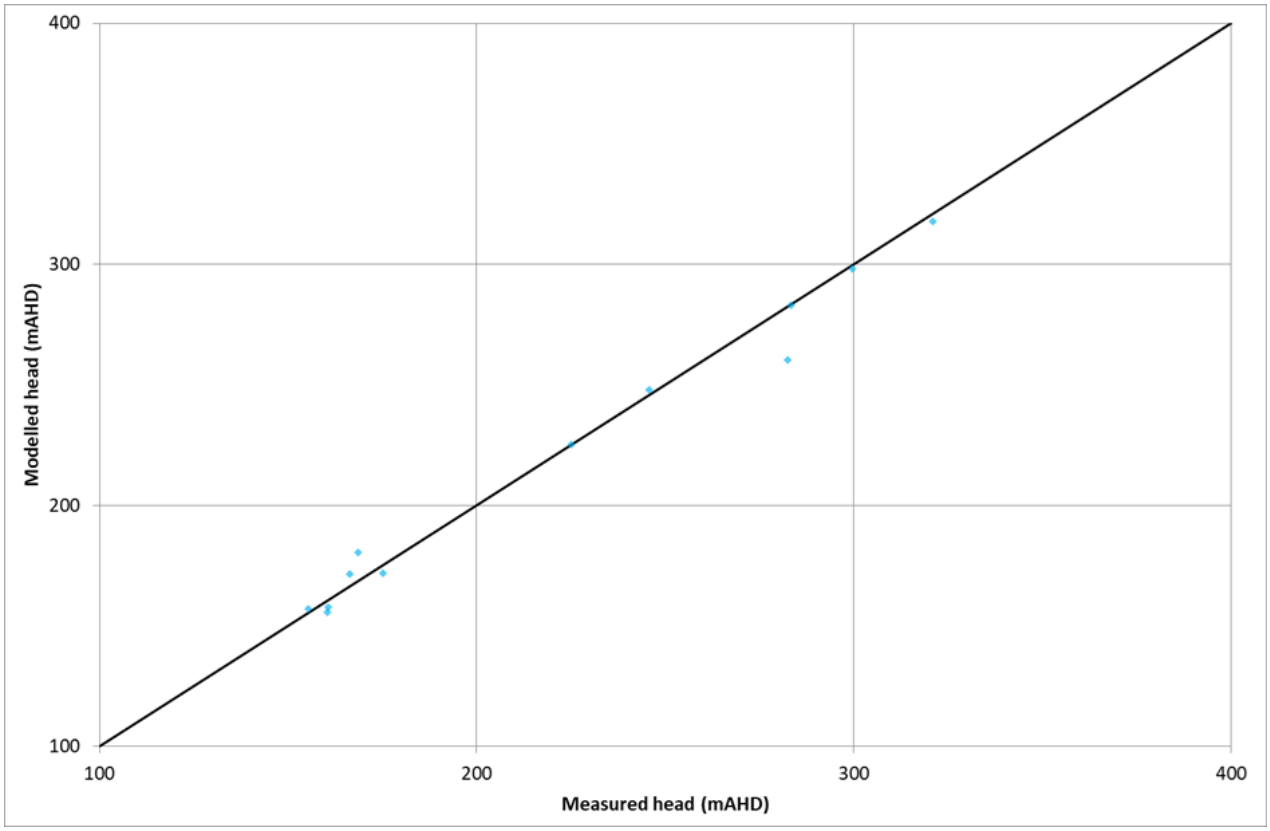


Figure 4.3 Scatter plot of steady state modelled versus measured heads in bores near the lower reservoir

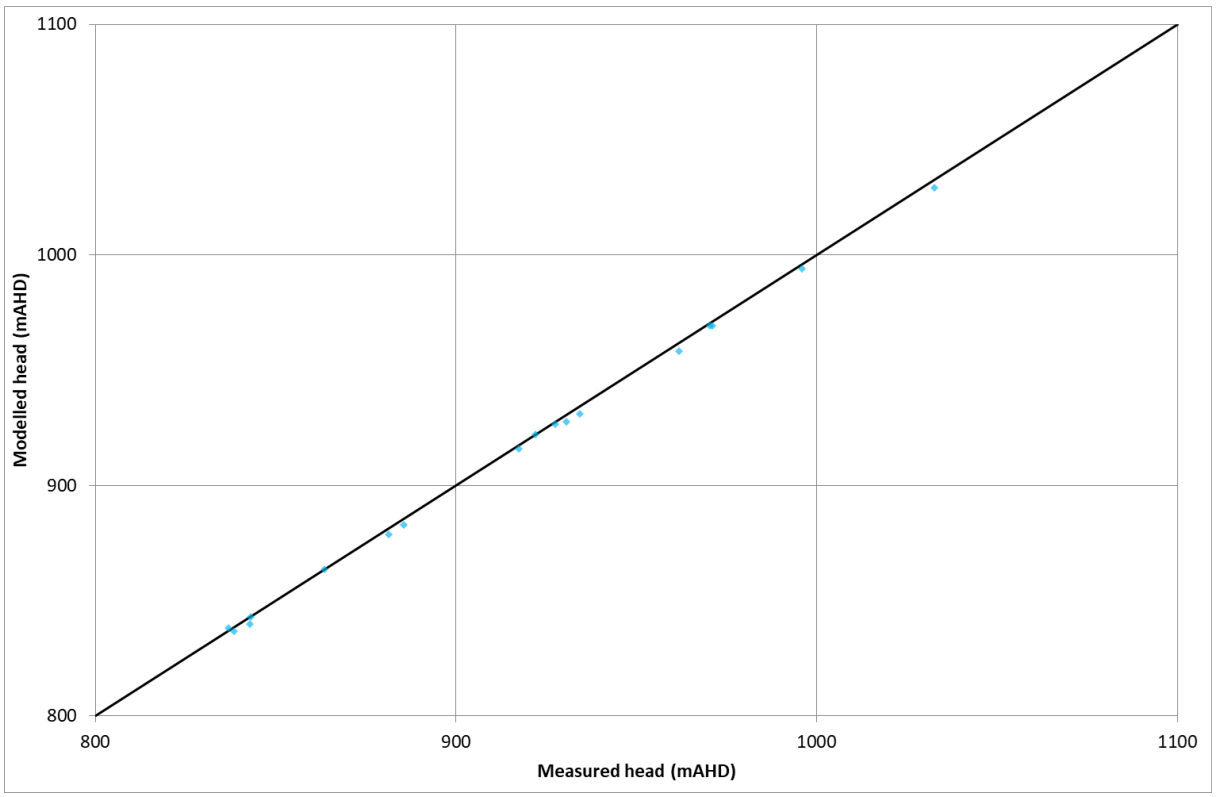


Figure 4.4 **Scatter plot of steady state modelled versus measured heads in bores near the upper reservoir and plateau**

A histogram of steady state residuals (modelled head minus measured head) is presented in Figure 4.5. This figure represents the residual frequency in bands of 1 m around the line of perfect of fit. Of the modelled steady state heads, 89.7% are within 5 m of measured and 93.1% are within 10 m.

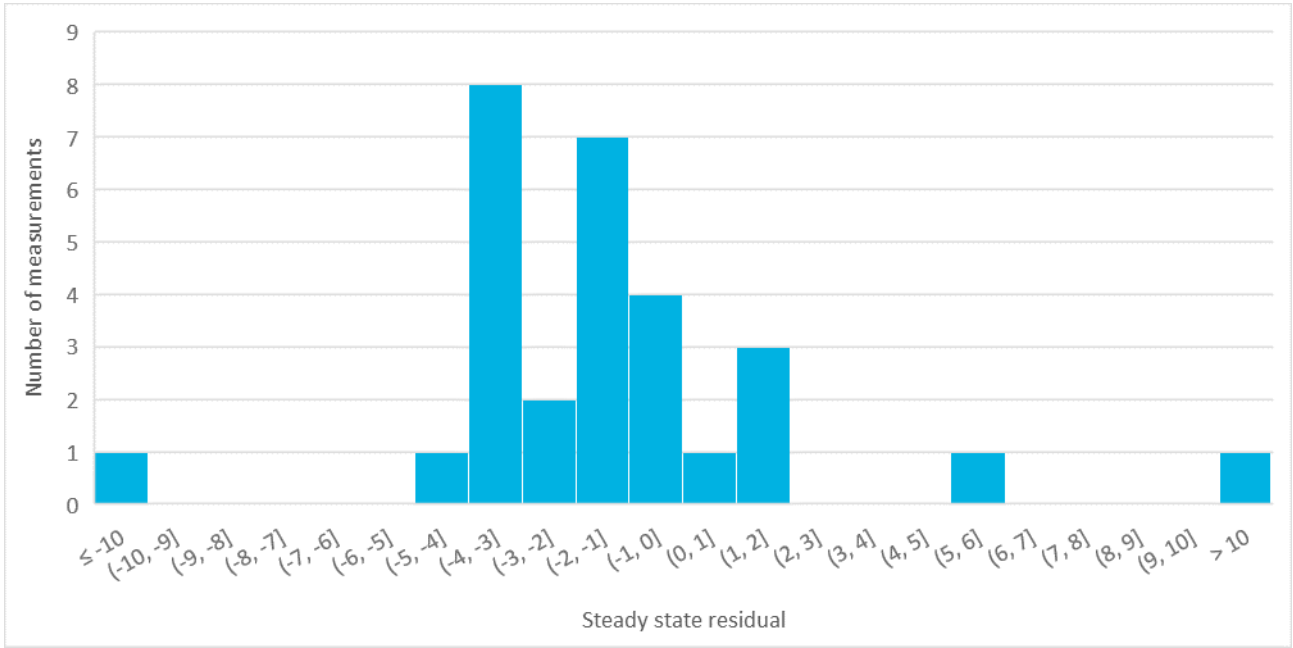


Figure 4.5 **Steady state hydraulic head residual distribution**

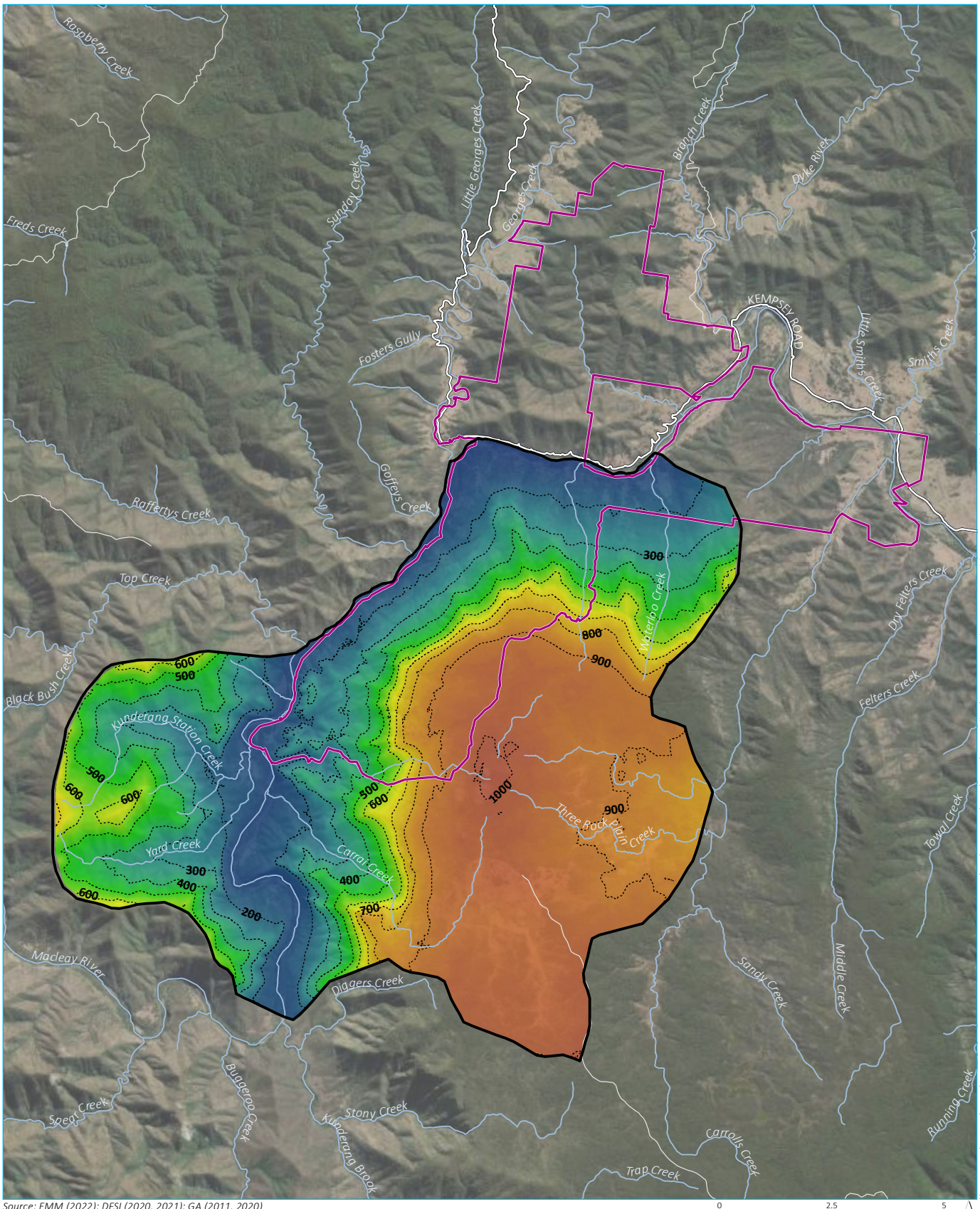
Modelled steady state watertable elevation is shown in Figure 4.6. Hydraulic head is largely controlled by topography and the model replicates the conceptual groundwater flow behaviour described in Section 2.8.2. In the model groundwater generally flows from recharge zones in the plateau and western catchment towards the discharge zone along the Macleay River floodplain. The watertable tends to largely occur within the alluvium/colluvium/weathered bedrock layer and underlying fractured bedrock.

The modelled steady state potentiometric surface and residuals for the upper fractured bedrock (layer 2) are presented in Figure 4.7. The head in this layer has extremely similar levels to the water table shown in Figure 4.6, which is expected since the water table resides in this layer across most of the model domain.

The residuals from monitoring bores in the upper fractured bedrock are reasonably distributed spatially, with the largest ones occurring in areas where topography is changing more sharply in the escarpment area. Modelled water levels on the plateau are low overall but are biased toward being lower than the measured values. Modelled residuals near the lower reservoir have a higher magnitude, and are generally balanced between positive and negative.

Finally, the modelled steady state potentiometric surface for the deeper tight bedrock is presented in Figure 4.8. The head in this layer shows a smooth transition from high head in the plateau to low head in the discharge zone with no influence from smaller surface variations.

Overall, the three figures represent a generally reasonable starting condition for groundwater level distribution under baseline steady state conditions.



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

KEY

- Project area
- Model domain
- Modelled water table elevation (mAHD)

Existing environment

- Major road
- Minor road
- Named watercourse

Modelled groundwater elevation (mAHD)

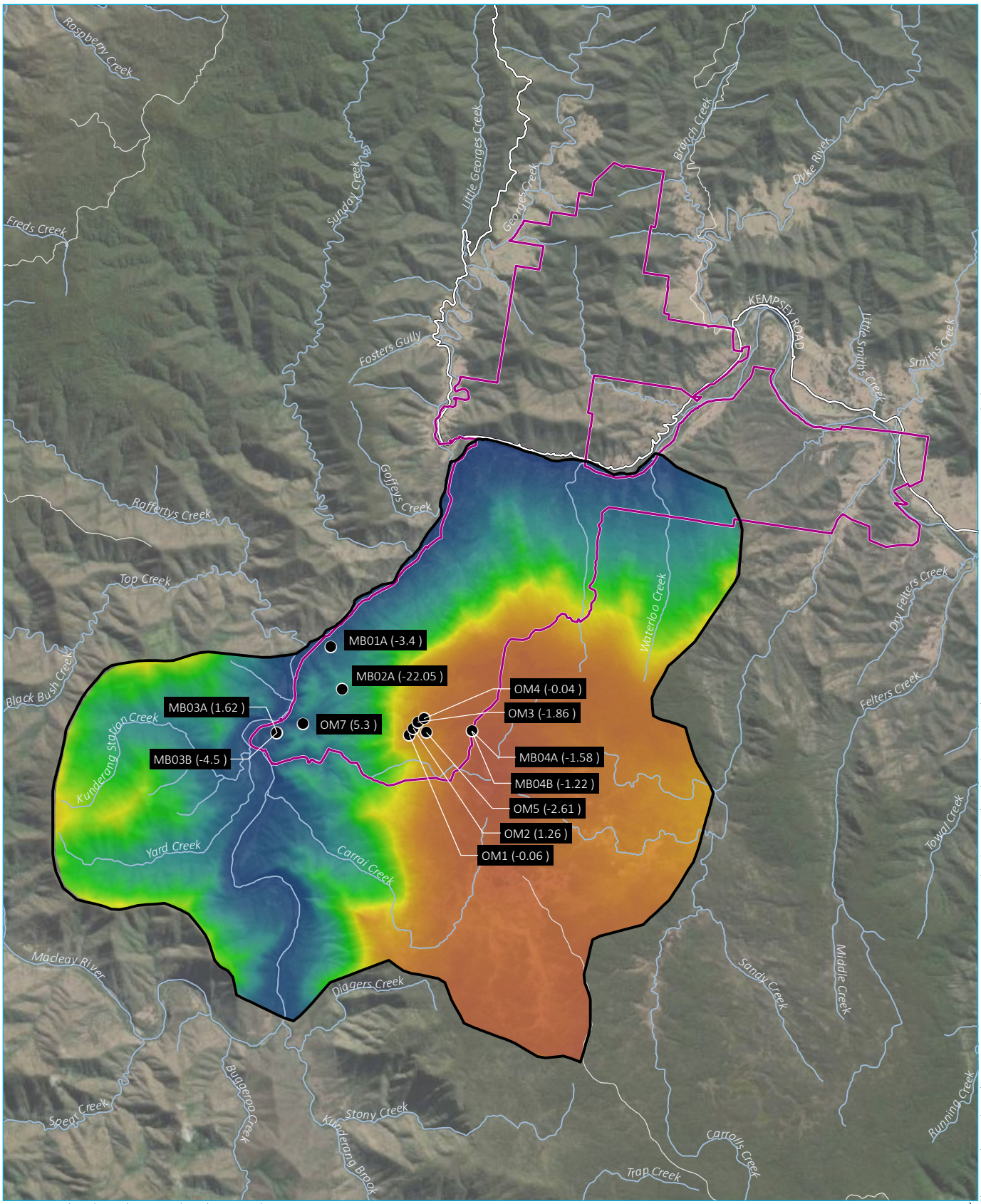
1024.91

118.61

Modelled steady state water table elevation

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Figure 4.6

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Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

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KEY

- Project area
- Residuals
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse

Modelled groundwater elevation (mAHD)

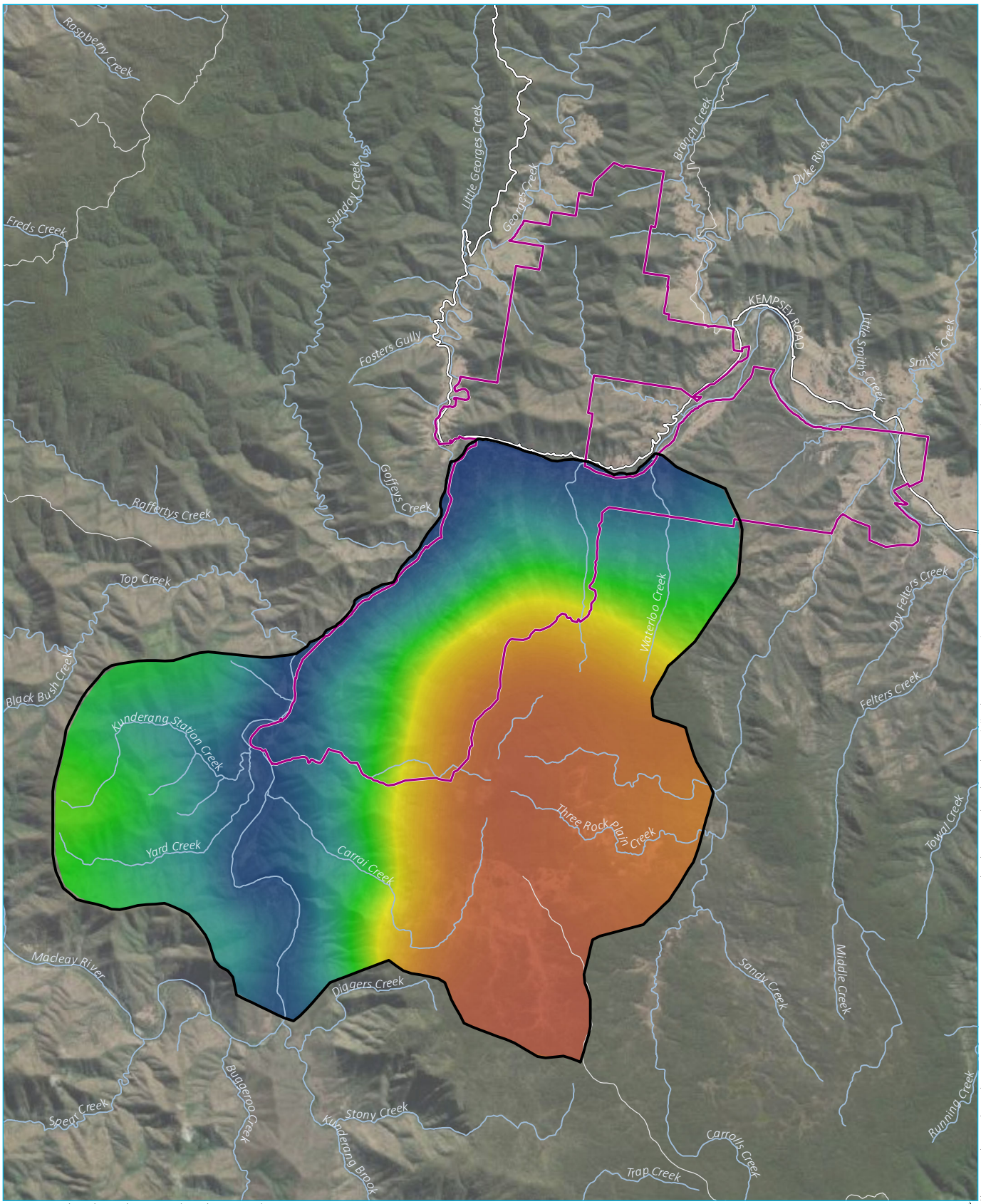
1024.91

118.91

Modelled steady state potentiometric surface and residuals for upper fractured rock

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Figure 4.7

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Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse

Modelled groundwater elevation (mAHD)

970.38

127.92

Modelled steady state potentiometric surface for deeper tight bedrock

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Figure 4.8

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ii Transient

A scatter plot of modelled against measured hydraulic head data for the complete history-matching dataset is presented in Figure 4.9. Based on this figure, some key observations on the transient model performance include:

- there is a reasonable representation of transient groundwater level change that tends to mimic the ideal theoretical line; and
- there is no systematic bias in under or over-predicting dynamic changes in groundwater levels.

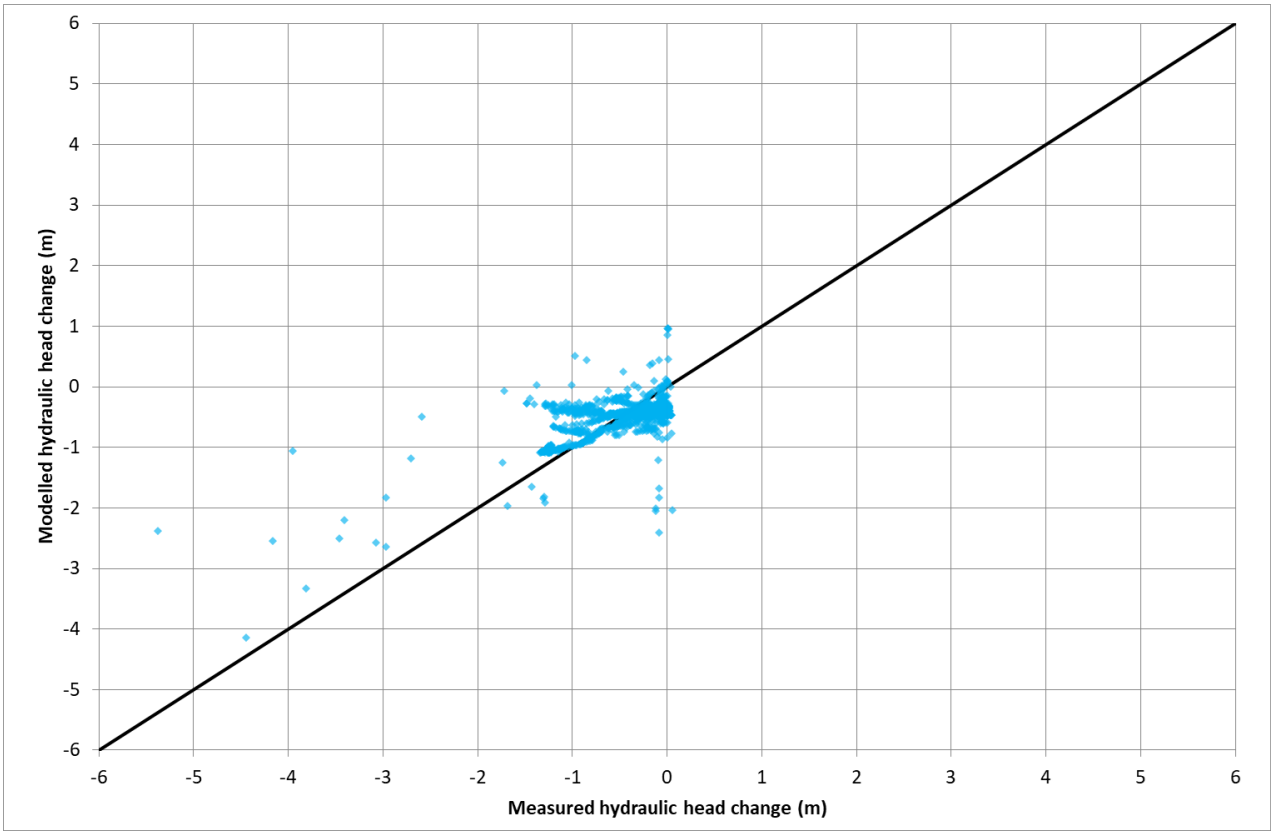


Figure 4.9 Scatter plot of transient hydraulic head change

Hydrographs of modelled and measured head are presented in Figure 4.10 to Figure 4.12. The locations of the bores with respect to the geographic focus areas are presented spatially on Figure 4.13. The bores represent a spread of monitoring across different geographic domains and HSUs. The transient history-matching performance at each of these monitoring sites is summarised in Table 4.3. The overall history-matching performance is deemed to be acceptable, given the assumptions associated with using an EPM approach, the scale of the study area, the influence of steep topographic relief on groundwater flow processes, the necessary model complexity, and the overall modelling objectives.

Table 4.3 Transient history-matching performance at individual bores

Bore	Geographic focus area	HSU	Magnitude of heads	Timing of seasonal response in heads	Magnitude of seasonal response in heads	Overall performance
OM1	Plateau	Fractured bedrock	Generally within 1–2 m of measured	Model predicts more seasonality than what was observed.	Model predicts more seasonality than what was observed.	Excellent match to heads and over-prediction of seasonality.
OM2	Plateau	Fractured bedrock	Generally within 1–2 m of measured	Model predicts timing of seasonality accurately.	Model predicts magnitude of seasonality accurately.	Excellent match to heads and seasonality.
OM3	Plateau	Fractured bedrock	Generally within 3 m of measured	Model predicts timing of seasonality reasonably well.	Model predicts magnitude of seasonality reasonably well.	Excellent match to heads and reasonable match to seasonality.
OM4	Plateau	Fractured bedrock	Generally within 1–2 m of measured	Model predicts timing of seasonality accurately.	Model predicts magnitude of seasonality accurately.	Excellent match to heads and seasonality.
OM5	Plateau	Fractured bedrock	Generally within 5 m of measured	Not a good match to measured data which shows no response to rainfall.	Not a good match to measured data which shows no response to rainfall.	Reasonable match to heads and unable to match decaying groundwater levels.
MB04B	Plateau	Fractured bedrock	Generally within 2–4 m of measured	Measured much more dynamic than modelled.	Magnitude of dry season decay similar to measured.	Excellent match to heads and under-prediction of dynamic seasonality in measured data.
MB04A	Plateau	Residual soil	Generally within 2 m of measured	Dry season decay in levels well matched.	Magnitude of dry season decay very similar to measured.	Excellent match to heads and similar magnitudes and timing of seasonality.
HA2201	Plateau	Residual soil	Generally within 1 m of measured	Model predicts more seasonality than what was observed.	Model predicts more seasonality than what was observed.	Excellent match to heads and over-prediction of seasonality.
HA2202	Plateau	Residual soil	Generally within 1 m of measured	Timing of 2022 rainfall recharge and dry season decay in levels well matched.	Magnitude of rainfall recharge response very similar to measured.	Excellent match to heads and similar magnitudes and timing of seasonality.

Table 4.3 Transient history-matching performance at individual bores

Bore	Geographic focus area	HSU	Magnitude of heads	Timing of seasonal response in heads	Magnitude of seasonal response in heads	Overall performance
HA2203	Plateau	Residual soil	Generally within 1 m of measured.	Timing of 2022 rainfall recharge and dry season decay in levels well matched.	Magnitude of rainfall recharge response very similar to measured.	Excellent match to heads and similar magnitudes and timing of seasonality.
OM6	Escarpment	Fractured bedrock	Greater than 20 m difference between measured and modelled.	Model predicts more seasonality than what was observed.	Model predicts more seasonality than what was observed.	Unable to match magnitude of heads and seasonality.
OM7	Escarpment	Fractured bedrock	Generally within 5–10 m of measured.	Model predicts more seasonality than what was observed.	Model predicts more seasonality than what was observed.	Reasonable match to heads and over-prediction of seasonality.
MB01A	Escarpment	Fractured bedrock	Generally within 5 m of measured.	Timing of 2022 rainfall recharge and dry season flattening slightly delayed in model.	Magnitude of rainfall recharge response very similar to measured.	Reasonable match to measured data.
MB02A	Escarpment	Fractured bedrock	Greater than 20 m difference between measured and modelled.	Timing of rising and falling limbs of hydrograph well matched.	Magnitude of rising and falling limbs associated with recharge are well matched.	Unable to match magnitude of heads, but reasonable seasonality match.
MB03A	River floodplain	Fractured bedrock	Generally within 1–2 m of measured.	Model predicts timing of seasonality accurately.	Model predicts magnitude of seasonality accurately.	Excellent match to heads and seasonality.
MB03B	River floodplain	Fractured bedrock	Generally within 5–7 m of measured.	Model predicts timing of seasonality accurately.	Model predicts magnitude of seasonality accurately.	Reasonable match to heads and excellent match to seasonality.
MB02B	Escarpment	Deeper tight bedrock	Within several metres of measured.	Seasonal response not well captured.	Magnitude of seasonal response not well matched.	Excellent match to magnitude of head, unable to replicate seasonal behaviour in this deep bore.

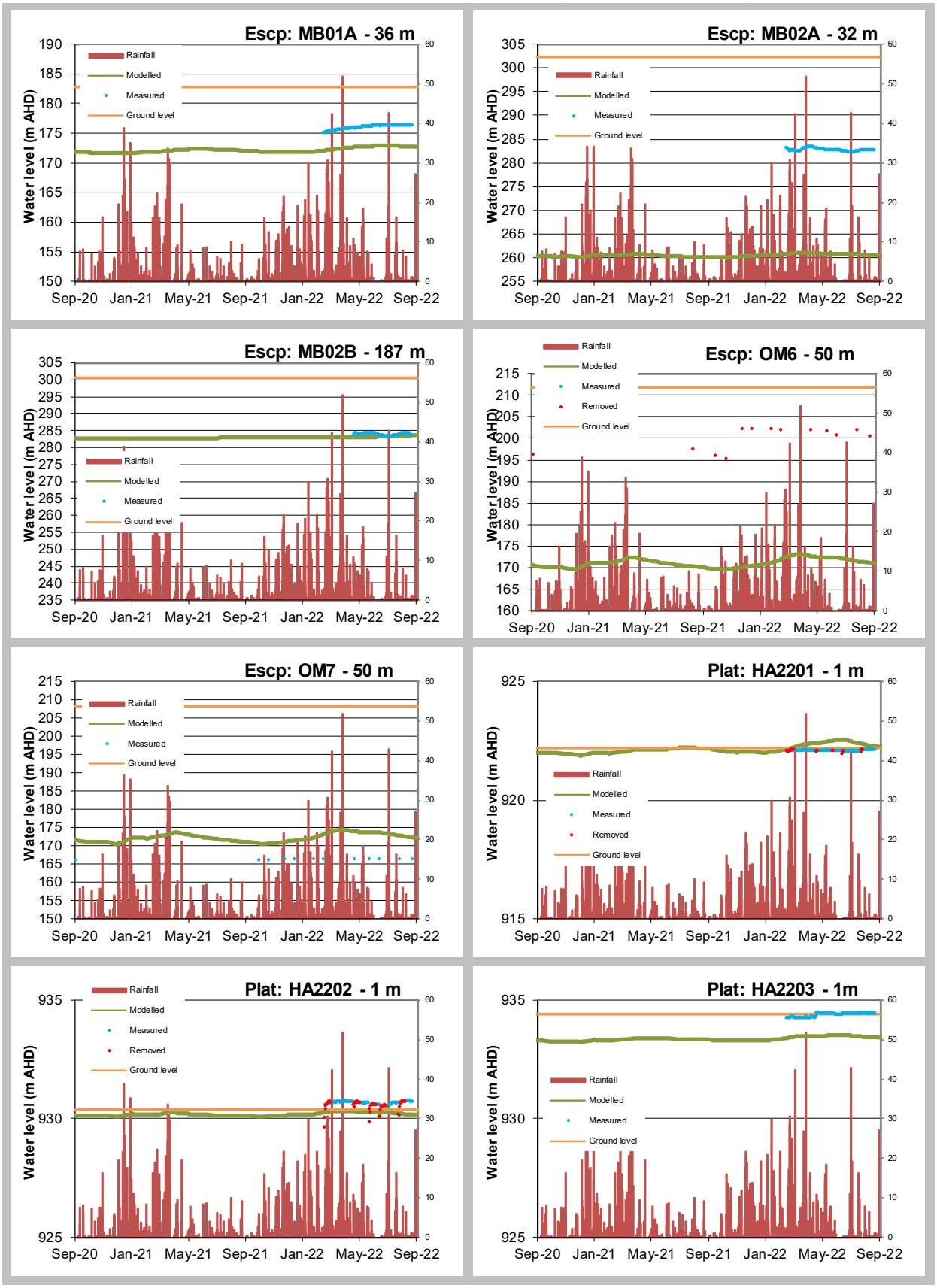


Figure 4.10 **Modelled and measured hydrographs over the history-matching period**

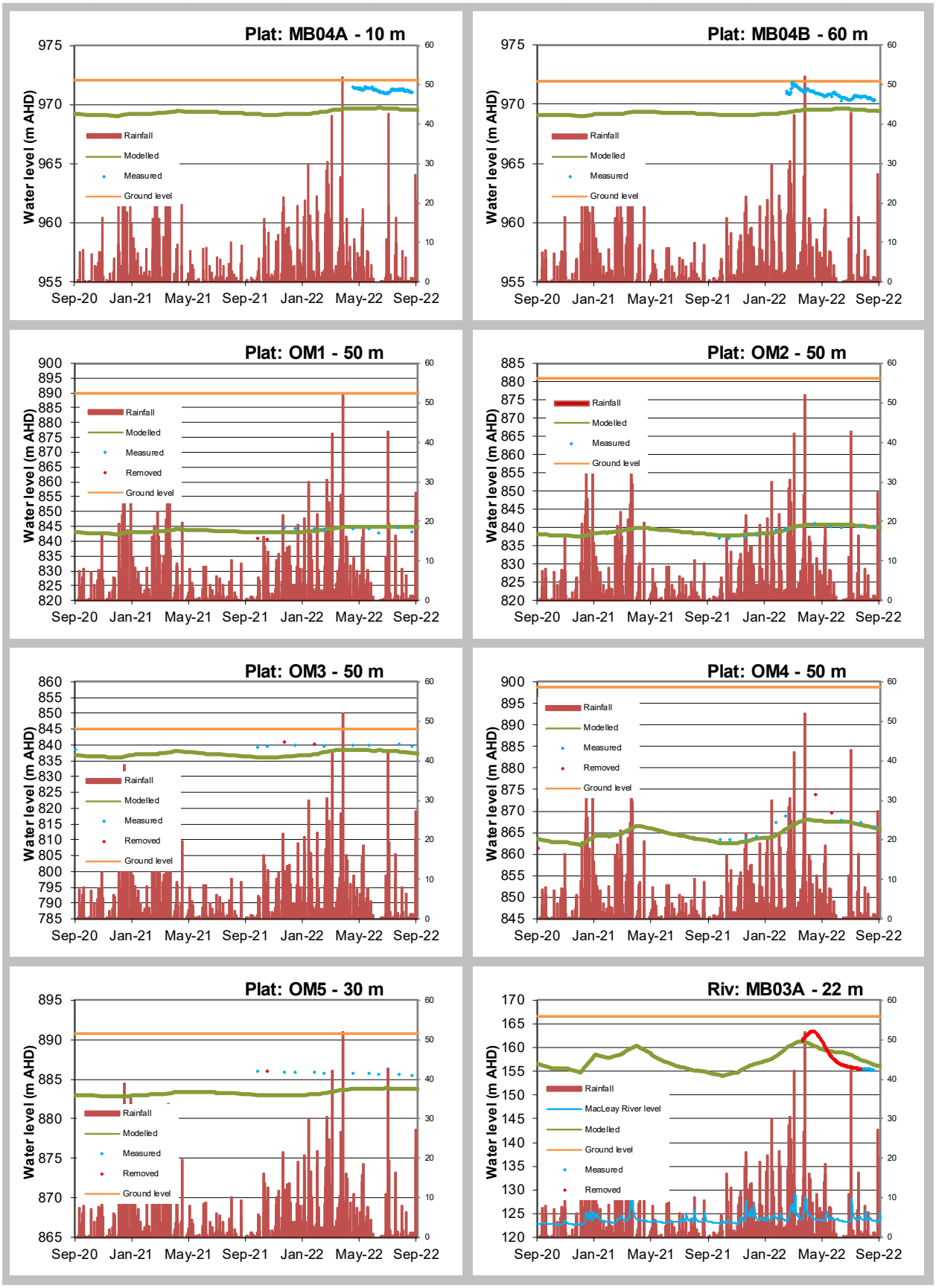


Figure 4.11 Modelled and measured hydrographs over the history-matching period

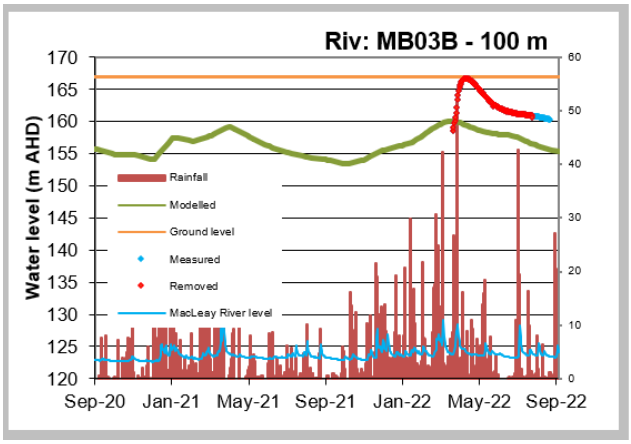


Figure 4.12 Modelled and measured hydrographs over the history-matching period

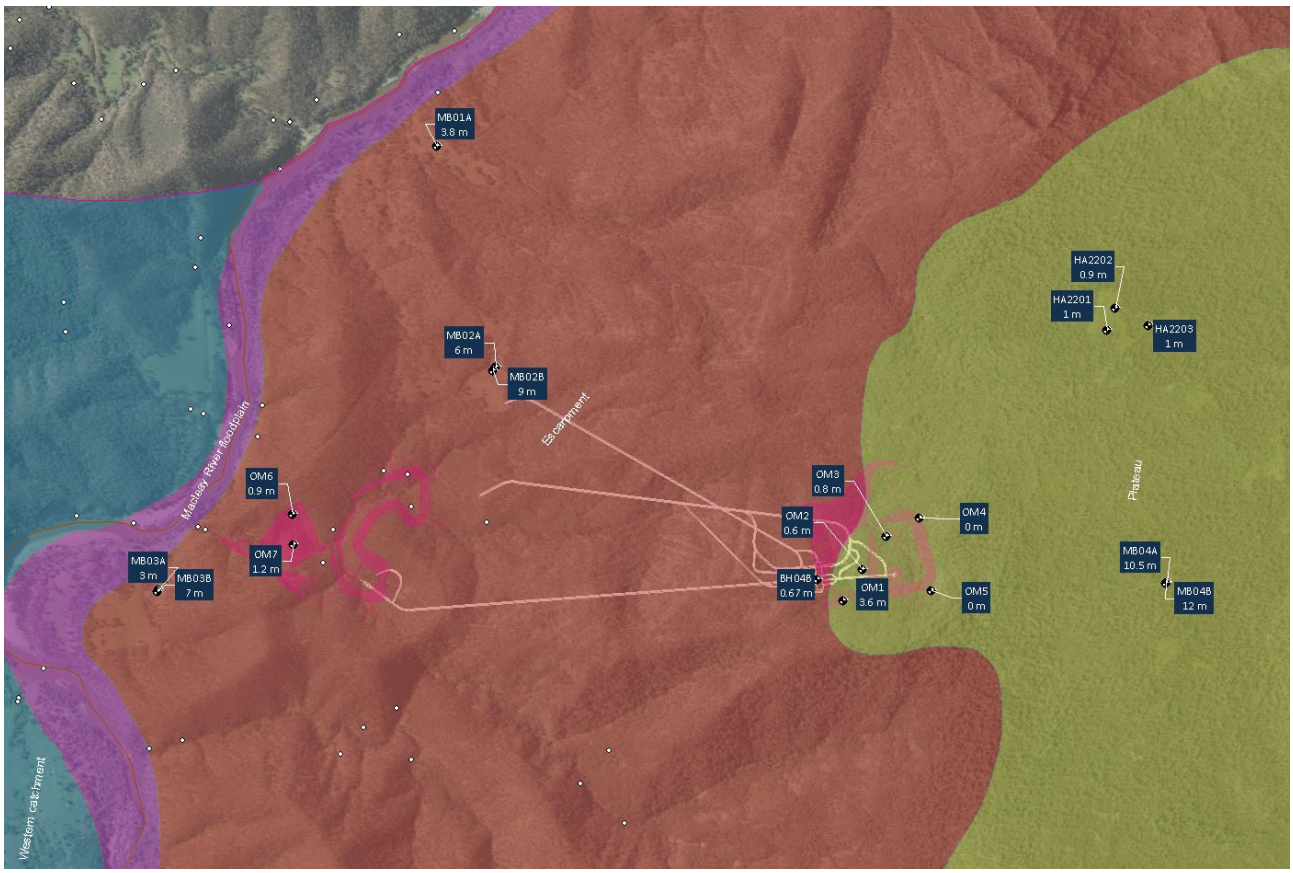


Figure 4.13 Hydrograph monitoring well locations

4.3 Water balance

Table 4.4 presents the modelled water balance for the base case steady state stress period. The corresponding transient time series for the history-matching period is shown on Figure 4.14. Rainfall recharge is the dominant input flux to the model during the baseline steady state stress period, with a minor contribution of river recharge. Discharge to rivers is the dominant output flux from the model, with a contributing flux from evapotranspiration. This steady state modelled water balance is consistent with the recharge and discharge processes of the HCM illustrated earlier in Figure 2.18. During the transient history-matching period, variability in recharge from rainfall results in changes in storage. There is conservation of mass in the steady state and transient history-matching stress periods of the model, and it comfortably achieves the target to have a modelled water balance error of < 0.5%.

Table 4.4 Modelled steady state pre-Project water balance

Water Balance Component	In (ML/d)	Out (ML/d)
Rainfall recharge	54.767	-
River recharge – Macleay River	12.270	-
River recharge – creeks and streams	0	-
Evapotranspiration	-	22.598
Discharge to rivers – Macleay River	-	16.415
Discharge to rivers – creeks and streams	-	28.024
Total	67.037	67.037
Water balance error	0.00%	

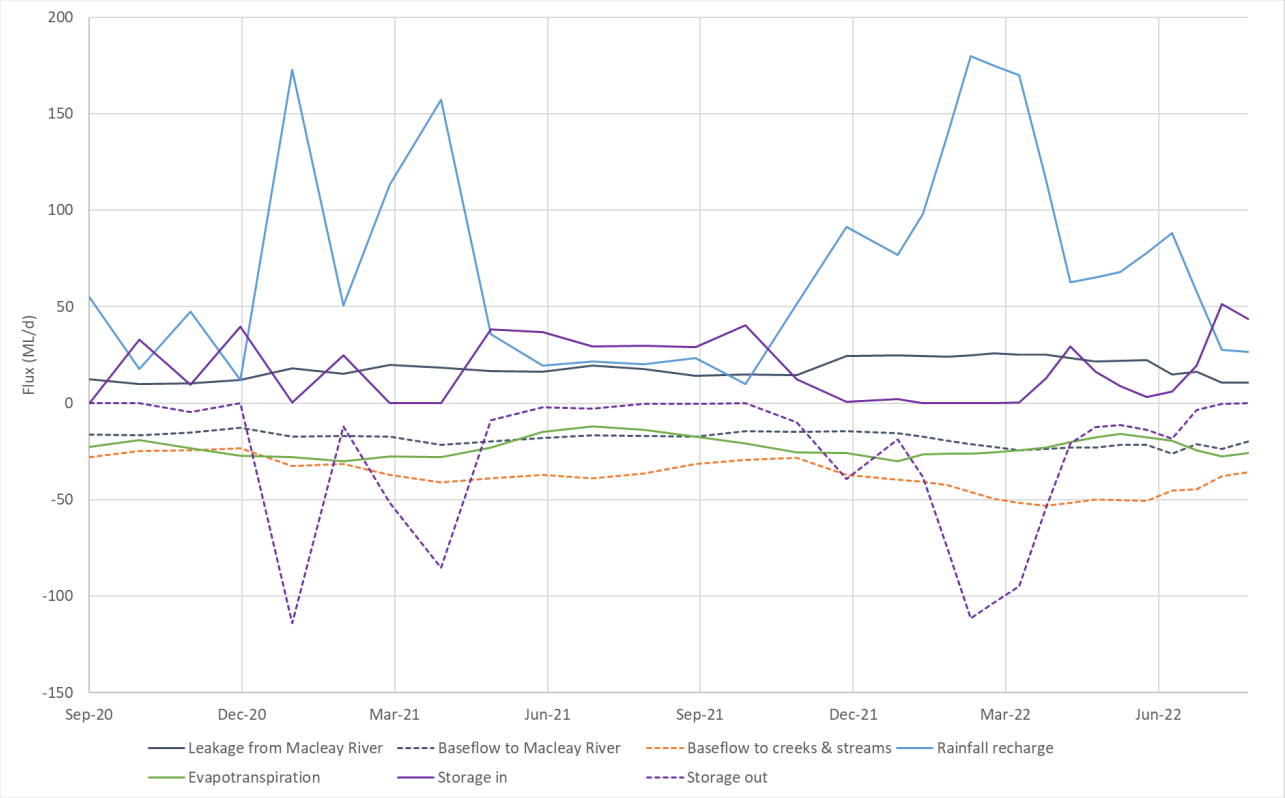


Figure 4.14 Modelled transient water balance over the history-matching period

4.4 Base case hydraulic properties

Table 4.5 presents a summary of modelled hydraulic properties resulting from the history-matching process, that are subsequently adopted as "base case" hydraulic parameters. Because pilot points were used to develop spatially variable parameters, the minimum, maximum and mean values that were derived from this highly parameterised approach are presented. The values for Kh of the weathered rock and fractured bedrock are reasonably consistent with the K estimates summarised in Section 2.5. The conceptual estimate of high K for the shallow and very coarse-grained alluvium/colluvium is consistent with estimates for sands and gravels in Freeze and Cherry (1979). The model has not established much anisotropy between Kh and Kv during history-matching, which is consistent with the regular fracturing at depth observed in the monitoring network (slug and packer tests, see Table 2.4). The storage properties are within plausible theoretical ranges as per Freeze and Cherry (1979).

Distributions of spatially variable Kh (m/d) for the alluvium/colluvium/weathered bedrock, the fractured bedrock and the tight bedrock are presented in Figure 4.15 to Figure 4.17, respectively. These figures are presented as a $\log_{10}$ transform of the conductivity to better show variations and since they were calibrated on a log scale.

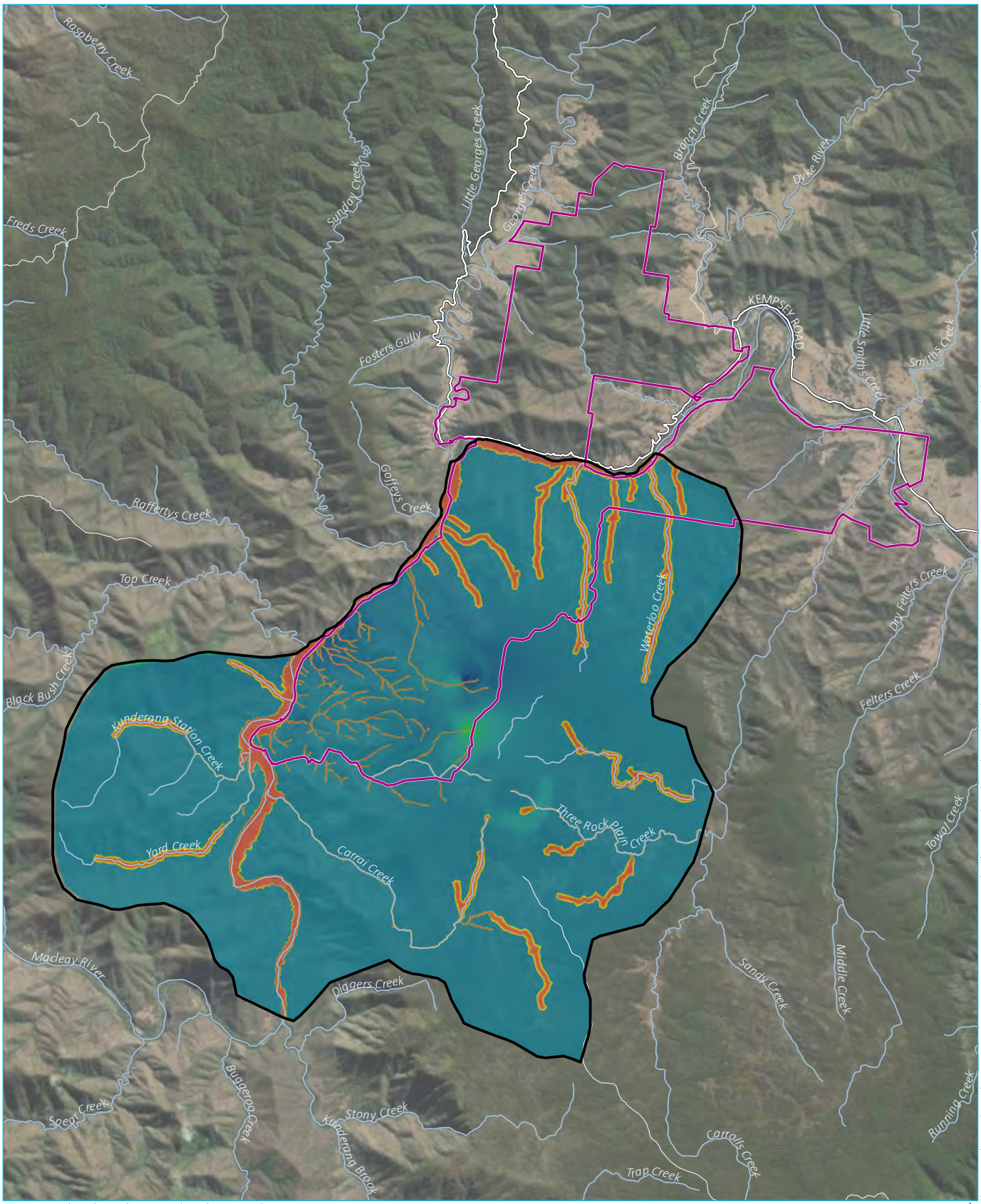
Table 4.5 Modelled aquifer properties

HSU	Kh (m/d)	Kv (m/d)	Sy (%)	Ss (1/m)
	(min, max, mean)	(min, max, mean)	(min, max, mean)	(min, max, mean)
Alluvium, colluvium[1]	71.3	50.0	0.2	$5x10^{-6}$
Weathered bedrock[2]	0.21, 2.03, 0.52	0.49, 0.51, 0.50	0.05, 0.25, 0.11	$5x10^{-6}$
Fractured bedrock	$1x10^{-3}$, 1.0, 0.12	0.01, 0.2, 0.11	$2x10^{-3}$, 0.05, 0.02	$9.3x10^{-7}$, $1.0x10^{-6}$, $1.0x10^{-6}$
Tight bedrock	$4.1x10^{-6}$, $2.0x10^{-4}$, $1.5x10^{-5}$	$5.3 x10^{-6}$, $1.2x10^{-5}$, $9.8x10^{-6}$	$1x10^{-3}$, $1x10^{-3}$, $1x10^{-3}$	$4.5x10^{-7}$, $1.0x10^{-6}$, $9.7x10^{-6}$

Notes: [1] only one pilot point used for alluvium and colluvium so single value for this HSU; [2] only one pilot point used for Ss of weathered bedrock so single value for this HSU

Table 4.6 Modelled recharge zones and rates

Model recharge zone	Representative Focus Area	Recharge rate (mm/yr) / Recharge % (% of annual avg rainfall - AAR)
1	Escarpment	141 mm/yr (14% of AAR)
2	Plateau	184 mm/yr (18% of AAR)
3	Alluvium	365 mm/yr (36% of AAR)
4	Model cells containing river boundary conditions	0 (0% of AAR)



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW026_ModelledHorizontalHC_Alluvium_20221103_02.mxd 14/12/2022

KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse

Log_{10} hydraulic conductivity (m/day)

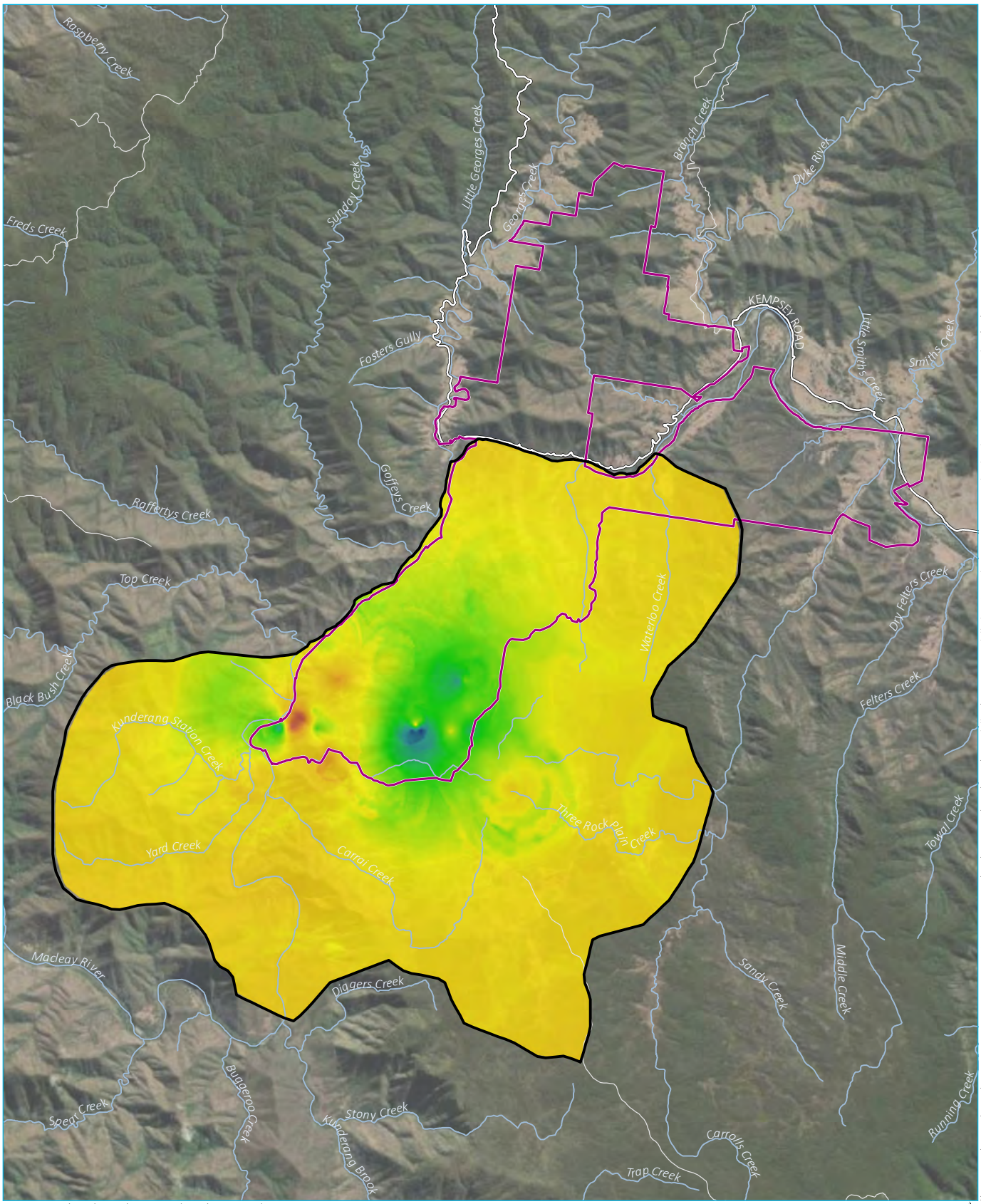
1.85

-0.65

Modelled horizontal hydraulic conductivity of alluvium, colluvium and residual soil

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd
Figure 4.15

EMM creating opportunities



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW027_ModelledHorizontalHC_UpperFracturedBedrock_20221103_02.mxd 14/12/2022

KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse

Log_{10} hydraulic conductivity (m/day)

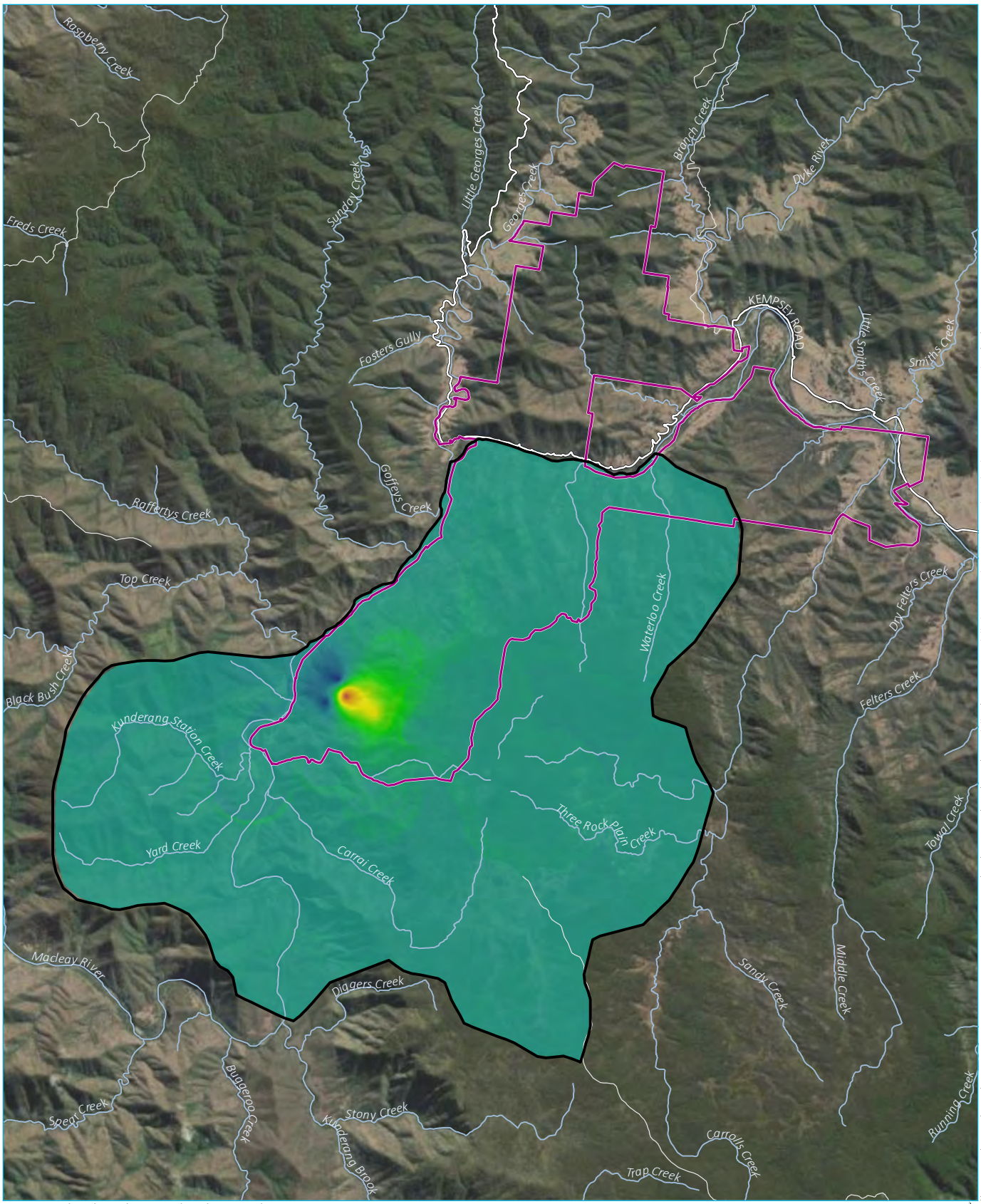
-0.06

-2.97

Modelled horizontal hydraulic conductivity of upper fractured bedrock unit

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd
Figure 4.16

EMM creating opportunities



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW028_ModelledHorizontalHC_DeeperTightBedrock_20221103_02.mxd 14/12/2022

KEY

- Project area
- Model domain

Existing environment

- Major road
- Minor road
- Named watercourse

Log_{10} hydraulic conductivity (m/day)

-3.71

-5.35

Modelled horizontal hydraulic conductivity of deeper tight bedrock

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd
Figure 4.17

EMM creating opportunities

4.5 Sensitivity

Following selection of a base case set of history-matched parameter values, PESTPP-GLM was run with the number of optimisation iterations set to -1, to calculate the Jacobian matrix and parameter sensitivities. The calculated relative composite sensitivities of the model input parameters are shown in Figure 4.18, calculated using hydraulic head targets described in Section 4.1.2. The parameters analysed include Kh, Kv, Ss, and Sy and the three recharge zones. The sensitivity of each parameter is related to its influence on model performance against measured data. Higher values (higher sensitivity) suggest that the parameter has a larger influence on history-matching performance, and may be better constrained. Parameters with a value close to 0 have a small influence on history-matching and are less constrained:

- the model is most sensitive to recharge in the plateau and escarpment;
- the model is more sensitive to the hydraulic conductivity parameters than storage;
- the fractured rock HSU has a generally high contribution to sensitivity; and
- the model is not very sensitive to parameters at pilot points 14 to 20, and is insensitive to changes at pilot points 31 to 39.

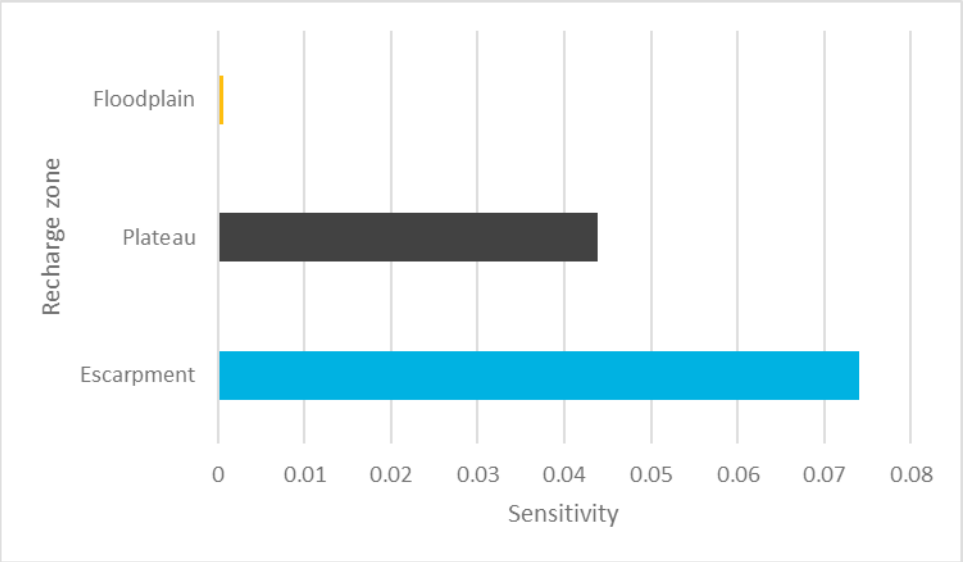


Figure 4.18 Relative composite sensitivity of recharge zones following history-matching

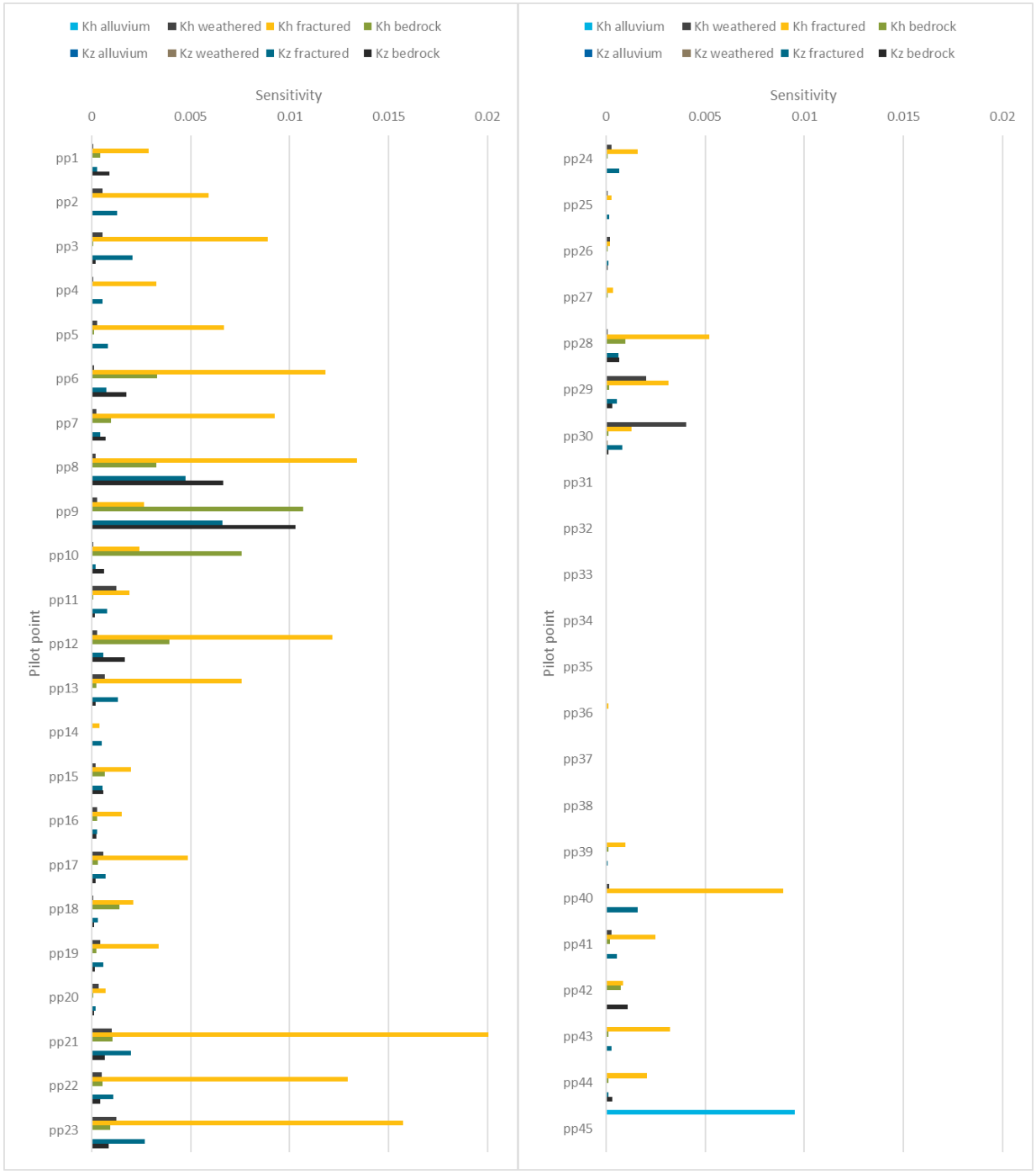


Figure 4.19 **Relative composite sensitivity of hydraulic conductivity pilot points following history-matching**

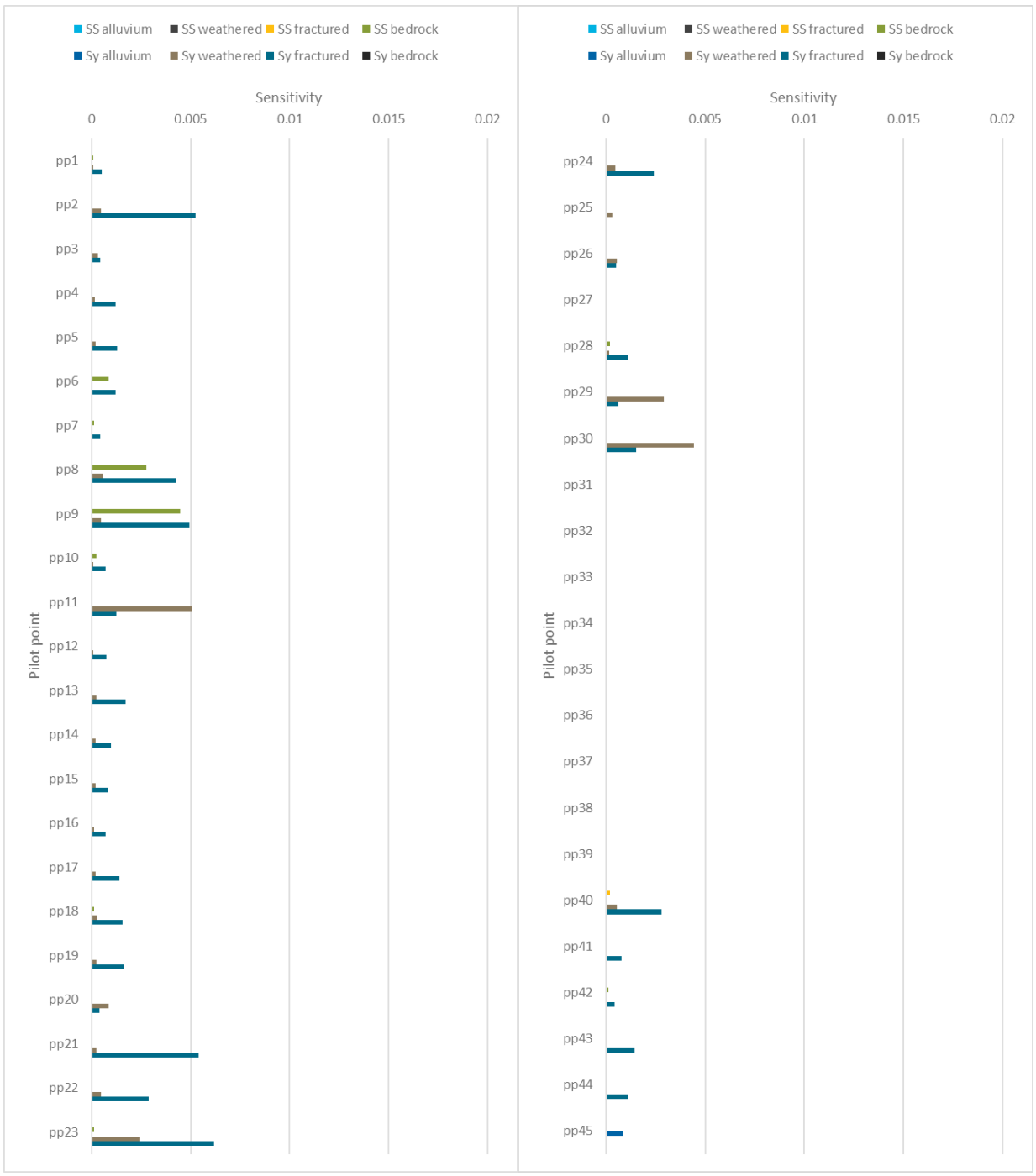


Figure 4.20 **Relative composite sensitivity of storage pilot points following history-matching**

5 Predictive modelling

5.1 Overview

As discussed in Section 3.6.7, construction and operation of the Project involve different groundwater-affecting activities and different requirements for time-varying and spatially-varying boundary conditions. As such, both the base case model and the suite of stochastic simulations were run for both a null case (no project) and for the project case, with stress periods defined for both construction and operation. This section of the report outlines the modelled scenarios and predictions for a suite of simulations including the base case. The model outputs are tailored to answer the modelling objectives outlined previously in Table 1.1, including spatial and temporal drawdown in key HSUs and sites of interest, as well as changes to the water balance.

5.2 Scenario definition and representation

In addition to the history-matched base case, 200 additional realisations of parameter values were generated in order to run a Monte Carlo predictive uncertainty analysis. Both the null case and project case were simulated for each of the realisations in the stochastic suite (with each stochastic realisation being highly parameterised) to produce a range of predictions. The set of project-related boundary conditions for both construction and operation were previously described in Section 3.6.7 and are summarised in Table 5.1 below for context of results presented in this section. Those boundary conditions were kept consistent across all stochastic realisations.

From a pool of 201 realisations, including the base case, 109 were accepted on the basis of their history-matching performance quantified via the PESTPP-GLM objective function. Both a null scenario and project scenario were modelled using each accepted realisation. The base case model is considered one of these 109 simulations and is differentiated graphically in Section 5.5 for the sake of clarity. The base case water balance is presented separately in Section 5.3 to provide context on the changes to the water balance resulting from those project-related groundwater-affecting activities.

Table 5.1 Summary of model representation of construction and operation stress periods

Model representation	Construction	Operation
Length of simulation	October 2023 to December 2026	Transient followed by steady state.
Headrace	MODFLOW drains with stage at invert of tunnel	No boundary conditions: headrace is steel lined during operation.
Tailrace	MODFLOW drains with stage at invert of tunnel	MODFLOW general head boundary adopting pressure of lower reservoir.
Power generator, surge shaft and penstocks	MODFLOW drains with stage at base of excavation	No boundary conditions: assumed concrete- or steel-lined.
Access portals	MODFLOW drains with stage at invert of tunnel	MODFLOW drains with stage at invert of tunnel.
Vertical shaft	MODFLOW drains with stage at invert of tunnel	MODFLOW general head boundary adopting pressure of upper reservoir.
Reservoirs	MODFLOW drains with stage at base of excavation	MODFLOW general head boundary with head established at mid operating level as per Table 3.6.

5.3 Base case water balance

The base case history-matched model was run deterministically to predict the "base case" impact of construction and operation of the project on:

- groundwater inflows to each component of the project during construction;
- river water balances during construction and operation; and
- groundwater inflows and outflows to key project components during steady state operation.

5.3.1 Groundwater inflow to project components during construction

The predicted groundwater inflow rates to each component of the Project during each quarter of construction is tabulated in Table 5.2 and presented as a stacked line plot in Figure 5.1. These show that construction of the access portal, the upper reservoir and the lower reservoir receive between 75% and 82% of the total predicted groundwater inflow for the entire construction schedule. The other main contributor is the tailrace construction adit which contributes ~17% of the total construction inflows for the first two quarters (October 2023 to March 2024), but then reduces to ~7% of the total inflows for the remaining 15 quarters of construction. The total predicted groundwater inflow rates to the scheme are approximately ~ 600 ML/yr until July of 2024 and then steadily reducing from <400 ML/yr in 2024 and 2025 to <300 ML/yr in 2026 and 2027.

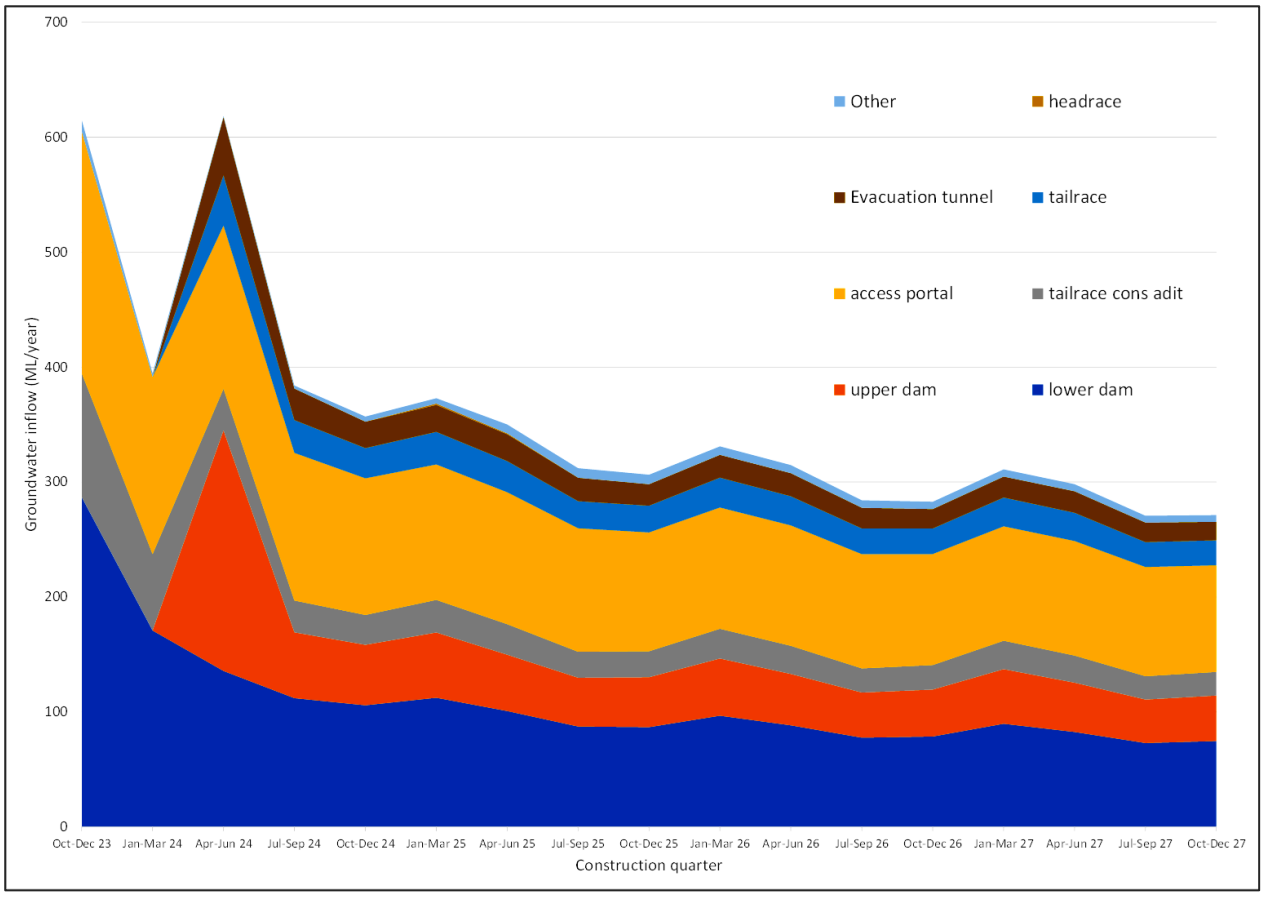


Figure 5.1 Groundwater inflow to project components during construction

Table 5.2 Groundwater inflow to project components during construction (ML/yr)

Project component	Oct–Dec 2023	Jan–Mar 2024	Apr–Jun 2024	Jul–Sep 2024	Oct–Dec 2024	Jan–Mar 2025	Apr–Jun 2025	Jul–Sep 2025	Oct–Dec 2025	Jan–Mar 2026	Apr–Jun 2026	Jul–Sep 2026	Oct–Dec 2026	Jan–Mar 2027	Apr–Jun 2027	Jul–Sep 2027	Oct–Dec 2027
Total	615.1	394.6	618.6	384.1	357.0	372.9	350.1	312.0	306.4	331.1	314.8	284.1	282.9	311.1	298.1	270.7	271.3
Lower reservoir	286.8	170.8	135.7	111.9	105.8	112.3	100.8	87.3	86.7	96.7	88.4	77.6	78.6	89.7	82.6	72.9	74.6
Upper reservoir	0.0	0.0	209.3	57.3	52.5	56.7	49.0	42.4	43.5	49.8	44.6	39.3	40.9	47.5	42.8	37.8	39.6
Tailrace adit	108.0	66.5	36.3	27.7	26.1	28.5	26.5	22.6	22.6	25.8	24.6	21.1	21.3	24.8	23.7	20.3	20.7
MAT	210.2	153.9	141.7	128.4	118.8	117.8	114.7	107.4	103.4	105.4	104.7	99.3	96.6	99.4	99.5	94.9	92.7
Tailrace	0.0	0.0	43.9	28.6	26.3	28.3	27.1	23.7	23.3	26.0	25.4	22.4	22.2	25.1	24.7	21.8	21.7
ECVT	0.0	0.0	50.6	27.4	23.0	23.5	23.4	20.3	18.7	19.8	19.9	18.0	16.9	18.2	18.6	17.0	16.1
Headrace	0.0	0.0	0.0	0.0	0.0	1.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All other features	10.1	3.5	1.2	2.8	4.5	4.7	7.7	8.4	8.4	7.6	7.1	6.5	6.4	6.3	6.2	6.0	5.9

5.3.2 Groundwater flow to/from project components during operation

During steady state operation the base case model predicts 319.9 ML/yr of groundwater take. This includes 158.4 ML/yr of groundwater inflow to excavated project components, and 161.5 ML/yr to the two reservoirs. The reservoirs also leak a combined total of 699.6 ML/yr back to the aquifer. Further breakdown of the gross takes and losses for the key project components is summarised in Table 5.3.

Table 5.3 Gross takes and losses from aquifer during operation (ML/yr)

Project component	Loss to aquifer	Take from aquifer
Total	700.2	319.9
Lower reservoir	641.8	117.3
Upper reservoir	57.8	44.2
Tailrace adit	0	
MAT	0	116.3
Tailrace	0.1	19.8
Pressure shaft	0.5	0.0
ECVT	0	19.8
Headrace	0	0
All other features	0	1.4

5.3.3 River water balances

Water balances for the Macleay River and all other creeks were calculated for the construction and operation periods. Each of those river types was differentiated in terms of either residing in the Macleay Gorges water source or the Macleay Valley water source and also in terms of the direction of flux (leakage from river to aquifer or baseflow from aquifer to river). Modelled river water balances are presented as a line plot in Figure 5.2. A positive flux in this figure represents a flux that is greater than the pre-construction steady state flux. For example, a rate of 100 ML/yr is 100 ML/yr greater than the steady state rate. As such it is a net change value. In contrast a negative flux rate on this plot translates as a rate that is less than the pre-construction river flux.

The figure shows that the Macleay River within the Macleay Gorges water source area leaks an additional 28 ML/yr on average over the construction period. This is associated with the period when the lower reservoir, the tailrace, the MAT and ECVT is being constructed in the near vicinity. Those project features create groundwater inflows and drawdowns that lead to enhanced leakage from the Macleay River. This trend is reversed during operation when the lower reservoir and tailrace are filled with water to create elevated hydraulic heads with respect to the river and leakage to the aquifer is less than the pre-construction period. The predicted baseflow to the Macleay River and other creeks in the Macleay Gorges water source area is reduced by up to ~115 ML/yr and ~50 ML/yr, respectively, during the construction period when project dewatering is occurring concurrently. During operation this trend is reversed as the Macleay River gains an additional ~211 ML/yr of baseflow and the other creeks receive ~152 ML/yr of baseflow. There is predicted negligible change to leakage or baseflow for all rivers in the Macleay Valley water source area.

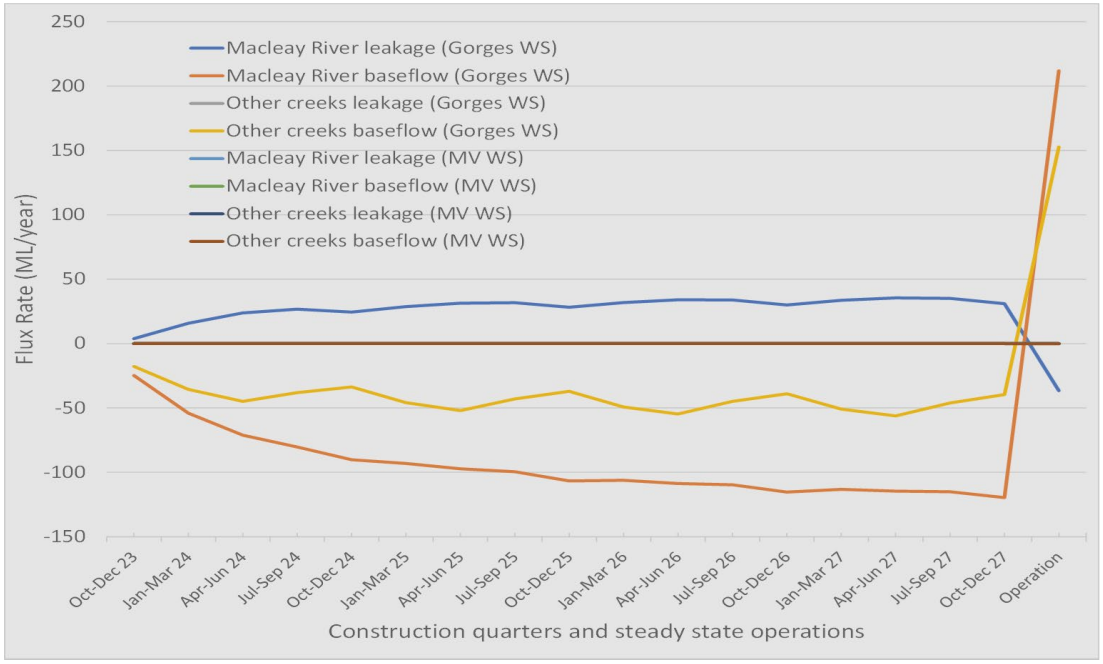


Figure 5.2 River water balances during construction and steady state operation relative to pre-construction baseline steady state

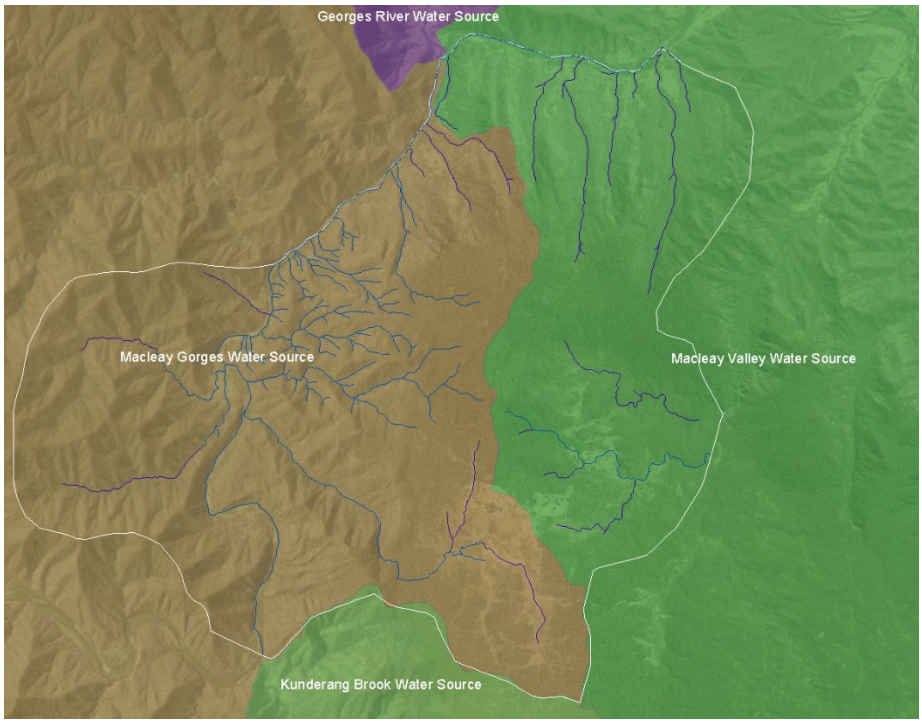


Figure 5.3 Differentiation of river types referred to in Figure 5.2

5.4 Uncertainty analysis workflow

A probabilistic predictive uncertainty analysis (PUA) workflow was adopted that aligns with the Type 3 method described in Middlemis and Peeters (2018), ie stochastic modelling with Bayesian probability quantification. The 8 steps of the PUA workflow are summarised below in Table 5.4. Steps 5 and 7 are described in more detail in sub-sections immediately below the table to provide transparency of model evaluation at the two key hold points.

Table 5.4 Uncertainty analysis workflow

Step	Process	Comments
1	Use PESTPP-GLM to history-match a highly parameterised (using pilot points across all main HSUs and layers) deterministic base case model.	Each model layer has up to 45 pilot points to allow for spatially varying Kh, Kv, Sy, Ss and recharge. Minimise objective function and assess model against history-matching criteria established in Table 4.1.
2	Use prior knowledge of hydraulic properties and theoretical limits (based on literature and fractured rock hydrogeology experience) to establish upper and lower bounds for each parameter in each HSU.	For Kh, Kv and Ss these bounds need to cover several orders of magnitude beyond the base case values, while for Sy these bounds need to cover tighter intervals. Recharge was fixed at the base case values (see section 5.4.1 for more details).
3	Develop a bespoke statistical workflow in Python to create probability distributions for each pilot point and parameter: Kh, Kv, Sy and Ss. There are 489 variable pilot points, with an additional 3,875 tied pilot points.	For the Monte Carlo analysis, Kh, Kv and Ss pilot point probability distributions were developed with a normal distribution in log space centred around each base case pilot point value. Sy pilot point probability distributions were developed using a triangular distribution centred around the base case pilot point values.
4	Develop a bespoke statistical workflow in Python that randomly samples each probability distribution for each pilot point and writes to 200 MODFLOW/PEST .par files.	The probability distributions for the 489 variable pilot points were each sampled to create 200 Monte Carlo realisations. The .par files generated include all 4,364 variable and tied pilot points for Kh, Kv, Sy and Ss.
5	**Hold point 1**: Once the .par files are created, all 200 are collectively re-imported into Python as a unified array to create statistical boxplots to check that the total probabilities across all 200 files are statistically meaningful.	The boxplots, compared with the calibrated deterministic base case pilot point values, are presented in Section 5.4.1.
6	200 new project scenario and 200 null case scenario simulations are then deployed across a network of computers.	Each of these 200 model realisations includes the baseline history-matching period prior to construction. For all 200, both a null case scenario and project scenario are simulated.
7	**Hold point 2**: The objective functions for the history-matching period of each of the 200 simulations are then evaluated in combination with transient history-matching hydrographs and an assessment of the model's ability to match heads and changes in heads.	A cumulative histogram of model objective functions is developed. Hydrographs are checked at incremental objective function values to make a conceptually informed criterion for which models are accepted and which are excluded. The contribution to the objective function from heads and changes in heads provides a holistic indicator of model acceptability.
8	The "accepted" cohort of 109 realisations is then carried forward to processing of prediction results.	For results discussion, see Section 5.5.

5.4.1 Statistical sampling for each pilot point

As described in Step 5 of the PUA workflow (Table 5.4), a key hold point is the evaluation of the statistical distributions of parameter values at each pilot point with respect to the base case values. In order to do this, all 200 .par files were re-imported into Python and amalgamated into a single dataframe array for all 4,364 pilot points including all 25 model layers and values for Kh, Kv, Ss, Sy and recharge. Each pilot point for each hydraulic parameter for each model layer was then visualised on individual boxplots to compare base case calibrated values against the probability distribution sampled across all 200 stochastic realisations.

Overall, the analysis at the hold point showed a that the expected large distribution of hydraulic parameters was explored at each individual pilot point and that the base case model values maintain a position of central tendency in all situations. As such, Step 5 was evaluated to be successful and the 200 realisations were deployed in MODFLOW. The prior boxplots are documented in Appendix B.

5.4.2 Determination of accepted realisations

Step 7 of the PUA workflow was to accept or reject each of the 200 model realisations with respect to:

- its ability to meet the PEST objective function criterion during the history-matching period; and
- the conceptual credibility of history-matching hydrographs.

Figure 5.4 presents a histogram of factored PEST objective function values across the 200 stochastic realisations. The base case model has a factored score of 1 (an objective function of 909) and a factored score of 2 represents an objective function of 1,818 (ie 2 times that of the base case). Modelled history-matching hydrographs were then scrutinised for individual model runs that were closest to factored objective functions at 0.25 increments (ie 1.5, 1.75, 2, 2.25 2.5 and so on). It was decided through this review that significant degradation of history-matching performance occurred above a factored objective function value of 2. Rejecting all models that had an objective function of more than two times the base case objective function led to accepting 109 of the 200 realisations.

Figure 5.5 presents the objective function performance of:

- the base case (objective function of 1 on far left);
- the next 27 accepted realisations that had factored objective function values between 1 and 1.5;
- the next 46 accepted realisations that had factored objective function values between 1.5 and 1.75;
- the next 35 accepted realisations that had factored objective function values between 1.75 and 2;
- the next 21 rejected realisations that had factored objective function values between 2 and 2.25;
- the next 23 rejected realisations that had factored objective function values between 2.25 and 2.5; and
- the next 48 rejected realisations that had factored objective function values greater than 2.5.

On this column plot each cohort of models within those factored objective function thresholds has an average total objective function (blue bar), the contribution of **heads only** to the objective function (orange bar) and the contribution of **head change** to the objective function (grey bar). This plot shows that the contribution of head change to the objective function degrades significantly for model realisations with a total objective function of >2. Given that two of the four stated model objectives (see Table 1.1) require accurate prediction of drawdown (ie change in heads related to change in stress), it was decided to reject realisations with factored objective function values > two times that of the base case.

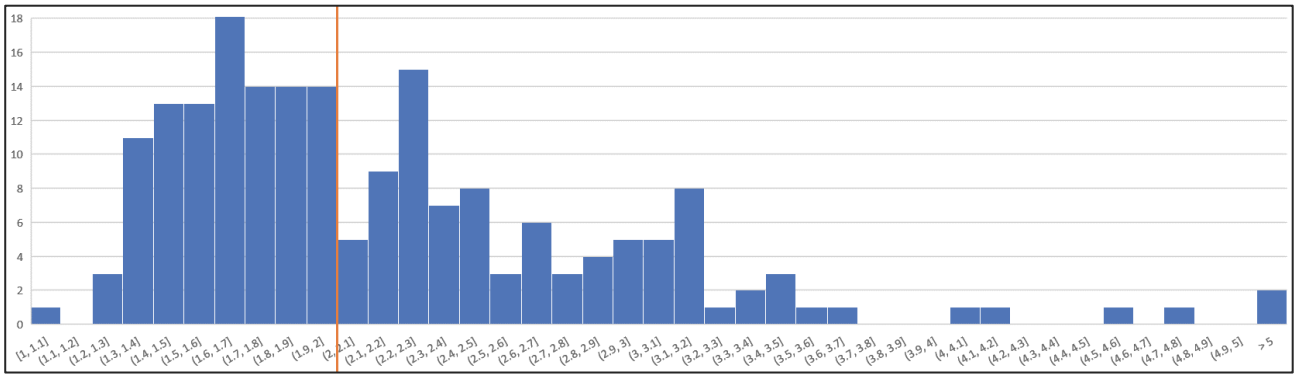


Figure 5.4 **Histogram of factored PEST objective function values for the 200 stochastic model realisations. Red line represents cut off between accepted and rejected models**

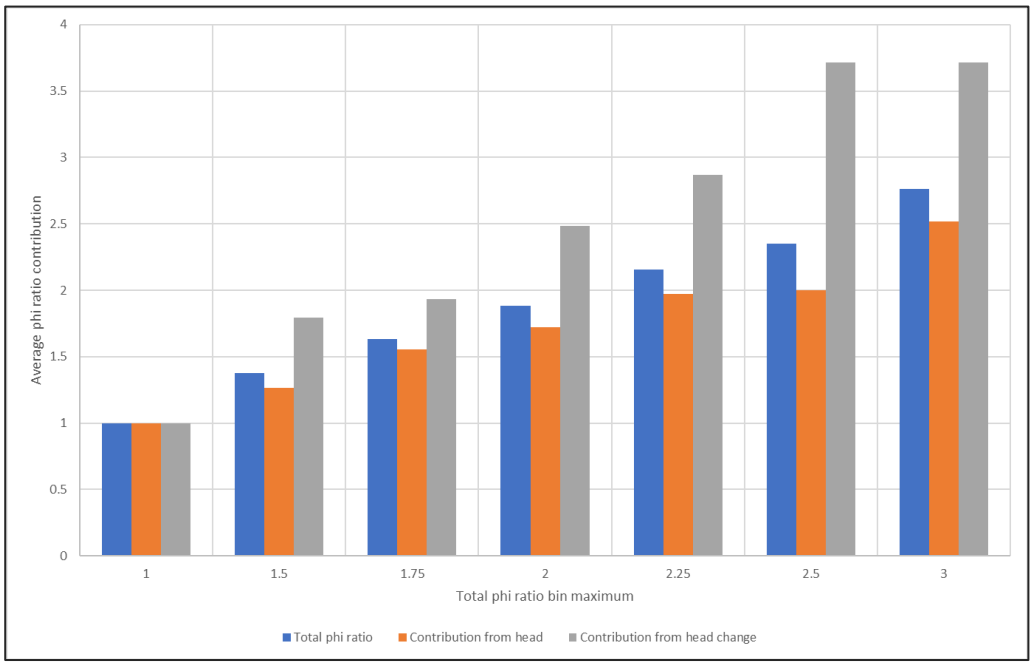


Figure 5.5 **Column plot of stochastic model contributions to factored objective function (phi) with consideration of total phi, phi contribution from heads only and contribution from change in heads**

5.4.3 Evaluation of statistical sampling for each pilot point

After rejecting realisations that did not meet the history-matching acceptance criterion, statistics of posterior Kh, Kv, Ss and Sy were collated. Figure 5.6 to Figure 5.12 present boxplots of the posterior parameter distributions. Boxplots of prior probability distributions are presented in Appendix B:

- Figure 5.6: presents the Kh for the alluvium (pilot point 45) and the weathered bedrock (pilot points 1-44) within model layer 1. This hydraulic conductivity will influence drawdown/mounding propagation towards key environmental receptors.
- Figure 5.7: presents the specific yield for model layer 1. As this unit is unconfined, this storage property will influence drawdown/mounding propagation towards key environmental receptors.
- Figure 5.8: presents the Kh for the fractured rock and will be the main aquifer interacting with the project infrastructure (access portals and water ways) and will be a significant influence on drawdown and mounding propagation.
- Figure 5.9: presents the Kv for the fractured rock and will influence recharge into this unit from layer 1 and propagation of drawdown and mounding to deeper tight bedrock.
- Figure 5.10: presents the specific yield for the unconfined fractured rock which will influence drawdown and mounding propagation towards environmental receptors.
- Figure 5.11: presents the Kh for the tight bedrock, which will have limited influence on drawdown and mounding at environmental receptors.
- Figure 5.12 presents the specific storage for the confined tight bedrock.

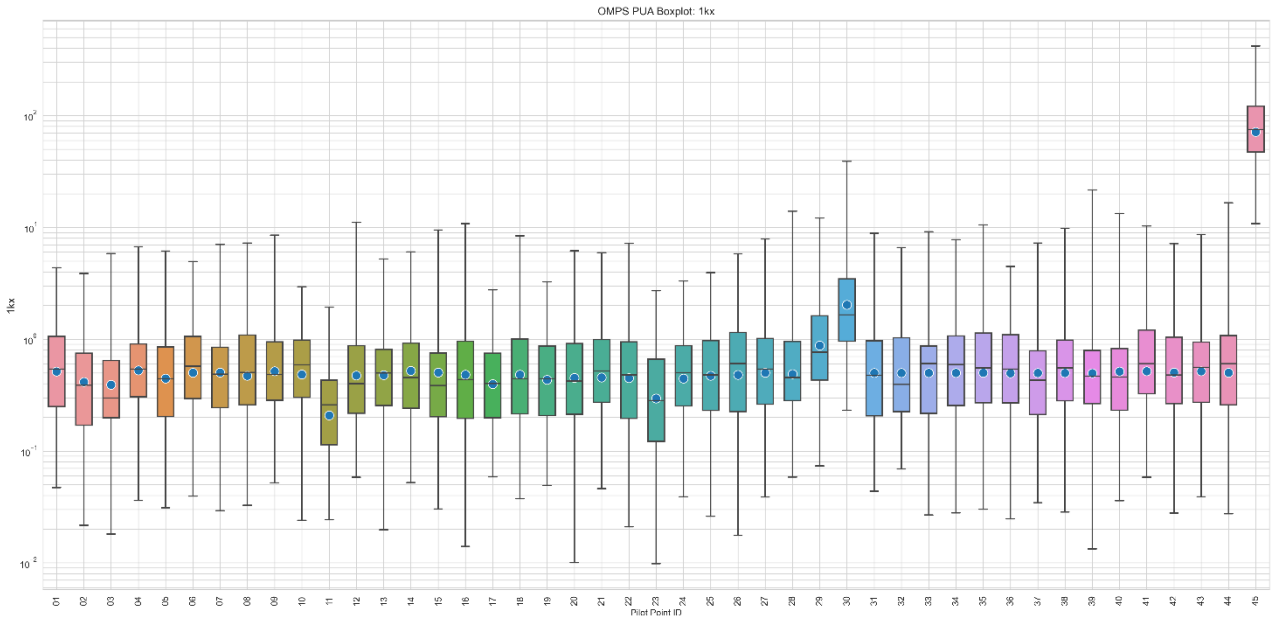


Figure 5.6 **Kh boxplots for each pilot point in model layer one (alluvium is pilot 45 and weathered bedrock is 1-44). The boxplots present the distribution across the 200 realisations and the symbols reflect the base case value for that pilot point**

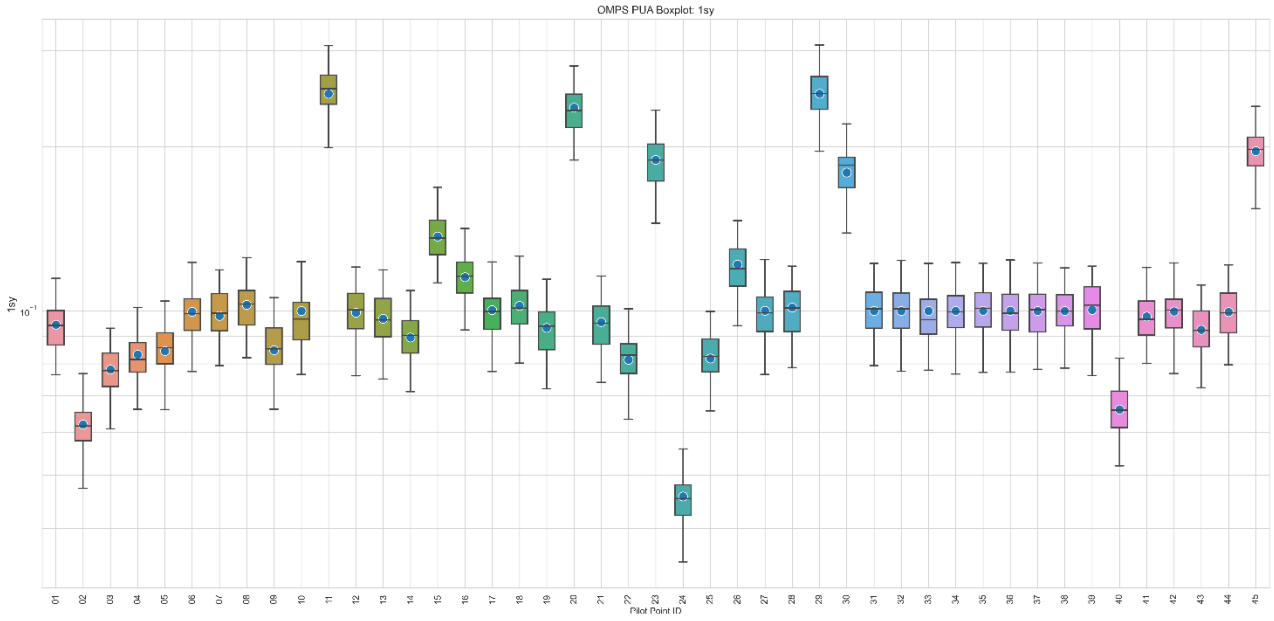


Figure 5.7 Sy boxplots for each pilot point in model layer one (alluvium is pilot 45 and weathered bedrock is 1-44).

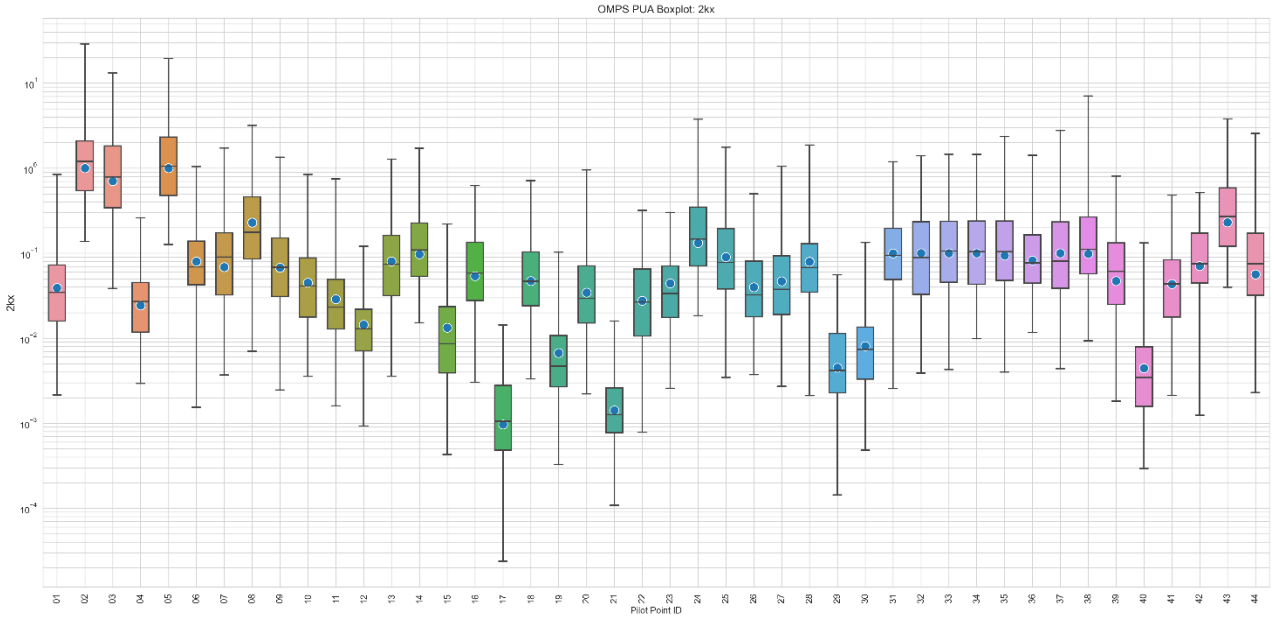


Figure 5.8 Kh boxplots for each pilot point in fractured bedrock unit

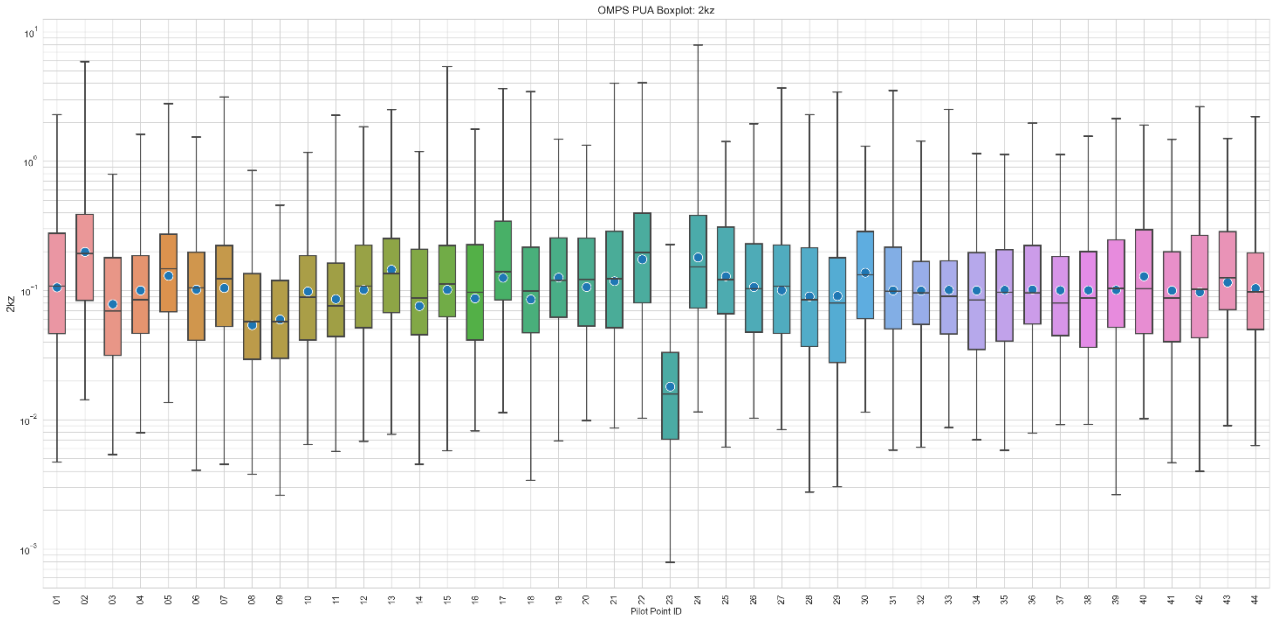


Figure 5.9 **Kv boxplots for each pilot point in fractured bedrock unit**

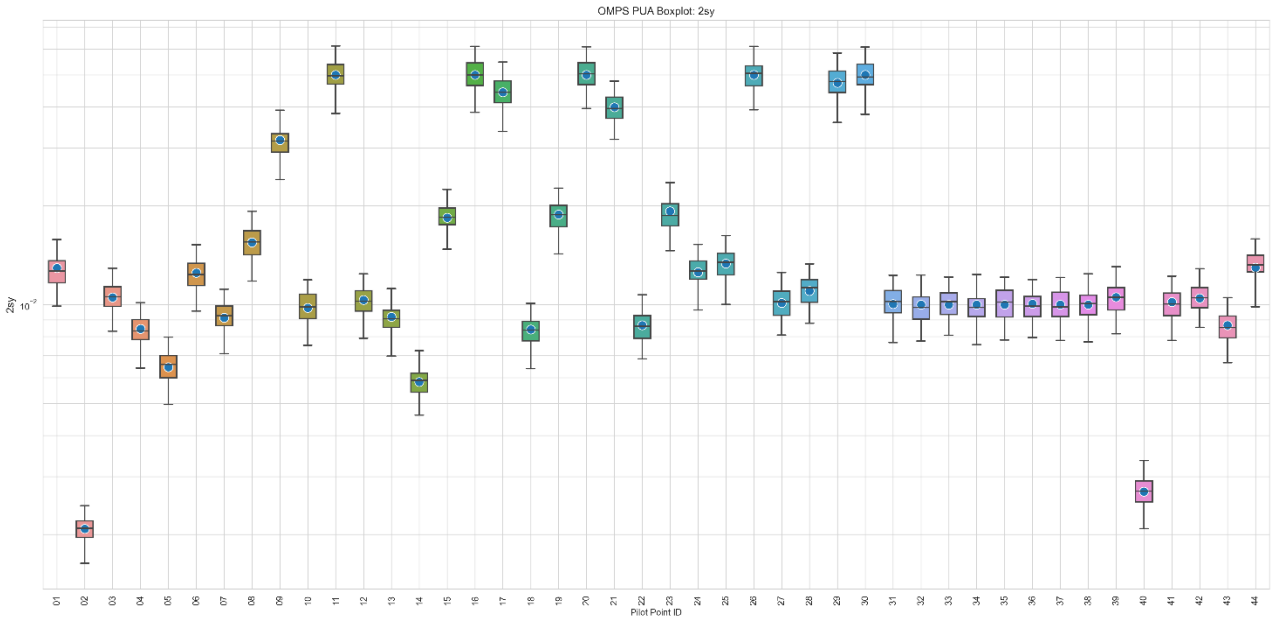


Figure 5.10 **Sy boxplots for each pilot point in fractured bedrock unit**

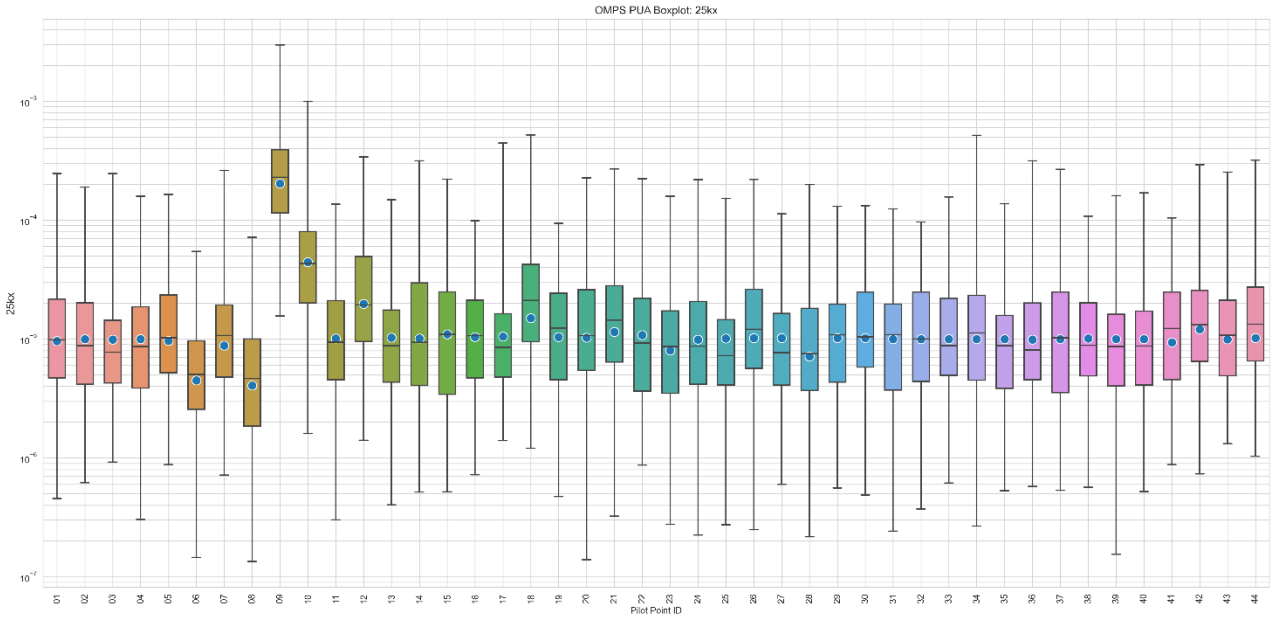


Figure 5.11 Kh boxplots for each pilot point in tight bedrock unit

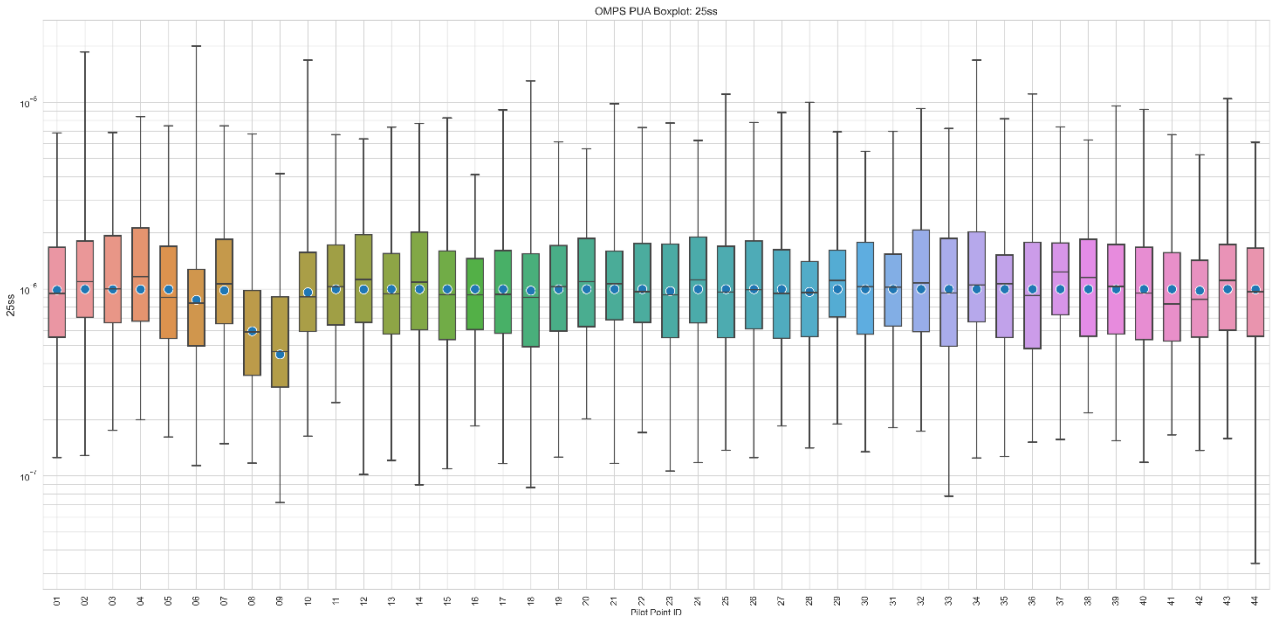


Figure 5.12 Ss boxplots for each pilot point in tight bedrock unit

5.4.4 Sensitivity to recharge

Recharge was not varied from the base case in the composite Monte Carlo uncertainty analysis above. Several different considerations went into this decision:

- The base case model recharge is parameterised by only three zones, not distributed continuously across the 44 pilot points in a layer;
- history-matching performance is much more sensitive to changes in recharge than hydraulic properties at individual pilot points, and it was considered that including recharge variation in the predictive uncertainty analysis would likely have led to a high proportion of realisations being rejected; and

- the base case adopted high recharge rates relative to the initial conceptual values : 14%, 18% and 36% (Table 4.6) versus 1%, 5% and 25% (section 3.6.2) of annual rainfall in the Escarpment, Plateau and Alluvium zones respectively. This is expected to result in conservative predictions of water take.

Subsequent to the Monte Carlo analysis, a limited recharge sensitivity was run: one run with all recharge increased 10% and one with all recharge reduced by 10%. All other parameters were kept the same as the base case.

The phi ratios for these two runs relative to the base case were 1.052 and 1.053 respectively, which are within the acceptance criteria. Effects on the project water balance are presented in Section 5.5.4

5.5 Results

This section of the report presents the stochastic modelling results for:

- site-wide drawdown and mounding;
- site-specific drawdown/mounding at environmental receptors;
- site-specific drawdown/mounding at the third-party groundwater user; and
- water balances for construction and operation (separate to the base case water balance presented in Section 5.3).

In this results section the base case deterministic simulation is not differentiated from the suite of 109 accepted stochastic realisations. The base case is considered one of the plausible realisations within that suite and presented as one cohesive set of models to understand the predictive uncertainty for the key model outputs described in the dot points immediately above.

5.5.1 Site-wide drawdown/mounding

The drawdown and mounding predicted for the watertable during construction and operation are presented in Figure 5.13 to Figure 5.18. The main environmental receptors with potential to be affected by drawdown and mounding are the GDEs, both throughout the plateau and across the escarpment and Macleay River floodplain. Those GDEs will be accessing water from the shallow watertable and sitewide impacts to that watertable are of key importance and are therefore the focus of these maps. Individual site-based temporal drawdown hydrographs are presented later in Sections 5.5.2 and 5.5.3.

Each of the drawdown and mounding maps present the likelihood of exceeding a threshold (2 m or 0.2 m) considering all of the accepted model realisations including the base case (110 simulations). At each model cell, the drawdown/mounding was ranked in terms of magnitude and then the P10, P33, P66, and P90 values were calculated. Each percentile value was then interpolated using an inverse distance weighted algorithm to produce a percentile-based surface (eg one surface for each percentile threshold). A 2 m contour and a 0.2 m contour were then generated from each percentile surface to allow each of the maps to be amalgamated. This approach is realisation independent and presents a conservative model cell-based approach to determine the maximum extents for drawdown and mounding at each likelihood threshold.

The rationale for the percentile approach to presenting predicted drawdown and mounding is based on Table 2 of Middlemis and Peeters (2018). Those uncertainty guidelines describe the importance of calibrated language and having a consistent and precise language to communicate impacts to decision makers. Table 5.5 provides a summary of the combined numeric, narrative and visual approach to describe likelihood of drawdown and mounding exceeding the 2 m or the 0.2 m thresholds, as a result of the Project. This table will provide the clarity on how to consider the likelihood bands presented on Figure 5.13 to Figure 5.18. Note, on these figures the <P10 band is not shown.

Table 5.5 Combined numeric, narrative, and visual approach for assessing the likelihood of drawdown and mounding resulting from the Project

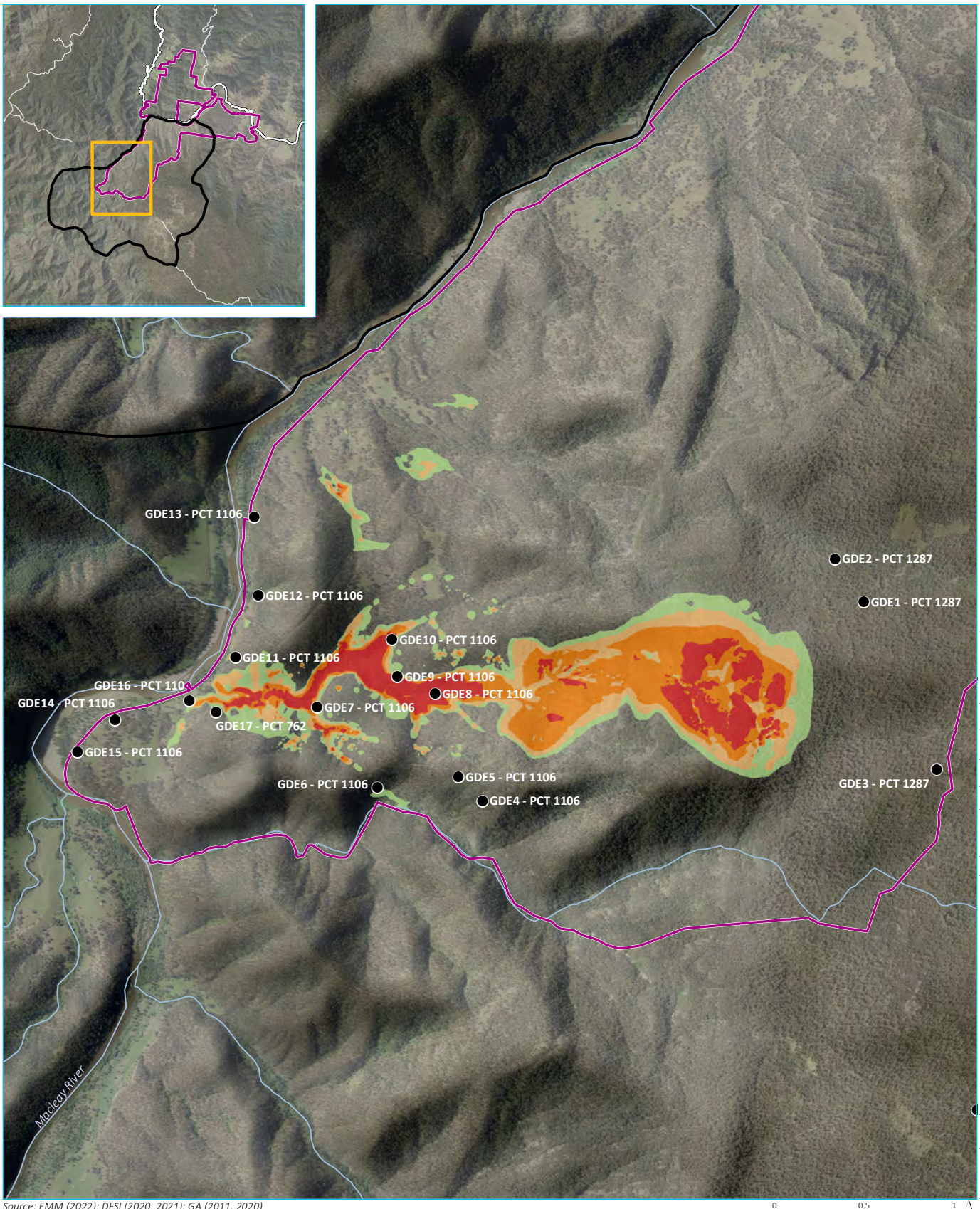
Percentile band (outcomes ranked from small to large)	Colour Code	Description of likelihood
<P10		It is **very unlikely** that the drawdown/mounding **exceeds** the threshold
P10 to P33		It is **unlikely** the drawdown/mounding **exceeds** the threshold
P33 to P67		It is **as likely as not** the drawdown/mounding **exceeds** the threshold
P67 to P90		It is **likely** the drawdown/mounding **exceeds** the threshold
>P90		It is **very likely** the drawdown/mounding **exceeds** the threshold

The following observations are made with respect to the collective drawdown and mounding maps during construction and operation of the Project:

- The drawdown extents at the 2 m threshold are greatest during construction when the upper and lower reservoirs are excavated and passively dewatered. At the same time the waterways and MAT and the power generation infrastructure are also excavated and passively dewatered. There is far less drawdown during operation of the scheme when the reservoirs are filled with water to design levels and the waterways are pressurised to facilitate water flow between the reservoirs and through the power generator. Drawdown during operation is restricted largely to the escarpment area up-gradient of the lower reservoir as a result of continued dewatering of the fractured bedrock associated with inflows to the (non-water filled) MAT and ECVT. The construction drawdown at the 2 m threshold is mainly centred around the upper and lower reservoir footprints and along the access portal and waterways. There is elongated west-east drawdown that largely connects the impact area to between the two reservoirs. Of note, the watertable drawdown propagates radially outward from the upper reservoir across the flat-lying plateau. In contrast, the much steeper terrain and incised topography associated with the escarpment leads to elongated drawdown along the west-east direction of groundwater flow and ridgelines.

- The drawdown extents at the 0.2 m threshold cover a slightly broader area, with most drawdown concentrated to within 200 m of the Project components. There are two new drawdown areas to the south and up to 1 km north of the lower reservoir. These drawdown areas occur along the river valleys and are associated with linear drawdown along the thin alluvium in those valleys that is then spatially connected to both the upper and lower reservoir areas and the various tunnels and portals. In reality, these discrete and highly localised alluvial stringers are most likely to be hydraulically disconnected from the deeper watertable within the weathered and fractured bedrock.

- Mounding during operation is largely restricted to areas down-gradient of the two reservoirs. This mounding occurs once the reservoirs are filled with water at an elevation that exceeds the pre-development groundwater levels. Similar to the drawdown, the mounding pattern is more radially outward from the upper reservoir due to the flatter plateau hydraulic gradients and more linear along the steep escarpment river valleys down-gradient of the lower reservoir.



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 0.5 1 km

GDA 1994 MGA Zone 56

N

KEY

- Project area
- GDEs
- Model domain

Existing environment

- Named watercourse

Modelled drawdown

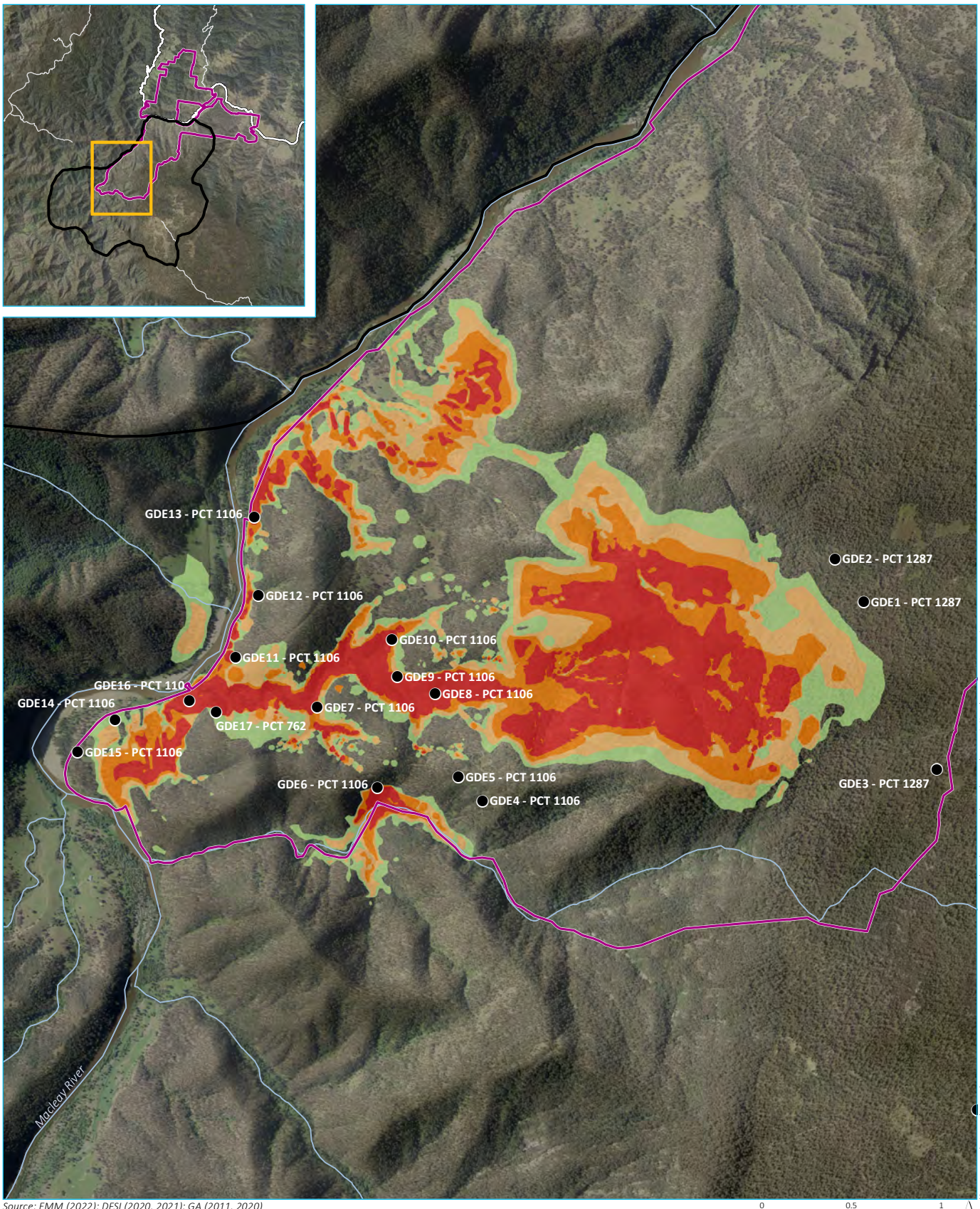
- Unlikely
- As likely as not
- Likely
- Very likely

Likelihood of watertable drawdown exceeding 2 m at the end of construction

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd
Figure 5.13

EMM creating opportunities

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW029_DrawdownEx2mConstruction_20221102_01.mxd 14/12/2022



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 0.5 1 km

GDA 1994 MGA Zone 56

N

KEY

- Project area
- GDEs
- Model domain

Existing environment

- Named watercourse

Modelled drawdown

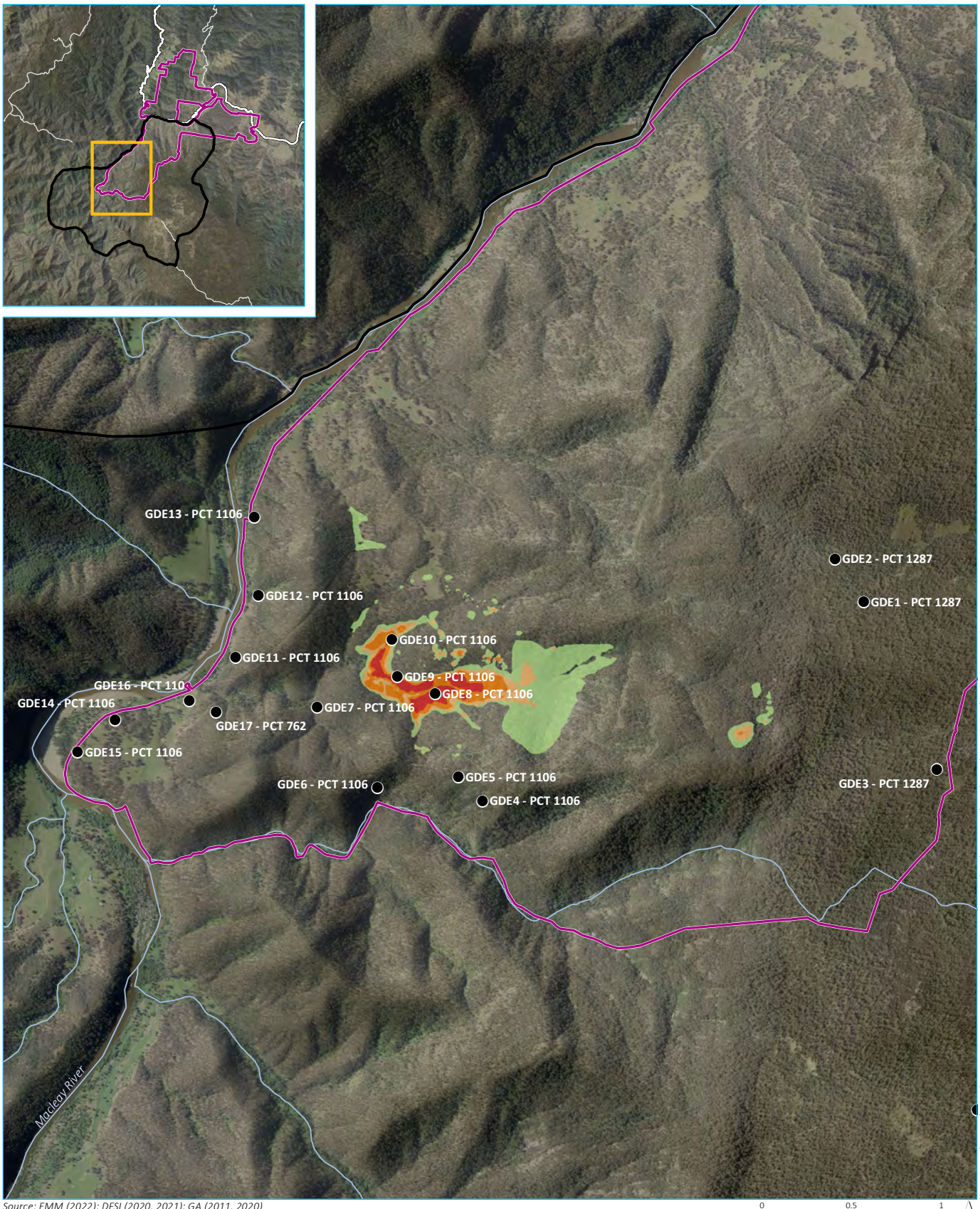
- Unlikely
- As likely as not
- Likely
- Very likely

Likelihood of watertable drawdown exceeding 0.2 m at the end of construction

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Groundwater modelling report
OMPS Pty Ltd
Figure 5.14

EMM creating opportunities

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW030_DrawdownExOp2mConstruction_20221103_01.mxd 14/12/2022



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 0.5 1 km

GDA 1994 MGA Zone 56

N

KEY

- Project area
- GDEs
- Model domain

Existing environment

- Named watercourse

Modelled drawdown

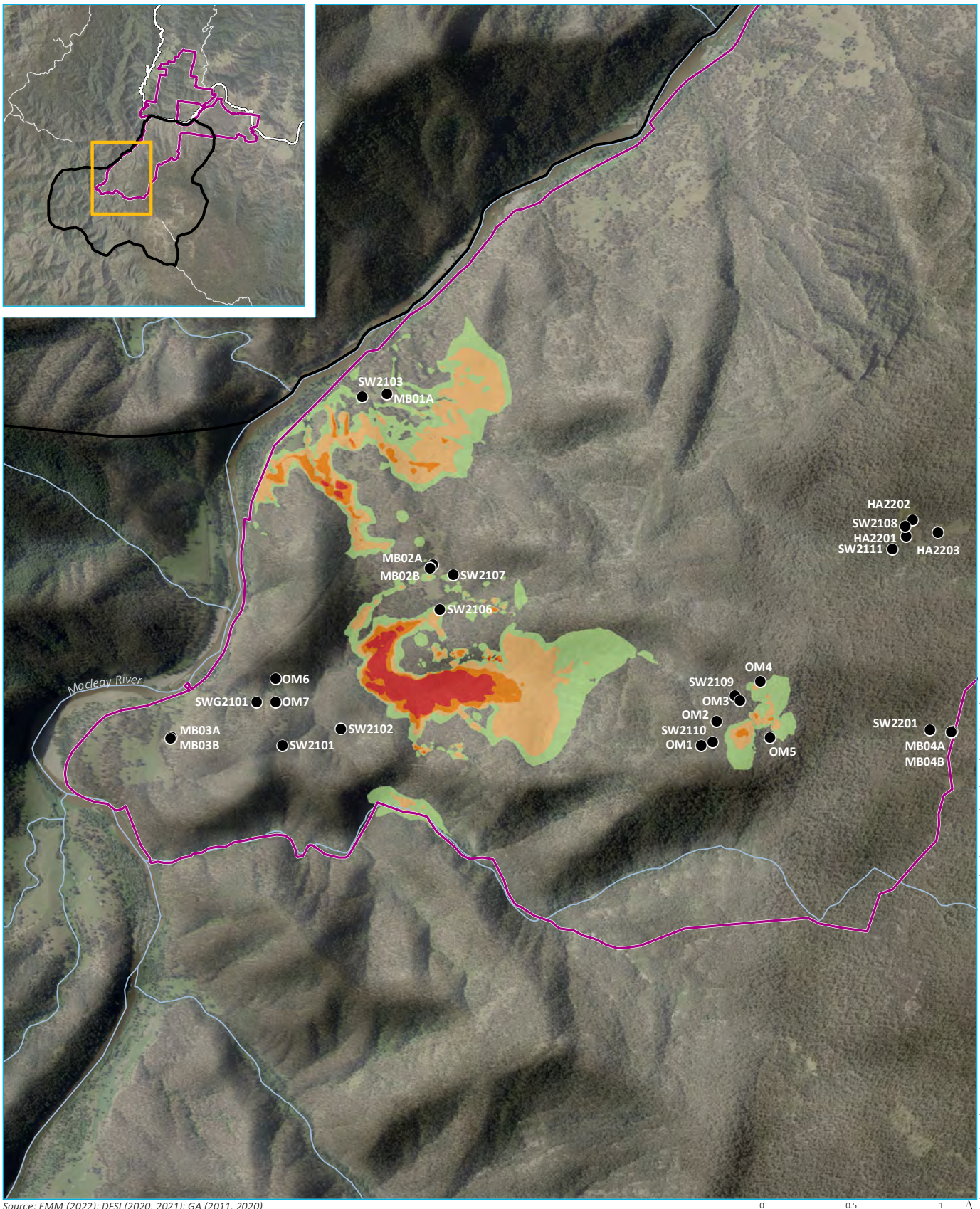
- Unlikely
- As likely as not
- Likely
- Very likely

Likelihood of watertable drawdown exceeding 2 m for steady state operation

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd
Figure 5.15

EMM creating opportunities

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW031_DrawdownEx2mOperation_20221103_01.mxd 14/12/2022



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 0.5 1 km

GDA 1994 MGA Zone 56

N

KEY

Project area

Model domain

Extraction bore

Existing environment

Named watercourse

Modelled drawdown

Unlikely

As likely as not

Likely

Very likely

Likelihood of watertable drawdown exceeding 0.2 m for steady state operation

Oven Mountain Pumped Hydro Energy Storage Project

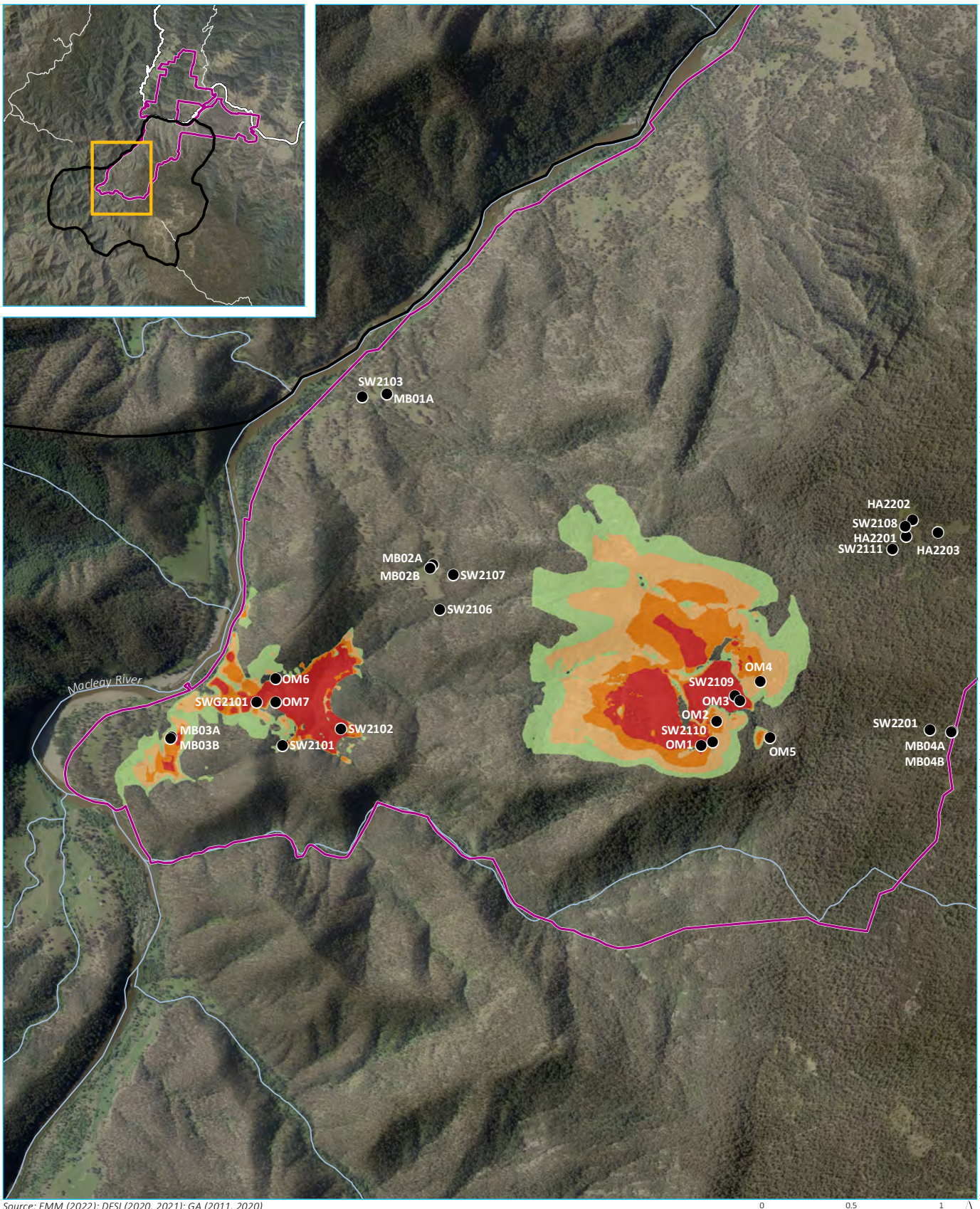
Groundwater modelling report

OMPS Pty Ltd

Figure 5.16

EMM creating opportunities

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW032_DrawdownExOp2mOperation_20221103_01.mxd 14/12/2022



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 0.5 1 km

GDA 1994 MGA Zone 56

N

KEY

- Project area
- Model domain
- Extraction bore

Existing environment

- Named watercourse

Modelled drawdown

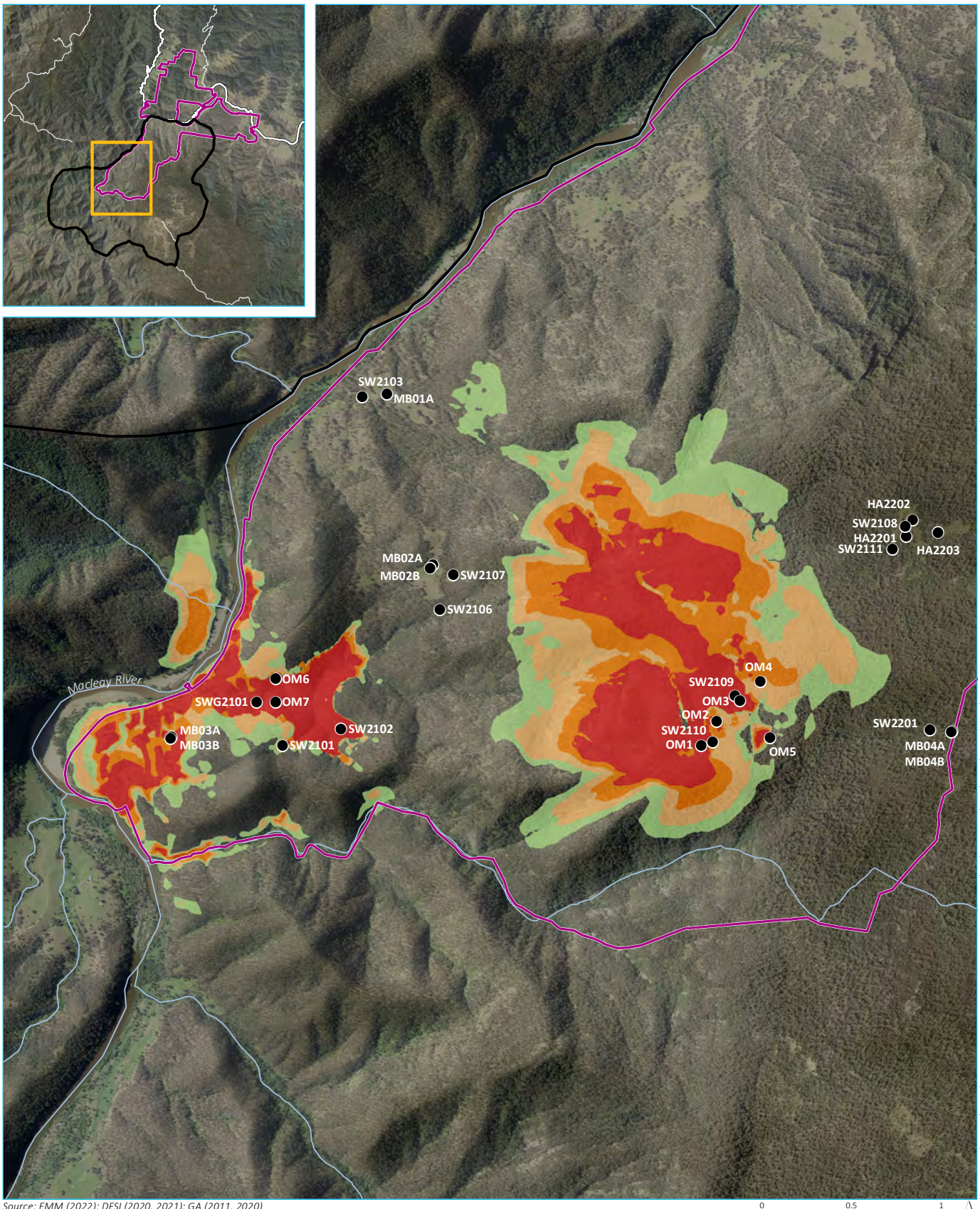
- Unlikely
- As likely as not
- Likely
- Very likely

Likelihood of watertable mounding exceeding 2 m for steady state operation

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd
Figure 5.17

EMM creating opportunities

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW033_MoundingEx2mOperation_20221103_01.mxd 14/12/2022



Source: EMM (2022); DFSI (2020, 2021); GA (2011, 2020)

0 0.5 1 km

GDA 1994 MGA Zone 56

N

\\emmsvr1\emm3\2021\J210465 - OMPS EIS - Generation Component\GIS\02_Maps_EIS_GW_Modelling\GW034_MoundingExOp2mOperation_20221103_01.mxd 14/12/2022

KEY

- Project area
- Model domain
- Extraction bore

Existing environment

- Named watercourse

Modelled drawdown

- Unlikely
- As likely as not
- Likely
- Very likely

Likelihood of watertable mounding exceeding 0.2 m for steady state operation

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
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Figure 5.18

EMM creating opportunities

5.5.2 Drawdown/mounding at environmental receptors

The complete set of site-specific drawdown and mounding predictions at designated environmental receptor locations for construction and operation is presented in Appendix C. Two select sites are presented in Figure 5.19: one (GDE1 at PCT1287) showing negligible impact, and one (SWG2101) showing large changes in drawdown (construction) and mounding (operation). Generally, across the 34 environmental receptors the following predictions are noted:

- there is negligible (< 0.1 m total drawdown/mounding) change in groundwater levels at 22 of 34 sites (SP01, SP02, SW2101, SW2107, SW2108, SW2111, GDE1/GDE2/GDE3 PCT1287, GDEs 4, 5, 6, 8, 11, 12 and 13-16 PCT1106, Carrai Waterholes, GDE18 PCT1287);
- there is up to 5 m of drawdown/mounding at six sites (SW2103, SW2106, GDE9, GDE13 and GDE16 PCT 1106, GDE17 PCT 762); and
- there is greater than 5 m of drawdown/mounding at six sites (SW2101, SW2109, SW2110, SWG2101, GDE7 and GDE10 PCT1106).

The context of these changes in groundwater levels in terms of impact is described further in the main body of the GIA report.

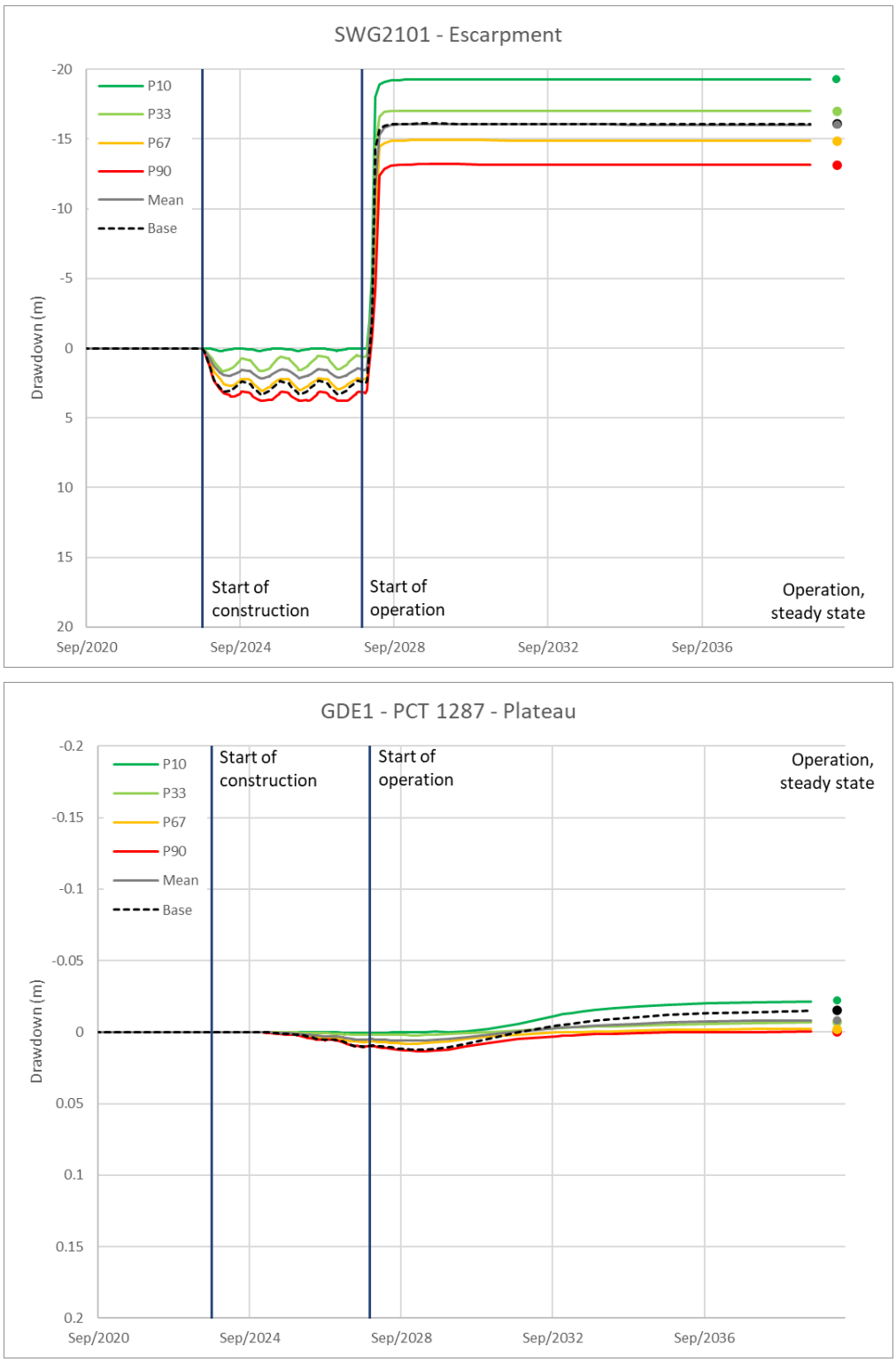


Figure 5.19 **Drawdown at select environmental receptors: a) surface water site SWG2101 on the escarpment; and b) GDE site PCT 1287 on the plateau**

5.5.3 Drawdown at third party bore

There is one landholder bore within the potential area of influence of the Project, being the East Kunderang Homestead bore (GW307320), located 1 km south-west of the lower reservoir. The bore is licenced for stock and domestic use. The bore is 60 m deep and screened in fractured shale of the Parabel Beds. As shown on Figure 5.20, there is negligible change (< 0.1 m total drawdown/mounding) in groundwater levels predicted at this bore throughout the construction and operation periods.

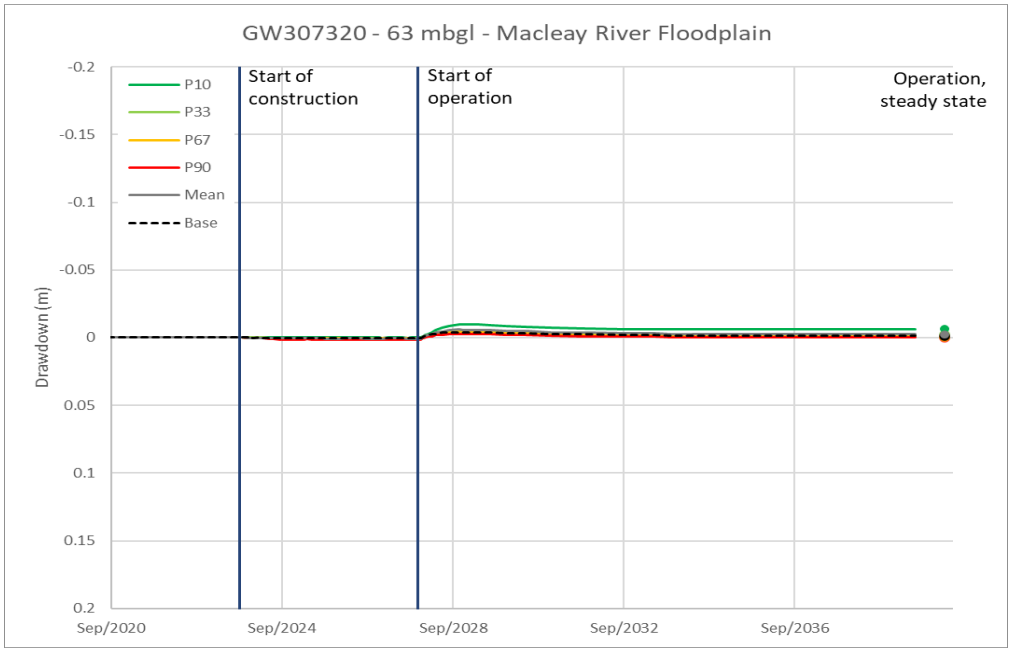


Figure 5.20 Drawdown at third party bore GW307320

5.5.4 Project and environmental water balance

Full project water balances are presented for pre-construction, the end of construction and operation in Table 5.6 to Table 5.8. Results for the other four construction years are documented in Appendix D. The tables present results from the stochastic suite of 109 realisations and show the probabilistic distribution of each component of the water balance, with the base case also separately documented.

The construction timeline is not aligned with water year output times: the water year 2023 balance contains 9 months of construction and 3 months of the transient bridging period prior to construction and the water year 2027 balance contains the final 6 months of construction and half a year of operation.

The following observations are made with respect to the water balance predictions:

- the base case generally sits towards the centre of the probabilistic water balance and the results discussed in Section 5.3 can be extended to the stochastic predictions;
- it is very unlikely that the groundwater take due to construction will be more than 489 ML in any water year, and it its very unlikely that the take during operation will be more than 377 ML/yr;
- under pre-construction steady-state conditions the water balance reflects the conceptual model with most water entering the model as rainfall recharge and most water exiting the model as evapotranspiration and baseflow discharge to the Macleay River and other rivers and creeks;

- during construction the project components that receive the most groundwater are the excavated reservoirs and the access tunnels. This water comes directly out of aquifer storage while maintaining a similar rate of recharge and baseflow discharge. This has led to drawdown of the aquifer system (See Section 5.5.1); and
- during steady state operation the reservoirs are filled with water, which provides a net inflow to the aquifer and translates to localised mounding down-gradient of the reservoirs (See Section 5.5.1). This localised mounding translates to enhanced hydraulic gradients towards the Macleay River and other creeks and causes enhanced aquifer to river discharge in the order of 400 ML/yr.

Table 5.6 Pre-construction steady state water balance (ML/yr)

Component	Flow direction	P10	P33	P67	P90	Base case
Entire model domain						
Recharge	In	20,004	20,004	20,004	20,004	20,004
ET	Out	7,307	8,092	8,698	9,267	8,286
Storage in	In	-	-	-	-	-
Storage out	Out	-	-	-	-	-
Macleay gorges SW source						
Macleay River to aquifer	In	1,631	2,813	4,717	6,303	3,474
Aquifer to Macleay River	Out	3,592	4,148	4,793	5,940	4,352
All other streams to aquifer	In	-	-	-	-	-
Aquifer to all other streams	Out	5,592	6,454	7,493	8,501	6,932
Macleay valley SW source						
Macleay River to aquifer	In	525	851	1,216	1,635	1,008
Aquifer to Macleay River	Out	1,221	1,616	1,989	2,340	1,644
All other streams to aquifer	In	-	-	-	-	-
Aquifer to all other streams	Out	2,788	3,030	3,355	3,808	3,300

Table 5.7 Construction water balance for water year 2027 (ML)

Component	Flow direction	P10	P33	P67	P90	Base case
Entire model domain						
Recharge	In	17,321	17,321	17,321	17,321	17,321
ET	Out	7,381	8,153	8,787	9,344	8,358
Storage in	In	2,939	3,057	3,144	3,203	3,113
Storage out	Out	724	753	788	813	769
Macleay gorges SW source						
Macleay river to aquifer	In	1,600	2,757	4,616	6,152	3,402
Aquifer to Macleay River	Out	3,257	3,806	4,464	5,641	4,012
All other streams to aquifer	In	-	-	-	-	-
Aquifer to all other streams	Out	5,227	6,079	7,003	7,937	6,506
Macleay valley SW source						
Macleay river to aquifer	In	495	805	1,153	1,562	956
Aquifer to Macleay River	Out	1,176	1,569	1,948	2,281	1,598
All other streams to aquifer	In	-	-	-	-	-
Aquifer to all other streams	Out	2,648	2,888	3,209	3,615	3,155
Project components						
Overall sum	Out	200.2	243.5	298.4	359.2	294.4
Lower reservoir	Out	64.7	78.4	98.1	119.4	95.5
Upper reservoir	Out	28.7	36.0	46.3	57.0	41.4
Tailrace construction adit	Out	5.2	8.2	11.2	15.2	10.3
MAT	Out	74.8	87.1	98.9	111.9	105.1
Tailrace	Out	14.0	17.0	21.2	26.7	20.8
Lower intake	Out	-	-	0.0	0.2	-
Surge shaft construction adit	Out	0.1	0.1	0.2	0.2	0.2
Gate shaft	Out	0.0	0.1	0.1	0.1	0.1
Tailrace vent shaft	Out	0.5	0.6	0.7	0.8	0.6
ECVT	Out	10.4	13.9	19.2	24.4	18.2
Transformer cabin top	Out	0.0	0.1	0.1	0.1	0.1
Transformer cabin bottom	Out	0.1	0.1	0.1	0.1	0.1
Power station top	Out	0.1	0.1	0.1	0.1	0.1
Power station middle	Out	0.1	0.2	0.2	0.3	0.2

Table 5.7 Construction water balance for water year 2027 (ML)

Component	Flow direction	P10	P33	P67	P90	Base case
Power station bottom	Out	0.0	0.1	0.1	0.2	0.1
IPB tunnels	Out	0.0	0.0	0.0	0.0	0.0
Draft tube	Out	-	-	-	-	-
Power station construction adit	Out	0.1	0.1	0.1	0.1	0.1
Penstock	Out	-	-	-	-	-
Penstock construction adit	Out	0.1	0.2	0.2	0.2	0.2
Surge shaft	Out	0.4	0.5	0.5	0.6	0.4
Headrace	Out	-	-	-	-	-
Egress tunnel	Out	0.1	0.1	0.1	0.2	0.1
Headrace construction adit	Out	0.2	0.2	0.3	0.4	0.3
Upper intake	Out	0.0	0.0	0.1	0.1	0.1
Pressure shaft	Out	0.5	0.6	0.7	0.8	0.5

Table 5.8 Steady-state operation water balance (ML/yr)

Component	Flow direction	P10	P33	P67	P90	Base case
Entire model domain						
Recharge	In	19,938	19,938	19,938	19,938	19,938
ET	Out	7,317	8,101	8,708	9,286	8,297
Storage in	In	-	-	-	-	-
Storage out	Out	-	-	-	-	-
Macleay gorges SW source						
Macleay river to aquifer	In	1,605	2,759	4,646	6,237	3,437
Aquifer to Macleay River	Out	3,776	4,342	5,103	6,273	4,566
All other streams to aquifer	In	-	-	-	-	-
Aquifer to all other streams	Out	5,833	6,730	7,564	8,556	7,085
Macleay valley SW source						
Macleay river to aquifer	In	525	851	1,216	1,635	1,008
Aquifer to Macleay River	Out	1,221	1,616	1,989	2,340	1,644
All other streams to aquifer	In	-	-	-	-	-

Table 5.8 Steady-state operation water balance (ML/yr)

Component	Flow direction	P10	P33	P67	P90	Base case
Aquifer to all other streams	Out	2,788	3,030	3,355	3,808	3,300
Project components						
Overall sum	Out	233.6	271.7	319.1	377.0	319.9
Lower reservoir	Out	91.8	102.9	118.7	139.8	117.9
Upper reservoir	Out	35.0	39.3	48.6	57.6	44.7
Tailrace construction adit	Out	-	-	-	-	-
MAT	Out	82.1	97.6	110.4	127.4	116.3
Tailrace	Out	12.7	15.6	19.2	23.2	19.8
Lower intake	Out	-	-	-	-	-
Surge shaft construction adit	Out	-	-	-	-	-
Gate shaft	Out	-	-	-	-	-
Tailrace vent shaft	Out	0.4	0.4	0.5	0.6	0.5
ECVT	Out	11.0	15.0	20.5	26.9	19.8
Transformer cabin top	Out	0.0	0.0	0.1	0.1	0.1
Transformer cabin bottom	Out	0.1	0.1	0.1	0.1	0.1
Power station top	Out	0.1	0.1	0.1	0.1	0.1
Power station middle	Out	0.1	0.1	0.2	0.3	0.2
Power station bottom	Out	0.0	0.1	0.1	0.2	0.1
IPB tunnels	Out	0.0	0.0	0.0	0.0	0.0
Draft tube	Out	-	-	-	-	-
Power station construction adit	Out	-	-	-	-	-
Penstock	Out	-	-	-	-	-
Penstock construction adit	Out	-	-	-	-	-
Surge shaft	Out	0.3	0.4	0.4	0.5	0.4
Headrace	Out	-	-	-	-	-
Egress tunnel	Out	0.1	0.1	0.1	0.1	0.1
Headrace construction adit	Out	-	-	-	-	-
Upper intake	Out	-	-	-	-	-
Pressure shaft	Out	-	-	-	-	-

Table 5.8 Steady-state operation water balance (ML/yr)

Component	Flow direction	P10	P33	P67	P90	Base case
Outflow from project components						
Lower reservoir	In	278.7	317.0	372.1	424.0	320.9
Upper reservoir	In	10.8	22.0	33.7	51.7	28.9
Tailrace	In	0.0	0.1	0.2	0.5	0.0
Pressure shaft	In	0.2	0.3	0.4	0.4	0.2

i Recharge sensitivity

Water balance sensitivity to recharge during operation, as described in Section 5.4.3, is presented in Table 5.9. Results demonstrate that inflow to project components and evapotranspiration vary almost proportionally with changes in recharge. Varying recharge induces small changes in surface water interactions with groundwater. Outflow from project components is essentially unimpacted.

Table 5.9 Water balance sensitivity to recharge

	Base case	10% recharge increase	10% recharge decrease
Recharge (ML/yr)	19,938	21,932	17,944
Evapotranspiration (ML/yr)	8,297	9,126 (110.0% of base case)	7,471 (90.0% of base case)
Leakage from Macleay River (ML/yr)	4,445	4,346 (97.8% of base case)	4,552 (102.4% of base case)
Baseflow to rivers & creeks (ML/yr)	16,595	17,636 (106.3% of base case)	15,559 (93.8% of base case)
Inflow to project components (ML/yr)	319.9	351.5 (109.1% of base case)	291.0 (90.7% of base case)
Outflow from project components (ML/yr)	350.0	346.3 (99.0% of base case)	353.9 (101.1% of base case)

5.6 Independent peer review

The AIP requires that models submitted in support of major projects meet the following criteria:

- undergo independent review;
- be consistent with the *Australian Groundwater Modelling Guidelines* (Barnett et al. 2012); and
- be fit for purpose to the satisfaction of the Minister for Planning.

Chris Nicol of Groundwater Logic was engaged to undertake an independent review of the groundwater modelling. Chris is a Principal Hydrogeologist who has been practicing since 2002 in both the United Kingdom and Australia. He has a strong background in conceptual hydrogeological model development, data analysis and groundwater modelling. Chris' review is attached as Appendix E. Chris's review found that the modelling is fit for purpose and the modelling objectives are satisfied.

6 Summary

The Project is an off-river pumped hydro energy storage system located approximately half-way between Kempsey and Armidale adjacent to the Macleay River in northern NSW. At a basic level, the Project will consist of upper and lower water reservoirs, a pipeline connecting them, and a hydro-electric power station connected, to the NEM, that is capable of generating or consuming electricity.

The construction and operation of the Project will potentially impact on groundwater levels due to tunnelling and dam construction activities and associated works. To support the GIA, a three-dimensional numerical groundwater flow model has been developed to quantify groundwater level and flow impacts due to construction and throughout the operation phase. The model objectives included:

- predicting drawdown/mounding at nearby water users;
- predicting magnitude and duration of potential groundwater level changes at GDEs and other identified sensitive receptors;
- predicting groundwater inflow to the Project infrastructure during the construction and operation periods; and
- predicting changes to the water balance as a result of the Project to support groundwater and/or surface water licensing.

A new HCM was developed for this greenfield site. This utilised groundwater level, groundwater quality and hydraulic testing data from 18 groundwater monitoring bores constructed into various HSUs across the plateau, escarpment and Macleay River floodplain focus areas. Three groundwater flow systems were identified across the project area, including:

- local perched or shallow water-bearing zones/aquifers in weathered rock and alluvium;
- an intermediate flow system within fractured bedrock to a depth of ~100 m; and
- a deep groundwater flow system associated with competent bedrock with less intense fracturing at depth.

An EPM sitewide numerical groundwater flow model was built using the MODFLOW-USG simulation code. This model employs a Voronoi polygon mesh across an irregularly shaped domain to follow hydrogeological, hydrological and Project features. The model covers an area that spans ~14 km (south-north) by ~15 km (west-east) across 25 model layers. Model history-matching included both steady state and transient stress periods to allow matching to heads and changes in head as a result of recharge-discharge processes. The model employs a highly parameterised approach via pilot points deployed in every model layer to allow for spatially distributed fields for Kh, Kv, Ss and Sy as well as recharge zonation. The base case deterministic model was deemed to be appropriately history-matched to achieve the stated metrics in Section 4.1 and generally align attributes of a Class 2 model.

Both a null case scenario and project scenario were simulated for a suite of 109 stochastic realisations (with each stochastic realisation being highly parameterised) to allow for a range of drawdown (null scenario minus project scenario), mounding and water balance changes to be predicted. The Project case includes separate boundary condition representation for construction dewatering activities and operation activities including filling of the reservoirs and pressuring the waterways. The 109 realisations (from a pool of 200) best matching the historical groundwater monitoring data were accepted to produce a suite of stochastic predictions.

The groundwater flow model predictions include:

- The sitewide drawdown extents at the 2 m threshold are greatest during construction when the upper and lower reservoirs and tunnels and portals are excavated and passively dewatered. There is far less drawdown during operation of the scheme when the reservoirs are filled with water to design levels and the waterways are pressurised to facilitate water flow between the reservoirs and through the power generator. Drawdown during operation is restricted largely to the escarpment area up-gradient of the lower reservoir because of continued dewatering of the fractured bedrock associated with inflows to the (non-water filled) MAT and ECVT. Watertable drawdown propagates radially outward from the upper reservoir across the flat-lying plateau. In contrast, the much steeper terrain and incised topography associated with the escarpment leads to elongated drawdown along the west-east direction of groundwater flow and ridgelines.

- The sitewide drawdown extents at the 0.2 m threshold cover a slightly broader area, with most drawdown concentrated to within 200 m of the Project components and a small amount up to 1 km to the north-west. There are two new drawdown areas to the north and south of the lower reservoir. These drawdown areas occur along the river valleys and are associated with linear drawdown along the thin alluvium in those valleys that is then spatially connected to both the upper and lower reservoir areas and the various tunnels and portals.

- Mounding during operation is largely restricted to areas down-gradient of the two reservoirs. This mounding occurs once the reservoirs are filled with water at an elevation that exceeds the pre-development groundwater levels. Similar to the drawdown, the mounding pattern is more radially outward from the upper reservoir due to the flatter plateau hydraulic gradients and more linear along the steep escarpment river valleys down-gradient of the lower reservoir.

- Across the 31 environmental receptors there is negligible (< 0.1 m total drawdown/mounding) change in groundwater levels at 25 of 31 sites, there is up to 5 m of drawdown/mounding at two sites, and there is greater than 5 m of drawdown/mounding at four sites. The impacts of those groundwater level changes are considered within the GIA.

- There is negligible change (< 0.1 m total drawdown/mounding) in groundwater levels predicted at the one landholder bore within the potential area of influence of the Project, being the East Kunderang Homestead bore (GW307320).

- The base case generally sits towards the centre of the suite of 109 stochastic models with respect to water balance and drawdown.

- It is very unlikely that the groundwater take due to construction will be more than 489 ML in any water year, and it its very unlikely that the take during operation will be more than 377 ML/yr.

- Under pre-construction steady-state conditions the water balance reflects the conceptual model with most water entering the model as rainfall recharge and most water exiting the model as evapotranspiration and baseflow discharge to the Macleay River and other rivers and creeks.

- During construction the project components that receive the most groundwater are the excavated reservoirs and the access tunnels. This water comes directly out of aquifer storage while maintaining a similar rate of recharge and baseflow discharge. This has led to drawdown of the aquifer system.

- During steady state operation the reservoirs are filled with water, which provides a net inflow to the aquifer and translates to localised mounding down-gradient of the reservoirs (See Section 5.5.1). This localised mounding translates to enhanced hydraulic gradients towards the Macleay River and other creeks and causes enhanced aquifer to river discharge in the order of 400 ML/yr.

7 Model limitations

The conceptual and numerical models are supported by a dataset that is concentrated around the upper and lower reservoirs, away from these areas there is limited hydrogeological information. The record from the monitoring network is relatively short in duration with monitoring commencing at some sites as recently as early 2022.

The monitoring record available to support history matching contains only climate stresses. These are small in both magnitude and duration relative to the stresses imposed during the predictive scenarios. In order to address the limited dataset available to constrain model parameters, a probabilistic uncertainty analysis was implemented. Parameters were allowed to adopt values from within wide plausible ranges, however structural controls such as fractures and faults were not modelled explicitly.

The model is not intended to simulate unsaturated zone or geotechnical processes, nor is it designed to simulate solute transport.

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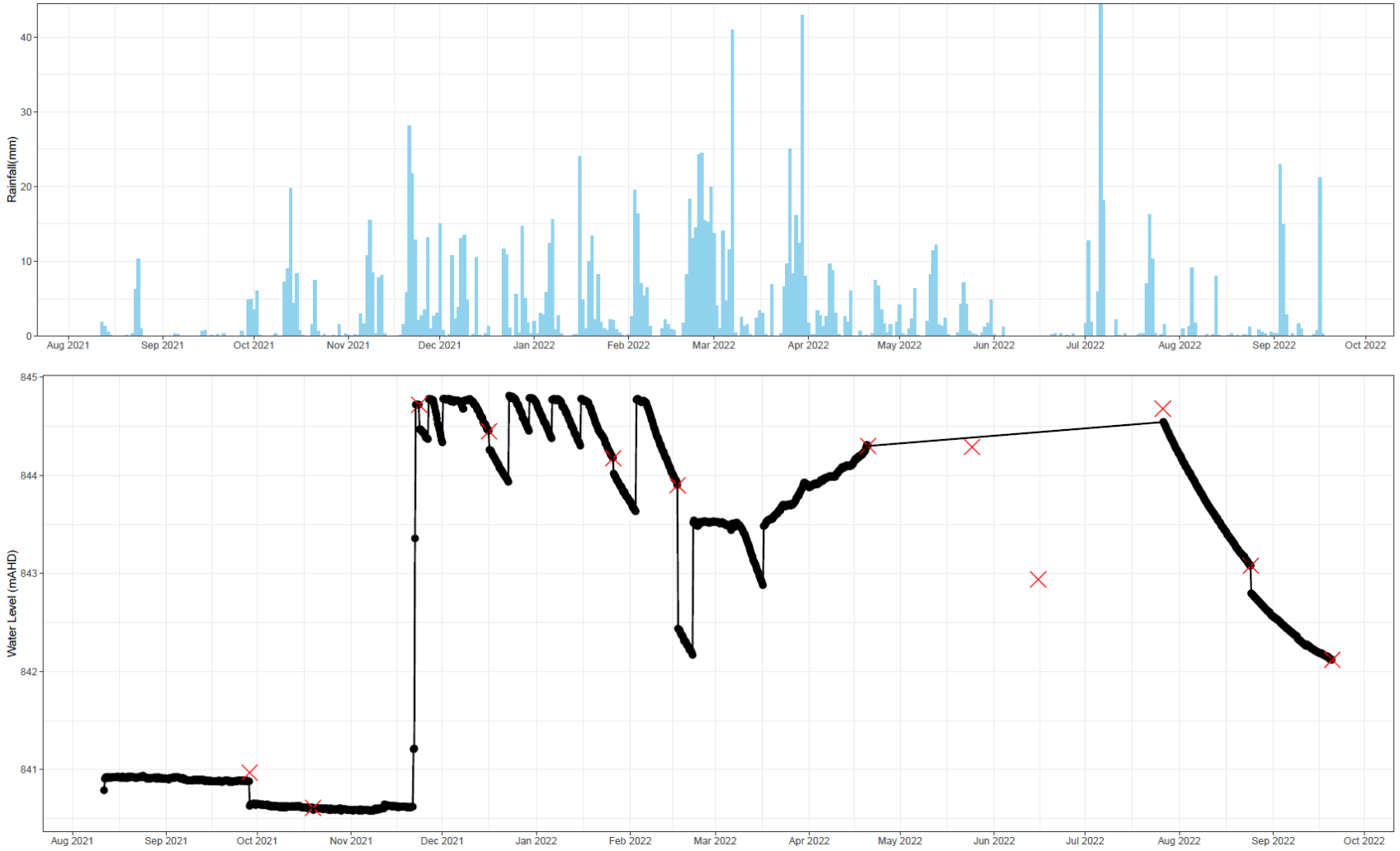
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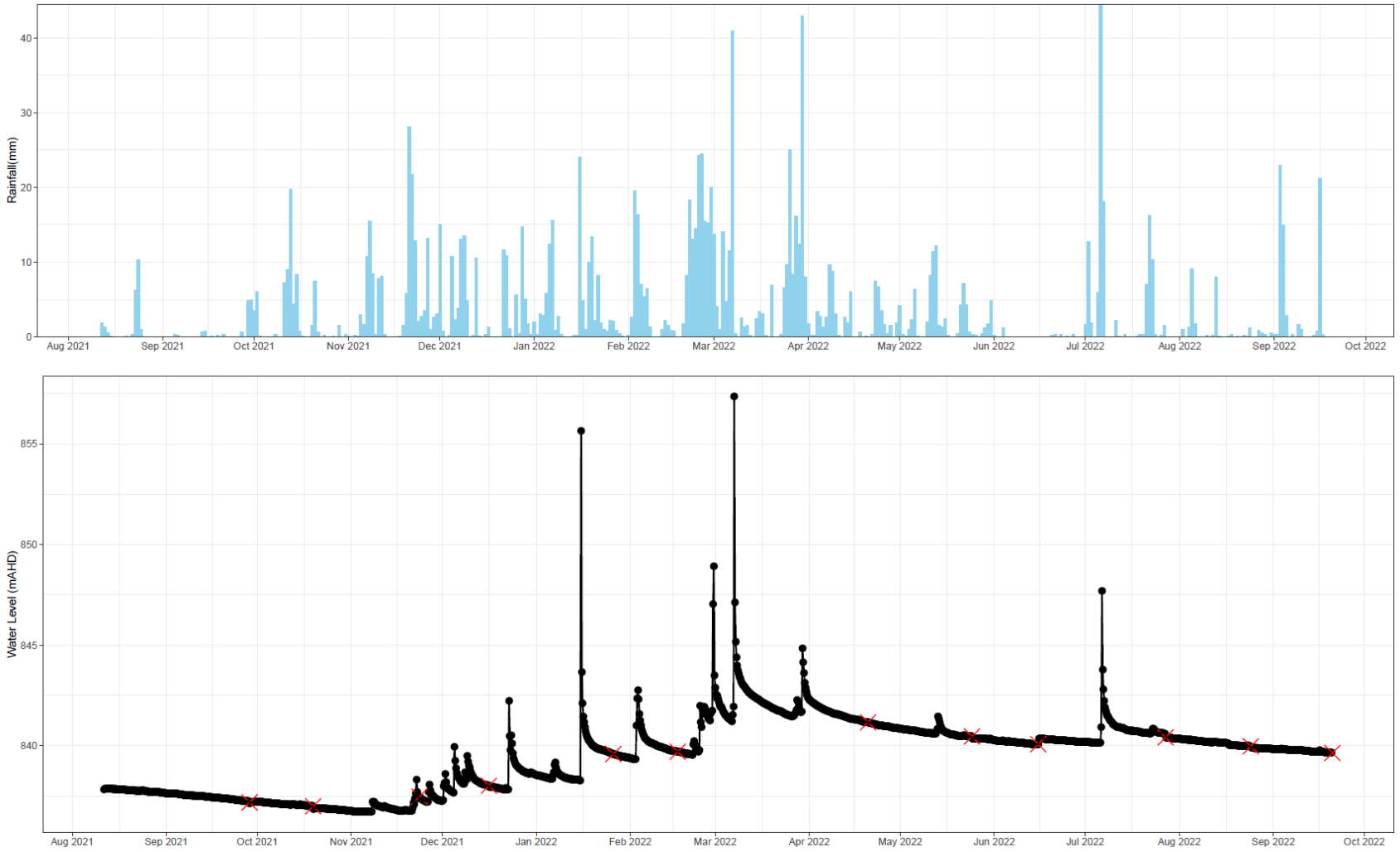
Appendix A
Groundwater hydrographs

EMM
creating opportunities



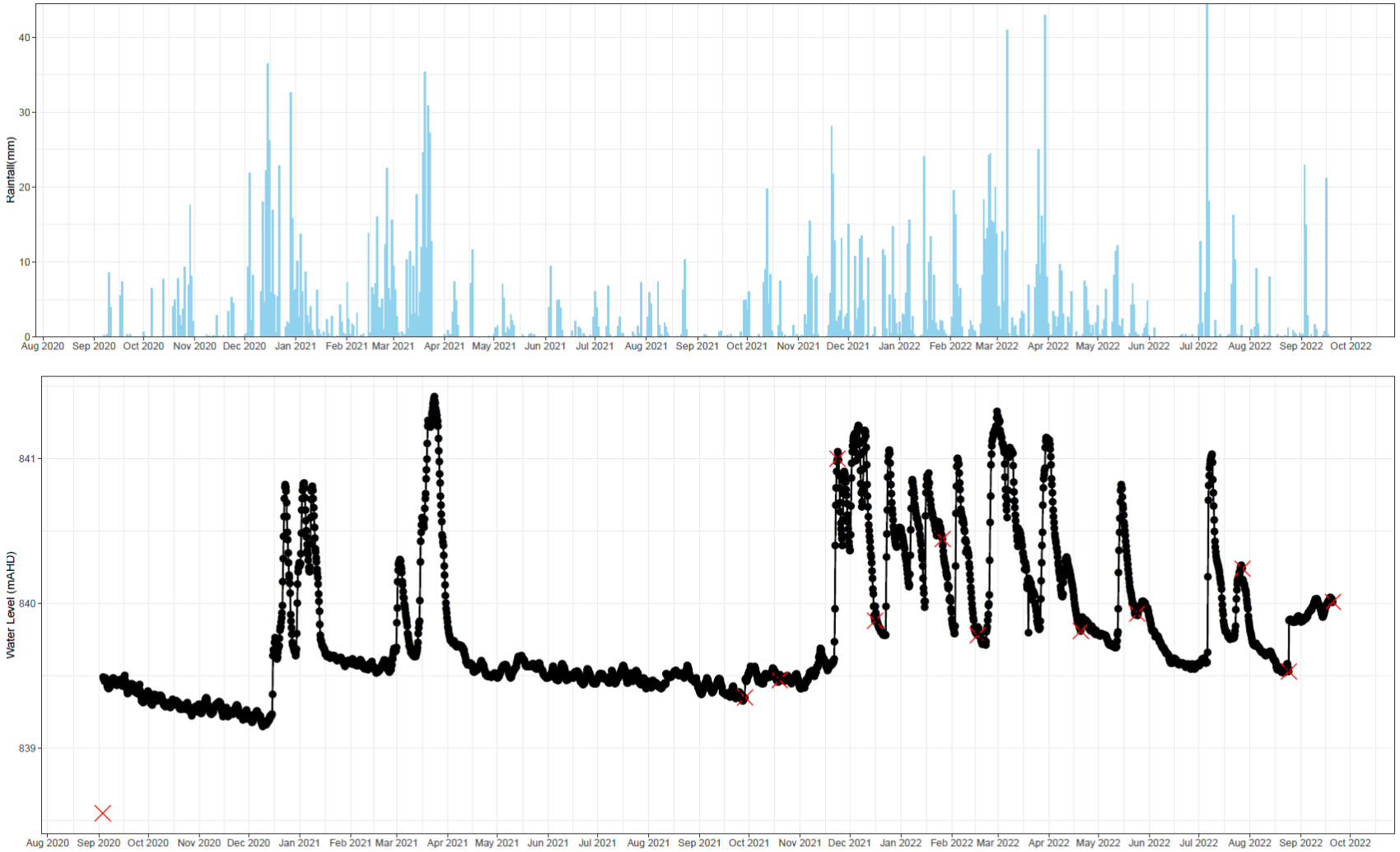
Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
http://www.longpaddock.qld.gov.au/silo

OM1 groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 1



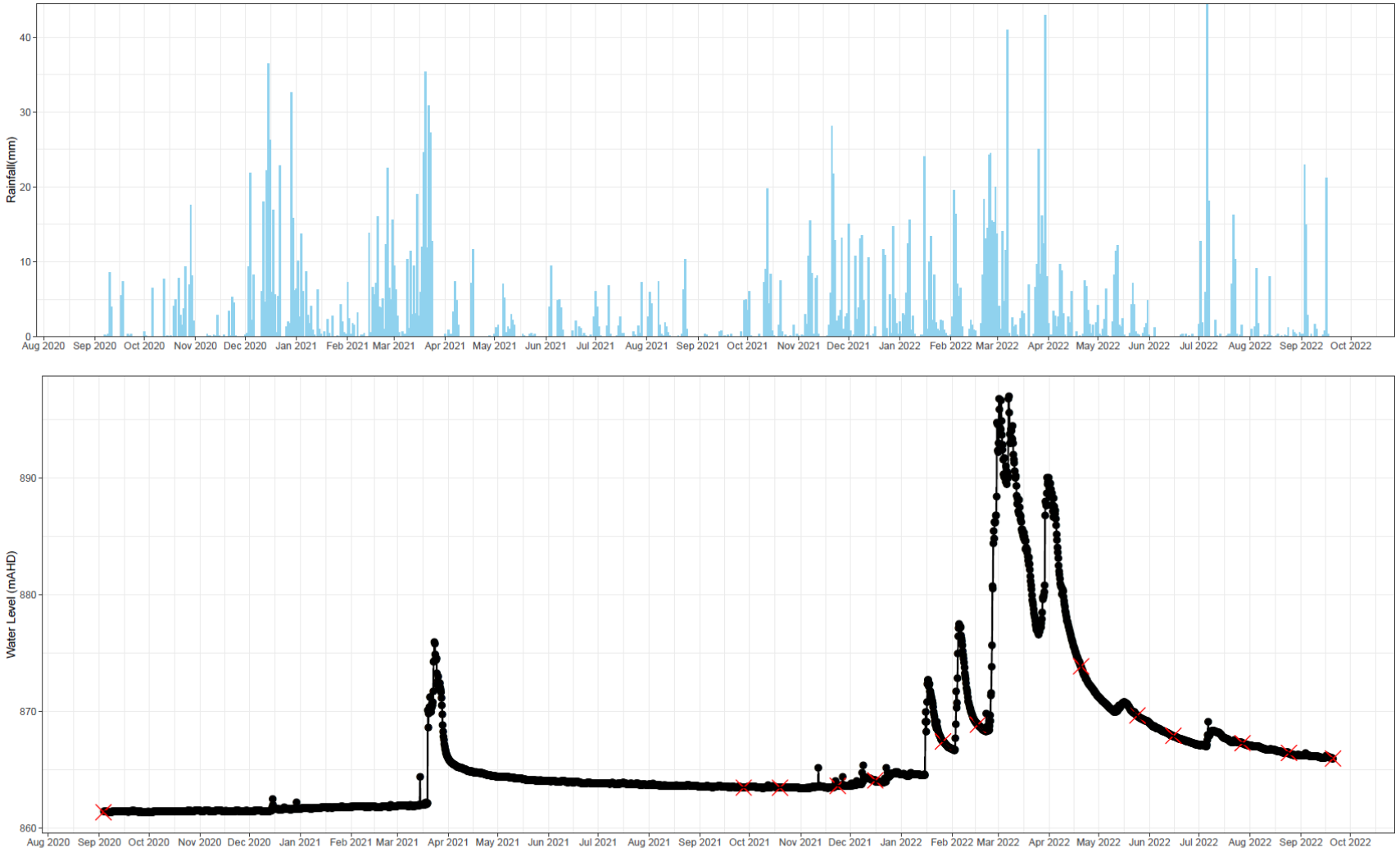
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OM2 groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 2



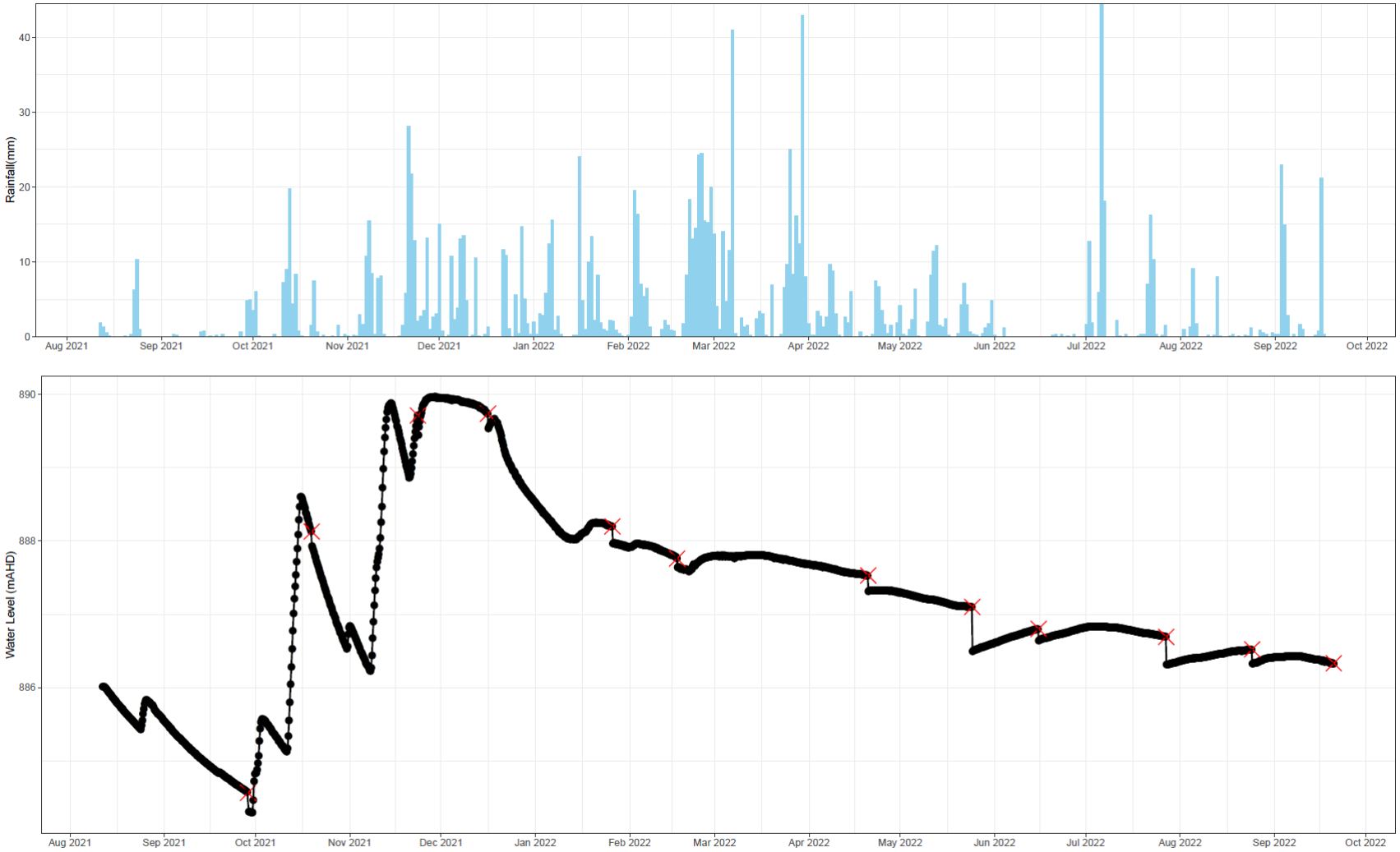
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OM3 groundwater level times series data
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Monthly groundwater monitoring report
Figure 3



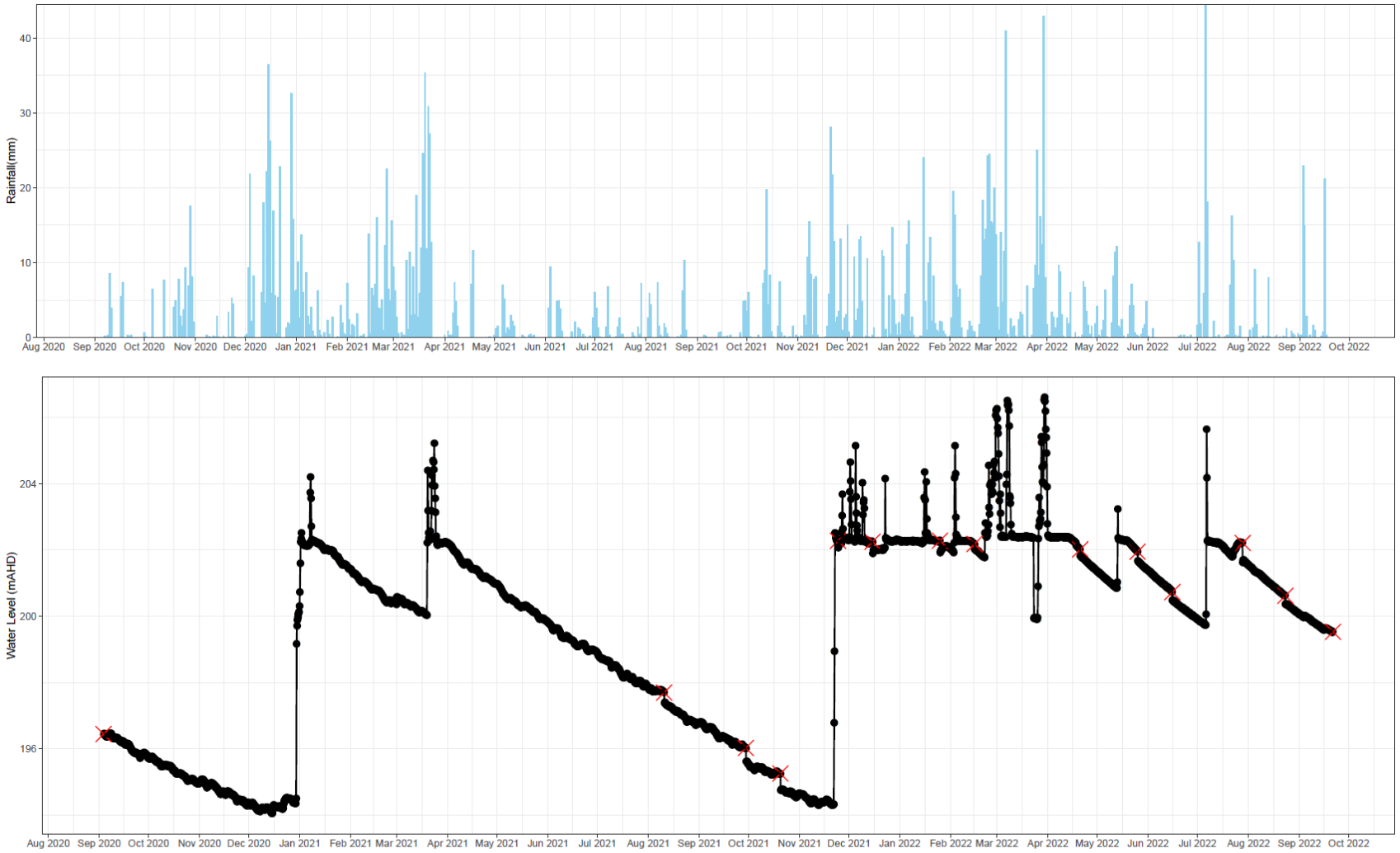
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OM4 groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 4



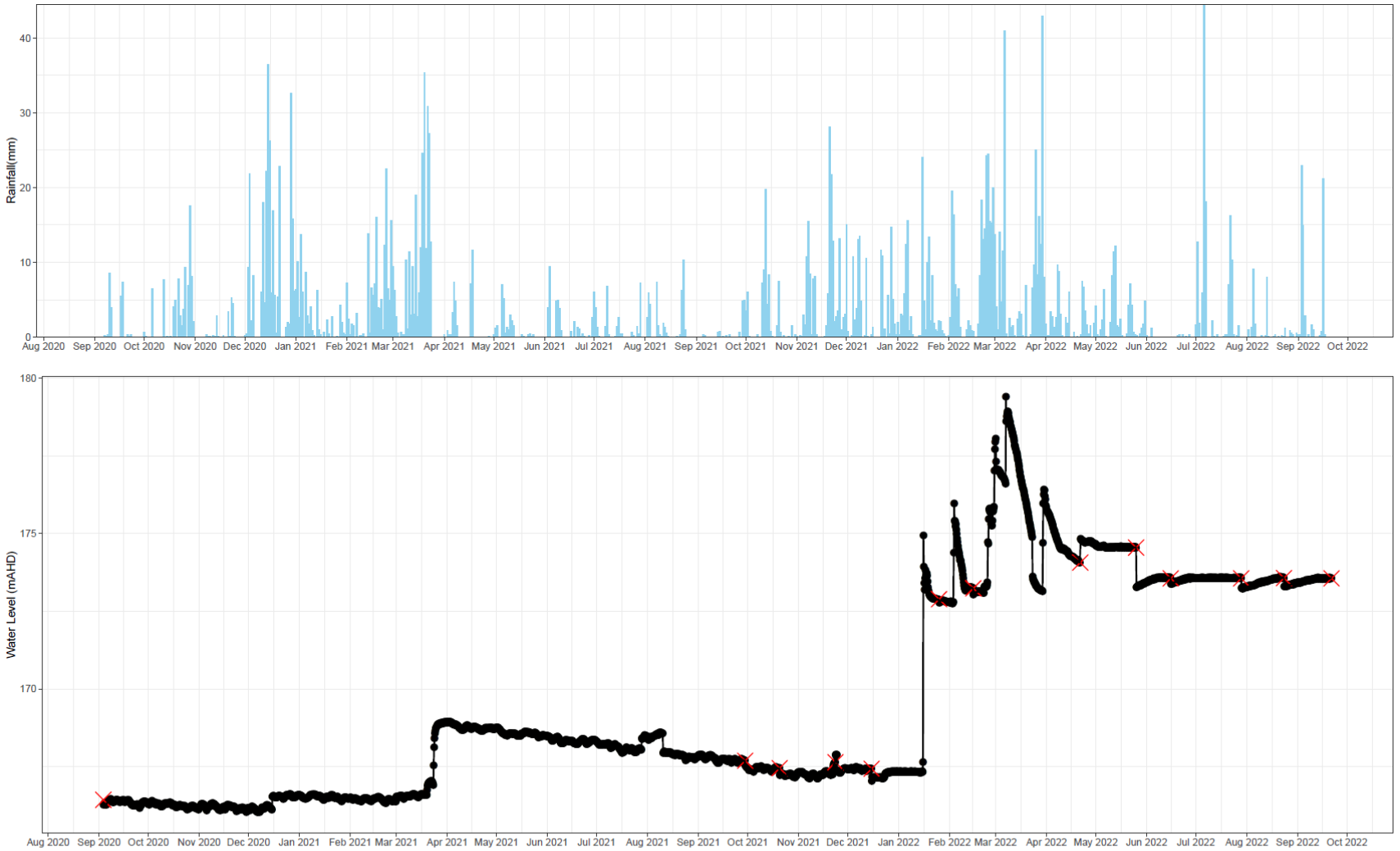
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OM5 groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 5



Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
http://www.longpaddock.qld.gov.au/silo

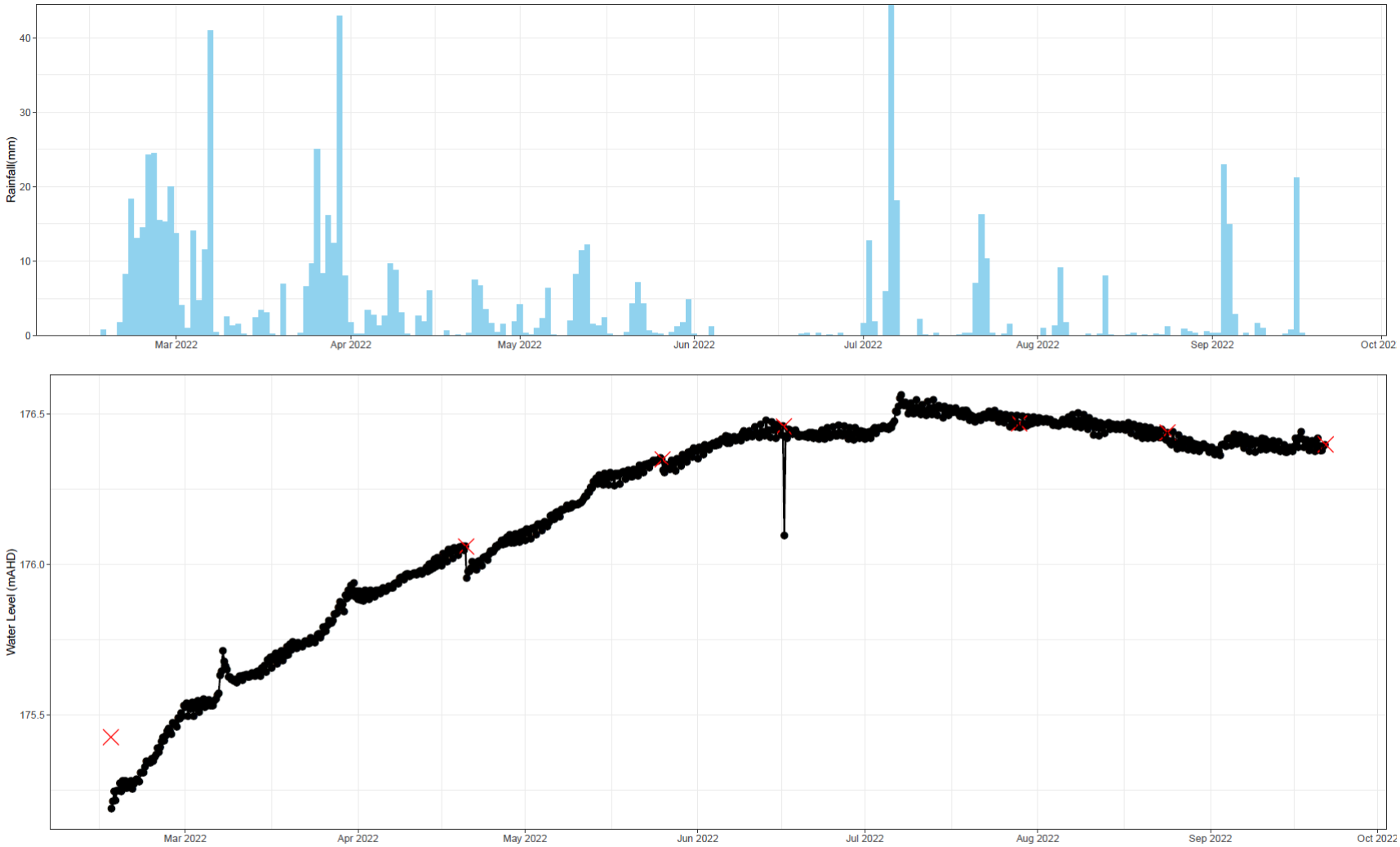
OM6 groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 6



EMM creating opportunities

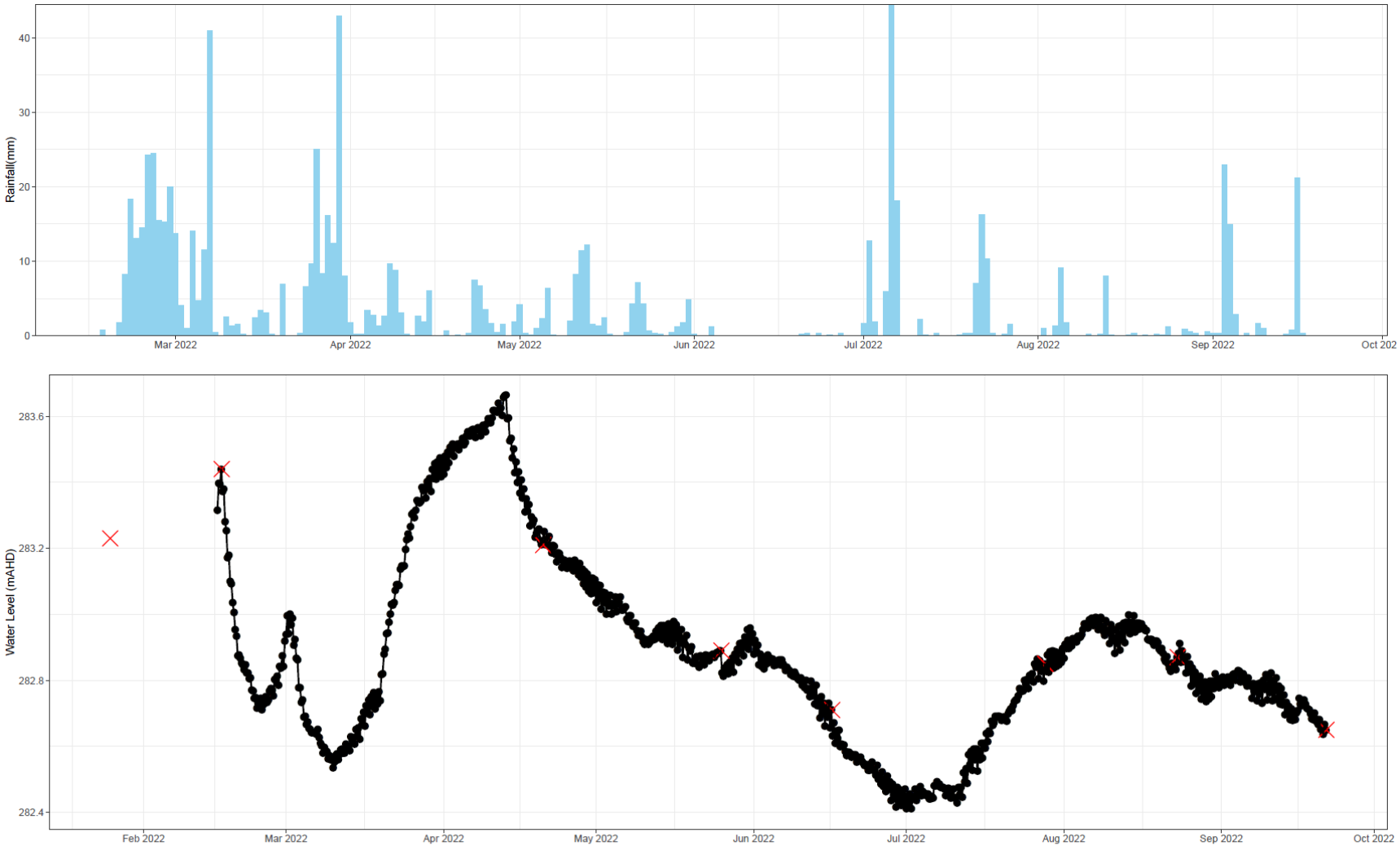
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OM7 groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 7



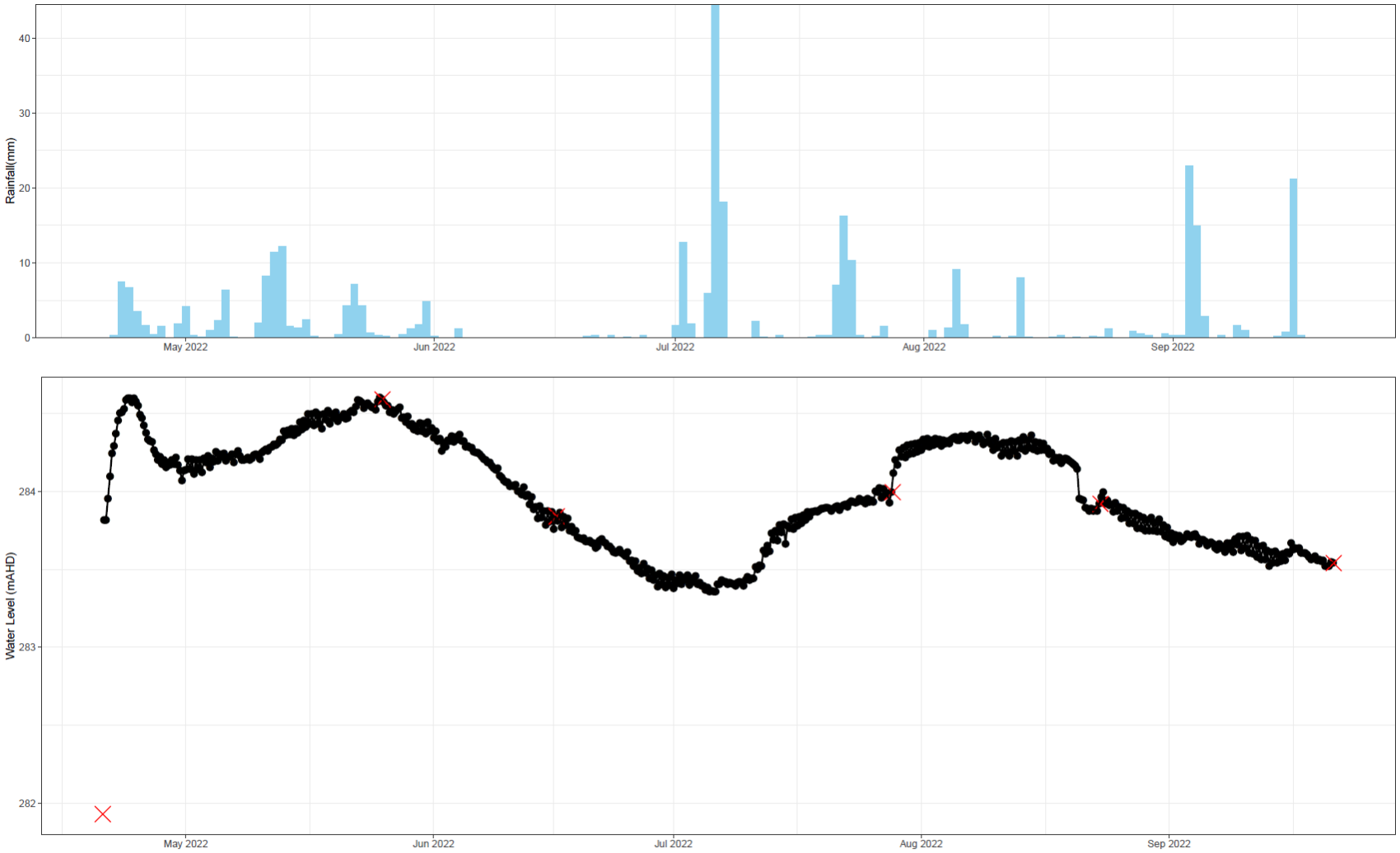
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MB01A groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 8



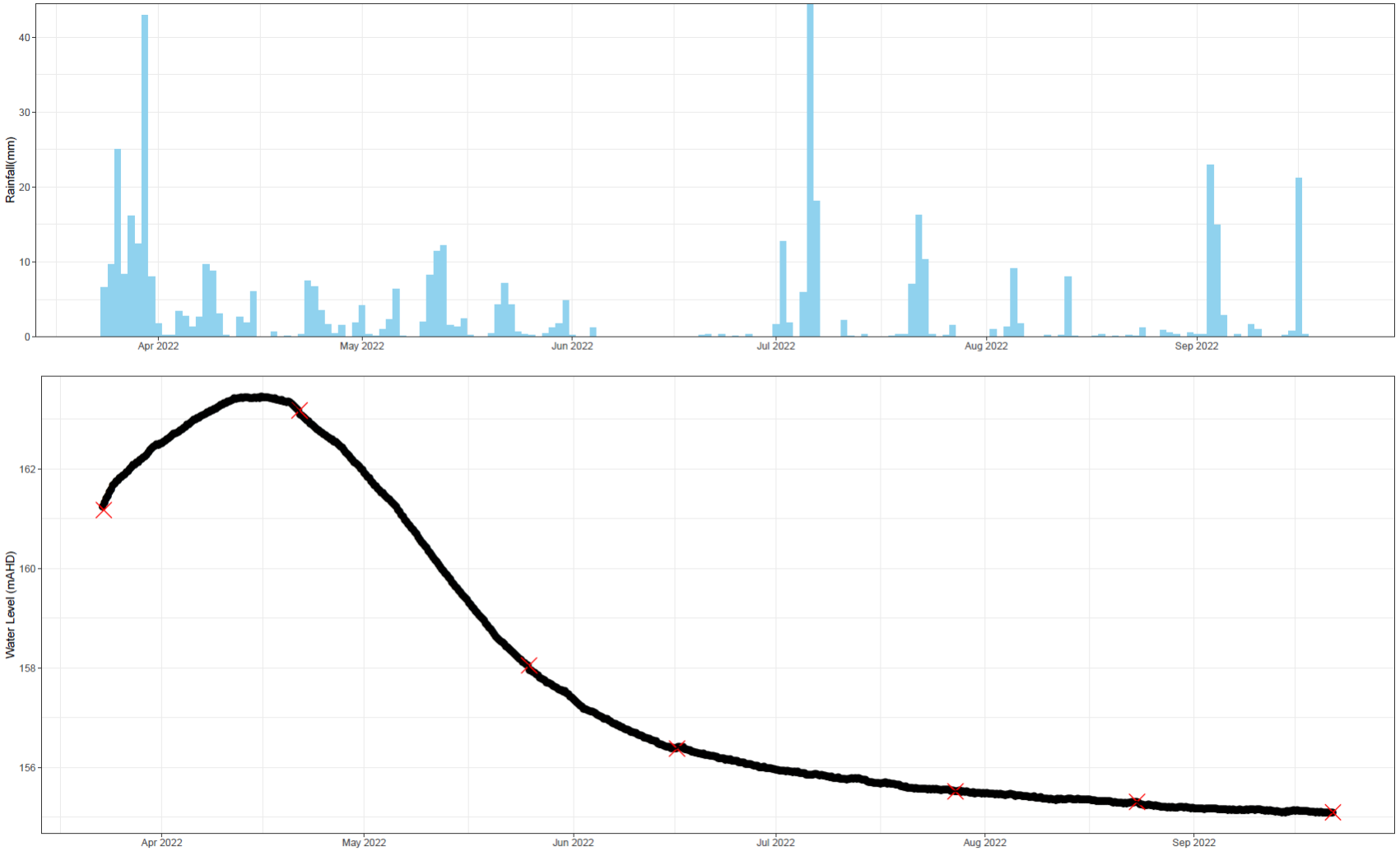
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MB02A groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 9



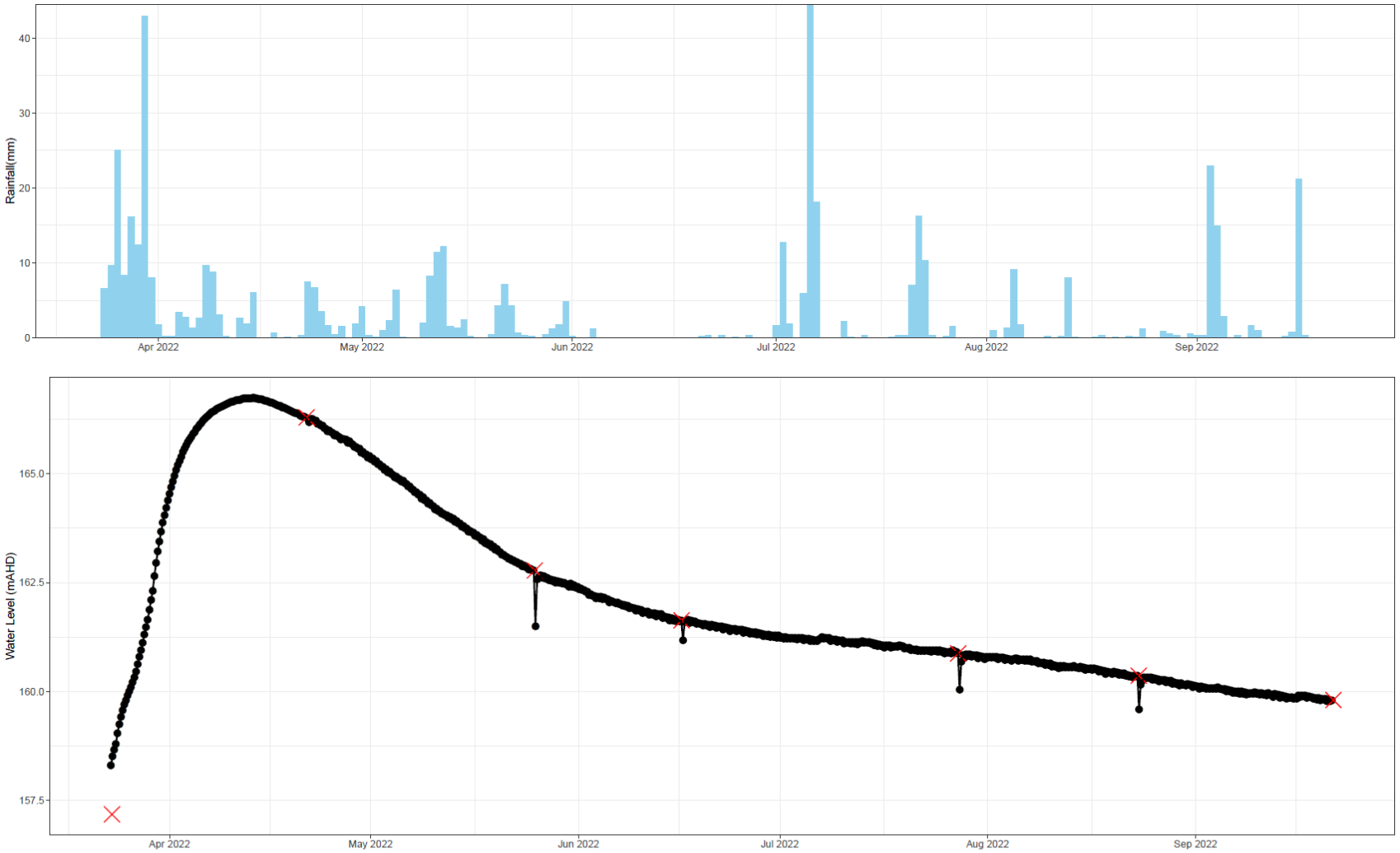
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MB02B groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 10



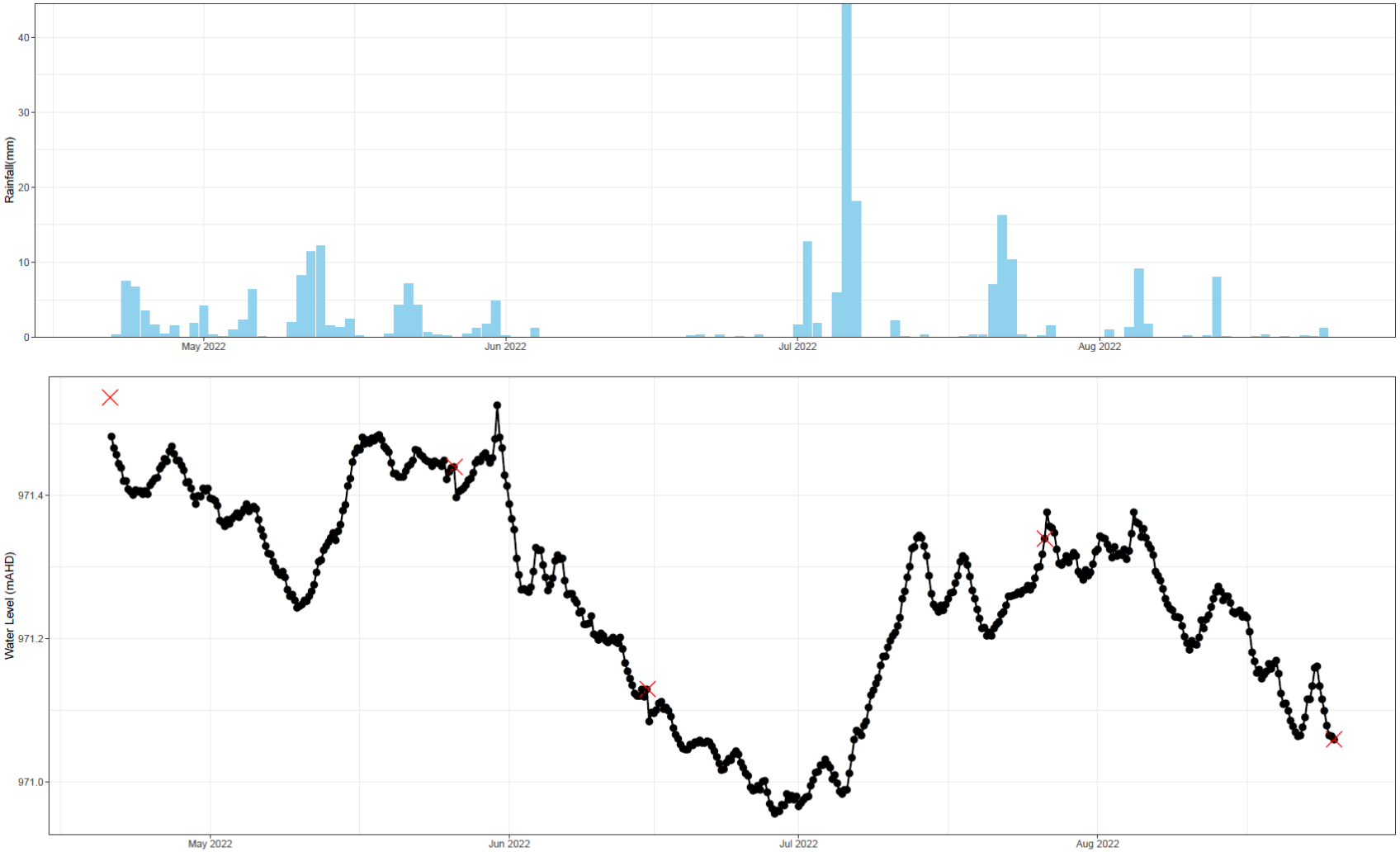
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MB03A groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 11



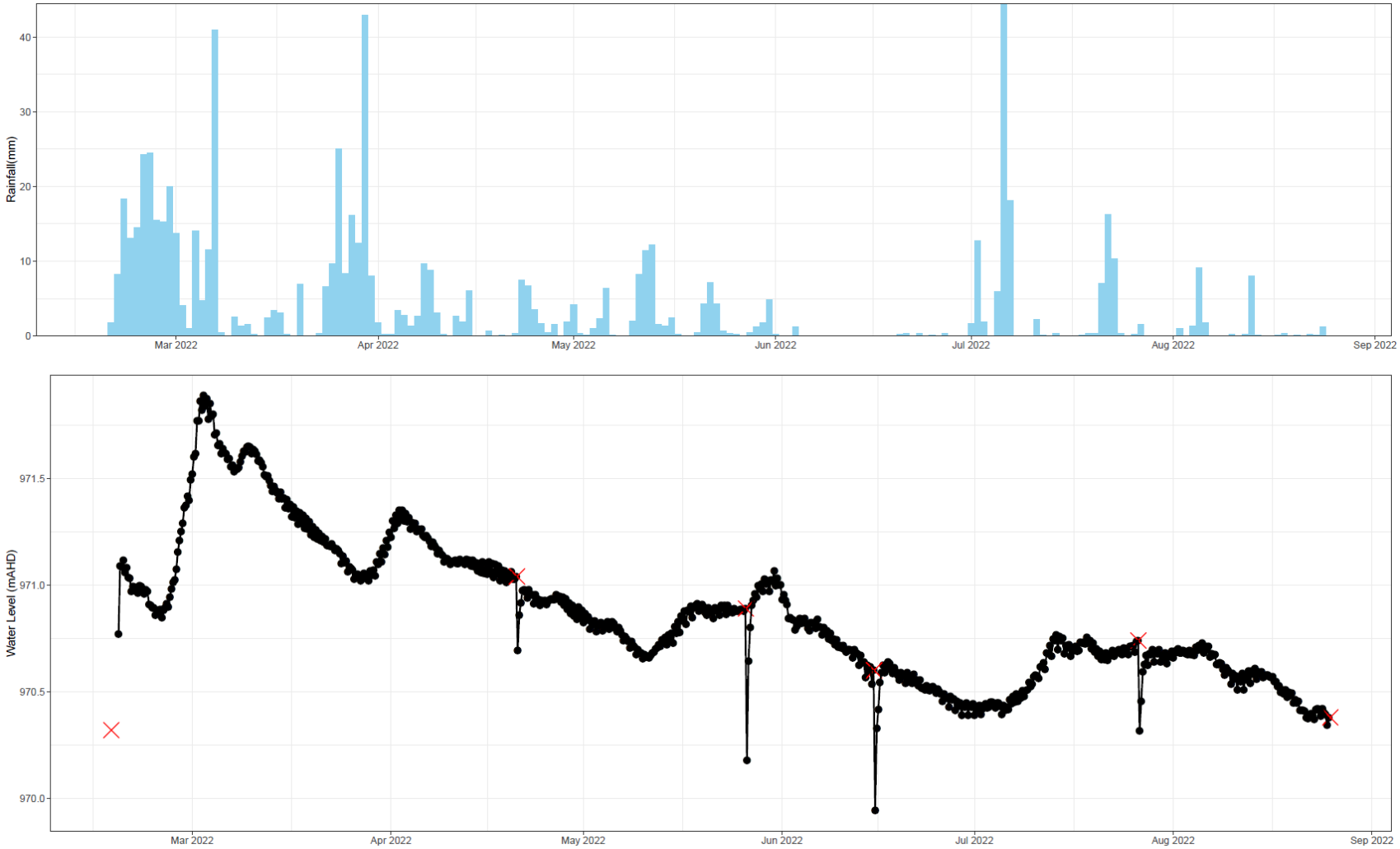
Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
http://www.longpaddock.qld.gov.au/silo

MB03B groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 12



Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
http://www.longpaddock.qld.gov.au/silo

MB04A groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 13



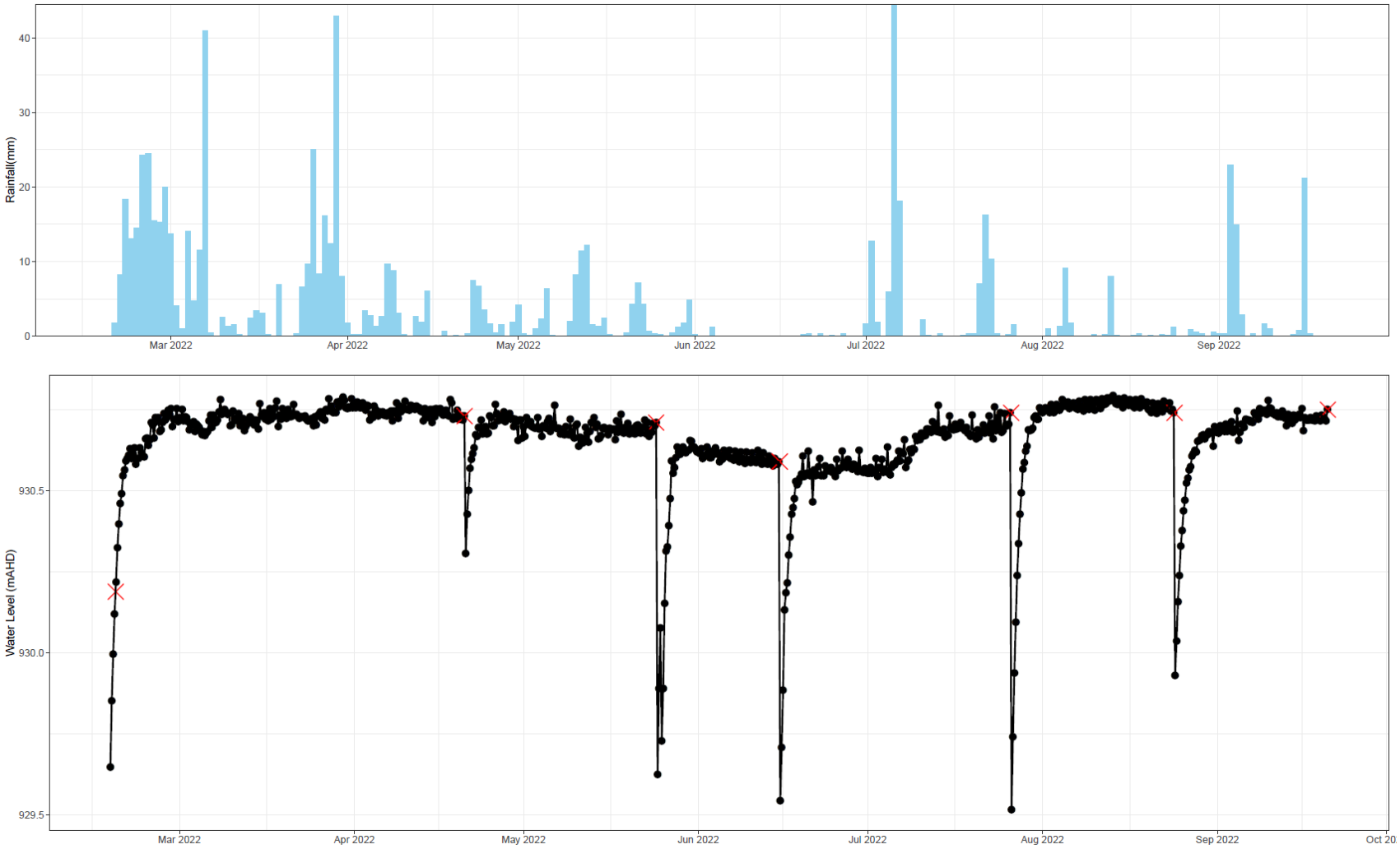
Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
http://www.longpaddock.qld.gov.au/silo

MB04B groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 14



Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
http://www.longpaddock.qld.gov.au/silo

HA2201 groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 15



Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
http://www.longpaddock.qld.gov.au/silo

HA2202 groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 16



Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
http://www.longpaddock.qld.gov.au/silo

HA2203 groundwater level times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Monthly groundwater monitoring report
Figure 17

Appendix B

Prior distributions of uncertainty parameters

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B.1 Prior distribution boxplots

The figures below show the distributions for all the same parameters as Figure 5.6 to Figure 5.12, but prior to the uncertainty analysis and contain all 201 (including the base case) realisations.

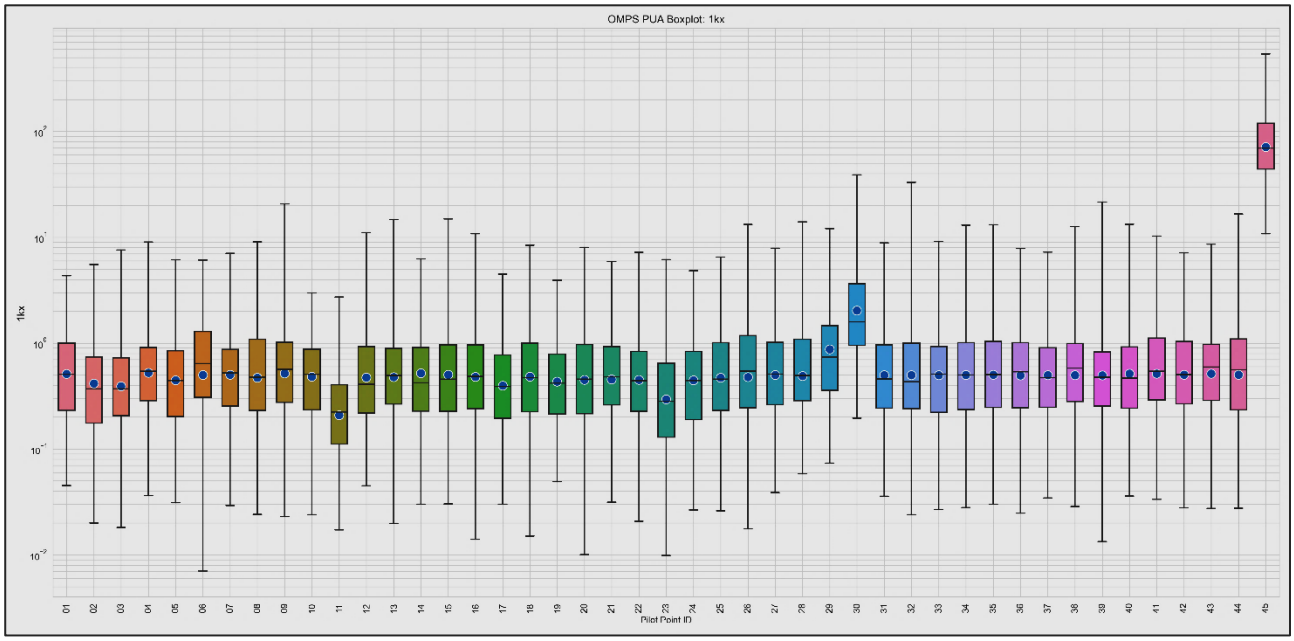


Figure B.1 **Kh boxplots for each pilot point in model layer one (alluvium is pilot 45 and weathered bedrock is 1-44). The boxplots present the distribution across the 200 realisations and the symbols reflect the base case value for that pilot point**

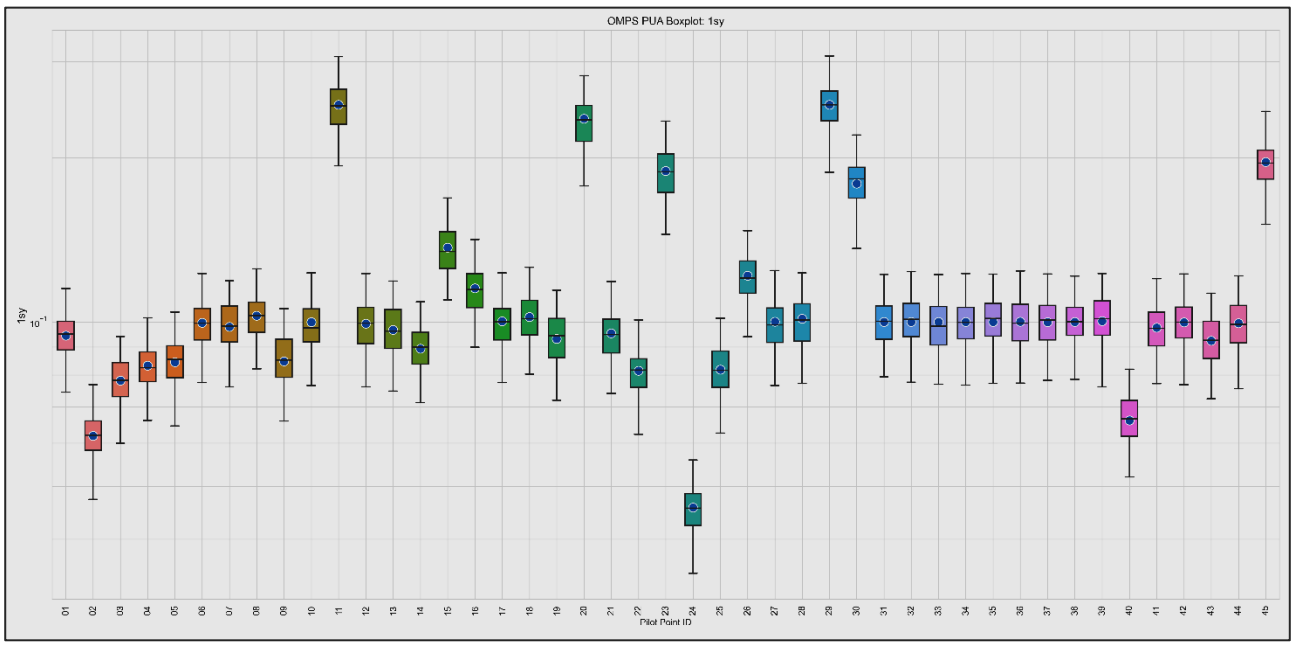


Figure B.2 **Sy boxplots for each pilot point in model layer one (alluvium is pilot 45 and weathered bedrock is 1-44).**

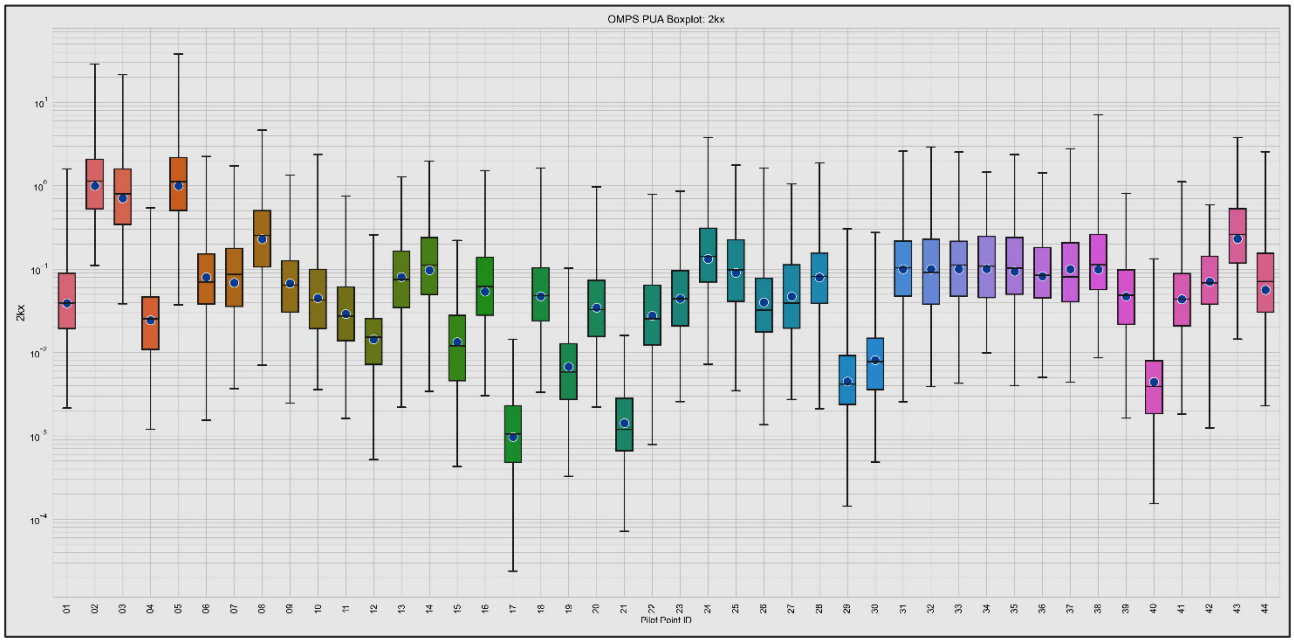


Figure B.3 Kh boxplots for each pilot point in model layer two (fractured bedrock)

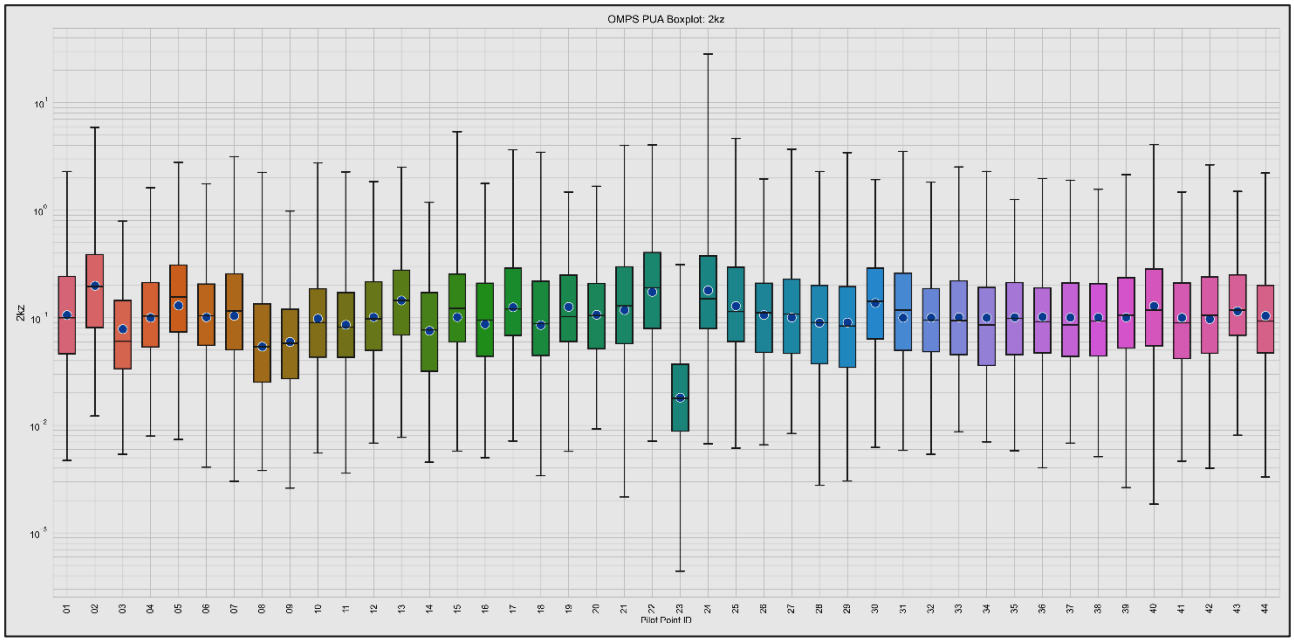


Figure B.4 Kv boxplots for each pilot point in model layer two (fractured bedrock)

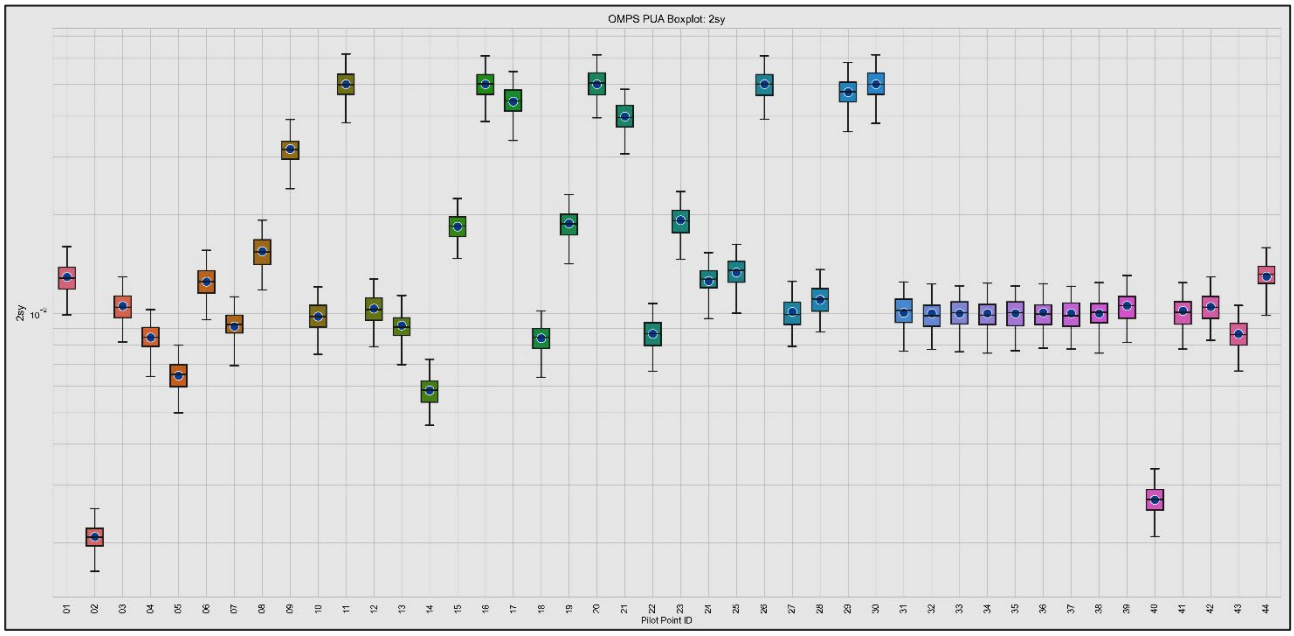


Figure B.5 Sy boxplots for each pilot point in model layer two (fractured bedrock)

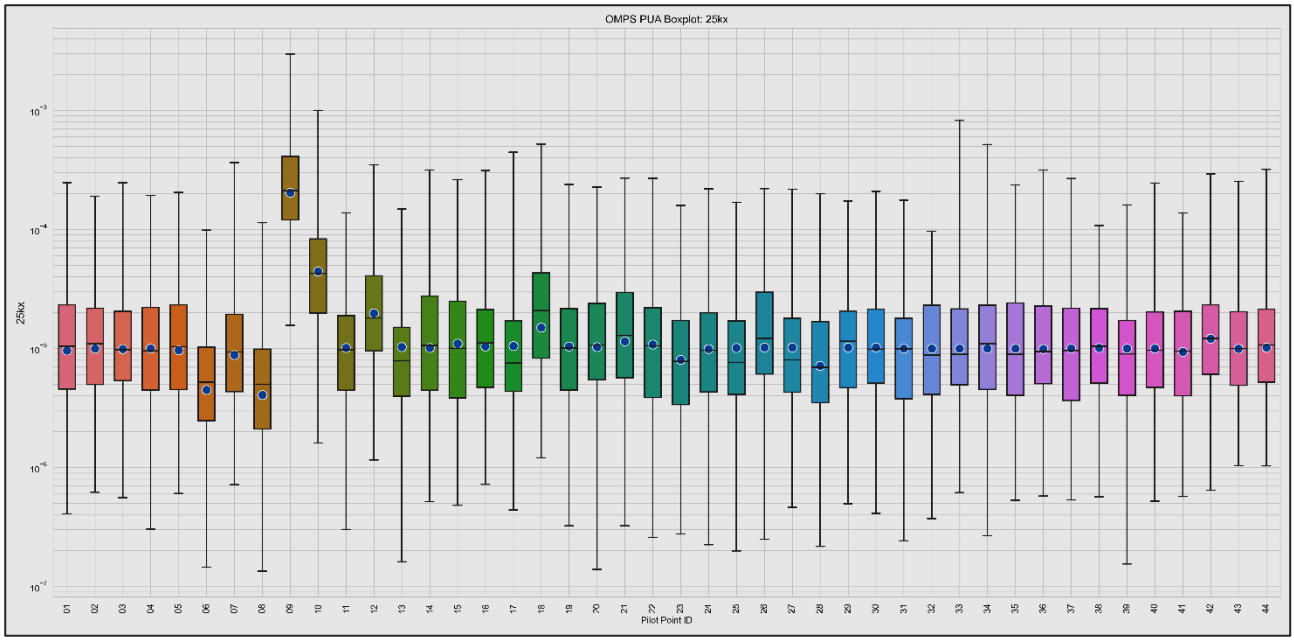


Figure B.6 Kh boxplots for each pilot point in model layer three (tight bedrock)

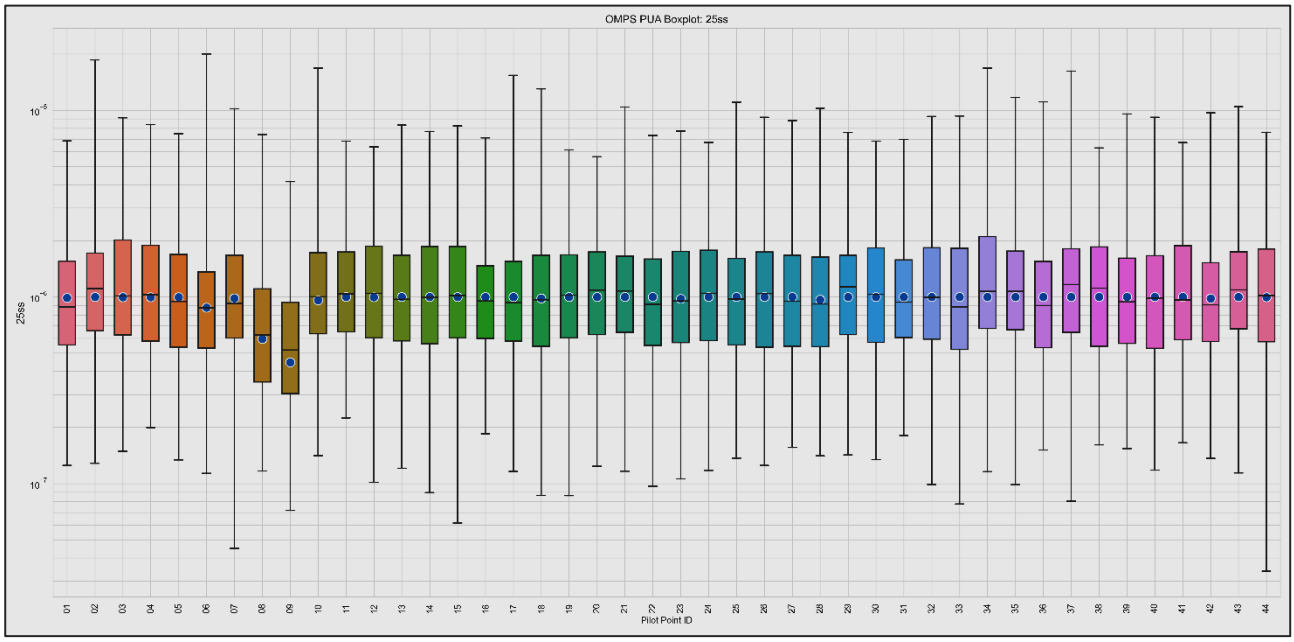
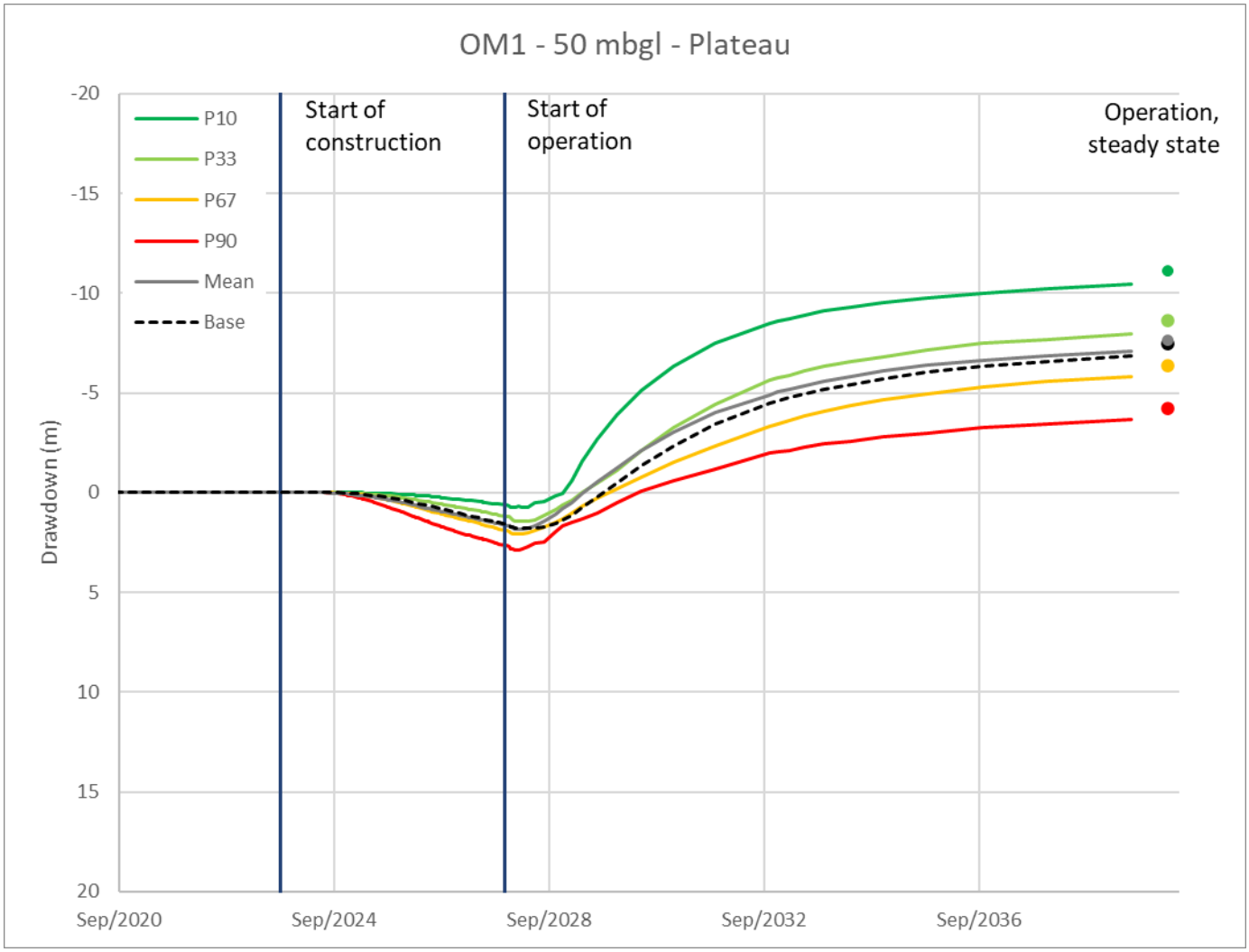


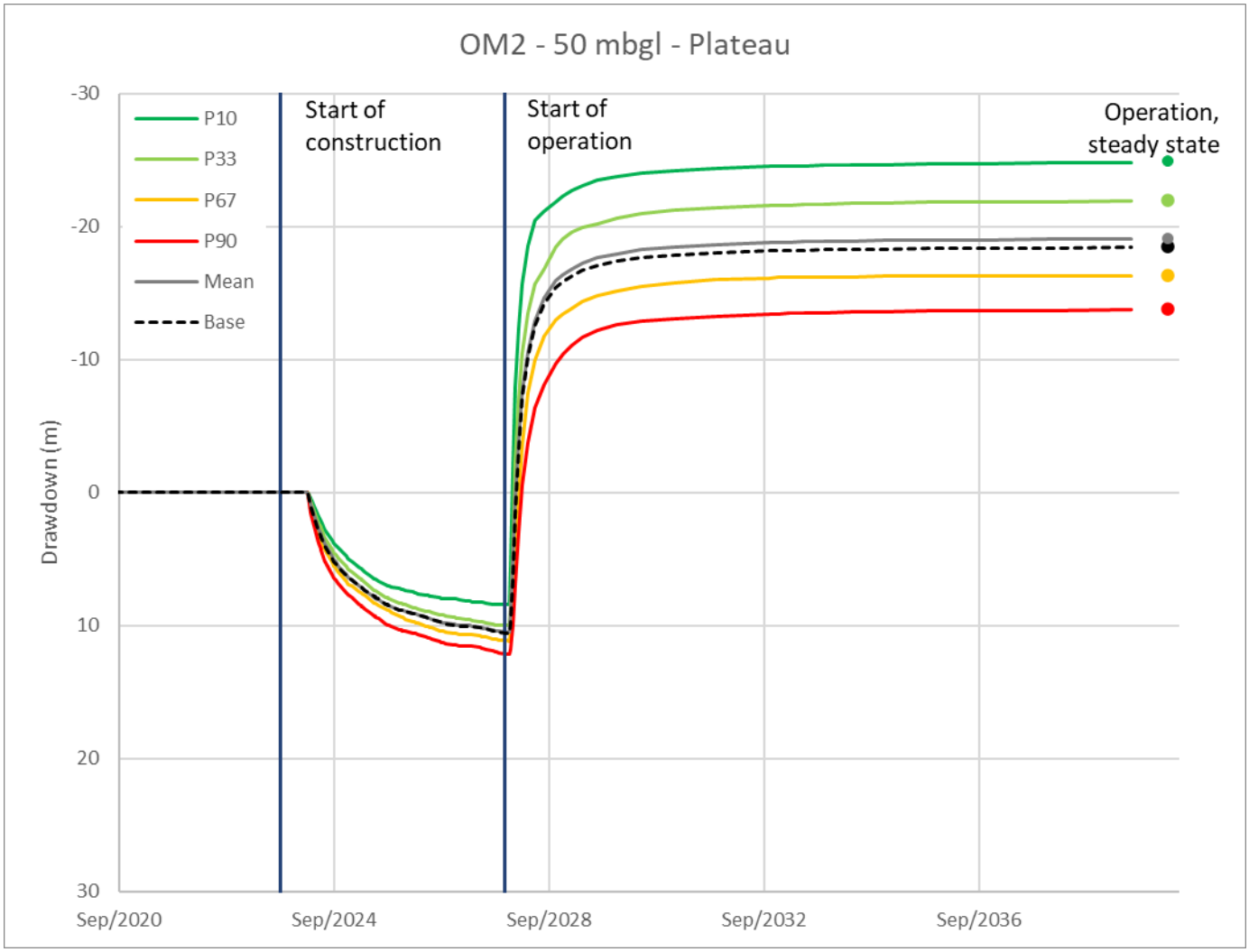
Figure B.7 Ss boxplots for each pilot point in model layer three (tight bedrock)

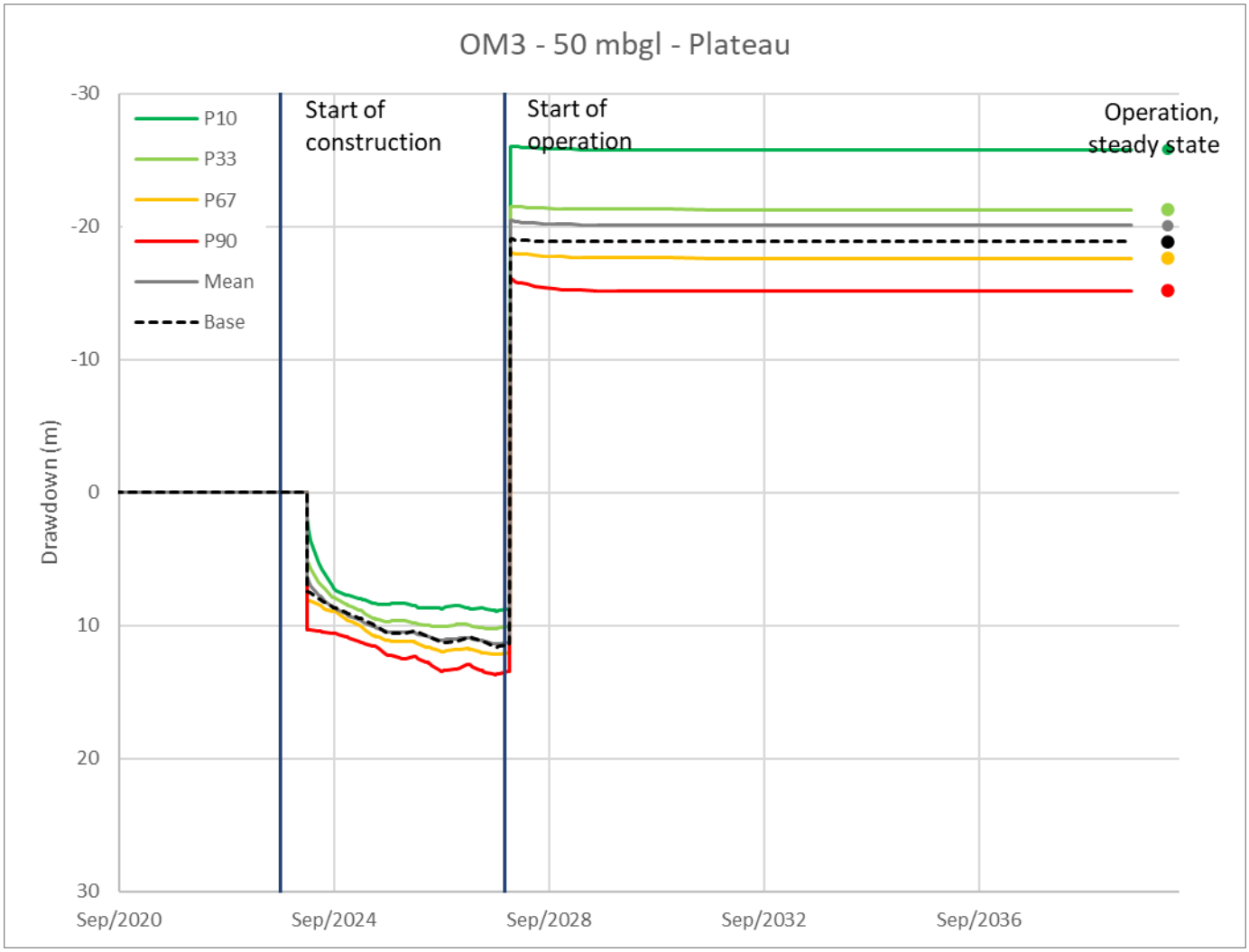
Appendix C

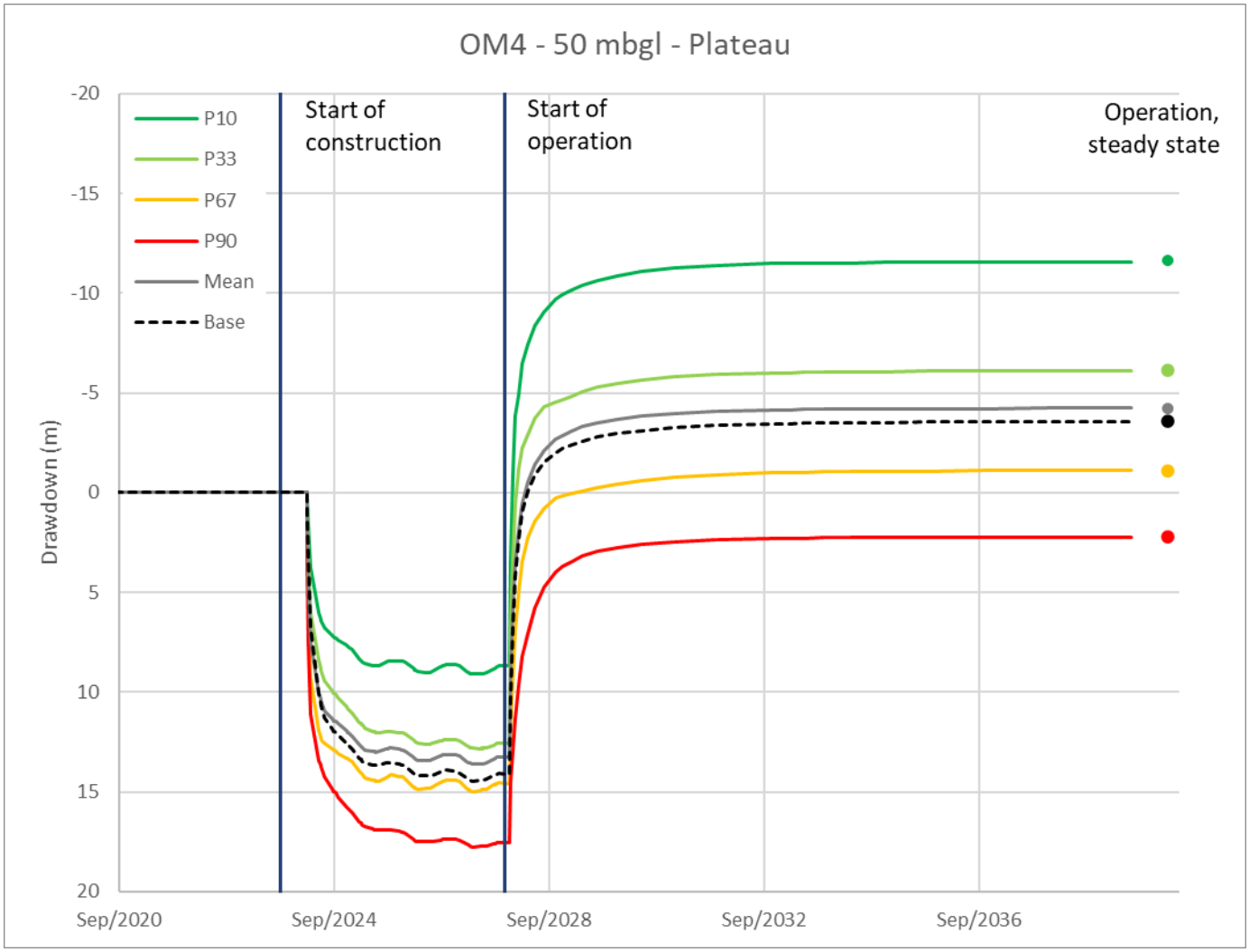
Predicted hydrographs at environmental receptors

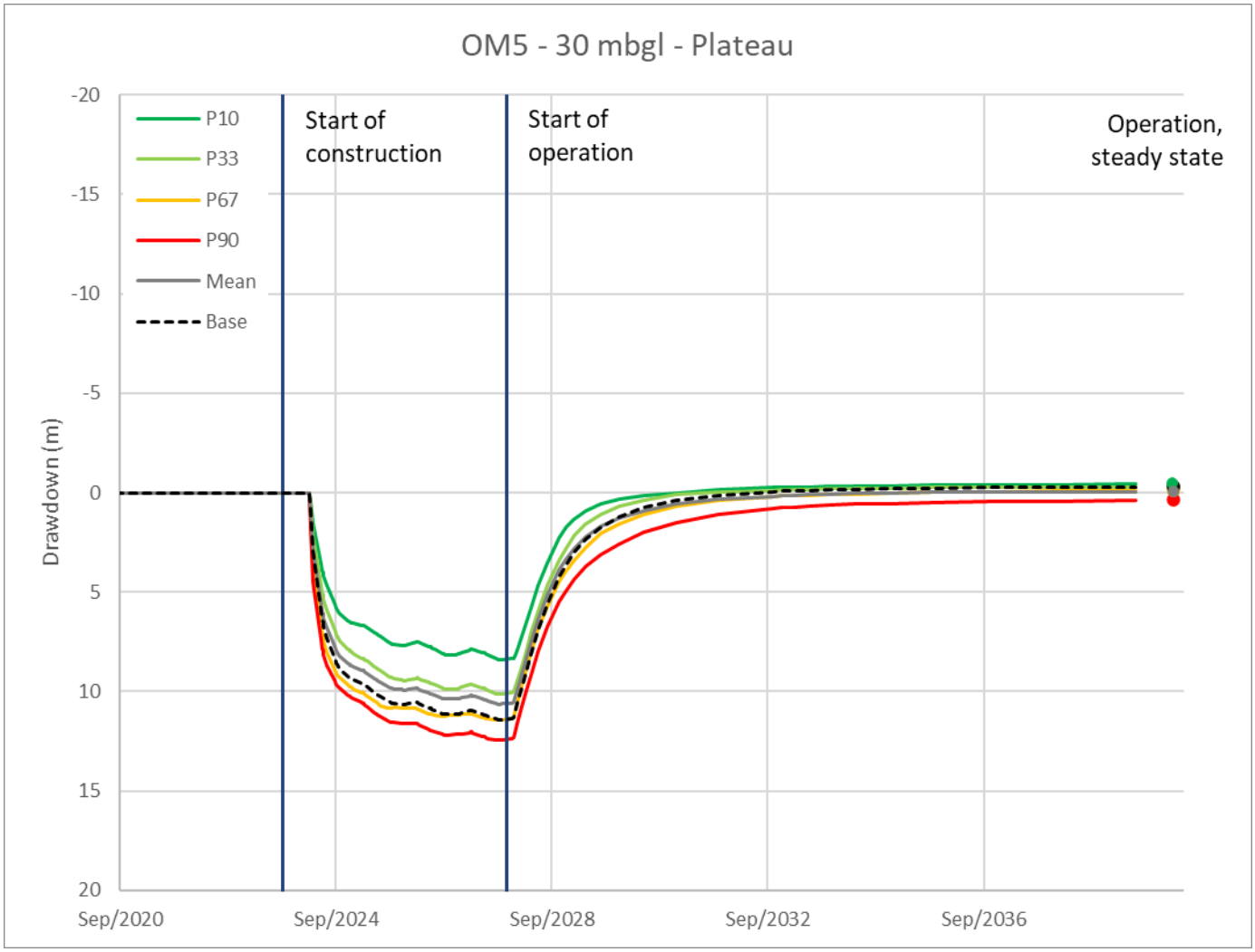
EMM
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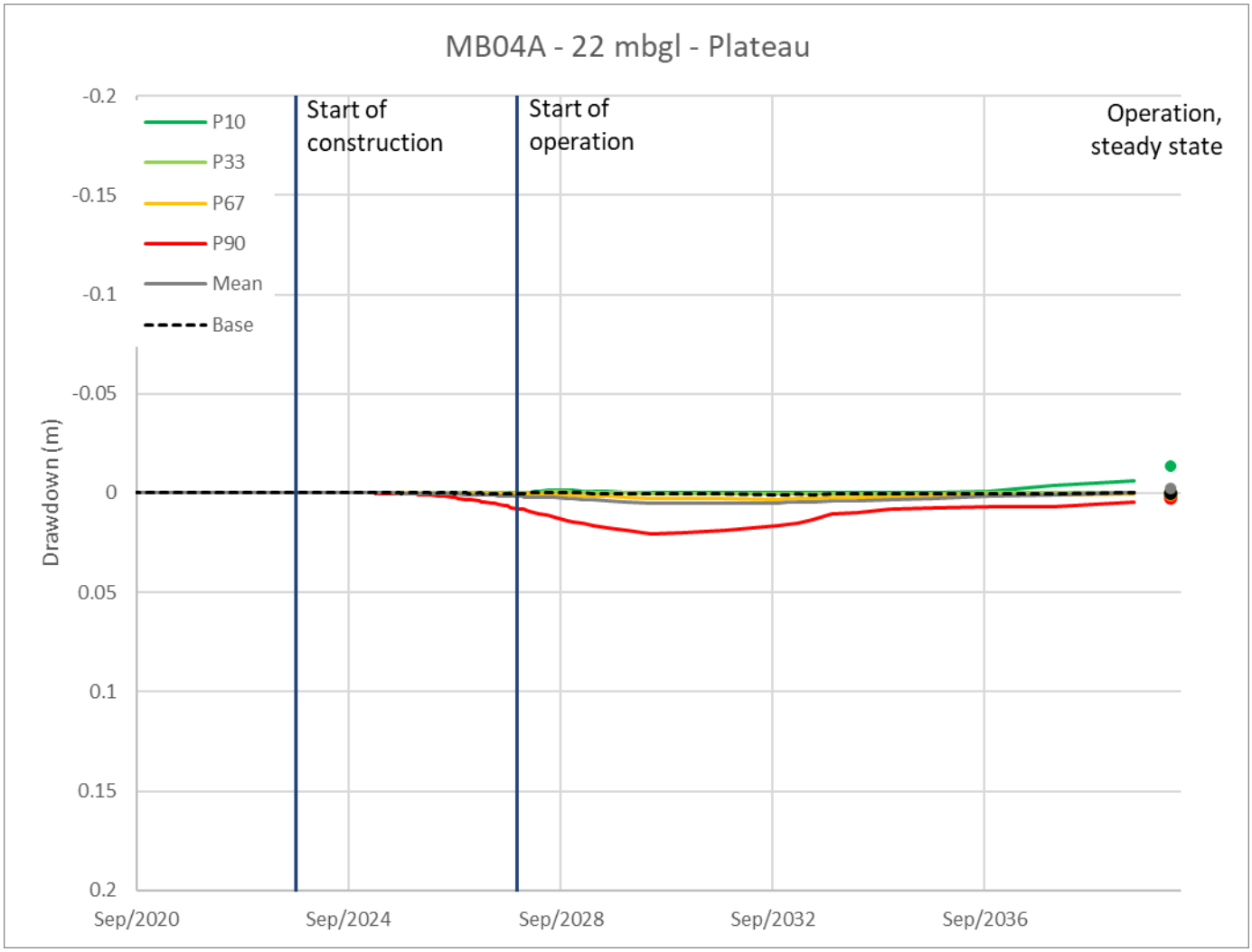

OM1 - 50 mbgl - Plateau
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-20
-15
-10
-5
0
5
10
15
20
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

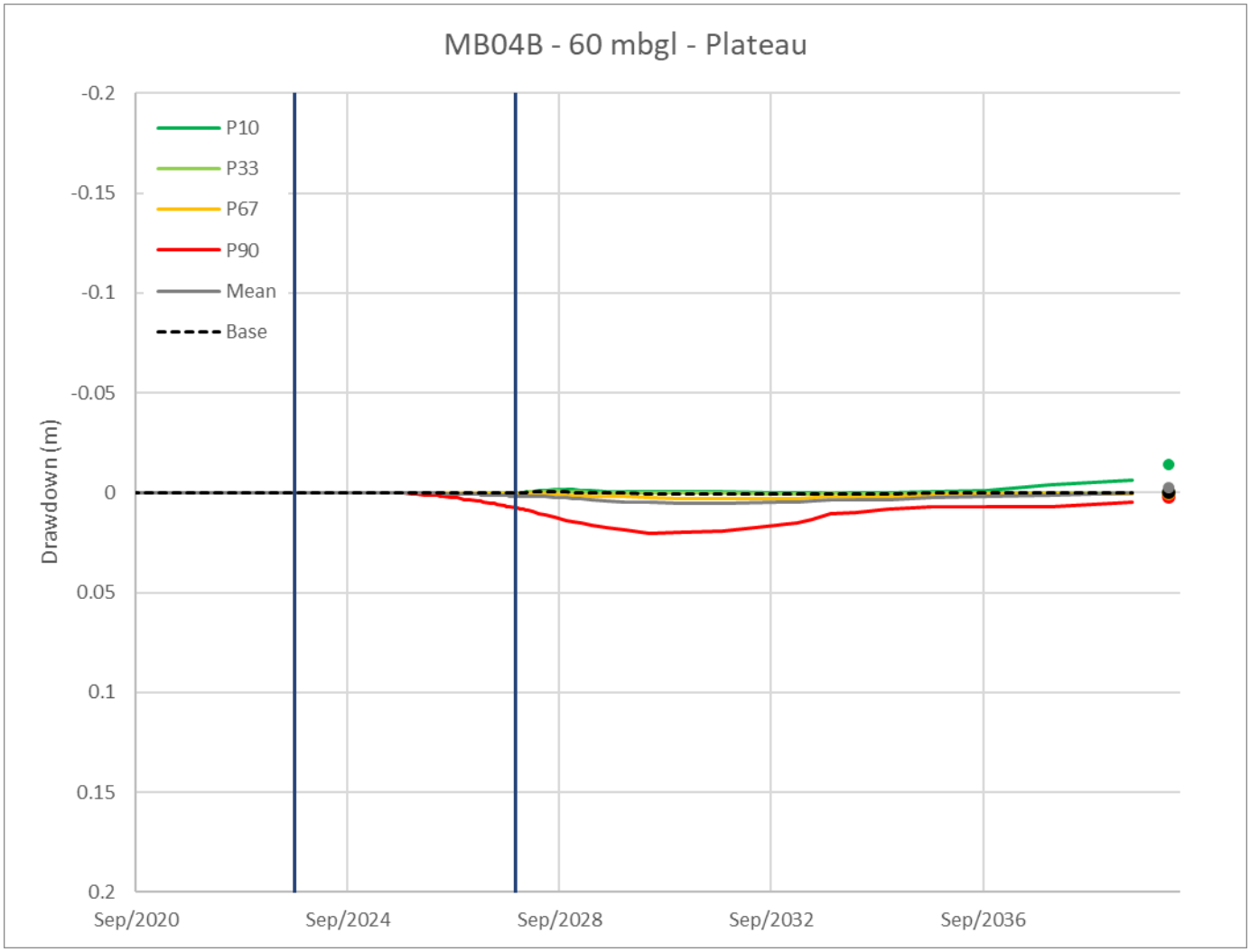

OM2 - 50 mbgl - Plateau
Drawdown (m)
-30
-20
-10
0
10
20
30
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state

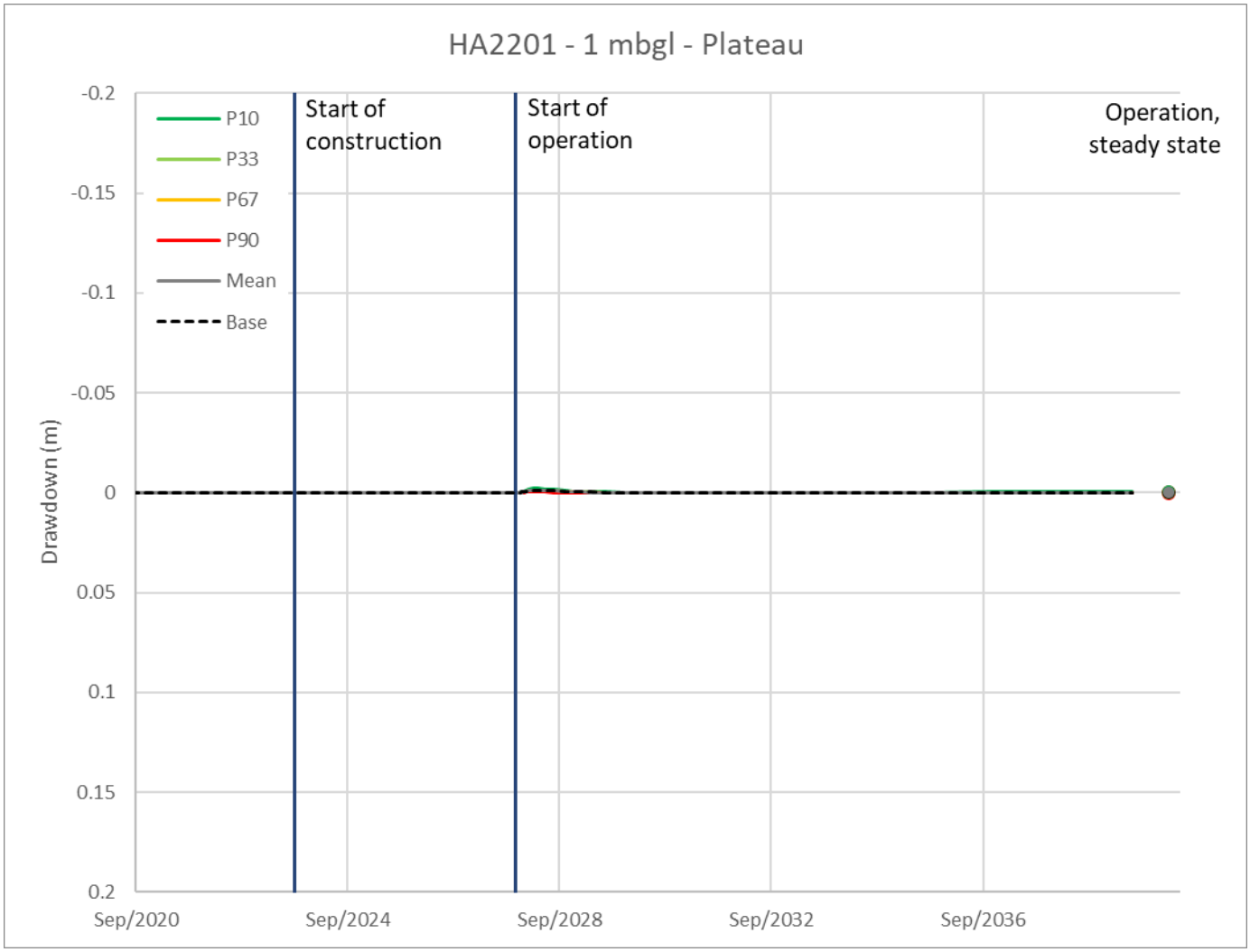

OM3 - 50 mbgl - Plateau
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-30
-20
-10
0
10
20
30
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

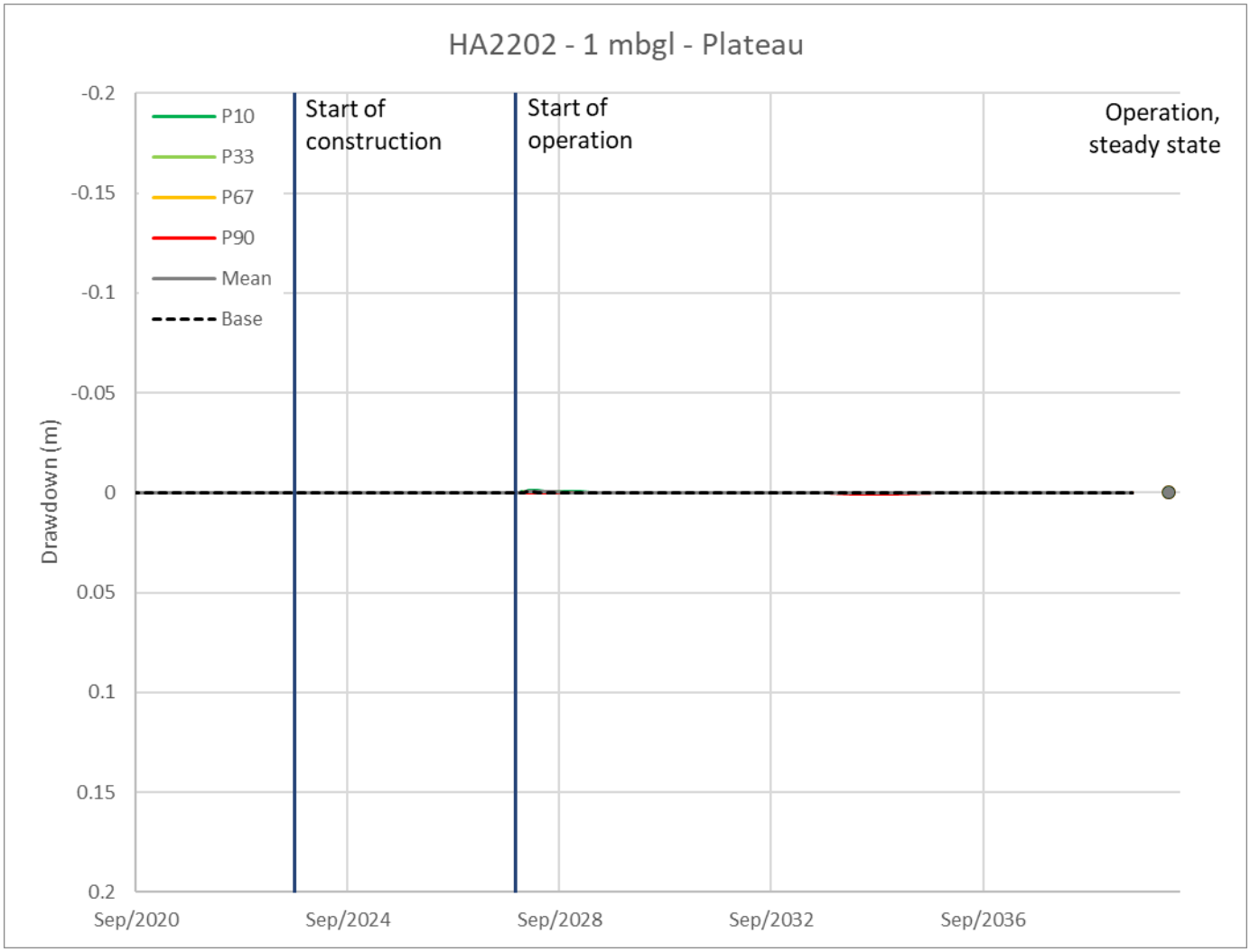

OM4 - 50 mbgl - Plateau
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-20
-15
-10
-5
0
5
10
15
20
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

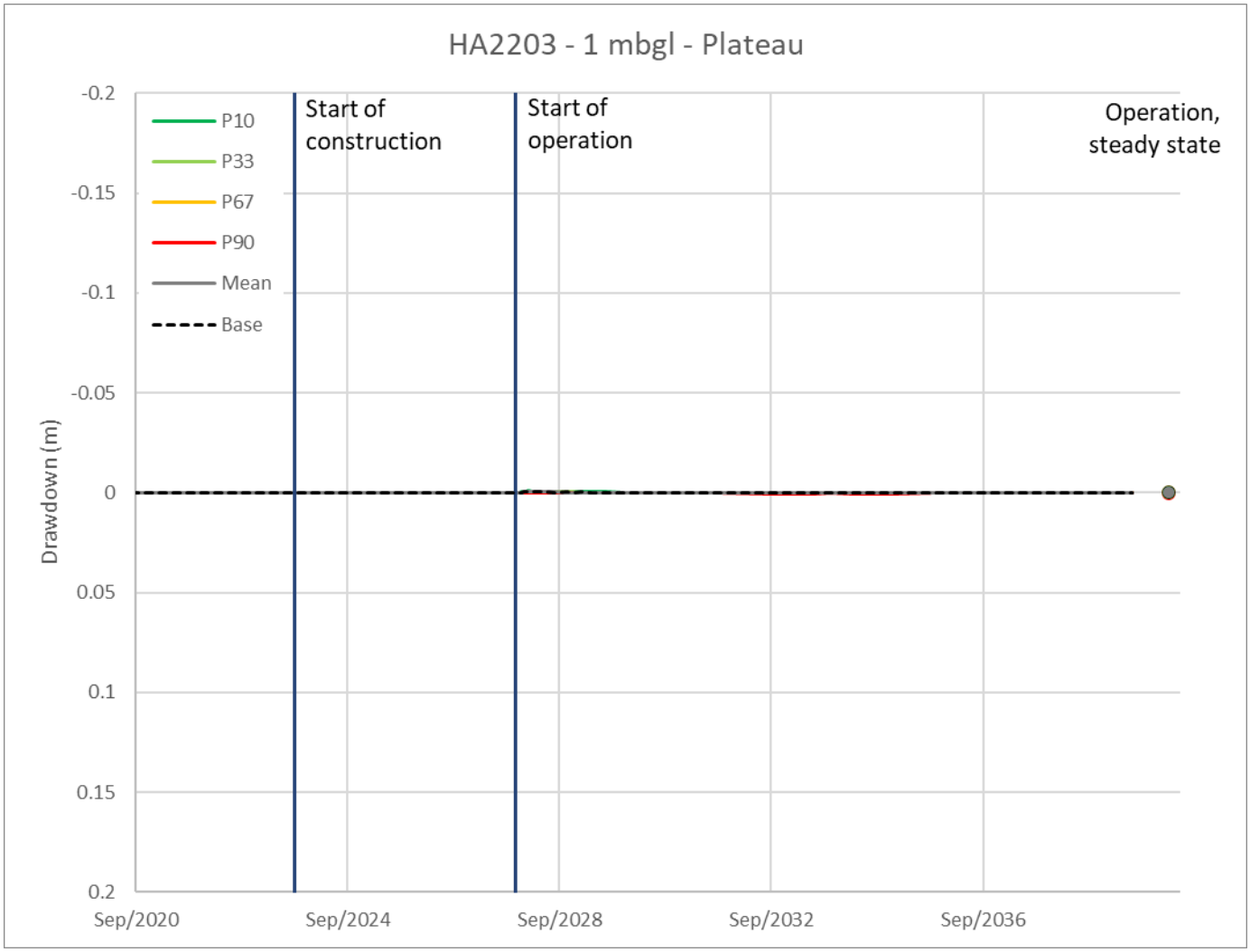

OM5 - 30 mbgl - Plateau
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-20
-15
-10
-5
0
5
10
15
20
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036


MB04A - 22 mbgl - Plateau
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

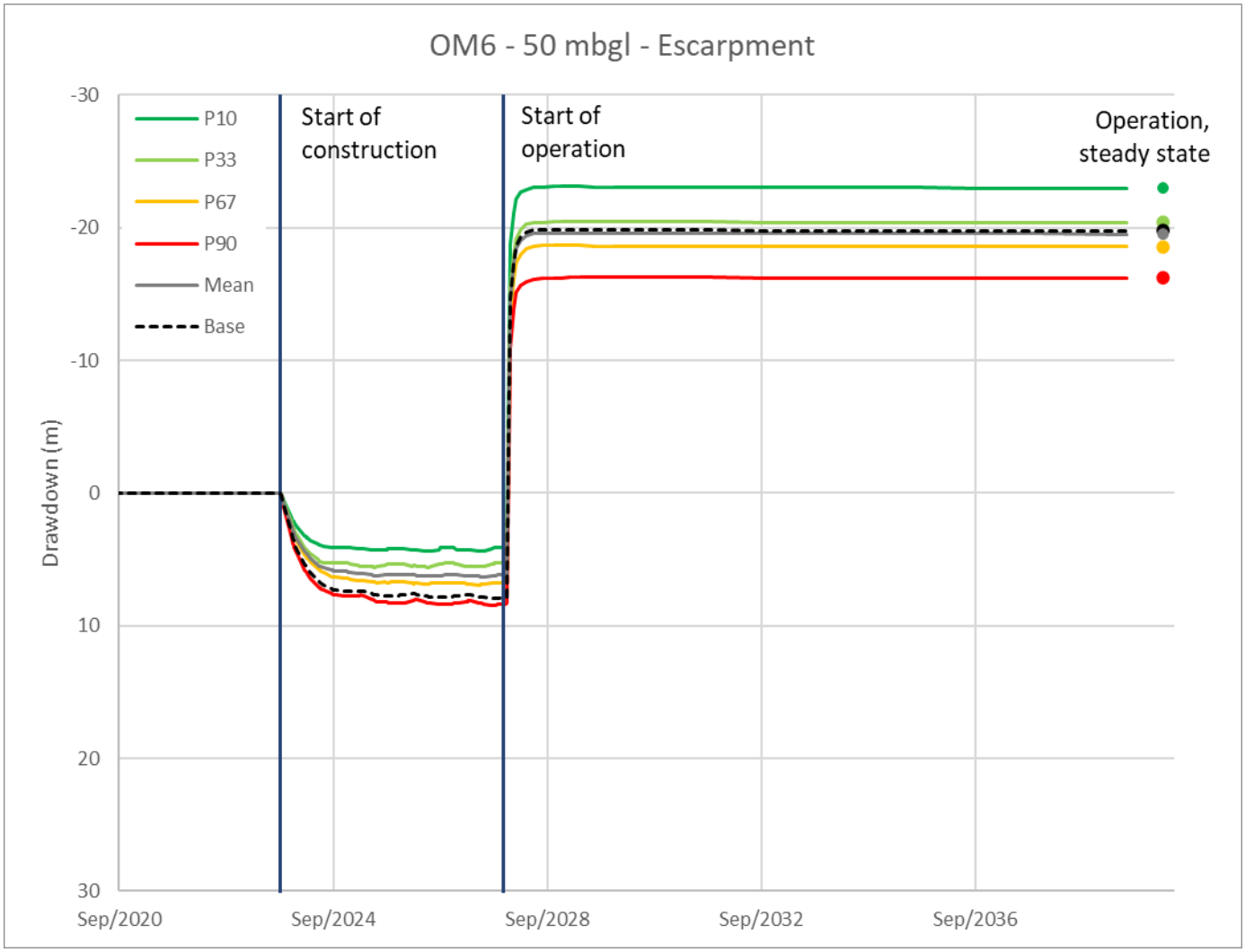

MB04B - 60 mbgl - Plateau
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

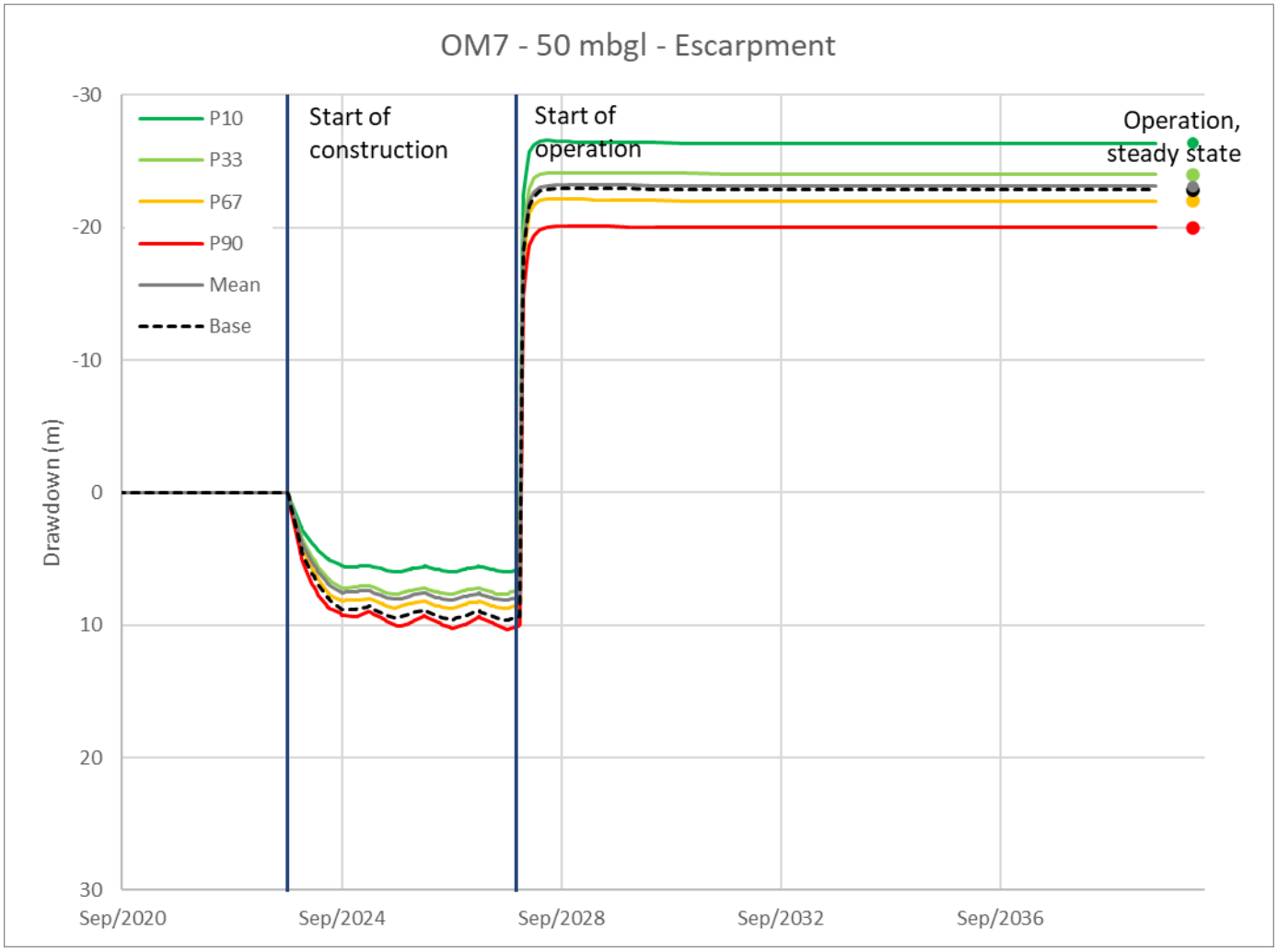

HA2201 - 1 mbgl - Plateau
Drawdown (m)
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

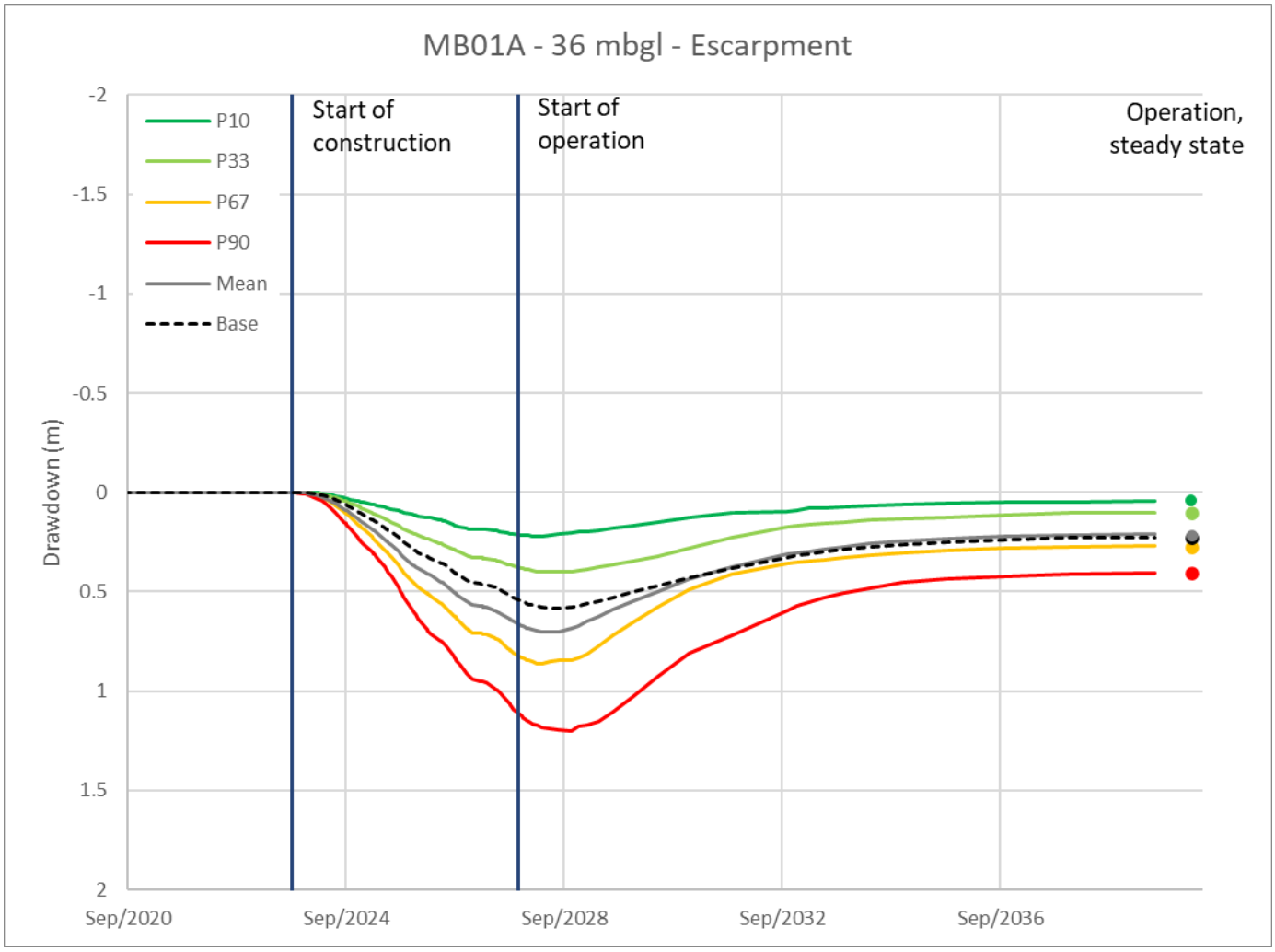

HA2202 - 1 mbgl - Plateau
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

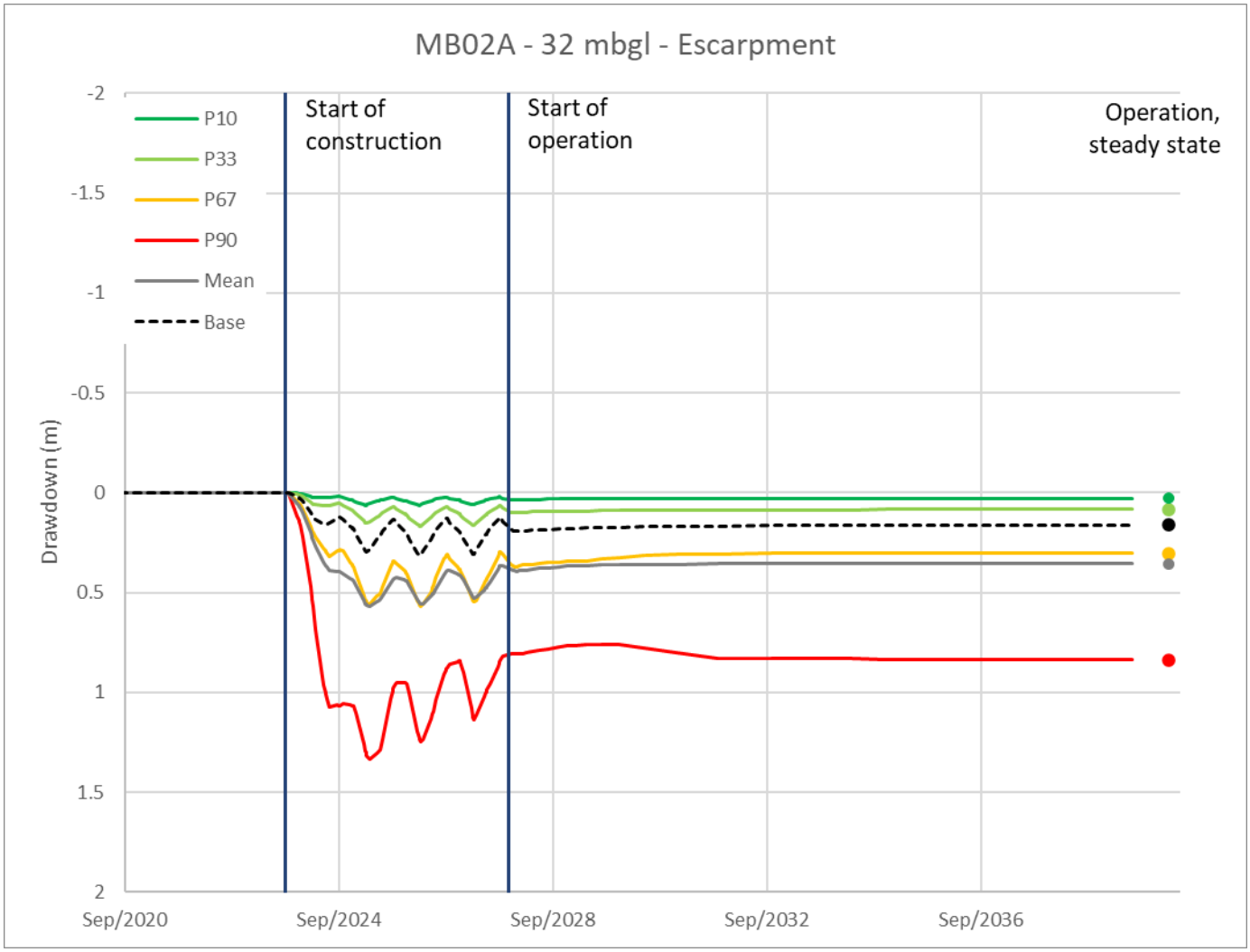

HA2203 - 1 mbgl - Plateau
Drawdown (m)
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

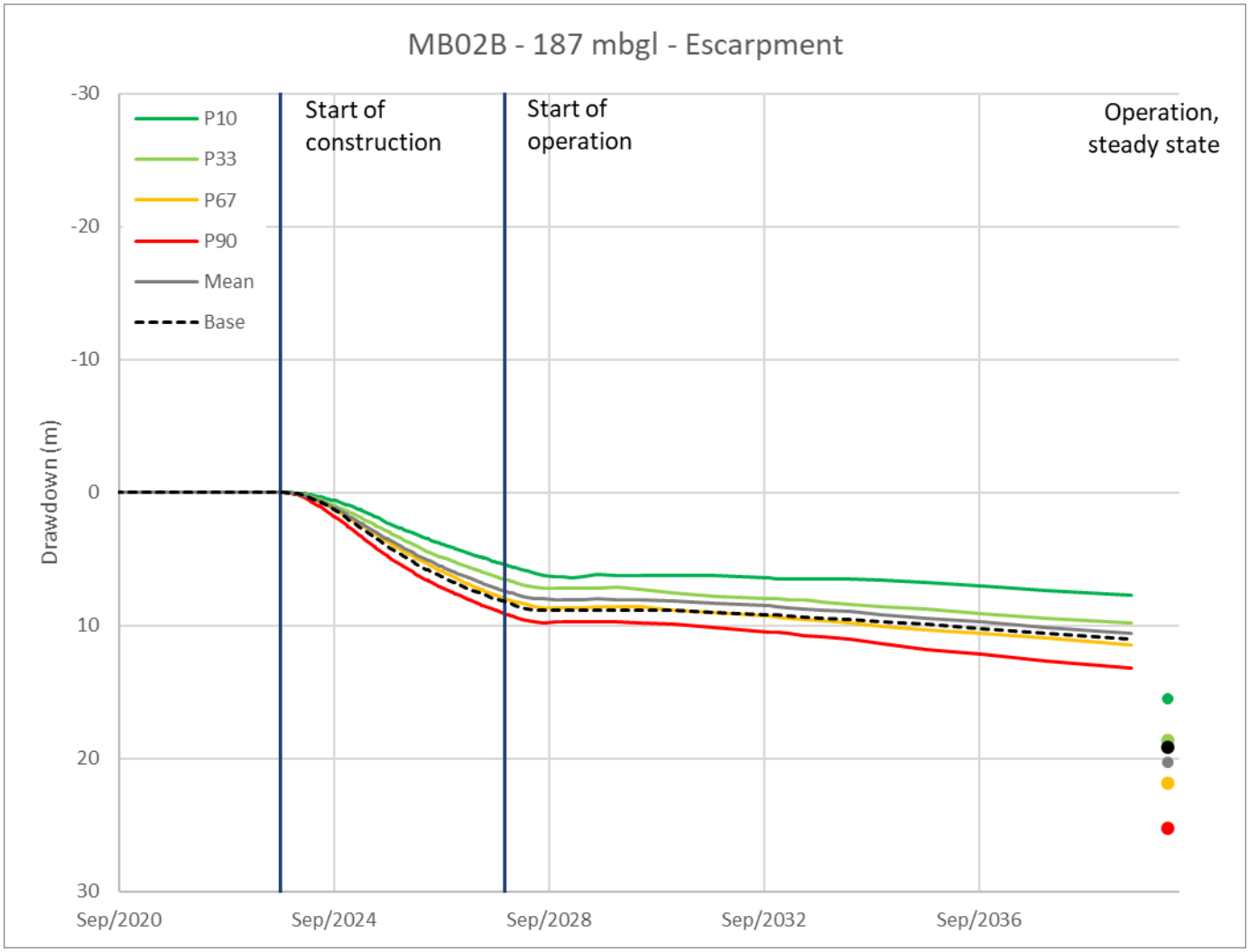
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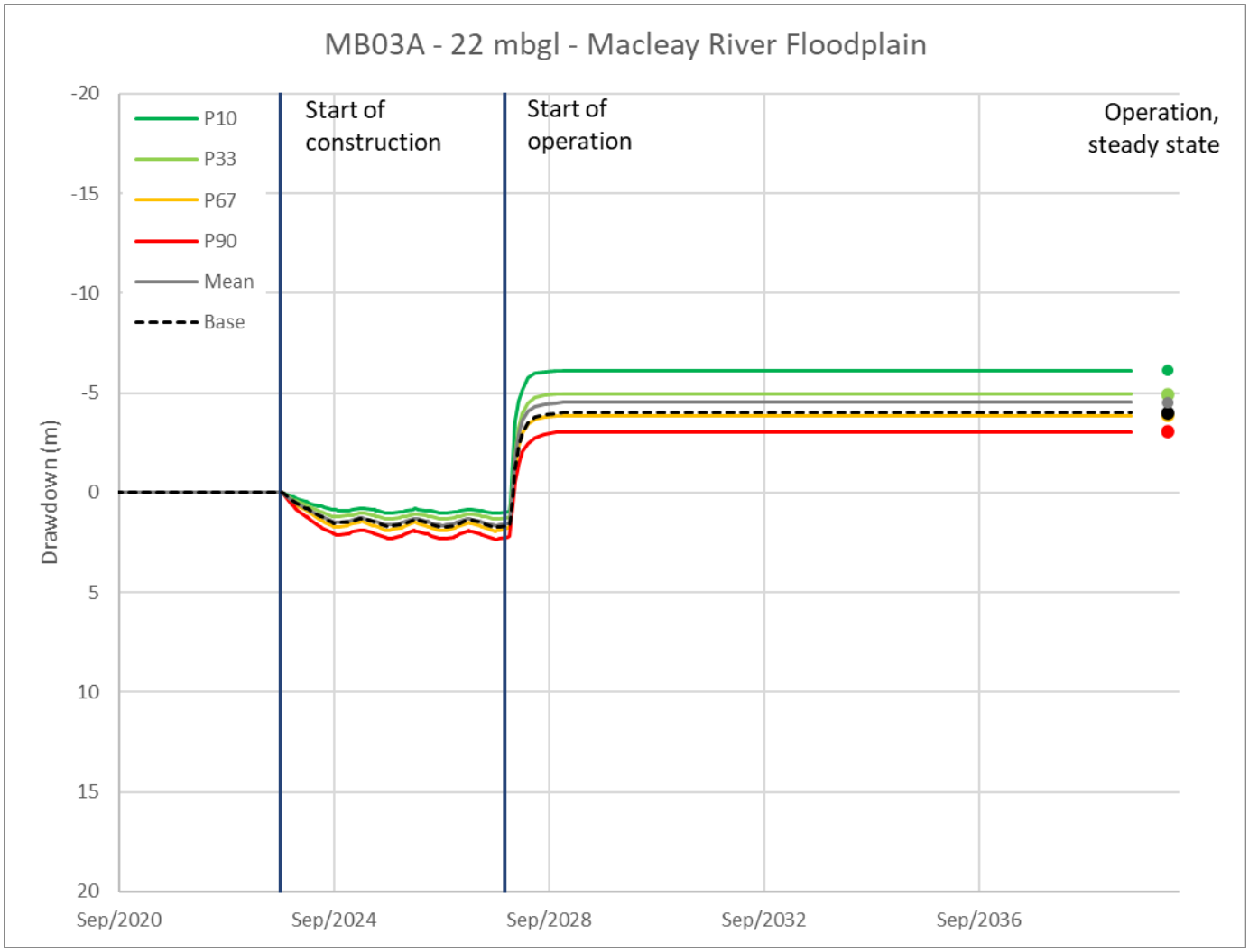

OM6 - 50 mbgl - Escarpment
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-30
-20
-10
0
10
20
30
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

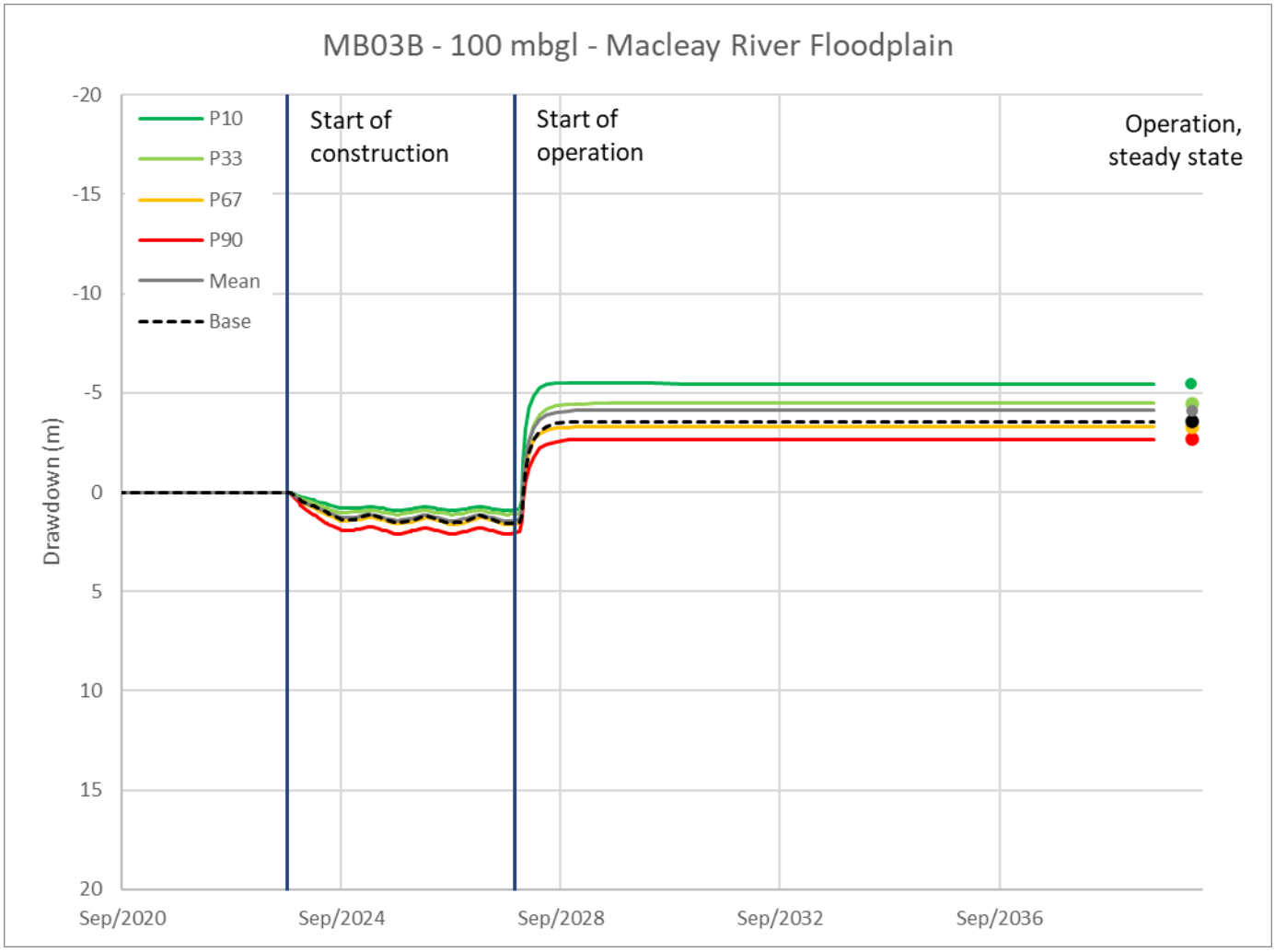

OM7 - 50 mbgl - Escarpment
Drawdown (m)
-30
-20
-10
0
10
20
30
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state

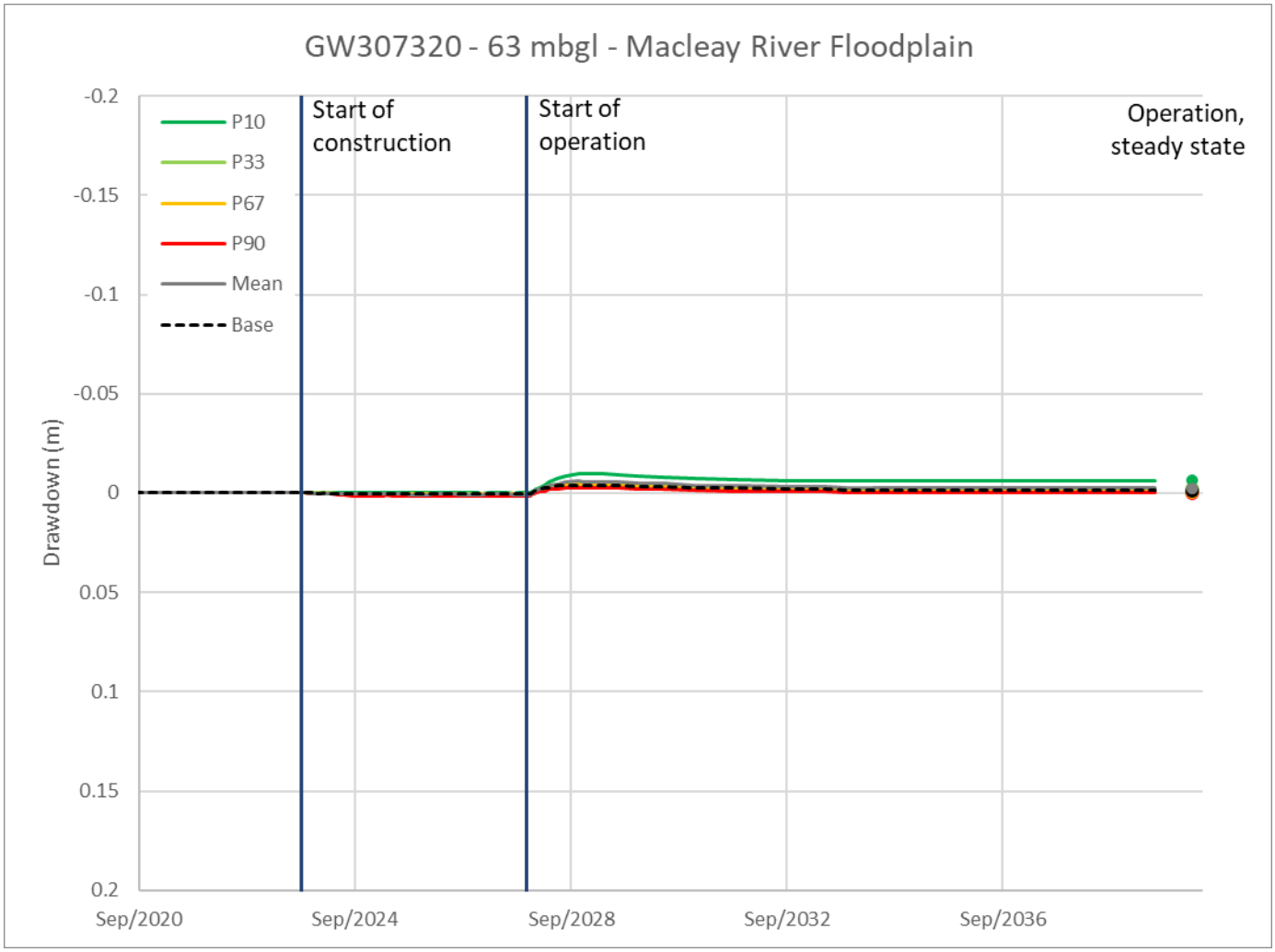

MB01A - 36 mbgl - Escarpment
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

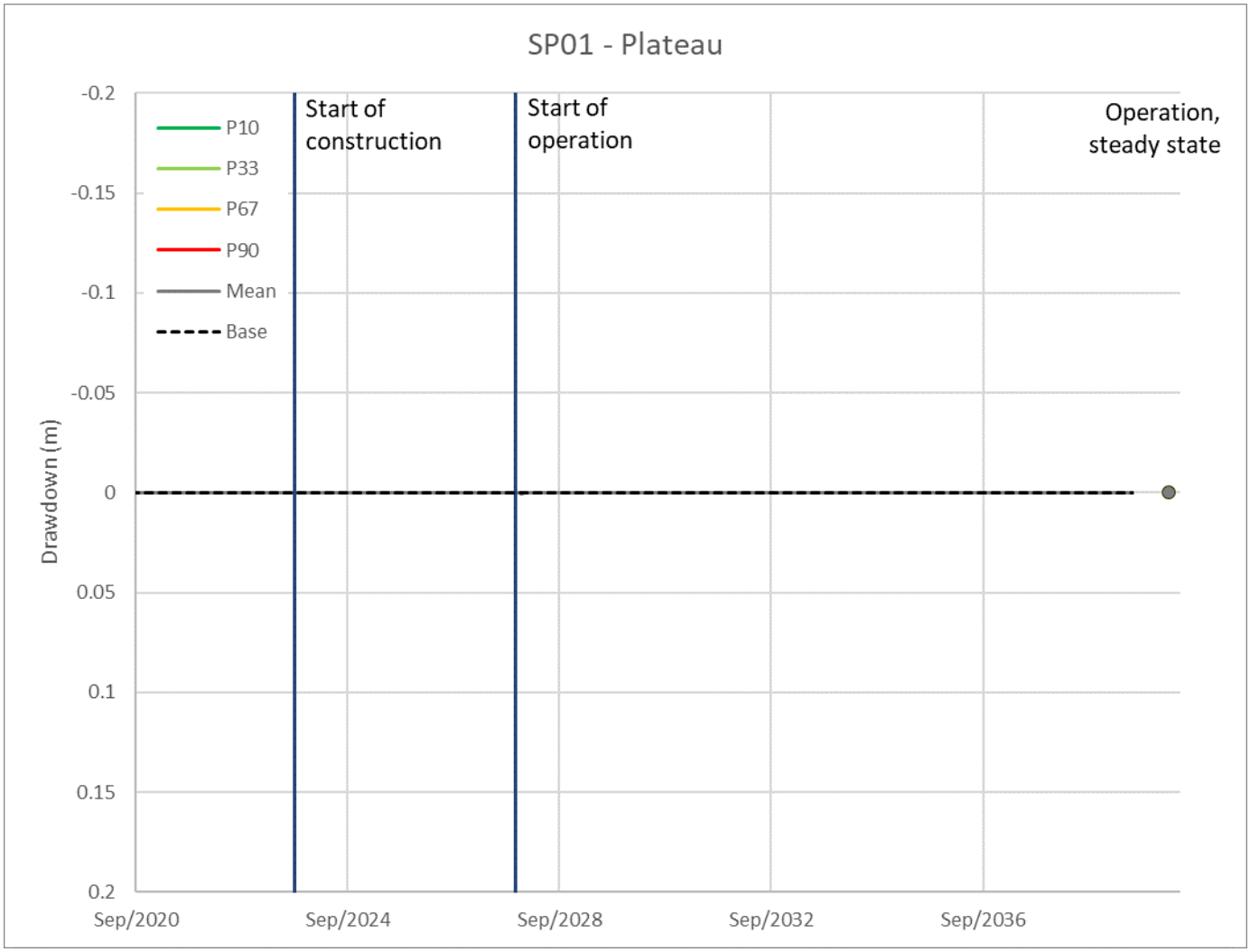

MB02A - 32 mbgl - Escarpment
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

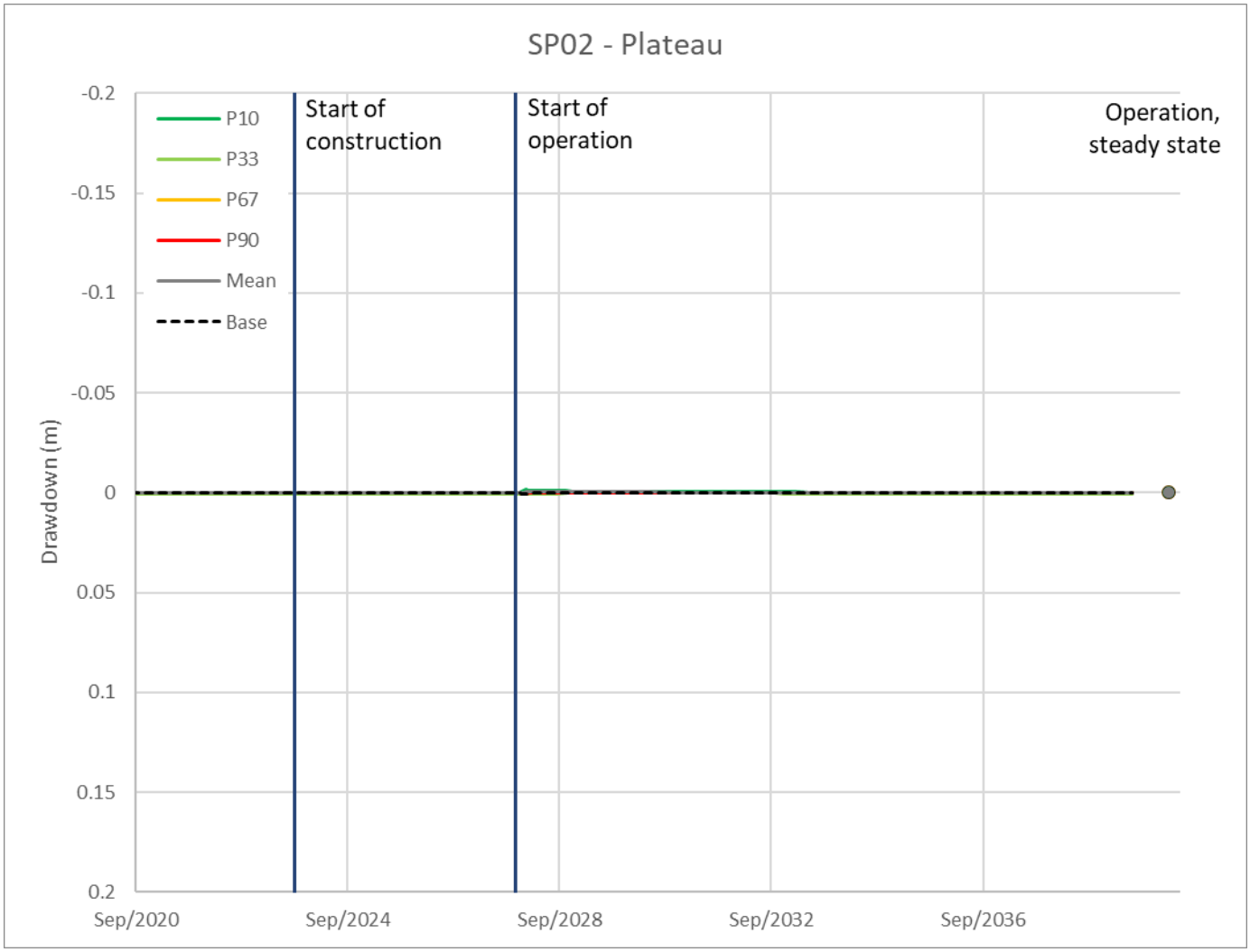

MB02B - 187 mbgl - Escarpment
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-30
-20
-10
0
10
20
30
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

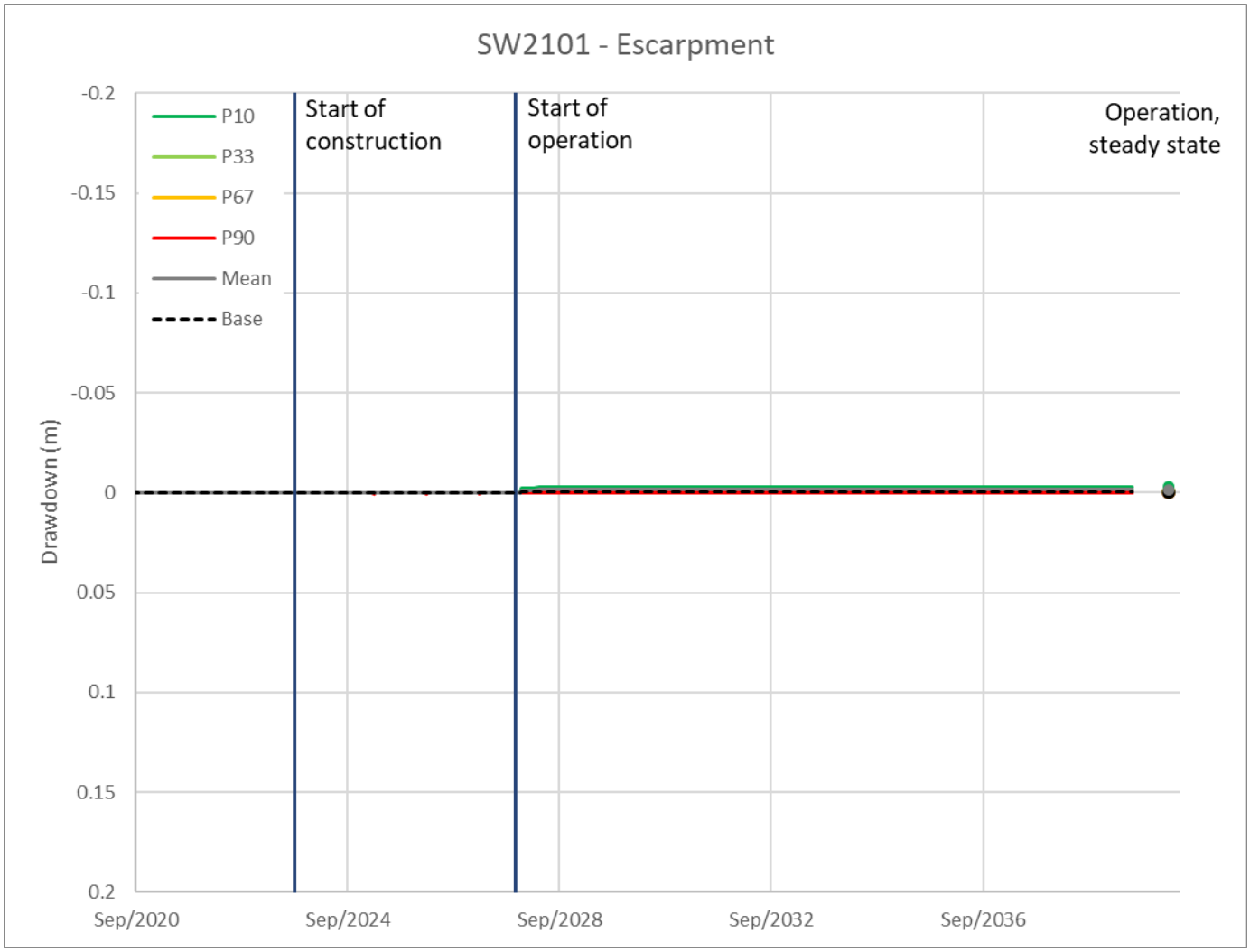

MB03A - 22 mbgl - Macleay River Floodplain
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-20
-15
-10
-5
0
5
10
15
20
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

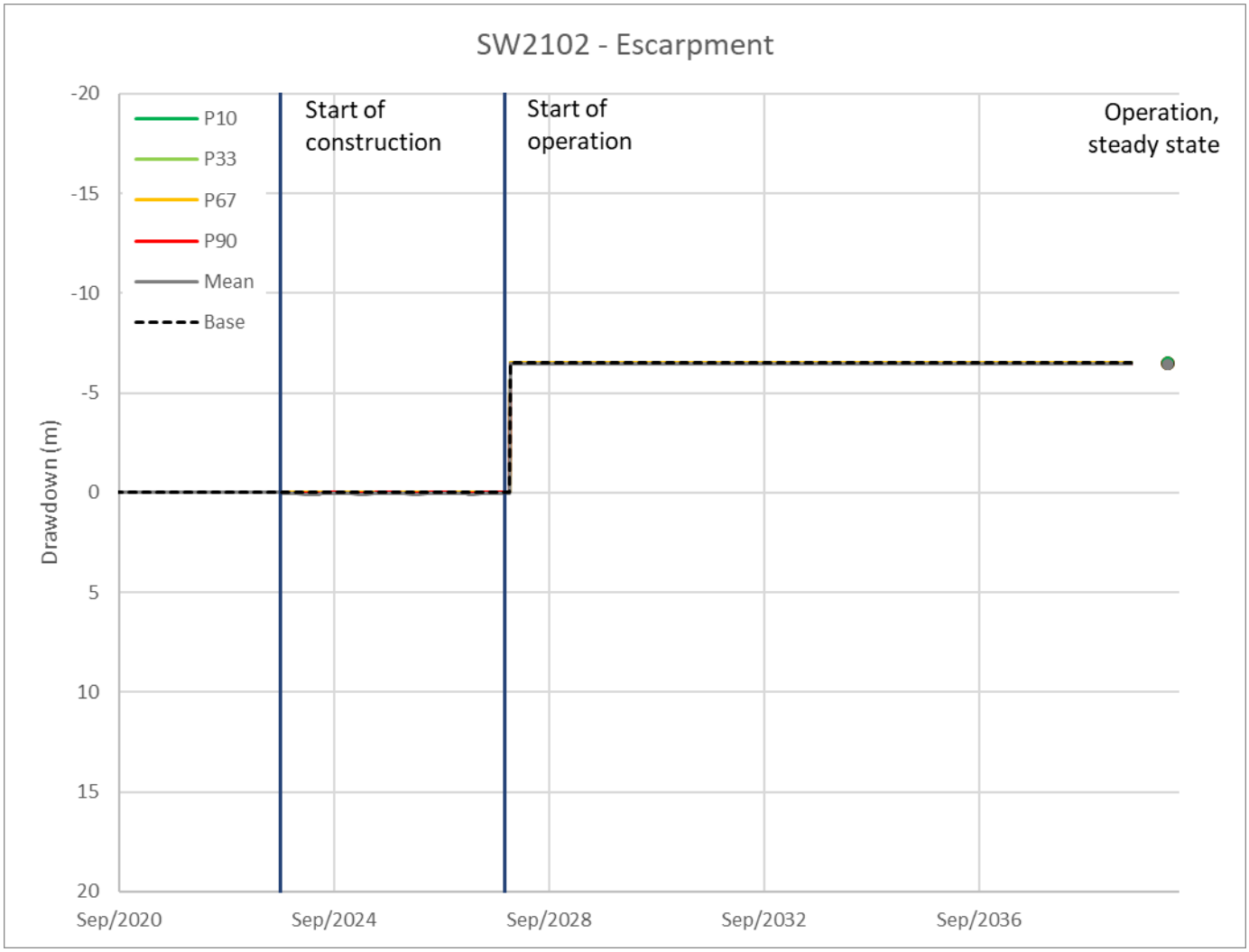

MB03B - 100 mbgl - Macleay River Floodplain
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-20
-15
-10
-5
0
5
10
15
20
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

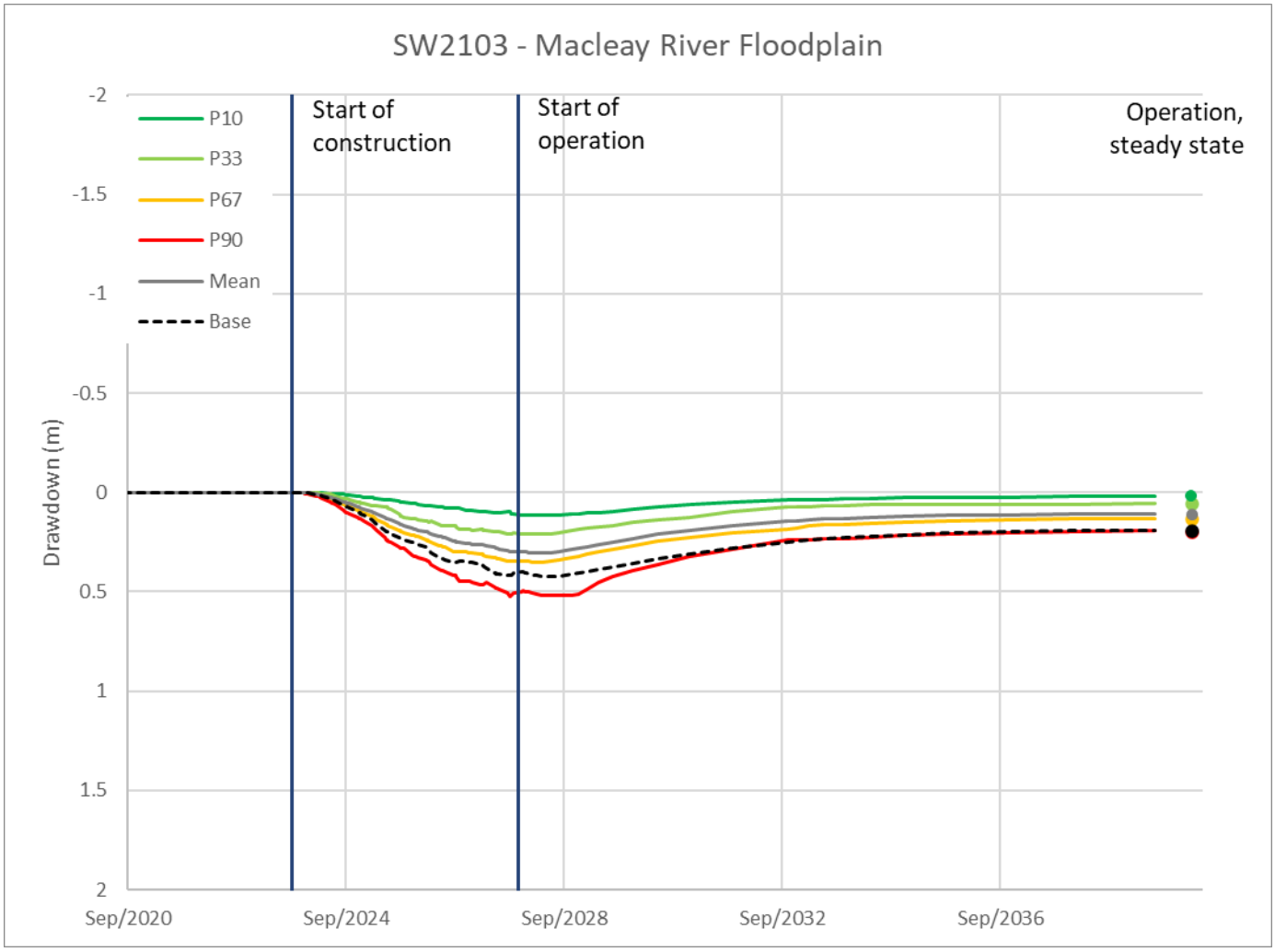

GW307320 - 63 mbgl - Macleay River Floodplain
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036


SP01 - Plateau
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

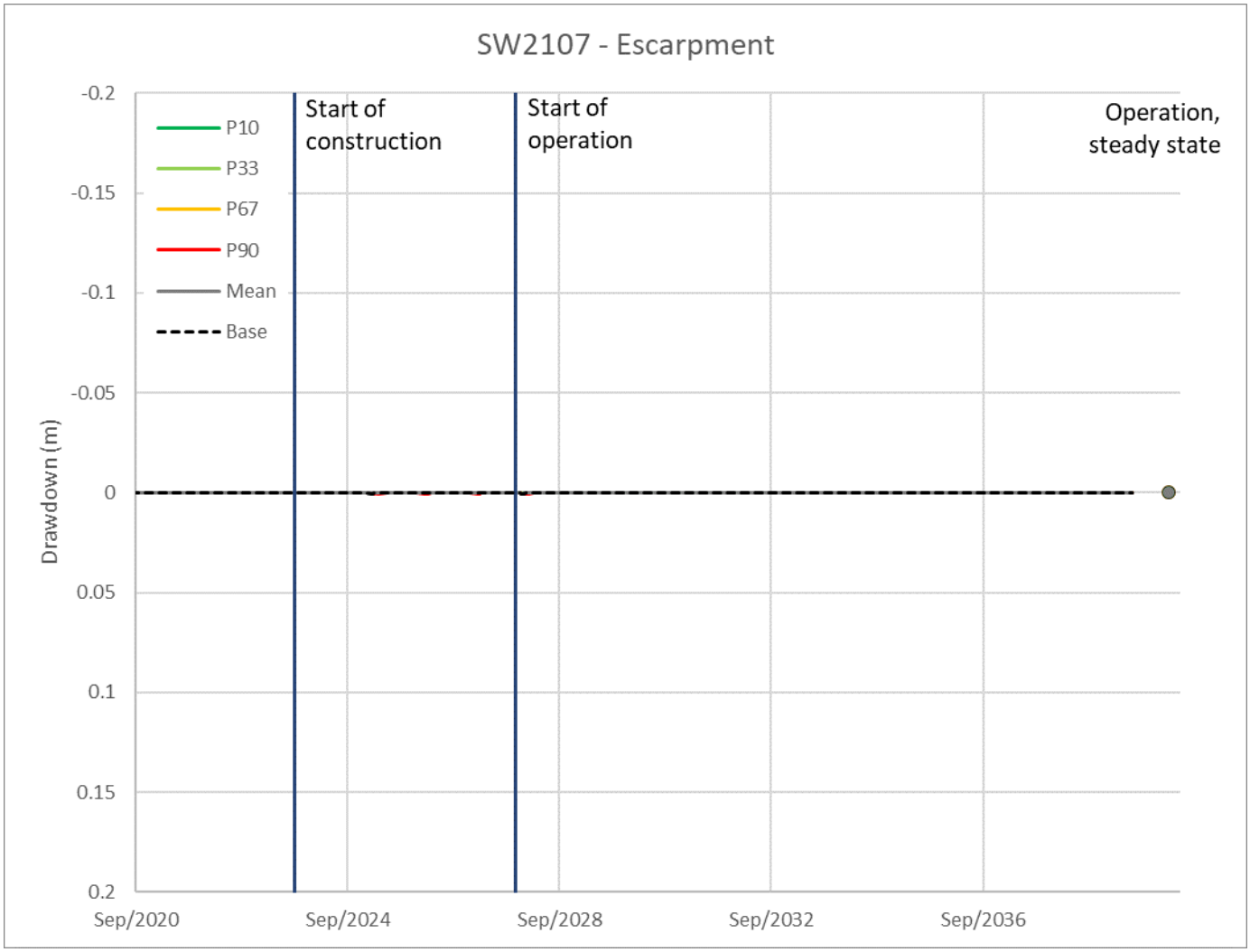

SP02 - Plateau
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

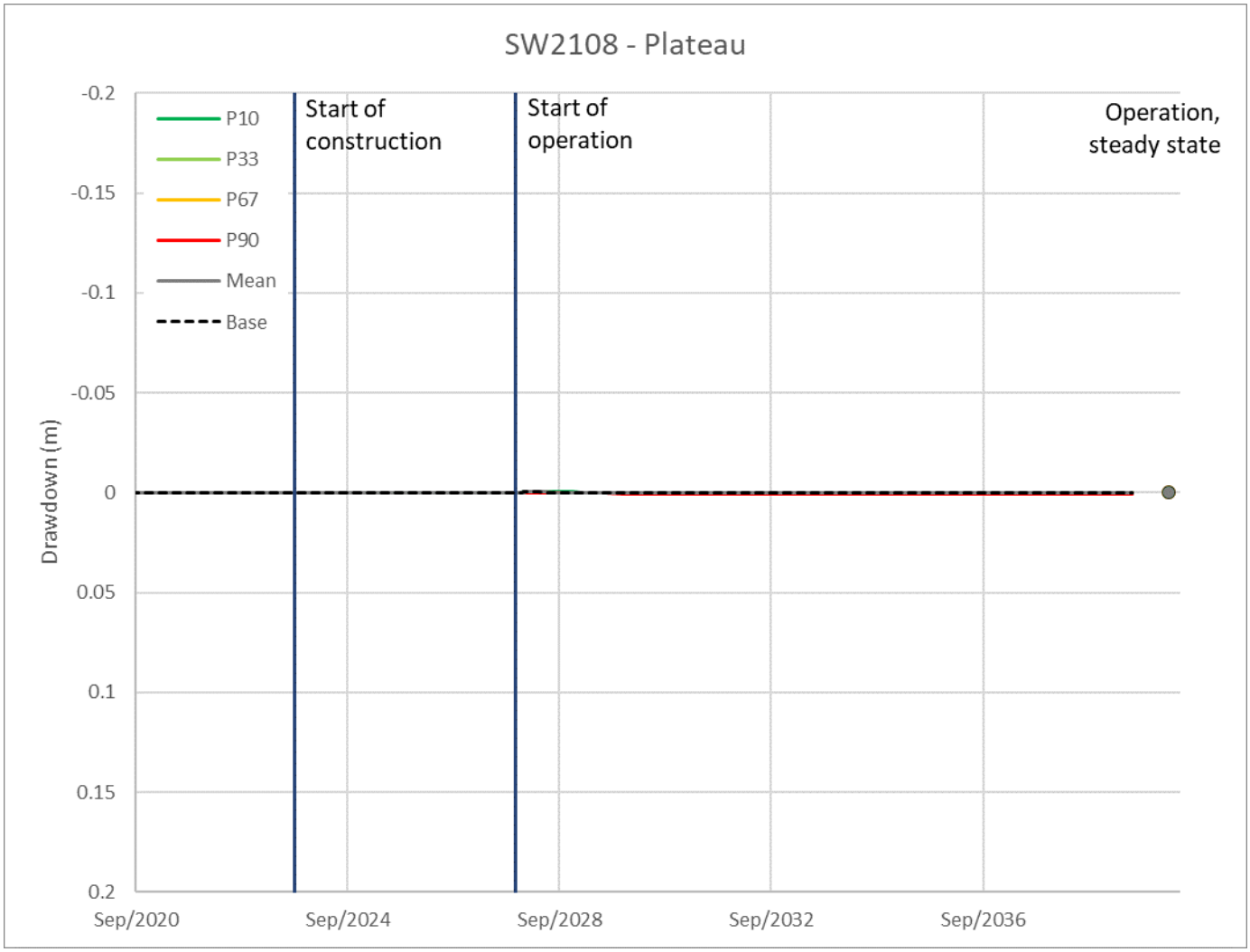

SW2101 - Escarpment
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

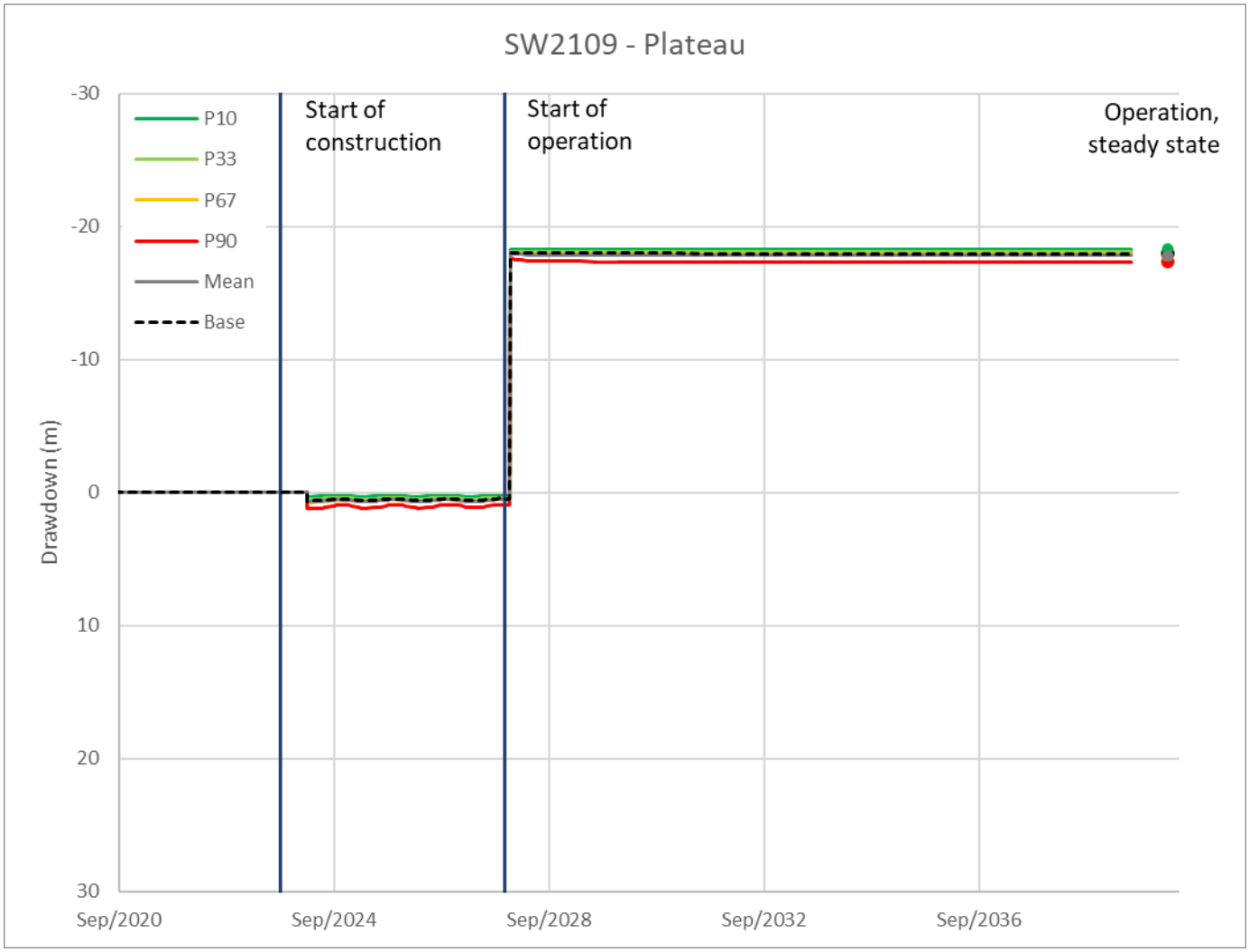

SW2102 - Escarpment
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-20
-15
-10
-5
0
5
10
15
20
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

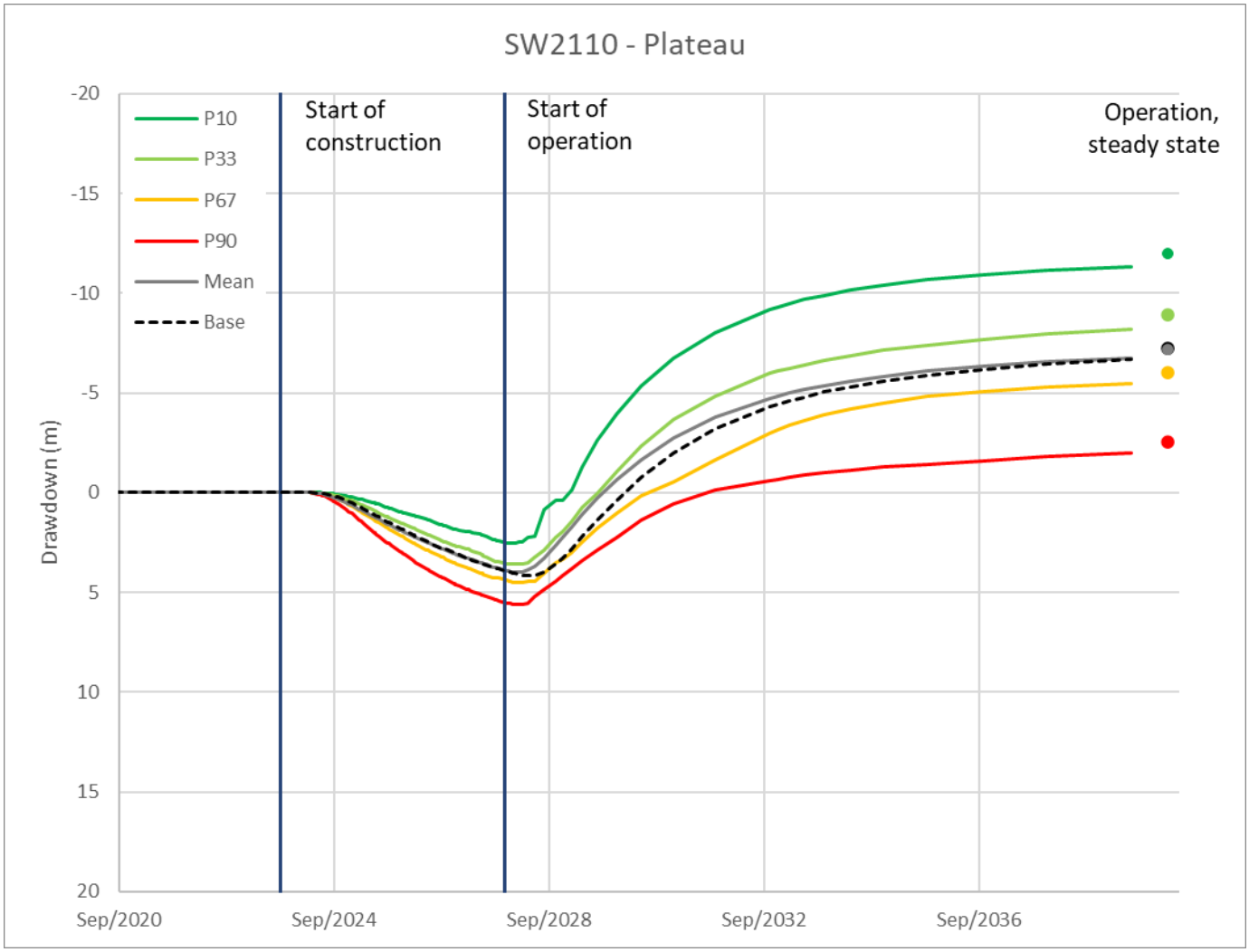

SW2103 - Macleay River Floodplain
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

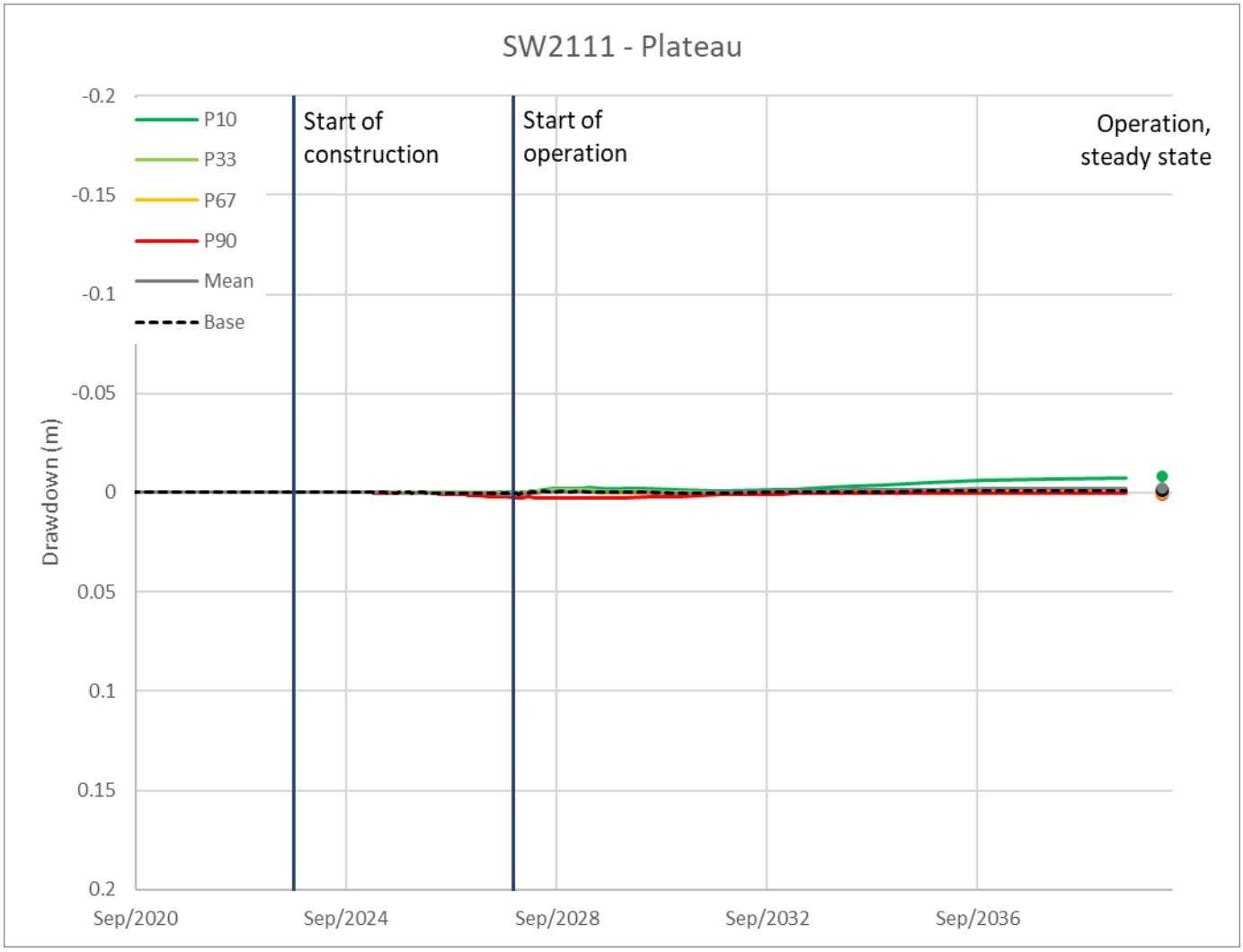

SW2106 - Escarpment
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-20
-15
-10
-5
0
5
10
15
20
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

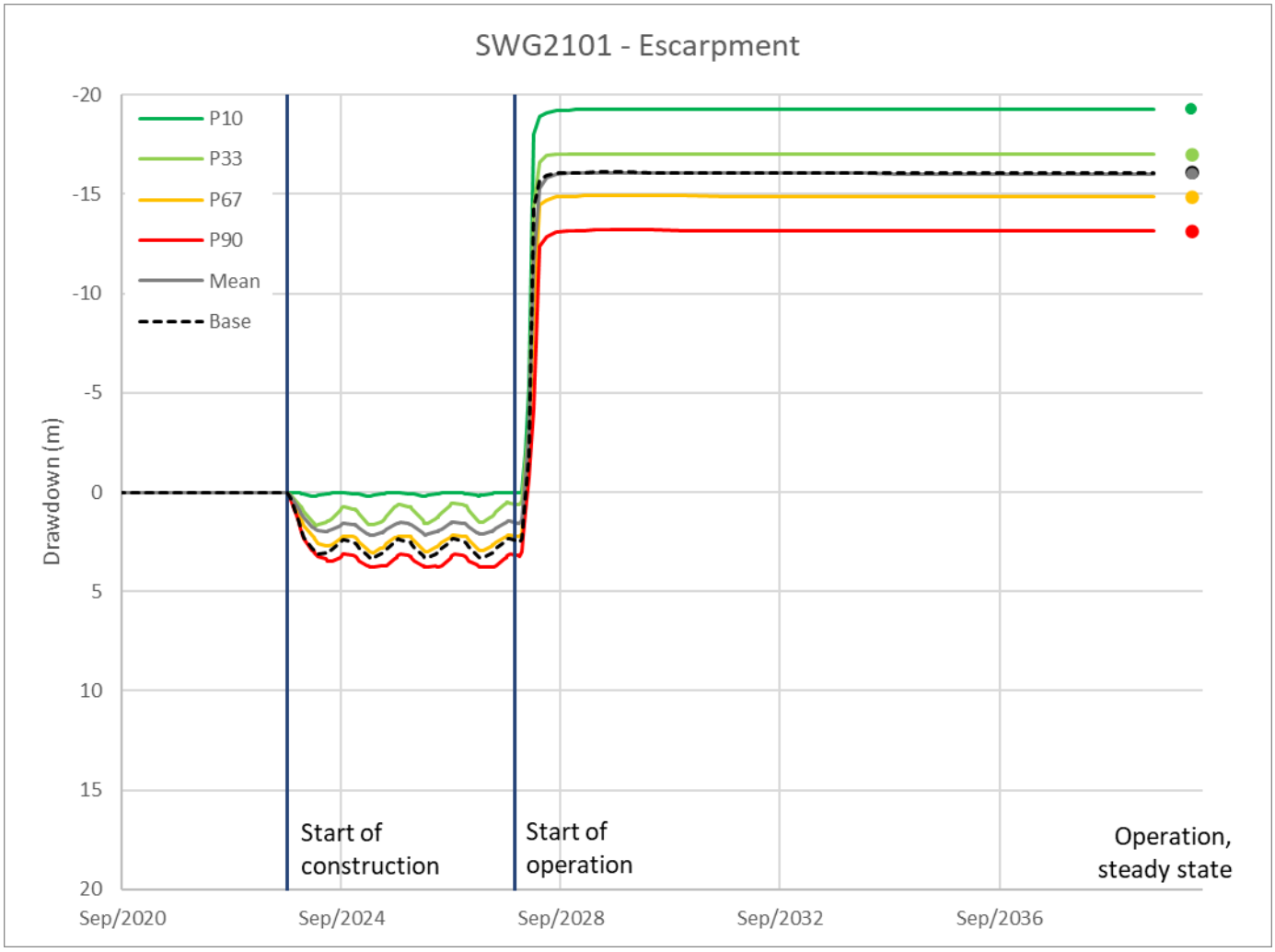

SW2107 - Escarpment
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

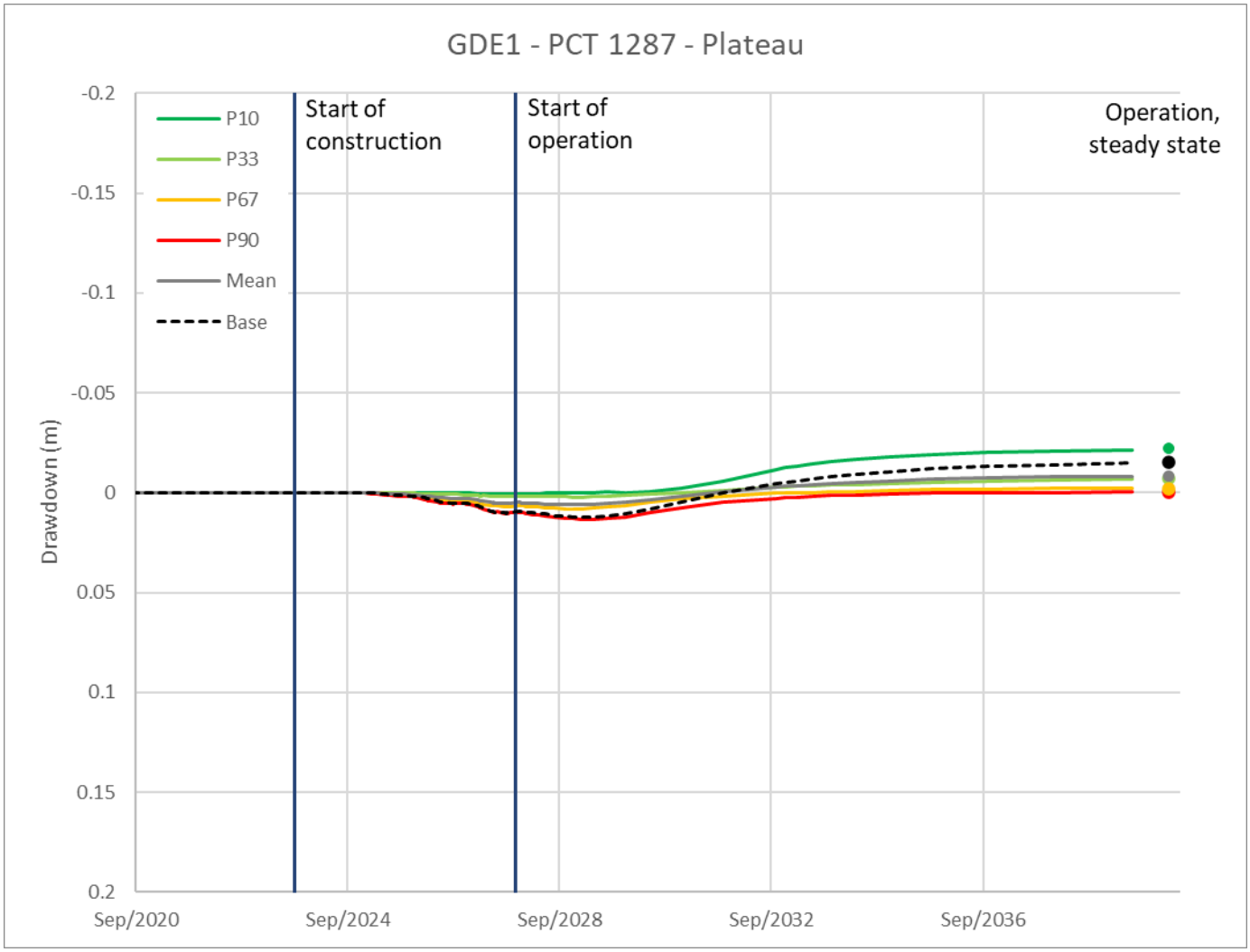

SW2108 - Plateau
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

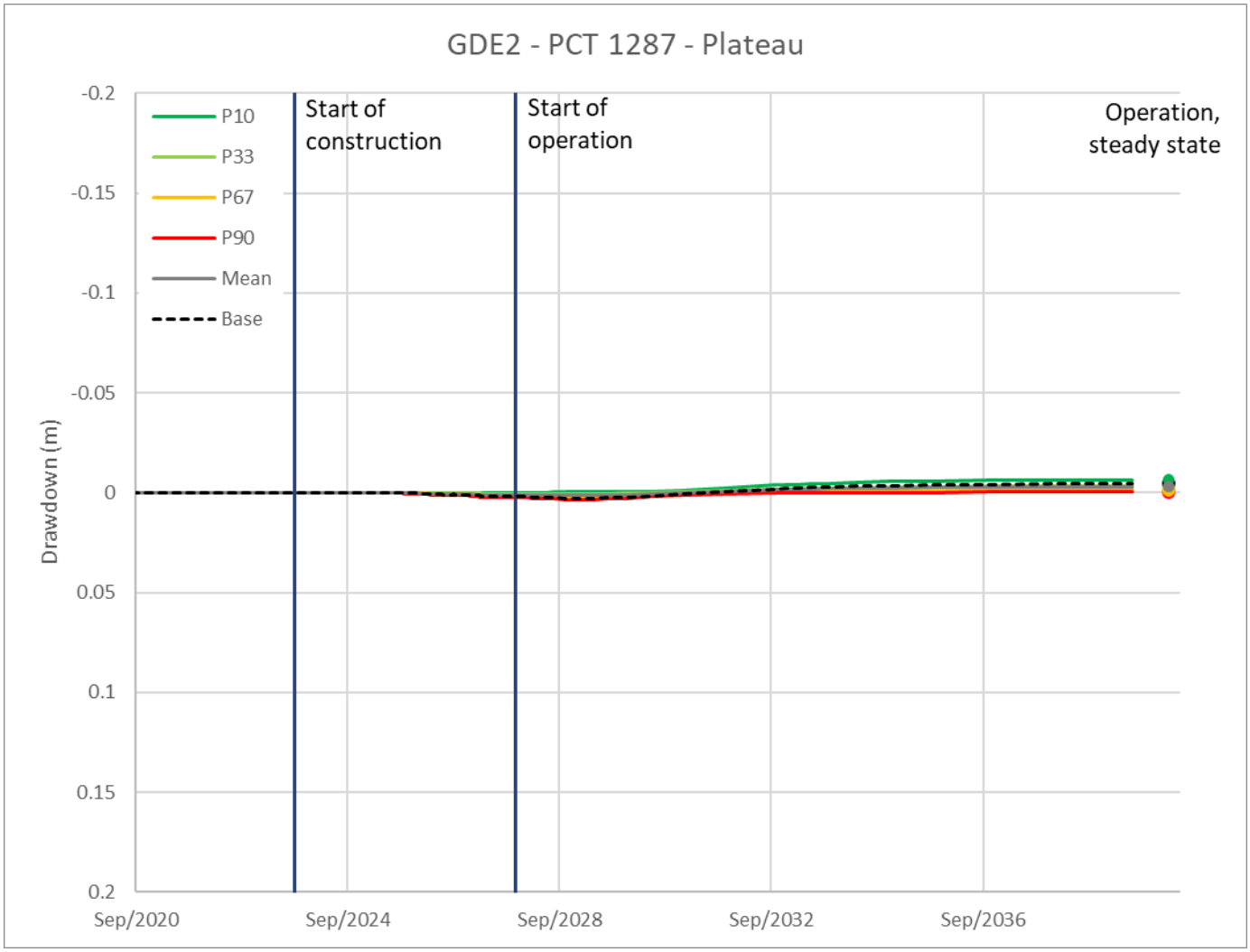

SW2109 - Plateau
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-30
-20
-10
0
10
20
30
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

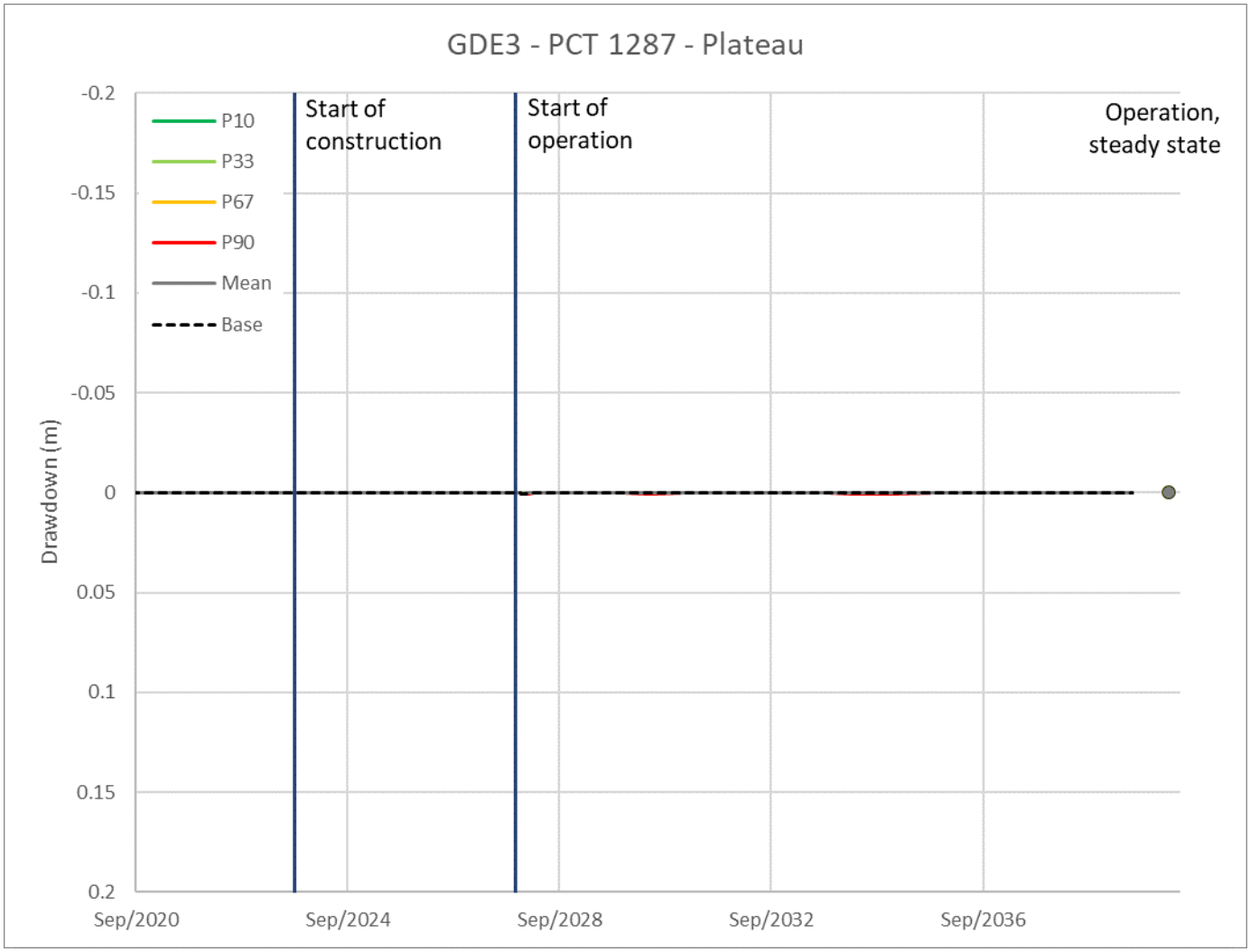

SW2110 - Plateau
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-20
-15
-10
-5
0
5
10
15
20
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

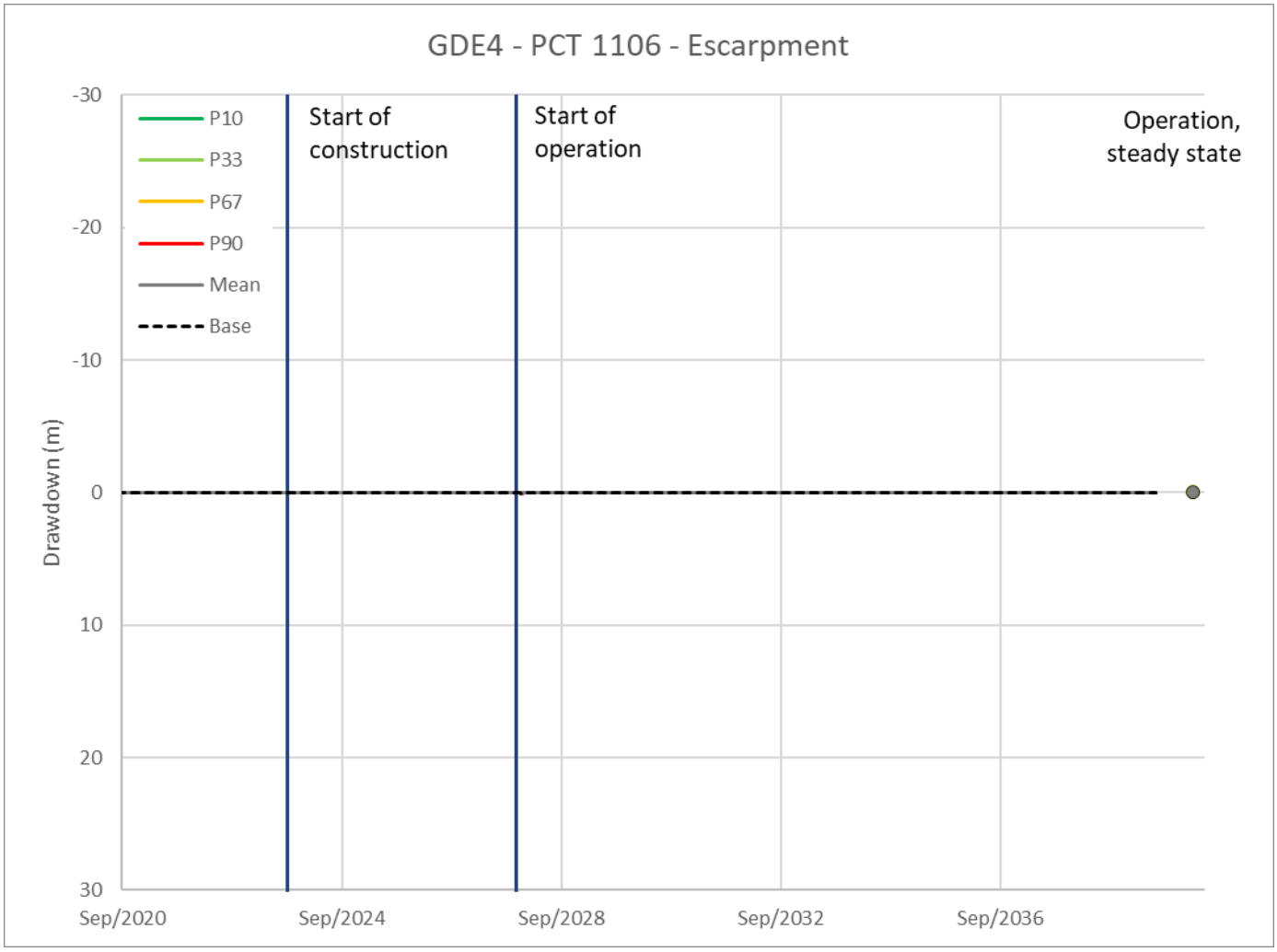

SW2111 - Plateau
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

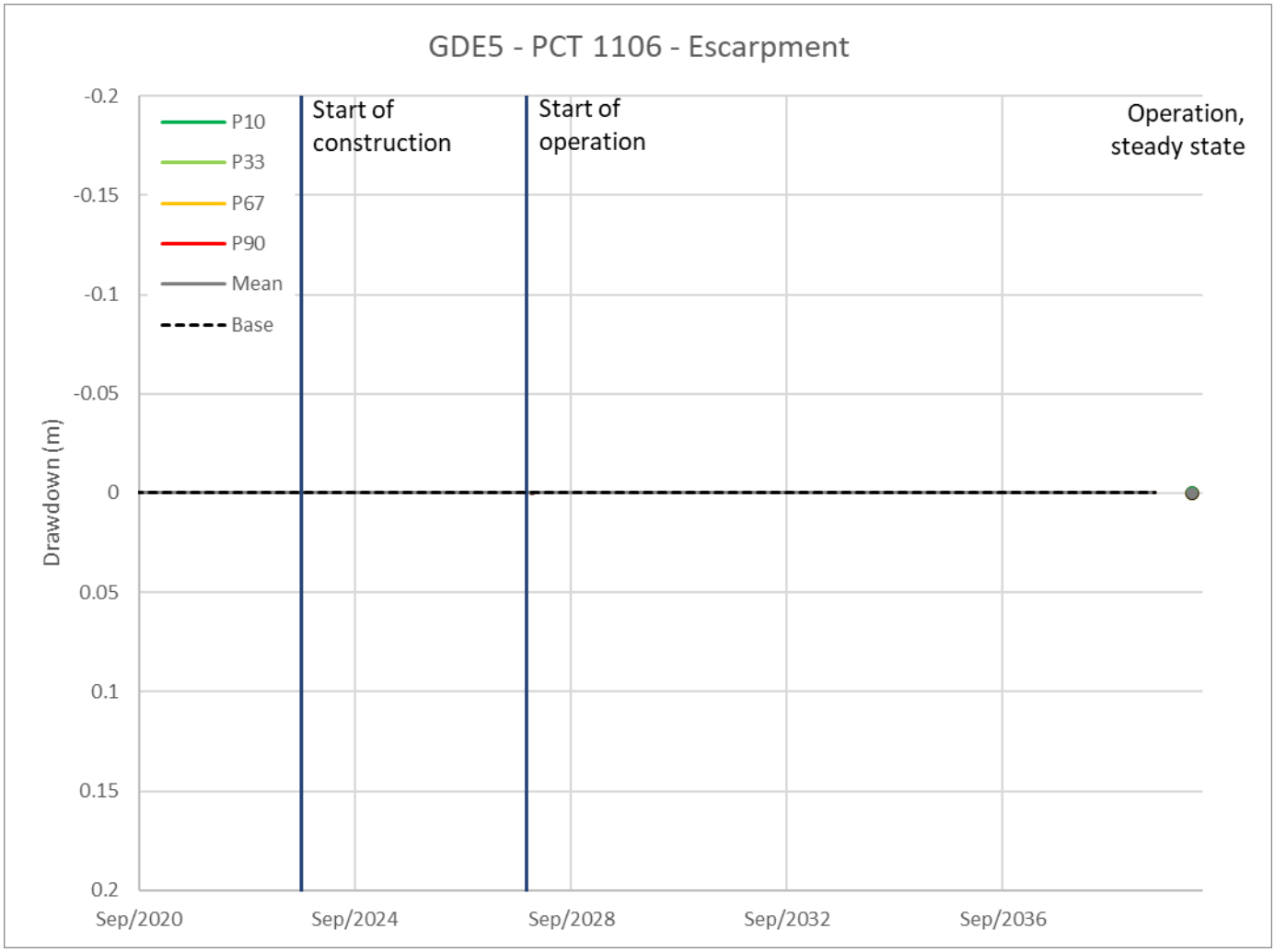

SWG2101 - Escarpment
P10
P33
P67
P90
Mean
Base
Drawdown (m)
-20
-15
-10
-5
0
5
10
15
20
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

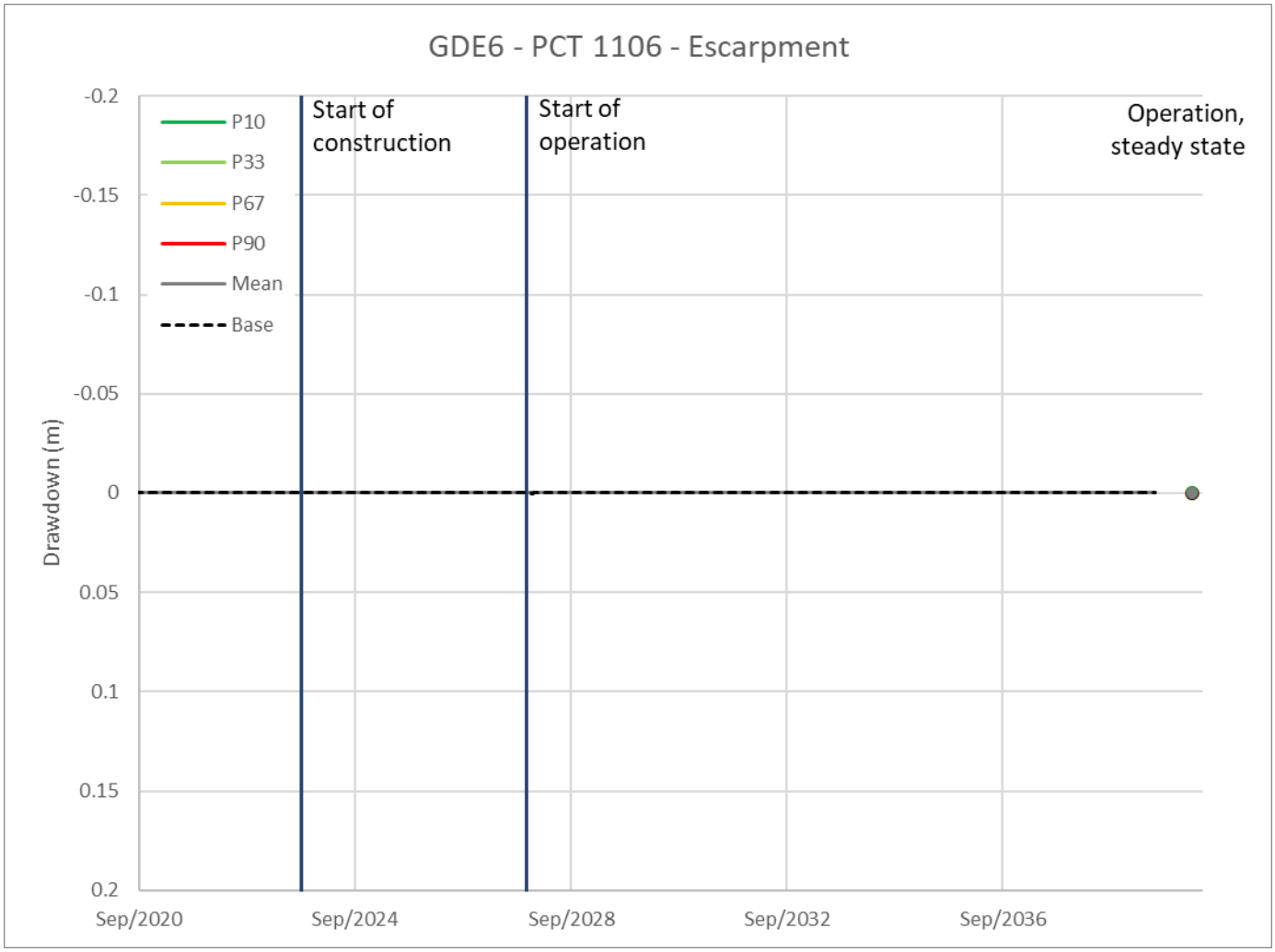

GDE1 - PCT 1287 - Plateau
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

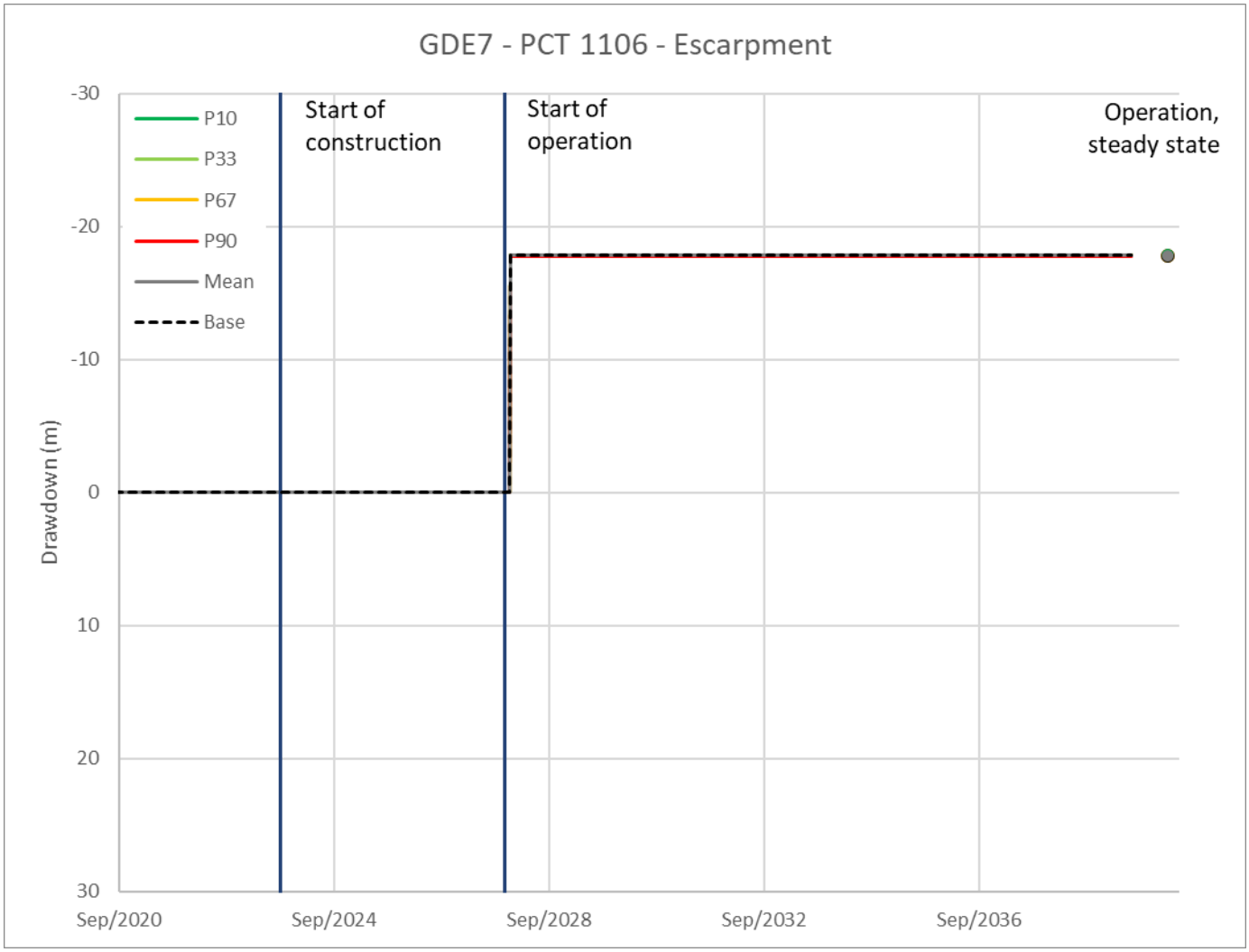

GDE2 - PCT 1287 - Plateau
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

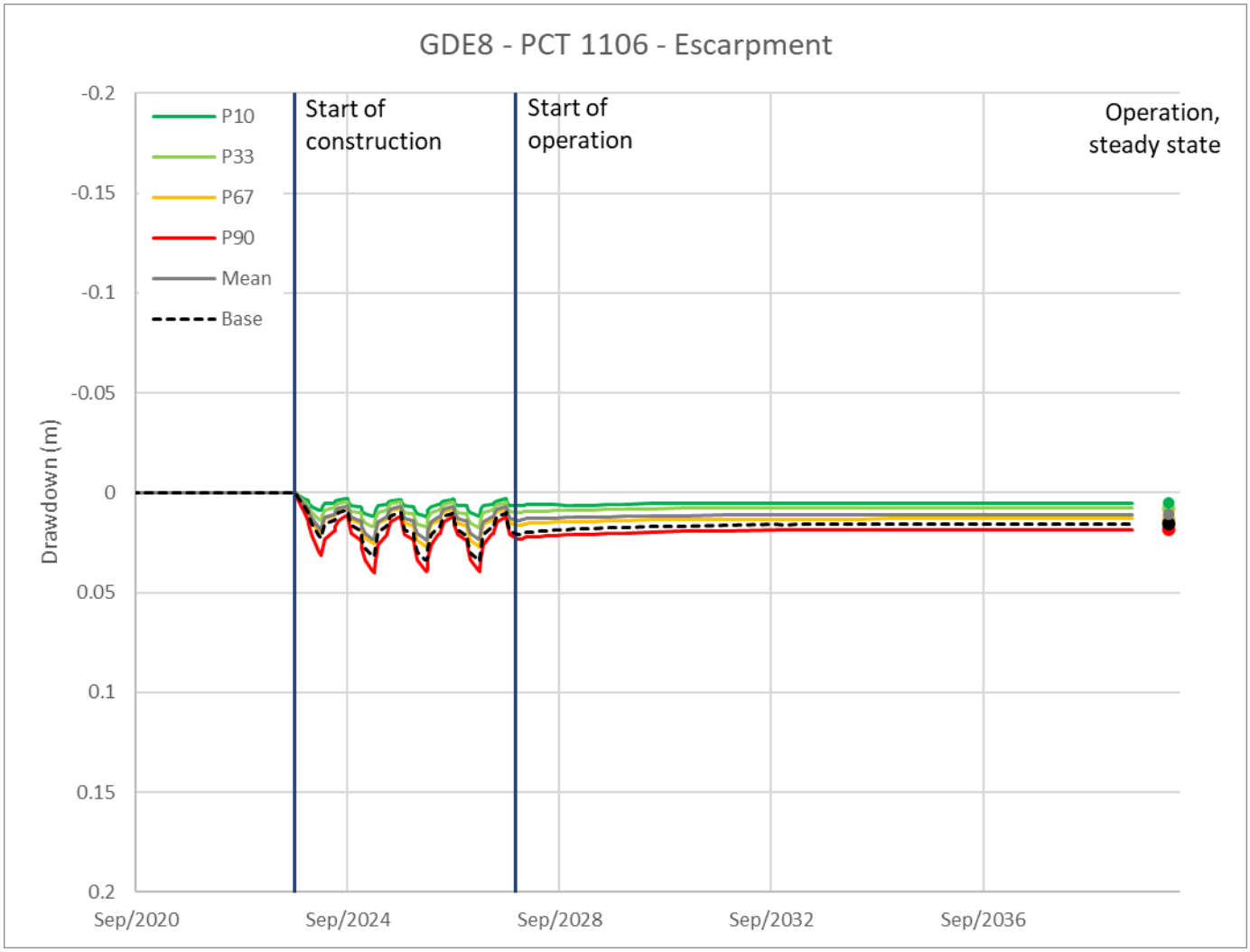

GDE3 - PCT 1287 - Plateau
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

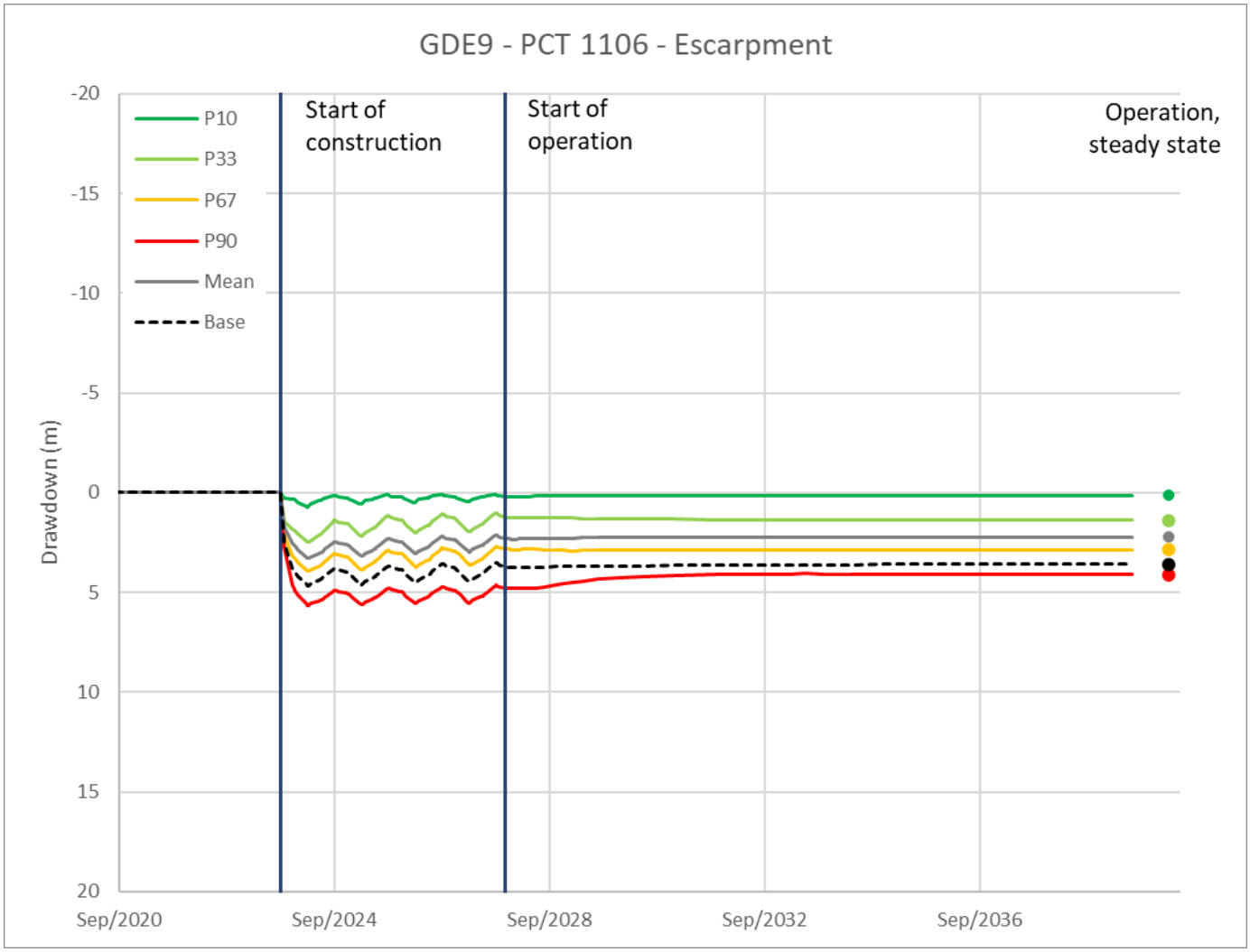

GDE4 - PCT 1106 - Escarpment
-30
-20
-10
0
10
20
30
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

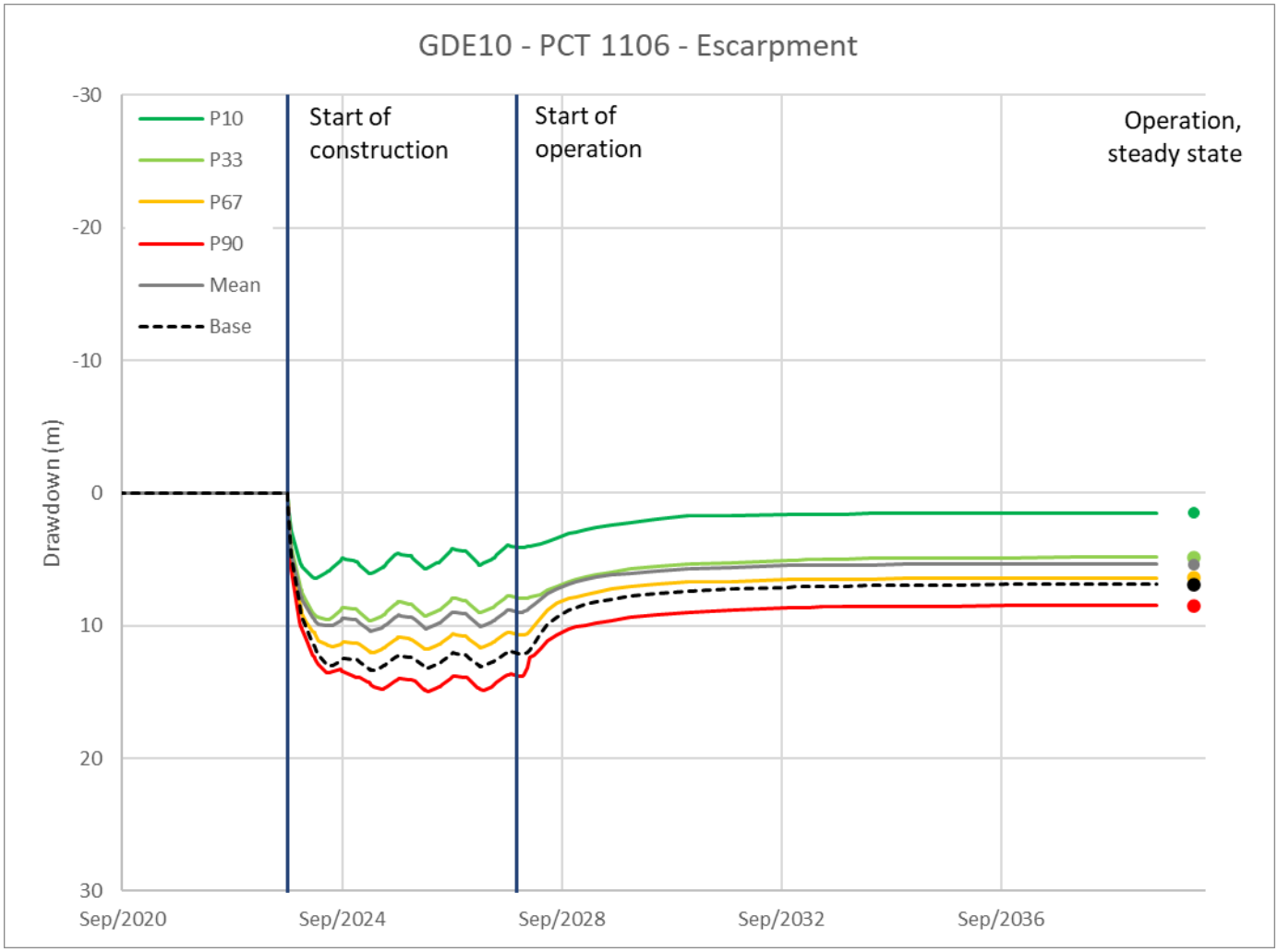

GDE5 - PCT 1106 - Escarpment
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

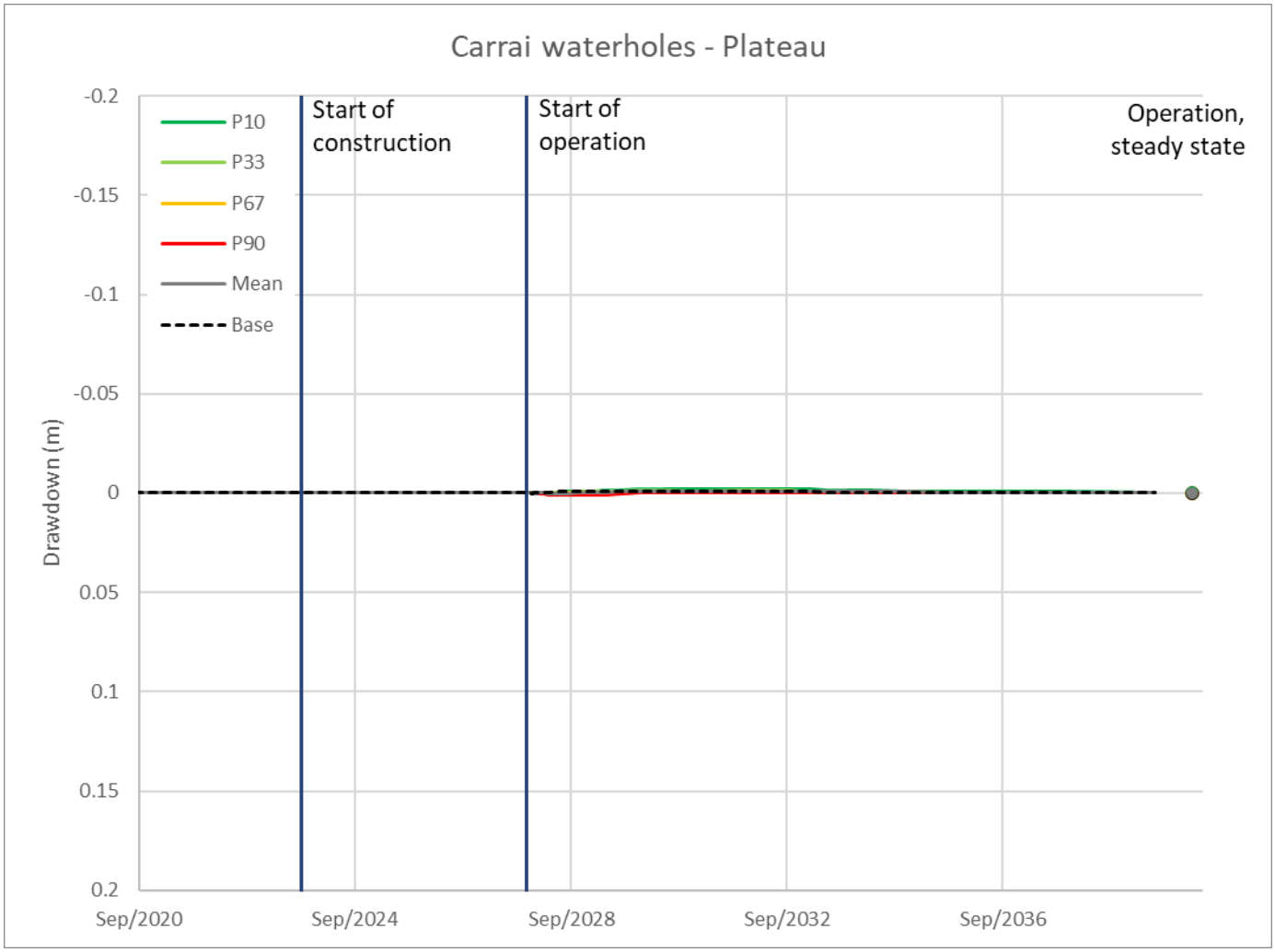

GDE6 - PCT 1106 - Escarpment
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

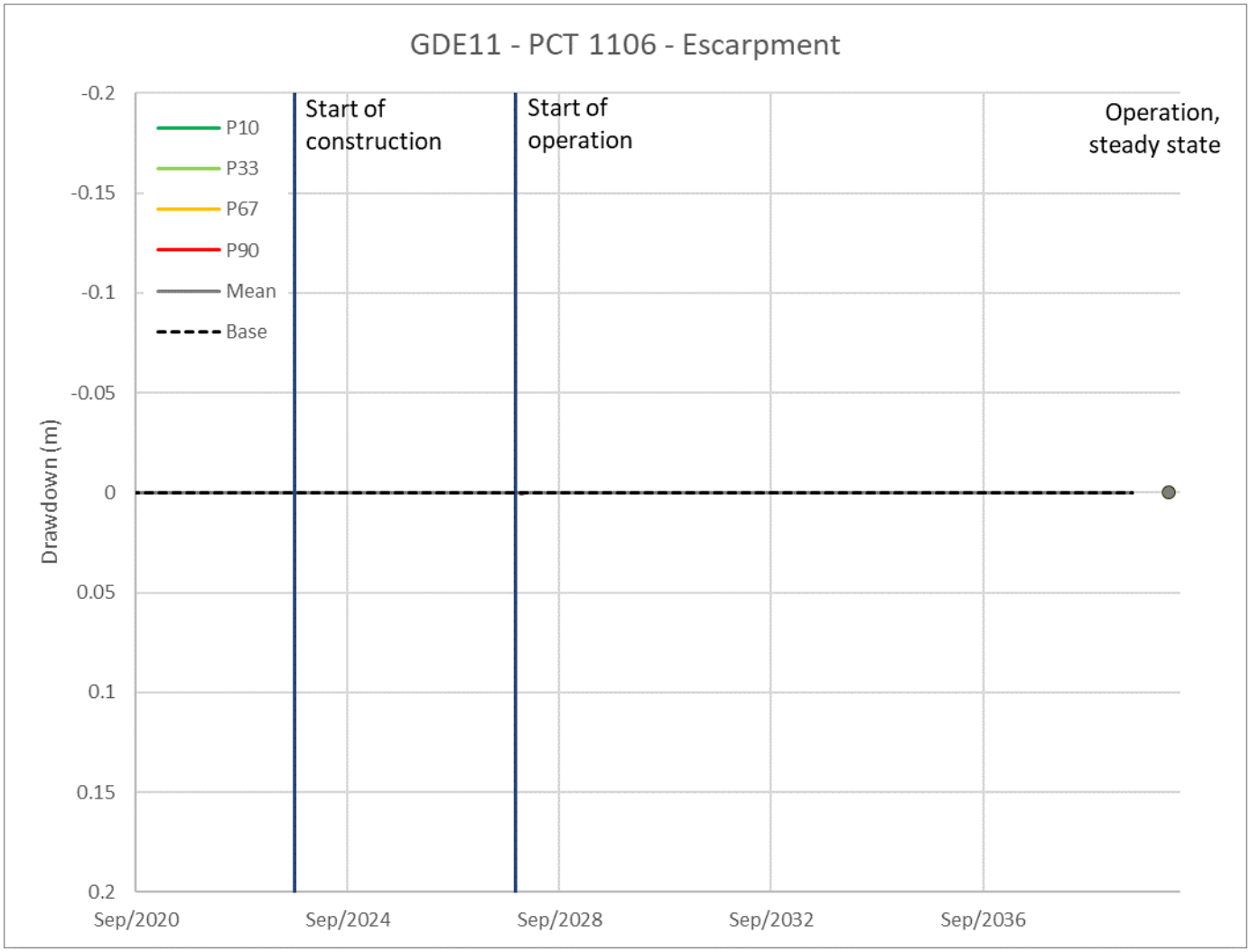

GDE7 - PCT 1106 - Escarpment
-30
-20
-10
0
10
20
30
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

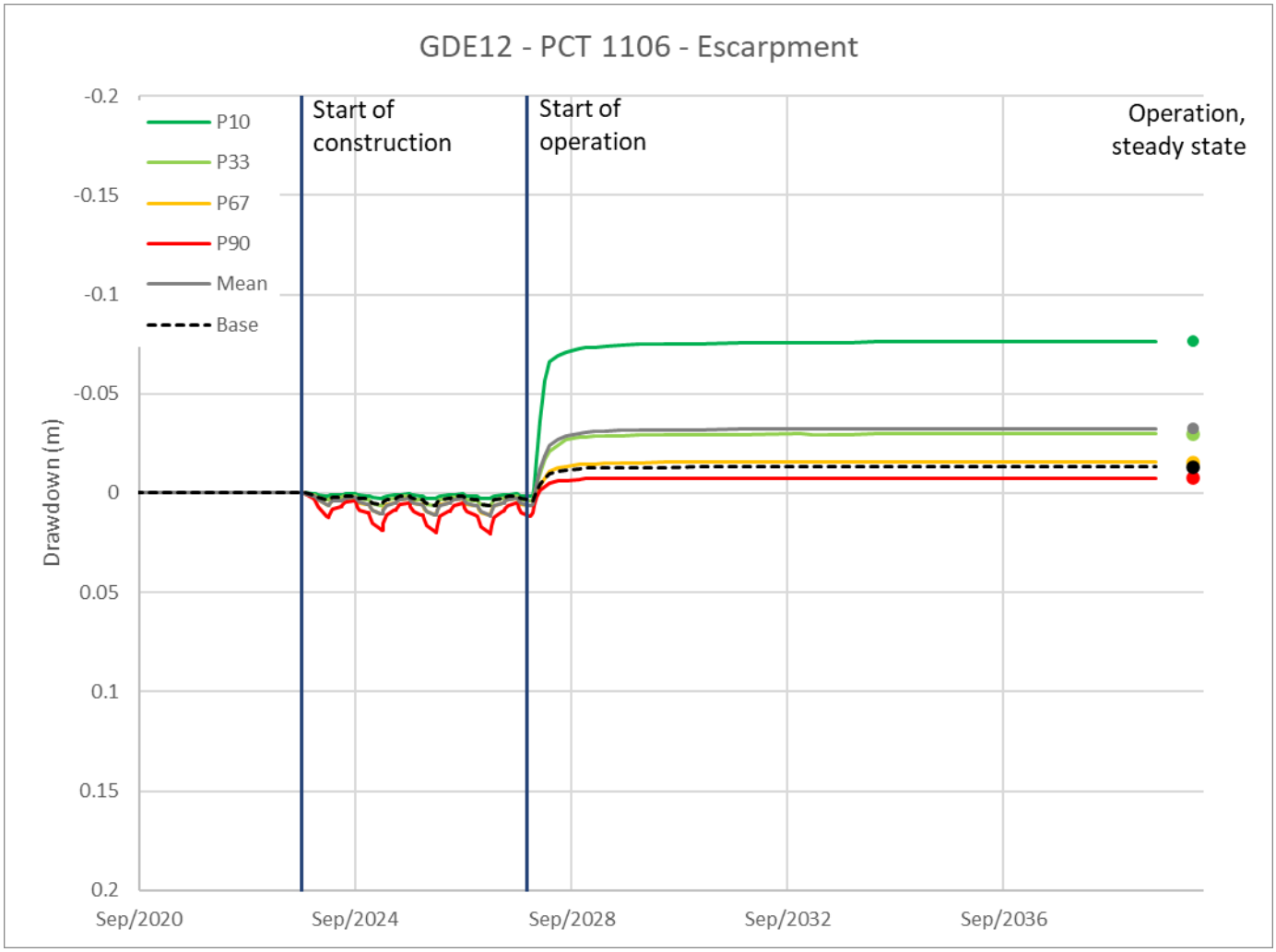

GDE8 - PCT 1106 - Escarpment
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

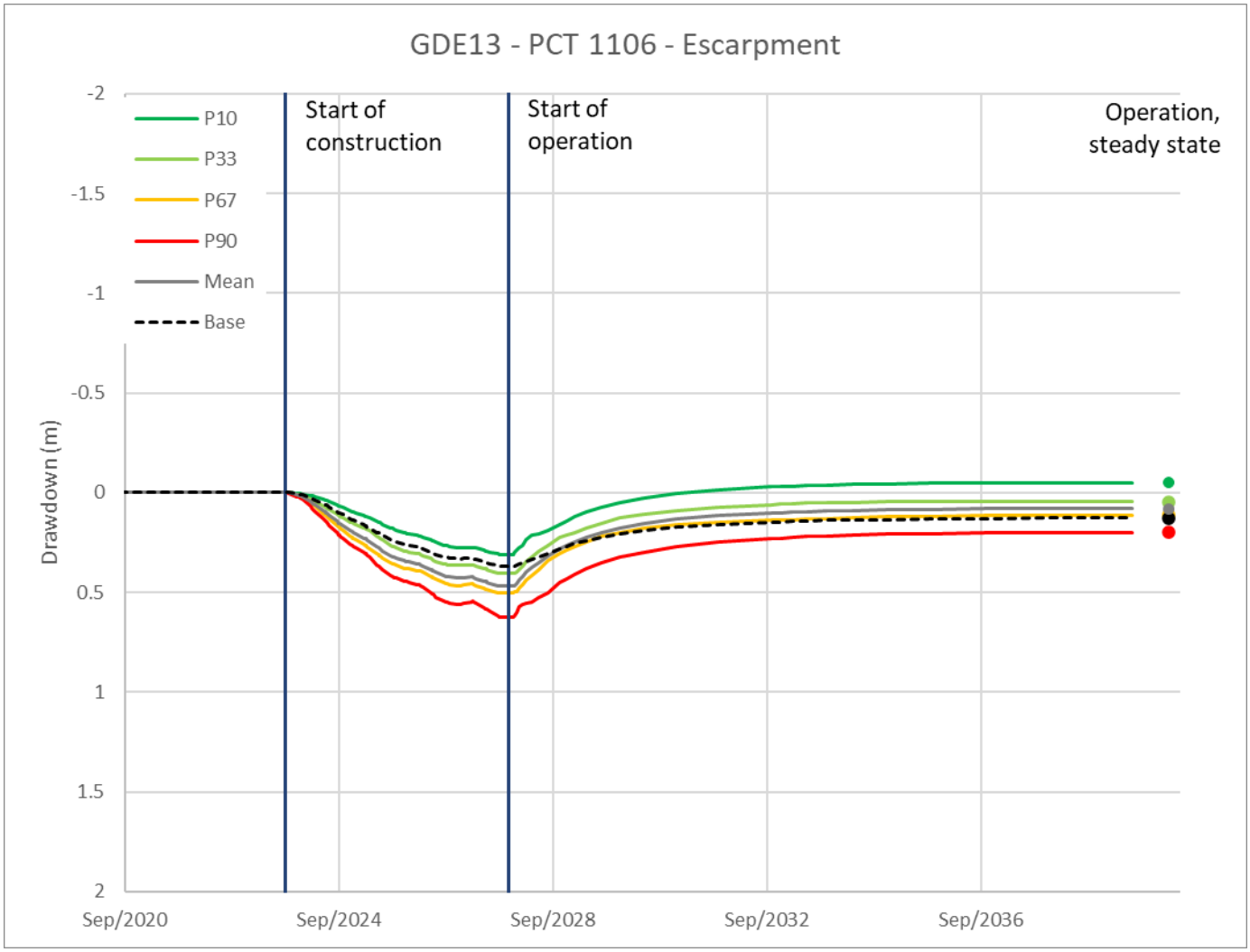

GDE9 - PCT 1106 - Escarpment
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-20
-15
-10
-5
0
5
10
15
20
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

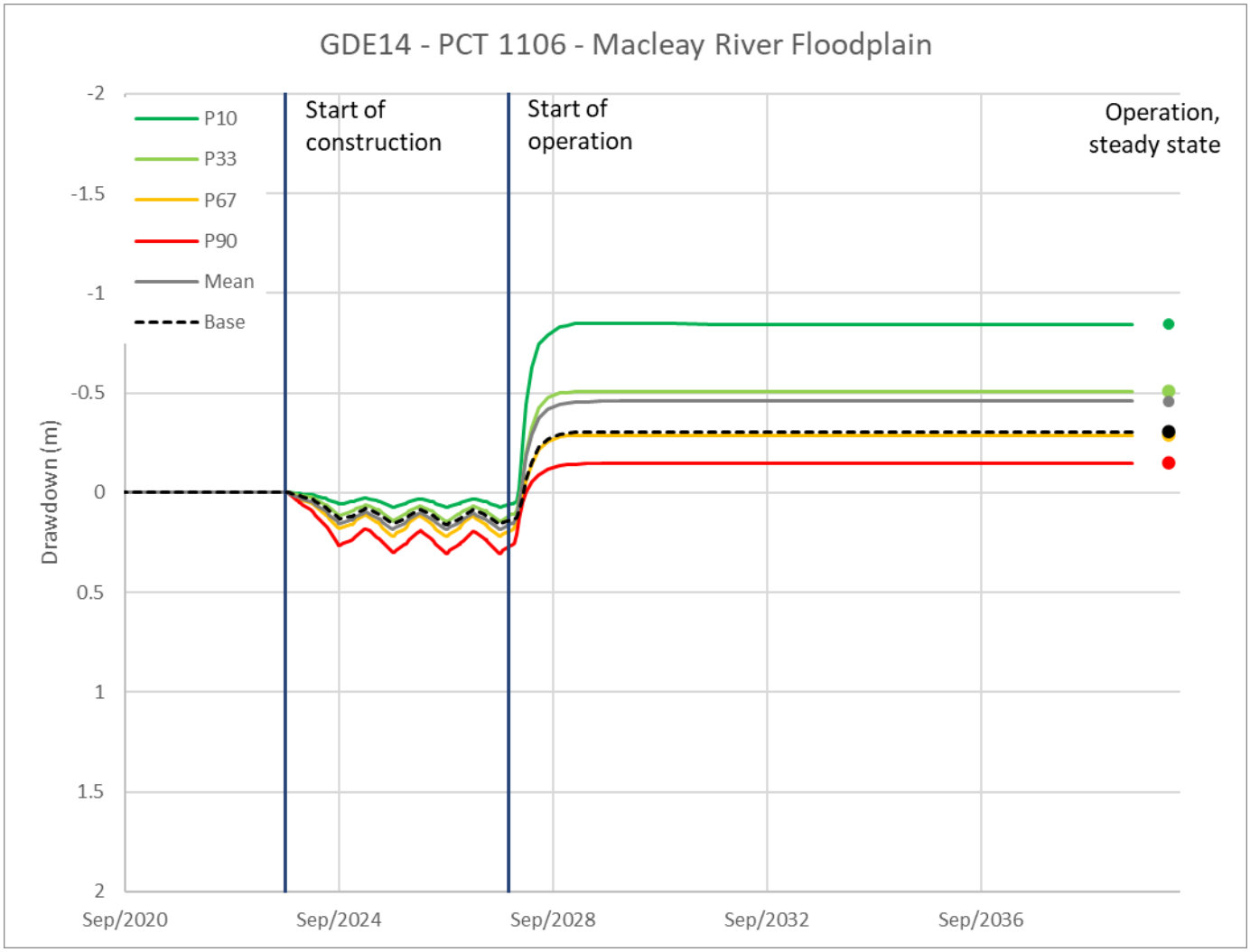

GDE10 - PCT 1106 - Escarpment
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-30
-20
-10
0
10
20
30
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

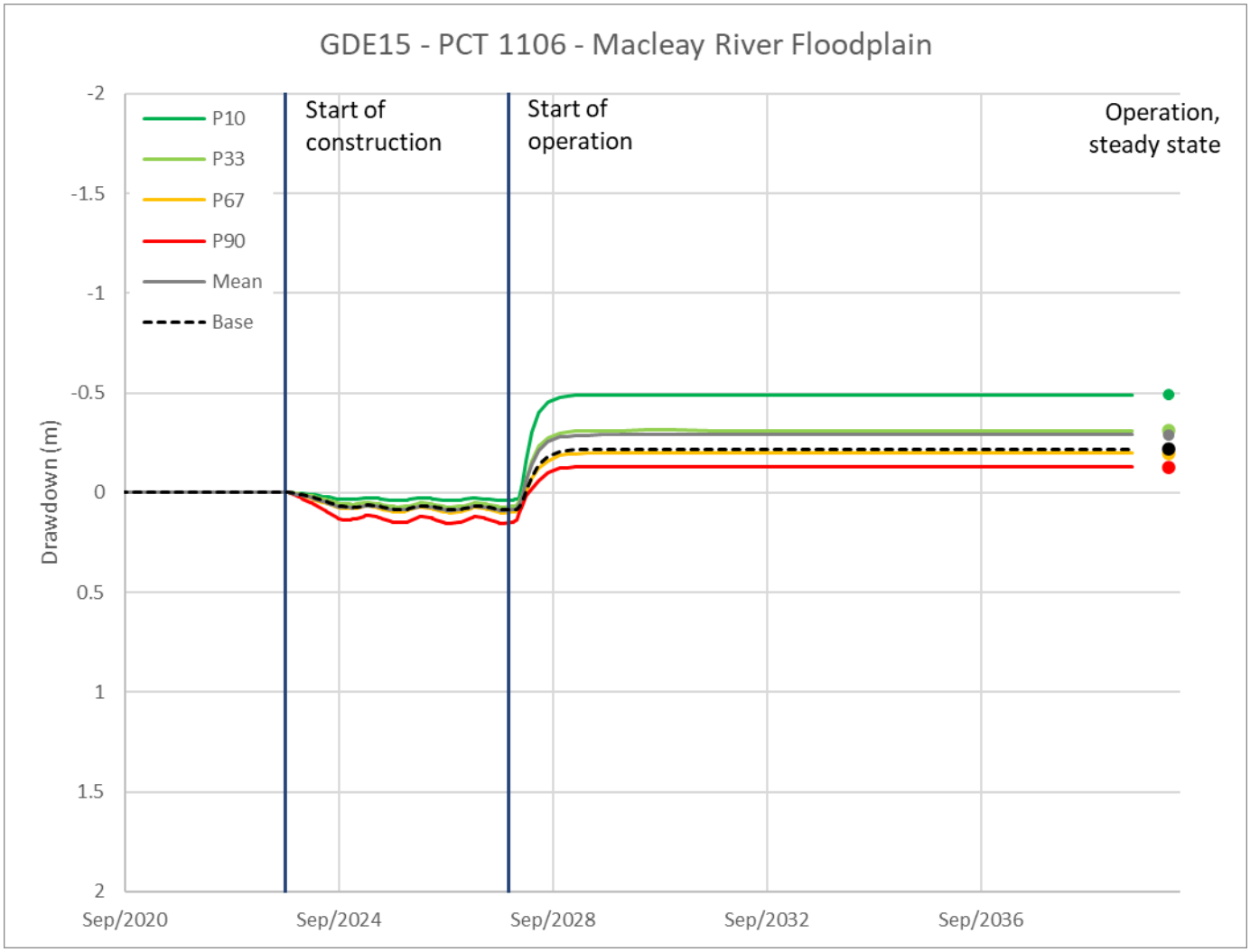

Carrai waterholes - Plateau
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

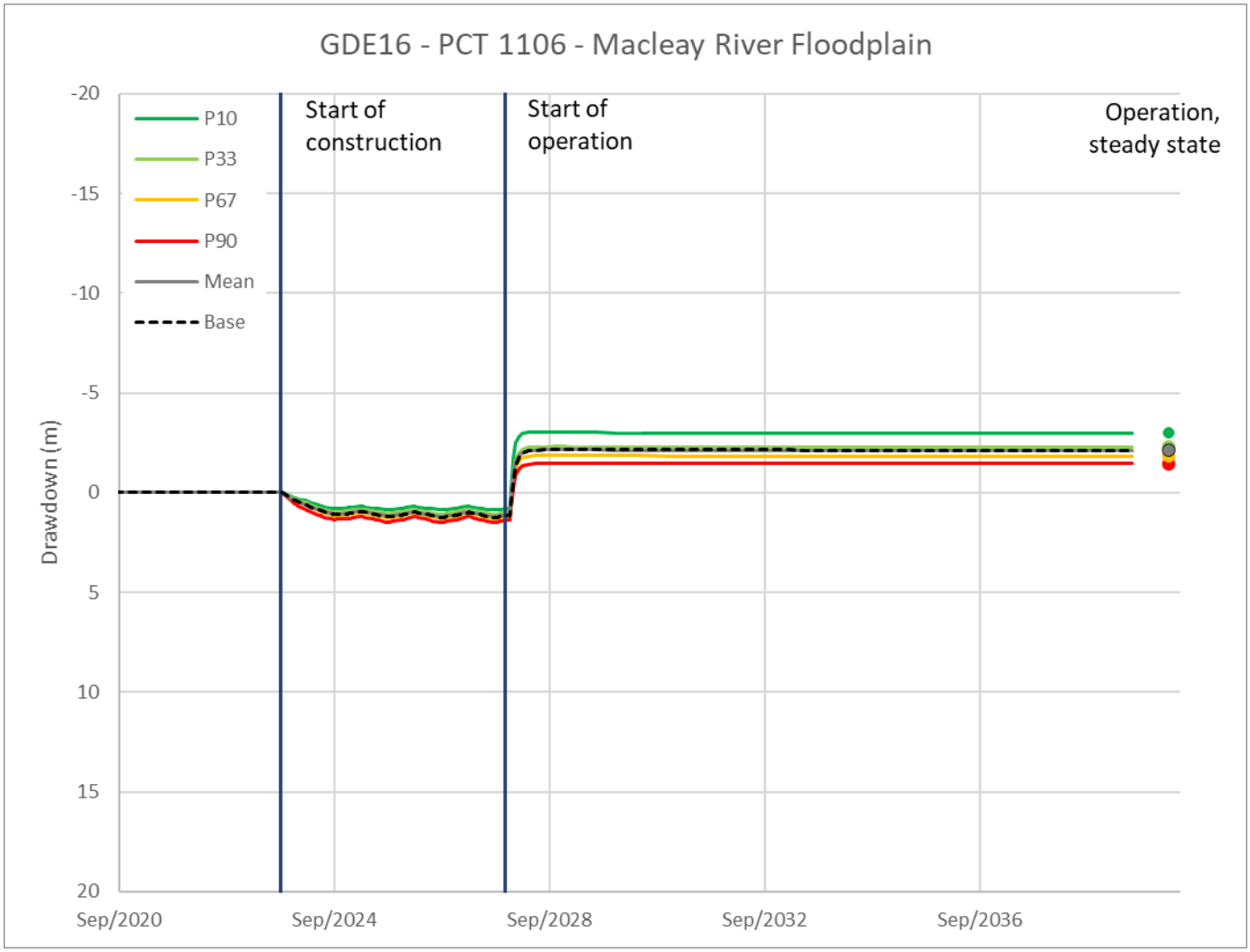

GDE11 - PCT 1106 - Escarpment
Drawdown (m)
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

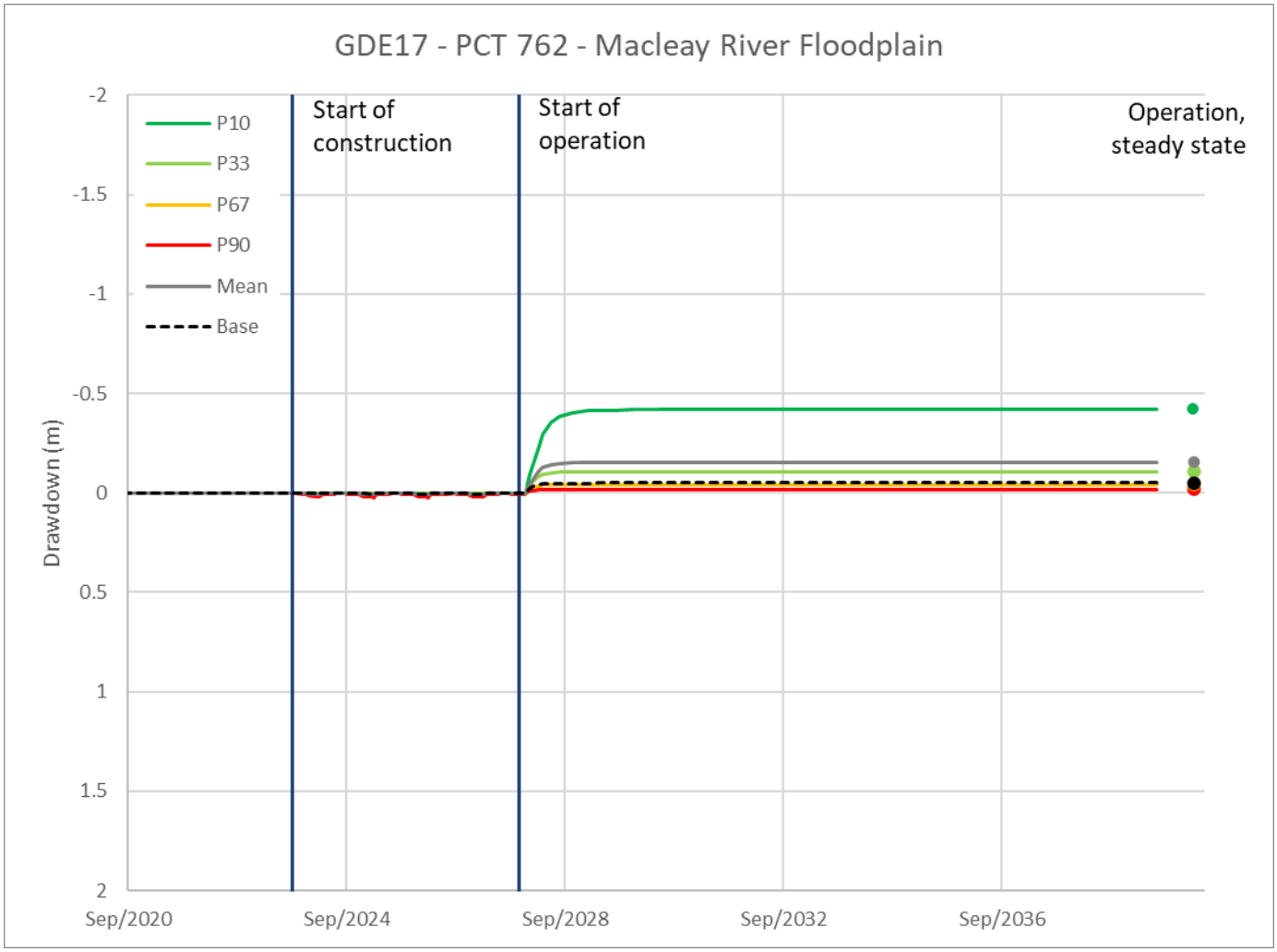

GDE12 - PCT 1106 - Escarpment
Start of construction
Start of operation
Operation, steady state
P10
P33
P67
P90
Mean
Base
Drawdown (m)
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

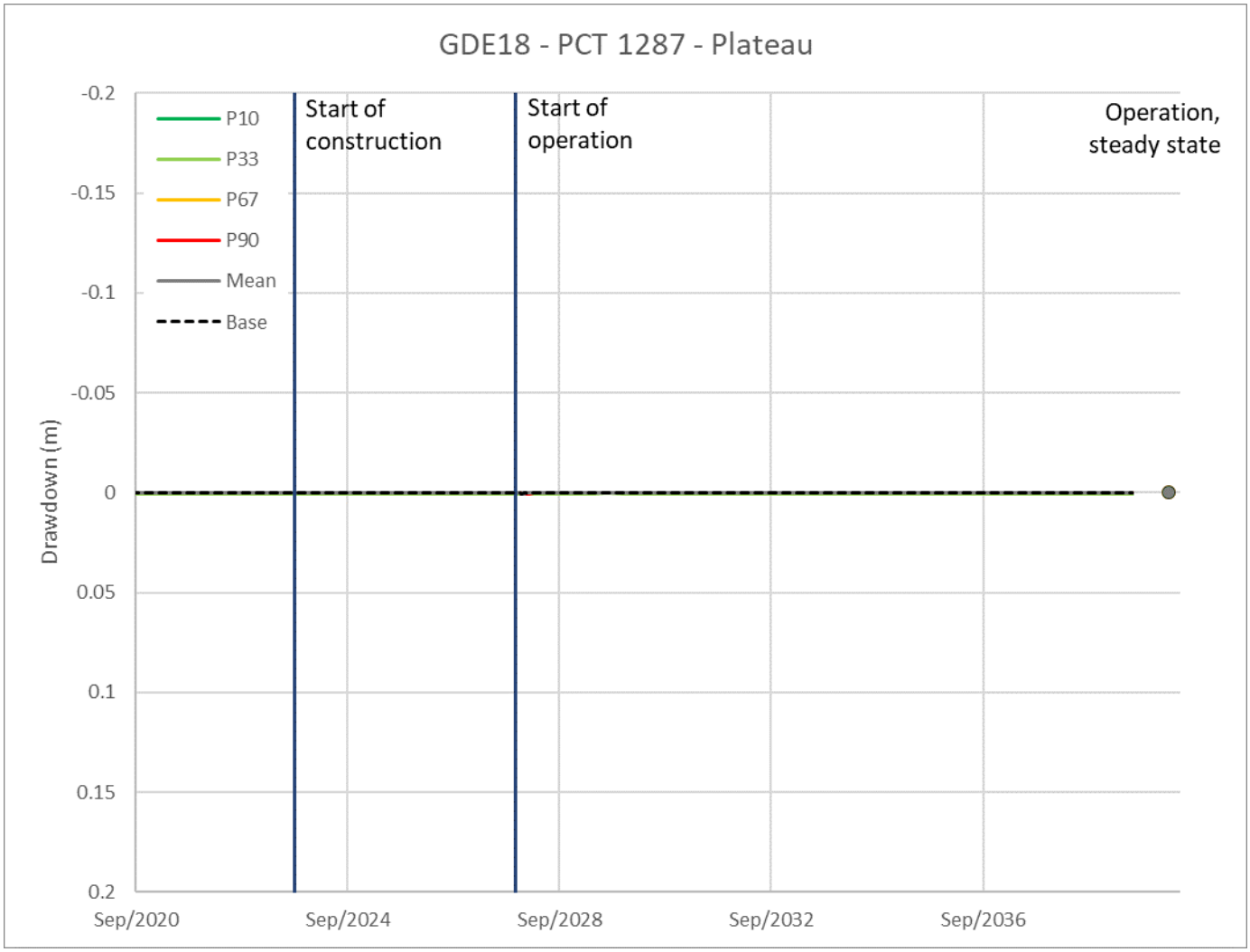

GDE13 - PCT 1106 - Escarpment
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036


GDE14 - PCT 1106 - Macleay River Floodplain
Start of construction
Start of operation
Operation, steady state
P10
P33
P67
P90
Mean
Base
Drawdown (m)
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036


GDE15 - PCT 1106 - Macleay River Floodplain
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036


GDE16 - PCT 1106 - Macleay River Floodplain
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-20
-15
-10
-5
0
5
10
15
20
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036


GDE17 - PCT 762 - Macleay River Floodplain
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Drawdown (m)
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036


GDE18 - PCT 1287 - Plateau
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Drawdown (m)
P10
P33
P67
P90
Mean
Base
Start of construction
Start of operation
Operation, steady state
Sep/2020
Sep/2024
Sep/2028
Sep/2032
Sep/2036

Appendix D

Probabilistic water balances at key times

EMM
creating opportunities

D.1 Probabilistic water balances at key times

Table 8.1 Pre-construction steady state water balance (ML/yr)

Component	Flow direction	P10	P33	P67	P90	Base case
Entire model domain						
Recharge	In	20,004	20,004	20,004	20,004	20,004
ET	Out	7,307	8,092	8,698	9,267	8,286
Storage in	In	-	-	-	-	-
Storage out	Out	-	-	-	-	-
Macleay gorges SW source						
Macleay River to aquifer	In	1,631	2,813	4,717	6,303	3,474
aquifer to Macleay River	Out	3,592	4,148	4,793	5,940	4,352
all other streams to aquifer	In	-	-	-	-	-
aquifer to all other streams	Out	5,592	6,454	7,493	8,501	6,932
Macleay valley SW source						
Macleay River to aquifer	In	525	851	1,216	1,635	1,008
Aquifer to Macleay River	Out	1,221	1,616	1,989	2,340	1,644
All other streams to aquifer	In	-	-	-	-	-
Aquifer to all other streams	Out	2,788	3,030	3,355	3,808	3,300

Table 8.2 Construction water balance for water year 2023 (ML)

Component	Flow direction	P10	P33	P67	P90	Base case
Entire model domain						
Recharge	In	20,119	20,119	20,119	20,119	20,119
ET	Out	7,848	8,675	9,348	9,910	8,878
Storage in	In	4,113	4,250	4,381	4,475	4,354
Storage out	Out	2,579	2,674	2,783	2,864	2,741
Macleay gorges SW source						
Macleay river to aquifer	In	1,640	2,825	4,746	6,338	3,496
Aquifer to Macleay River	Out	3,672	4,241	4,896	6,055	4,437
All other streams to aquifer	In	-	-	-	-	-
Aquifer to all other streams	Out	5,906	6,794	7,824	8,861	7,288
Macleay valley SW source						
Macleay river to aquifer	In	522	858	1,230	1,640	1,019
Aquifer to Macleay River	Out	1,242	1,637	2,047	2,415	1,663
All other streams to aquifer	In	-	-	-	-	-
Aquifer to all other streams	Out	2,964	3,214	3,554	4,011	3,522
Project components						
Overall sum	Out	290.2	348.4	420.6	488.9	406.9
Lower reservoir	Out	106.9	127.2	157.2	187.4	148.3
Upper reservoir	Out	39.7	47.7	56.4	63.2	52.3
Tailrace construction adit	Out	36.3	46.4	57.8	69.6	52.7
Access tunnel	Out	93.0	107.6	120.6	132.2	126.5
Tailrace	Out	8.1	9.7	11.7	13.8	11.0
Lower intake	Out	0.8	2.2	4.1	6.7	3.3
Surge shaft construction adit	Out	-	-	-	-	-
Gate shaft	Out	-	-	-	-	-
Tailrace vent shaft	Out	-	-	-	-	-
ECVT	Out	5.3	7.5	12.5	15.7	12.6
Transformer cabin top	Out	-	-	-	-	-
Transformer cabin bottom	Out	-	-	-	-	-
Power station top	Out	-	-	-	-	-
Power station middle	Out	-	-	-	-	-

Table 8.2 Construction water balance for water year 2023 (ML)

Component	Flow direction	P10	P33	P67	P90	Base case
Power station bottom	Out	-	-	-	-	-
IPB tunnels	Out	-	-	-	-	-
Draft tube	Out	-	-	-	-	-
Power station construction adit	Out	-	-	-	-	-
Penstock	Out	-	-	-	-	-
Penstock construction adit	Out	-	-	-	-	-
Surge shaft	Out	-	-	-	-	-
Headrace	Out	-	-	-	-	-
Egress tunnel	Out	-	-	-	-	-
Headrace construction adit	Out	-	-	-	-	-
Upper intake	Out	0.1	0.1	0.2	0.3	0.2
Pressure shaft	Out	-	-	-	-	-

Table 8.3 Construction water balance for water year 2024 (ML)

Component	Flow direction	P10	P33	P67	P90	Base case
Entire model domain						
Recharge	In	20,119	20,119	20,119	20,119	20,119
ET	Out	7,593	8,382	9,047	9,601	8,581
Storage in	In	3,552	3,667	3,782	3,866	3,749
Storage out	Out	2,895	2,997	3,107	3,191	3,070
Macleay gorges SW source						
Macleay river to aquifer	In	1,658	2,860	4,792	6,393	3,534
aquifer to Macleay River	Out	3,566	4,121	4,775	5,944	4,314
all other streams to aquifer	In	-	-	-	-	-
aquifer to all other streams	Out	5,712	6,608	7,644	8,673	7,087
Macleay valley SW source						
Macleay river to aquifer	In	530	861	1,233	1,653	1,022
aquifer to Macleay River	Out	1,230	1,625	2,014	2,372	1,651
all other streams to aquifer	In	-	-	-	-	-
aquifer to all other streams	Out	2,870	3,123	3,462	3,906	3,406
Project components						
Overall sum	Out	245.5	300.4	377.2	450.6	365.4
Lower reservoir	Out	72.2	87.8	115.8	140.9	107.7
Upper reservoir	Out	34.8	45.4	60.5	74.4	53.9
Tailrace construction adit	Out	15.8	23.2	29.8	38.3	27.2
Access tunnel	Out	85.8	99.1	111.1	122.1	119.9
Tailrace	Out	20.4	24.0	29.6	36.9	27.6
Lower intake	Out	-	0.0	0.2	1.0	0.0
Surge shaft construction adit	Out	0.3	0.3	0.3	0.4	0.3
Gate shaft	Out	0.1	0.2	0.3	0.3	0.2
Tailrace vent shaft	Out	-	-	-	-	-
ECVT	Out	13.1	16.7	25.1	30.7	24.3
Transformer cabin top	Out	0.1	0.1	0.1	0.2	0.1
Transformer cabin bottom	Out	-	-	-	-	-
Power station top	Out	0.1	0.1	0.1	0.2	0.1

Table 8.3 Construction water balance for water year 2024 (ML)

Component	Flow direction	P10	P33	P67	P90	Base case
Power station middle	Out	0.1	0.1	0.1	0.2	0.1
Power station bottom	Out	-	-	-	-	-
IPB tunnels	Out	-	-	-	-	-
Draft tube	Out	0.3	0.4	0.4	0.5	0.4
Power station construction adit	Out	0.3	0.3	0.4	0.4	0.4
Penstock	Out	0.5	0.6	0.8	1.0	0.7
Penstock construction adit	Out	0.3	0.4	0.4	0.5	0.4
Surge shaft	Out	-	-	-	-	-
Headrace	Out	0.4	0.4	0.5	0.6	0.5
Egress tunnel	Out	0.0	0.1	0.1	0.1	0.1
Headrace construction adit	Out	0.5	0.6	0.7	0.9	0.7
Upper intake	Out	0.1	0.1	0.2	0.3	0.2
Pressure shaft	Out	0.4	0.5	0.6	0.7	0.5

Table 8.4 Construction water balance for water year 2025 (ML)

Component	Flow direction	P10	P33	P67	P90	Base case
Entire model domain						
Recharge	In	20,119	20,119	20,119	20,119	20,119
ET	Out	7,486	8,263	8,918	9,466	8,457
Storage in	In	3,336	3,448	3,553	3,634	3,522
Storage out	Out	3,018	3,121	3,230	3,308	3,194
Macleay gorges SW source						
Macleay river to aquifer	In	1,666	2,874	4,805	6,413	3,547
aquifer to Macleay River	Out	3,530	4,074	4,732	5,899	4,272
all other streams to aquifer	In	-	-	-	-	0
aquifer to all other streams	Out	5,633	6,535	7,578	8,604	7,014
Macleay valley SW source						
Macleay river to aquifer	In	533	863	1,235	1,659	1,023
aquifer to Macleay River	Out	1,225	1,620	2,002	2,357	1,647
all other streams to aquifer	In	-	-	-	-	0
aquifer to all other streams	Out	2,836	3,089	3,423	3,872	3,364
Project components						
Overall sum	Out	203.7	255.0	322.0	393.4	314.7
Lower reservoir	Out	53.8	69.6	93.8	118.7	89.8
Upper reservoir	Out	27.8	38.2	50.9	64.1	45.1
Tailrace construction adit	Out	13.1	19.6	25.8	34.2	23.9
Access tunnel	Out	74.5	85.9	97.1	107.3	105.2
Tailrace	Out	17.9	21.0	26.1	33.5	24.6
Lower intake	Out	-	-	0.1	0.7	0.0
Surge shaft construction adit	Out	0.3	0.4	0.4	0.5	0.4
Gate shaft	Out	0.1	0.1	0.2	0.3	0.2
Tailrace vent shaft	Out	1.2	1.3	1.6	1.7	1.4
ECVT	Out	11.4	14.6	20.7	25.9	19.7
Transformer cabin top	Out	0.1	0.1	0.1	0.1	0.1
Transformer cabin bottom	Out	0.0	0.1	0.1	0.1	0.1
Power station top	Out	0.1	0.1	0.1	0.1	0.1
Power station middle	Out	0.1	0.2	0.2	0.3	0.2

Table 8.4 Construction water balance for water year 2025 (ML)

Component	Flow direction	P10	P33	P67	P90	Base case
Power station bottom	Out	0.1	0.1	0.2	0.3	0.1
IPB tunnels	Out	-	-	-	-	-
Draft tube	Out	0.1	0.1	0.1	0.1	0.1
Power station construction adit	Out	0.2	0.2	0.2	0.3	0.2
Penstock	Out	0.2	0.3	0.3	0.4	0.3
Penstock construction adit	Out	0.3	0.3	0.4	0.5	0.4
Surge shaft	Out	0.6	0.7	0.7	0.8	0.6
Headrace	Out	-	-	-	-	-
Egress tunnel	Out	0.1	0.2	0.2	0.2	0.2
Headrace construction adit	Out	0.4	0.6	0.7	0.9	0.6
Upper intake	Out	0.1	0.1	0.1	0.2	0.1
Pressure shaft	Out	1.2	1.4	1.7	2.0	1.2

Table 8.5 Construction water balance for water year 2026 (ML)

Component	Flow direction	P10	P33	P67	P90	Base case
Entire model domain						
Recharge	In	20,119	20,119	20,119	20,119	20,119
ET	Out	7,436	8,208	8,857	9,402	8,400
Storage in	In	3,239	3,353	3,456	3,535	3,425
Storage out	Out	3,081	3,187	3,291	3,367	3,258
Macleay gorges SW source						
Macleay river to aquifer	In	1,670	2,882	4,812	6,423	3,553
aquifer to Macleay River	Out	3,513	4,054	4,711	5,876	4,252
all other streams to aquifer	In	-	-	-	-	-
aquifer to all other streams	Out	5,597	6,500	7,547	8,574	6,979
Macleay valley SW source						
Macleay river to aquifer	In	535	863	1,235	1,662	1,024
aquifer to Macleay River	Out	1,223	1,618	1,997	2,349	1,645
all other streams to aquifer	In	-	-	-	-	-
aquifer to all other streams	Out	2,819	3,074	3,405	3,856	3,345
Project components						
Overall sum	Out	185.8	235.6	301.0	368.4	292.8
Lower reservoir	Out	46.2	61.9	85.7	109.0	82.1
Upper reservoir	Out	25.7	36.1	48.5	61.3	42.6
Tailrace construction adit	Out	12.2	18.4	24.6	32.8	22.7
Access tunnel	Out	70.1	80.5	91.8	101.2	98.7
Tailrace	Out	17.0	20.1	25.2	32.5	23.6
Lower intake	Out	-	-	0.1	0.6	0.0
Surge shaft construction adit	Out	0.3	0.3	0.3	0.4	0.3
Gate shaft	Out	0.0	0.1	0.2	0.3	0.2
Tailrace vent shaft	Out	0.8	0.9	1.0	1.1	0.9
ECVT	Out	10.5	13.7	19.2	23.8	18.0
Transformer cabin top	Out	0.1	0.1	0.1	0.1	0.1
Transformer cabin bottom	Out	0.1	0.1	0.1	0.1	0.1
Power station top	Out	0.1	0.1	0.1	0.1	0.1
Power station middle	Out	0.1	0.2	0.2	0.3	0.2

Table 8.5 Construction water balance for water year 2026 (ML)

Component	Flow direction	P10	P33	P67	P90	Base case
Power station bottom	Out	0.1	0.1	0.2	0.3	0.1
IPB tunnels	Out	0.0	0.0	0.1	0.1	0.0
Draft tube	Out	-	-	-	-	-
Power station construction adit	Out	0.1	0.2	0.2	0.2	0.2
Penstock	Out	-	-	-	-	-
Penstock construction adit	Out	0.3	0.3	0.4	0.5	0.4
Surge shaft	Out	0.5	0.6	0.7	0.8	0.5
Headrace	Out	-	-	-	-	-
Egress tunnel	Out	0.1	0.1	0.2	0.2	0.2
Headrace construction adit	Out	0.4	0.5	0.7	0.8	0.6
Upper intake	Out	0.1	0.1	0.1	0.2	0.1
Pressure shaft	Out	1.1	1.2	1.5	1.7	1.1

Table 8.6 Construction water balance for water year 2027 (ML)

Component	Flow direction	P10	P33	P67	P90	Base case
Entire model domain						
Recharge	In	17,321	17,321	17,321	17,321	17,321
ET	Out	7,381	8,153	8,787	9,344	8,358
Storage in	In	2,939	3,057	3,144	3,203	3,113
Storage out	Out	724	753	788	813	769
Macleay gorges SW source						
Macleay river to aquifer	In	1,600	2,757	4,616	6,152	3,402
aquifer to Macleay River	Out	3,257	3,806	4,464	5,641	4,012
all other streams to aquifer	In	-	-	-	-	-
aquifer to all other streams	Out	5,227	6,079	7,003	7,937	6,506
Macleay valley SW source						
Macleay river to aquifer	In	495	805	1,153	1,562	956
aquifer to Macleay River	Out	1,176	1,569	1,948	2,281	1,598
all other streams to aquifer	In	-	-	-	-	-
aquifer to all other streams	Out	2,648	2,888	3,209	3,615	3,155
Project components						
Overall sum	Out	200.2	243.5	298.4	359.2	294.4
Lower reservoir	Out	64.7	78.4	98.1	119.4	95.5
Upper reservoir	Out	28.7	36.0	46.3	57.0	41.4
Tailrace construction adit	Out	5.2	8.2	11.2	15.2	10.3
Access tunnel	Out	74.8	87.1	98.9	111.9	105.1
Tailrace	Out	14.0	17.0	21.2	26.7	20.8
Lower intake	Out	-	-	0.0	0.2	-
Surge shaft construction adit	Out	0.1	0.1	0.2	0.2	0.2
Gate shaft	Out	0.0	0.1	0.1	0.1	0.1
Tailrace vent shaft	Out	0.5	0.6	0.7	0.8	0.6
ECVT	Out	10.4	13.9	19.2	24.4	18.2
Transformer cabin top	Out	0.0	0.1	0.1	0.1	0.1
Transformer cabin bottom	Out	0.1	0.1	0.1	0.1	0.1
Power station top	Out	0.1	0.1	0.1	0.1	0.1
Power station middle	Out	0.1	0.2	0.2	0.3	0.2

Table 8.6 Construction water balance for water year 2027 (ML)

Component	Flow direction	P10	P33	P67	P90	Base case
Power station bottom	Out	0.0	0.1	0.1	0.2	0.1
IPB tunnels	Out	0.0	0.0	0.0	0.0	0.0
Draft tube	Out	-	-	-	-	-
Power station construction adit	Out	0.1	0.1	0.1	0.1	0.1
Penstock	Out	-	-	-	-	-
Penstock construction adit	Out	0.1	0.2	0.2	0.2	0.2
Surge shaft	Out	0.4	0.5	0.5	0.6	0.4
Headrace	Out	-	-	-	-	-
Egress tunnel	Out	0.1	0.1	0.1	0.2	0.1
Headrace construction adit	Out	0.2	0.2	0.3	0.4	0.3
Upper intake	Out	0.0	0.0	0.1	0.1	0.1
Pressure shaft	Out	0.5	0.6	0.7	0.8	0.5

Table 8.7 Steady-state operation water balance (ML/yr)

Component	Flow direction	P10	P33	P67	P90	Base case
Entire model domain						
Recharge	In	19,938	19,938	19,938	19,938	19,938
ET	Out	7,317	8,101	8,708	9,286	8,297
Storage in	In	-	-	-	-	-
Storage out	Out	-	-	-	-	-
Macleay gorges SW source						
Macleay river to aquifer	In	1,605	2,759	4,646	6,237	3,437
aquifer to Macleay River	Out	3,776	4,342	5,103	6,273	4,566
all other streams to aquifer	In	-	-	-	-	-
aquifer to all other streams	Out	5,833	6,730	7,564	8,556	7,085
Macleay valley SW source						
Macleay river to aquifer	In	525	851	1,216	1,635	1,008
aquifer to Macleay River	Out	1,221	1,616	1,989	2,340	1,644
all other streams to aquifer	In	-	-	-	-	-
aquifer to all other streams	Out	2,788	3,030	3,355	3,808	3,300
Project components						
Overall sum	Out	233.6	271.7	319.1	377.0	319.9
Lower reservoir	Out	91.8	102.9	118.7	139.8	117.9
Upper reservoir	Out	35.0	39.3	48.6	57.6	44.7
Tailrace construction adit	Out	-	-	-	-	-
Access tunnel	Out	82.1	97.6	110.4	127.4	116.3
Tailrace	Out	12.7	15.6	19.2	23.2	19.8
Lower intake	Out	-	-	-	-	-
Surge shaft construction adit	Out	-	-	-	-	-
Gate shaft	Out	-	-	-	-	-
Tailrace vent shaft	Out	0.4	0.4	0.5	0.6	0.5
ECVT	Out	11.0	15.0	20.5	26.9	19.8
Transformer cabin top	Out	0.0	0.0	0.1	0.1	0.1
Transformer cabin bottom	Out	0.1	0.1	0.1	0.1	0.1
Power station top	Out	0.1	0.1	0.1	0.1	0.1
Power station middle	Out	0.1	0.1	0.2	0.3	0.2

Table 8.7 Steady-state operation water balance (ML/yr)

Component	Flow direction	P10	P33	P67	P90	Base case
Power station bottom	Out	0.0	0.1	0.1	0.2	0.1
IPB tunnels	Out	0.0	0.0	0.0	0.0	0.0
Draft tube	Out	-	-	-	-	-
Power station construction adit	Out	-	-	-	-	-
Penstock	Out	-	-	-	-	-
Penstock construction adit	Out	-	-	-	-	-
Surge shaft	Out	0.3	0.4	0.4	0.5	0.4
Headrace	Out	-	-	-	-	-
Egress tunnel	Out	0.1	0.1	0.1	0.1	0.1
Headrace construction adit	Out	-	-	-	-	-
Upper intake	Out	-	-	-	-	-
Pressure shaft	Out	-	-	-	-	-
Outflow from project components						
Lower reservoir	In	278.7	317.0	372.1	424.0	320.9
Upper reservoir	In	10.8	22.0	33.7	51.7	28.9
Tailrace	In	0.0	0.1	0.2	0.5	0.0
Pressure shaft	In	0.2	0.3	0.4	0.4	0.2

Appendix E
Independent peer review

EMM
creating opportunities

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DATE:	2nd December 2022
TO:	EMM Doug Weatherill
FROM:	Chris Nicol, Hydrogeologist
RE:	Peer review: Oven Mountain Pumped Storage Groundwater Modelling
OUR REF:	EMM001/c002_rev1

1. Introduction

This brief report summarises the primary findings of an independent technical review of a numerical groundwater flow model developed by EMM for the Oven Mountain Pumped Storage (OMPS) project, as described by EMM (2022). The reader is referred to EMM (2022) for a summary of the project.

The objective of the groundwater modelling is to assess the potential effects of construction and operation of the OMPS scheme on groundwater and connected surface water systems, including Groundwater Dependent Ecosystems (GDEs). Potential groundwater effects arising from scheme development centre around groundwater depressurisation during tunnelling and dam construction, followed by ongoing operational period depressurisation around certain scheme features, and potential groundwater mounding around the scheme's upper and lower surface water storages.

2. Review Methodology

The evidentiary basis of this review is limited to: "*Oven Mountain Pumped Storage Groundwater Modelling Version 1*" (EMM, 2022). This includes a summary of the conceptual hydrogeological model that is used as a basis model design and end use. The review was conducted after all modelling and associated reporting were completed; the reviewer was not involved during the modelling process. Model files were not inspected for this review.

This review of the OMPS groundwater model was undertaken in broad alignment with the principles of the Australian Groundwater Modelling Guidelines ('the Guidelines herein'; Barnett et al., 2012). Reference was also made to:

- The body of work surrounding development of PEST and related codes (see Doherty, 2022 and works cited therein).
- The Independent Expert Scientific Committee's (IESC's) uncertainty analysis guidance (Middlemis and Peeters, 2018).

In conjunction with the above guidance documents, my experience in the modelling industry was used to assess the following broad aspects of the modelling process:

- Planning – the intended use of the model, the questions to be answered, the modelling objectives and the type of model needed to meet the project objectives.
- Conceptualisation – the development of an objective-relevant conceptual model through analysis of available data and knowledge.
- Design and construction – representation of the conceptualisation in the numerical model, and the representation of key hydrological processes, as of greatest relevance to model end use - specifically, the simulation of construction and operation activities, and their potential effects on groundwater and surface water systems, features, and behaviour.
- History-matching – the process of assimilating historical observation data into the model by informing and constraining model parameters and processes. Incorporated observation data should, where possible, be of direct import to model parameters that affect key model outputs, thereby reducing their uncertainty (Doherty, 2022).
- Forecasts and their uncertainty – how the model has been used to provide outputs that address the questions defined in the modelling objectives, in consideration of model uncertainty and its implications.
- Model reporting – clear communication of the conceptualisation, model development and outputs. This should allow stakeholders and reviewers to understand the process and key outcomes of the assessment, to enable assessment of model fitness for satisfying modelling and project objectives.

Review checklist Table 9-2 of the Guidelines (Barnett et al., 2012) forms the detailed framework for this review, to assess conformance with best practice. This, as pertaining to review of the OMPS groundwater model, is provided as Attachment 1; it forms a basis for recording reviewer questions and answers from the modelling team and recording detailed points arising from the review process. The modelling team is specifically referred to the key questions and items identified in column D ("suggested actions"); a level of importance is assigned to each of these items in column E.

3. Review Outcomes Summary

The hydrogeological conceptualisation and associated model planning and design are generally thorough and well thought-out, with a focus on model end use in meeting the project objectives and the needs of dependent study disciplines.

There are no historical observation data relating to the anthropogenic depressurisation- and mounding-related aquifer stress responses that the model is ultimately used to forecast. This is a commonly encountered situation. However, the potential future effects of these project-related stresses are well thought through and conceptualised and are ultimately used to inform an appropriate model design, including code selection, layering, boundary conditions, mesh, and temporal discretisation.

The modelling workflow follows some aspects of current best practice and includes a reasonable assessment of forecast model uncertainty. EMM's report quality is generally high; some suggestions for improvement were provided in Attachment 1, most of which have been addressed by the modelling team; a couple of points of slight disagreement remain, but these are insignificant in terms of implications for model end use.

One *potential* weakness of note, although not considered critical, is that the method used to parameterise the stochastic forecast models appears to have not made best (or even standard) use of the information obtained about model parameters from the history-matching process[1]; this is in some

[1] Prior parameter uncertainty appears to have been sampled, rather than posterior (history-matched) parameter uncertainty.

ways a deviation from current best practice. Clarification was provided by the modelling team to the reviewer regarding specific details[2].

However, given that there are no historical groundwater observation data that reflect responses to the (mainly construction-related) aquifer stresses that the model is designed to forecast, this is not considered a critical issue. The adopted approach may even prove a more appropriately risk-conservative approach in this case because there is less potential for undesirable model parameter bias incurred through training the model to historical data that contains no information on stress responses directly related to those that are forecast.

As a final note on this point, the method used for stochastic parameter sampling does not reflect current best practice, and future model updates should aim to implement such methods (for example using PEST tools such as MKPPSTAT and PPCOV_SVA, possibly alongside tools like PREDUNC7); again, this is probably not a critical issue, but it is not ideal.

Other lower priority potential improvements for consideration in future model updates include the following:

- Inclusion of recharge rate and Macleay River stage uncertainty in the forecast uncertainty analysis.
    - Currently only hydraulic conductivity and storage parameter uncertainty is assessed. It is however recognised that conducting this for recharge rates would probably mean a significant additional amount of work (posterior parameter resampling, potentially followed by at least one optimisation iteration for the 109 stochastic models). It would ideally also likely require the introduction of pilot points to represent recharge variability within the currently defined zones, although this would further increase the amount of work required.
    - The current approach taken to define Macleay River stage is unusual in the reviewer's opinion (a "baseflow-equivalent stage height" is used). Fortunately, the predictive model stress periods are quarterly or longer, and hence this change is unlikely to significantly alter model forecasts. In future model updates, it is however recommended that river stage is defined using stress period average stage heights (unfiltered) to better align with the physics of groundwater-surface water interaction.
- Present history-match quality across the filtered set of stochastic models in a more directly meaningful way than is presented in the reviewed report. I.e., stochastic representations of modelled and observed hydrographs, scatter plots, and standard statistical measures of history-match quality. This way, readers and reviewers can better appreciate model quality and limitations.
- Forecast simulation sensitivity analysis under different climate change scenarios (i.e., up- or down-scaled recharge rates and river stage heights). It is noted that this is a requirement of the "*Minimum Groundwater Modelling Requirements for SSD/SSI projects*" (DPE, 2022). This could be indirectly addressed through the inclusion of recharge in the uncertainty analysis.

As an overarching comment on EMM's groundwater modelling for OMPS, the reviewer is of the view that there are no critical issues and concludes that the modelling is fit for use in meeting the modelling and project objectives. The modelling has been conducted to a good standard and includes assessment of forecast uncertainty analysis that utilises some aspects of current best practice principles. This is important in any case, but particularly so for this project given the lack of historical

[2] Which tools and methods were used? *PESTPP-GLM*. Was the history-match Jacobian used to inform parameter sampling? *No*. Was any covariance between pilot points applied in the stochastic sampling (e.g., separation distance-based)? *No*.

data of direct import to the groundwater stresses that the model is used to forecast, and which inform project-related decision-making and regulation.

4. References

Barnett B, Townley L, Post V, Evans R, Hunt R, Peeters L, Richardson S, Werner A, Knapton A and Boronkay A., 2012. Australian Groundwater Modelling Guidelines. Waterlines report 82, National Water Commission, Canberra. http://webarchive.nla.gov.au/gov/20160615064846/http://archive.nwc.gov.au/library/waterlines/82

Doherty, J., 2022. Scientifically-Based, Decision-Support Groundwater Modelling: A Conceptual Framework. Draft of Part 1. https://gmdsi.org/blog/scientifically-based-decision-support-groundwater-modelling/

DPE. 2022. Minimum groundwater modelling requirements for Major Projects in NSW. Technical note prepared for the Water Division, NSW Department of Planning and Environment as part of the Groundwater Modelling Toolbox Project.

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Middlemis H and Peeters LJM., 2018. Uncertainty analysis - Guidance for groundwater modelling within a risk management framework. Prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development. http://www.iesc.environment.gov.au/publications/information-guidelines-explanatory-note-uncertainty-analysis

Regards,



Chris Nicol

Groundwater Logic

Attachments:

1. *c001_EMM001_NWC2012_Review_Oven_Mountain_rev1.xlsx - Review checklist Table 9-2 of the Guidelines (Barnett et al., 2012)*

Review questions	*Yes / No / N/A [1] / U [2] / C [3]*	*Comment*	*Suggested Actions*	*Suggested Action Item Importance / Significance*	*EMM response*	*Reviewer issue Closed-out?*
1. Planning						
1.1 Are the project objectives stated?	Yes					
1.2 Are the model objectives stated?	Yes	Could possibly detail the specifics of the DPE 2022 guidelines on this front (i.e., minimum impact criteria).				
1.3 Is it clear how the model will contribute to meeting the project objectives?	Yes					
1.4 Is a groundwater model the best option to address the project and model objectives?	Yes					
1.5 Is the target model confidence-level classification stated and justified?	Yes	As you are probably aware, it is worth noting that there are afoot industry moves away from this system of classification. It is probably more worthwhile using this section to talk around how model / history-matching process design make suitable use of the (purposefully-collected / processed) data to best support the required model forecasts and their associated workflow.				
1.6 Are the planned limitations and exclusions of the model stated?	C	A few planned limitations are detailed in section 1.6 in reference to model complexity, and some in section 3.1 too.	Ideally dedicate a short subsection in chapter 1 or 3 describing model limitations at the planning stage, including their potential implications for end use / how they are accomodated / dealt with (where possible). Then again include a sub-section for example in chapter 5 (or later) identifying any further limitations and implications that have been identified during the modelling process. I know some people don't like this, but in my view, omitting this info is a false economy - the project is better served by being transparent about the inevitable limitations. If implications of those limitations are discussed / accommodated then people who are (unnecessarily) alarmed by this type of info seem to be more satisfied than they otherwise might be. Similarly, if you couch it in terms of why identifying limitations is better than ignoring them (because at least then they can be accommodated / decision-makers made aware of them - "known unknowns"), then most people seem more satisfied in my experience.	Moderate	addressed in new chapter 7	Yes
2. Conceptualisation						
2.1 Has a literature review been completed, including examination of prior investigations?	Yes					
2.2 Is the aquifer system adequately described?	Yes					
2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...)	Yes					
2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds	Yes					
2.2.3 aquifer geometry including layer elevations and thicknesses	Yes					
2.2.4 confined or unconfined flow and the variation of these conditions in space and time?	Yes					
2.3 Have data on groundwater stresses been collected and analysed?	Yes					
2.3.1 recharge from rainfall, irrigation, floods, lakes	Yes					
2.3.2 river or lake stage heights	C	No, but not particularly important to the CHM. Somewhat strangely, a filtered baseflow time series is used to define an equivalent "baseflow stage height" for RIV boundary conditions. See comment in section 3 below			addressed below	
2.3.3 groundwater usage (pumping, returns etc)	Yes					
2.3.4 evapotranspiration	Yes					
2.3.5 other?	N/A					

2.4 Have groundwater level observations been collected and analysed?	Yes			
2.4.1 selection of representative bore hydrographs	Yes	Would be easier to digest if hydrographs in section 2.8 mentioned monitored units / depths / rough location (eg scarp, plateau, valley).	figure 2.9 has the spatial location of the bores. Table 2.6 gives the screened depth and lithology	Yes
2.4.2 comparison of hydrographs	C	There's no reference between hydrograph discussion and the hydrograph pics in section 2.8, which makes reading / interp difficult. Eg OM1 is mentioned, but OM2 is in the figures.	OM2 is very close to OM1 and the water table is also about 50 mbgl. Have just changed the text to refer to OM2 instead.	Yes
2.4.3 effect of stresses on hydrographs	Yes	vaguely…see above		
2.4.4 water table maps/piezometric surfaces?	Yes			
2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data?	N/A			
2.5 Have flow observations been collected and analysed?	Yes			
2.5.1 baseflow in rivers	Yes			
2.5.2 discharge in springs	C	Commentary provided, but no gaugings - but this is notoriously difficult if not impossible to reliably measure.	spring discharge was not measured. The history matching points for the springs were based on water table at surface at a specific time	Yes, good
2.5.3 location of diffuse discharge areas?	Yes			
2.6 Is the measurement error or data uncertainty reported?	No			
2.6.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)	No	No big deal though. Model structural error likely much larger.		
2.6.2 spatial variability/heterogeneity of parameters	Yes	Mostly vertical, but also by unit and location		
2.6.3 interpolation algorithm(s) and uncertainty of gridded data?	N/A	No real implications of this.		
2.7 Have consistent data units and geometric datum been used?	Yes			
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			
2.8.2 Is the conceptual model based on all available, relevant data?	Yes			
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	Yes			
2.9.1 Are the relevant processes identified?	Yes			
2.9.2 Is justification provided for omission or simplification of processes?	Yes			
2.10 Have alternative conceptual models been investigated?	No	But there probably aren't any given no major conceptual uncertainties.		

3. Design and construction

3.1 Is the design consistent with the conceptual model?	Yes			
3.2 Is the choice of numerical method and software appropriate?	Yes			
3.2.1 Are the numerical and discretisation methods appropriate?	Yes	However, I think layering could have been significantly simplified down by using CLNs to simulate construction (shaft/race) features. This may have provided a smaller faster model, and so more opportunity to do more with uncertainty exploration.	we have used this approach in several previous model projects (notably for Snowy 2.0) and are more comfortable with it than a potentially more efficient CLN approach this method also allows for simpler error checking and updates in case there were any changes to the project design of tunnel locations or timing	Yes
3.2.2 Is the software reputable?	Yes			

3.2.3 Is the software included in the archive or are references to the software provided?	Yes					
3.3 Are the spatial domain and discretisation appropriate?	Yes					
3.3.1 1D/2D/3D	Yes					
3.3.2 lateral extent	Yes					
3.3.3 layer geometry?	Yes	However see comment 3.2.1 above				
3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	Yes	More than enough				
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?	C	* However see comment 3.2.1 above. * A cross section (or several) through the model mesh would be very useful to aid in interpreting the layer design. I found myself trying to draw pictures of your description - which could well be an incorrect interpretation... * Also, I don't really understand the need for the 100m thick deep aquifer sub-layers - but as long as this is no hindrance to end use of model outputs in decision making, fine I guess, your call.	Suggest including at least one model cross section to help explain the layering / discretisation.	High	added as figure 3.4	Yes
3.4 Are the temporal domain and discretisation appropriate?	Yes					
3.4.1 steady state or transient	Both					
3.4.2 stress periods	Yes					
3.4.3 time steps?	Yes					
3.5 Are the boundary conditions plausible and sufficiently unrestrictive?	Yes					
3.5.1 Is the implementation of boundary conditions consistent with the conceptual model?	C	Somewhat strangely, a filtered baseflow time series is used to define an equivalent "baseflow stage height" (whatever that is) for RIV boundary conditions. Why not use gauged (total flow) stage height given that is what determines interaction between the river and groundwater, and is actually measured? Gauged height is one of the few things you know accurately, at least at the location of the gauge. In practice, this is probably not that big a deal, but it doesn't make any sense. I guess it could mean more potential for baseflow impact to the Macleay River during construction (because stage is lower at peak and therefore more gw discharge to riv), and more impact from long term mounding effects. But I *imagine* it would be slight, particularly given your quarterly stress periods (lucky you!). Another question: Is Macleay River RIV stage adjusted for topo down river, or is it treated as a flat surface? If the latter, what is the river bed (topo) elevation difference from upstream to downstream across the model? What is the elevation difference across the main impact area along the river? Are RIVs assigned to layers based on this elevation? Could be worth checking what the RIV stage depth below ground is and assigned layers are - could the latter in particular affect the impact forecasts along the river? Again, probably not a big deal given K down through the layers is not *vastly* different (based on the CHM data), but it's possibly worth checking.	* Suggest you clarify what "baseflow stage height" is / how it is defined, and conceptually justify it. If redoing the model at some point, I suggest using stress-period average gauged (/interpolated) stage height instead, as that is what drives gw-sw interaction, not "baseflow stage height" (whatever that is). * Consider clarifying river stage interpolation (or not) along the Macleay River. Related to this, describe how RIVs are assigned to layers.	1. High 2. Moderate	a methodology was applied to remove the quickflow elements from the river gauge data. This was then further averaged over stress period durations. 2. the measured level at the gauge was used to define stage above the river bottom. The DEM was used to identify the rise in streambed along the length of the river such that upstream was modelled with a higher stage. The temporal variation measured at the gauge was assigned along the length of the Macleay River All river boundaries are assigned to model layer 1, which represents the weathered and alluvium units	Yes. Re: 1) I still find this conceptually unsupported / wrong. I don't expect any major implications however.
3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	Yes	Model boundary conditions align with natural flow system boundaries, and the domain is big enough to simulate the expected extent of impact from project activities.				
3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level?	Yes	Simple and sufficient				
3.5.4 Are lateral boundaries time-invariant?	Yes					
3.6 Are the initial conditions appropriate?	Yes					
3.6.1 Are the initial heads based on interpolation or on groundwater modelling?	Yes	SS modelling				

3.6.2 Is the effect of initial conditions on key model outcomes assessed?		Question: Are there different recharge rates for the SS period compared to the transient period? Seems like it, but it's hard to tell. I.e., can pest make SS rates higher or lower than the long term average of the transient periods (in the example case that average of the TR periods is used to define the SS rates), or are SS and TR periods linked in the calc?	* Clarify the question to the left	Low	Section 3.6.2 explains that recharge multipliers are used - this means that recharge, as a proportion of rainfall, is linked between SS and TR but can vary dynamically.	Yes
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					
3.7.1 Solution method/solver	Yes	SMS, newton				
3.7.2 Convergence criteria	Yes					
3.7.3 Numerical precision	Yes					

4. Calibration and sensitivity

4.1 Are all available types of observations used for calibration?	Yes	Heads and temporal head differences.
4.1.1 Groundwater head data	Yes	
4.1.2 Flux observations	C	A good go at it in an indirect way - I like the inclusion of spring locations in your head obs - good idea. An alternative next time could be one-way "penalty" RIV(DRN) flux obs (i.e. discharge must be >0 at springs when seepage has been observed).
4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc.	No	Could have potentially used vertical gradient data, although I note you have included qualitative checks on recharge and discharge area gradients in Table 4-1 (despite the actual hisotry matching results not being presented/discussed in this regard).
4.2 Does the calibration methodology conform to best practice?	C	It would have been better to have properly sampled the posterior for your 200 realisations (see discussion in 4.2.4 below).
4.2.1 Parameterisation	Yes	Reasonably highly parameterised. It would have been better to use IES and include more spatial parameter uncertainty at potentially less computational expense. It would also help the assessment to include Macleay River stage uncertainty, particularly given the unusual RIV stage definition method used (see 3.5.1 above).
4.2.2 Objective function	Yes	Reasonably well thought out relativities
4.2.3 Identifiability of parameters	No	Identifiability would be much more informative than the composite sensitivities reported - and for no additional work…not a big deal, but for future reference, I suggest using IDENTPAR if you've gone to the trouble of constructing a jacobian. There are some good examples in the USGS PEST docs of how to present / interpret these stats.

4.2.4 Which methodology is used for model calibration?	Yes	PESTPP-GLM (I think…this needs to be spelt out). Questions: 1. Was the base case model optimised using PESTPP-GLM? You need to specify which of the PESTPP program was used. 2. Were the stochastic realisations drawn from the prior or posterior covariance matrix (the latter presumably being derived from the base case pest optimisation)? The report reads as though it is kind of a hybrid but mainly prior uncertainty approach, and the history-matched jacobian was not used for sampling. Is this correct? 3. Were the 200 realisations optimised at all, or just filtered on unoptimised phi (to select the 109 models)? Re: 2) above, you could have used predunc7, pyemu, or PESTPP-GLM internal methods to sample the posterior (eg https://github.com/usgs/pestpp/blob/master/documentation/pestpp_users_manual.md#628-first-order-second-moment-uncertainty-analysis-and-monte-carlo). I'm not saying you have to do this - a filtered (kind-of) prior uncertainty assessment is fine, but the chosen approach begs the question. It is also not a great method, because as it currently reads, you have got zero relation between pilot points (ie covariance via variograms etc as is normal practice). What this means is that: * you will have quite bizarre looking (unrealistically "spotty") K/S arrays (I note there are no maps provided). It's probably fortunate you have quite sparse pilot point spacings; * all information collected through history matching (in the jacobian) has been left unused / wasted....this is pretty weird / disappointing given how little work is involved in using tools like predunc7 and randpar as described above. * you will have massively decalibrated your 200 models, guaranteed. Which really makes me question what that 2*phi threshold you've used for filtering really means in practice (noting that parameter ranges / maps across those 109 models have not been presented, nor have history match stats/hydrographs	* Specify which program is used for history matching (GLM?). * Address the questions to the left in the report; particularly in table 5.4 - "a bespoke statistical workflow in python" is not very meaningful to anyone - what did you actually do? * Also comment 4.4 below	High	1. Yes, PESTPP-GLM was used. Have updated some references to PEST to refer to PESTPP-GLM where appropriate. 2. Stochastic realisations were not drawn from the covariance matrix, but Monte Carlo sampling with the mean set to the base case value. 3. no optimisations on the realisations (except for the base case). * probabalistic hydrographs in appendix give an idea of the 109 models for clustering and against the base case * boxplots changed to posterior stats	1. Yes 2. Yes. But this is a weak approach. 3. Yes 4. No. I am asking about checking calibration hydrographs, not predictive hydrographs (read my comment again). Probably not a big deal given we are basically doing a prior uncertainty analysis anyway. That'll do. 5. yes, although worth noting that your prior is not really a prior, it is an unfiltered sample around your posterior base case.
4.3 Is a sensitivity of key model outcomes assessed against?	Yes					
4.3.1 parameters	Yes					
4.3.2 boundary conditions	No	RIV stage could have been included. But time would be better spent exploring prediction sensitivity (which implicitly incorporates history match sensitivity, assuming stochastic mdoels are history-matched using parameterised riv stage…).			PEST was not allowed to vary RIV stage during history-matching. It was considered a known input based on the gauge at Georges Junction. It is very unlikely to affect the outcomes of predictive modelling.	Yes, agreed unlikely to affect outcomes significantly. Disagree that the head is based on known (measured) data - it's not, it's based on a digital filter of known data - filtered data that play no role in groundwater surface water interaction hydraulics that the boundary is intended to simulate.
4.3.3 initial conditions	C	See question re: 3.6.2 above re SS vs TR recharge.				
4.3.4 stresses	Yes	Recharge. See question re: 3.6.2 above.				
4.4 Have the calibration results been adequately reported?	C	There's no description of the ensemble history match - only from the "base case" model. The report would benefit from writing up the ensemble stats and presenting ensemble hydrographs, to provide an indication of how informed the uncertainty assesment is by the available data.	* Need to describe what exactly is discussed in section 4.2 - is it the optimised model from a PESTPP-GLM run? Is it the base realisation from IES? * Should really present ensemble stats and hydrographs here too. Although I guess in this case, given that we have no historical stress data (other than recharge), this is of limited value in informing the effect of history matching quality on the forecasts of interest (project-related drawdown and mounding). If you can easily provide some realisation statsor plots, that would be useful, but understand if too much work (posterior K/S plots are a better use of your time - 6.3 below)	1. High 2. Moderate	1. Yes, the base case is an optimised model from a PESTPP-GLM run. IES was not used. 2. History matching performance of the suite of realisations is presented in Figure 5.4 & 5.5. 3. Figure 5.6-5.12 now show posterior K/S distributions instead of prior. Prior moved to appendix.	1. Yes. 2. Disagree - like I said, this is not interpetable. But probably no major implications to predictions given you are effectively doing a prior analysis. 3. Yes
4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale?	Yes	Could be a bit more zoomed to improve clarity, but it's ok.				
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	No		Probably worth a quick plot or two of vertical gradients	Low		

4.4.3 Are calibration statistics reported and illustrated in a reasonable [illegible]?	C	See 4.4 above	See 4.4 above			
4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?	Yes	With the caveat that ensemble history match quality is not clearly presented (see 4.4 above).				
4.5.1 spatially	Yes	Mostly				
4.5.2 temporally	Yes	Mostly				
4.6 Are the calibrated parameters plausible?	Yes	* A few odd kriging artefacts (Figure 4.16) due to sparse point spacings and/or the method used; no big deal though. * It is noted that Kv can exceeed Kh (for weathered and tight bedrock; table 4.5) - not sure this is explained / justified in the CHM. Not a huge deal as it is probably only one pilot point, but worth noting.				
4.7 Are the water volumes and fluxes in the water balance realistic?	C	Yes for steady state (Table 4.4), but no transient data presented.	Figure 4.14 (transient water balance) is missing from the report.	High	figure included	Yes, thanks.
4.8 has the model been verified?	N/A	Best practice is to use all available data for history matching; this is what has been done. Verification could be done at a later date eg during or after construction.				

5. Prediction

5.1 Are the model predictions designed in a manner that meets the model objectives?	Yes					
5.2 Is predictive uncertainty acknowledged and addressed?	Yes					
5.3 Are the assumed climatic stresses appropriate?	C	* Recharge stresses seem ok, although it would be better if recharge uncertainty had been modelled (tables 5.6/5.7 make it seem to be assumed fixed, or perfectly known - which is not the case). In contradiction, Table 5.4 suggests it is not fixed. * No climate scenarios modelled, contrary to the DPE guidelines referenced in the report. There is no understanding of how impacts may change under varying recharge / river stage regimes, which will undoubtedly occur. This is probably more important than I would normally consider it to be, because recharge is not included in the uncertainty analysis.	* If time permits, I would suggest redoing the uncertainty analysis using a posterior sample, and include recharge and river stage heights in the analysis (you'd have to extend your existing jacobian in this case). If including recharge, this would probably only be worthwhile by introducing pilot points within your zones ("highly parameterised", as you put it); otherwise the optimised rates are unlikely to exhibit much uncertainty at all. * And/or fix the recharge (zero uncertainty) issue in tables 5.6/5.7, and/or the description in Table 5.4. * Different climate (recharge) scenarios should be tested. Should be done for the base case realisation at a minimum. Report effects on key forecast metrics.	1. Low 2. High 3. High	1. Recharge was not included in the stochastic uncertainty analysis. Each zone was calibrated in the PESTPP-GLM base case, and these values were used for all of the other 200 realisations. 2. Table 5.4 updated. 3. A predictive sensitivity analysis to recharge +-10% has been added. See sections 5.4.3 and 5.5.4 i. Rerunning PEST on the base case with recharge pilot points is not feasable at this stage	Yes
5.4 Is a null scenario defined?	Yes					
5.5 Are the scenarios defined in accordance with the model objectives and confidence level classification?	Yes	class 2 confidence assigned on this basis, whatever that means. Nothing can be done about this anyway - except for uncertainty analysis, which has been done (to a point).				
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?	No/Yes					
5.5.2 Are well losses accounted for when estimating maximum pumping rates per well?	N/A					
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?	No/Yes					
5.5.4 Are the assumed stresses and timescale appropriate for the stated objectives?	Yes					
5.6 Do the prediction results meet the stated objectives?	Yes		Suggest including a map of the impacted GDEs.	Moderate	GDEs are in impact maps (fig 5.13-5.17)	Yes, thanks
5.7 Are the components of the predicted mass balance realistic?	Yes	Except recharge uncertainty and its effect on water balance uncertainty is not assessed.				
5.7.1 Are the pumping rates assigned in the input files equal to the modelled pumping rates?	N/A					
5.7.2 Does predicted seepage to or from a river exceed measured or expected river flow?	No					

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					
5.7.4 Is diffuse recharge from rainfall smaller than rainfall?	Yes					
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?	N/A					

6. Uncertainty

6.1 Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?	Yes					
6.2 Is the model with minimum prediction-error variance chosen for each prediction?	C	No, but this is not possible to define because we have no observations of predictions. The minium error variance (history match) model has been chosen to center the predictions around, which is the best that can be achieved.				
6.3 Are the sources of uncertainty discussed?	C	Partly. K/S parameters only. Only the prior unfiltered parameter ranges are presented. It is currently impossible to ascertain whether the 109 stochastic models used to assess forecast uncertainty cover a reasonable range of parameter uncertainty, and therefore whether the forecast uncertainty presented is a reasonable estimate. This is important in this case because you have effectively sampled the prior (which is currently shown in your parameter box and whisker plots), with subsequent filtering; hence you need to show what that filtering has done to parameter PDFs, especially given that no history matching stats have been provided for the stochastic realisations.	* Present the filtered parameter ranges and/or maps (replace figures 5.4 through 5.10; if you want to include the prior (200) stats, chuck them in an appendix or something, but really a mention / table of mean and range per parameter (Kx, Kz, Ss, Sy) would do the same job in much less space...). Also: A figure showing a random selection of say ten Kh, Kv, Ss and Sy realisations, and maybe a figure showing the mean, base case, minimum and maximum for Kh, Kv, Ss and Sy across the stochastic models would be useful given the unusual sampling methods applied. * See also 4.2.4 above re: table 5.4.	High	*have replaced prior boxplots with posterior ones. Added new heading for the posterior stats *prior boxplots moved to new appendix.	Yes
6.3.1 measurement of uncertainty of observations and parameters	C	Partly (selected parameters only). Some discussion around observation weighting (with respect to history matching only).				
6.3.2 structural or model uncertainty	No	River boundary condition and recharge rates not included in the uncertainty analysis. I've inferred that recharge rate uncertainty is not assessed based on the water balance uncertainty not showing any variability in recharge; but table 5.4 states that it is included, so it's unclear which of these is wrong - but one of them must be.	Either update table 5.4 to reflect the fact that recharge was not included in the uncertainty analysis, or fix the issue of zero recharge uncertainty in tables 5.6/5.7.	High	table 5.4 updated	Yes
6.4 Is the approach to estimation of uncertainty described and appropriate?	C	Vaguely described, greater clarity needed. See comments 4.2.4 and 4.4 above.				
6.5 Are there useful depictions of uncertainty?	Yes	I really like your drawdown likelihood maps. GDE drawdown timeseries uncertainty will be useful for the GIA / other disciplines.	* Consider including drawdown and mounding on the one plot (two different colour schemes, or a diverging scale) * Consider presenting the water balance impacts uncertainty graphically. It's hard to digest in table form.	1. Low 2. Moderate	1.These will likely overlap if plotted together, and be very hard to portray clearly 2. not addressed. Could not manage this in any sort of coherent form given the number of dimensions (modelled time, each mass balance item (or group) and the 4 likelyhood values + base case) and plotting them meaningfully against each other	Yes

7. Solute transport

7.1 Has all available data on the solute distributions, sources and transport processes been collected and analysed?	N/A	
7.2 Has the appropriate extent of the model domain been delineated and are the adopted solute concentration boundaries defensible?	N/A	
7.3 Is the choice of numerical method and software appropriate?	N/A	

7.4 Is the grid design and resolution adequate, and has the effect of the discretisation on the model outcomes been systematically evaluated?	N/A	
7.5 Is there sufficient basis for the description and parameterisation of the solute transport processes?	N/A	
7.6 Are the solver and its parameters appropriate for the problem under consideration?	N/A	
7.7 Has the relative importance of advection, dispersion and diffusion been assessed?	N/A	
7.8 Has an assessment been made of the need to consider variable density conditions?	N/A	
7.9 Is the initial solute concentration distribution sufficiently well-known for transient problems and consistent with the initial conditions for head/pressure?	N/A	
7.10 Is the initial solute concentration distribution stable and in equilibrium with the solute boundary conditions and stresses?	N/A	
7.11 Is the calibration based on meaningful metrics?	N/A	
7.12 Has the effect of spatial and temporal discretisation and solution method taken into account in the sensitivity analysis?	N/A	
7.13 Has the effect of flow parameters on solute concentration predictions been evaluated, or have solute concentrations been used to constrain flow parameters?	N/A	
7.14 Does the uncertainty analysis consider the effect of solute transport parameter uncertainty, grid design and solver selection/settings?	N/A	
7.15 Does the report address the role of geologic heterogeneity on solute concentration distributions?	N/A	

8. Surface water–groundwater interaction

8.1 Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives?	Yes	
8.2 Is the implementation of surface water–groundwater interaction appropriate?	C	Yes, except stage height definition is odd (not physics-based) and could be improved.
8.3 Is the groundwater model coupled with a surface water model?	N/A	
8.3.1 Is the adopted approach appropriate?	Yes	
8.3.2 Have appropriate time steps and stress periods been adopted?	Yes	
8.3.3 Are the interface fluxes consistent between the groundwater and surface water models?	N/A	

NOTES		
1	***N/A***	***Not applicable***
2	***U***	***Unknown***
3	***C***	***Comment***

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