
Appendix F

Groundwater Impact Assessment

Oven Mountain Pumped Hydro Energy Storage Project

Groundwater Impact Assessment

Prepared for OMPS Pty Ltd

August 2024

Oven Mountain Pumped Hydro Energy Storage Project

Groundwater Impact Assessment

OMPS Pty Ltd

E230869C Submissions report - Groundwater Impact Assessment

August 2024

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Approved by



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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 supplying 900 megawatts (MW) of dispatchable electricity generation and load capacity, providing up to eight hours of dispatchable energy at full generation to be stored and made available to the NEM.

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.

The groundwater resources for the Project are managed under the Macleay Unregulated and Alluvial Water Sources 2016 (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.

Surface water resources (as assessed in the Surface Water Impact Assessment (EMM 2024a)) within the Project area comprise the Macleay River Catchment. There are four surface water sources within the Project area that are managed under the Macleay WSP, including:

- Macleay Gorges Water Source
- Macleay Valley Water Source

- Dyke River Water Source
- Georges River Water Source.

ES3 Baseline monitoring program

A water monitoring network was 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, vibrating wire piezometers, third-party landholder bores and groundwater springs. The network covers 34 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 Climate Change, Energy, the Environment and 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 4 kilometres (km) north of the Project across the escarpment area and west of the Carrai Plateau.

Based on the groundwater modelling, watertable drawdown is predicted to have minor impacts on terrestrial groundwater dependant ecosystems (GDEs), none of which are identified as high priority GDEs in a WSP. There will be a minor reduction in baseflow available to rivers and creeks. 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 or any groundwater/surface water user.

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

Monitoring of groundwater drawdown and inflow will be monitored during construction of the Project as part of a Water Management Plan developed and implemented for the Project. 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 be implemented to reduce groundwater inflow.

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) as well as 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. The peak, cumulative take (including direct take, arising from inflow to Project components and in-direct take, arising from reduced baseflow to watercourses) occurs over the fourth year of construction (537 ML).

OMPS currently hold licences for 407 unit shares within the NEFB Coast Groundwater Source. There is sufficient groundwater entitlement available within the applicable groundwater source to secure the remaining licence volume to account for the peak predicted take for the Project.

The NSW Government has periodically released additional entitlements within the NEFB Coast Groundwater Source via controlled allocation. The next controlled allocation order is yet to be confirmed; however, OMPS will be able to apply for the required licences at this time, providing a pathway for acquisition of the remaining licence volume (including in-direct take requirements).

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.

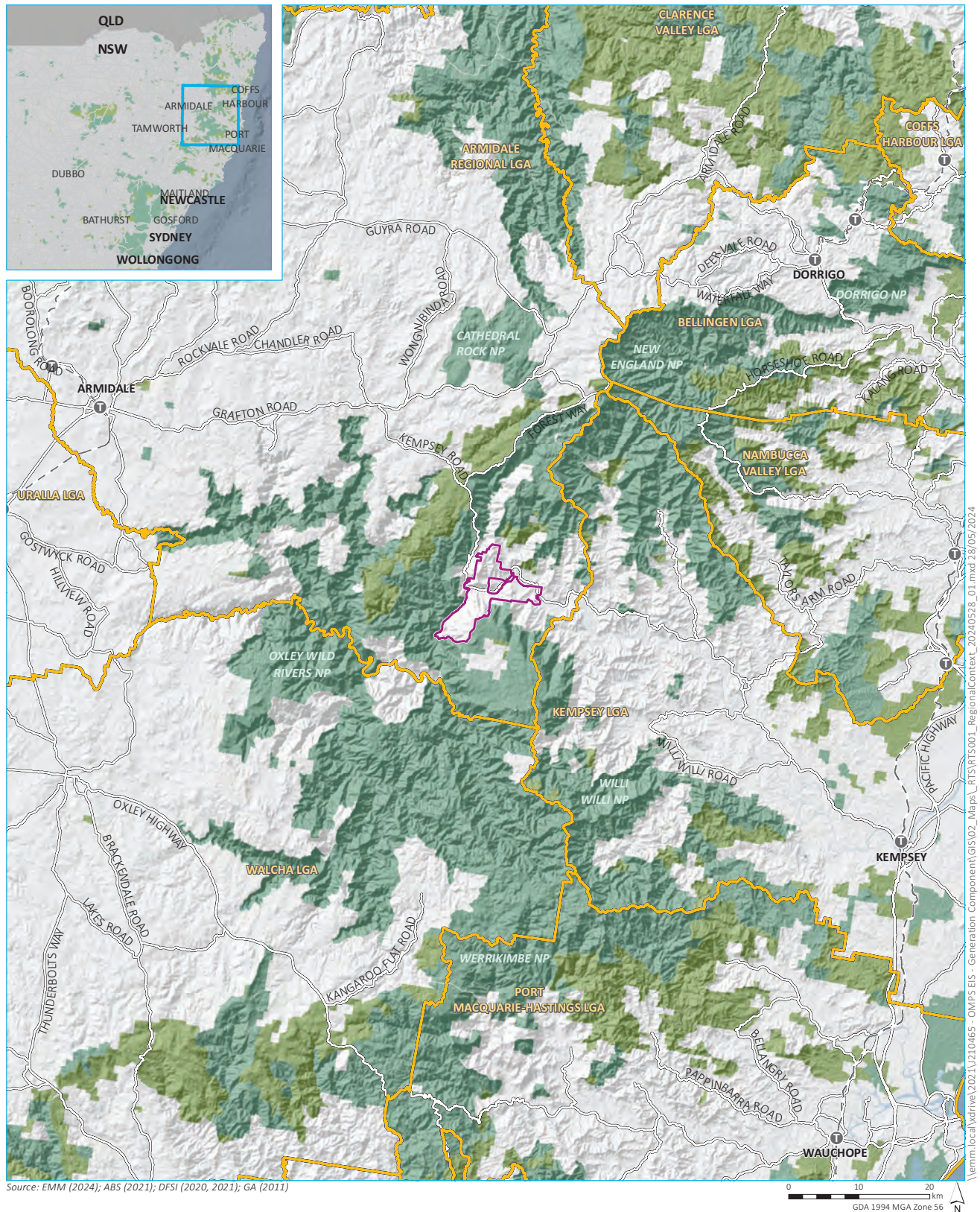
The Project will broadly comprise upper and lower water reservoirs, a power waterway (connecting the reservoirs), a hydro-electric power station and ancillary tunnels (for access, cabling and ventilation).

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 megawatts (MW) of electricity generating capacity, the Project will aid in the transition of the National Electricity Market (NEM) towards cleaner, more reliable and affordable electricity. It will also provide eight hours of dispatchable energy at 900 MW generation to be stored and made available to the NEM. The expected operational lifespan of the Project is in excess of 100 years.

The Project is proposed within the steep topography of the Great Dividing Range, providing ideal conditions for pumped hydro energy generation. Energy is stored by pumping water to the upper reservoir during periods of low NEM demand. Generation occurs when water is circulated from the upper reservoir to the lower reservoir, via the hydro-electric power station. This storage and generation power cycling effectively enables the Project to act as a large battery, supporting the NEW with cleaner, more reliable and affordable electricity.

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.



KEY

- Project area
- T 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



Source: EMM (2024); ABS (2021); DFSI (2020, 2021); GA (2011, 2020); ESRI (2024)

KEY

- Project 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

1.3 Purpose of this report

An Amendment Report is being submitted to address changes in the Project design following exhibition of the Environmental Impact Statement (EIS). This revised groundwater impact assessment (GIA) has been prepared as an input to the Amendment Report and addresses the Project changes as relevant to groundwater. This groundwater impact assessment (GIA) has been updated to consider the amended design and response to submissions and should be read in conjunction with the EIS GIA report (EMM 2023). The assessment in this updated GIA follows the same approach as used in the GIA for the EIS.

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 2024a) and biodiversity development assessment report (BDAR), (EMM 2023b). This GIA should be read in conjunction with these reports.

1.4 Assessment guidelines and requirements

1.4.1 Secretary's Environmental Assessment Requirements (SEARs)

This GIA has been prepared to address the SEARs issued by NSW Department of Planning, Industry and Environment (DPIE), now the Department of Climate Change, Energy, the Environment and Water (DCCEEW) 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.	Chapter 12.2 and Chapter 12.3 SWA – Chapter 7.2 (EMM 2024a) SWA – Chapter 9 (EMM 2024a)
An assessment of the impacts of the Project on:	
• the quantity and quality of the region's surface and groundwater	Chapter 6, Chapter 9 and Chapter 10
• resources, including Macleay River and Fingerboard Crossing Creek	Chapter 9.2.6 SWA – Chapter 6 (EMM 2024a) SWA – Chapter 7 (EMM 2024a)

Requirement	Section addressed
water security for local downstream receivers	Chapter 9.2.5vi SWA – Chapter 6.5 (EMM 2024a) SWA – Chapter 7.5 (EMM 2024a)
hydrological flows on site, including any potential flooding impacts	SWA – Chapter 7.8 (EMM 2024a)
key water features on site, including potential impacts on riparian land	SWA – Chapter 5.9 (EMM 2024a) SWA – Chapter 6.3 (EMM 2024a) SWA – Chapter 7.3 (EMM 2024a)
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.	Chapter 9.2.5vi SWA – Chapter 6.7 (EMM 2024a) SWA – Chapter 7.7 (EMM 2024a)
A description of the likely changes to the hydrological regime of the Macleay River, and any associated biodiversity impacts.	Chapter 9.2.6 BDAR – Chapter 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 <i>Guidelines for Controlled Activities on Waterfront Land</i> (DoI 2018) and (if necessary) <i>Why Do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings</i> (Fairfull and Witheridge 2003); and <i>Policy & Guidelines for Fish Habitat Conservation & Management</i> (DPI 2013).	SWA – Chapter 5.9 (EMM 2024a)
A strategy to manage spoil and enhance any new landforms created.	Chapter 10.3.1 Rehabilitation and closure strategy – Chapter 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.	Chapter 9.2.5v Chapter 9.2.6 SWA - Chapter 6.3 (EMM 2024a) SWA - Chapter 7.3 (EMM 2024a) BDAR – Chapter 7 (EMM 2023b)

1.4.2 Response to submission summary

Groundwater relevant responses to submissions were available on the Major Projects website (DPE 2024) from 23 October 2023. A summary of the relevant responses received from agencies/departments is provided in Table 1.2.

Table 1.2 **Summary of groundwater relevant agency advice**

Department / agency	Identifier	Recommendation	Chapter addressed
¹ DPE Water	1.2	The proponent should improve the maximum annual groundwater take estimation from aquifer interference activities and/or other groundwater extraction. This estimation should be itemised by groundwater source for each water year of the five-year construction period and for the operational life of the scheme. The ability to obtain sufficient entitlement in the water source/s needs to be demonstrated.	Chapter 12.2.3 Table 12.1
	1.4	The proponent should confirm the requirement to construct and operate groundwater supply bores for the project. Should bores be required, the proponent should provide an impact assessment on water users, water source/s and dependent ecosystems.	Chapter 12.4.1
	1.6	The proponent should acquire sufficient water entitlement in a Water Access Licence (WAL), in the relevant water source/s, to account for the maximum predicted water take prior to the take occurring.	Chapter 12.3
	2.1	The proponent should provide potential viable options for managing the infiltration and groundwater mounding arising from reservoir and tunnel construction/operation.	Chapter 11.4.1 Chapter 11.4.2
	2.2	The proponent should provide a detailed tabulation that describes how the monitoring and modelling requirements advised by DPE Water have been incorporated into:	See below
		• the monitoring network	Chapter 5.2.1
		• the initial numerical model design	Chapter 9.2.2
		• ongoing refinement of the model at review milestones.	Chapter 11.4.3
	2.3	The proponent should develop a construction and operational groundwater management plan in consultation with DPE Water that includes a groundwater monitoring, reporting and trigger action response programme. The construction and operational plans must include:	See below
		• specific groundwater dependent ecosystem (GDE) monitoring to enable detection of potential water table drawdown during the construction phase	Chapter 11.4.1
		• monitoring of mounding effects during the operational phase, which could enhance baseflow discharge to the Macleay River valley and spring discharges.	Chapter 11.4.1

Department / agency	Identifier	Recommendation	Chapter addressed
	2.4	The proponent should install monitoring device/s and or bore/s close to and deeper than the deepest part of the scheme. These are to be located near the station cavern and deeper than its base, and installed and used as follows: - the deep monitoring setup must be installed as soon as practicably possible to enable the use of its data in the required first round of model validation and updating - monitored to collect hydrogeological data to confirm the parameter values used in the corresponding model layer - monitored to use groundwater head data in model validation (post-audit) that is required to be part of future model updating - included in the monitoring plan.	See below Chapter 5.2.1 Chapter 5.2.3 Chapter 5.2.3 Chapter 11.4.1
	2.5	The proponent should complete groundwater model validation (post audit) and updating as follows: - Validate and update the model within three months of the following milestones: a) One year and 3 years from the start of construction. b) One year and 6 years from the end of the construction, the later corresponds to 10 years from the start of construction. - Incorporate deep layer measurements (parameters and observed heads). - Consider all remaining comments from the independent peer review in the future models. - Check model validity using recently collected data. - Refine and/or recalibrate the model if needed. - Revise predictions if needed, including uncertainty analysis.	Chapter 11.4.3
¹ DPE Water (Licensing and Approvals)		For the operational and decommissioning phases of the Project, the Proponent confirms the water supply for all stages of the Project. If required, the proponent will need to demonstrate the ability to obtain a secure and appropriately authorised water supply for all stages of the Project. This is to include relevant agreements where required and to demonstrate sufficient water entitlements can be acquired where necessary.	Chapter 12.2.3 Chapter 12.3
		The Proponent obtains sufficient entitlement in the New England Fold Belt Coast Groundwater Source to accommodate direct groundwater take and the take from reduced baseflows to the Project's surface water sources (497 ML/year).	Chapter 12.3
		If water supply for construction is to be accessed from groundwater supply bores during the Project, a WAL with sufficient entitlement to account for the groundwater take must be obtained, unless an exemption applies. A water supply work approval will also be required from DPE Water for any groundwater supply bores that have not been identified and assessed as part of the Project EIS.	Chapter 12.4.1

Department / agency	Identifier	Recommendation	Chapter addressed
EPA	4.2	There are no baseline groundwater monitoring bores within the vicinities of the proposed soil emplacement areas. Comparisons of infiltrated leachate to baseline groundwater quality cannot be determined as a result of the spatial limitations with the existing monitoring network. It is recommended that further shallow monitoring locations are installed downgradient of proposed spoil emplacements.	Chapter 10.3.2
	4.3(a)	Please provide a more succinct comparison table for all sampled groundwater quality events, with details regarding the adopted guidelines used for comparison is requested. This will enable a more thorough analysis of the variability of naturally occurring leachable metals across the site.	Chapter 6.3.3 Annexure D

Notes: 1. Department of Planning and Environment: Water, currently referred to as the Department of Climate Change, Energy, Environment and Water

1.4.3 Regulator engagement outcomes

Engagement was held with DPE Water on 4 March 2022. Email correspondence was received by EMM on 1 April 2022. Comments have been addressed as per Table 1.3.

Table 1.3 Regulator

Department / agency	Engagement comment	Representative	Chapter addressed
¹ DPE Water	Modelling will need to validate the assumed numerical parameters for the deeper part of the pluton with information gained from in bore hole tests when information is available at project depth. Results will need to be forwarded to and discussed with DPE, meeting preferred to discuss reported results, revised model, and implications to for groundwater impacts.	Lyle Sawyer	Chapter 5.2 Chapter 11.4.3
	Isotope tracers may be useful to enhance conceptual understanding.	Hisham Zarour	Chapter 5.3
	I think we may need to assess the climatic changes in weather. We will need a good approach for uncertainty.	Hisham Zarour	Chapter 5.3

Notes: 1. Department of Planning and Environment: Water, currently referred to as the Department of Climate Change, Energy, Environment and Water



Source: EMM (2024); ABS (2021); DFSI (2020, 2021); GA (2011, 2020)

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
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Figure 1.3



\\emh.local\drive\2021\210465 - OMPS EIS - Generation Component\GIS\02_Maps\RTS_GW_GIA\015_ProjectStudyArea_20240705_01.mxd 9/07/2024

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. These are further broken down into the Project’s key elements 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.

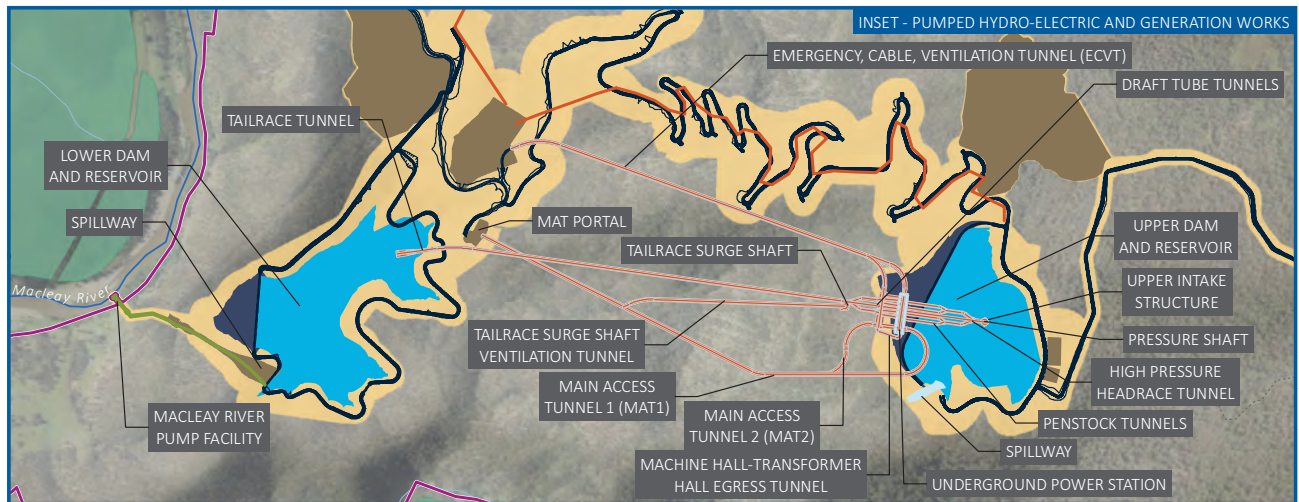
2.3 Amendments to design

A detailed description of the Amended Project is provided in the Amendment Report. An overview of each of the amendments to the Project in comparison to the Project exhibited in the EIS is provided in Table 2.1. As part of these amendments, the project area, construction envelope, disturbance footprint and operational footprint, have also consequently all been revised to accommodate stakeholder feedback, design changes and refined construction requirements.

Table 2.1 Overview of the project amendments in comparison to the project

Project element	Description of change	Summary of the Project as exhibited in EIS	Summary of the amended Project
Internal roads			
Eastern Access Road (EAR) realignment	Realignment of the EAR to reduce need for earthworks, improve road safety and address drainage issues. This includes extending into areas outside of the proposed EIS construction envelope. This amendment is proposed to reduce the period of internal road construction and therefore overall construction period, and improve effectiveness of emergency response measures (access and egress).	Approximately 11.4 km	Approximately 12.1 km
Temporary bridges	A temporary bridge will be utilised prior to the construction of the two permanent bridges (referred to as Eastern Access Temporary Bridge). A secondary, temporary access is proposed via the construction of a new, temporary bridge crossing of the Macleay River about 600 m upstream and north-west of Georges Junction (referred to as Western Access Temporary Bridge).	One temporary bridge: Eastern Access Temporary Bridge. One permanent bridge.	Two temporary bridges: Eastern Access Temporary Bridge (EATB) and Western Access Temporary Bridge (WATB). One permanent bridge.
Upper Dam Access Road (UDAR) refinement	Realignment of the UDAR to allow more feasible heavy vehicle access and to address drainage issues. This includes extending into areas outside of the proposed EIS construction envelope.	Approximately 7.1 km	Approximately 6.4 km
Construction			
Temporary or fly camps	While fly camps were previously anticipated for the project, up to three fly camps are confirmed to be required and located near Smiths Bluff (Eastern fly camp), the intersection of the Main Access Road and the EAR (Western fly camp), and the upper reservoir (within spoil emplacement area) (Southern fly camp). The camps will accommodate up to about 20 workers and be established within the first year of construction. All services will be trucked in and out of the sites, with no permanent facilities or services proposed.	Temporary or fly camps may be required. The location and size will be documented during the detailed design phase.	Three temporary or fly camps will provide small scale temporary work accommodation for workers completing initial road works until the main accommodation camp is completed. Proposed locations in proximity of EATB, WATB, and Upper reservoir.
Blasting and rock crushing/processing	Allowing blasting as a construction method for road works and other above-ground works. Rock processing/crushing facilities will be required in the lower reservoir (LR) and upper reservoir (UR) areas to process rock for use in dams.	Blasting required for tunnels and portals.	Blasting required for tunnels and portals, reservoirs and road works.
Construction water requirements	Increasing the estimated water requirements for use in construction (e.g. dust suppression, concrete batching, etc).	Approximately 1 ML/day	Approximately 3 ML/day

Project element	Description of change	Summary of the Project as exhibited in EIS	Summary of the amended Project
Drainage/erosion and sediment control	Allowing sufficient area for retention basins within the construction envelope, in particular for early works. This may include extending into areas outside of the proposed EIS construction envelope.	See 'disturbance footprint'.	See 'disturbance footprint'.
Construction envelope	Updates to the construction envelope to accommodate stakeholder feedback, design changes and refined construction requirements.	Approximately 780 ha	Approximately 768 ha
Disturbance footprint	Updates to the disturbance footprint to accommodate stakeholder feedback, design changes and refined construction requirements.	Approximately 330 ha	Approximately 367 ha
Spoil and materials			
Laydown/stockpile areas	There will be four areas used for stockpiling and material laydown. One area is located along the main access road (between transmission towers 14–16), one area is located in proximity to the batching plant, one area is located near Georges Junction, and one is located near the Eastern Access Temporary Bridge on the eastern side of the Macleay River. The largest of the four areas has also been flagged as available for other ancillary uses, to provide further flexibility as the detailed design progresses.	There will be two areas used for stockpiling and material laydown, covering a total area of 114,000 m ²	There will be four areas used for stockpiling and material laydown, covering a total area of 119,600 m ²
Spoil emplacement	Revised spoil estimates were derived following changes to the underground arrangement and sizing. This, in addition to incorporating agency feedback, required changes to the conceptual landform design. The conceptual landform design presents reduced height and slopes however requires a greater disturbance area as a result.	Three permanent spoil emplacement locations to store around 2.9 Mm ³ plus dead storage within the reservoirs with approximate capacity 300,000-400,000 m ³ .	Two permanent spoil emplacement locations to store around 3.55 Mm ³ . Use of dead storage in reservoir only if surplus material.
Operational footprint	Updates to the operational footprint to accommodate design changes (including permanent spoil emplacement and transmission alignment along the UDAR).	Approximately 270 ha	Approximately 280 ha
Underground arrangement and sizing			
Underground arrangement and sizing for improved generation capacity	The Project will provide up to around 900 MW of electricity generating capacity and up to eight hours of energy storage at full generating capacity.	Up to 900 MW and between 8 and 12 hours of energy storage. Underground arrangement and tunnel sizes reflect lower energy storage capacity	Up to 900 MW and up to 8 hours of energy storage. Underground arrangement and tunnel sizes reflect greater energy storage capacity. Re-location of MAT portal to align with amended arrangement.



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

KEY

 Project area	 Construction envelope	 Surface works
— Power station	— Pump station	— Tunnels, portals, intakes, shafts
— Transmission overhead lines	— Permanent road	— Dam wall
— Reservoir	— Spillway	— Macleay River
— Watercourse/drainage line	— Major road	— Minor road
— Vehicular track	— Existing transmission line	— NPWS reserve
— State forest		

Key project elements

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

2.4 Project area terminology

Approval for the Project is being sought based on preliminary 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.

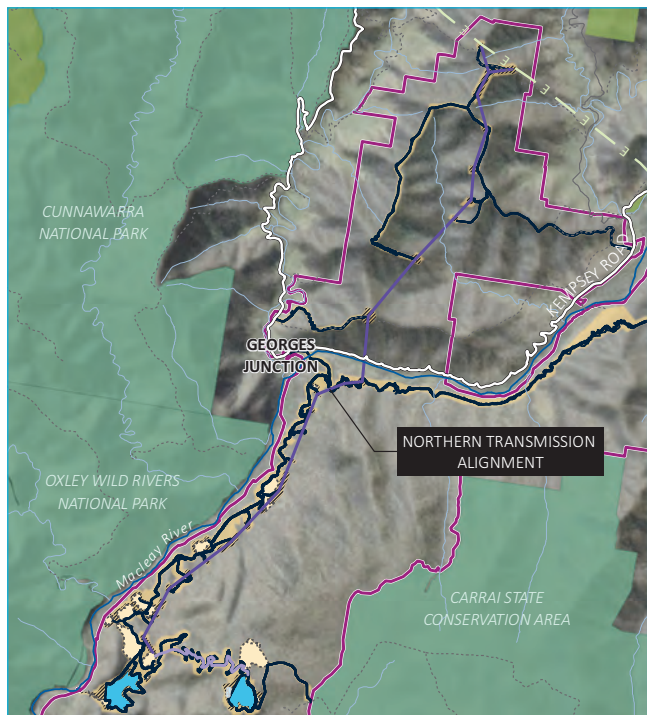
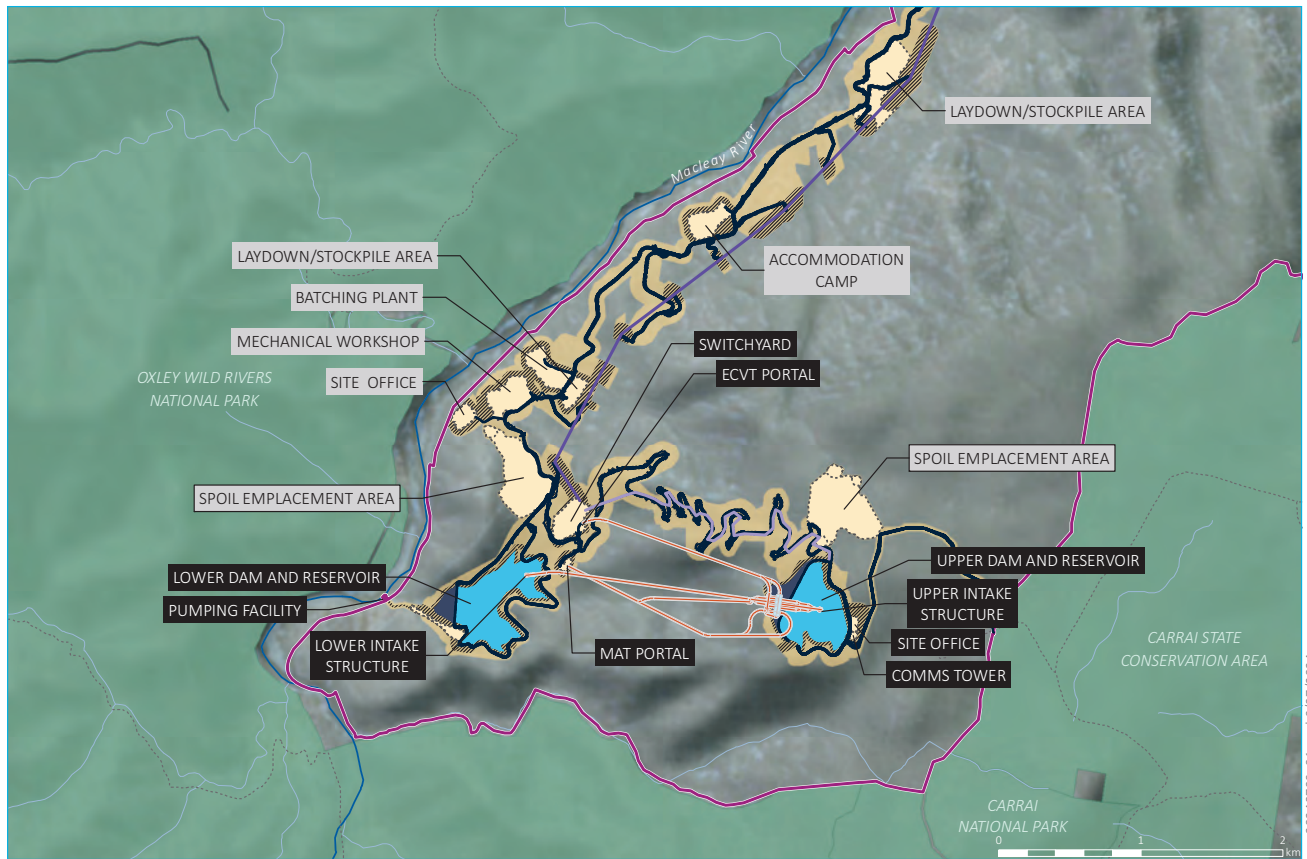
The *Project area* is the broader area within which the Project will be built and operated, and the extent within which direct impacts from the Project are anticipated. Importantly, the Project area does not represent a footprint for the construction works, but rather indicates an area that was investigated 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 768 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 367 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 is around 280 ha.

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



Source: EMM (2024); DFSI (2020); GA (2011); SMEC (2022); ALINTA (2024)

KEY

- Project area
- Disturbance footprint
- Construction envelope
- Surface works
- Project operational elements
- Underground power station complex
- Power and communications lines
- Transmission overhead lines
- Tunnels, portals, intakes, shafts
- Permanent road
- Reservoir
- Dam wall
- Existing environment
- Macleay River
- Watercourse/drainage line
- Kempsey-Armidale Road
- Vehicular track
- Existing transmission line
- NPWS reserve

Label format

SURFACE PERMANENT INFRASTRUCTURE

UNDERGROUND PERMANENT INFRASTRUCTURE

TEMPORARY INFRASTRUCTURE

PERMANENT SPOIL EMPLACEMENT

Project areas overview

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater Impact Assessment
OMPS Pty Ltd
Figure 2.2



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 Chapter 1.1), encompasses the:

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

As discussed in Chapter 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 detailed assessment incorporating the study area. Further discussion is provided in Chapter 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

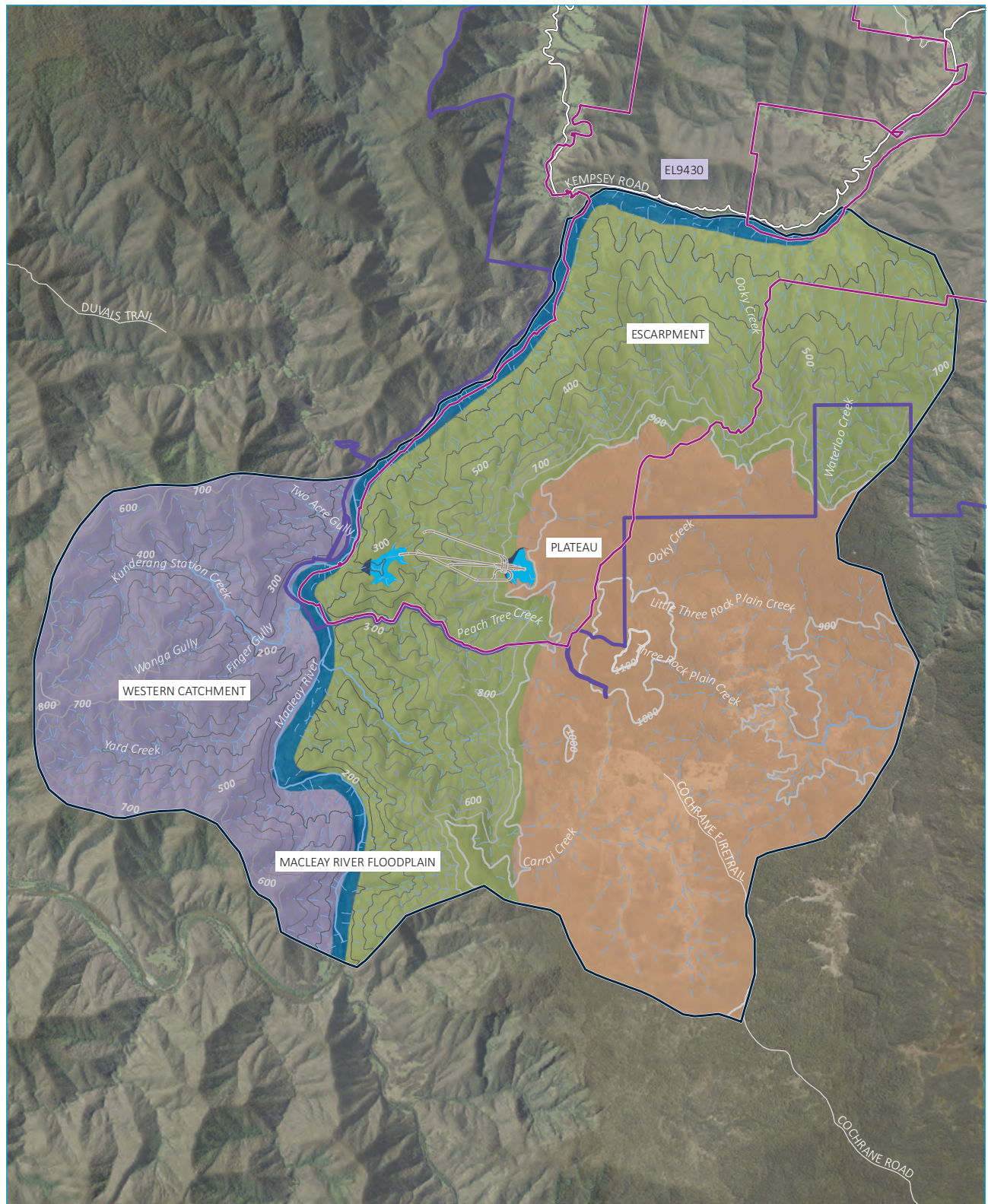
The topography of the plateau is relatively level at an average elevation of approximately 1,000 mAHD. The escarpment dips down to the west and north-west from the plateau, where the relief levels out at an average elevation of 145 mAHD along the Macleay River floodplain.

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 (2024); DFSI (2020, 2021); GA (2011, 2020)

KEY

 Project area	 Existing environment	 Topographic contour (100 m interval)
 Study area	 Major road	 200
 Exploration lease EL9430	 Minor road	 300
 Dam wall	 Streams within study area	 400
 Reservoir	 Perennial	 500
 Tunnels, portals, intakes, shafts	 Non-perennial	 600
 Focus area		 700
 Escarpment		 800
 Macleay River floodplain		 900
 Plateau		 1000
 Western catchment		 1100

Focus areas, topography and land use

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater Impact Assessment
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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.

To assess rainfall trends across the study area, noting there are two distinct climatic zones (refer Chapter 3.3.1), climate records were accessed from the gridded SILO database (DES 2022). The gridded SILO dataset interpolates climate data between available weather stations (refer Table 3.1), providing an average climate across a broader area. Rainfall records indicate the study area has experienced long-term climate cycles with distinct wet and dry periods, as indicated in Figure 3.2.

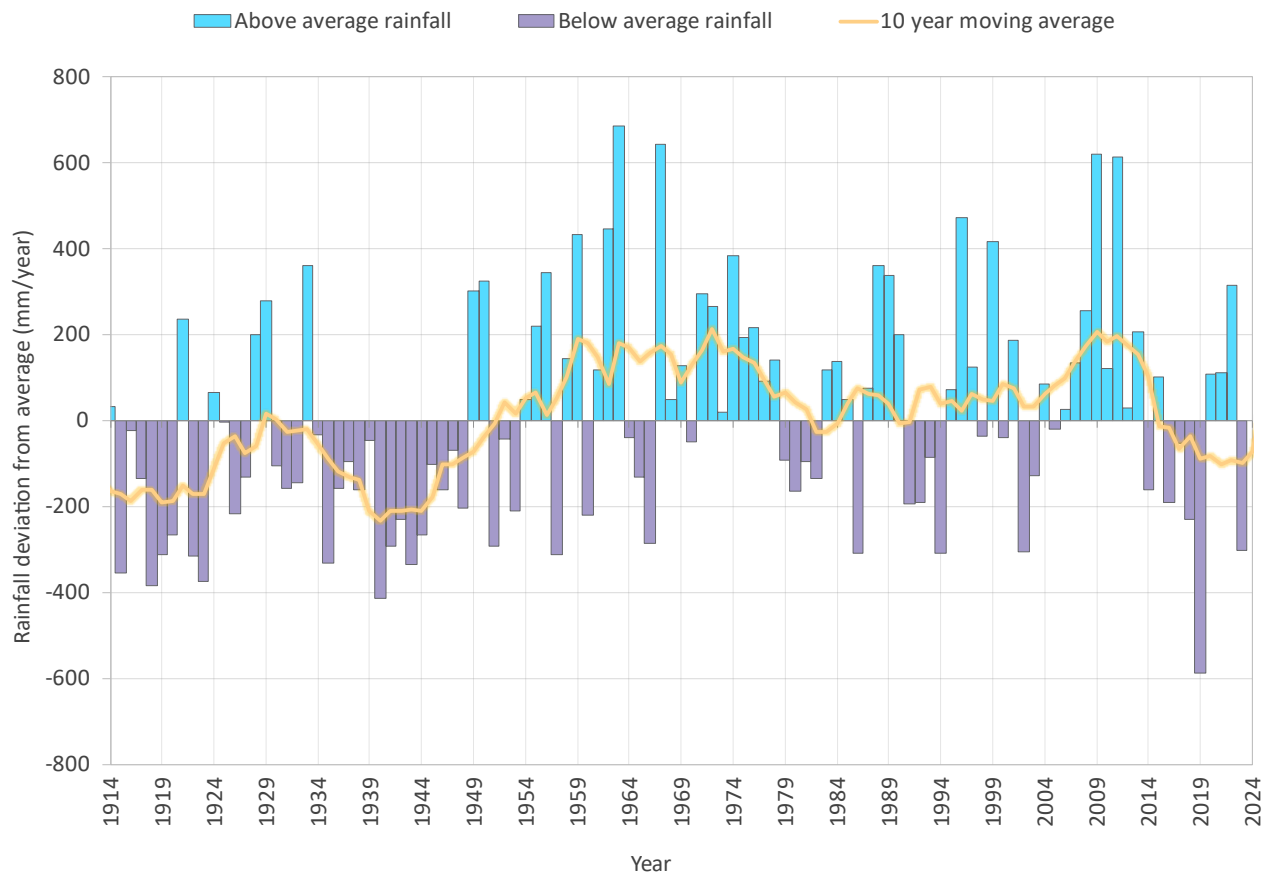


Figure 3.2 Historical climate trends across study area (co-ordinates 30.80; 152.15)

3.3.3 Recent climate trends

Inferred rainfall and evaporation records accessed from the gridded SILO database (DES 2022) have been used to summarise recent climate trends for the study area. The previous six years of evaporation and rainfall data between 2018 and 2024 is provided in Figure 3.3, generally indicating:

- dry periods (relatively high evaporation and low rainfall, compared to average) between:
 - January 2018 and December 2020
 - May 2023 and October 2023
- a wet period (relatively high rainfall and low evaporation, compared to average) between January 2020 and April 2023
- average and stable climate between November 2023 and January 2024.

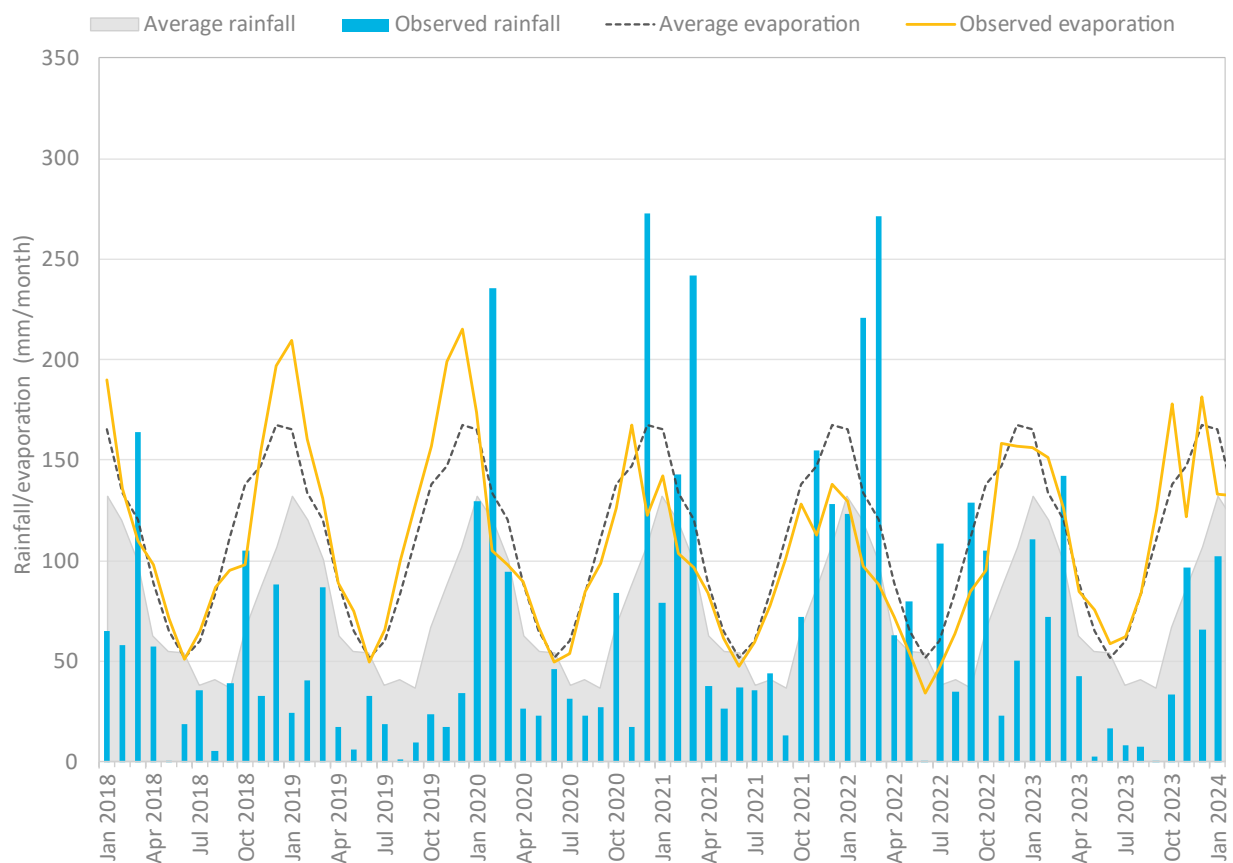


Figure 3.3 Monthly rainfall and evaporation variability across study area (co-ordinates 30.80; 152.15)

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 ($\leq 15\%$)
- 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 comprises pale grey, medium grained sand with minor clay inclusions
- metamorphic rock (hornfels and metasediments) typically comprises 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 Chapter 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.

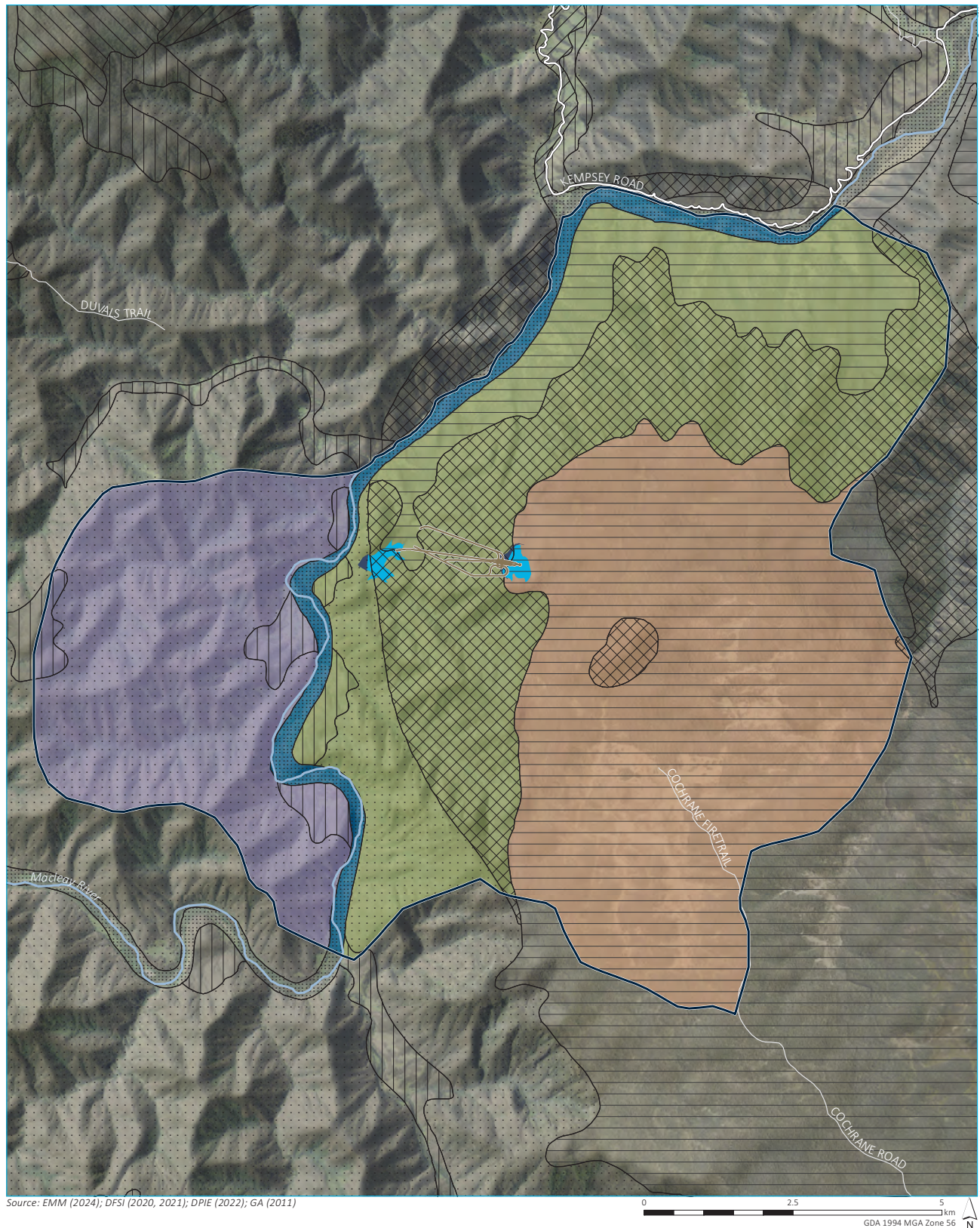
The study area lies within the New England Orogen (NEO). The NEO extends approximately 2,000 km along the east coast of Australia from Townsville, QLD (north) to Newcastle, NSW (south), and is bordered by the Sydney-Gunnedah-Bowen Basin to the west (Jessop et al. 2019). Differing geodynamics in the early 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. It is 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.

Period	Formation	Typical description (Colquhoun et al. 2022)
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.



KEY

- Study area
- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts
- Existing environment
- Major road
- Minor road
- Macleay River

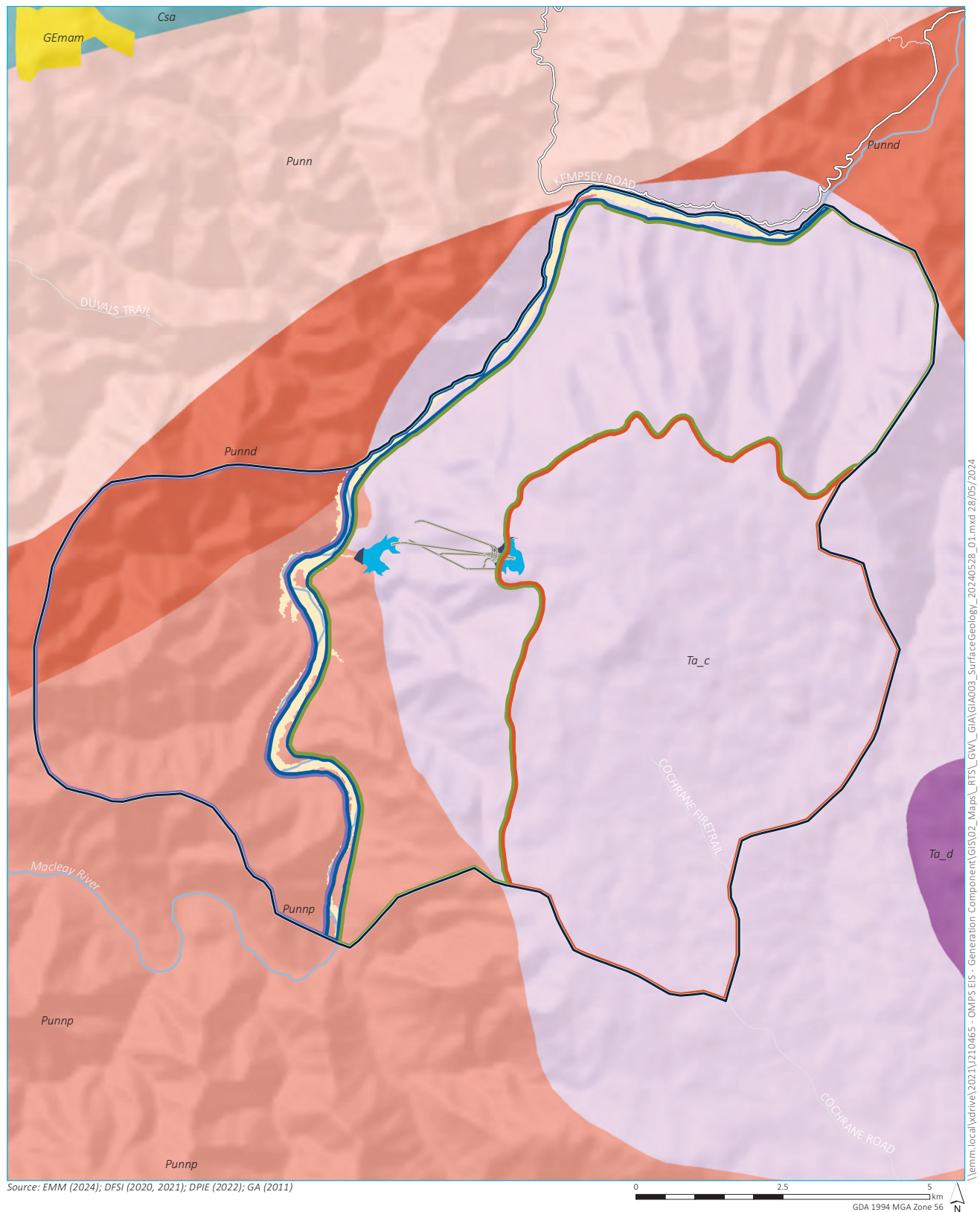
- Focus area
- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

- Soil type (ASC)
- Dermosols
- Ferrosols
- Kandosols
- Kurosols
- Rudosols
- Rudosols (alluvial)
- Tenosols

Soil distribution within
the Carrai, NSW region

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Figure 3.4





KEY

	Study area		Escarpment		Priabonian
	Dam wall		Macleay River floodplain		Maybole Volcanics (GEmam)
	Reservoir		Plateau		Late Triassic
	Tunnels, portals, intakes, shafts		Western catchment		Carrai Granodiorite (Ta_c)
	Inferred alluvium				Daisy Plains Leucosyenogranite (Ta_d)
	Existing environment				Permian
	Major road				Nambucca beds (Punn)
	Minor road				Parrabel beds (Punnp)
	Macleay River				Pee Dee beds (Punnd)
					Carboniferous
					Sandon Association (Csa)

Surface geology within the Carrai, NSW region

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater impact assessment
OMPS Pty Ltd
Figure 3.5

3.5 Surface water

The study area is located within the Macleay River catchment, covering approximately 11,400 km² 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.

Surface water within the study area generally 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 ecosystems
 - 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)) at 30–58 metres depth (i.e. 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

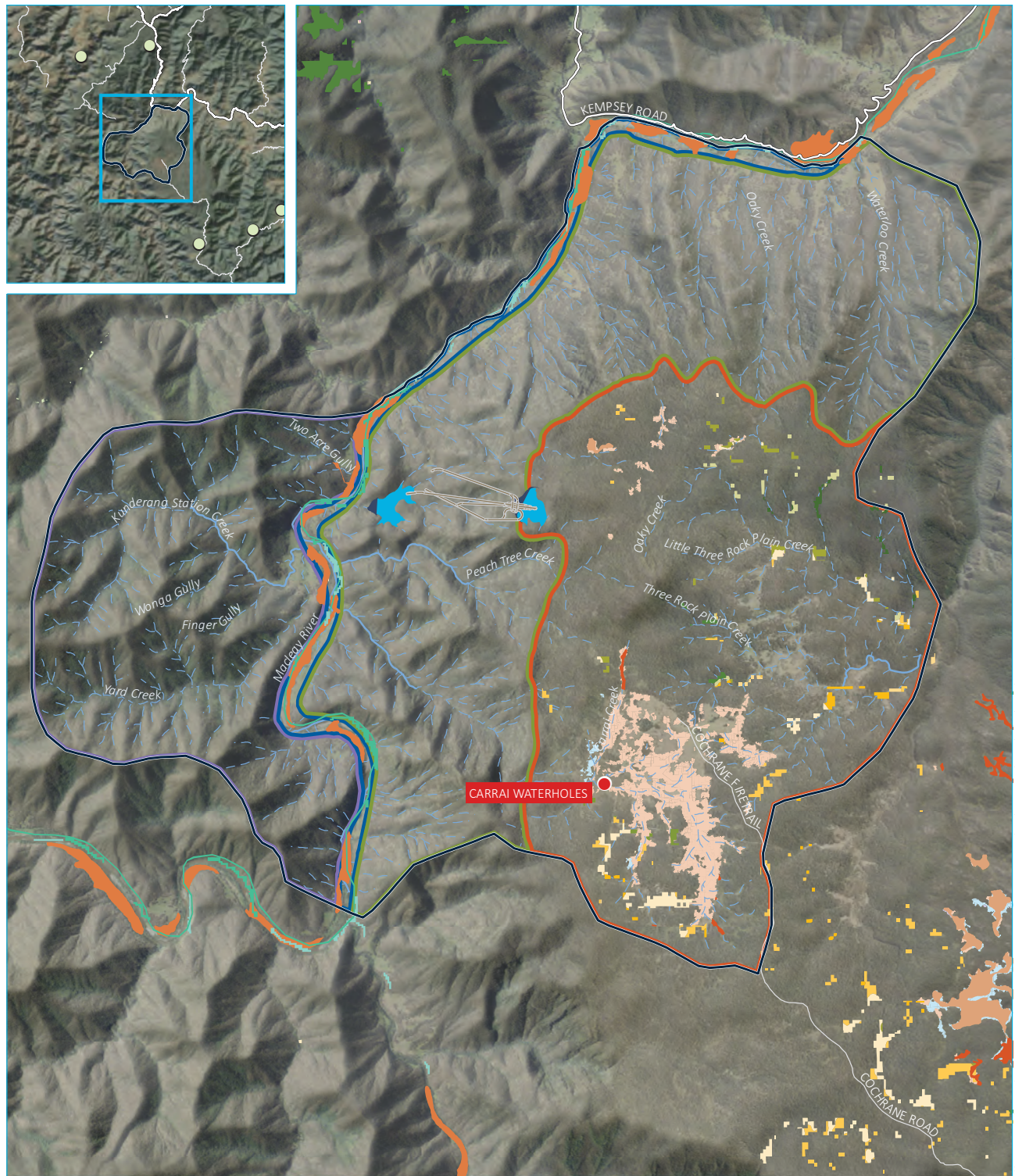
Category	Groundwater dependent ecosystem	Focus area	Source
Terrestrial	River Oak	Macleay River floodplain	¹ BoM GDE atlas
	Freshwater Wetland	Plateau	¹ BoM GDE atlas
	Sedgeland/rushland	Plateau	¹ BoM GDE atlas
	New England Tableland Carex Fens (PCT3944)	Plateau	² HEVAE database
	Eastern New England Granites 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 (2024); BoM (2022); DFSI (2020, 2021); DPIE (2022); GA (2011); HEVAE (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
- 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 - Macleay River
 - Moderate potential GDE - Macleay River

- GDE Terrestrial (BoM)
 - Moderate potential GDE
 - Alpine Gum
 - Diehard Stringybark-New England Blackbutt
 - Grassy New England Blackbutt-Tallowood-Blue Gum
 - Manna Gum
 - Mid North Coast Wet Brushbox-Tallowood-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

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 Chapter 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 Mcintyre Dam, providing raw water supply for Kempsey, NSW
- Gara Dam, part of a former hydro-electric scheme operating 1895–1907 (Gojak, Giopoulos and 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 2024a)), 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).

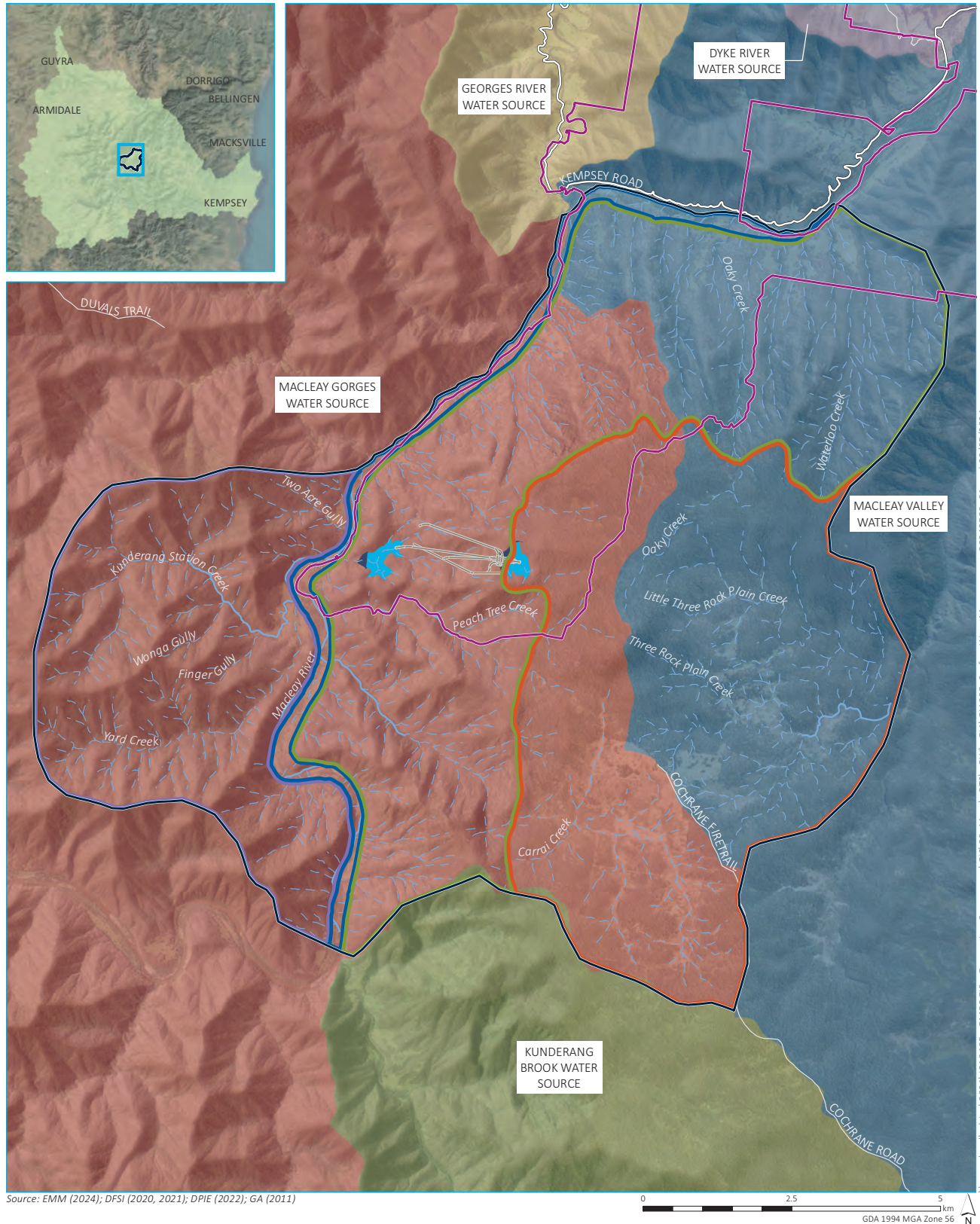
The Macleay WSP includes management measures for the water “contained within the alluvial sediments below the surface of the ground...” (DPI 2016a), including the:

- Coastal Macleay Floodplain Alluvial Groundwater Source (135 ML of share components in the 2023/2024 water year)
- upriver alluvial sediments within the:
 - Macleay Valley Water Source (281 ML of share components in the 2023/2024 water year)
 - remaining water sources, within the Macleay WSP (0 ML of share components in the 2023/2024 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 km² 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 16,910 ML of aquifer licence share components in the 2023/2024 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.

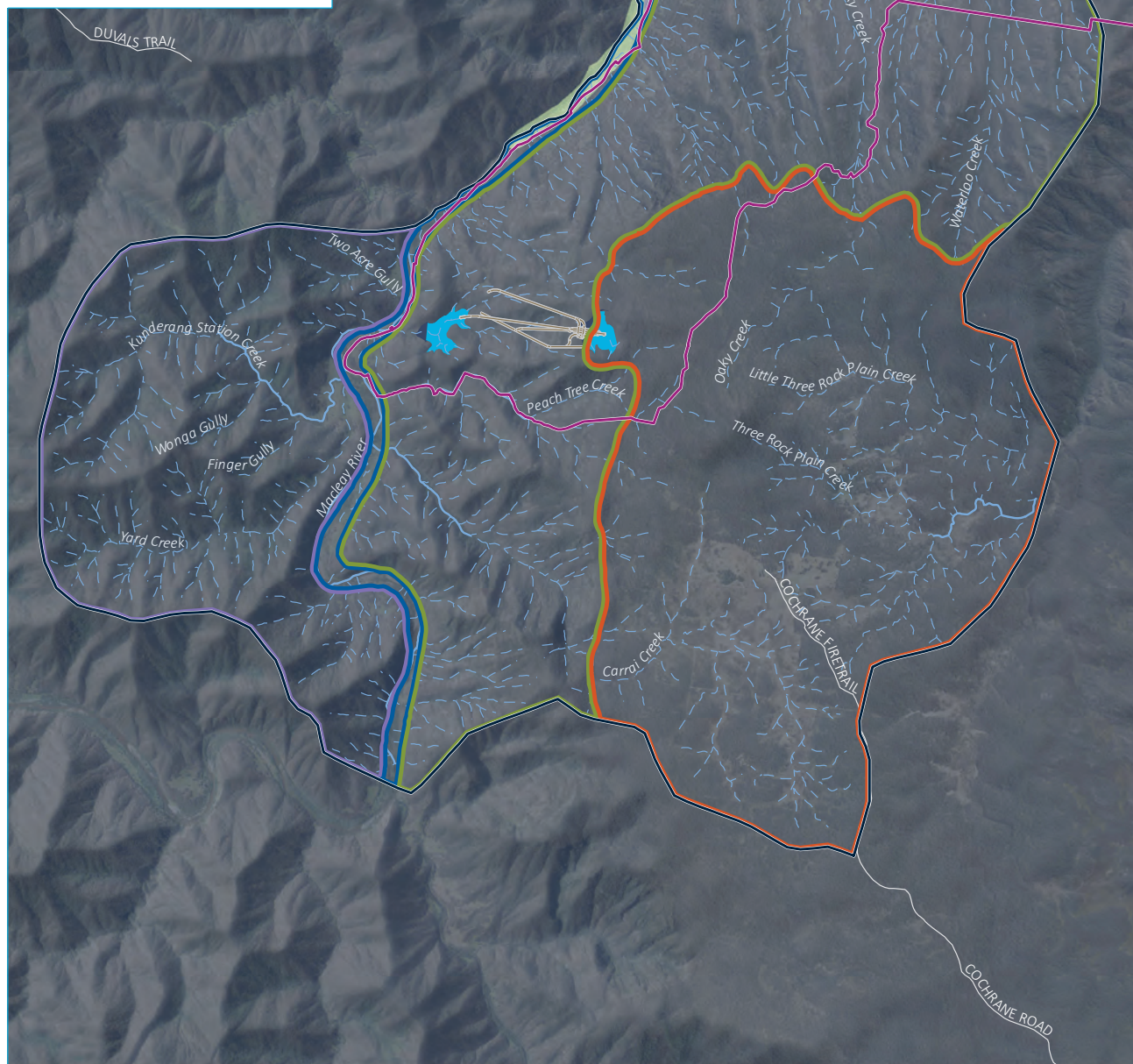


KEY

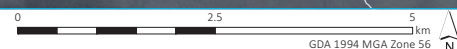
	Project area		Existing environment		Macleay WSP (see inset)
	Study area		Major road		Surface water sources (Macleay WSP)
	Dam wall		Minor road		Dyke River Water Source
	Reservoir		Streams within study area		Georges River Water Source
	Tunnels, portals, intakes, shafts		Perennial		Kunderang Brook Water Source
	Focus area		Non-perennial		Macleay Gorges Water Source
	Escarpment				Macleay Valley Water Source
	Macleay River floodplain				
	Plateau				
	Western catchment				

Surface water management and sources

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Figure 3.7



Source: EMM (2024); DFSI (2020, 2021); DPIE (2022); GA (2011)



KEY

 Project area	 Study area	 Major road	 Minor road	 Reservoir	 Perennial
 Tunnels, portals, intakes, shafts	 Non-perennial	 Focus area	 Streams within study area	 Escarpment	 Groundwater WSP
 Macleay River floodplain	 Plateau	 Western catchment	 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

Owen Mountain Pumped Hydro Energy Storage Project
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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 (³ML/yr)					
High environmental value areas	480,000				
Not high environmental value areas	1,500,000			Not applicable	
Total long-term average annual rainfall recharge (LTAARR)	1,980,000				
Planned environmental water, as per the relevant WSP (³ML/yr)					
High environmental value areas	480,000 ⁴				
Not high environmental value areas	1,440,000 ⁵			Not applicable	
Total planned environmental water	1,920,000				
Long-term average annual extraction limit, as per the relevant WSP (³ML/yr)					
Long term average annual extraction limit (LTAAEL)	60,000 (~3% of LTAARR)			Not applicable	
Requirements for share components, as per the relevant WSP (³ML/yr)					
Domestic and stock rights	9,605	14	483	8	8
Native title	0	0	0	0	0

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 2023/2024 water year (share components/year)					
Domestic and stock	0	0	8	0	0
Aquifer	16,910	0	281	0	0
Local water utility	240	0	0	0	0
Local water utility (domestic and stock)	100	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/yr⁶)	26,855	16	14,292	8	8
Unassigned share components (LTAAEL minus total requirements for water, ML/yr³)	33,145	Not applicable	Not applicable	Not applicable	Not applicable
Total registered water usage in the 2022/2023 water year	84.8	0	2,458.4	0	0

Notes: 1. Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016.
2. Water Sharing Plan for the Macleay Unregulated and Alluvial Water 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 45% allocated, with an additional 33,145 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 Chapter 4.3.2).

Surface water licences required for Project construction and operation are discussed in the Surface Water Impact Assessment (EMM 2024a).

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 2022/23 water year was minimal (84.8 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 175 unit shares within the NEFB Coast Groundwater Source, purchased through the 2021 and 2022 CAOs, respectively. This volume covers the peak predicted direct take anticipated to be intercepted by the Project however, additional entitlements will be required for the in-direct take component (refer Chapter 12.2).

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 the monitoring indicate that the actual inflow in a water year is likely to exceed the licensed volume 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.

New England Fold Belt Coast - Groundwater entitlements

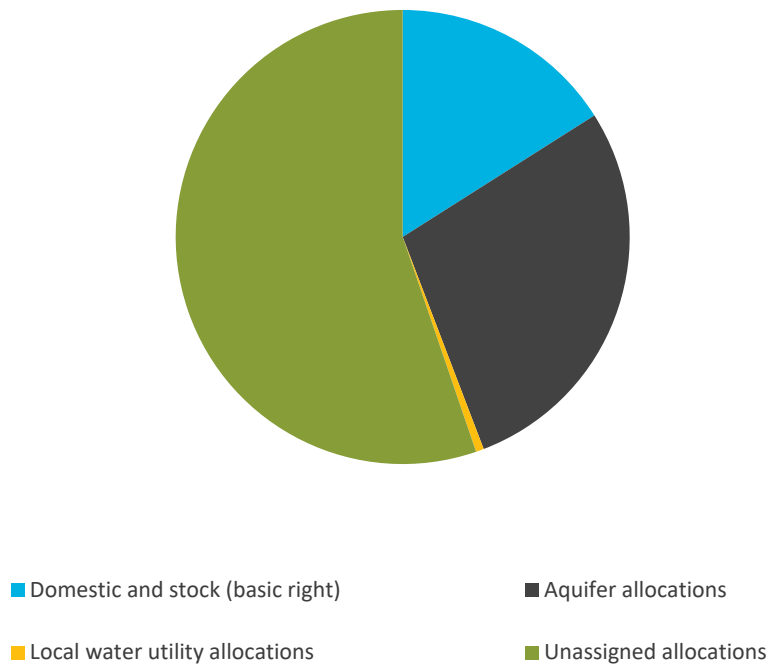


Figure 4.1 Groundwater availability – New England Fold Belt Coast groundwater source

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 out 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).

DCCEEW 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 and illustrated on Figure 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.

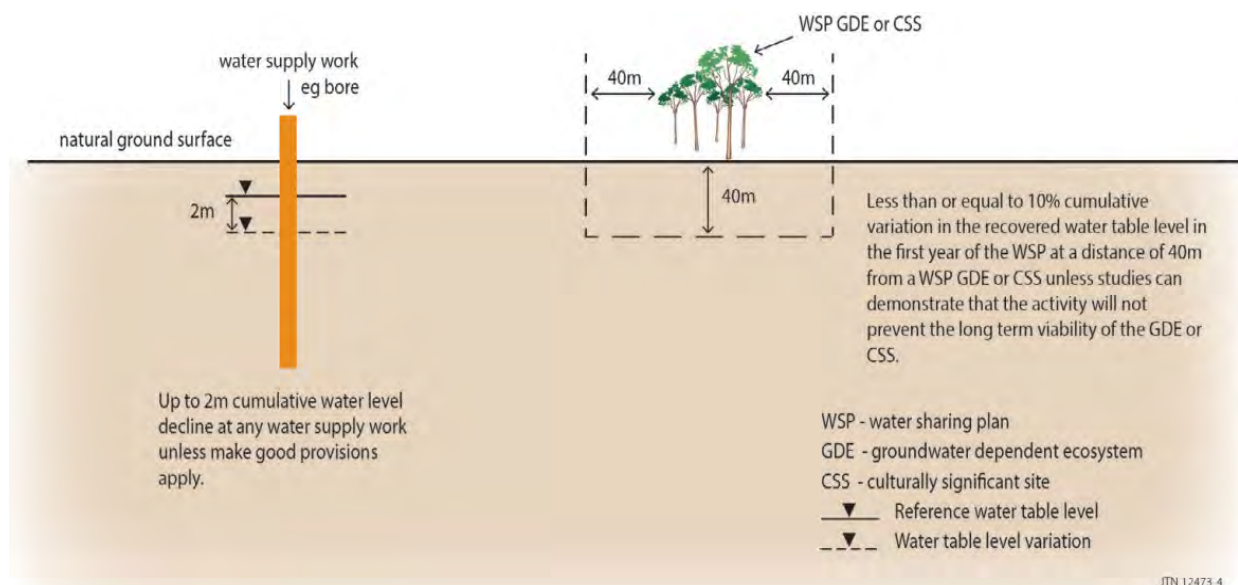


Figure 4.2 Fractured rock groundwater source minimal impact considerations

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 and Williams 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). This concept is illustrated on Figure 4.3.

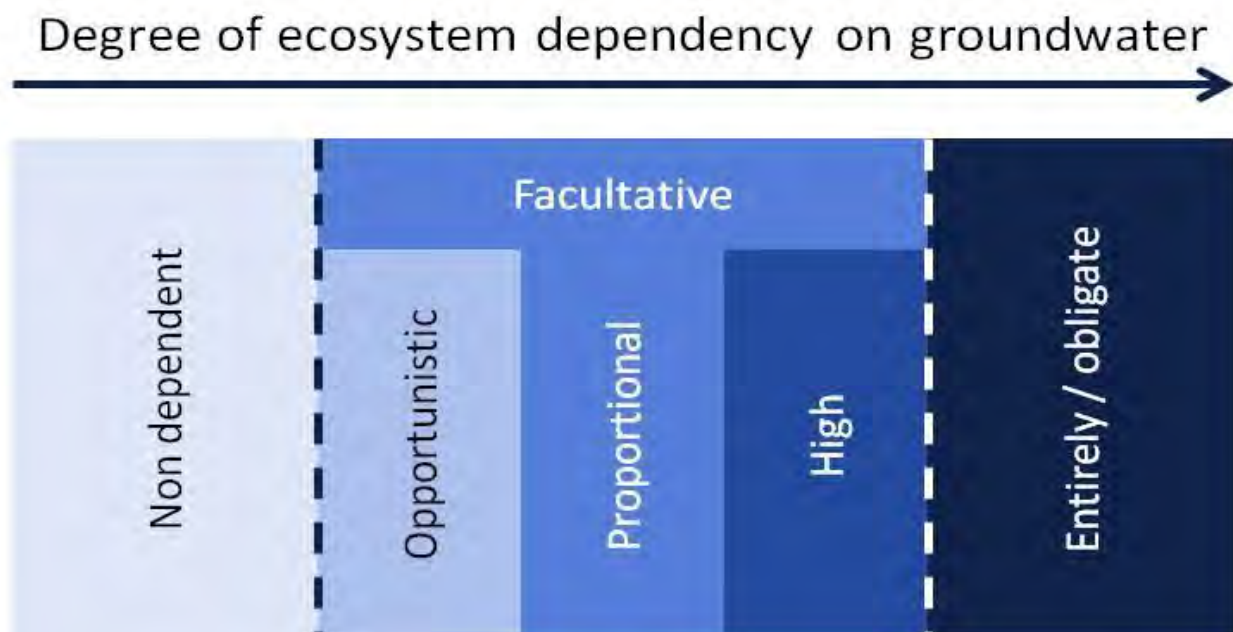


Figure 4.3 Ecosystem level of dependence on groundwater

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.

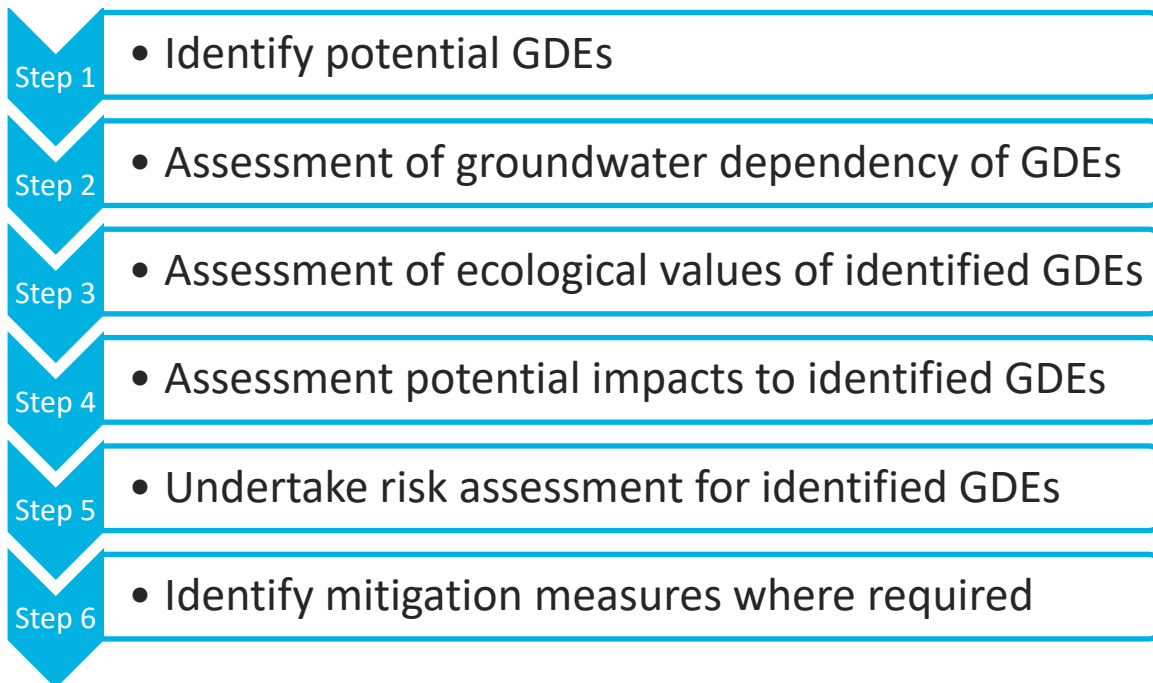


Figure 4.4 GDE risk assessment

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 and Williams 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 Chapter 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 Chapter 4.7.3).

4.7.3 Australian Drinking Water Guidelines

The Australian Drinking Water Guidelines (ADWG) (NHMRC & NRMCC 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 Chapter 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 Chapter 10.2.

5 Baseline monitoring program

5.1 Overview

Baseline monitoring is essential for characterising the hydrogeological conditions within the study area, prior to the proposed Project development. Baseline water level and quality data (baseline data) was used to:

- establish baseline groundwater conditions (i.e. water levels, climatic responses and water quality)
- identify and characterise hydrogeological units within the study area, focussing on characterising groundwater flow and quality
- provide spatial representation and flux of pressure heads across the Project area to investigate potential vertical hydraulic gradients and connectivity between hydrogeological units
- investigate the potential for surface water–groundwater interaction
- understand and monitor potential sensitive features, including watercourses, landholder bores and GDEs.

The understanding developed from the baseline data assists with the development of a hydrogeological conceptual model (conceptual model) and subsequently, a numerical groundwater flow model (numerical model). The conceptual and numerical model provide the fundamental tools for predicting the potential Project induced effects on groundwater.

A summary of the baseline water monitoring network (the baseline network) is provided in Chapter 5.2.

5.2 Baseline water monitoring network

5.2.1 Summary

Groundwater and surface water monitoring commenced in August 2020 (and is currently ongoing). Data collection increased throughout the baseline monitoring period as additional locations were identified or constructed.

The baseline network includes both background (regional) monitoring locations and targeted monitoring locations at/near key Project infrastructure. The baseline network was designed to capture geological, spatial and temporal variations within the study area, supporting a groundwater assessment in accordance with the AIP (DPI 2012).

The baseline network included:

- seven (7) cased boreholes (refer Table 5.1), drilled in 1996 during a geotechnical site investigation program (SMEC 1997)
- A dedicated groundwater monitoring network (refer Table 5.1), designed by EMM and in consultation with DPE Water, comprising:
 - eight (8) conventional monitoring bores targeting the regional groundwater systems, as documented in the hydrogeological investigation program report (attached as Annexure A)
 - three (3) fen monitoring bores, targeting high potential groundwater dependant ecosystems
 - one (1) third-party production bore.
- eleven (11) spring locations and one (1) seep location (refer Table 5.3), opportunistically sampled during routine monitoring events when visibly flowing

- four (4) boreholes containing nine (9) vibrating wire piezometer (VWPs) sensors in total (refer Table 5.2) targeting key infrastructure components (as advised by DPE-Water, refer Table 1.2)
- eight (8) surface water monitoring sites (refer Table 5.4), comprising:
 - six (6) locations within the Macleay River
 - one (1) location within a second order ephemeral stream
 - one (1) location within an upper tributary of the Macleay River catchment (east of Armidale, NSW).

The baseline monitoring network is summarised in Table 5.1–Table 5.4. A location plan is provided as Figure 5.1.

Table 5.1 Baseline network – Cased boreholes and 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	28.50	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
	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)

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	
	HA2203	422925.50	6592371.30	935.10	1.00	0.50	1.00	Sandy clay (residual soil)
Production bores (third party)								
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 Baseline network – Vibrating wire piezometers

Borehole ID	¹ Easting (GDA94)	¹ Northing (GDA94)	¹ Ground elevation (² mAHD)	Number of sensors	Sensor depths (³ mBGL)
BH1001	421728	6591732.38	724	2	56.30
					22.20
BH1002	421631	6591614	724	2	54.20
					50.14
BH1003	421504	6591317	735	2	65.80
					46.90
BH3001	421498	6591281	733	3	800.00
					600.00
					395.00

Notes: 1. interpreted from geographical software. 2. metres above Australian height datum. 3. metres Below Ground Level.

Table 5.3 Baseline network – Groundwater springs

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

Spring ID	¹ Target	² Easting (GDA94)	² Northing (GDA94)	² Elevation (³ mAHD)
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 5.4 Baseline network – Surface water monitoring sites

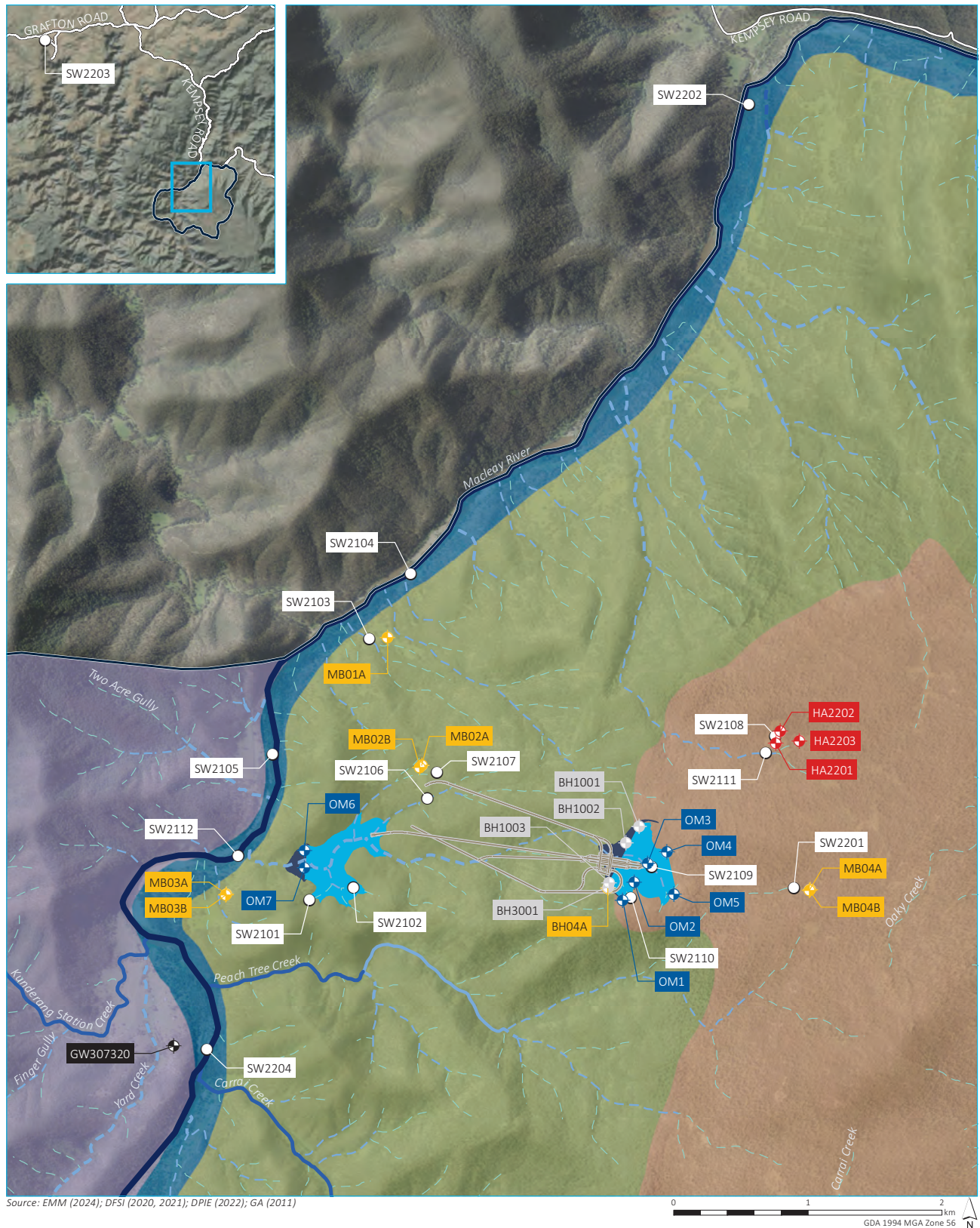
Spring ID	¹ Target	² Easting (GDA94)	² Northing (GDA94)	² Elevation (³ mAHD)
SW2104	Macleay River	420024	6593617	139
SW2105	Macleay River	418994	6592271	141
SW2112	Macleay River	418739	6591515	140
SW2202	Macleay River	422548	6597117	135
SW2203	Bakers Creek	393481	6620735	950
SW2206	Macleay River	418392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

Notes:

As per the Strahler stream database (GSNSW 2022) or site observations.

Interpreted from geographical software.

Metres above Australian height datum.



KEY

Study area	Existing environment	Landholder bore
Dam wall	Major road	Surface water sampling location
Reservoir	Streams within study area	Groundwater monitoring network
Tunnels, portals, intakes, shafts	1st order (non-perennial)	Borehole
Focus area	2nd order (non-perennial)	Fen monitoring bore
Escarpment	3rd order (perennial)	Monitoring bore
Macleay River floodplain	3rd order (non-perennial)	Additional geotechnical site investigation
Plateau	4th order (perennial)	
Western catchment	4th order (non-perennial)	
	9th order (perennial)	

Water monitoring locations

Ovens Mountain Pumped Hydro Energy Storage Project
Groundwater Impact Assessment
OMPS Pty Ltd
Figure 5.1



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.

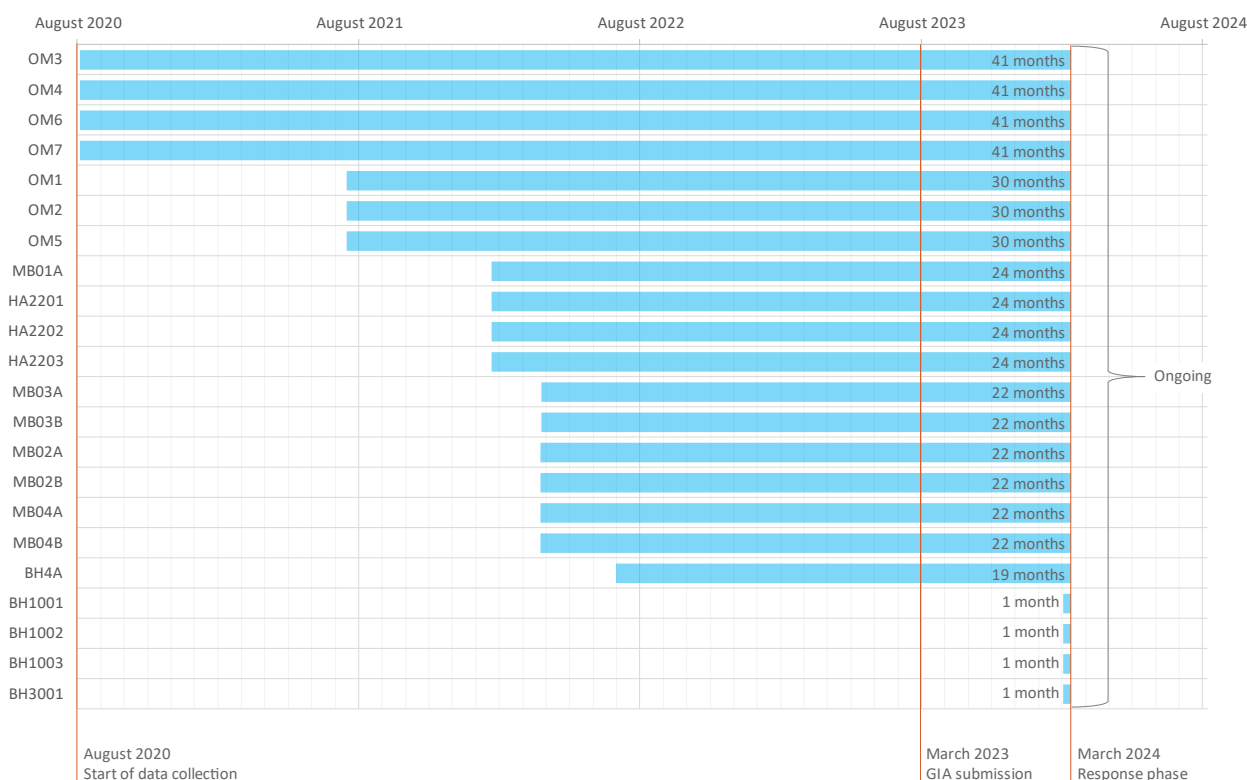


Figure 5.2 Groundwater level monitoring durations

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 was typically undertaken monthly until June 2023, whereafter samples were collected quarterly. Samples were collected in accordance with AS/NZS 5667.11:1998 Australian Standard for Water Quality Sampling. Dedicated sampling pumps (Solinst™ double-valve pumps) are installed in 8 of the 14 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 5.5. A record of monitoring events is shown in Table 5.6.

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 5.5 **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)	
Major ions	Calcium, chloride, magnesium, sodium, potassium, sulphate.	Analysis undertaken by a NATA certified laboratory
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 5.6 **Groundwater quality sampling event summary**

Location	2021					2022										2023										2024	Count
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jul	Aug	Dec	Mar		
Groundwater monitoring bore locations																											
OM1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	25	
OM2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	23	
OM3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X			X	22	
OM4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X			X	22	
OM5	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X			X	22	
OM6	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	24	
OM7	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		23	
HA2201							X	X	X	X	X	X	X			X	X	X	X	X	X	X			X	16	
HA2202							X	X	X	X	X	X	X			X	X	X	X	X	X	X			X	16	
HA2203							X	X	X	X	X	X	X			X	X	X	X	X	X	X			X	16	
MB01A			X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	21	
MB02A					X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X		X	18	
MB02B							X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	18	
MB03A								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	18	
MB03B								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	18	
MB04A						X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	18	
MB04B						X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	18	
BH4A											X	X			X	X	X	X	X	X	X	X				11	
GW307320							X			X					X											3	

Location	2021					2022										2023										2024	Count
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jul	Aug	Dec	Mar		
Groundwater spring locations																											
SW2101	X										X					X				X	X	X		X	X	8	
SW2102	X									X	X	X	X		X	X				X	X	X		X	X	12	
SW2103	X				X		X	X		X	X	X	X		X	X	X		X	X	X	X			X	16	
SW2106	X							X	X	X	X	X	X		X	X		X	X	X	X					13	
SW2107	X							X	X	X	X	X				X				X						8	
SW2108	X							X	X	X	X	X	X						X		X	X			X	11	
SW2109	X							X	X	X	X	X	X		X	X	X	X	X	X	X	X			X	16	
SW2110	X							X	X		X	X	X		X	X		X	X	X	X				X	13	
SW2111	X							X	X	X	X	X	X			X		X	X	X	X	X			X	14	
SW2201							X	X	X	X	X	X	X		X	X		X	X	X	X	X	X		X	16	
SW2204									X	X	X	X	X		X	X			X		X			X	X	11	

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 was typically undertaken monthly until June 2023, whereafter samples were collected quarterly. Samples were collected 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 5.5. A record of monitoring events is shown in Table 5.7.

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 5.7 **Surface water quality sampling event summary**

Location	2021					2022										2023										2024	Count
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jul	Aug	Dec	Mar		
Surface water locations																											
SW2104	X									X	X	X	X		X	X		X							X	X	10
SW2105	X																									X	2
SW2112					X		X	X			X	X	X		X	X									X	X	10
SW2202							X	X			X	X	X		X	X	X		X	X	X	X			X	X	14
SW2203								X		X		X	X		X	X		X							X	X	9
SW2206										X	X	X	X		X	X					X				X	X	9
SW2207										X																	1
SWG2201					X		X	X			X	X	X		X	X			X								9

5.3 Isotope assessment

Isotope samples were collected from seven groundwater monitoring bores, targeting the main hydrogeological units relevant to the Project (refer Chapter 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 ($\delta^{13}\text{C}_{\text{DIC}}$)
- tritium (^3H).

A summary of the isotope assessment results is provided in Table 5.8.

Table 5.8 Summary of isotope assessment results

Sampled bore	Geological unit	Relative depth	Focus area	^{14}C Age based on ^{14}C (years prior to 1950)	^3H Age based on ^3H (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 and 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), indicating limited regional groundwater recharge occurs to the shallower hydrogeological units supporting the sensitive receptors. Residence times are also highest in the lower escarpment (MB03A and MB03B), near the Macleay River floodplain, indicating recharge occurs near the plateau area and discharge near the lower escarpment. Further information is provided in the isotope assessment report, attached as Annexure 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 (five in total) and core (nine 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 Chapter 0), 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 Chapter 0), ranging between 1 and 5.9 mg/L
- aluminium within all identified geological units relevant to the study area (refer Chapter 0), ranging between 2.4 and 4.2 mg/L
- one of the seven samples (MB01A) analysed for antimony marginally exceeded (0.016 mg/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 2024d).

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.

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 & NRMCC 2011).

Baseline characterisation of water quality is provided in Chapter 6.

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 metamorphism 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 streambeds 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 the Macleay River.

6.3 Hydrogeological characterisation

6.3.1 Groundwater levels and flow

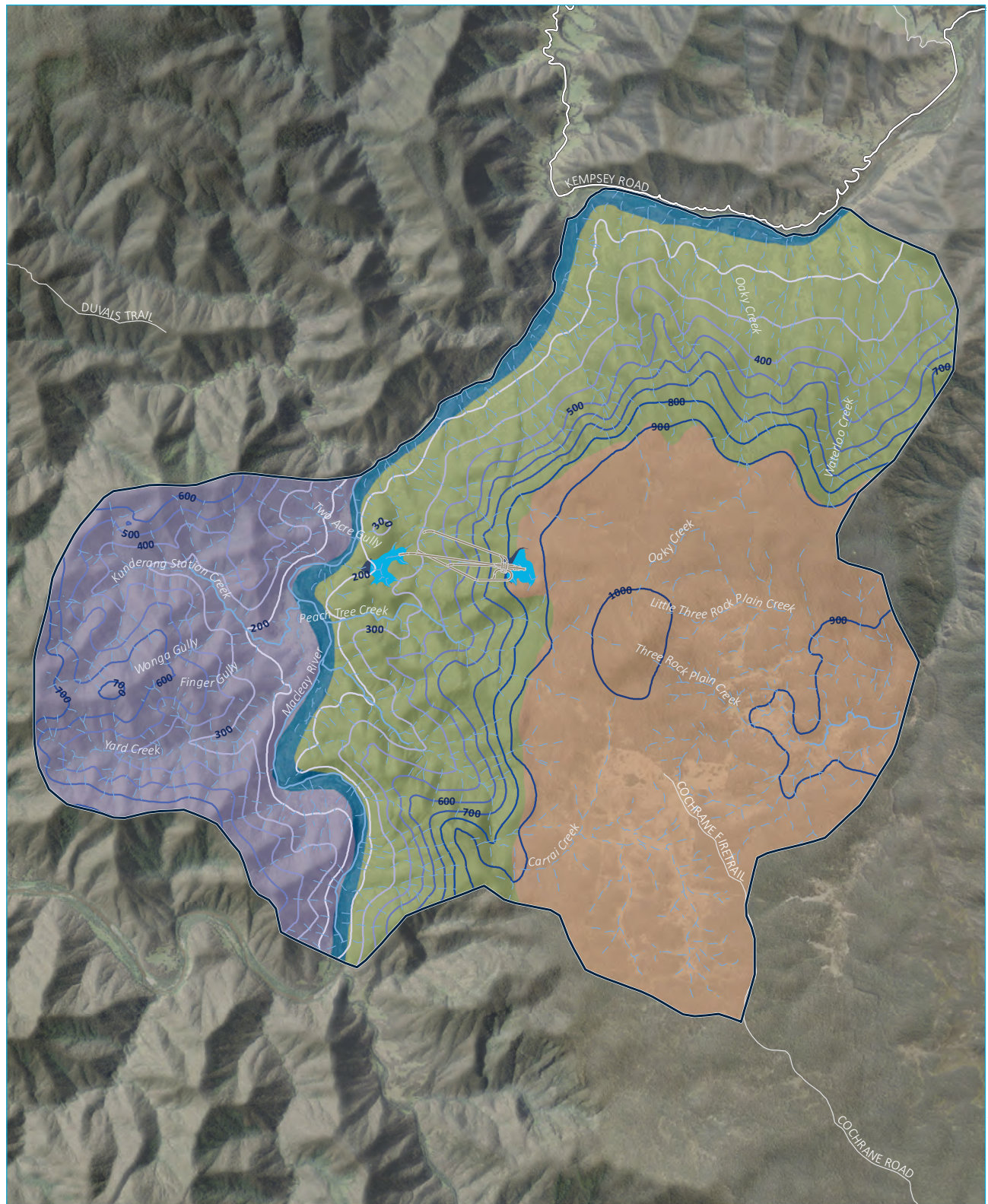
Groundwater levels reflect the topography within the study area, with the regional groundwater table shallowest in the upper plateau (~1–2 mBGL at MB04A) and deepest near the top of the escarpment and proposed pressure shaft decline (~50 mBGL at OM1). Groundwater levels within the alluvium is highly 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.

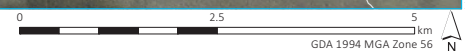
Groundwater levels in the localised pockets of weathered rock are above the base of the ephemeral watercourses following rainfall, providing interflow to the ephemeral streams during a period proportional to the magnitude and duration of the rainfall.

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 (2024); DFSI (2020, 2021); GA (2011)



KEY

Study area	Existing environment	Groundwater level contours (m AHD)
Dam wall	Major road	200
Reservoir	Minor road	300
Tunnels, portals, intakes, shafts	Streams within study area	400
Focus area	Perennial	500
Escarpment	Non-perennial	600
Macleay River floodplain		700
Plateau		800
Western catchment		900
		1000

Groundwater level contours

Owen Mountain Pumped Hydro Energy Storage Project
Groundwater dependent ecosystem assessment
OMPS Pty Ltd
Figure 6.1



\\emh.local\drive\2021\210465 - OMPS EIS - Generation Component\GIS\02_Maps\RTS_GW_GIA\009_GroundwaterLevelContours_20240528_01.mxd 24/06/2024

6.3.2 Hydraulic conductivity

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

- 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 and 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 (m/s)		
	Minimum	Maximum	Average
Residual soil (weathered Carrai Granodiorite)	2.8×10^{-5}	2.8×10^{-5}	2.8×10^{-5}
Carrai Granodiorite (shallow)	5.4×10^{-7}	4.3×10^{-6}	2.7×10^{-6}
Carrai Granodiorite (deep)	5.0×10^{-7}	5.0×10^{-7}	5.0×10^{-7}
Parrabel Beds (shallow)	2.0×10^{-5}	2.0×10^{-5}	2.0×10^{-5}
Parrabel Beds (deep)	1.7×10^{-7}	1.7×10^{-7}	1.7×10^{-7}
² Hornfels (undifferentiated)	$<1 \times 10^{-9}$	$\sim 2.4 \times 10^{-7}$	$\sim 4.1 \times 10^{-8}$

Notes: 1. Metres per second.
2. As interpreted from lugeon packer testing.

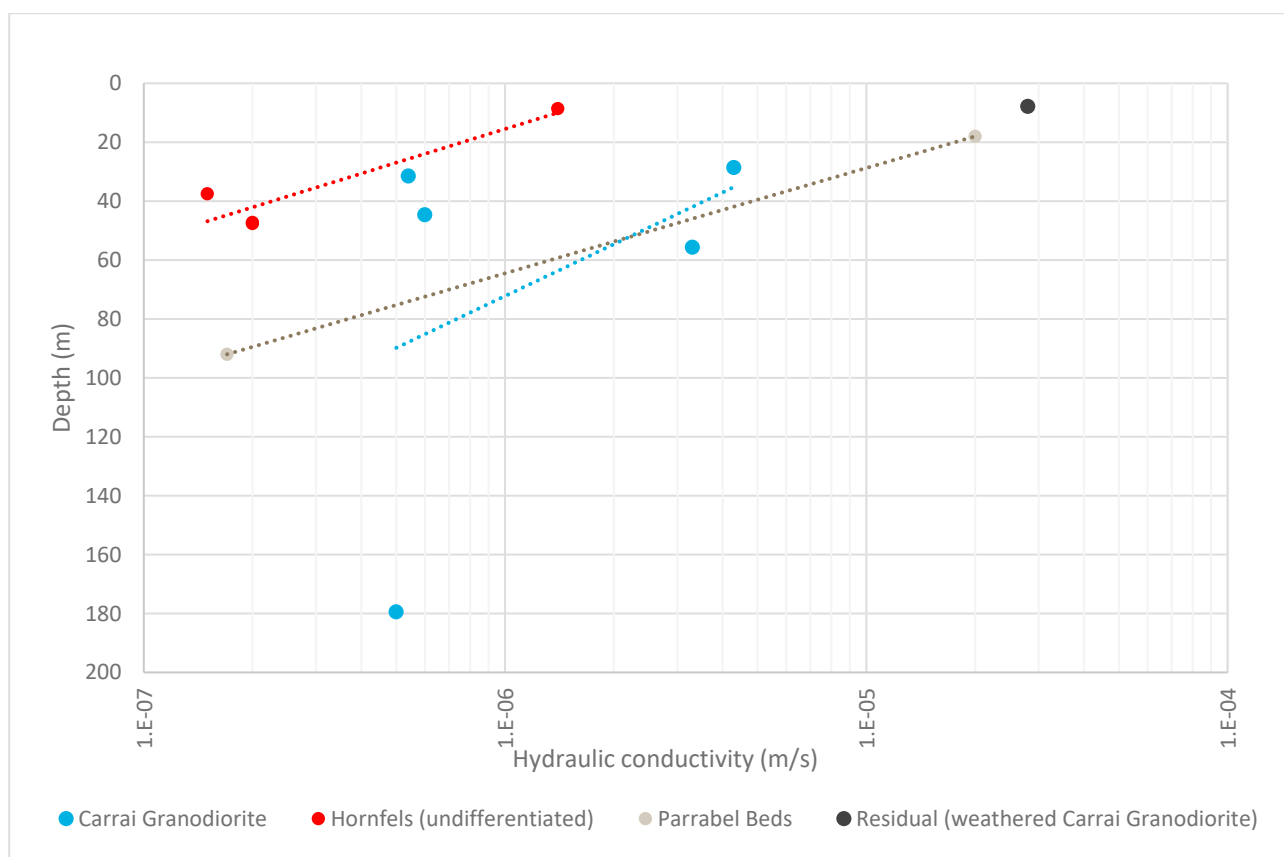


Figure 6.2 Hydraulic conductivity vs depth

6.3.3 Water chemistry

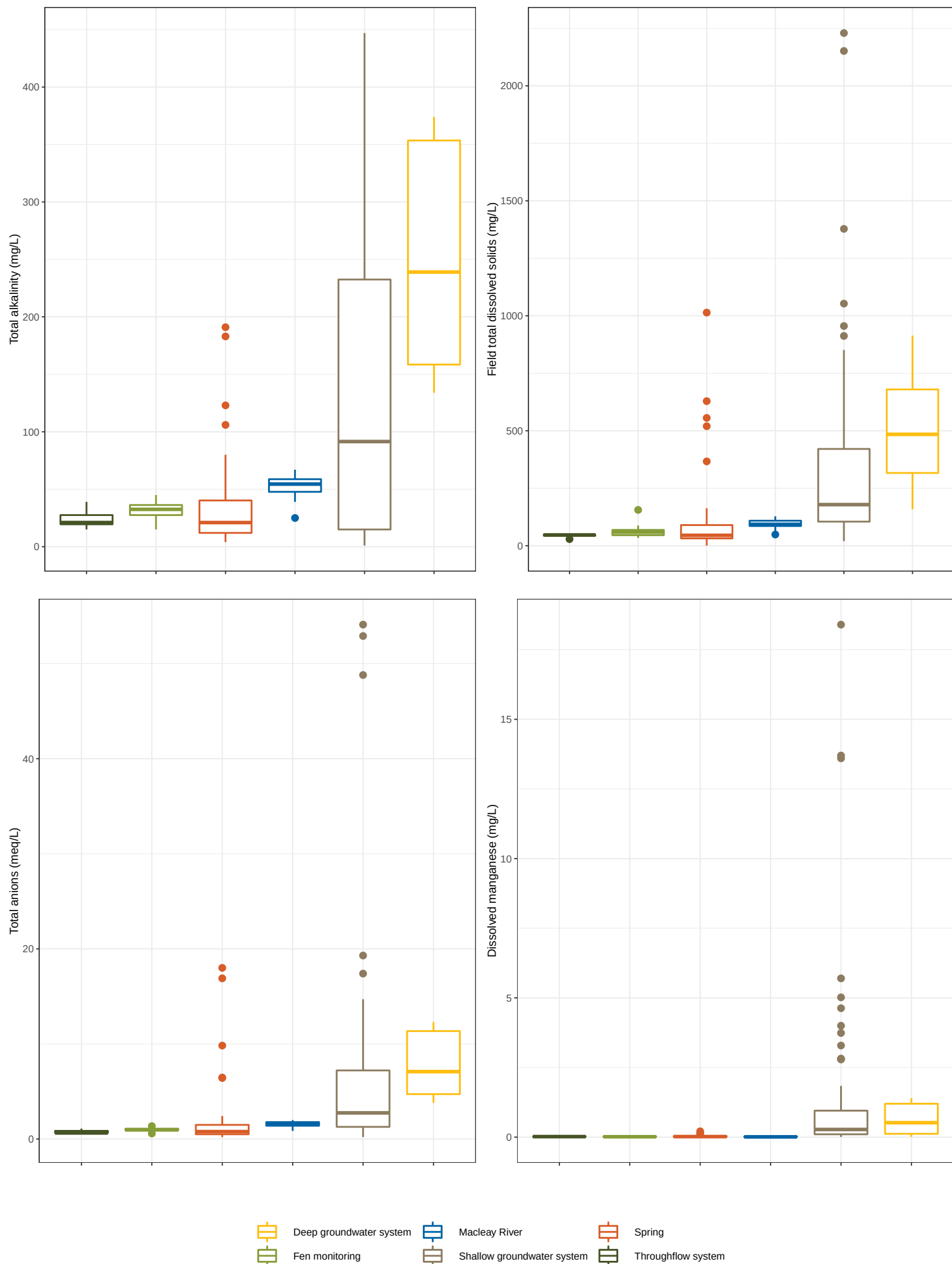
General groundwater quality within the study area is summarised below:

- 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 Chapter 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. In general, there is a noticeable differentiation of water chemistry between the deep groundwater system and the shallow groundwater system, Macleay River, fens and throughflow systems. In accordance with request 4.3(a), submitted by the NSW Environment Protection Authority, groundwater chemistry hydrographs for dissolved metals are attached as Annexure D.



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 Chapter 0), 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 Chapter 0), 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 Chapter 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 Chapter 0), 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 Chapter 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 Chapter 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
- indirect 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 indirect 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) the following:

- Pocket springs, visible flow of groundwater from the localised groundwater systems described in Chapter 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.

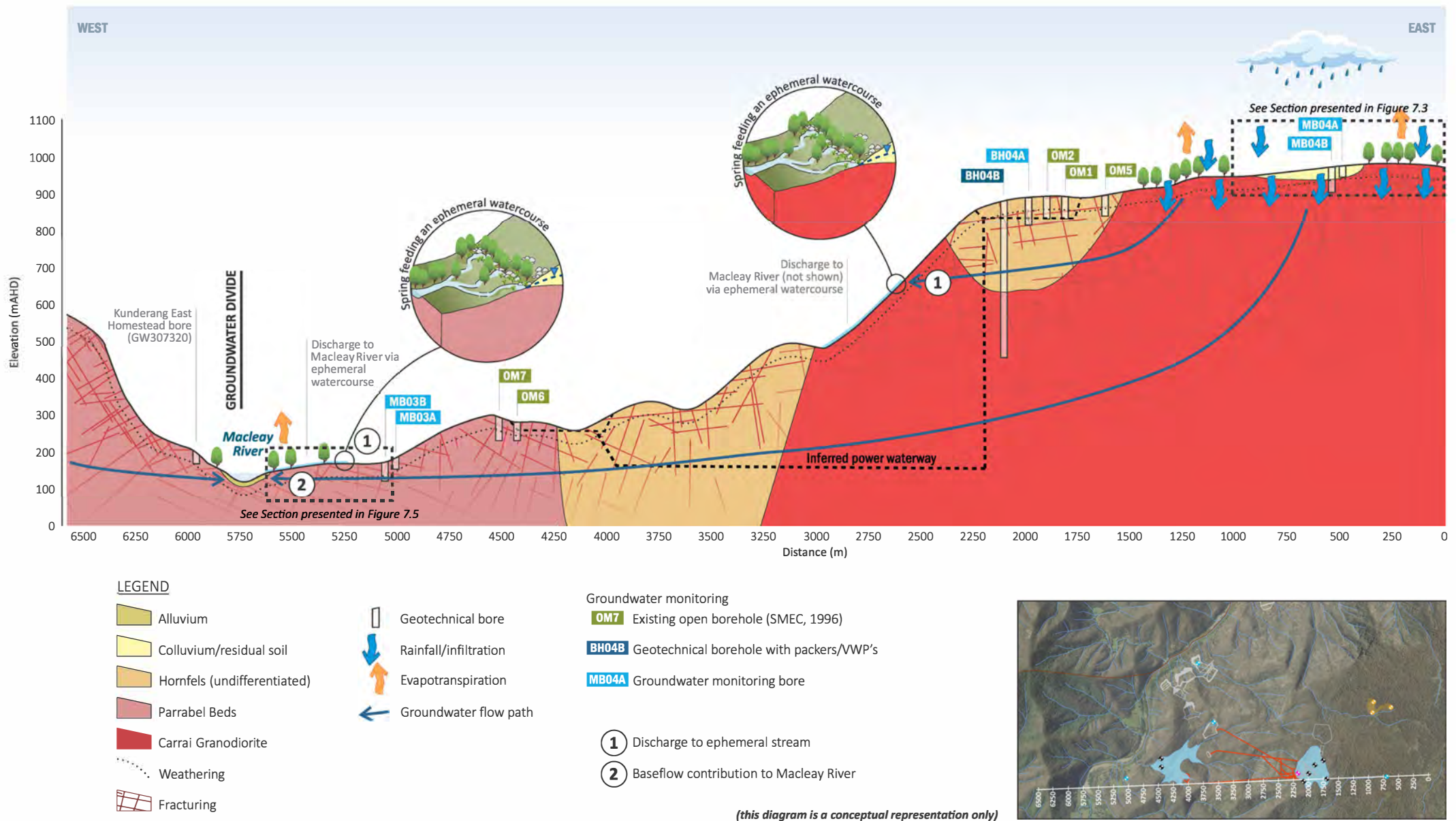


Figure 7.1 Groundwater occurrence and flow - simplified concept

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 indirectly receives 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 Chapter 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). Other PCTs are non-dependent on groundwater.

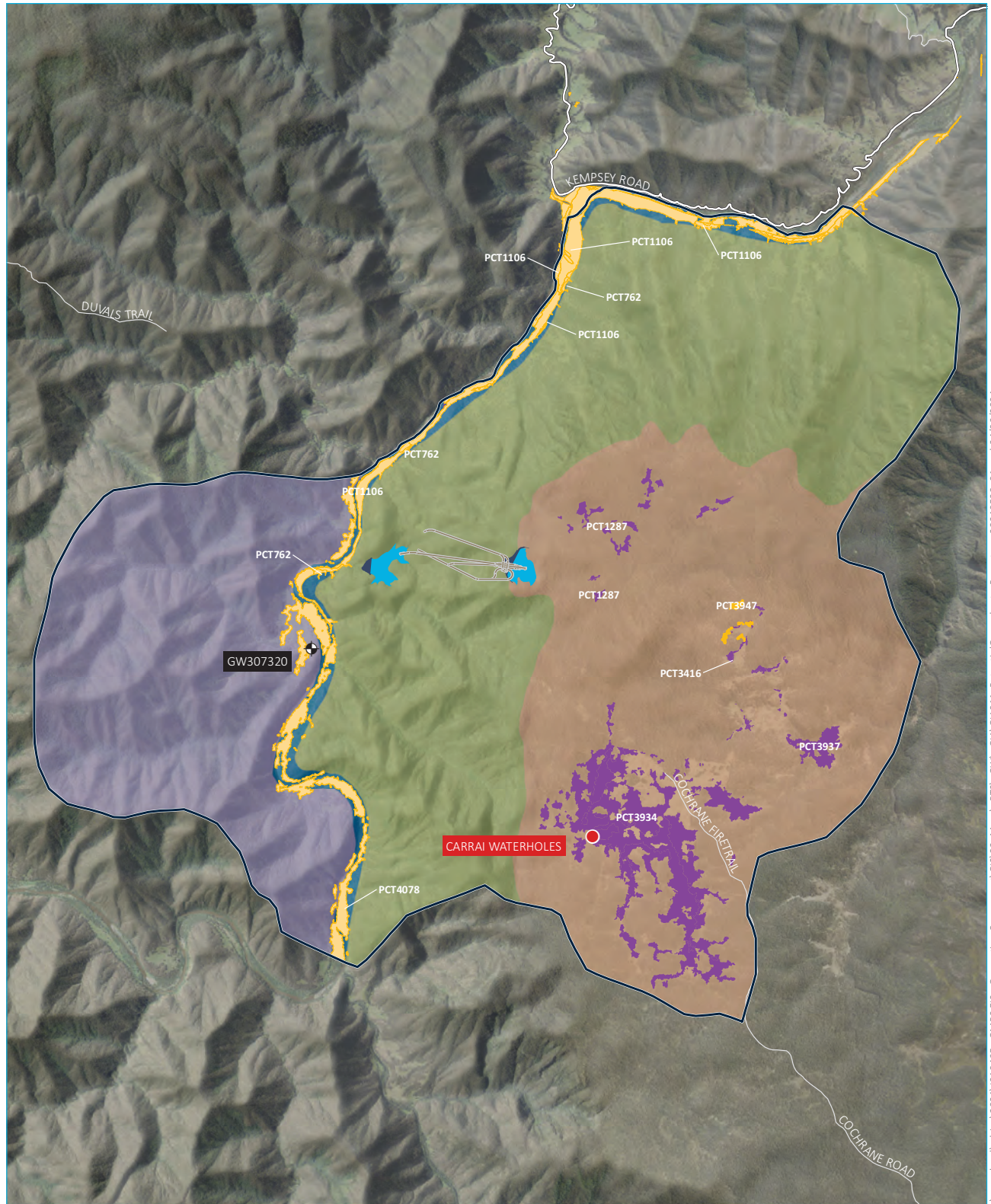
Where there is a reduction in depth to groundwater, or variability in climate, this may be reflected as a proportional change in ecosystem prevalence for facultative-opportunistic PCTs, but the ecosystem remains resilient in the absence of groundwater (Serov, Kuginis and Williams 2012). Terrestrial GDEs are provided on Figure 7.2.

7.6.2 Aquatic

The Macleay River and Floodplain Wetlands identified in Chapter 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 assumedly 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 (2024); DFSI (2020, 2021); DPIE (2022); GA (2011)

0 2.5 5 km
GDA 1994 MGA Zone 56

KEY

- Study area
- Dam wall
- Reservoir
- Tunnels, portals, intakes, shafts
- Existing environment
- Major road
- Minor road

- Focus area
- Escarpment
- Macleay River floodplain
- Plateau
- Western catchment

- Landholder bore
- Carrai Waterholes (approximately)
- GDEs within study area
 - Facultative – high
 - Facultative – opportunistic
 - Obligate

Summary of potential groundwater receptors for assessment

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

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 Chapter 8.1.2) and indirect impacts at identified groundwater receptors (discussed in Chapter 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 Chapter 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 Chapter 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 Chapter 3.6.2) have been defined as an EV however, and 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.

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. it 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. via 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 agriculture, 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 affecting 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 Numerical modelling overview

This chapter provides a summary of the numerical groundwater flow modelling undertaken for the Project. Only Project-related groundwater level and flow 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. Justification for model Class levels is 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 mostly complies with current best practise with regards to design, calibration and prediction. Further detail of the groundwater flow modelling (including a copy of the peer review) is provided in Annexure C.

9.2 Numerical groundwater flow modelling

9.2.1 Modelling objectives

The numerical groundwater model was used to support the GIA by predicting:

- drawdown/mounding at nearby groundwater users
- drawdown/mounding at GDEs and other identified sensitive receptors
- groundwater inflow volumes to the Project infrastructure during construction and operation periods
- 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, et al. 2017). The model employs a spatial domain sufficiently large to encompass the anticipated extent of drawdown/mounding resulting from construction and operation of the Project (refer Figure 9.3). It contains all groundwater-affecting components of the Project, the Macleay River, GDEs in the vicinity and the sole third-party groundwater well in the study 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 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:

- 18 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
- 555 head difference transient targets, defined as the difference between the current and previous measured hydraulic head. These behave similarly to drawdown targets provide greater confidence when there is uncertainty around steady state heads.

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 0.60% against steady state targets and 0.71% 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 in *Uncertainty analysis – guidance for groundwater modelling within a risk management framework* (Middlemiss and 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, of which 144 completed calibration. 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 63 realisations and acceptance of a suite of 81 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.

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:

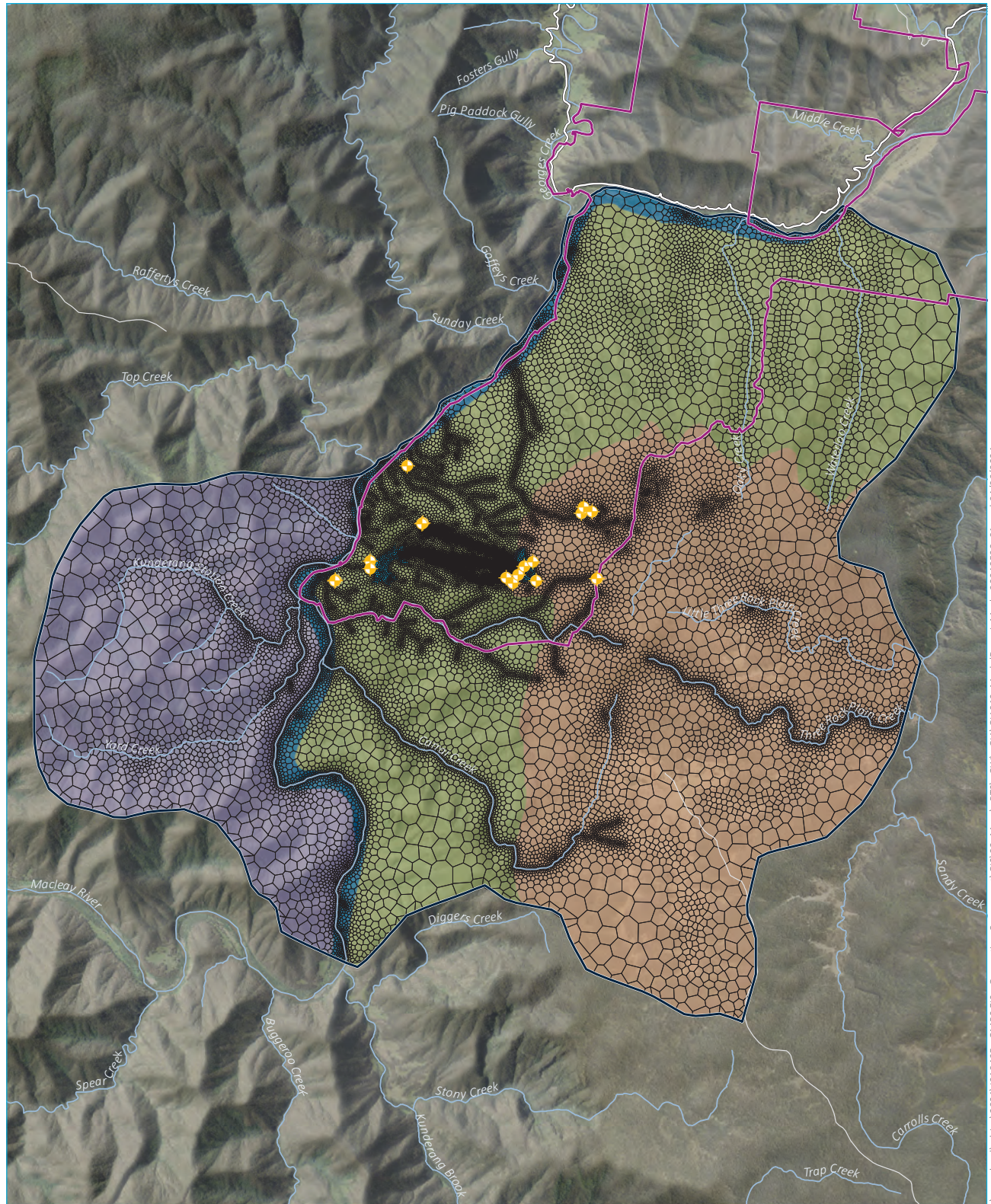
- Upper and lower reservoirs are simulated using the Drain (DRN) package with stage set to the bottom of the excavation for a given model cell and the conductance set at 10,000 metres squared per day (m^2/d) so that discharge is not limited by the boundary condition, but rather the transmissivity of the intersected hydrogeological units.
- 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 (2024); DFSI (2020, 2021); DPI (2003); DPIE (2021); GA (2011, 2020)

KEY

- | | |
|----------------------|--------------------------|
| Project area | Groundwater bore network |
| Study area | Model mesh |
| Dam wall | Focus area |
| Reservoir | Escarpment |
| Existing environment | Macleay River floodplain |
| Major road | Plateau |
| Minor road | Western catchment |
| Named watercourse | |

Model domain and major features

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Figure 9.1

9.2.5 Predicted water table drawdown

i Overview

Water table drawdown (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 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 or concrete lining). During construction the discrete fractures that yield excess water will be grouted, 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 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 drawdown has been assessed at each node in the model and used for predicting potential impacts. Drawdown less than 0.2 m was not considered in this impact assessment, noting the practical threshold of the numerical groundwater model predictions over the large study area.

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 drawdown has been summarised for the construction (refer Chapter 9.2.5ia) and operational (refer Chapter 9.2.5ib) phases of the Project.

a Predicted water table drawdown during construction

During the construction period, drawdown progressively increases over time as seepage occurs over an increasing excavation area, generally as additional infrastructure components are excavated (and only prior to lining at steel-lined elements, including the penstock branching, tailrace branching and high pressure tailrace tunnel).

Drawdown at the end of construction is predicted within approximately 976 hectares (ha) of the study area, extending up to 2.7 km from the power station complex. A summary of drawdown area and extent, at the end of Project construction, is provided in Table 9.2.

Table 9.2 Predicted water table drawdown at the end of Project construction

Drawdown magnitude (¹ m)	Area (² ha)	Extent (³ km)
>40	59.5	1.0
20–40	58.5	1.5
10–20	74.5	1.8
5–10	109.4	2.7
2–5	190.3	3.0
0.2–2	484.2	4.0

Notes: 1. Metres 2. Hectares 3. Inferred across maximum extent of drawdown polygon (kilometres)

The predicted drawdown at the end of project construction (i.e. maximum drawdown during construction) is presented on Figure 9.3.

b Predicted water table drawdown during operation

During operation, the Project induces drawdown near structural features that continually intercepting the 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.

Drawdown during operation is predicted within approximately 998 ha of the study area, extending up to 2.9 km from the power station complex. Watertable mounding is predicted within approximately 157 ha of the study area, extending up to 800 m from the reservoirs (i.e. the main source of water for infiltration).

A summary of water table drawdown/mounding area and extent, during operations, is provided in Table 9.3.

Table 9.3 Predicted water table drawdown and mounding during Project operation

Drawdown magnitude (¹ m)	Area (² ha)	Extent (³ km)
>40	90.3	1.3
20–40	55.6	1.6
10–20	62.1	1.9
5–10	73.9	2.3
2–5	177.4	3.2
0.2–2	539.1	5.3
Mounding magnitude (¹ m)	Area (² ha)	Extent (³ km)
>10	23.4	0.5
5	22.5	0.7
2	29.6	0.9
0.2	81.4	1.2

Notes: 1. Metres 2. Hectares 3. Inferred across maximum extent of drawdown/mounding polygon (kilometres)

The predicted water table drawdown/mounding during operation of the Project is presented on Figure 9.4.

ii Potential impacts on culturally significant areas

The Carrai Waterholes are approximately 12 km from the extent of project induced groundwater drawdown. Impacts to the Carrai Waterholes are therefore negligible.

iii Potential impacts on terrestrial GDEs

a Terrestrial GDEs

As discussed in Chapter 3.6.1, there are no high priority GDEs within the study area and in accordance with the minimal impact criteria presented in the AIP (DPI 2012), there is no impact to high priority GDEs. However, drawdown has been assessed approximately forty metres from the identified obligate, terrestrial GDEs.

Water table drawdown is predicted within forty metres of two obligate GDEs during construction, comprising PCT 1287 (Upland heath swamps of the New England bioregion), located on the plateau to the north-east and east of the proposed upper reservoir. Drawdown is not predicted (within the minimum drawdown threshold) during operation. Drawdown was not predicted at the remaining two obligate GDE communities during either construction or operation.

Water table drawdown at model nodes located approximately forty metres from relevant obligate GDEs (refer Figure 9.3 and Figure 9.4), during construction and operation of the Project, is provided on Figure 9.2.

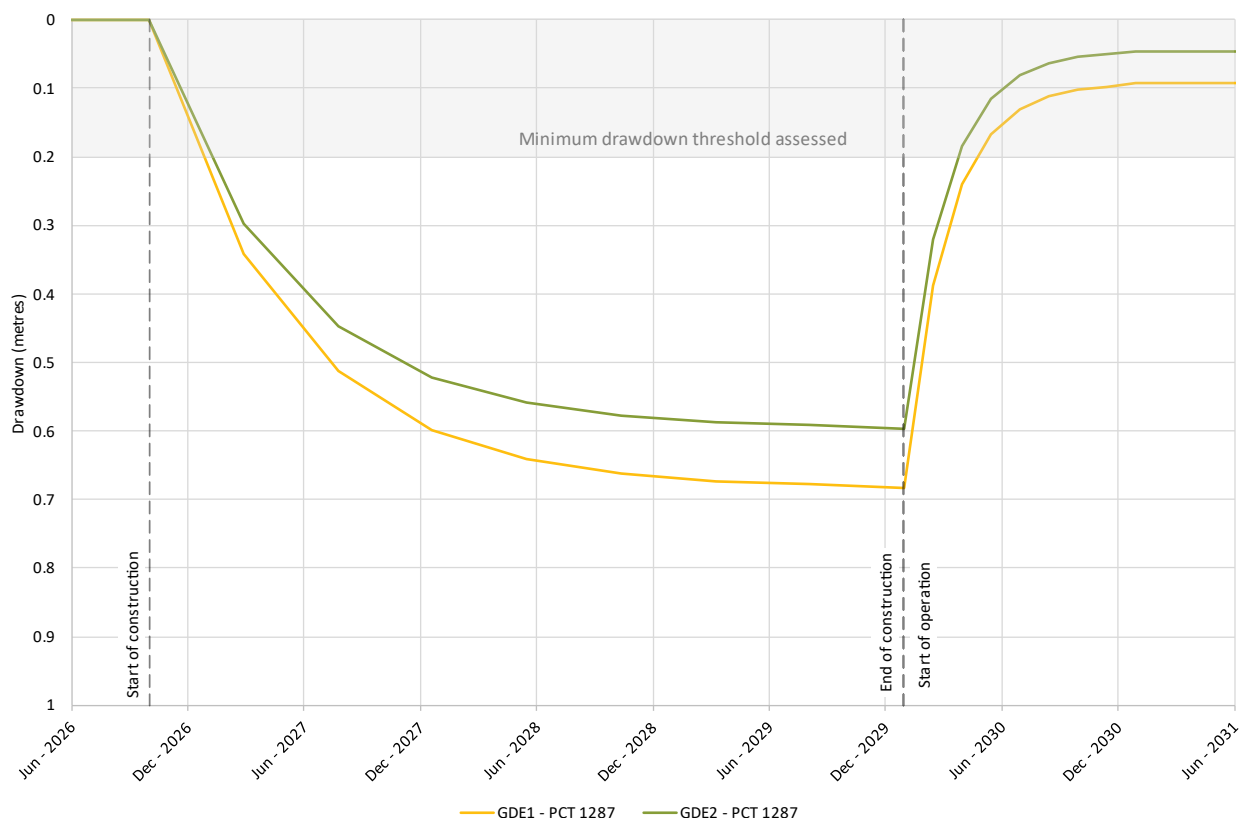


Figure 9.2 Water table drawdown at obligate groundwater dependent ecosystems

As discussed in Chapter 9.2.5i, the numerical groundwater model is considered to conservatively represent the drawdown impacts induced by the Project. Noting the relatively low magnitude of predicted drawdown (<0.7 m) at the obligate GDE communities (refer Figure 9.3 and Figure 9.4), further validation and verification (via ongoing monitoring) of the numerical groundwater model will be undertaken, as discussed in Chapter 11.3.

b Facultative opportunistic terrestrial GDEs

Water table drawdown has been assessed approximately forty metres from the identified facultative / opportunistic, terrestrial GDEs. A summary of predicted drawdown at model nodes approximately forty metres from impacted facultative/opportunistic GDEs is presented in Table 9.4. Model node locations are provided on Figure 9.2 and Figure 9.3.

Table 9.4 Predicted water table drawdown at facultative/opportunistic GDEs

Location ID	Water table drawdown (¹m)	
	End of construction	²Operation
GDE4 - PCT 1106	7.43	15.47
GDE5 - PCT 1106	2.99	16.27
GDE6 - PCT 1106	1.97	2.94
GDE7 - PCT 1106	6.75	-20.20
GDE8 - PCT 1106	7.24	14.46
GDE9 - PCT 1106	23.25	12.83
GDE10 - PCT 1106	15.35	6.71
GDE11 - PCT 1106	³0.13	-1.60
GDE13 - PCT 1106	³0.03	0.24
GDE17 - PCT 762	³0.08	-0.22

Notes:

1. Metres
2. Negative drawdown indicates predicted groundwater mounding
3. Values are below the minimum drawdown threshold and considered negligible

As discussed in Chapter 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 9.3 and Figure 9.4.

iv 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).

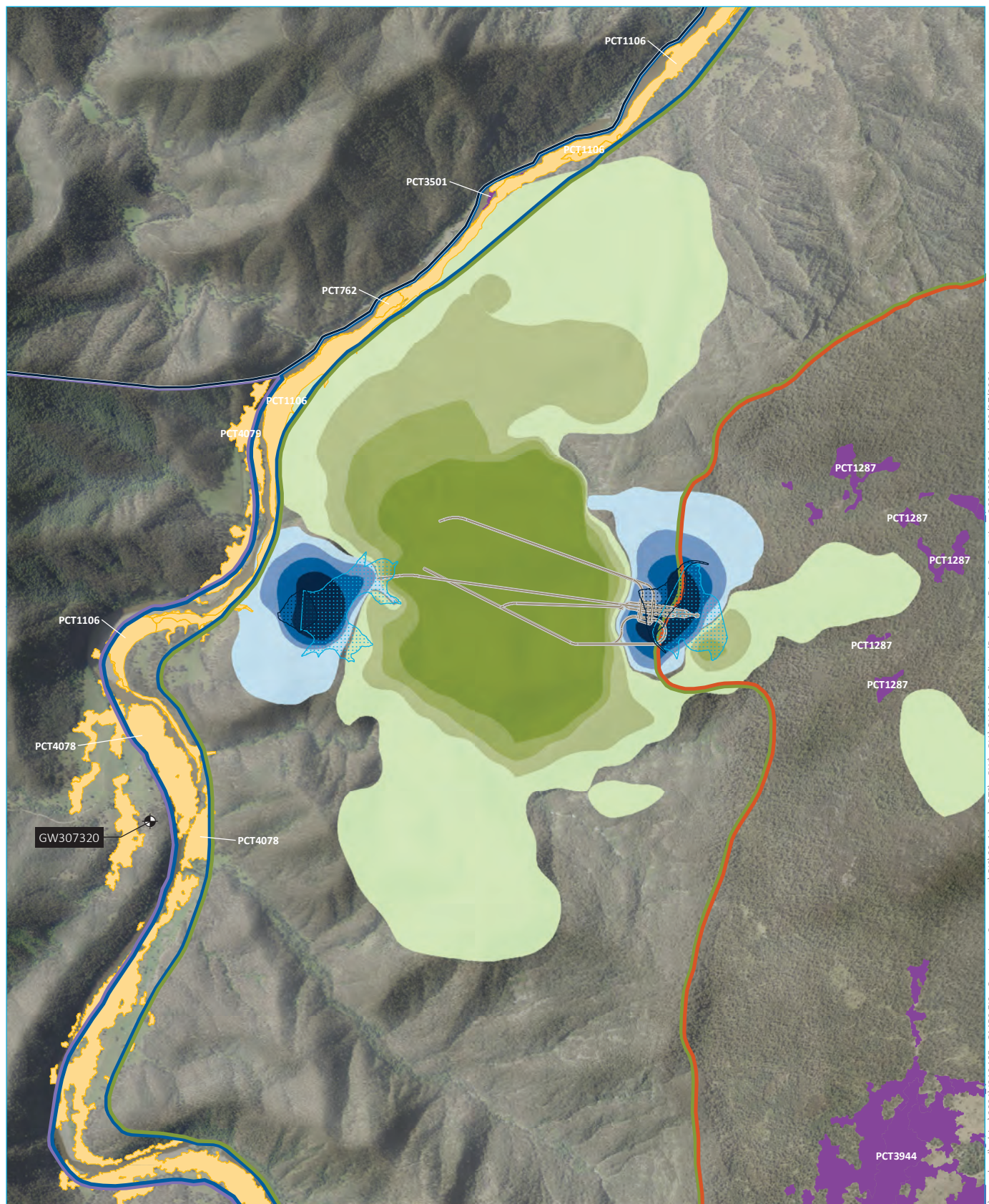
Stygofauna communities are considered to be at high risk (Serov, Kuginis and Williams 2012). However, only a relatively small area of the regional groundwater system (approximately 976 ha) of habitat is predicted to be affected by drawdown, and species of stygofauna have not been identified during site investigations (refer Chapter 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 unmitigated tunnel construction methods.

v 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.

vi Predicted impacts on groundwater users

In 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 (2024); DFIG (2020, 2021); DPIE (2022); GA (2011)

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

5 - 10

2 - 5

0.2 - 2

Operation probabilistic drawdown (m)

0.2 - 2

2 - 5

5 - 10

> 10

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

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Figure 9.4

9.2.6 Predicted baseflow impacts

Baseflow reductions to the Macleay River and adjoining watercourses within the study area are predicted during construction of the Project. The maximum reduction is realised in the fourth year of construction (119.8 ML/yr) and represents a 0.2% reduction of baseflow relative to pre-Project conditions.

During operation of the Project, water retained in the reservoirs and power waterway infiltrates into the groundwater system and decreases the overall reduction of baseflow to the Macleay River and adjoining watercourses. Baseflow reduction is predicted to be 94.3 ML/year during operation of the Project, representing less than 0.1% reduction in baseflow, relative to pre-Project conditions. Baseflow reductions are described in Figure 9.5 and Figure 9.6.

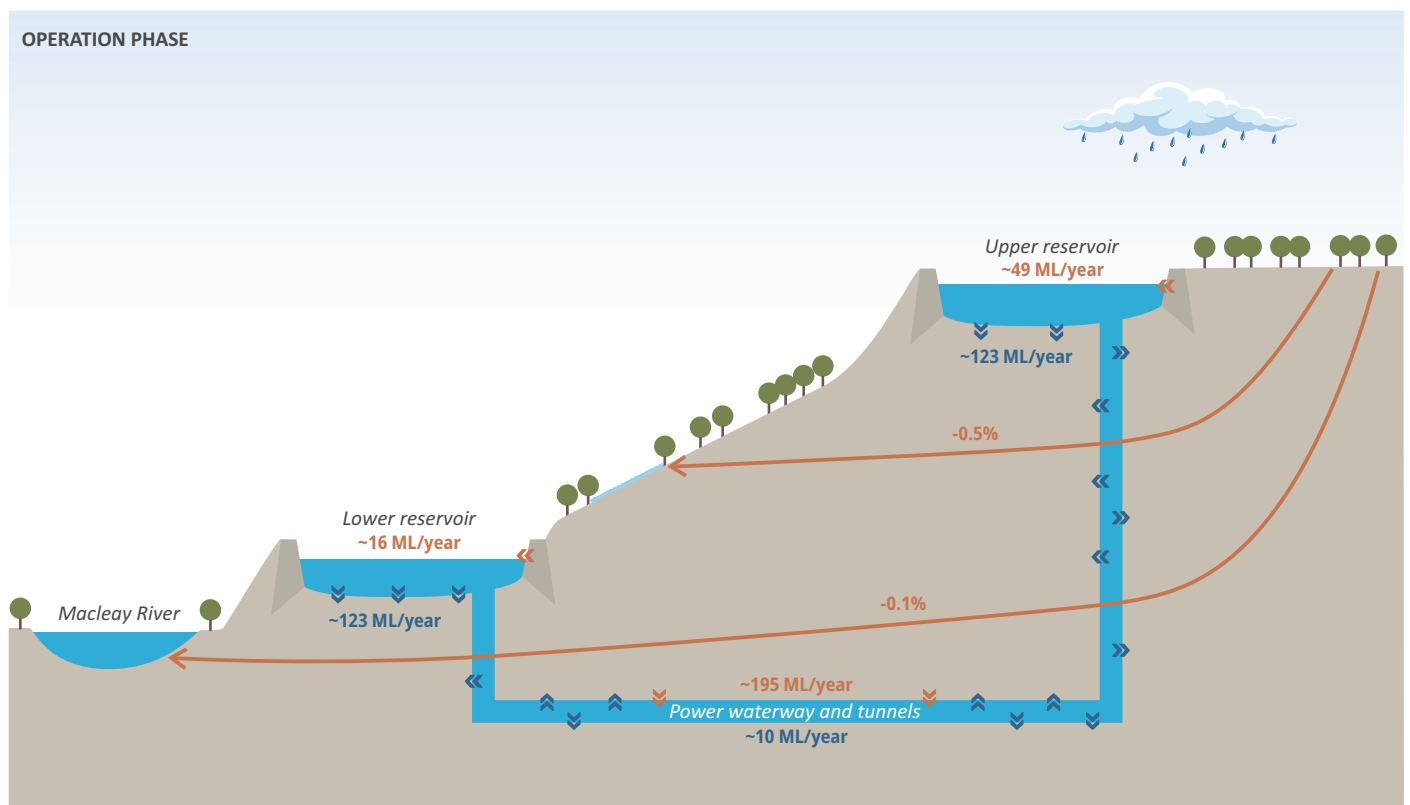
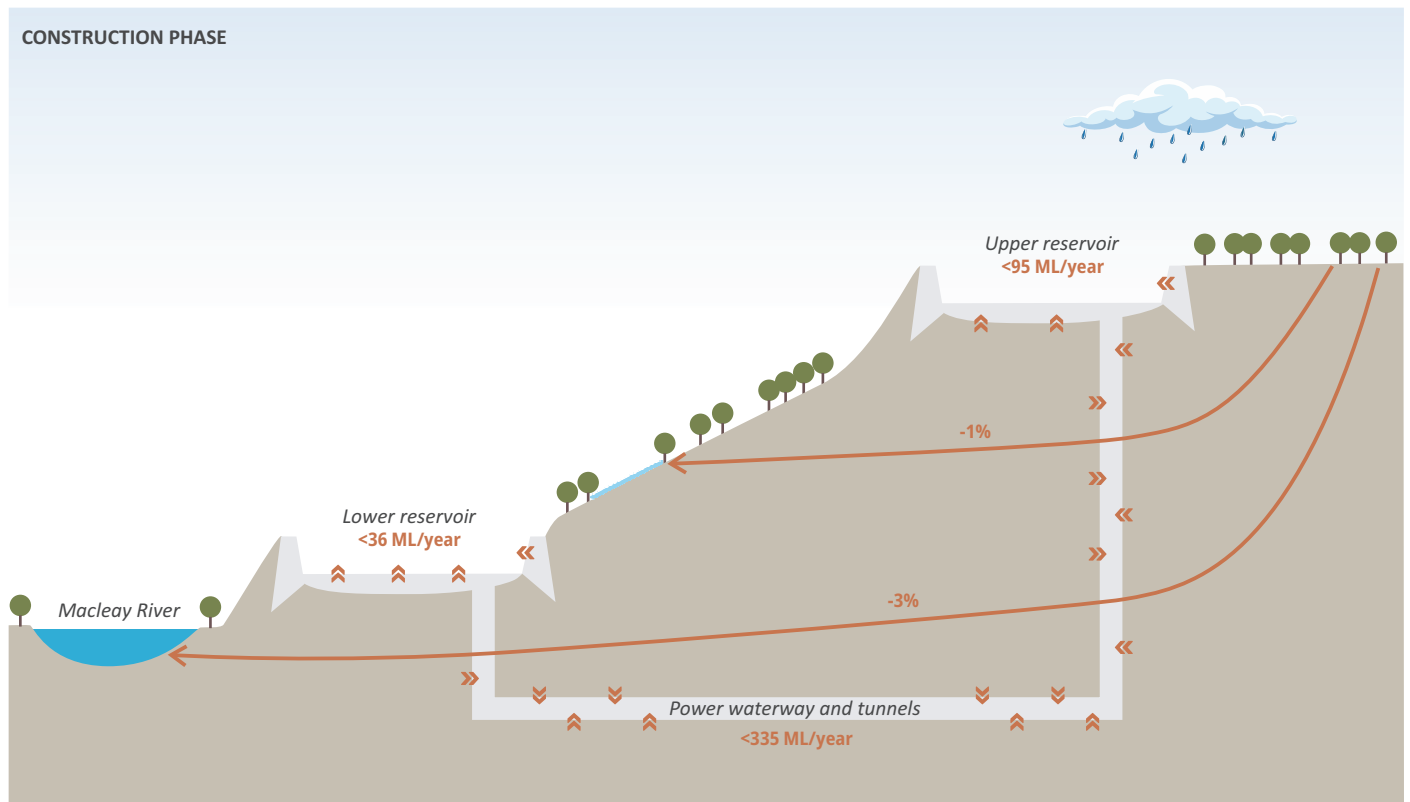
A summary of baseflow reduction resulting from project construction and operation is provided in Table 9.5.

Table 9.5 Predicted baseflow reduction during project construction and operation

Project phase	Baseflow reduction (¹ ML/year)		
	Macleay River	Other creeks	Total
Construction year 1	0	32.7	32.7
Construction year 2	0.4	56.1	56.5
Construction year 3	2.5	95.5	98.0
Construction year 4	5.3	114.5	119.8
Operation	6.0	88.3	94.3

Notes: 1. Megalitres per year

Given the relatively low reduction in baseflow (0.2% and <0.1% during construction and operation, respectively) reduced baseflow is not anticipated to have a significant impact.

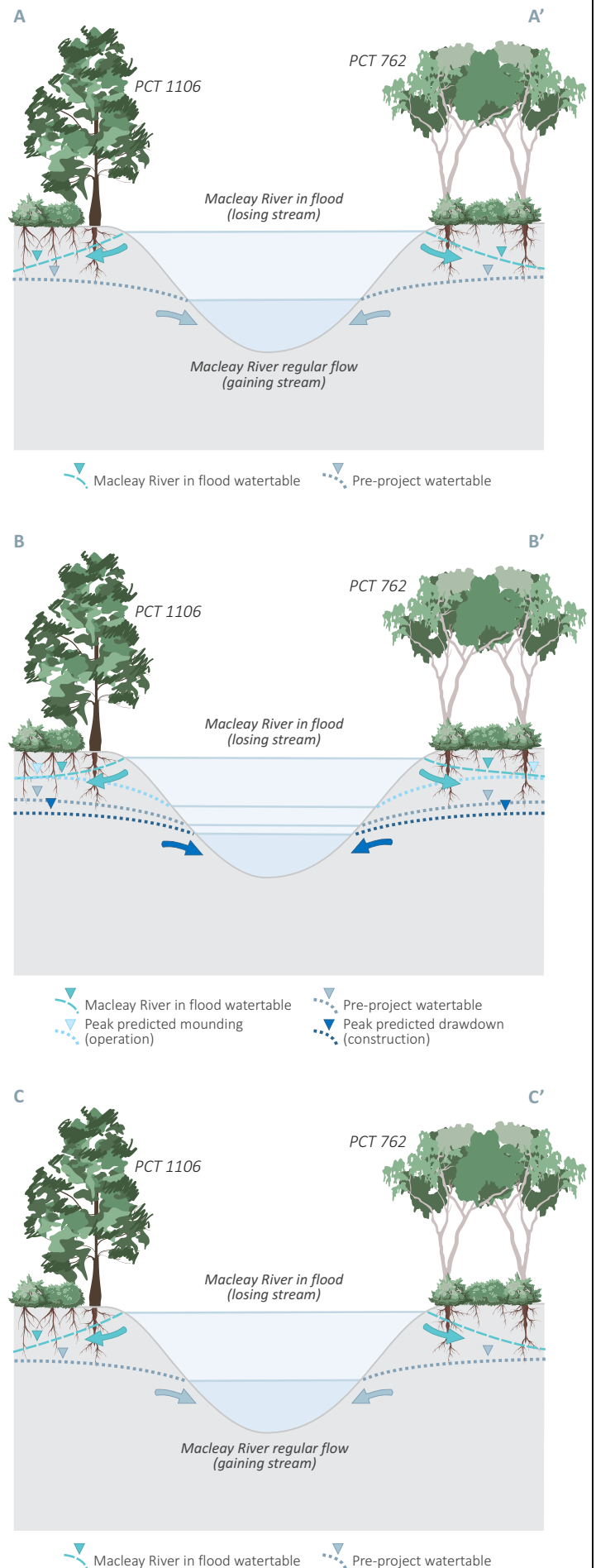
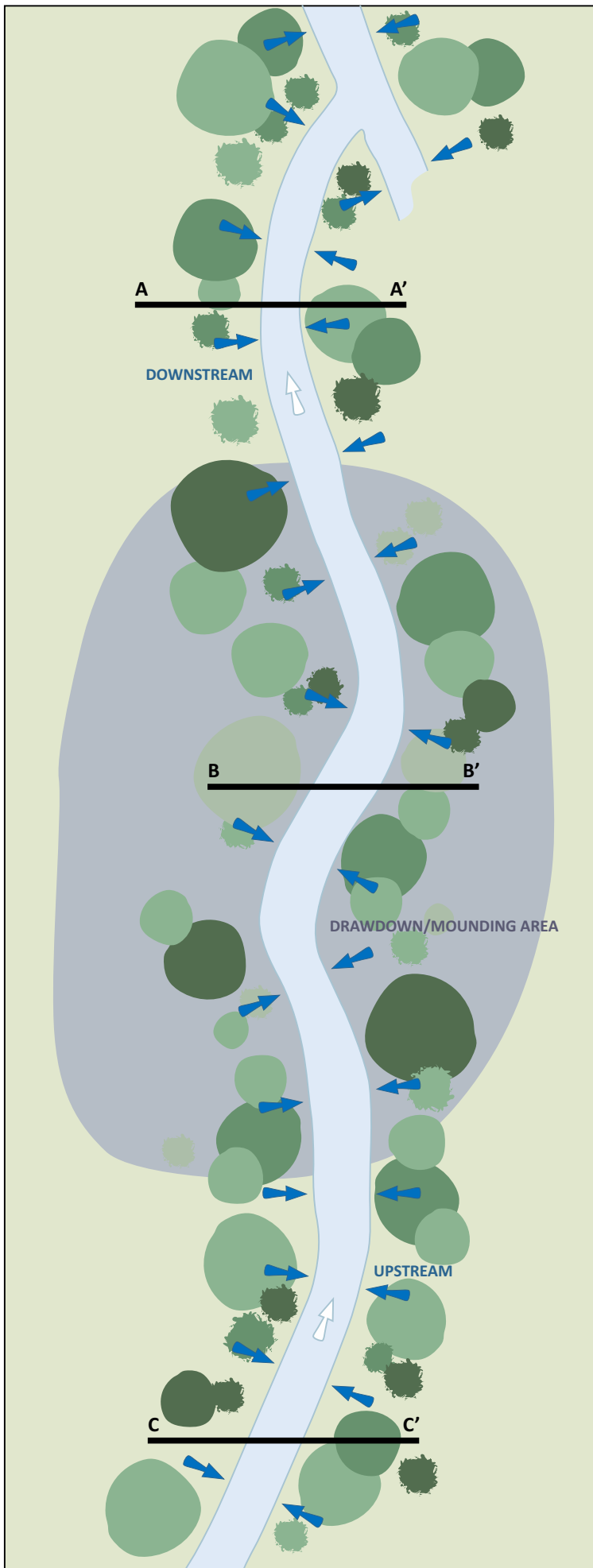


Changes to baseline flow (relative to pre-project)

 X ML/year Groundwater flow into or away from Project features

 X ML/year

Figure 9.5 Changes to baseflow conceptualisation



Baseflow impacts within the area of groundwater drawdown

OMPS Pty Ltd

Groundwater impact assessment

Figure 9.6

10 Water quality assessment

10.1 Overview of water affecting activities

As discussed in Chapter 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 site specific trigger values (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, et al. 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, et al. 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 Chapter 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	-

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 Contaminant mobilisation

As outlined in the Geochemistry Characterisation Report (EMM 2024d), the geological units intercepted by the Project have the potential to induce metalliferous drainage. In the event that groundwater flow was increased (i.e. by infiltration from the power waterway and reservoirs), it would be reasonable to assume contaminants may travel to the Macleay River and other creeks as baseflow. As discussed in Chapter 9.2.5v, groundwater derived baseflow to the Macleay River and adjoining watercourses is predicted to decrease during construction and operation of the Project. The risk of contaminant mobilisation during operation of the Project is considered negligible.

10.3.2 Material stockpiling

Spoil material will be stockpiled within the boundaries presented in Figure 2.1. As outlined in the Geochemistry Characterisation Report (EMM 2024d), 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 metalliferous drainage.

Rainfall infiltrating through the stockpiles may mobilise minor concentrations of metals however, the overall risk of infiltration to the groundwater system (noting the low infiltration potential of the prepared pad and geological units underlying the stockpile) is considered low. Noting access constraints limit the potential for meaningful monitoring bores to be established near the proposed stockpile emplacements, seepage sampling will be detailed in the water management plan (further discussed in Chapter 11.4.1). Impacts associated with material stockpiling is further explored in the Geochemistry Characterisation Report (EMM 2024d).

Iron sulphide (or pyrite) has been observed within the Project area (refer Annexure 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. Further discussion is presented in the Geochemistry Characterisation Report (EMM 2024d).

10.3.3 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 Annexure 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 Annexure C) results predict drawdown.
Possible (P)	An event that may occur during the lifetime of an operation or Project.	I.e. the P67 (refer Annexure 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 Annexure C) results predict drawdown.
Rare (R)	An event with a low probability to occur during the lifetime of an operation or Project.	No (refer Annexure 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

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

11.3.1 Management of groundwater

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 and Hauer 2022).

The residual risk levels, which are presented in Chapter 11.3.2, reflect the outcomes of management and mitigation measures.

11.3.2 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.

While 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 where potential deviations from the model predictions and identified impacts may occur. 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.
Groundwater quality sampling indicates changes from baseline conditions	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

Two water management plans (WMP) will be developed for the Project to support construction activities and operation. The WMPs will be a sub-plan of the construction environmental management plan (CEMP) and Operational Environment Management Plan (OEMP). The WMPs 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 WMPs will be prepared in consultation with DCCEEW, the EPA and key local stakeholders, and would consider concerns raised during the exhibition and approvals process for the Project.

The WMPs 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 WMPs 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 monitoring network, as developed in consultation with DCCEEW (formerly DPE Water), provides spatial coverage across the Project area and targets key hydrological and hydrogeological features. Groundwater level and quality data will be collected throughout the Project approval phase.

The baseline monitoring network also allows for data collection throughout Project construction and operation, allowing for validation of the predicted:

- Project induced groundwater drawdown and mounding
- seasonal groundwater level and quality variations in response to climatic stresses.

The baseline monitoring network will be expanded to include:

- water metering from excavations, allowing for validation of numerical model inflow predictions (refer Chapter 11.4.3)
- water quality sampling from captured groundwater, ensuring releases to the Macleay River from the WTP (if required) are in accordance with the WMP.

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

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, and the following timelines are suggested at one year and three years from the start of construction.

Significant deviations from the predicted impacts will be investigated and reported on annually.

Model recalibration will be considered every two years (based on analysis of predicted versus actual impacts) and completed as required to:

- incorporate deep layer measurements (parameters and observed heads)
- consider all remaining comments from the independent peer review in the future models
- check model validity using recently collected data
- refine and/or recalibrate the model if needed
- revise predictions if needed, including uncertainty analysis.

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 for 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 and resultant take

Groundwater inflow to Project components constitutes a direct take of groundwater, as predicted by the numerical groundwater model. Indirect take is a consequence of direct take and is divided into baseflow reduction (groundwater that would typically flow to a gaining, connected watercourse) and streamflow losses (losses from the watercourse to underlying, de-pressurised groundwater systems).

During construction of the Project, direct take is predicted to decrease, generally as project components are lined and localised de-pressurisation occurs. Indirect take is predicted to increase over the construction period, as groundwater drawdown propagates outward from the Project.

During construction, the peak:

- inflow (direct take) is predicted during the third year of construction (419 ML)
- baseflow reduction (indirect take) is predicted during the fourth year of construction (120 ML)
- streamflow losses (indirect take) are predicted during the fourth year of construction in the Macleay Gorges and Macleay Valley water sources (<1 ML), with no predicted change in the Dyke River or Georges River water sources.

During operation of the Project, direct take occurs as a result of groundwater inflow to a portion of the reservoirs and un-lined project components that do not form part of the power waterway (i.e. the MAT and ECVT). The power waterway (where un-lined) and a portion of the reservoirs will contribute water to the groundwater system, via seepage losses to the formation. Lined project components are considered to have negligible interaction with the surrounding groundwater system.

During operations, the peak:

- steady state inflow (direct take) is predicted to be 234 ML/yr
- baseflow reduction (indirect take) is predicted to be 95 ML/yr
- streamflow losses (indirect take) are predicted in the Macleay Gorges and Macleay Valley water sources (<1 ML), with no predicted change in the Dyke River or Georges River water sources.

12.2.2 Water sources for Project inflow and baseflow reductions

The groundwater model predicts water take from groundwater sources (both direct and indirect) and indirect take from surface water sources. The predicted baseflow reductions are restricted to areas immediately adjacent to the Project alignment, resulting in baseflow reduction across localised portions of the Macleay River and associated tributaries.

The reductions to baseflow are considered over time and the source of this water has also been considered in accordance with the AIP. The AIP requires the peak groundwater inflow (direct take), baseflow reductions (indirect take) and streamflow losses (indirect take) to be considered for licensing purposes.

Baseflow reduction 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 licensing perspective) are either:

- reduced groundwater available for baseflow contributions (i.e. less gaining stream – but ultimately still a gaining stream) – this is licensed as a groundwater take, 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 a surface water take.

This GIA presents discussion on the licensing of groundwater related take, including direct take and indirect take as a result of baseflow reduction. Indirect take volumes resulting from streamflow losses is presented in this GIA for completeness; however, the relevant licensing strategy for the surface water component is presented in the Surface Water Impact Assessment (EMM 2024a).

The source of the water has been determined in the groundwater modelling to be a result of both groundwater inflow, baseflow reduction and streamflow losses. Therefore:

- groundwater inflow (direct take) will be licensed as groundwater from within the NEFB Coast Groundwater Source
- baseflow reduction (indirect take) will be licensed as groundwater from within the NEFB Coast Groundwater Source
- streamflow losses (indirect take) will be licensed as surface water from within the respective surface water source, as further discussed in the Surface Water Impact Assessment (EMM 2024a).

i New England Fold Belt Coast Groundwater Source

The maximum direct and indirect take from the NEFB Coast Groundwater Source is 419 ML/yr (in the third year of construction) and 120 ML/yr (in the fourth year of construction), respectively. The maximum cumulative take is 537 ML/yr, predicted in the fourth year 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 1 ML/yr during construction. Further discussion is presented in the Surface Water Impact Assessment (EMM 2024a).

12.2.3 Total Project licence requirements

The total Project licence requirements to cover the direct and indirect take of water, resulting from groundwater interception are presented in Table 12.1 and on Figure 12.1. Surface water licensing requirements (including induced leakage from the Macleay river and adjoining watercourses) is discussed in the Surface Water Impact Assessment (EMM 2024a).

Table 12.1 Required licences and licence components (groundwater)

Year ending	Project year	NEFB Coast Groundwater Source ¹		
		Direct take Flow to excavations (ML) ²	Indirect take Baseflow reduction (ML)	Total take (ML)
2026	Construction year 1	57	33	90
2027	Construction year 2	284	57	341
2028	Construction year 3	419	98	517
2029	Construction year 4	417	120	537
	Steady State (operations)	234	95	329
	Maximum	419 (year 3)	120 (year 4)	537 (year 4)

Notes: 1. New England Fold Belt Coast Groundwater Source 2. ML = megalitres

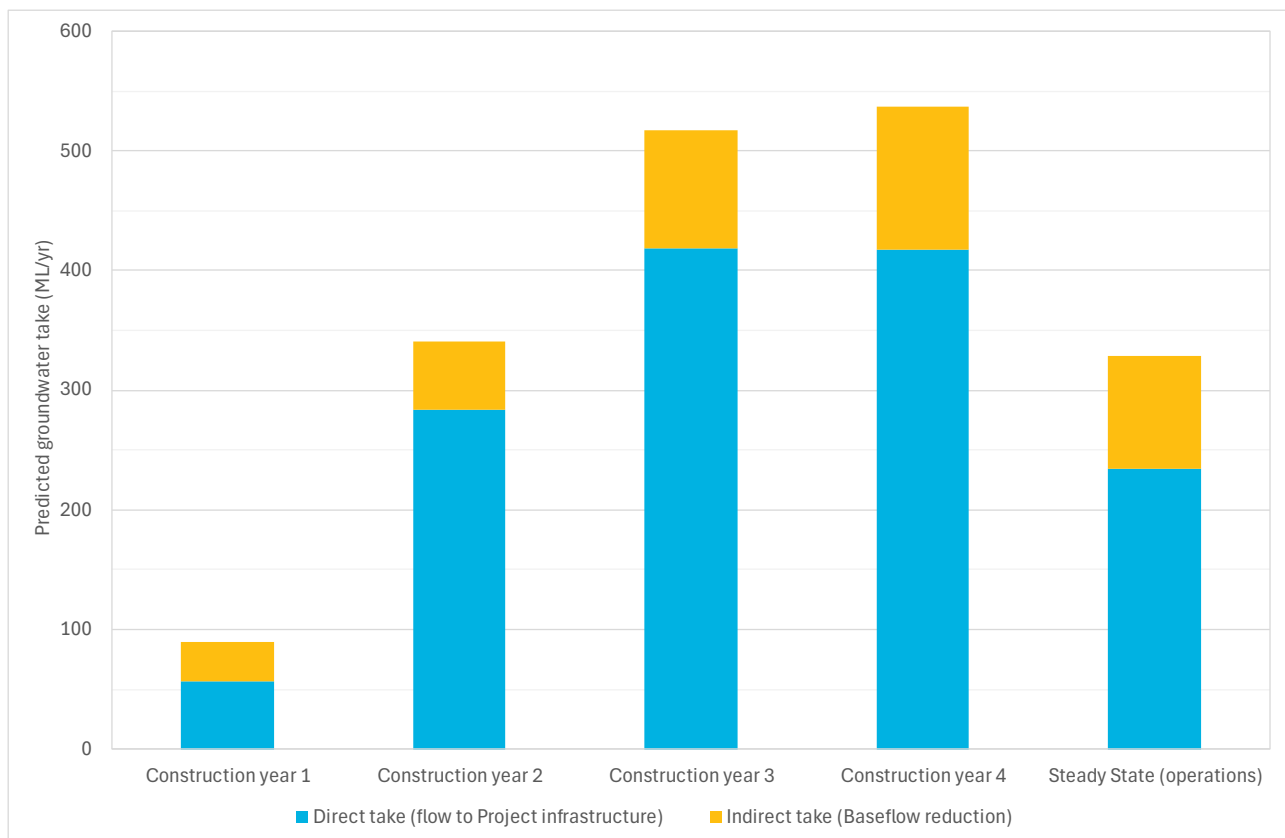


Figure 12.1 New England Fold Belt Coast Groundwater Source yearly licence requirements

12.3 Groundwater licensing summary

OMPS have successfully participated in two controlled allocation orders:

- Controlled Allocation Order (Various Groundwater Sources) 2021 between 1 and 30 November 2021, resulting in OMPS successfully securing 232 ML/year in the NEFB Coast groundwater source
- Controlled Allocation Order (Various Water Sources) 2022 between 18 March 2022 and 18 April 2022, resulting in OMPS successfully securing 175 ML/year of entitlement in the NEFB Coast groundwater source.

OMPS intend to secure the remaining entitlements required (132 ML/year) in the subsequent controlled allocation order. At the time of compiling this document, OMPS have not been made aware of a proposed date for the controlled allocation order.

A summary of secured groundwater allocations, maximum groundwater take (cumulatively direct and in-direct) and additional groundwater allocations required is summarised in Table 12.2. Surface water licensing discussion is presented in the Surface Water Impact Assessment (EMM 2024a).

Table 12.2 Oven Mountain – Groundwater licensing summary

Groundwater source	WAL details	Allocation secured (ML/year)	Total allocation secured (ML/year)	Maximum groundwater ² take (ML/year)	Additional allocation required (ML/year)
¹ NEFB Coast	WAL44583	232	407	537	130
	WAL44944	175			

Notes: 1. New England Fold Belt 2. Representing both direct and in-direct take

12.4 Additional licensing considerations

12.4.1 Project groundwater supply

OMPS have secured an approval to construct a test bore (approval number 30WA324646) within the NEFB Coast Groundwater Source. OMPS may elect to undertake a test bore drilling program to establish potential water supply options. Test bores would be constructed in accordance with the Groundwater WSP and the test bore approval.

In the event that a test bore provides adequate groundwater yield and quality, an amendment would typically be submitted to convert the test bore approval to a water supply work approval.

This GIA does not include an assessment of impacts resulting from groundwater supply bores associated with the Project. An impact assessment would require details that are confirmed throughout the test bore drilling program (i.e. location, construction detail and extraction volumes), which may be undertaken after Project approval.

In order to mitigate environmental impacts resulting from groundwater extraction, OMPS will undertake an impact assessment in line with Section K of the *Application guide - Amended water supply work approvals and/or water use approvals* (DPE 2022), providing an understanding of impacts on:

- water users
- water source/s
- groundwater dependent ecosystems.

The impact assessment will be provided with a covering letter outlining the intent to convert the test bore/s to production bore/s.

Groundwater extracted production bores associated with the Project will require sufficient entitlements within the NEFB Coast groundwater source. Total groundwater take for the Project would be measured during Project construction (refer Chapter 11.4.2) from the NEFB Coast groundwater source. Noting the entitlements currently held by OMPS are based on the conservative predictions provided by the numerical groundwater model (refer Chapter 9.2.5i), overall take (including groundwater extracted from production bores) may not exceed the held entitlements.

In the event that groundwater extraction is predicted to exceed the entitlements held by OMPS, additional entitlements will be sought within the NEFB Coast groundwater source from either:

- a controlled allocation order, noting the groundwater source is ~43% allocated (refer Chapter 4.3.2)
- temporary or permanent trading of existing allocations with water users (i.e. entering the water market).

13 AIP assessment framework

This chapter reproduces the AIP assessment framework with commentary to assist DCCEEW 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 Chapter 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 Chapter 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 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 Chapter 12.2.2.
6	Described how any licence exemptions might apply?	Yes, this has been described in the <i>Surface Water Impact Assessment</i> (EMM 2024a)
7	Described the characteristics of the water requirements?	Yes, this has been provided in Chapter 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 Chapter 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 Chapter 4.3.1.
10	Determined how it will obtain the required water?	Yes, the approach to obtain the required water has been outlined in the <i>Surface Water Impact Assessment</i> (EMM 2024a)
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.
Will uncertainty in the predicted inflows have a significant impact on the environment or other authorised water users?		Yes.
If yes , items 14–16 must be addressed.		

#	AIP requirement	Proponent response
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 Annexure 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 Annexure 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 Annexure C. The model has been developed in accordance with the requirements of the <i>Australian Groundwater Modelling Guidelines</i> (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 5.2.

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.

#	AIP requirement	Proponent response
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

One water source is impacted – the NEFB Coast Groundwater Source. This water source is defined as a ‘less productive’ groundwater system 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 <i>during operation</i> ?	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 <i>post closure</i> ?	Not applicable.

#	AIP requirement	Proponent response
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 high priority GDEs and water supply works
 - 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 watercourses within the study area (maximum of 120 ML over construction year 4). During operation of the Project, baseflow reductions are predicted to be 95 ML/year. 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 over year 3 of construction and is 419 ML. This, combined with the baseflow reductions results in a maximum cumulative take of 537 ML/yr. During operation of the Project, inflow to the Project reduces to 234 ML/yr. OMPS have acquired an initial 232 share components within the NEFB Coast Groundwater Source, purchased through the 2021 CAO. OMPS intend to bid for the remaining share components through the next COA (yet to be announced).

Watertable drawdown is predicted during construction and operation of the Project, with drawdown propagating approximately 4 km north-east of the Project. There is no impact predicted to the Carrai Waterholes. There are no identified high priority GDEs within the study area; however, watertable drawdown impacts are predicted at two localised communities of obligate GDEs identified across the plateau. Water table drawdown is also 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 within 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.

Annexure A

Hydrogeological investigation program

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
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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).

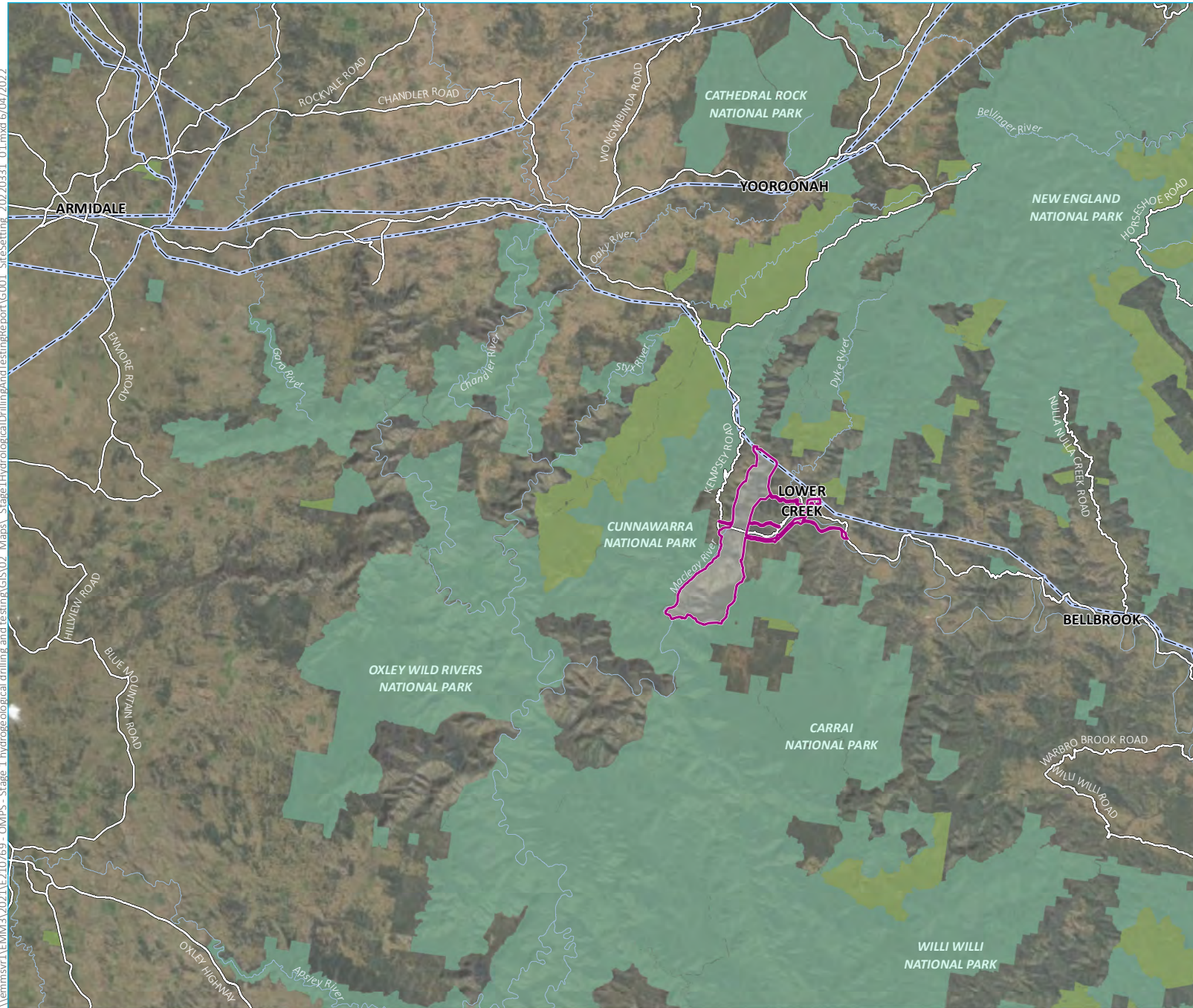
In accordance with the proposal (EMM 2021), EMM provided the client with the scope of works outlined in Section 1.2. This report provides a factual summary of the subsequent monitoring bore installation and testing program.

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.

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- KEY**
- Project area
 - Existing environment
 - Major road
 - Watercourse/drainage line
 - Transmission line
 - NPWS reserve
 - State forest

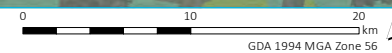
Site setting

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

Figure 1.1



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



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

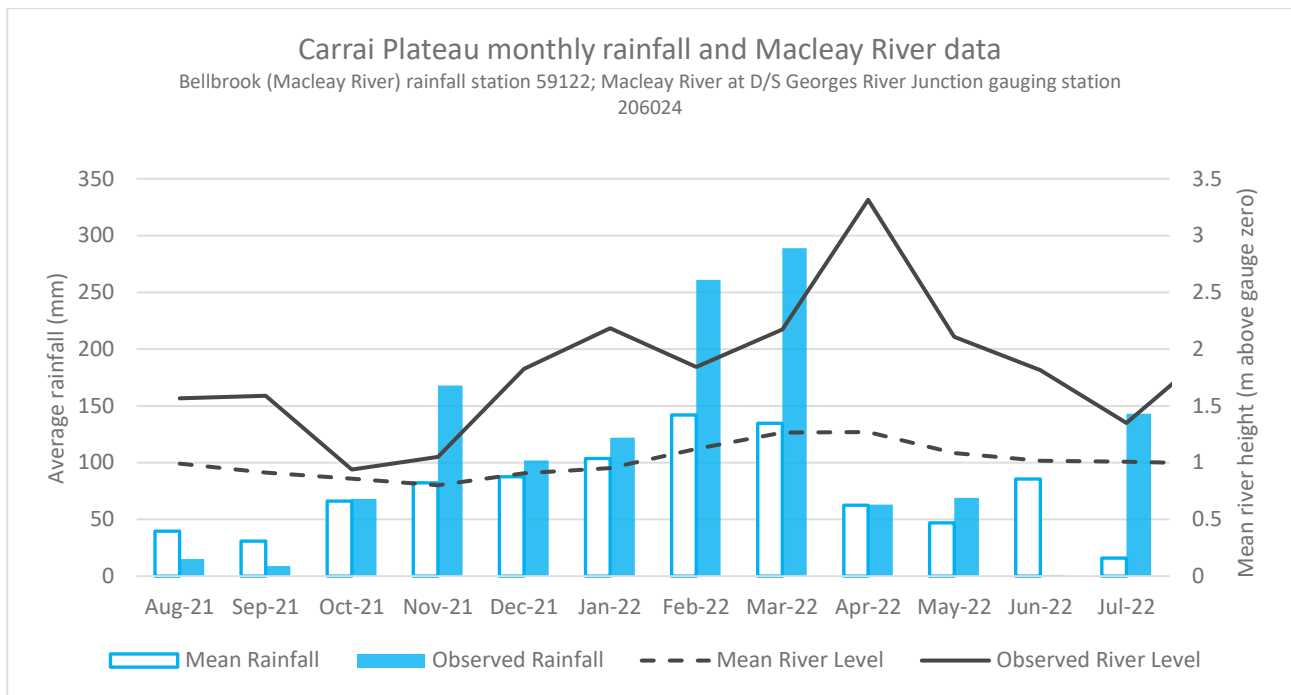
Rainfall data obtained from the Bureau of Meteorology (BoM) Bellbrook (Macleay River) rainfall station (BoM: 59122, located approximately 30 km east of the project area) indicates 52% of the yearly rainfall is typically received between December and March (BoM, 2022).

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:

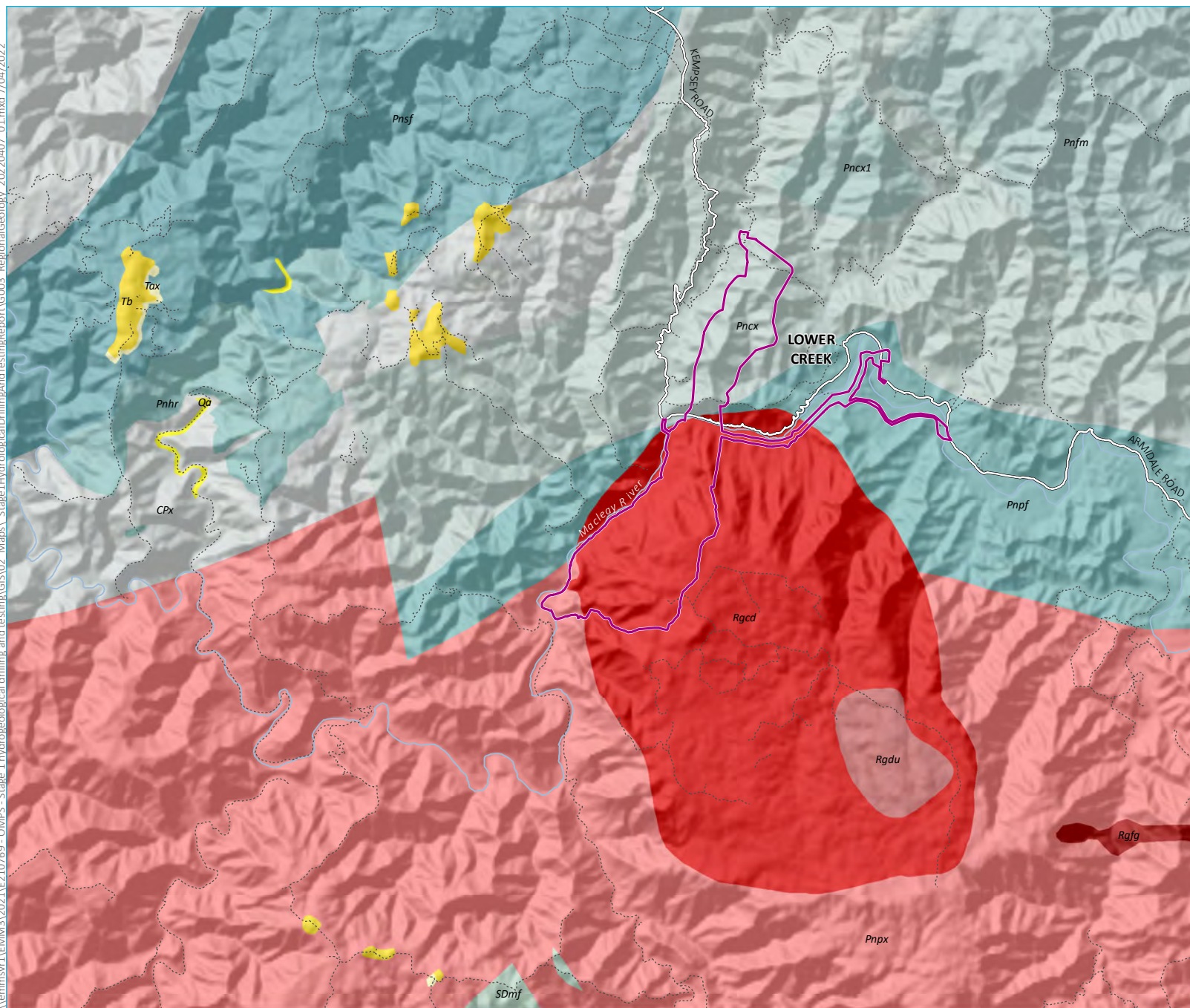
- a surficial localised groundwater system, within the unconsolidated colluvial and alluvial materials deposited within the incised valleys, and adjacent to the Macleay River; and
- a deeper fractured rock groundwater system, within the Triassic Carrai Granodiorite and Permian Parrabel Beds.

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.

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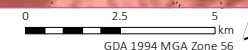
- KEY**
- Project area
 - Major road
 - Vehicular track
 - Macleay River
 - Geology 250k period and formation**
 - Quaternary**
 - Qa - Quaternary, unnamed
 - Tertiary**
 - Tax - Tertiary
 - Tb - Tertiary
 - Permian**
 - Pnpx - Permian, Parrabel bed
 - Rgcd - Permian, Carrai Granodiorite
 - Rgdu - Permian, 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

Regional geology

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



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



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 4.3 to 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:

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

Where: RPD is relative percentage difference;
C₁ is the concentration of analyte from sample 1; and
C₂ 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			
		Easting ¹	Northing	Top of casing (mAHD) ²	Ground level (mAHD)	Depth (mbgl) ³	Diameter (mm)	Material	Diameter (mm)	Screen		Formation	Water level (mbgl)	Logger		DVP intake (mbgl)
										Top (mbgl)	Bottom (mbgl)			Depth (mAHD)	Serial number	
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 —	—

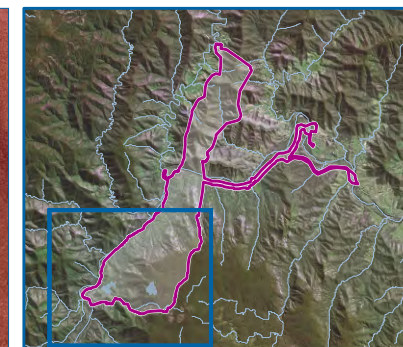
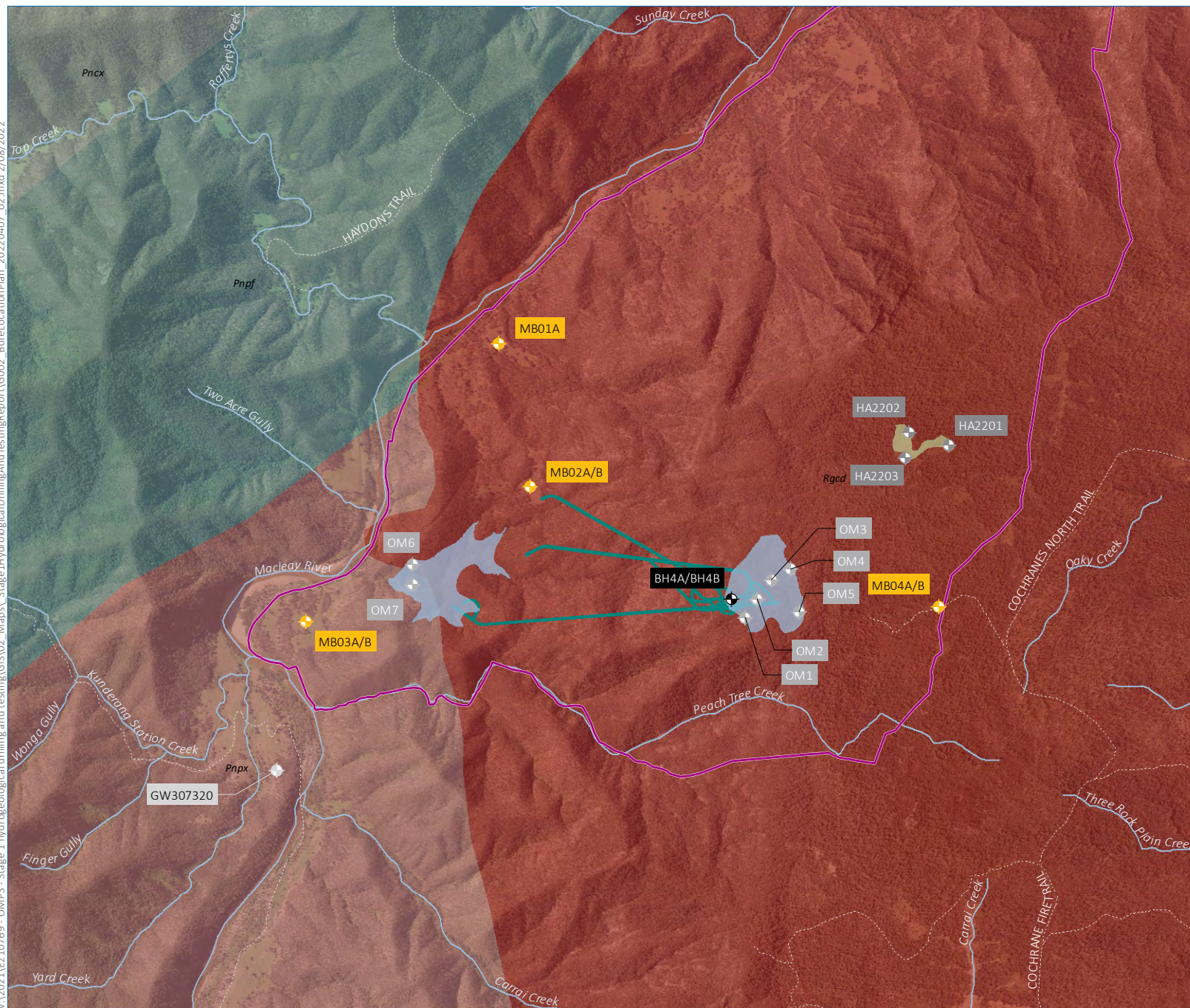
Notes: 1. co-ordinates are provided in GDA1994/MGA zone 56.

2. mAHD = metres Australian Height Datum.

3. mbgl = metres below ground level.

4. Logger serial number not available

V:\2021\10769 - OMPS - Stage 1 hydrogeological drilling and testing\GIS\02_Maps\Stage 1 hydrogeological drilling and testing\G002_BoreLocationPlan_20220407_02.mxd 2/08/2022



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

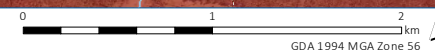
Bore location plan

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

Figure 4.1



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



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	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 CaCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	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

Hydrogeological notes and symbols

In general accordance with AS1726-2017

Groundwater observations

Ø Yield test K Water strike ∇ Water dip ▬ Water level

Soil

Components	Division	Size (mm)	Fraction	Components	Size (mm)	Fraction
 Boulder		>200	Oversize	 Silt	0.002-0.075	Fine grained
 Cobble		63-200		 Clay	<0.002	
 Gravel	Coarse Medium Fine	19.00-63.00 6.70-19.00 2.36-6.70	Coarse grained	 Peat	Soil comprising >25% organic content	
 Sand	Coarse Medium Fine	0.60-2.36 0.21-0.60 0.075-0.21		 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 Mudex, TR30, 1/4" coated bentonite chips	 Gravel pack Blue Circle specialised sand, 2 mm, washed	 Grout Cement based grout, approximately 1:1 mix	 Pipe PVC, 50 mm diameter, class 18, threaded with O-ring	 Screen PVC, 50 mm diameter, class 18, horizontal slots, 0.4 mm aperture, threaded with O-ring
--	---	--	---	--

EMM Sydney Office
Level G, 20 Chandos Street
St Leonards NSW 2065
(02) 9493 9589

Monitoring bore

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

ID: MB01A

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

[illegible]

Company: Numac Drilling Services Pty Ltd

Water quality: pH = 7.23; SPC = 647 $\mu\text{S}/\text{cm}$; Temp = 20.8°C; ORP = 95.1 mV

Driller: Justin Collyer

Termination details: Borehole terminated at target depth of 36.5 m

Page 1 of 2

Monitoring bore

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

ID: MB01A

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

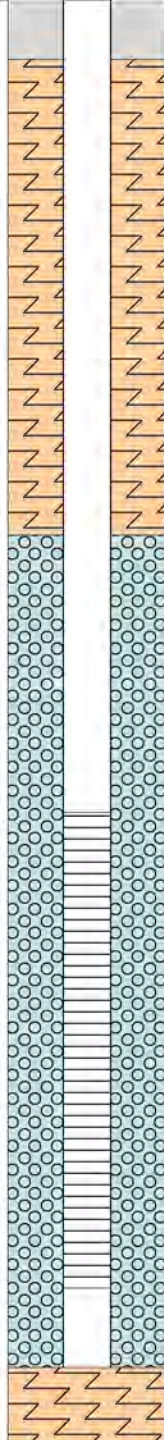
Drilling method/s: Pneumatic hammer

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

Company: Numac Drilling Services Pty Ltd

Water quality: pH = 7.23; SPC = 647 $\mu\text{S}/\text{cm}$; Temp = 20.8°C; ORP = 95.1 mV

Driller: Justin Collyer

Termination details: Borehole terminated at target depth of 36.5 m

Page 2 of 2

EMM Sydney Office
Level G, 20 Chandos Street
St Leonards NSW 2065
(02) 9493 9589

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		Water obs.	Additional notes	Bore design		RL (mAHD)
			Graphic	Formation					
0	150 mm pneumatic hammer			Residual	N	4 m: Depleting, potential perched surface contact			300
									
				Carrai Granodiorite					
						6.8–7 m: Highly weathered section			
10						11.2–12 m: Moderately weathered section			290

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.

EMM Sydney Office
Level G, 20 Chandos Street
St Leonards NSW 2065
(02) 9493 9589

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		Water obs.	Additional notes	Bore design	RL (mAHD)
			Graphic	Formation				
20	150 mm pneumatic 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.

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		Water obs.	Additional notes	Bore design		RL (mAHD)
			Graphic	Formation					
0	200 mm pneumatic hammer			Residual					300
					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% hornblende and mica				
10				Carrai Granodiorite					290
					GRANODIORITE: Coarse grained, grey to white with some yellow oxidation, moderately weathered, 40% quartz, 40% plagioclase, 20% hornblende, trace mica.				
					GRANODIORITE: As above, trace green, slightly weathered	Ø 13 m: <0.01 L/sec, pH 11.41, SPC 233 µS/cm, Temp 20.3°C, Eh 49.0 mV			
					GRANODIORITE: As above, fresh	Ø 16 m: <0.01 L/sec, pH 10.91, SPC 187 µS/cm, Temp 18.4°C, Eh 187.1 mV Ø 19 m: <0.01 L/sec, pH 10.27, SPC 343.7 µS/cm, Temp 22.3°C, Eh 50.7 mV			
20						19.05 m: Recovered water level			280
						Ø 22 m: <0.01 L/sec, pH 11.20, SPC 303.7 µS/cm, Temp 22.1°C, Eh 51.7 mV			
						Ø 25 m: <0.01 L/sec, pH 11.78, SPC 292.5 µS/cm, Temp 22.2°C, Eh 42.5 mV			
30									270

EMM Sydney Office
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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		Water obs.	Additional notes	Bore design		RL (mAHD)
			Graphic	Formation					
	200 mm pneumatic hammer			Carrai Granodiorite					
				GRANODIORITE: As above, slightly weathered					
				GRANODIORITE: As above, fresh					
40					Ø	34 m: <0.02 L/sec, pH 10.66, SPC 335.1 µS/cm, Temp 19.3°C, Eh 122.3 mV			260
					Ø	37 m: <0.02 L/sec, pH 10.56, SPC 373.6 µS/cm, Temp 18.6°C, Eh 128.7 mV			
					Ø	40 m: <0.02 L/sec, pH 5.50, SPC 381.8 µS/cm, Temp 19.8°C, Eh 120.1 mV			
					Ø	43 m: no WQ, too much foam			
50									250
					Ø	52 m: <0.02 L/sec, pH 11.3, SPC 325.9 µS/cm, Temp 21.4°C, Eh 105.2 mV			
				GRANODIORITE: As above, slightly weathered					
				GRANODIORITE: As above, fresh					
					Ø	55 m: <0.02 L/sec			
60					Ø	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.

EMM Sydney Office
Level G, 20 Chandos Street
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(02) 9493 9589

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		Water obs.	Additional notes	Bore design		RL (mAHD)
			Graphic	Formation					
	200 mm pneumatic hammer			Carrai Granodiorite					
						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, trace clay in return, potential weathered seam.			
						GRANODIORITE: As above, fresh			
70						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, trace low durability chips in return, slightly weathered			
						76 m: <1 L/sec			
						GRANODIORITE: As above, 70% hornblende 30% quartz			
						GRANODIORITE: As above, fresh			
80						79 m: <1 L/sec, pH 10.61, SPC 494.1 µS/cm, Temp 20.3°C, Eh 31.3 mV			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.

EMM Sydney Office
Level G, 20 Chandos Street
St Leonards NSW 2065
(02) 9493 9589

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

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		Water obs.	Additional notes	Bore design		RL (mAHD)					
			Graphic	Formation			Description (See AS1726-2017)							
130	200 mm pneumatic hammer			Carrai Granodiorite		Ø 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					Ø	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					Ø	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					Ø	145 m: <0.7 L/sec, pH 8.39, SPC 511.2 µS/cm, Temp 23.0°C, Eh 96.2 mV			
150													Ø 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 $\mu\text{S}/\text{cm}$; 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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Level G, 20 Chandos Street
St Leonards NSW 2065
(02) 9493 9589

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

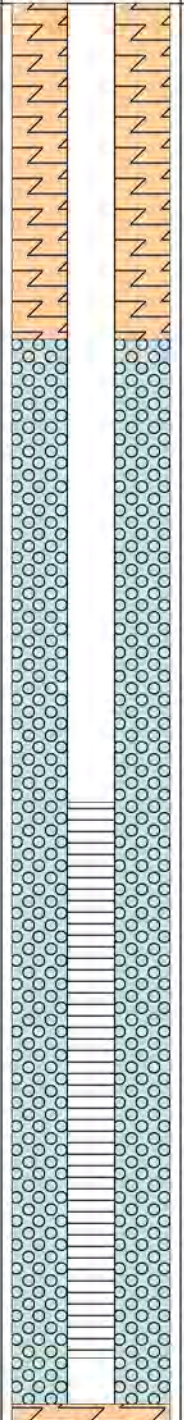
Drilling method/s: Pneumatic hammer

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		Water obs.	Additional notes	Bore design	RL (mAHD)
			Graphic	Formation				
160	200 mm pneumatic hammer			Carrai Granodiorite	Ø	157 m: <0.6 L/sec, pH 8.40, SPC 520 µS/cm, Temp 22.3°C, Eh 97.5 mV		140
					Ø	163 m: <0.6 L/sec, pH 8.45, SPC 525 µS/cm, Temp 22.9°C, Eh 73.6 mV		
170					Ø	169 m: <0.6 L/sec, pH 8.40, SPC 523 µS/cm, Temp 23.5°C, Eh 57.9 mV		
					Ø	175 m: <0.7 L/sec, pH 8.32, SPC 528 µS/cm, Temp 23.3°C, Eh 102.2 mV		
180					Ø	181 m: <0.6 L/sec, pH 8.26, SPC 524 µS/cm, Temp 23.3°C, Eh 78.2 mV		
					Ø	187 m: <0.6 L/sec, pH 8.30, SPC 541 µS/cm, Temp 23.5°C, Eh 69.7 mV		
			Description (See AS1726-2017)					
			GRANODIORITE: Grey and dark grey, trace ferruginous colouring, slightly weathered					
			GRANODIORITE: Pale grey and dark grey, fresh					
			GRANODIORITE: Grey and dark grey, trace ferruginous colouring, slightly weathered					
			GRANODIORITE: Pale grey and dark grey, fresh					
			GRANODIORITE: Grey and dark grey, trace 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.

EMM Sydney Office
Level G, 20 Chandos Street
St Leonards NSW 2065
(02) 9493 9589

Monitoring bore

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

ID: MB03A

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

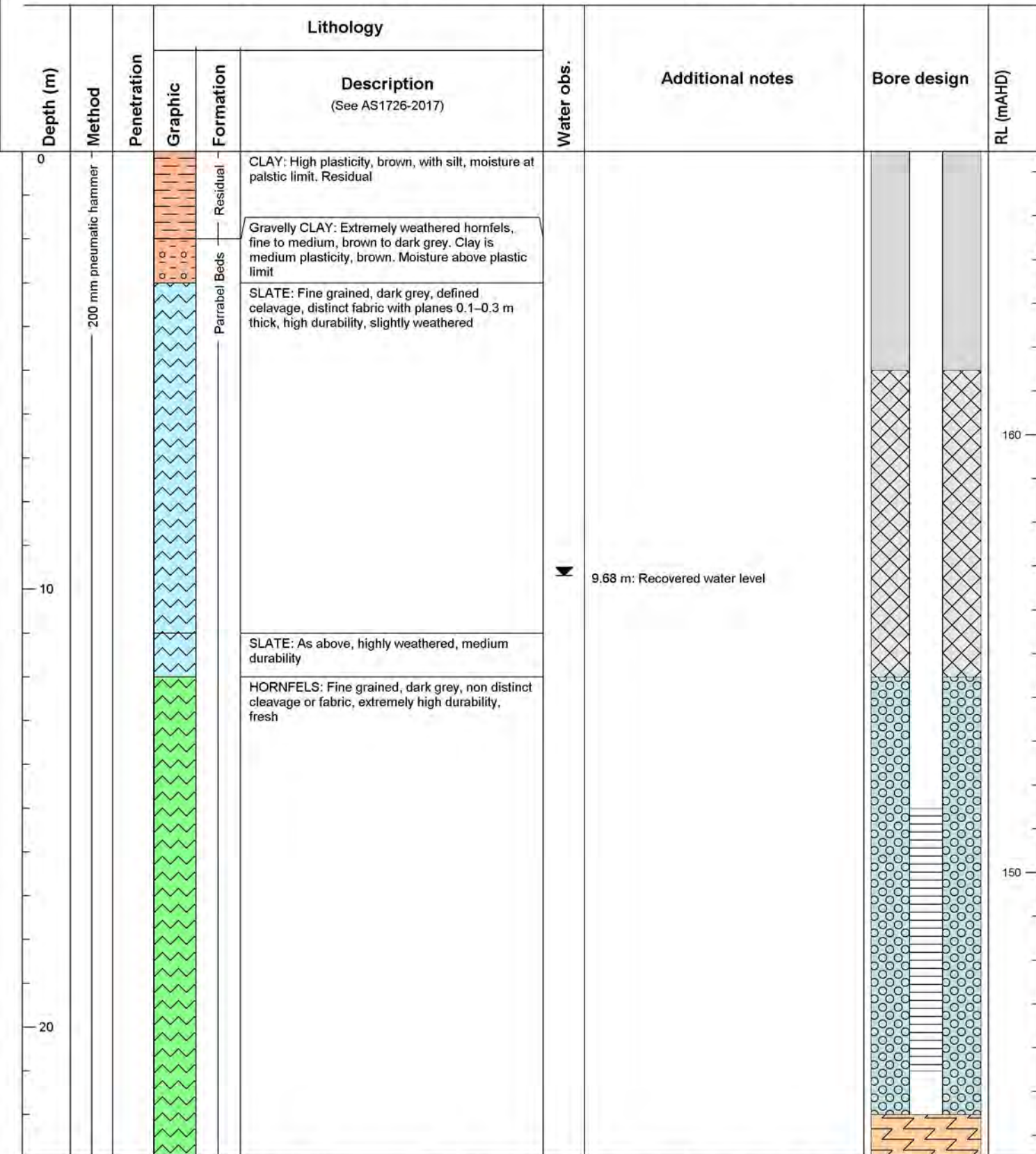
Drilling method/s: Pneumatic hammer

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 terminated at target depth of 23 mbgl

EMM Sydney Office
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St Leonards NSW 2065
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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		Water obs.	Additional notes	Bore design		RL (mAHD)				
			Graphic	Formation			Description (See AS1726-2017)						
0	200 mm pneumatic hammer			Parrabel Beds		10.63 m: Recovered water level 16–17 m: Potential quartz sill 36–37 m: Aplitic intrusion, with pyrite, likely sill from nearby pluton			160				
10				Parrabel Beds					150				
20				Parrabel Beds					140				
30				Parrabel Beds					130				
40				Parrabel Beds					120				
50		Parrabel Beds											

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

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

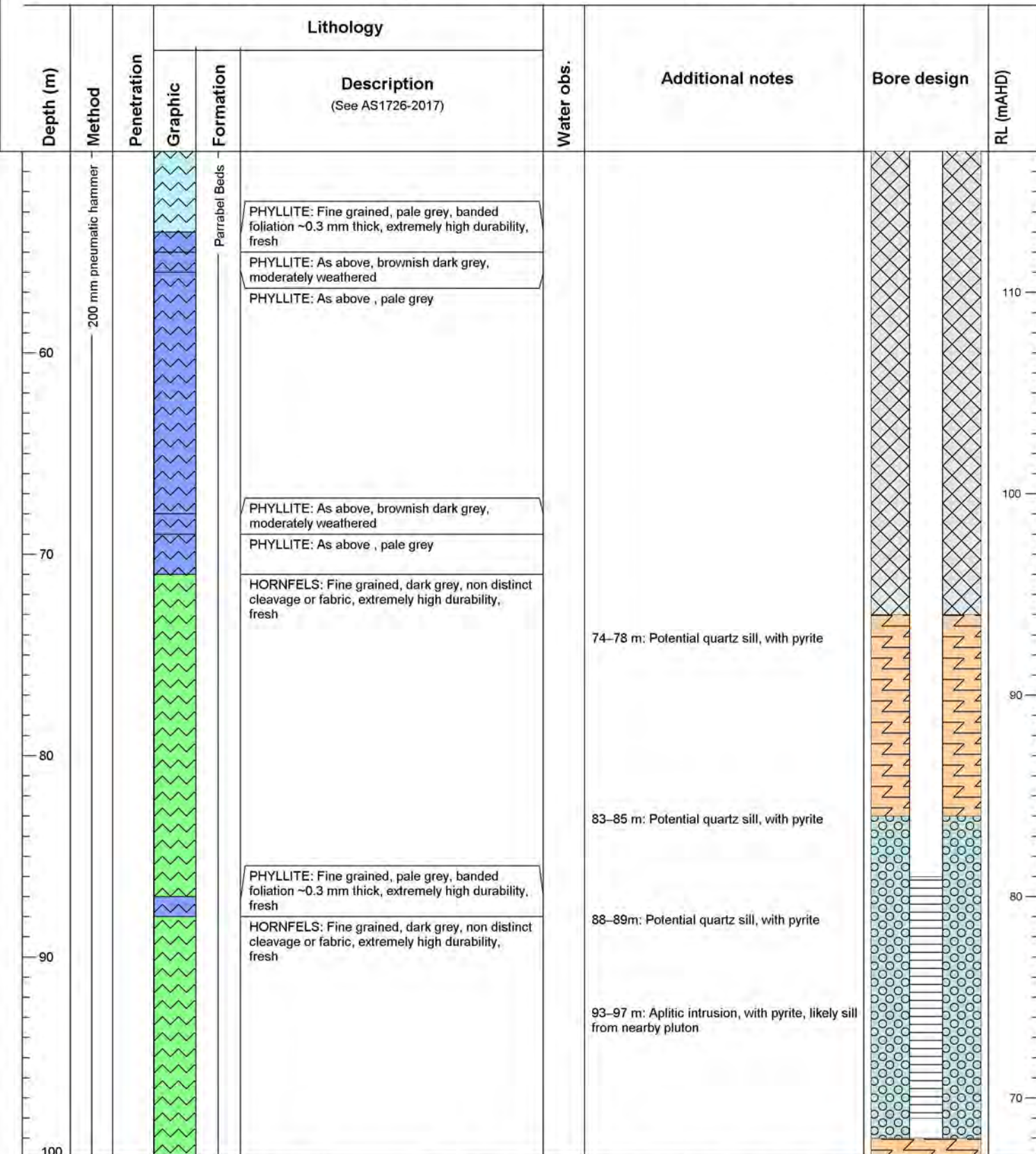
Drilling method/s: Pneumatic hammer

Water level depth: 10.63 mbgl

Screened depth: 86–98 mbgl

Total depth: 100 mbgl

Level date; time: 19/3/2022: 09:30



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

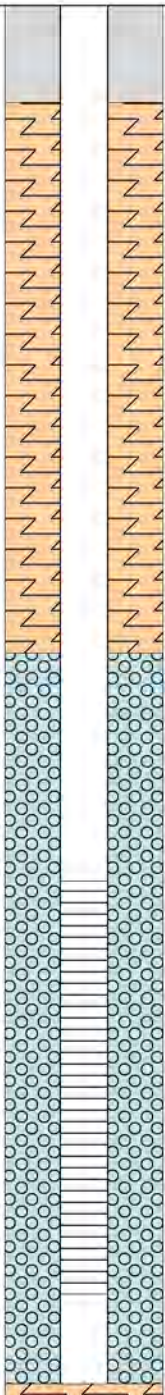
Drilling method/s: Tri cone

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		Water obs.	Additional notes	Bore design	RL (mAHD)
			Graphic	Formation				
0	Tri-cone with HWT string			Colluvium	 0.25 m: Recovered water level  1.4 m: 0.5 L/sec  6 m: 4 L/sec Casing method doesnt allow sampling		970	
		Residual		SAND: Medium to coarse grained, grey, angular, quartzose, with clay, pale grey, dry. Residual				
	Shoe bit on PWT casing		Carrai Granodiorite	SAND: As above, wet				
10								
					</			

Company: Terratest Pty Ltd

Water quality: pH = 5.93; SPC = 75.7 $\mu\text{S}/\text{cm}$; Temp = 21.6°C; ORP = 101.4 mV

Driller: Toby Osborne

Termination details: Borehole terminated on competent rock at 10.5 m

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EMM Sydney Office
Level G, 20 Chandos Street
St Leonards NSW 2065
(02) 9493 9589

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		Water obs.	Additional notes	Bore design	RL (mAHD)
			Graphic	Formation				
0	Tri-cone with HWT string		X X X X X		K ▼	0.2 - 0.4 m: Possible perched aquifer ~0.5L/s 1.01 m: Recovered water level		970
	125 mm pneumatic hammer		Carrai Granodiorite		K	1 L/s. Casing method doesn't allow sampling		960
10	125 mm pneumatic hammer		Carrai Granodiorite		K	Yield increasing to 4 L/sec until 8.6 m and surface casing installed		960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960
	125 mm pneumatic hammer		Carrai Granodiorite		K			960

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		Water obs.	Additional notes	Bore design	RL (mAHD)
			Graphic	Formation				
	125 mm pneumatic hammer			Carrai Granodiorite				
40				GRANODIORITE: As above, slightly weathered	Ø	33 m: 0.4 L/sec, pH 7.78, SPC 72.1 µS/cm, Temp 19.1°C, Eh 39.5 mV		940
					Ø	36 m: 0.4 L/sec, pH 7.78, SPC 72.1 µS/cm, Temp 19.1°C, Eh 39.5 mV		
					Ø	39 m: 2 L/sec, pH 7.46, SPC 110.8 µS/cm, Temp 18.8°C, Eh 44.4 mV		
				GRANODIORITE: As above, fresh, pale green and pale grey	Ø	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	Ø	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		
50				GRANODIORITE: As above	Ø	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		
					Ø	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 drilling, iron staining, potential fracture zone		920
					Ø	54 m: 0.05 L/sec, pH 8.73, SPC 148.6 µS/cm, Temp 25.5°C, Eh 31.5 mV		
60					Ø	57 m: 0.04 L/sec, pH 8.62, SPC 160.1 µS/cm, Temp 25.8°C, Eh 35.3 mV		

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.

Appendix B

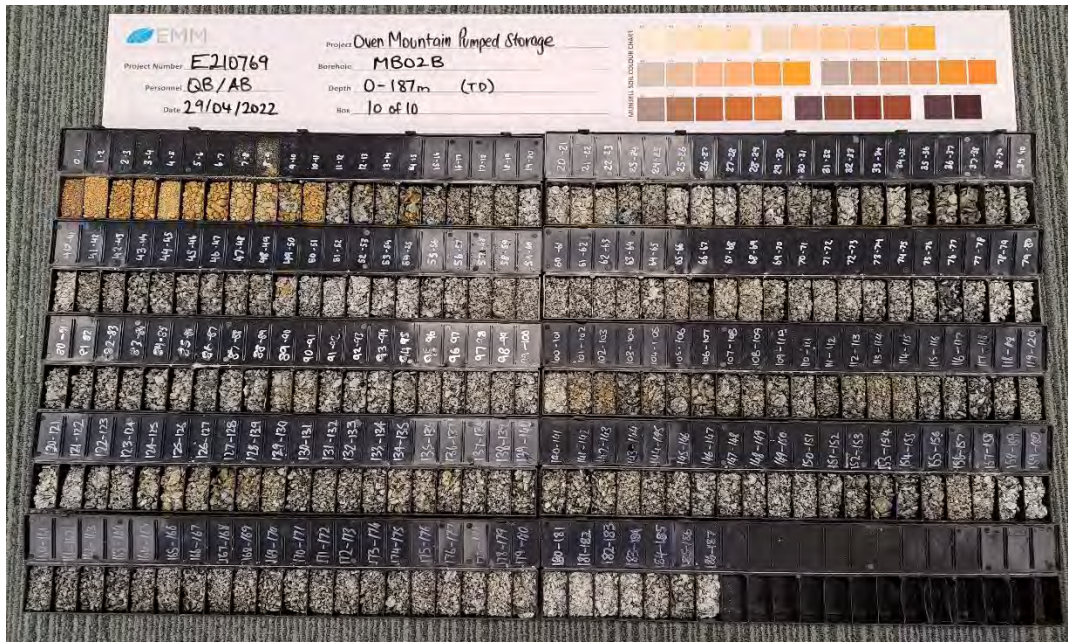
Photographic plates



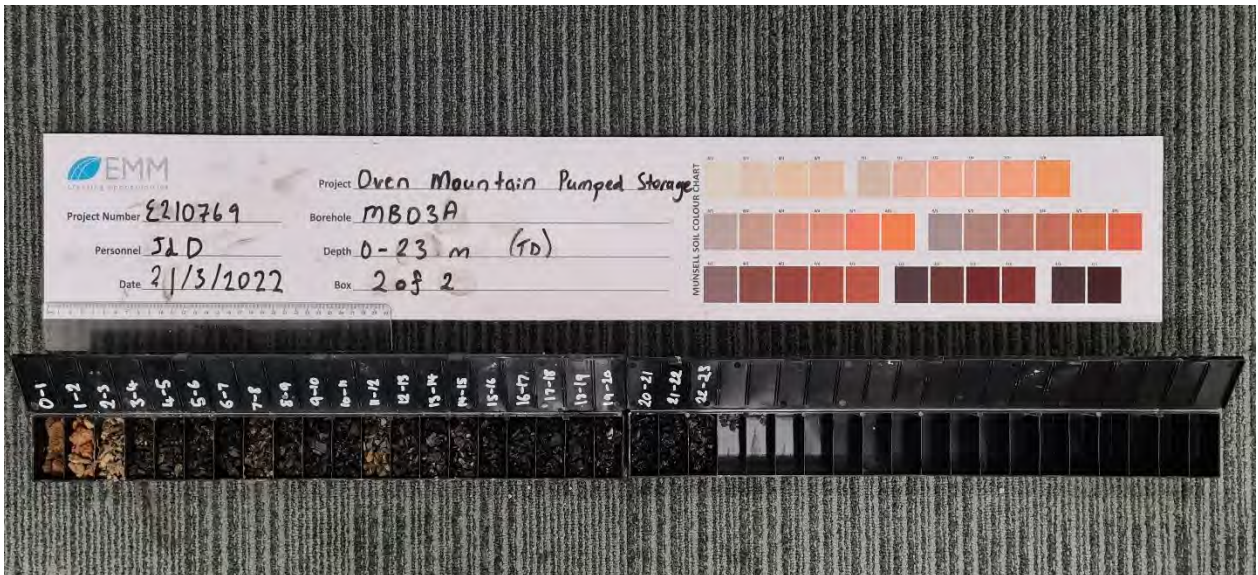
MB01A chip trays from 0—36 m below ground level
21 October 2021
Oven Mountain Pumped Storage Project
[Photograph B.1](#)



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



Appendix C

Laboratory certificates of analysis

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		



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.

<i>Signatories</i>	<i>Position</i>	<i>Accreditation Category</i>
Ashesh Patel	Senior Chemist	Sydney Inorganics, Smithfield, NSW
Edwandy Fadjjar	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									
∅ Total Anions	----	0.01	meq/L		7.85	----	----	----	----
∅ Total Cations	----	0.01	meq/L		7.64	----	----	----	----
∅ 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	----	----	----	----

Page : 6 of 6
Work Order : ES2138245
Client : EMM CONSULTING PTY LTD
Project : E210769 OMPS-Stage 1 Hydrogeological drilling/Testing



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



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		

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.

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 insufficient 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									
∅ Total Anions	----	0.01	meq/L		9.02				
∅ Total Cations	----	0.01	meq/L		8.39				
∅ 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



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 pompe 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		

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



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 raised 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								
∅ Total Anions	----	0.01	meq/L	7.60				
∅ Total Cations	----	0.01	meq/L	7.74				
∅ 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				

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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- Analytical Results
- Surrogate Control Limits

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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.

<i>Signatories</i>	<i>Position</i>	<i>Accreditation Category</i>
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW
Edwandy Fadjjar	Organic Coordinator	Sydney Organics, Smithfield, NSW
Wisam Marassa	Inorganics Coordinator	Sydney Inorganics, Smithfield, NSW



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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.
- 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	----	----	----

Page : 6 of 6
Work Order : ES2203887
Client : EMM CONSULTING PTY LTD
Project : E210769 OMPS-Stage 1 Hydrogeological drilling/Testing



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



Work Order	: ES2146443
Client	: EMM CONSULTING PTY LTD
Contact	: HENRY NOAKES
Address	: Ground Floor Suite 1 20 Chandos Street St Leonards NSW NSW 2065
Telephone	: ----
Project	: J200096 Oven Mountain Pumped Storage Project
Order number	: J200096
C-O-C number	: ----
Sampler	: ----
Site	: ----
Quote number	: EN/112/21
No. of samples received	: 12
No. of samples analysed	: 12

Page : 1 of 10
Laboratory : Environmental Division Sydney
Contact : Sepan Mahamad
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164

Telephone : +61 2 8784 8555
Date Samples Received : 17-Dec-2021 17:00
Date Analysis Commenced : 18-Dec-2021
Issue Date : 30-Dec-2021 12:12



This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits

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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
Wisam Marassa	Inorganics Coordinator	Sydney Inorganics, Smithfield, NSW



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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**)

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
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

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	
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									
∅ Total Anions	----	0.01	meq/L	2.71	17.4	6.29	6.17	----	
∅ Total Cations	----	0.01	meq/L	2.55	17.2	5.63	5.63	----	
∅ 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	----	----	----

Page : 10 of 10
Work Order : ES2146443
Client : EMM CONSULTING PTY LTD
Project : J200096 Oven Mountain Pumped Storage Project



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

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		



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.

<i>Signatories</i>	<i>Position</i>	<i>Accreditation Category</i>
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW
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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 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.

Laboratory Duplicate (DUP) Report

Sub-Matrix: **WATER**

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)									

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 Work Order : ES2146443
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 Project : J200096 Oven Mountain Pumped Storage Project



Sub-Matrix: **WATER**

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)									

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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	2	µg/L	<2	<2	0.0	No Limit
			106-42-3						
		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	2	µg/L	<2	<2	0.0	No Limit
			106-42-3						
		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	2	µg/L	<2	<2	0.0	No Limit
			106-42-3						
		EP080: ortho-Xylene	95-47-6	2	µg/L	<2	<2	0.0	No Limit

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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**

Sub-Matrix: WATER				Method Blank (MB) Report	Laboratory Control Spike (LCS) Report			
					Spike Concentration	Spike Recovery (%)	Acceptable Limits (%)	
Method: Compound	CAS Number	LOR	Unit			Result	LCS	Low
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**

Sub-Matrix: WATER				Method Blank (MB) Report	Laboratory Control Spike (LCS) Report			
					Spike Concentration	Spike Recovery (%)	Acceptable Limits (%)	
Method: Compound	CAS Number	LOR	Unit	Result		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				Method Blank (MB) Report Result	Laboratory Control Spike (LCS) Report			
					Spike Concentration	Spike Recovery (%)	Acceptable Limits (%)	
						LCS	Low	High
CAS Number	LOR	Unit						
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**

Sub-Matrix: WATER				Method Blank (MB) Report	Laboratory Control Spike (LCS) Report			
					Spike Concentration	Spike Recovery (%)	Acceptable Limits (%)	
Method: Compound	CAS Number	LOR	Unit	Result			LCS	Low
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	2	µg/L	<2	10 µg/L	91.7	69.0	121
	106-42-3							
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**

Sub-Matrix: WATER				Matrix Spike (MS) Report			
				Spike	SpikeRecovery(%)	Acceptable Limits (%)	
Laboratory sample ID	Sample ID	Method: Compound	CAS Number	Concentration	MS	Low	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

Page : 11 of 12
 Work Order : ES2146443
 Client : EMM CONSULTING PTY LTD
 Project : J200096 Oven Mountain Pumped Storage Project



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	25 µg/L	107	70.0	130
			106-42-3				



Sub-Matrix: WATER

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	25 µg/L	81.7	70.0	130
			106-42-3				
		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



Work Order	: ES2213920
Client	: EMM CONSULTING PTY LTD
Contact	: HENRY NOAKES
Address	: Ground Floor Suite 1 20 Chandos Street St Leonards NSW NSW 2065
Telephone	: ----
Project	: J200096 Oven Mountain Pumped Storage Project
Order number	: J200096
C-O-C number	: ----
Sampler	: KB
Site	: ----
Quote number	: EN/112/21
No. of samples received	: 10
No. of samples analysed	: 10

Page : 1 of 9
Laboratory : Environmental Division Sydney
Contact : Sepan Mahamad
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61 2 8784 8555
Date Samples Received : 22-Apr-2022 15:00
Date Analysis Commenced : 23-Apr-2022
Issue Date : 29-Apr-2022 17:36



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.

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.

<i>Signatories</i>	<i>Position</i>	<i>Accreditation Category</i>
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 insufficient 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									
∅ Total Anions	----	0.01	meq/L		----	----	<0.01	2.25	11.6
∅ Total Cations	----	0.01	meq/L		----	----	<0.01	2.15	13.9
∅ 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)				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
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									
∅ Total Anions	----	0.01	meq/L		5.83	7.95	5.67	11.5	11.3
∅ Total Cations	----	0.01	meq/L		6.09	7.71	5.28	11.1	11.4
∅ 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

EMM Sydney Office
Level G, 20 Chandos Street
St Leonards NSW 2065
(02) 9493 9500

Permeability assessment

ID: MB01A

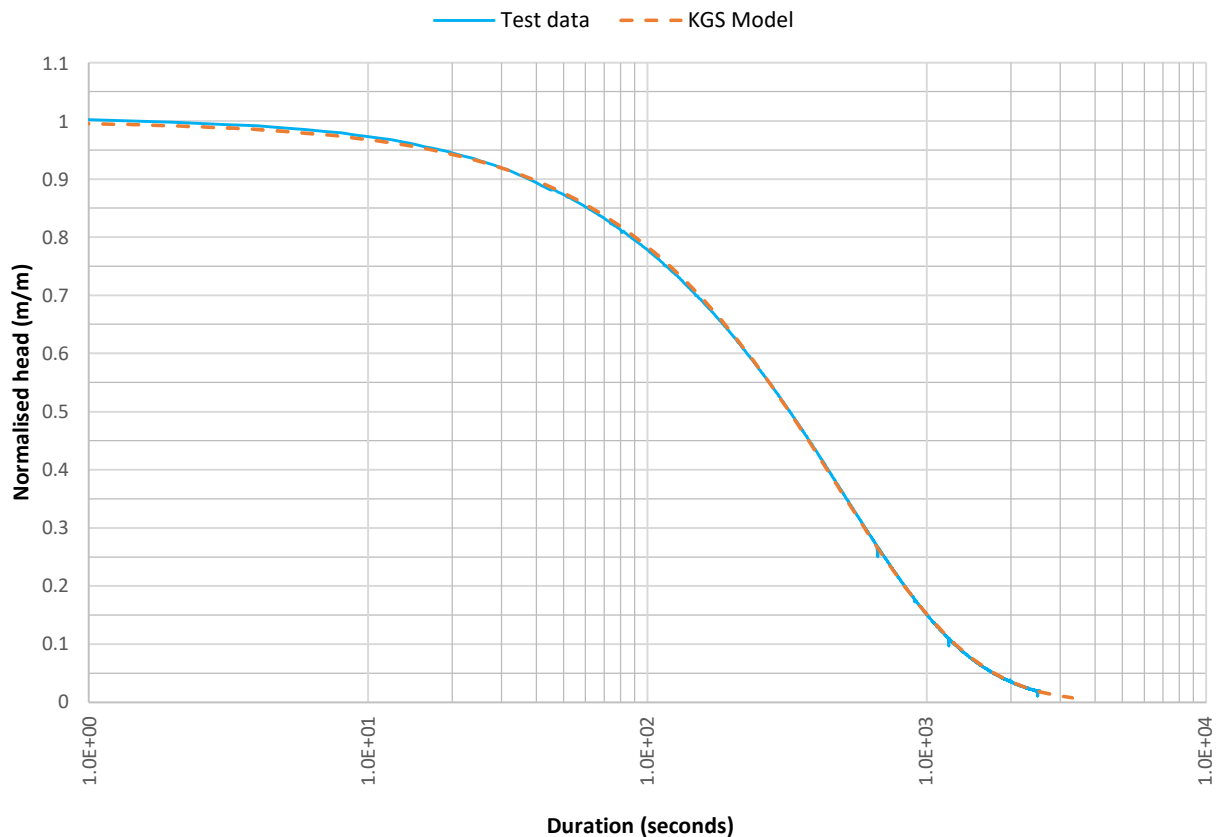
Client: SMEC Australia Pty Limited
Site: Oven Mountain, Carrai NSW
Project: Oven Mountain Pumped Hydro
Reference: E210769
Field personnel: AB
Analysed by: HJN

Test type: Rising head test
Equipment: Pneumatic apparatus
Test start: 15 February 2022; 14:16
Test finish: 15 February 2022; 14:58
Duration: 42 minutes
Data method: Automated (transducer)

Testing stratigraphy: Triassic Carrai Granodiorite
General description: Granodiorite, fresh to slightly weathered
Drill method: 125 mm diameter air hammer
Aquifer type: Unconfined
Bore construction: Partial penetration
Analytical model: KGS (Hyder et al. 1994)

Well type: PVC monitoring bore
Screen top depth: 28.5 m
Screen bottom depth: 34.5 m
Screen length: 6 m
Casing radius: 25 mm
Well radius: 62.5 mm
Well skin radius: - Note 1
Logger depth: 15.03 m
Initial water depth: 8.43 m
Final water depth: 8.43 m
Approximate recovery: 100%
Induced displacement: 1.48 m
Water column height: 26.08 m
Saturated thickness: 26.08 m Note 2

MB01A - Modelled vs actual response



$$K = 5.4 \times 10^{-7} \text{ m/s}$$

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)

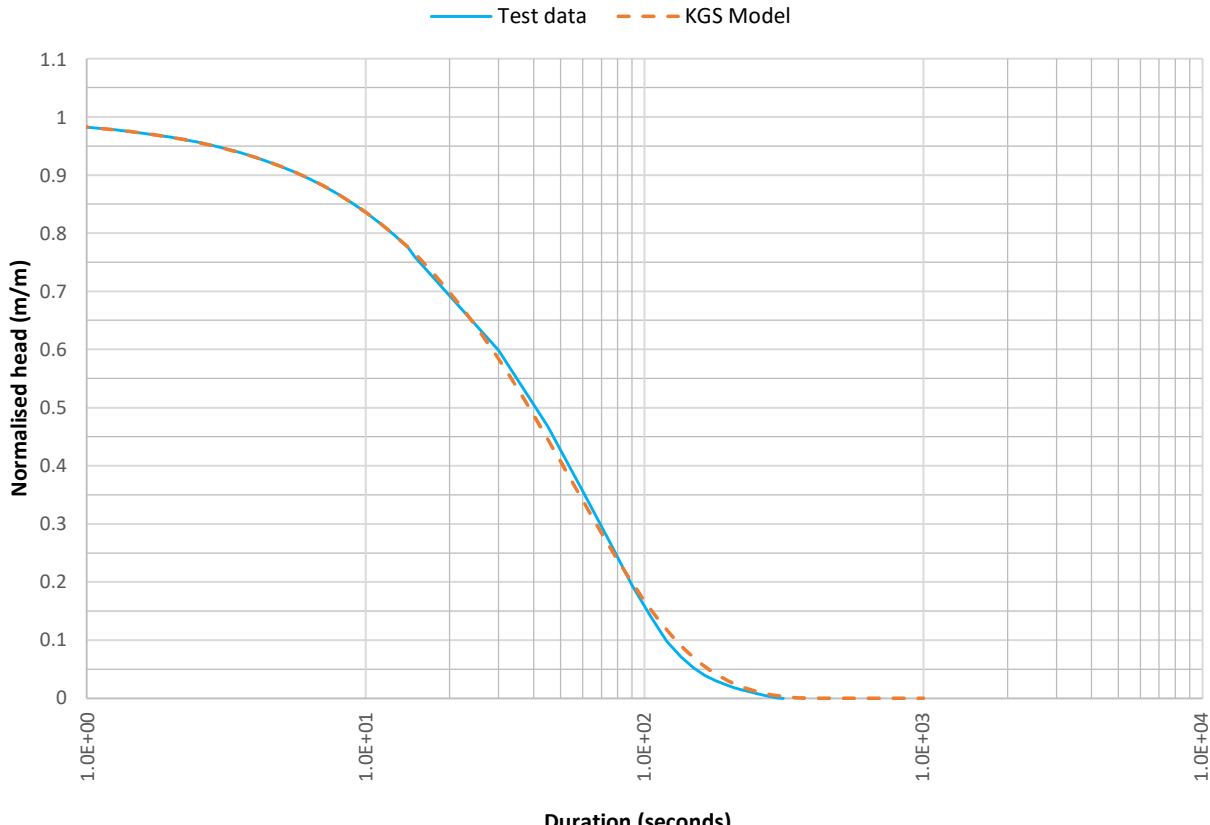
Hyder, Z, Butler, J, McElwee, C & Liu, W 1994. Slug tests in partially penetrating wells, *Water Resources Research*, vol. 30, no. 11, pp. 2945-2957.

 creating opportunities www.emmconsulting.com.au EMM Sydney Office Level G, 20 Chandos Street St Leonards NSW 2065 (02) 9493 9500	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:	-	Saturated thickness:	12.18 m	Note 2

MB02A - Modelled vs actual response

— Test data

--- KGS Model



Duration (seconds)	Normalised head (m/m) - Test data	Normalised head (m/m) - KGS Model
1.0E+00	0.98	0.98
1.0E+01	0.85	0.85
1.0E+02	0.15	0.18
1.0E+03	0.02	0.05
1.0E+04	0.00	0.00

$K = 4.3 \times 10^{-6} \text{ m/s}$

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.

EMM Sydney Office
Level G, 20 Chandos Street
St Leonards NSW 2065
(02) 9493 9500

Permeability assessment

ID: MB02B

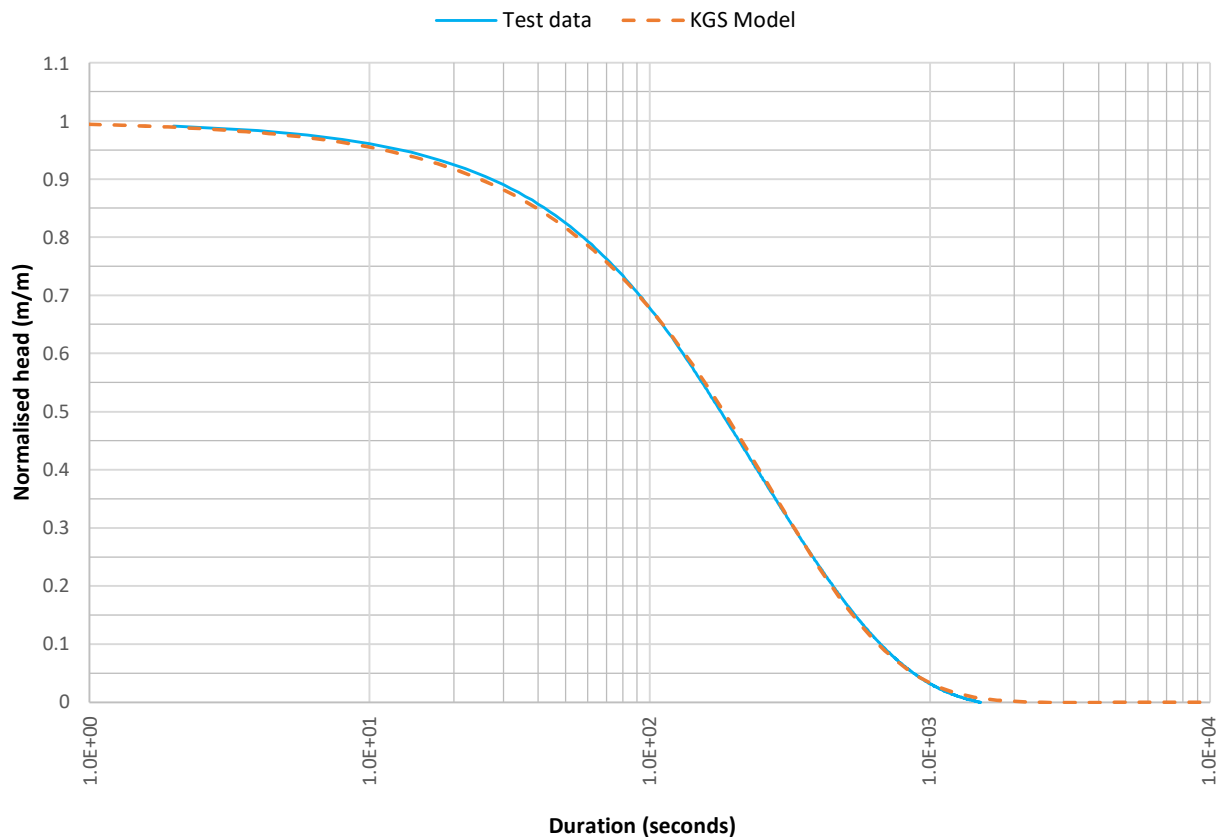
Client: SMEC Australia Pty Limited
Site: Oven Mountain, Carrai NSW
Project: Oven Mountain Pumped Hydro
Reference: E210769
Field personnel: AB
Analysed by: AB

Test type: Rising head test
Equipment: Pneumatic apparatus
Test start: 20 April 2022; 12:57
Test finish: 20 April 2022; 13:22
Duration: 24 minutes
Data method: Automated (transducer)

Testing stratigraphy: Triassic Carrai Granodiorite
General description: Granodiorite, fresh to slightly weathered
Drill method: 152.4 mm diameter air hammer
Aquifer type: Unconfined
Bore construction: Partial penetration
Analytical model: KGS (Hyder et al. 1994)

Well type: PVC monitoring well
Screen top depth: 173.5 m
Screen bottom depth: 185.5 m
Screen length: 12 m
Casing radius: 25 mm
Well radius: 76.2 mm
Well skin radius: - Note 1
Logger depth: 43.13 m
Initial water depth: 18.57 m
Final water depth: 18.57 m
Approximate recovery: 100%
Induced displacement: 2.38 m
Water column height: 166.93 m
Saturated thickness: 166.93 m Note 2

MB02B - Modelled vs actual response

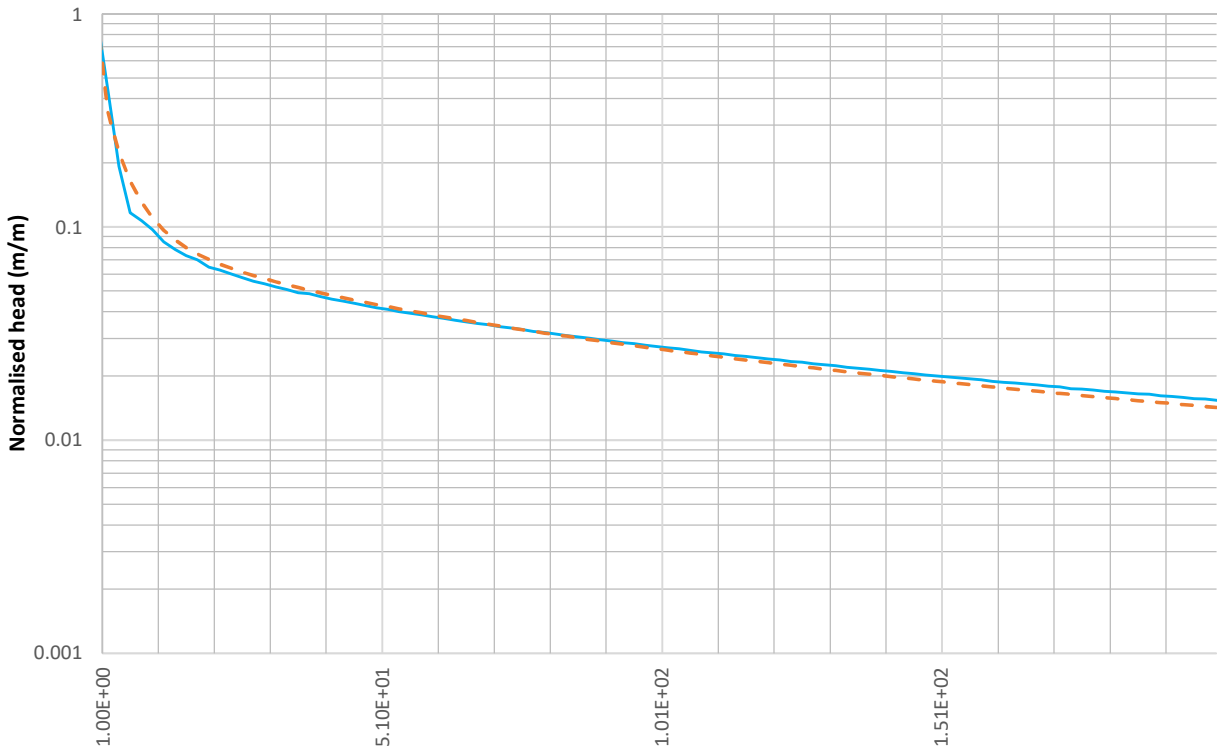


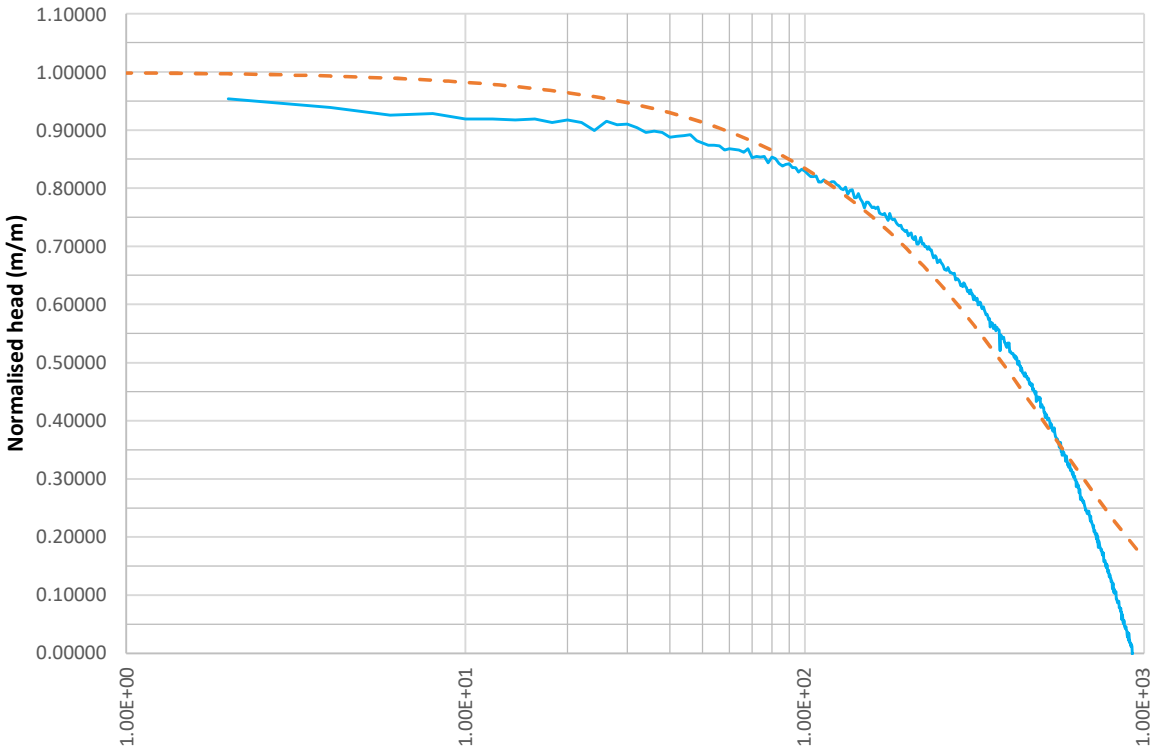
$$K = 5.0 \times 10^{-7} \text{ m/s}$$

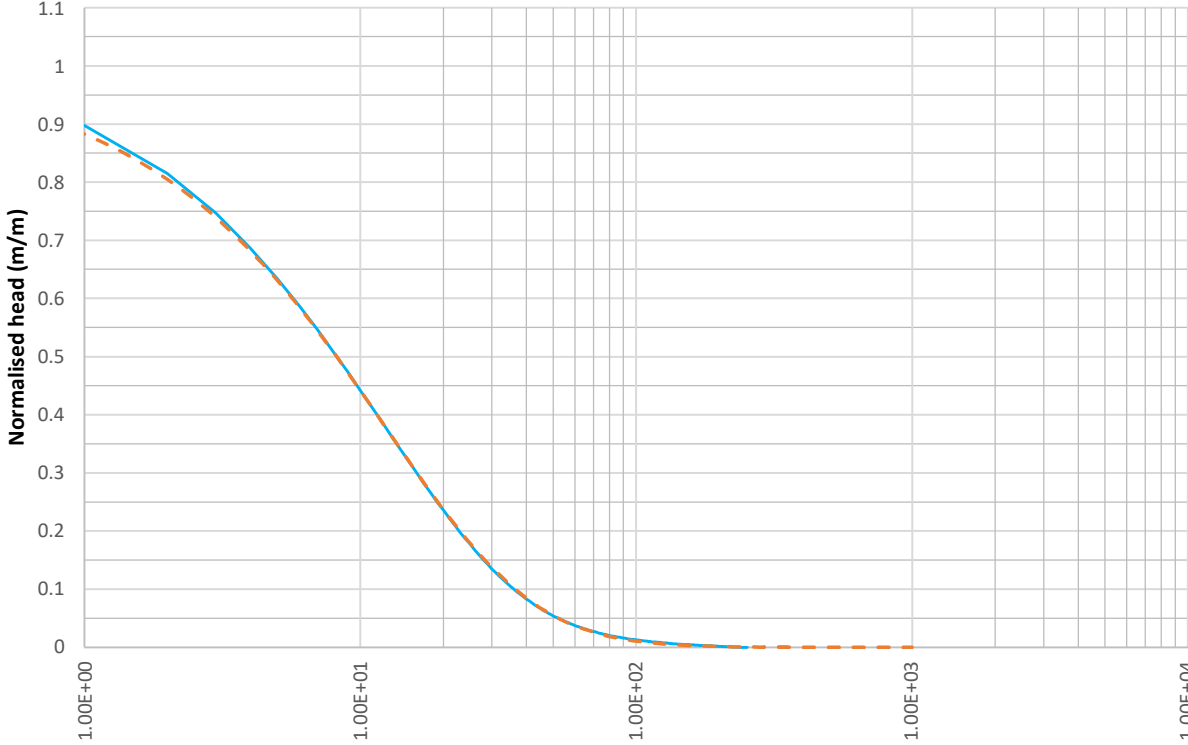
Notes:

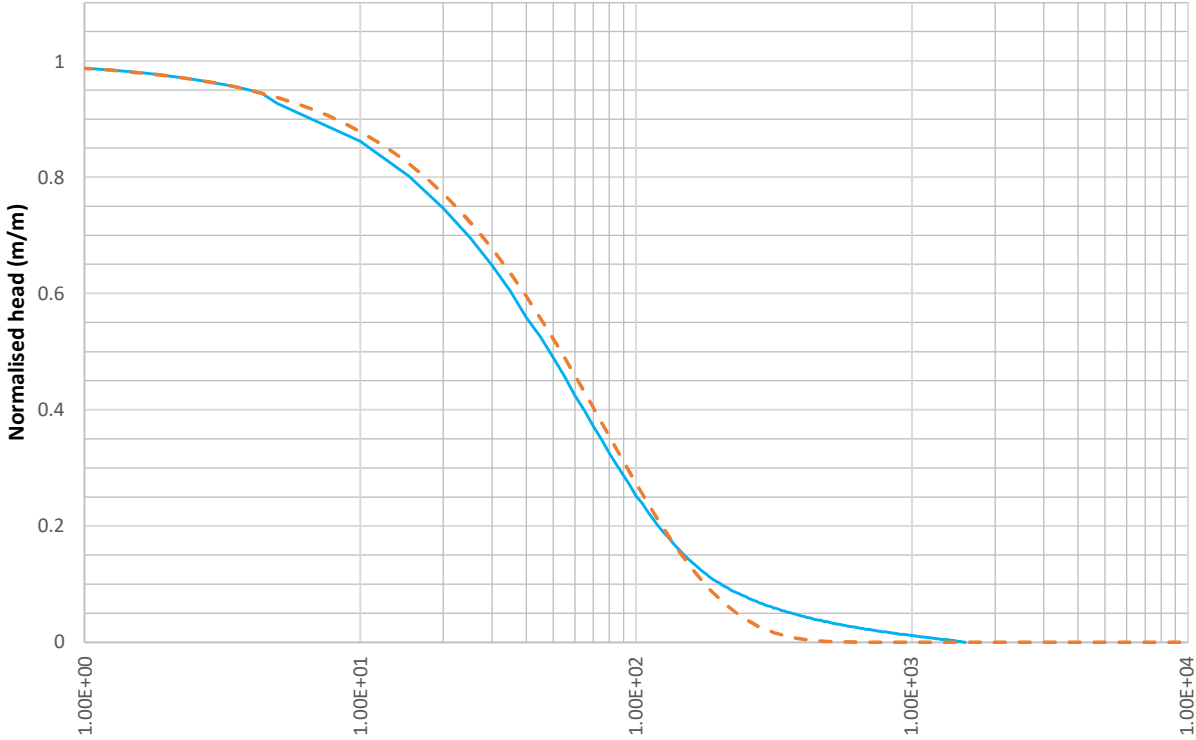
- Note 1 well skin radius not accounted for in the referenced analytical model;
Note 2 saturated thickness assumed to be equal to water column height for partially penetrating wells;

Reference (as accessed through Hydrosolve Inc - Aqtesolv software)

 creating opportunities www.emmconsulting.com.au EMM Sydney Office Level G, 20 Chandos Street St Leonards NSW 2065 (02) 9493 9500	Permeability assessment		ID: MB03A	
	Client: SMEC Australia Pty Limited Site: Oven Mountain, Carrai NSW Project: Oven Mountain Pumped Hydro Reference: E210769 Field personnel: AB Analysed by: AB	Test type: Rising head test Equipment: Pneumatic apparatus Test start: 21 April 2022; 09:12 Test finish: 21 April 2022; 09:35 Duration: 22 minutes Data method: Automated (transducer)		
Testing stratigraphy: Triassic Carrai Granodiorite General description: Granodiorite, fresh to slightly weathered Drill method: 152.4 mm diameter air hammer		Aquifer type: Unconfined Bore construction: Partial penetration Analytical model: KGS (Hyder et al. 1994) w/skin		
Well type: PVC monitoring well Screen top depth: 15 m Screen bottom depth: 21 m Screen length: 6 m Casing radius: 25 mm Well radius: 76.2 mm Well skin radius: 0.4 m		Logger depth: 11.72 m Initial water depth: 3.127 m Final water depth: 3.127 m Approximate recovery: 100% Induced displacement: 2.71 m Water column height: 17.873 m Saturated thickness: 17.873 m Note 1		
MB03A - Modelled vs actual response — Test data - - - KGS Model w/skin 				
$K = 2.0 \times 10^{-5} \text{ m/s}$				
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, <i>Water Resources Research</i> , vol. 30, no. 11, pp. 2945-2957.				

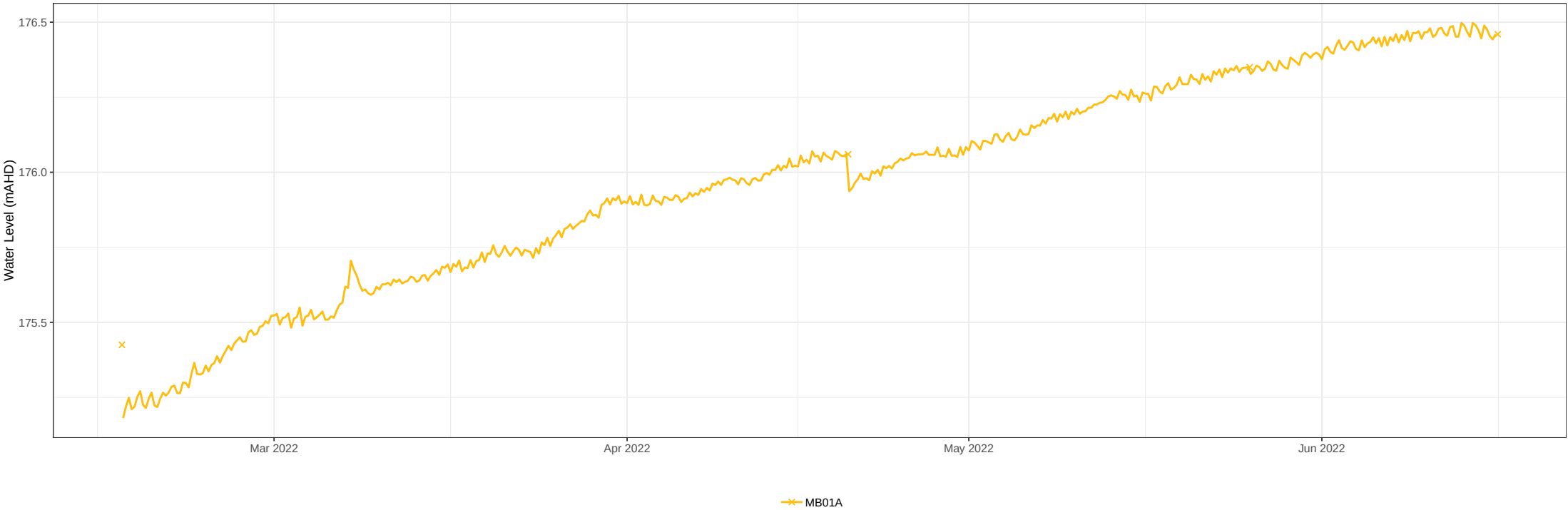
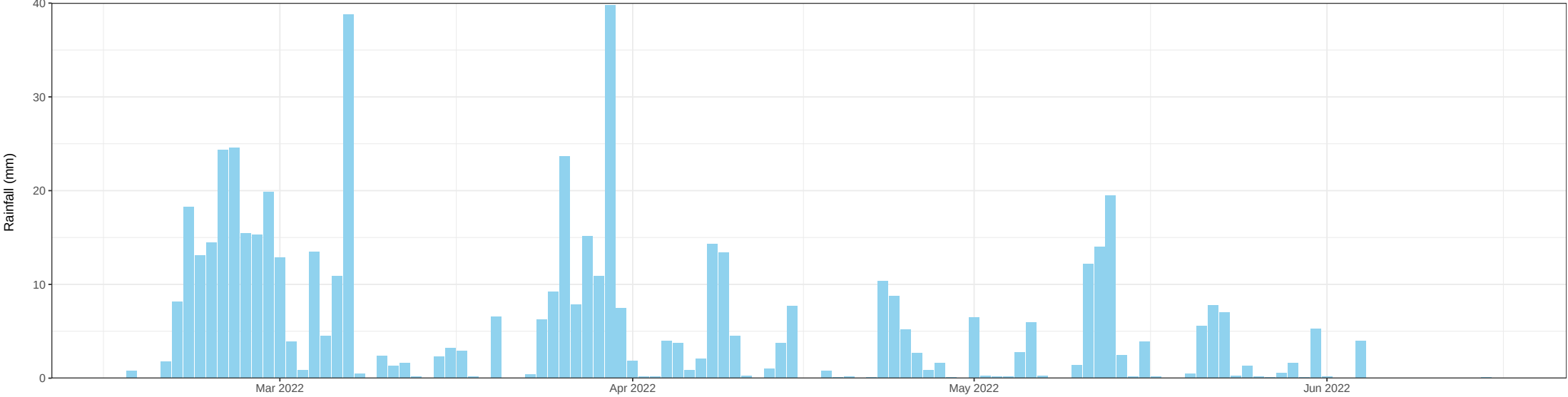
 www.emmconsulting.com.au EMM Sydney Office Level G, 20 Chandos Street St Leonards NSW 2065 (02) 9493 9500	Permeability assessment	ID: MB03B
	Client: SMEC Australia Pty Limited Site: Oven Mountain, Carrai NSW Project: Oven Mountain Pumped Hydro Reference: E210769 Field personnel: AB Analysed by: AB	Test type: Rising head test Equipment: Pneumatic apparatus Test start: 21 April 2022; 10:10 Test finish: 21 April 2022; 10:25 Duration: 15 minutes Data method: Automated (transducer)
Testing stratigraphy: Triassic Carrai Granodiorite General description: Granodiorite, fresh to slightly weathered Drill method: 152.4 mm diameter air hammer	Aquifer type: Unconfined Bore construction: Partial penetration 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	
MB03B - Modelled vs actual response — Test data --- KGS Model 		
$K = 1.7 \times 10^{-7} \text{ m/s}$		
<u>Notes:</u> 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; <u>Reference (as accessed through Hydrosolve Inc - Aqtesolv software)</u> Hyder, Z, Butler, J, McElwee, C & Liu, W 1994. Slug tests in partially penetrating wells, <i>Water Resources Research</i> , vol. 30, no. 11, pp. 2945-2957.		

 www.emmconsulting.com.au EMM Sydney Office Level G, 20 Chandos Street St Leonards NSW 2065 (02) 9493 9500	Permeability assessment Client: SMEC Australia Pty Limited Site: Oven Mountain, Carrai NSW Project: Oven Mountain Pumped Hydro Reference: E210769 Field personnel: AB Analysed by: HJN	ID: MB04A Test type: Rising head test Equipment: Pneumatic apparatus Test start: 17 February 2022; 10:25 Test finish: 17 February 2022; 10:29 Duration: 4 minutes Data method: Automated (transducer)
Testing stratigraphy: Triassic Carrai Granodiorite General description: Granodiorite, fresh to slightly weathered Drill method: 125 mm diameter air hammer	Aquifer type: Unconfined Bore construction: Partial penetration Analytical model: KGS (Hyder et al. 1994)	
Well type: PVC monitoring well Screen top depth: 6.35 m Screen bottom depth: 9.35 m Screen length: 3 m Casing radius: 25 mm Well radius: 62.5 mm Well skin radius: -	Logger depth: 5.15 m Initial water depth: 0.34 m Final water depth: 0.34 m Approximate recovery: 100% Induced displacement: 2.83 m Water column height: 9.01 m Saturated thickness: 9.01 m	Note 1 Note 2
MB04A - Modelled vs actual response — Test data --- KGS Model 		
$K = 2.8 \times 10^{-5} \text{ m/s}$		
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; <u>Reference (as accessed through Hydrosolve Inc - Aqtesolv software)</u> Hyder, Z, Butler, J, McElwee, C & Liu, W 1994. Slug tests in partially penetrating wells, <i>Water Resources Research</i> , vol. 30, no. 11, pp. 2945-2957.		

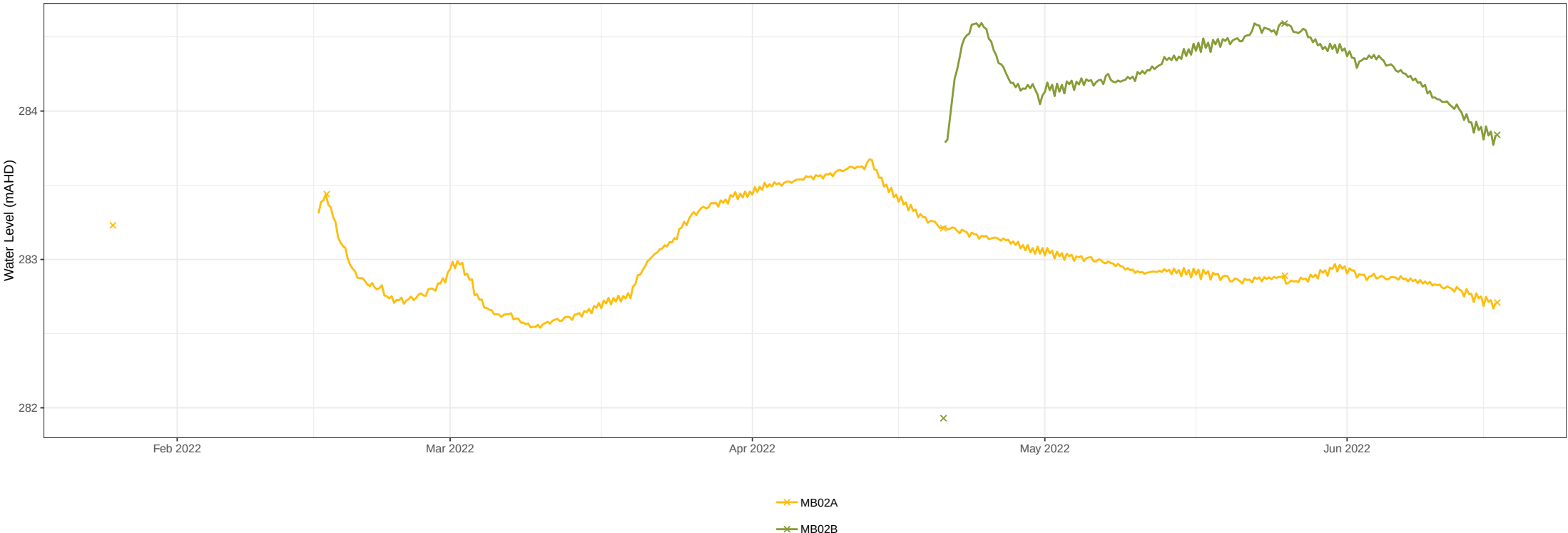
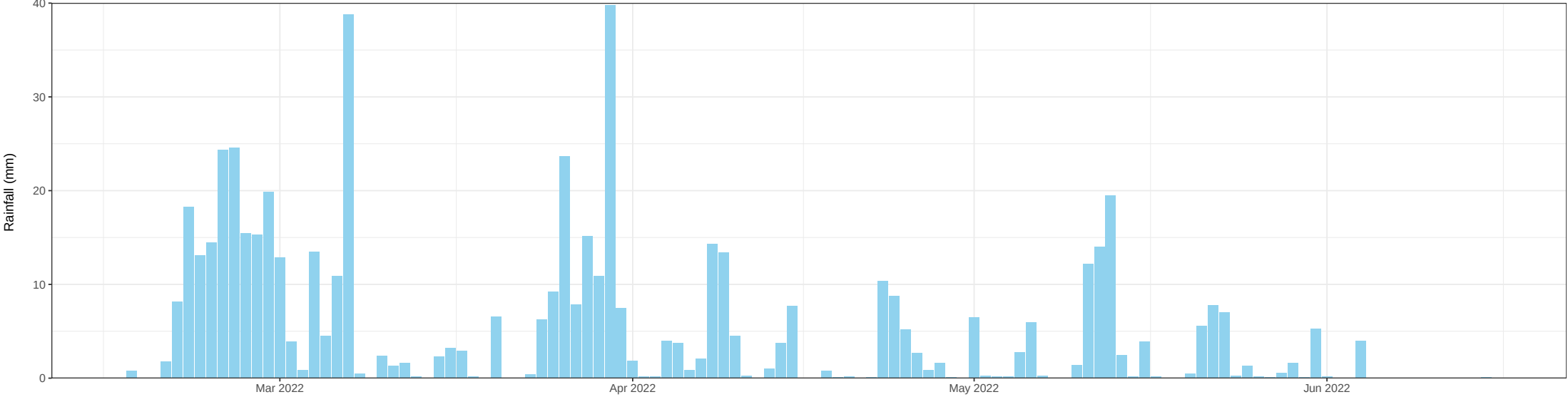
 www.emmconsulting.com.au EMM Sydney Office Level G, 20 Chandos Street St Leonards NSW 2065 (02) 9493 9500		Permeability assessment	ID: MB04B
Client: SMEC Australia Pty Limited		Test type: Rising head test	
Site: Oven Mountain, Carrai NSW		Equipment: Pneumatic apparatus	
Project: Oven Mountain Pumped 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
MB04B - Modelled vs actual response — Test data --- KGS Model 			
$K = 3.3 \times 10^{-6} \text{ m/s}$			
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

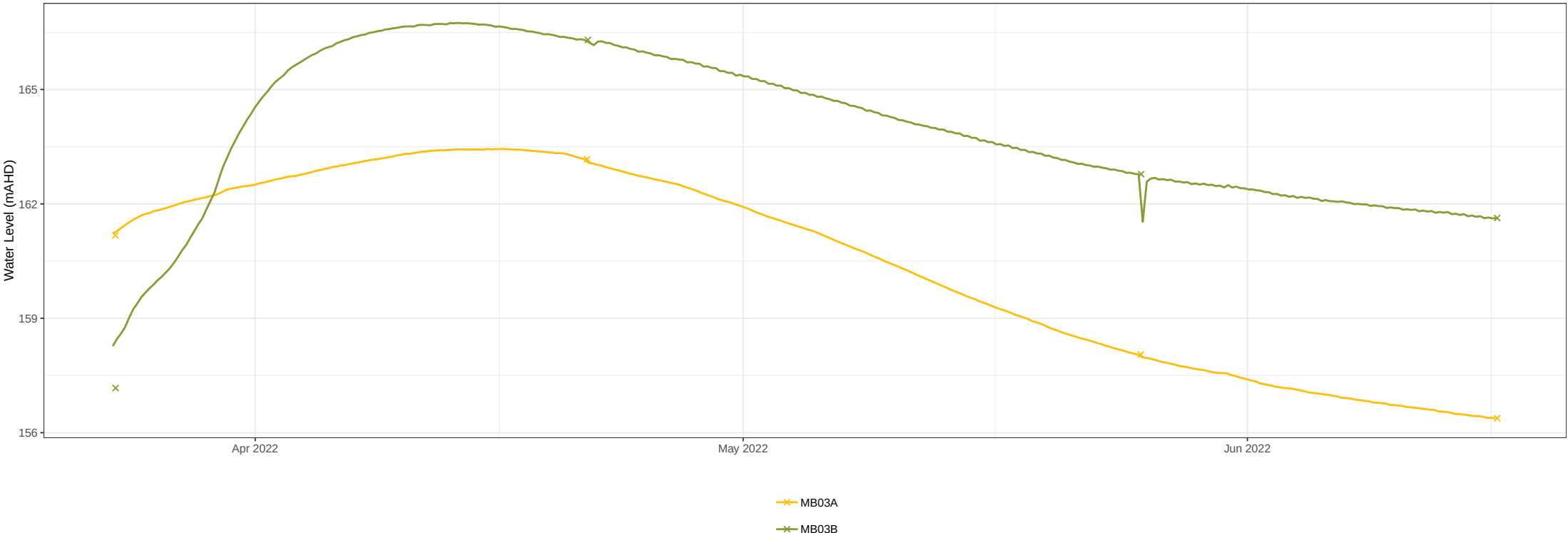
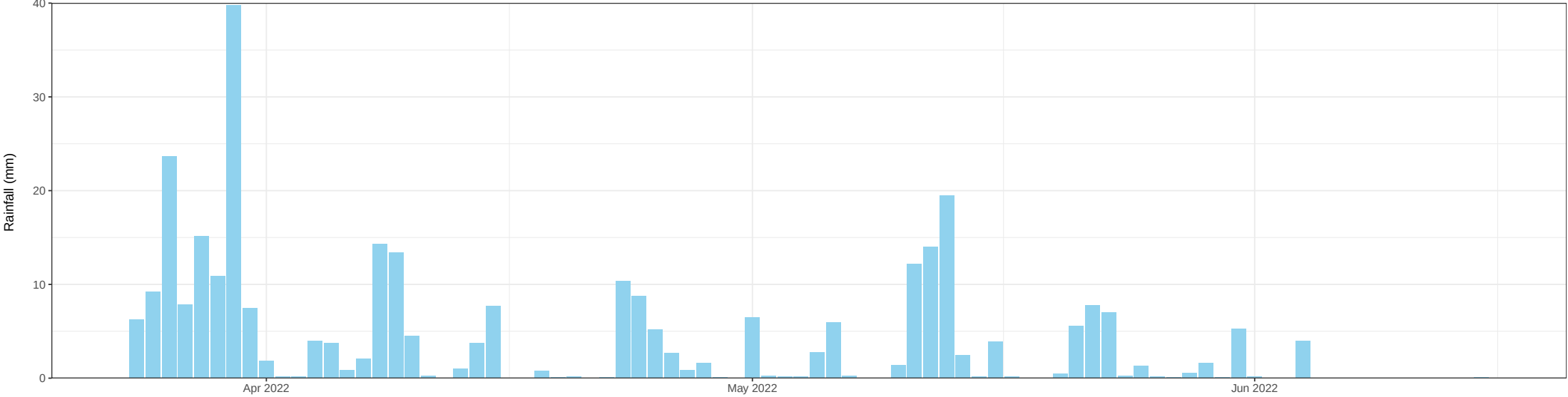


Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
<http://www.longpaddock.qld.gov.au/silo>

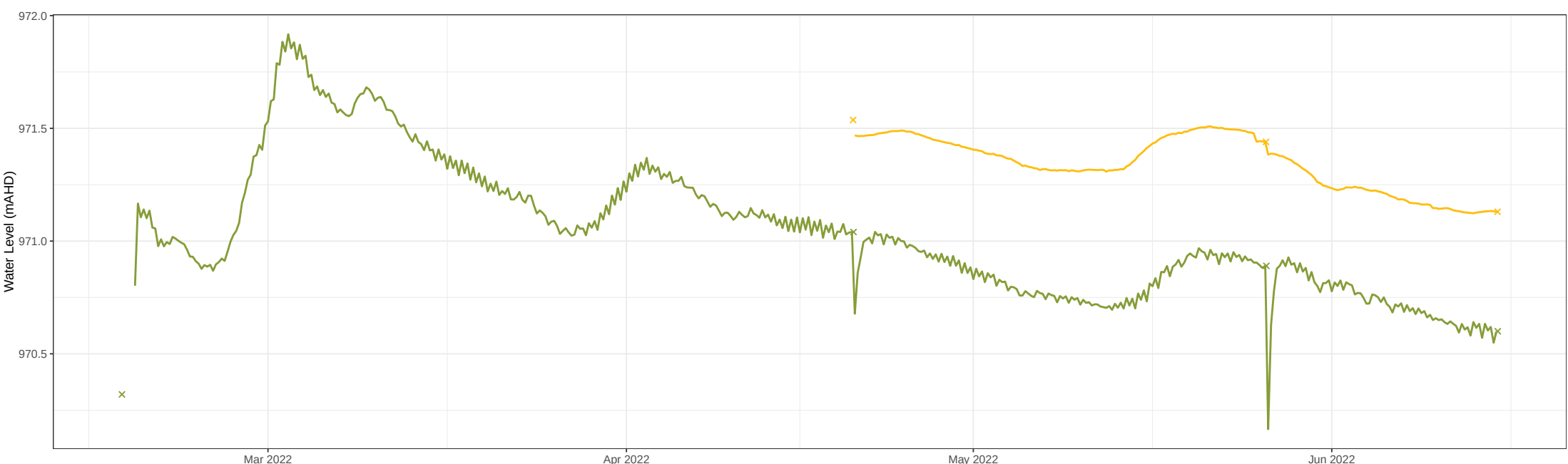
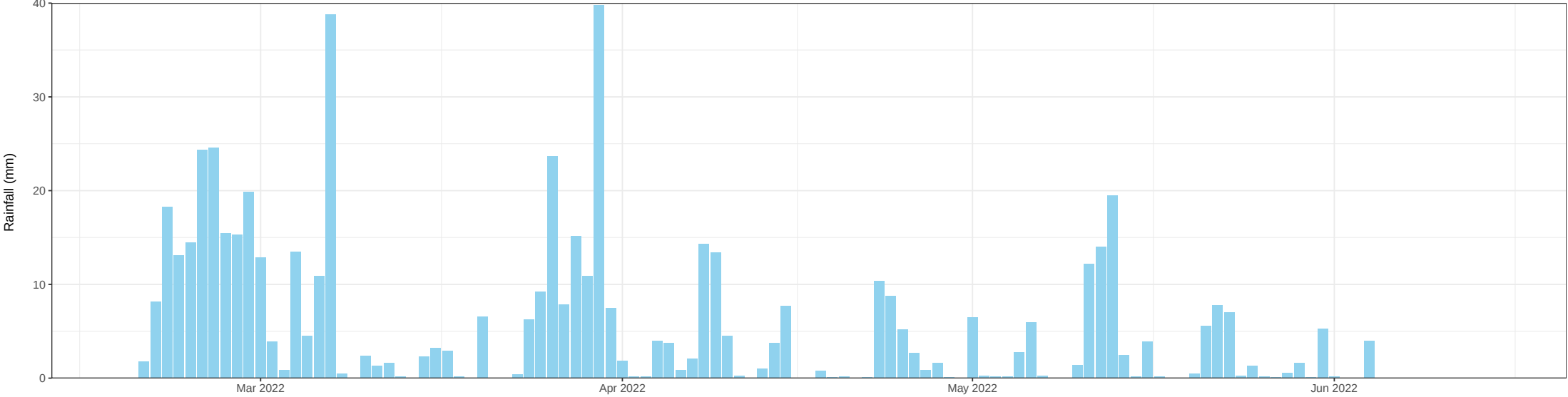


Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
<http://www.longpaddock.qld.gov.au/silo>

Groundwater level times series data – MB02A/B
Oven Mountain Pumped Hydro Energy Storage – SMEC Australia Pty Limited
Stage one hydrogeological drilling and testing



Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
<http://www.longpaddock.qld.gov.au/silo>



MB04A
MB04B



Notes
Rainfall measured at East Kunderang, Kenebree (station 57013)
<http://www.longpaddock.qld.gov.au/silo>

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Annexure B

Isotope assessment



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 (³H) and radiocarbon (¹⁴C_{DIC}) samples were sent to the respective laboratories for processing with samples logged and analytical codes assigned (Table 1). Results for ¹⁴C of dissolved inorganic carbon ¹⁴C_{DIC} were reported on the 25th of October 2022, with ³H results 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 ³H and ¹⁴C_{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

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 km² 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 Granodiorite 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

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 ^3H 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 ^3H 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 1σ 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 $\delta^{13}\text{C} = -25\text{‰}$, relative to PDB. The $\delta^{13}\text{C}$ isotopic composition of the graphite target was determined by AMS with an average precision of 0.66‰. The $\delta^{13}\text{C}$ is used in the correction of radiocarbon data. In general, direct water $\delta^{13}\text{C}_{\text{DIC}}$ is preferred for radiocarbon assessments as it better represents aquifer conditions. However, these were not available and graphite target $\delta^{13}\text{C}$ 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

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 $\mu\text{S}/\text{cm}$ in OM5 to 1240 $\mu\text{S}/\text{cm}$ 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 ($<100 \mu\text{S}/\text{cm}$), except for sample OM1 that displays the highest CBE while having an SC of 1050 $\mu\text{S}/\text{cm}$. 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).

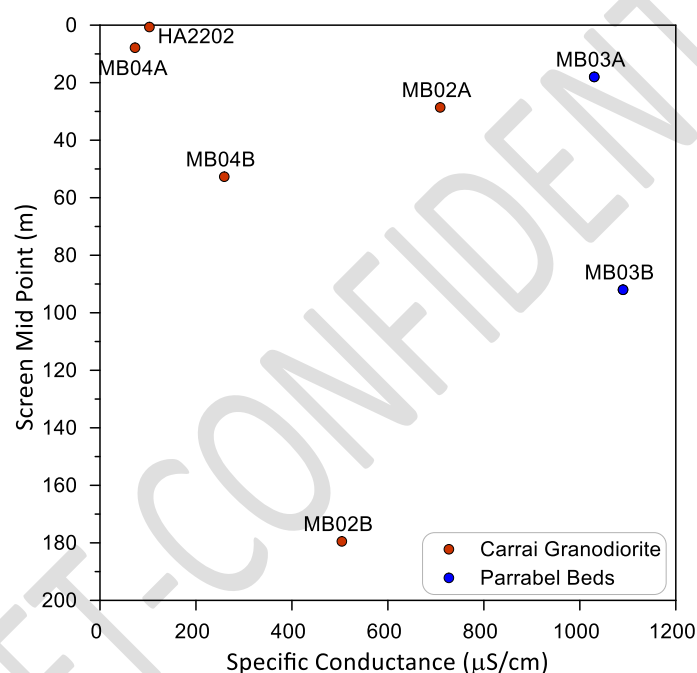


Figure 1 Relationship between depth to mid-screen point and observed specific conductance.

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
			$\mu\text{S}/\text{cm}$	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

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).

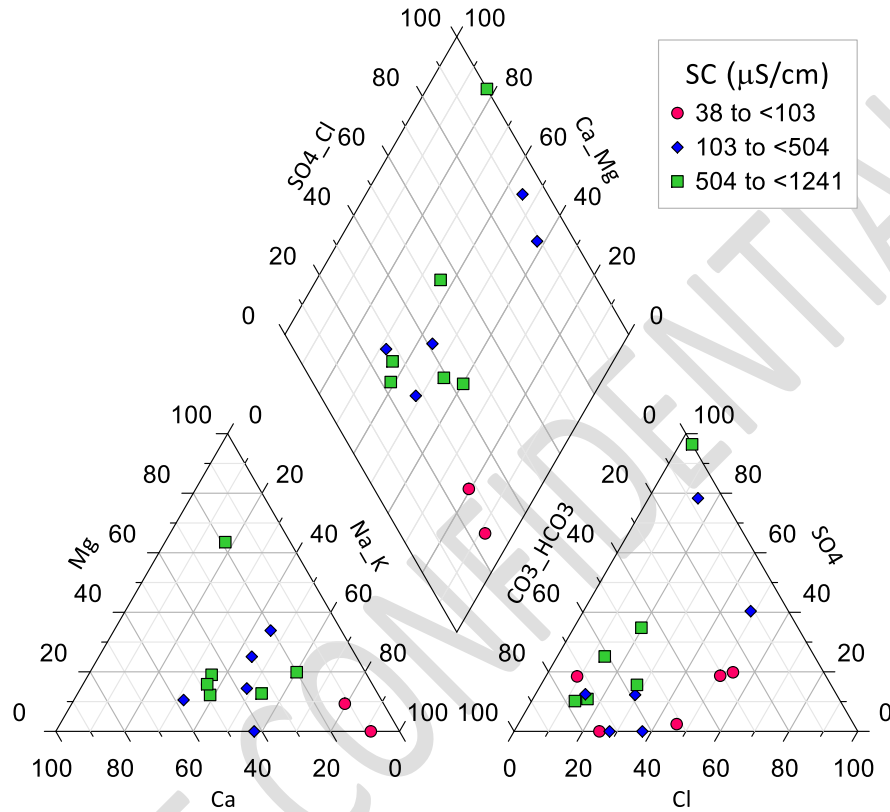


Figure 2 Piper plot for available groundwater major ion samples (meq/L). Colours and shapes represent samples containing low (red circle), medium (blue diamond) and high (green square) specific conductance (SC) values.

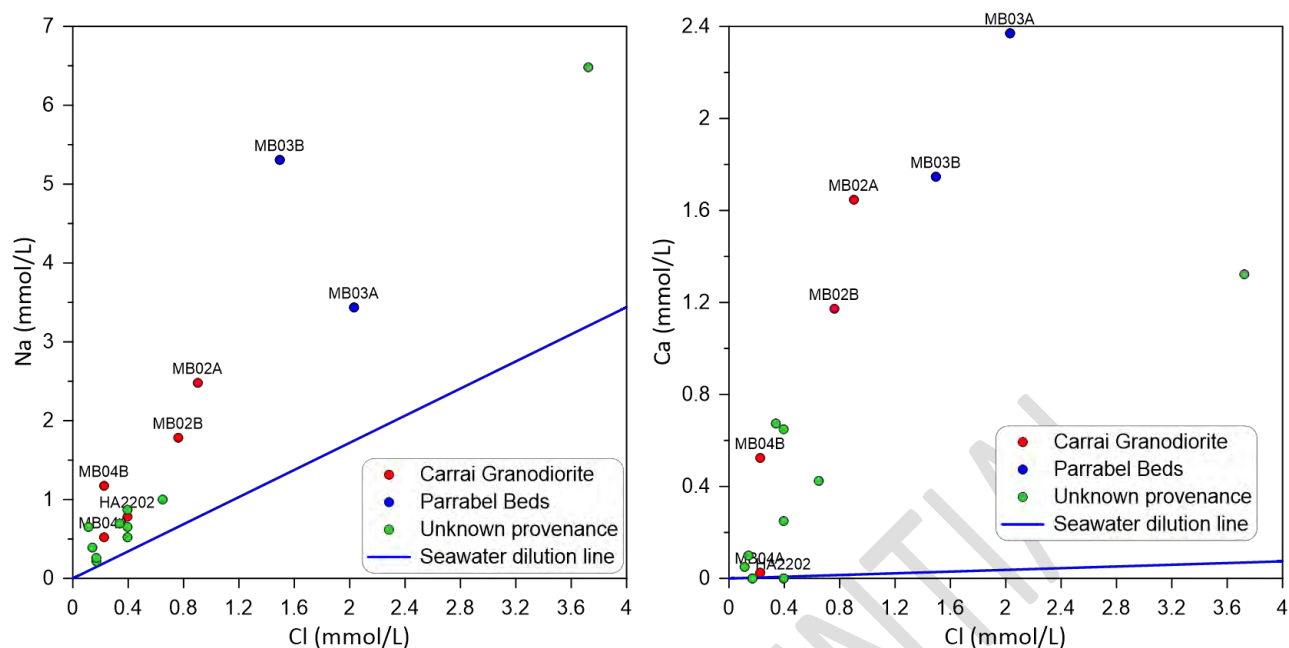


Figure 3 Na and Ca versus chloride plots. The seawater dilution line is depicted in blue for reference. Samples labelled as “unknown provenance” correspond to major ion results from other regional samples provided by EMM Consulting.

Radioactive tracers

Isotopic results for ^3H and $^{14}\text{C}_{\text{DIC}}$ are presented in Table 4 with interpretative plots in Figure 4. A strong trend with depth can be observed for ^3H in Figure 4(A). The very young nature of all groundwaters analysed inhibits an observable depth-decay relationship in the case of $^{14}\text{C}_{\text{DIC}}$. 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.

Table 4 Results and uncertainties associated for ^3H , $^{14}\text{C}_{\text{DIC}}$ and $\delta^{13}\text{C}$ in graphite-AMS

Bore ID	Sample Date	Aquifer/Lithology/Age	^3H (Tritium)	uncertainty	$\delta^{13}\text{C}$ graphite (AMS)	uncertainty	$^{14}\text{C}_{\text{DIC}}$	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

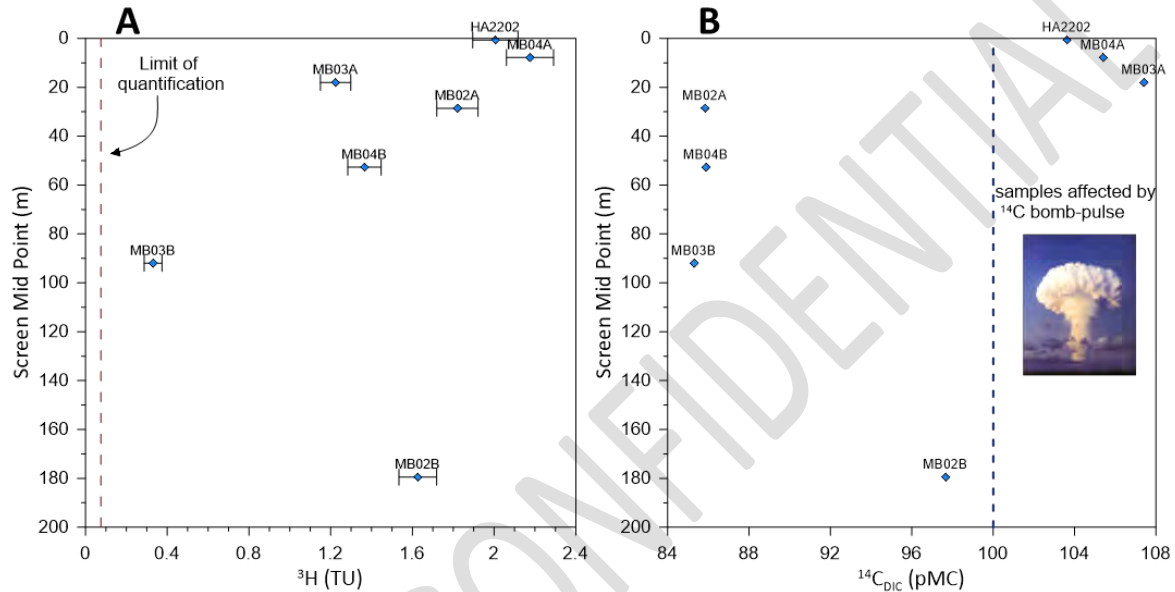


Figure 4 (A) ^3H as TU; (B) $^{14}\text{C}_{\text{DIC}}$ as pMC; for Carrai Granodiorite and Parrabel Beds. All isotopic results are plotted against depth expressed as screen mid-point. Samples affected by ^{14}C released into the atmosphere in the 1940's-1960's through nuclear bomb testing (^{14}C bomb-pulse) 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 $^{14}\text{C}_{\text{DIC}}$ 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 ^3H 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, $\delta^{13}\text{C}_{\text{DIC}}$, regional carbonates $\delta^{13}\text{C}$, etc.) are used to refine the ^{14}C interpretations. Additional approaches could be considered for this study area in the future to further refine ^3H 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.

Charge balances, saturation indices, the partial pressure of CO₂ (pCO₂), HCO₃⁻ and CO₃²⁻ 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 ¹⁴C in the aquifer matrix. The code NETPATH-XL (Plummer et al., 1994; Parkhurst and Charlton, 2008) has been used to apply specific ¹⁴C 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 ¹⁴C 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 ¹⁴C dilution factor.

Individual modelling assumptions varied according to calculations. In general, soil CO₂ (g) were assigned a value of δ¹³C = -25‰ (Cendón et al. 2014), and a ¹⁴C activity of 100 pMC. The δ¹³C 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 ¹⁴C 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 ¹⁴C corrected values yielded a modern age. Generally, we would not be able to refine that result further, however, the bomb-pulse contents in ¹⁴C combined with ³H results can help to provide residence-time assessment for all samples.

Table 5 Summary of ¹⁴C correction and ³H calculations. The green column “proposed approximate ages” shows the best groundwater residence time based on ¹⁴C and ¹⁴C bomb pulse. The blue shaded column shows groundwater ages based on ³H decay.

Bore ID	Sample Date	Aquifer	¹⁴ C					¹⁴ C bomb pulse	³ H
			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
δ ¹³ C _{carb} = 0‰, A=0 pMC									
A ₀ =100 pMC									
open system									
δ ¹³ C _{soilCO₂} = -25‰									

Radiocarbon results in the groundwater were compared to atmospheric ¹⁴C 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 ¹⁴C bomb-pulse (samples with ¹⁴C pMC values >100), and assuming no further sinks or sources of carbon, a direct comparison with atmospheric ¹⁴C can be

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).

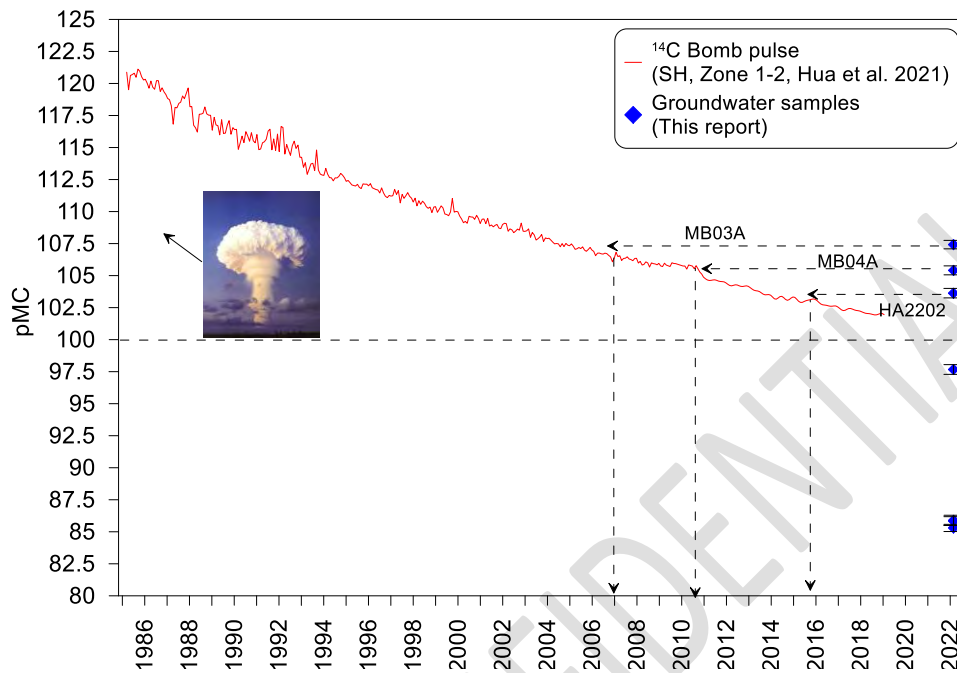


Figure 5. Evolution of ^{14}C in the atmosphere since 1986 following progressive decline of bomb-pulse derived ^{14}C since cessation of major above ground nuclear testing.

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 ^3H 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:

$$t = -17.93 \ln \frac{a_t \text{ } ^3\text{H}}{a_o \text{ } ^3\text{H}}$$

where t is the groundwater age or time since recharge (in years), a_t is the measured ^3H activity in the groundwater sample and a_o 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 ^3H 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 ^3H -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.

Conclusion of groundwater residence times

Based on the results in Table 5, Figure 5 and Figure 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).

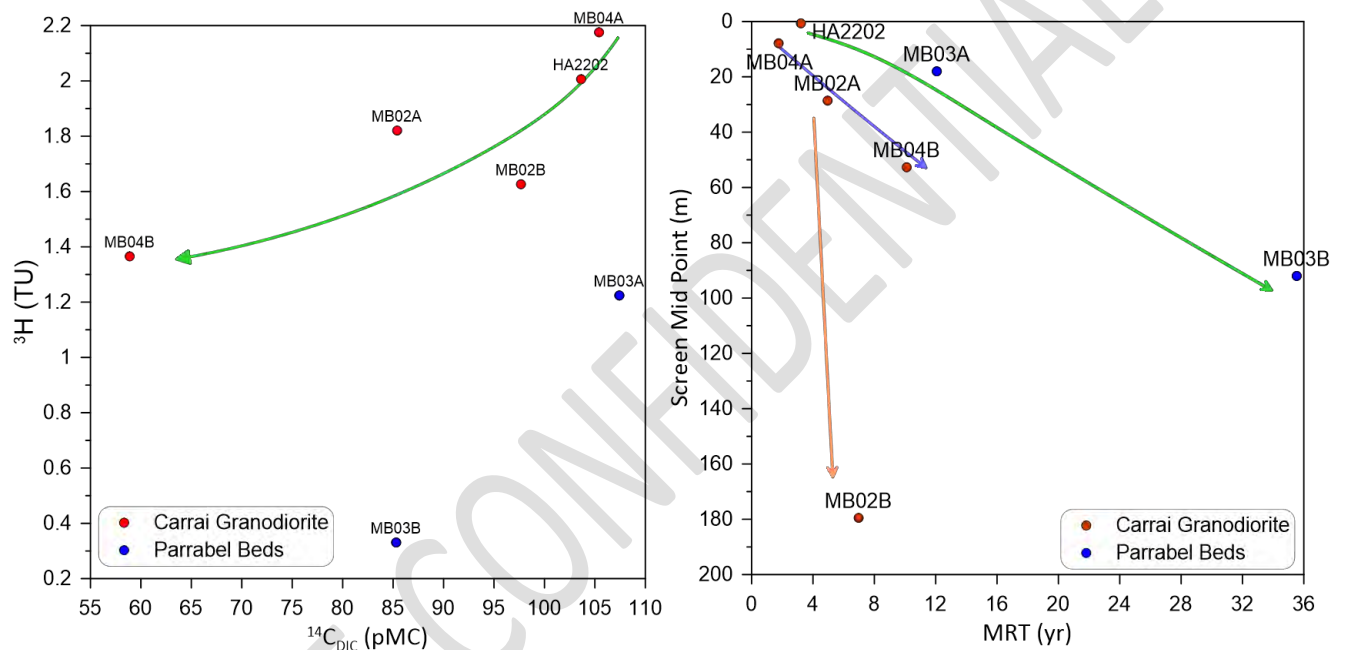


Figure 6 (A) ^{14}C groundwater (pMC) against ^3H (TU); (B) Screen mid-point (m) against mean residence time (MRT).

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DRAFT-CONFIDENTIAL

Appendix 1 – Analytical Data

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 Bq/kg	Uncertainty ¹ Bq/kg	LLOQ ² Bq/kg	Tritium Ratio TU	Uncertainty ¹ TU	LLOQ ² 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
2022/0147T-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 ($\sigma(C)/C$) 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

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Portal 14826 - EMM consulting Henry Noakes

RADIOCARBON RESULTS

ANSTO code	Sample Type	Submitter ID	$\delta(^{13}\text{C})$	percent Modern Carbon		Conventional Radiocarbon age	
			per mil	pMC	1 σ error	yrs BP	1 σ 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. $\delta(^{13}\text{C})$ values relate solely to the graphite derived from the fraction that was used for the radiocarbon measurement. It is sometimes the case that the $\delta(^{13}\text{C})$ 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 'S' which are accelerator based). Some $\delta(^{13}\text{C})$ 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).

Annexure C

Numerical groundwater modelling report

Oven Mountain Pumped Storage Groundwater Modelling

Prepared for OMPS Pty Limited

July 2024

Oven Mountain Pumped Storage

Groundwater Modelling

OMPS Pty Limited

E231319 RP2

July 2024

Version	Date	Prepared by	Reviewed by	Comments
1	24 May 2024	Tom Neill and Itsuo Camargo	Dr Doug Weatherill	Draft
2	18 July 2024	Tom Neill and Itsuo Camargo	Dr Doug Weatherill	Final

Approved by



Dr Doug Weatherill

Associate Groundwater Modeller

18 July 2024

Level 4 74 Pirie Street

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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
- 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)
- 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 following:

- 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 realisation 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 is 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 Limited (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).

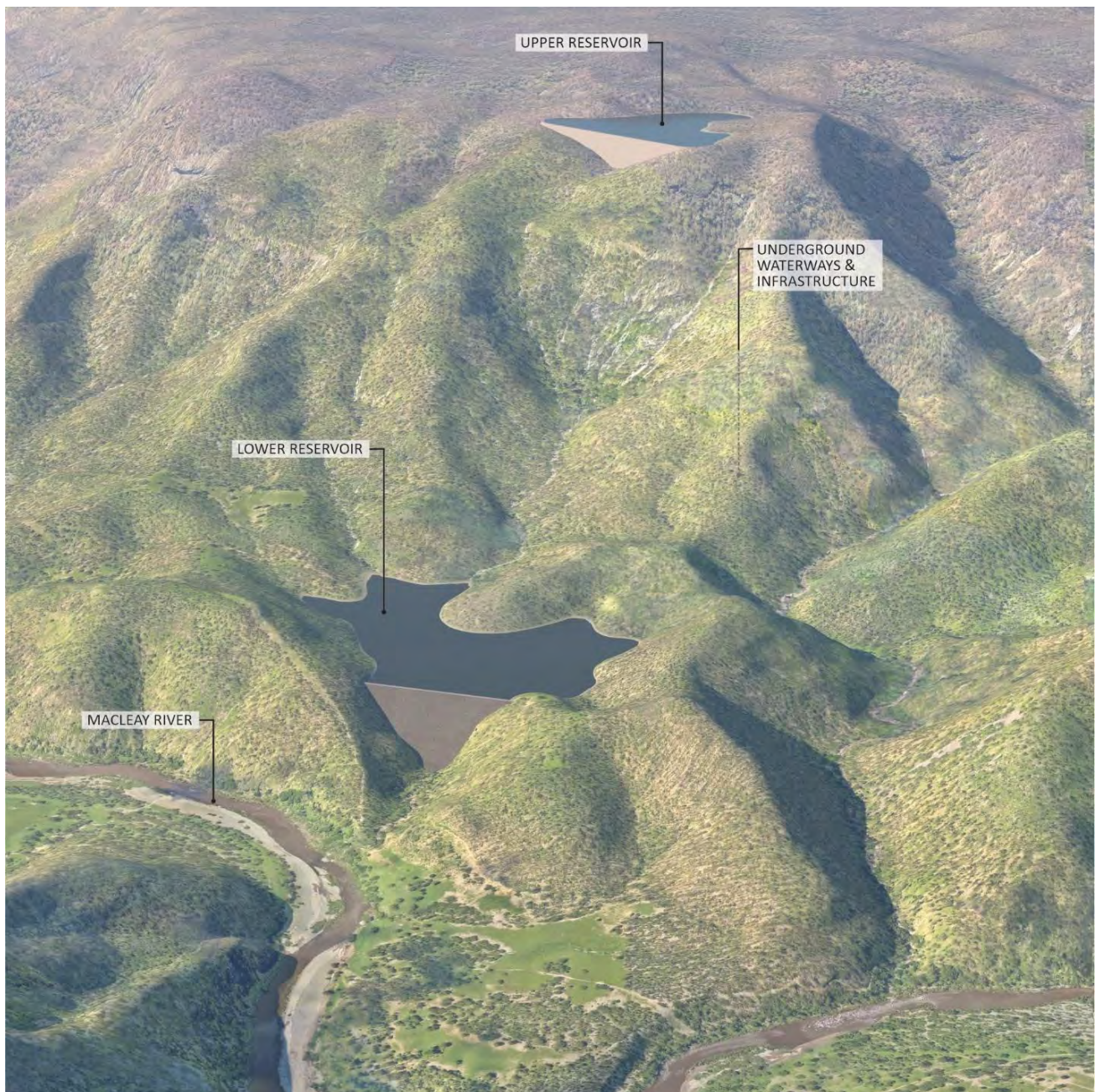


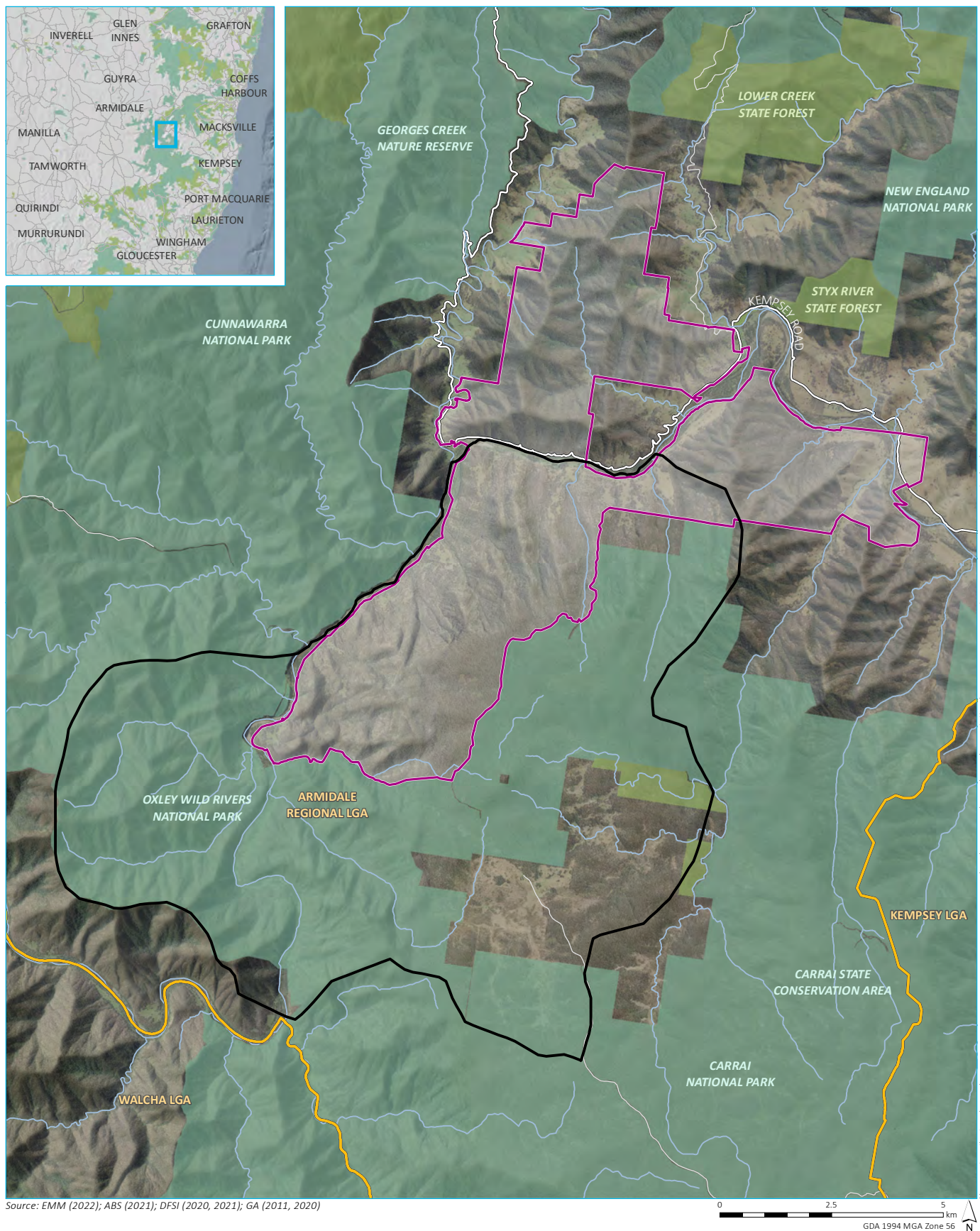
Figure 1.1 Concept visualisation of the upper and lower reservoirs at the Project site

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)
- 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.



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
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Figure 1.2

1.3 Groundwater-affecting activities

The Project involves groundwater-affecting activities which are described in detail in Section 2.1. 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 was 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 was 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 Project. 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 at key locations, with minimal influence resulting from boundary conditions.
- Simpler model layering in areas distant from the project infrastructure 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 was 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.
- 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					All model parameter values consistent with conceptual model.	3
						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 Groundwater Impact Assessment (EMM, 2024).

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.

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.

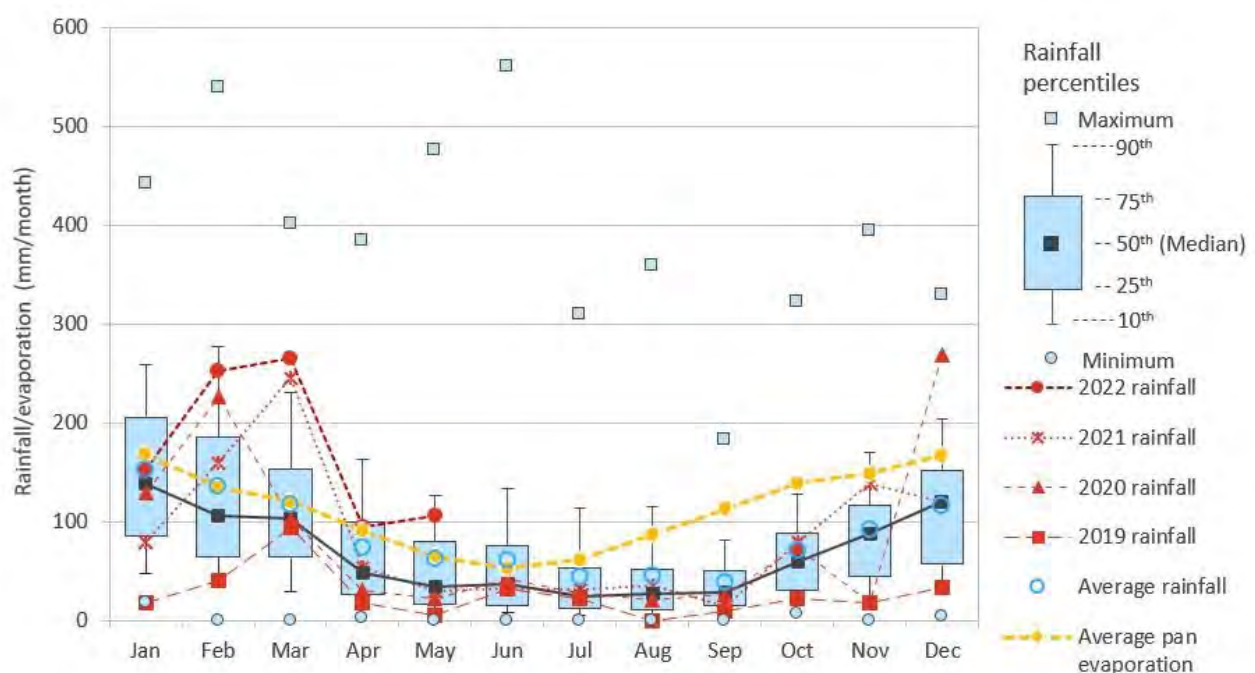


Figure 2.1 Historical rainfall trend across study area (coordinates 30.80; 152.15)

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.

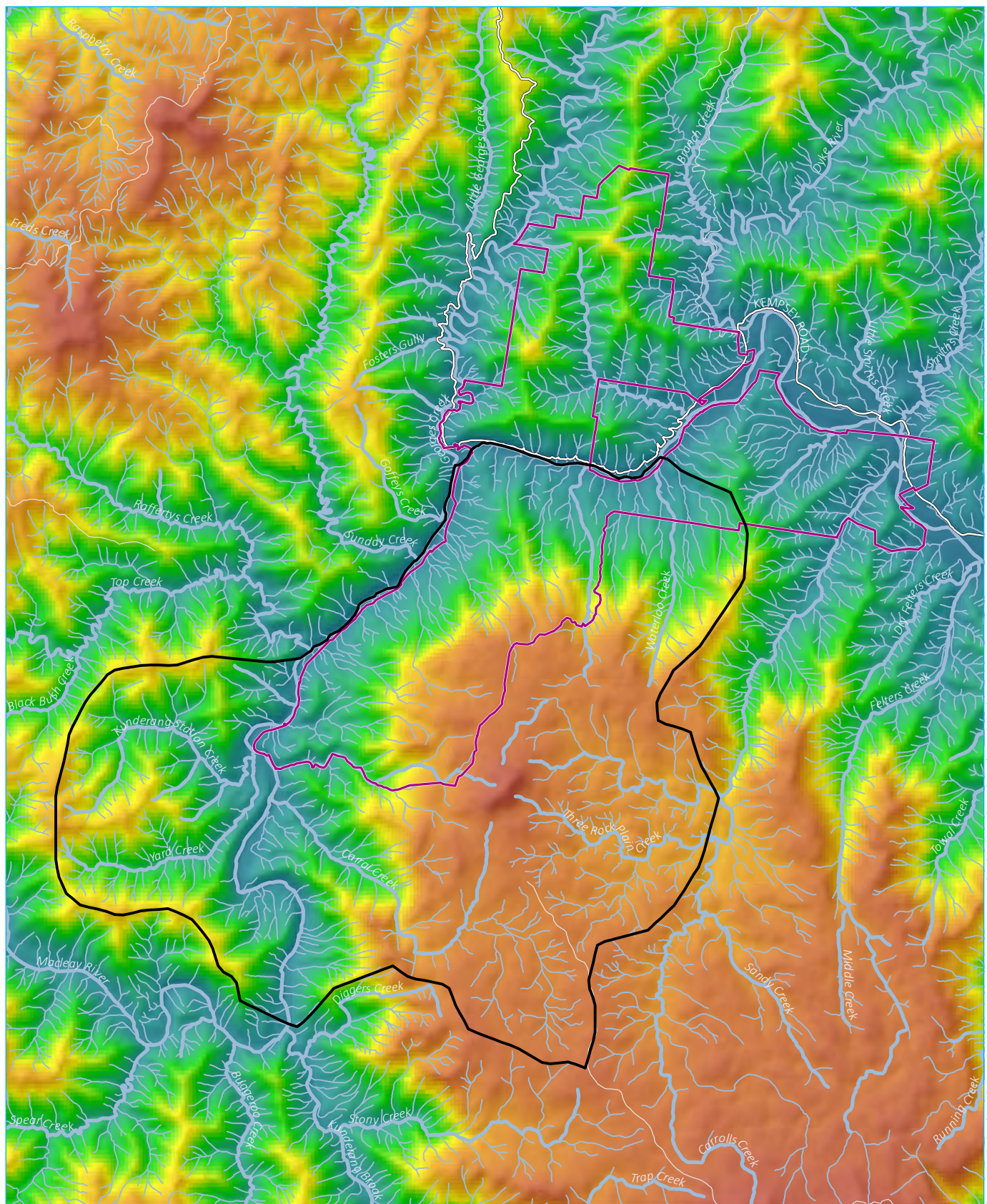
2.2.2 Topography

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:

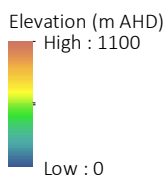
- the Carrai Plateau (the plateau), in the eastern portion of the study area
- the escarpment, extending west of the plateau
- the Macleay River floodplain, a relatively narrow area bordering the Macleay River
- the western catchment, on the western side of the Macleay River.



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

KEY

- Project area
- Model domain
- Existing environment
- Major road
- Minor road
- Named watercourse
- Watercourse/drainage line



0 2.5 5 km

GDA 1994 MGA Zone 56



Topographic and drainage map of the study area

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd
Figure 2.2

2.2.3 Hydrological setting

The study area is located within the Macleay River catchment, covering approximately 11,400 square kilometres (km²) 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.
- 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 (i.e. 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.

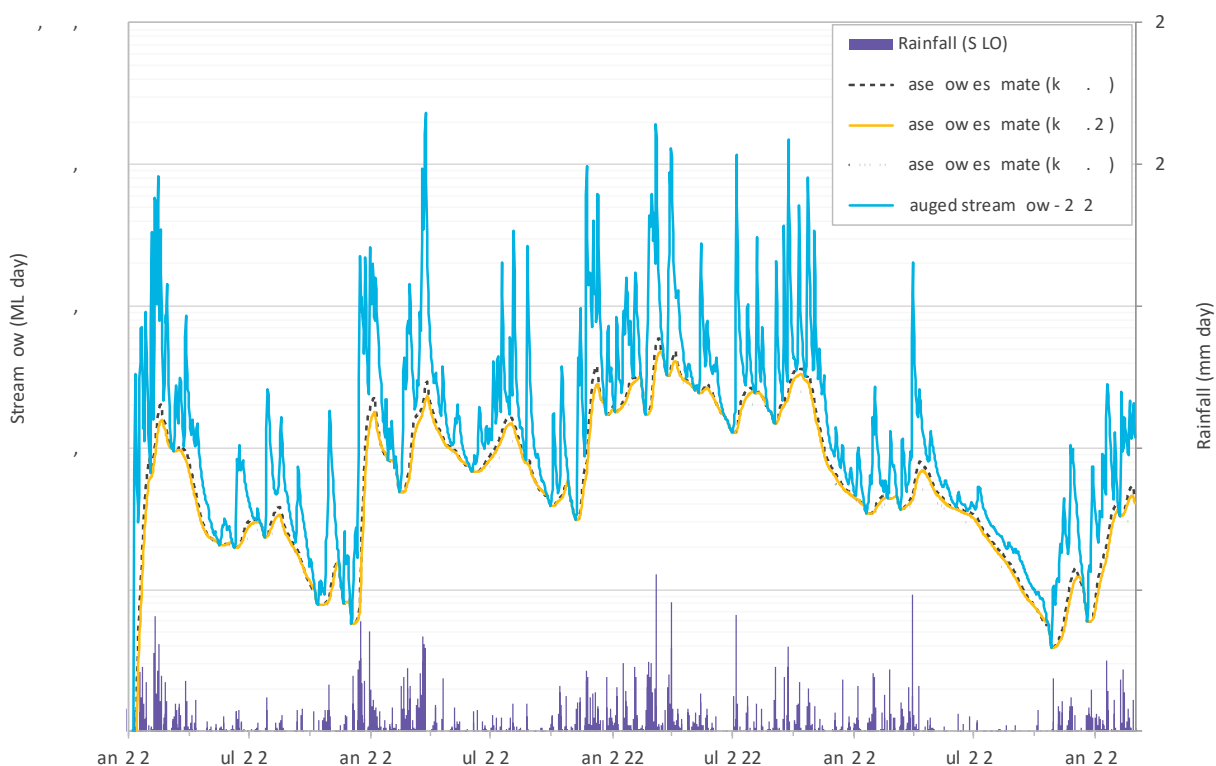


Figure 2.3 Streamflow, rainfall and calculated baseflow at gauge station 206024

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
- metamorphic rock (hornfels and metasediments) typically comprising of dark grey, medium–high plasticity clay.

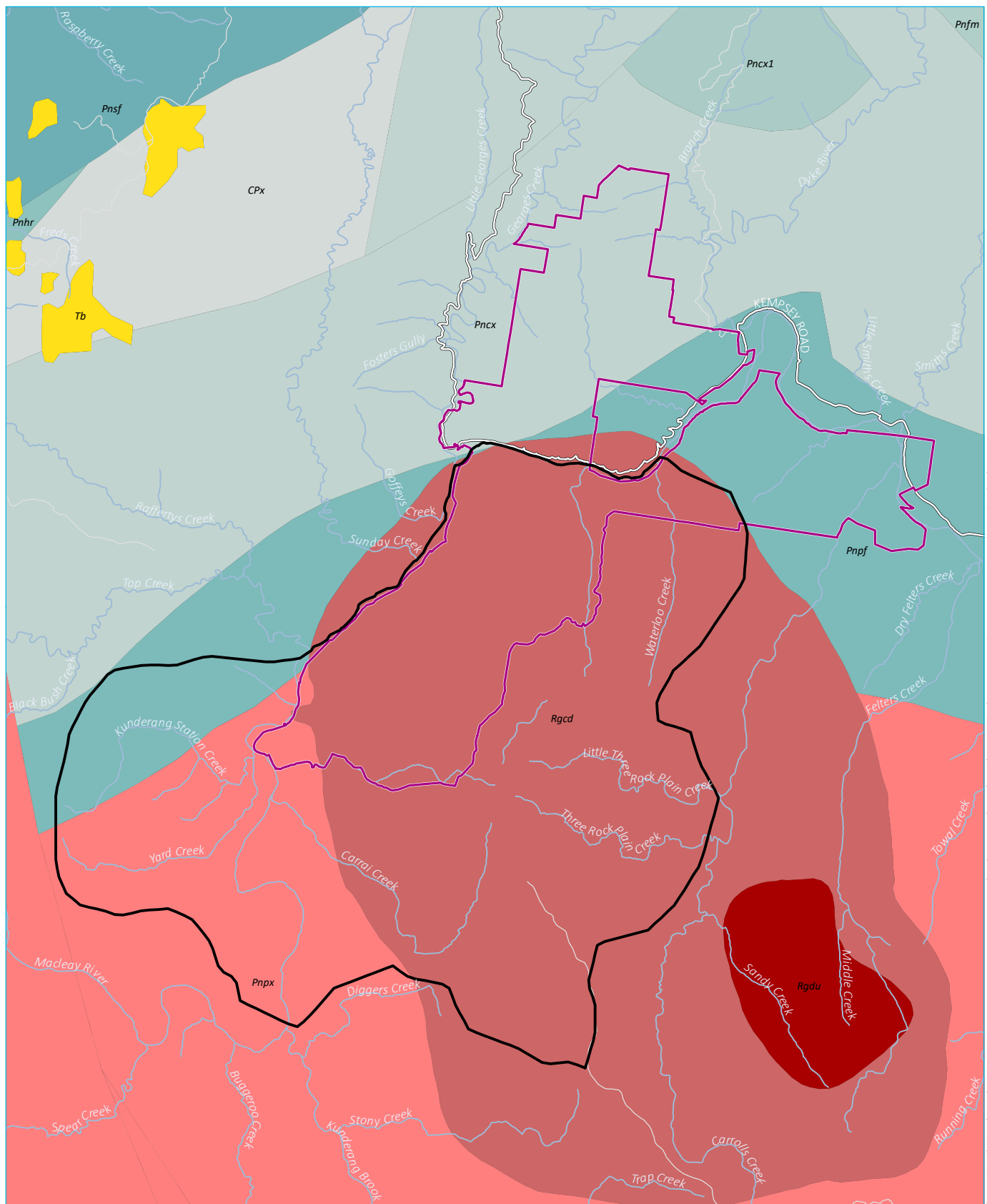
The study area lies within the New England Orogen. Differing geodynamics in the early Permian to Triassic led to a series of linked pluton structures (known collectively as the New England Batholith) which intruded the sedimentary units of the Permian-aged Parrabel Beds and Carboniferous-aged Pee Dee Beds. The Triassic-aged Carrai Granodiorite; a plutonic structure outcropping over approximately 168 km², 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 in 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 (≤ 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)



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

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
- 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 5–50 m depth. Eleven 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 to 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 $<1 \times 10^{-3}$ m/d, and where localised fractures are encountered the K can vary from 0.1 to 1×10^{-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 $<1 \times 10^{-3}$ m/d
- the difference in K observed by 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	4.32×10^{-2}	3.72×10^{-1}	1.64×10^{-1}
Parrabel Beds	1.30×10^{-2}	1.73	3.20×10^{-1}

Table 2.4 **Hydraulic properties**

Bore	Depth from (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
OM7	45.13	50.1	0.02	Packer	Parrabel Beds	Yes

Table 2.4 **Hydraulic properties**

Bore	Depth from (mbgl)	Depth to (mbgl)	K (m/d)	Test type	Geology	Saturated interval
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

Note: mbgl = metres below ground level

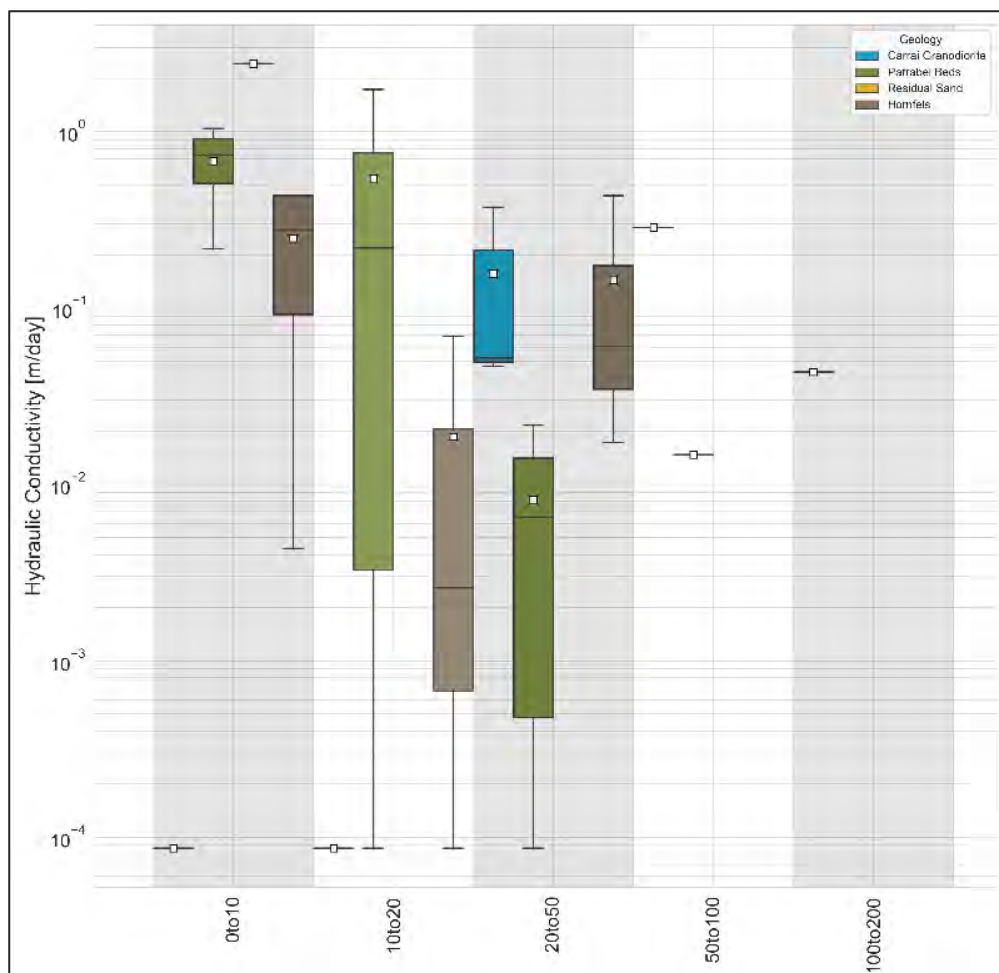


Figure 2.5 Hydraulic conductivity versus depth grouped by geological formation

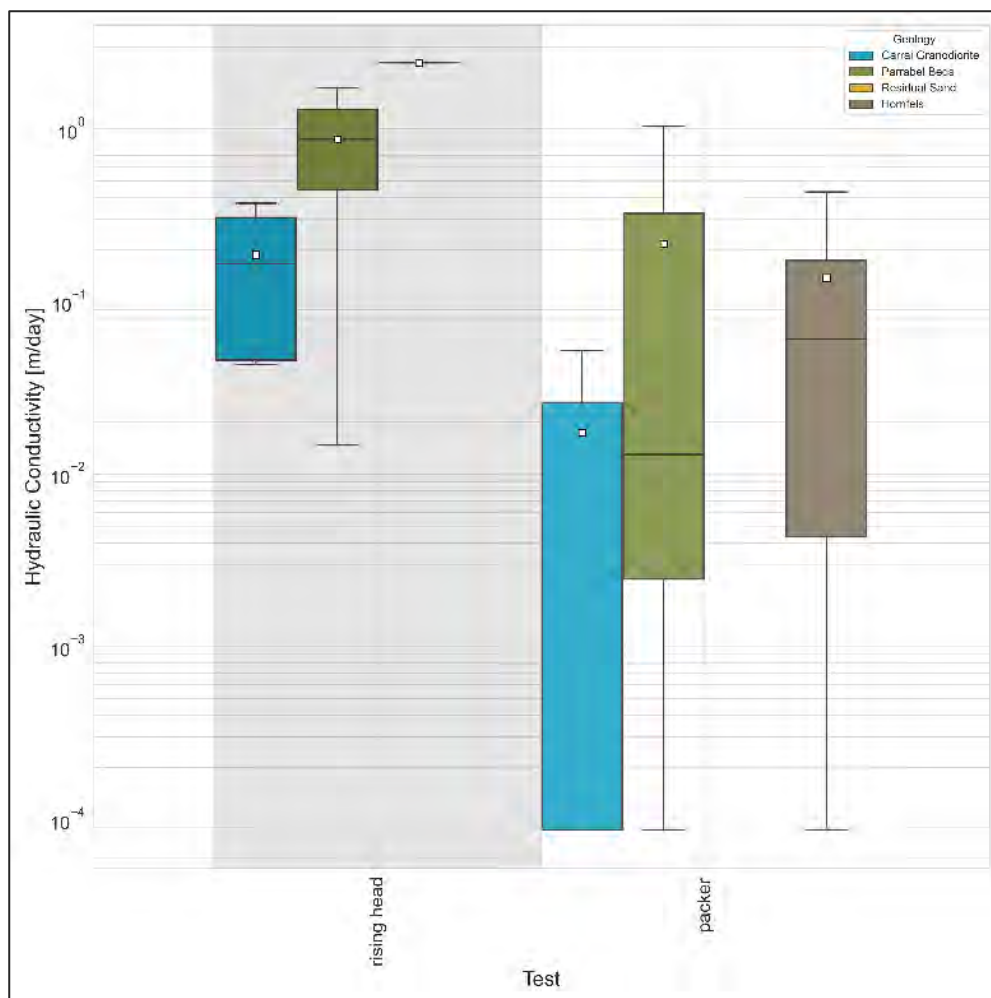


Figure 2.6 Hydraulic conductivity versus test type, grouped by geological formation

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 the following:

- 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 and metamorphic 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
- 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 the following (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
 - flow to the ephemeral streams following rainfall, with attenuated flow proportionate to rainfall magnitude and duration.

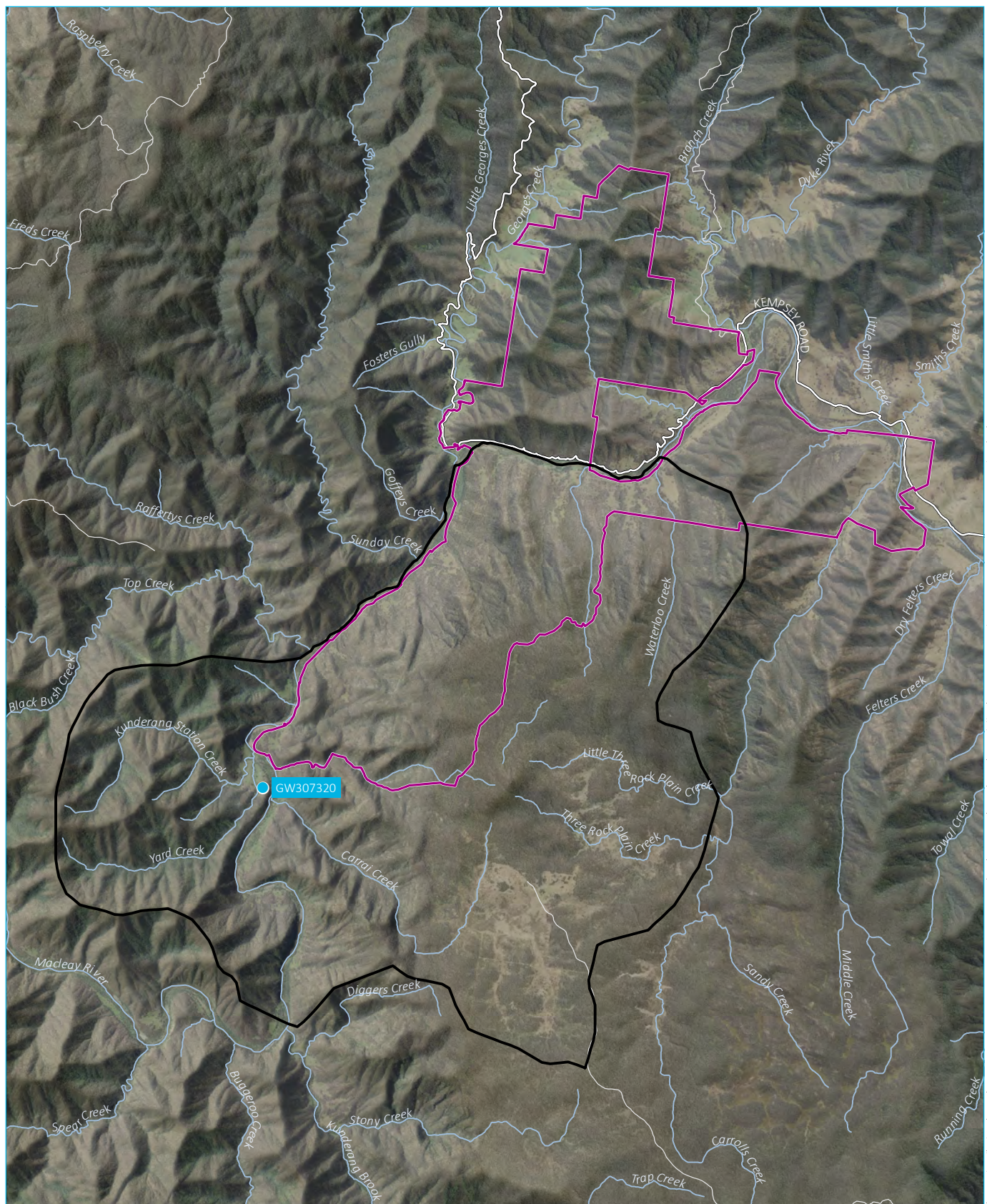
There is local variability and uncertainty regarding groundwater flow, vertical connectivity and baseflow contribution to bogs, fens and watercourses.

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 Parrabel 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 (e.g. 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



KEY

- | | |
|--|---|
| Project area | Existing environment |
| ● Groundwater extraction | Major road |
| Model domain | Minor road |
| | — Named watercourse |

Existing groundwater extraction location

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Groundwater modelling report
OMPS Pty Ltd
Figure 2.7

2.8 Groundwater levels and flow

2.8.1 Monitoring network

The groundwater level monitoring network used for model calibration 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 geotechnical boreholes drilled in 1996 (SMEC, 1997). The groundwater level monitoring network has been progressively expanded as new monitoring bores have been installed. The Project groundwater level monitoring network (as presented in Section 5 of the GIA) includes four additional bores (BH1001–BH1003 and BH3001) not listed in Table 2.6 however, reliable data was not available at the time of model history-matching. Groundwater level data from the additional bores will be included in subsequent validations of the numerical model (refer Section 11.4.3 of the GIA).

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

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	
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.

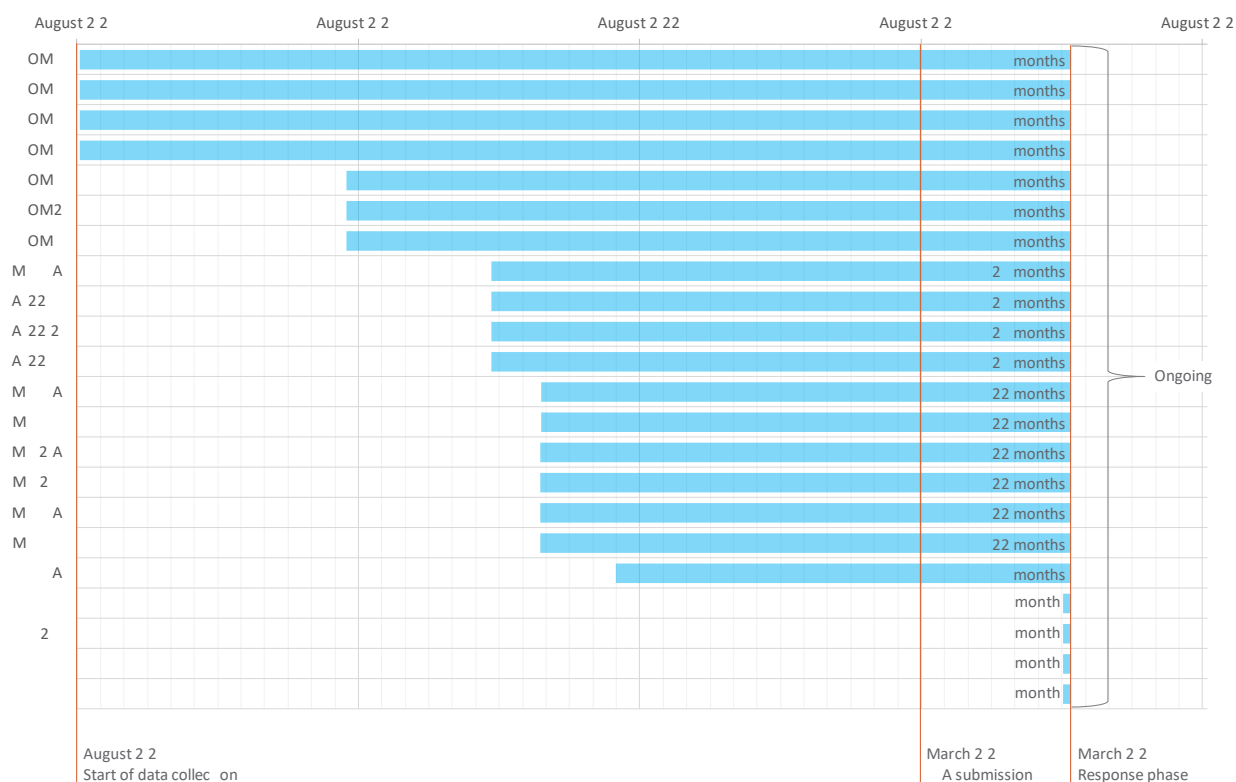
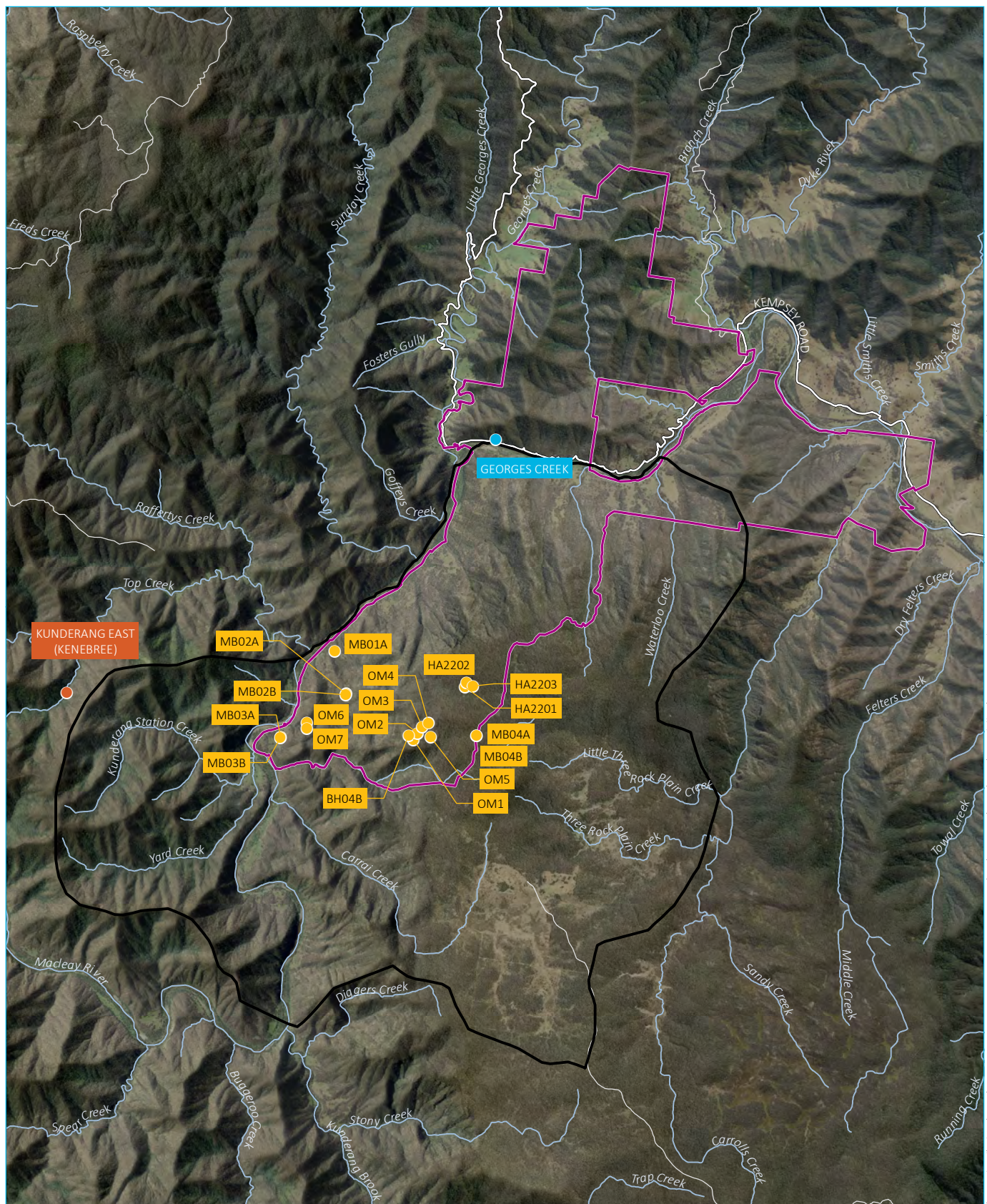


Figure 2.8 Groundwater level monitoring duration



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

KEY

- | | |
|--|--|
| Project area | Existing environment |
| Model domain | Major road |
| ● Monitoring location | Minor road |
| ● Climate station | Named watercourse |
| ● Stream gauge | |
| ● Groundwater | |

Groundwater, climate and surface water monitoring locations

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Figure 2.9

2.8.2 Groundwater flow processes and level trends

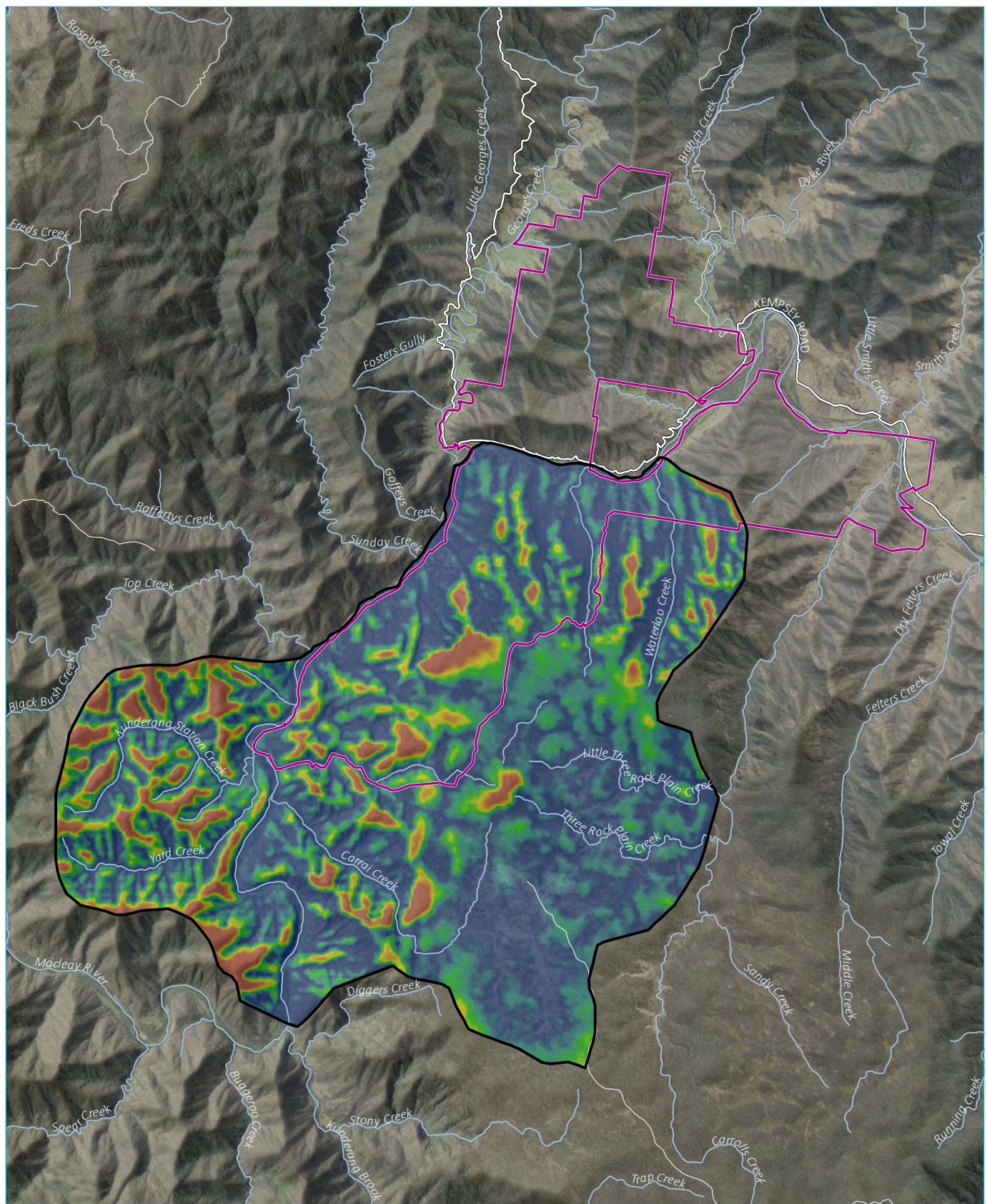
Watertable depth (below ground surface) and elevation maps are provided as Figure 2.10 and Figure 2.11. Selected groundwater level versus rainfall hydrographs are shown in Figure 2.12 to Figure 2.14.

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 to 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.

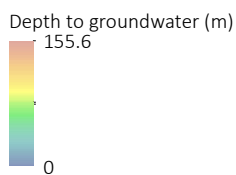
Groundwater levels in the localised pockets of weathered rock are above the base of the ephemeral watercourses following rainfall, providing interflow to the ephemeral streams during a period proportional to the magnitude and duration of the rainfall.



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020); DPI (2003)

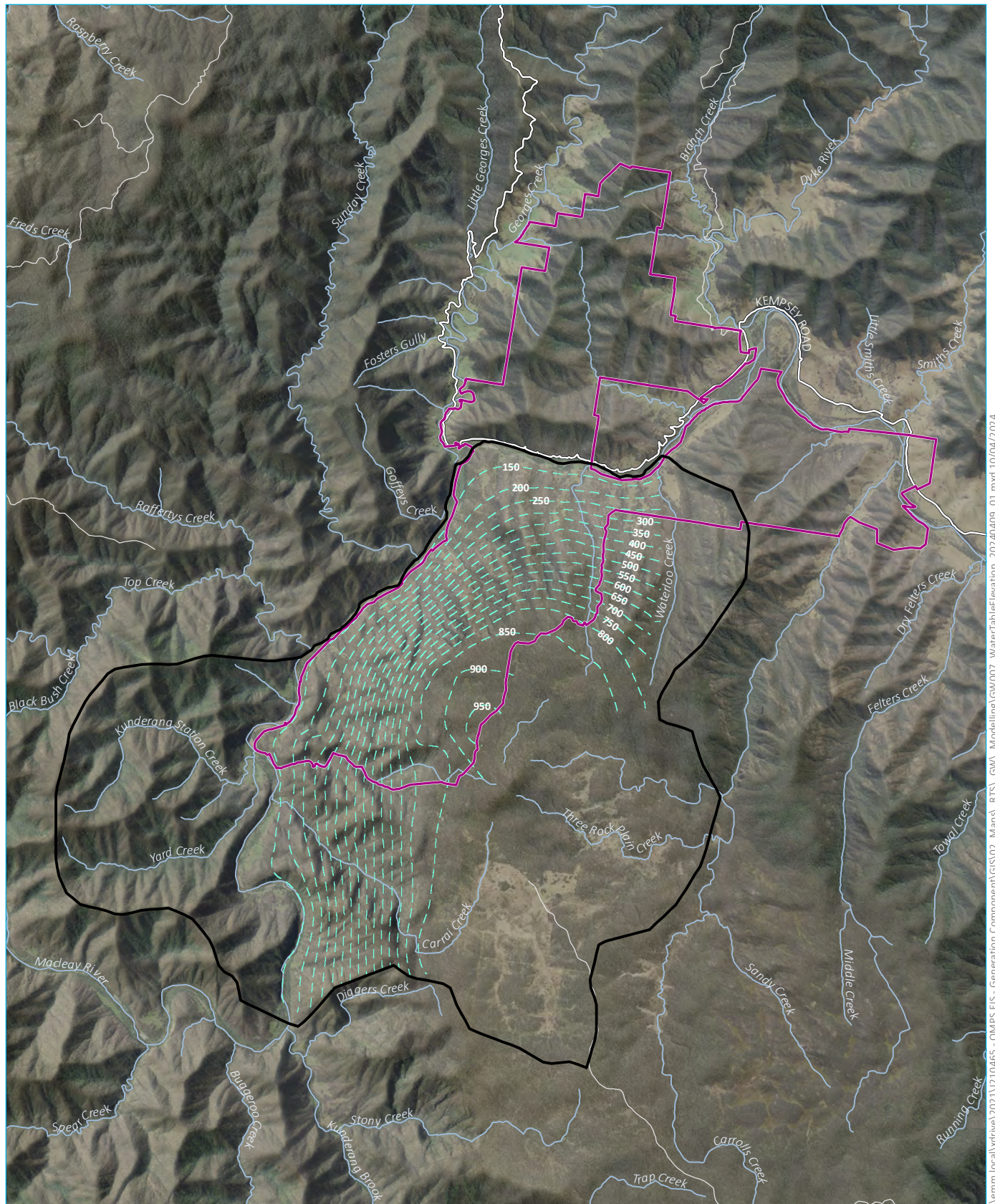
KEY

- Project area
- Model domain
- Existing environment
- Major road
- Minor road
- Named watercourse



Depth to water table

Oven Mountain Pumped Hydro Energy Storage Project
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Figure 2.10



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020); DPI (2003)

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

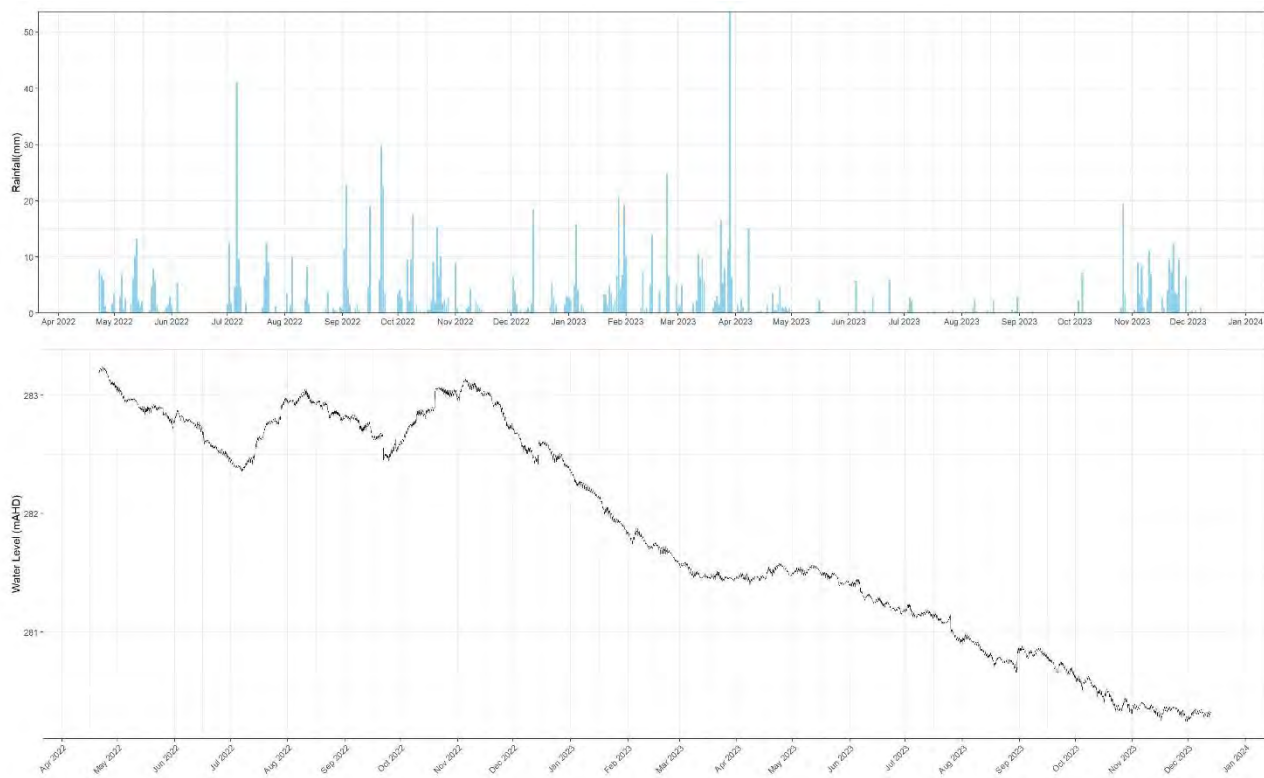


Figure 2.12 Hydrograph for bore MB02A and daily rainfall at East Kunderang, Kenebree (station 57013)

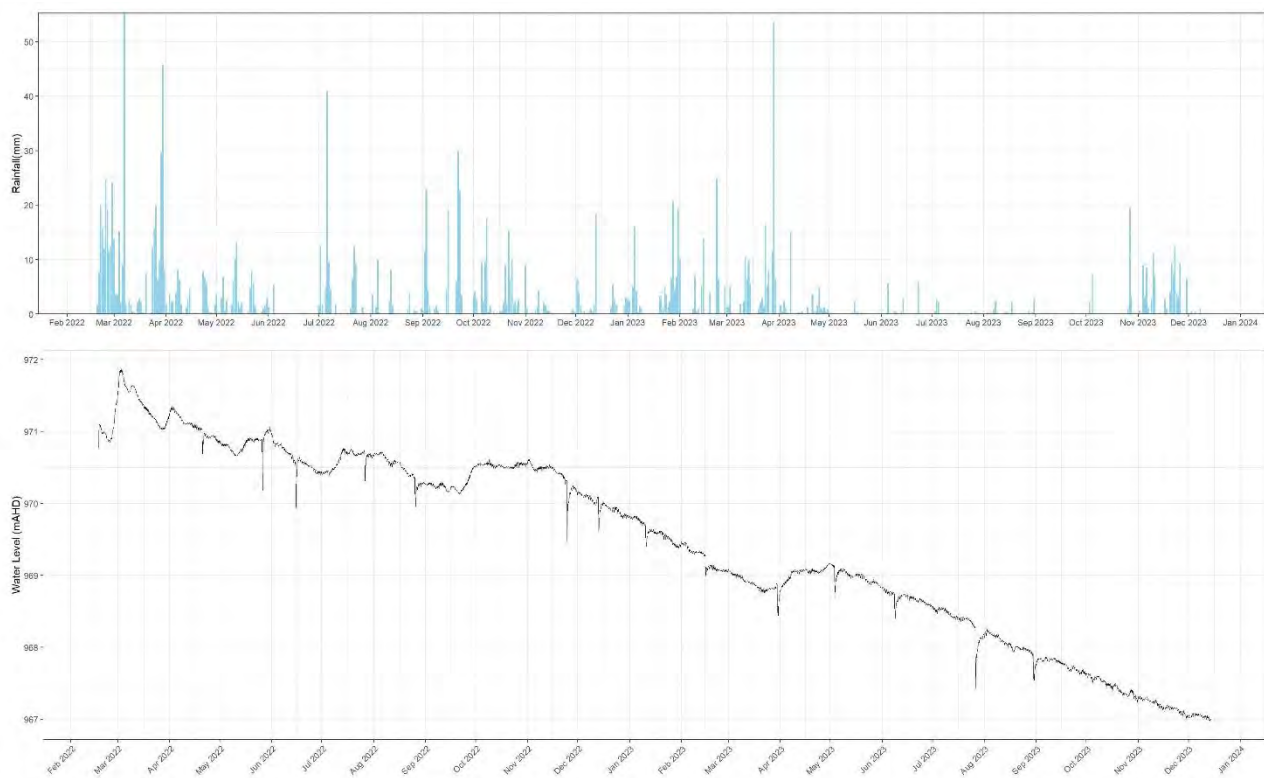


Figure 2.13 Hydrograph for bore MB04B and daily rainfall at East Kunderang, Kenebree (station 57013)

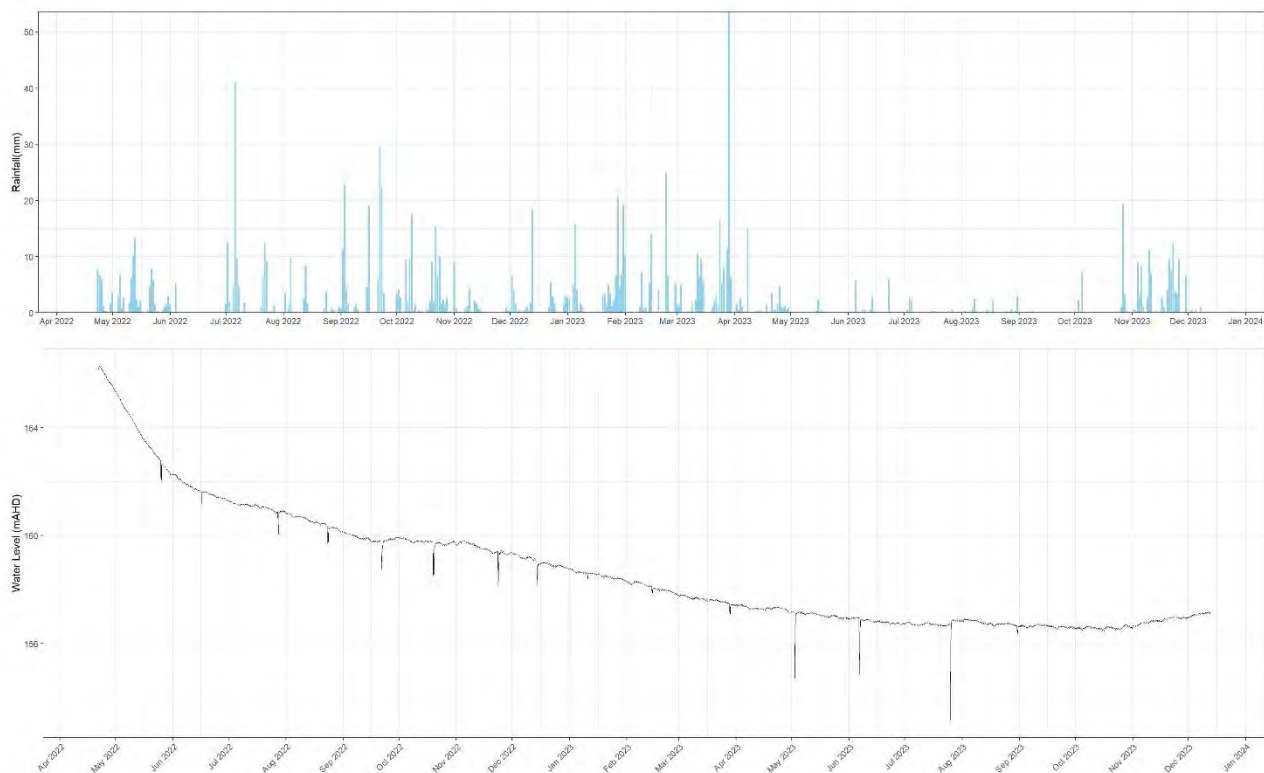


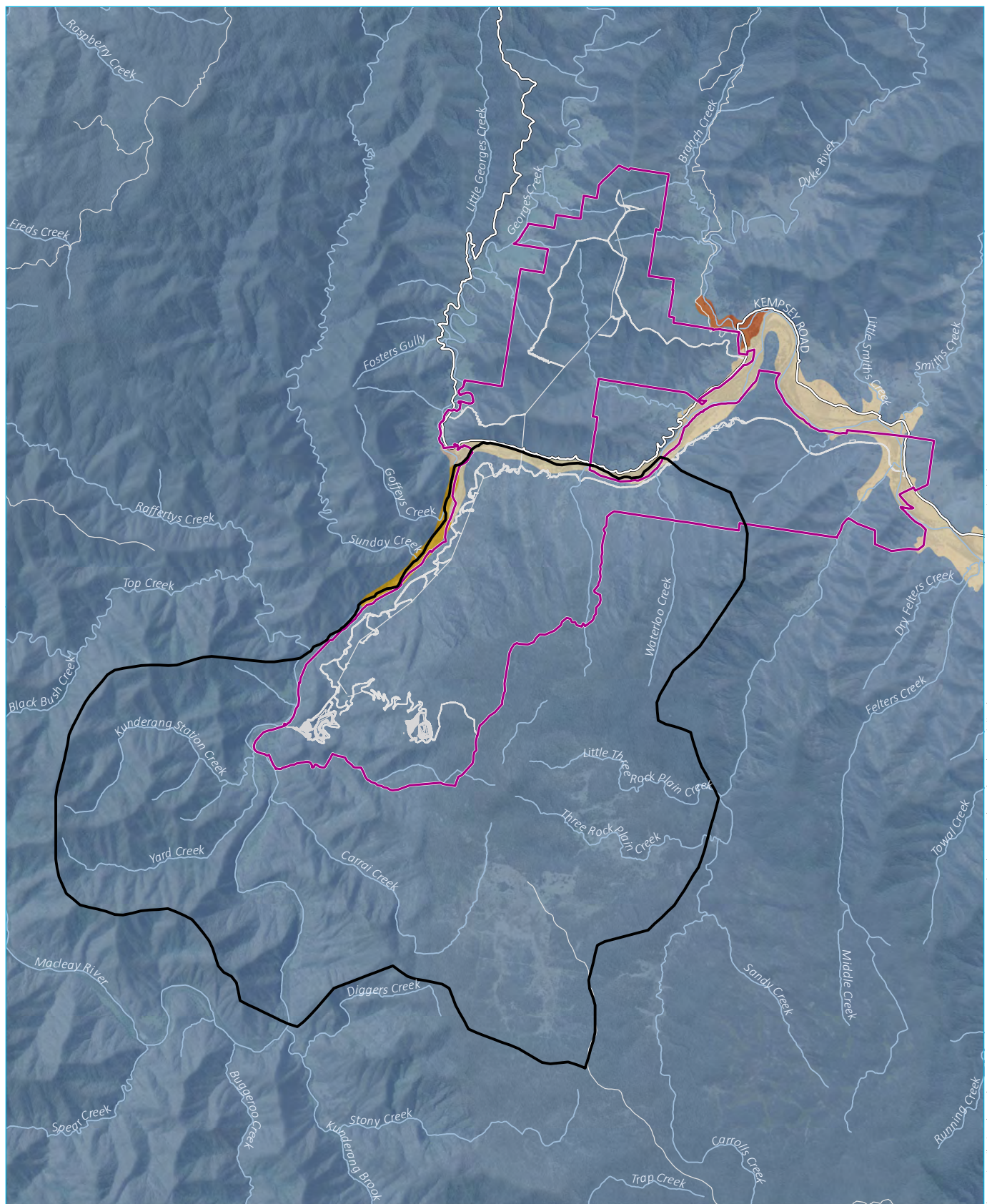
Figure 2.14 Hydrograph for bore MB03B and daily rainfall at East Kunderang, Kenebree (station 57013)

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
- 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 (2024); DFSI (2020, 2021); GA (2011, 2020); DPI (2003); DPIE (2021)

0 2.5 5 km
GDA 1994 MGA Zone 56

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

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 indirectly 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
- 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.

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**

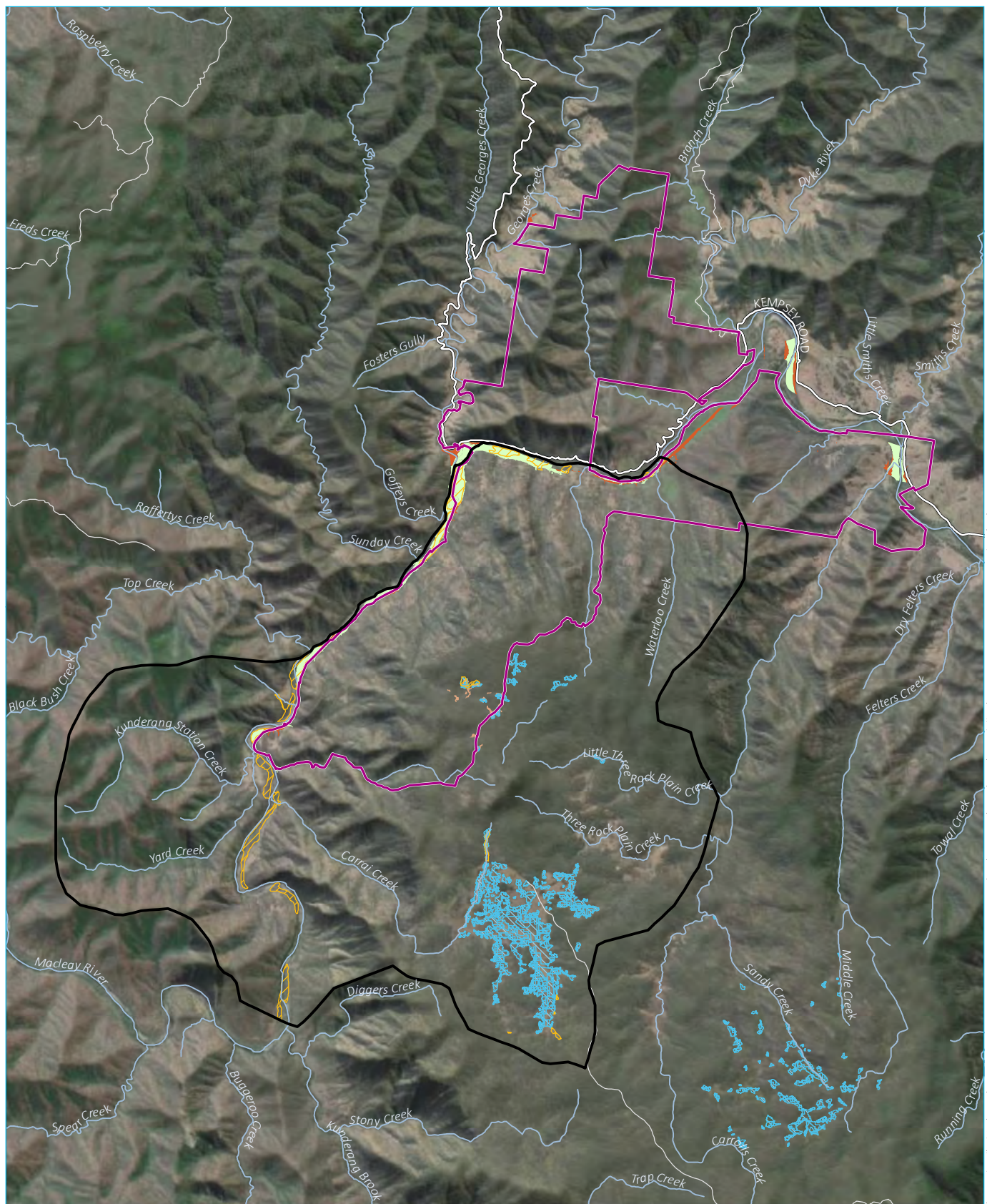
Category	Groundwater dependent ecosystem	Focus area	Source
Terrestrial	River Oak	Macleay River floodplain	¹ BoM GDE atlas
	Freshwater Wetland	Plateau	¹ BoM GDE atlas
	Sedgeland/rushland	Plateau	¹ BoM GDE atlas
	New England Tableland Carex Fens (PCT3944)	Plateau	² HEVAE database
	Eastern New England Granites 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 (2024); DFSI (2020, 2021); GA (2011, 2020); DPI (2003); DPIE (2021); BoM (2022)

KEY

- | | |
|---|--|
| Project area | Groundwater dependent ecosystems |
| Model domain | High potential GDE - from regional studies |
| Existing environment | High ecological value aquatic ecosystem - GDE |
| Major road | GDEs - PCT mapping |
| Minor road | 1106 |
| Named watercourse | 1287 |
| | 762 |

Mapped GDEs

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Figure 2.16

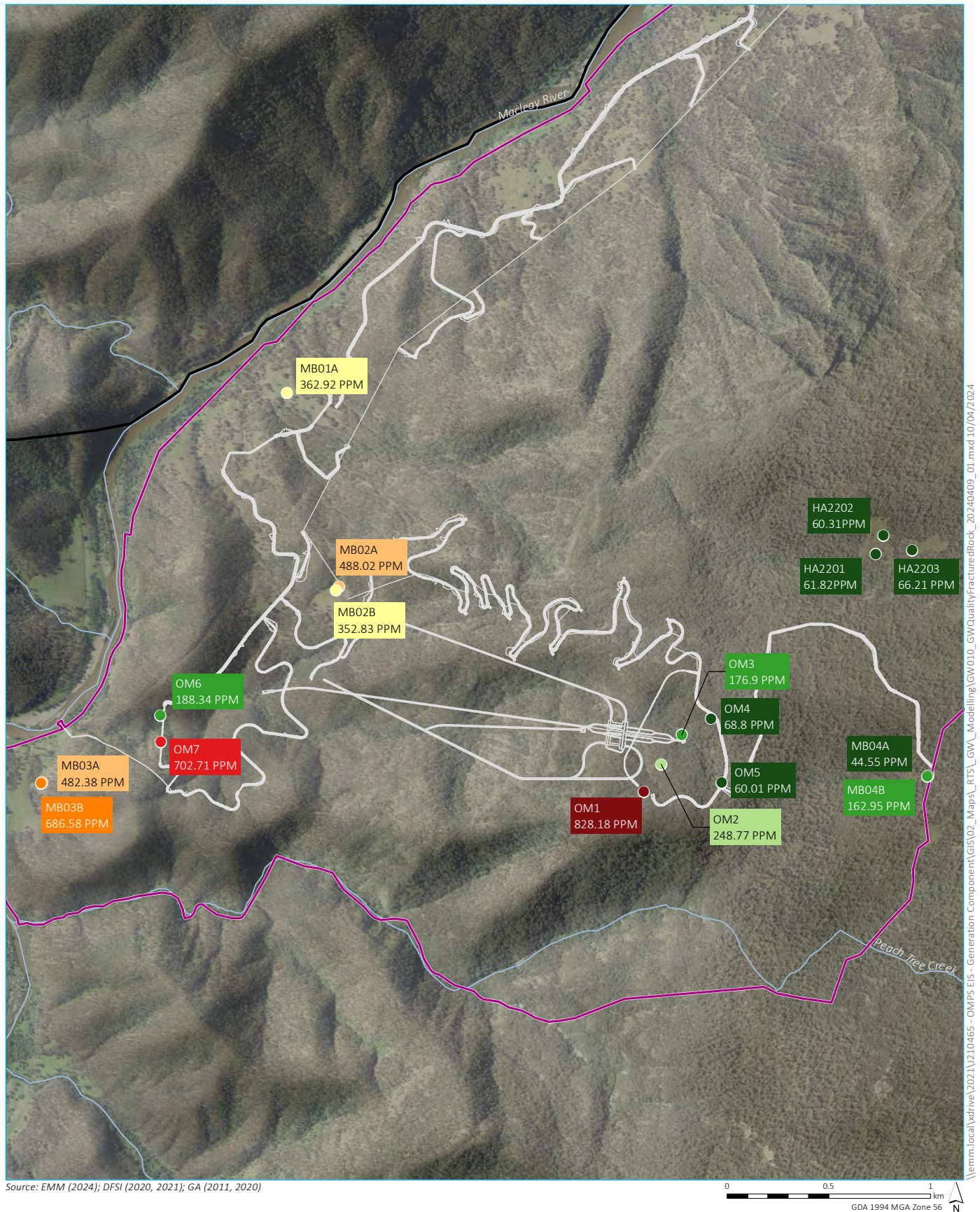
2.11.2 Groundwater relevant cultural areas

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 ($\mu\text{S}/\text{cm}$) (fresh) and 1,625 $\mu\text{S}/\text{cm}$ (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.



KEY

 Project area	Total dissolved solids (ppm)	 400 - 500
 Model domain	● < 100	 600 - 700
— Named watercourse	● 100 - 200	 700 - 800
— Site infrastructure	● 200 - 300	 > 800
	● 300 - 400	

Spatial variation of groundwater quality in fractured rock water source

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Figure 2.17

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.

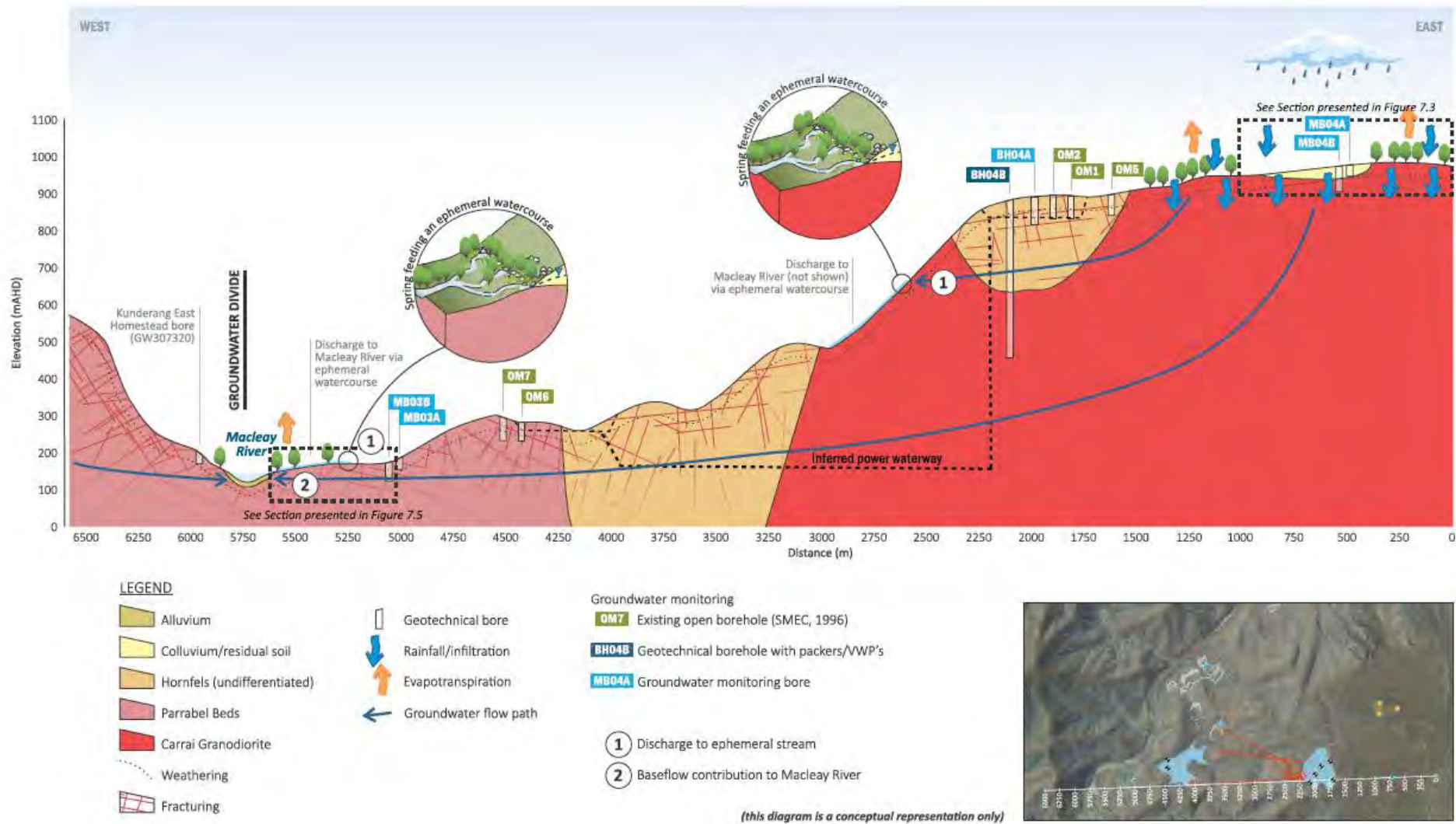


Figure 2.18 Conceptual model schematic

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 headrace, deep vertical pressure shaft, the power station, tailrace and ancillary tunnels 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 yield reduction 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 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 version 2.2.2 (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. 'US' is an initialism of 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 (e.g. 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 (i.e. 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.

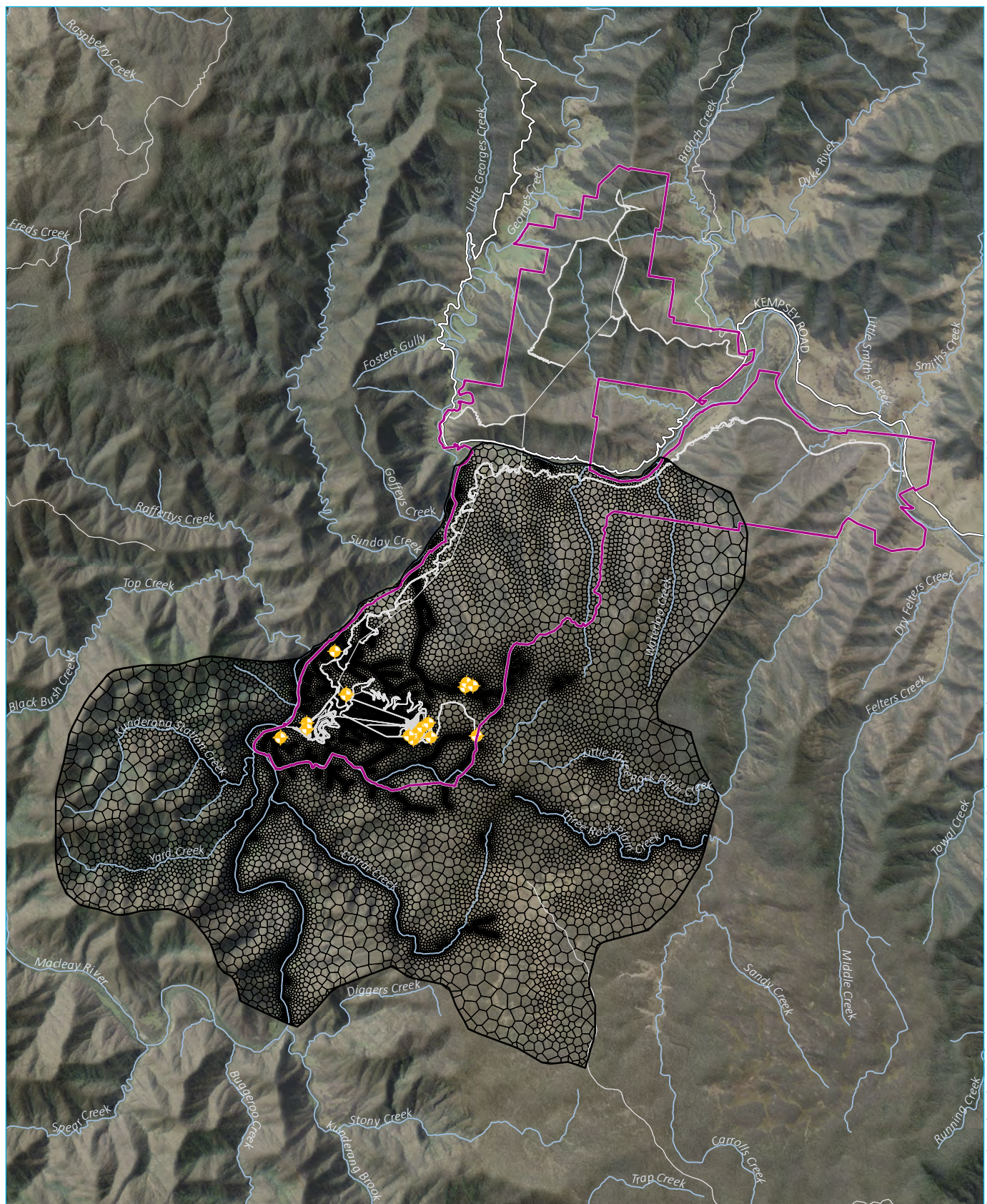
The model domain is discretised into 37,875 cells per model layer, and 25 model layers. The model uses a feature of MODFLOW-USG which allows cells to be “pinched out” where a layer is not present, or is less than 0.5 m thick, and the pinched out cells are treated as inactive and are removed from all calculations. Of the 946,875 total cells in the model, about half are pinched out resulting in a total of 471,995 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.

In a Voronoi mesh, the maximum ‘cell size’ used as a constraint in the creation process 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:

- 3 to 9 m at tunnels, reflecting the design
- 25 m at reservoirs
- 25 m at GDEs, springs and streams close to the Project
- 25 m at perennial rivers
- 90 m along primary stream lines not in the Project vicinity
- 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 (2024); DFSI (2020, 2021); GA (2011, 2020); DPI (2003); DPIE (2021)

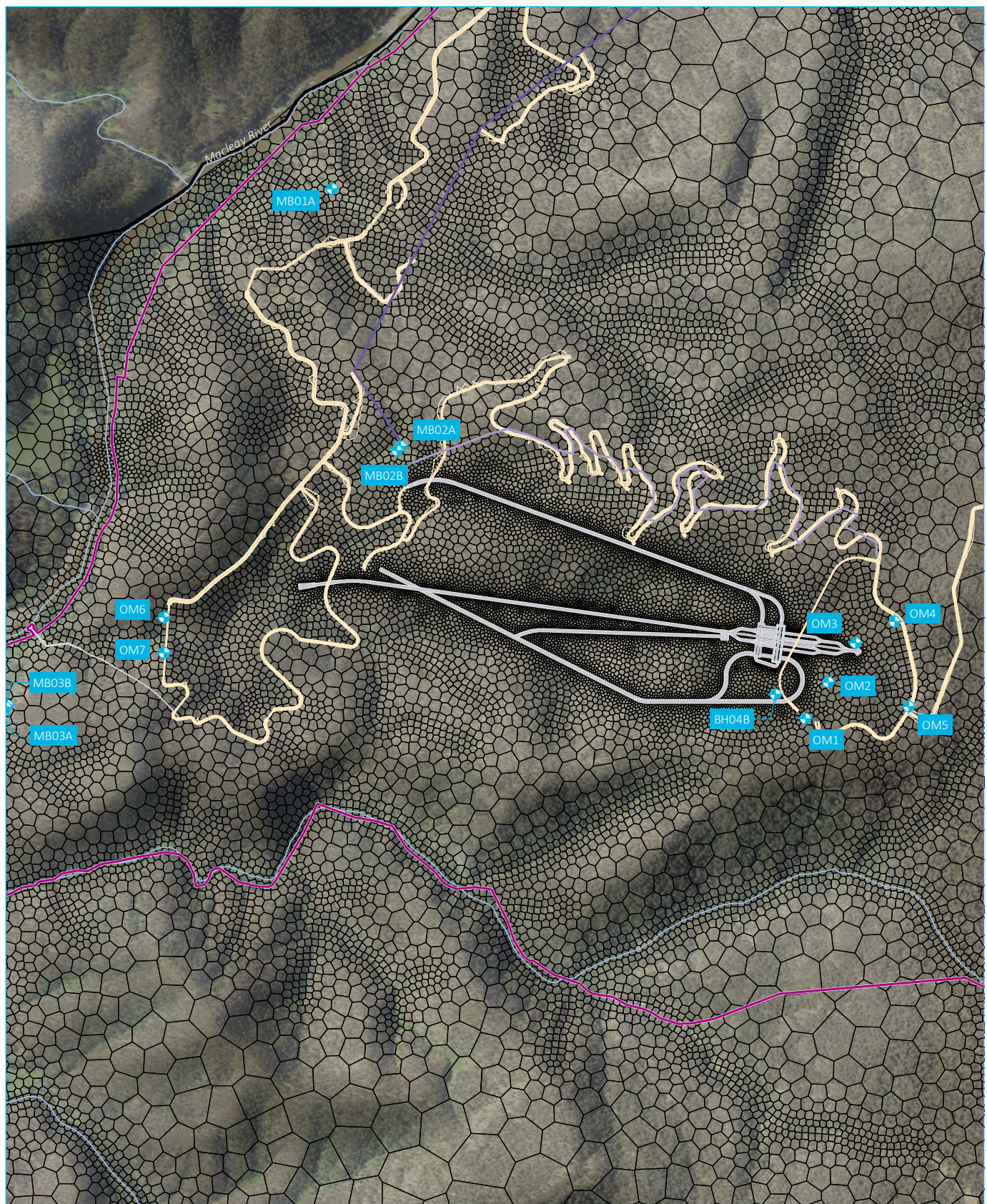
0 2.5 5 km
GDA 1994 MGA Zone 56

KEY

- | | |
|--|--|
| Project area | Existing environment |
| ◆ Groundwater bore network | Major road |
| Model domain | Minor road |
| Model mesh | — Named watercourse |
| | — Site infrastructure |

Model domain and Voronoi mesh

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Figure 3.1



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020); DPI (2003); DPIE (2021)

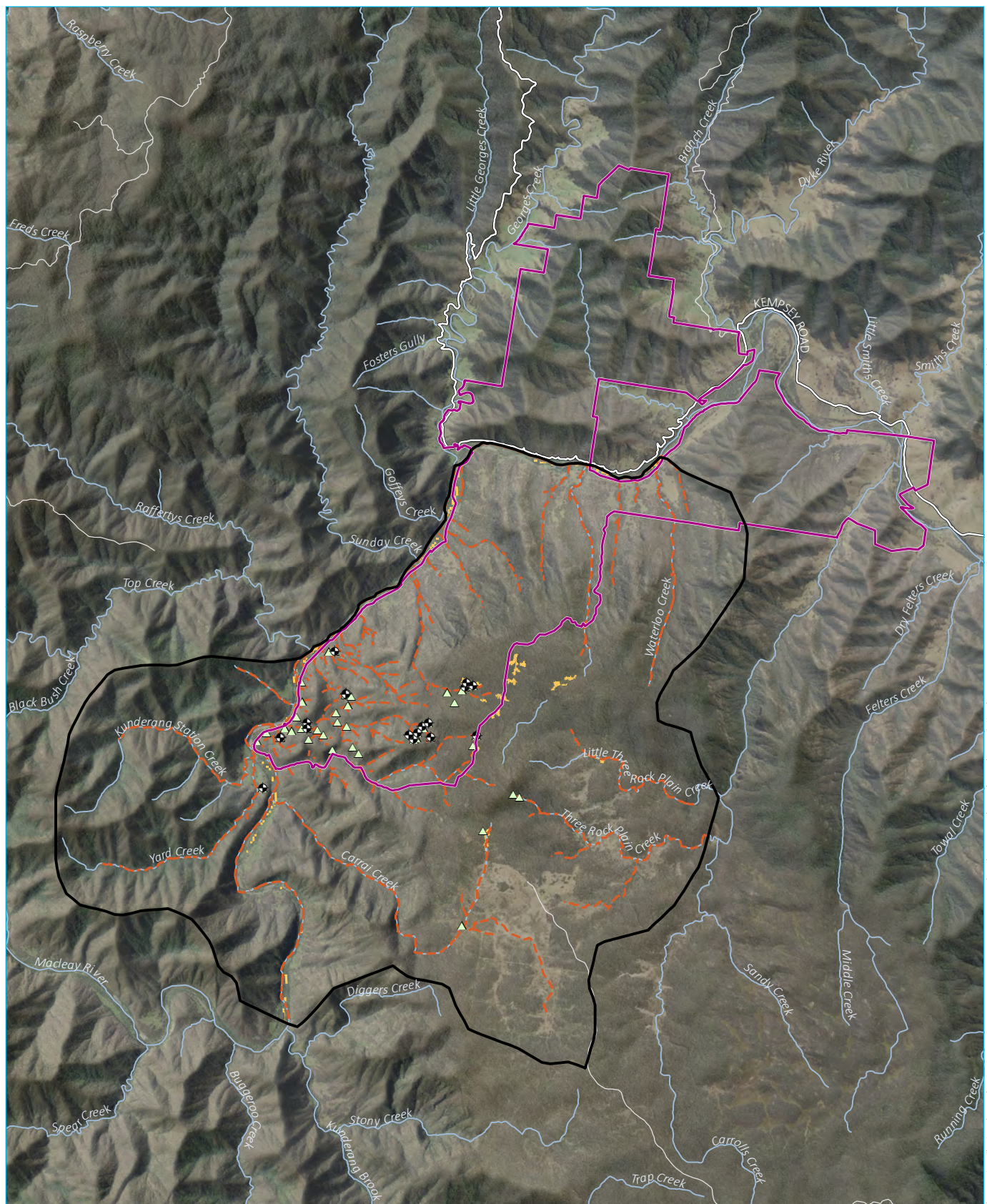
0 0.5 1 km
GDA 1994 MGA Zone 56

KEY

- | | |
|--|--|
| — Project area | — Operational elements |
| + Groundwater bore network | — Power and communications lines |
| — Model domain | — Transmission overhead lines |
| Model mesh | — Permanent road |
| Existing environment | — Underground power station complex |
| — Named watercourse | — 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



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020); BoM (2022)

KEY

- Project area
- Model domain
- Existing environment
- Major road
- Minor road
- Named watercourse

Features used in model mesh development

- Bores
- Environmental receptor
- Surface water feature
- GDE

Bore, GDEs and receptors used in the model mesh development

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd
Figure 3.3

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 storage 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
- 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 outward 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 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.

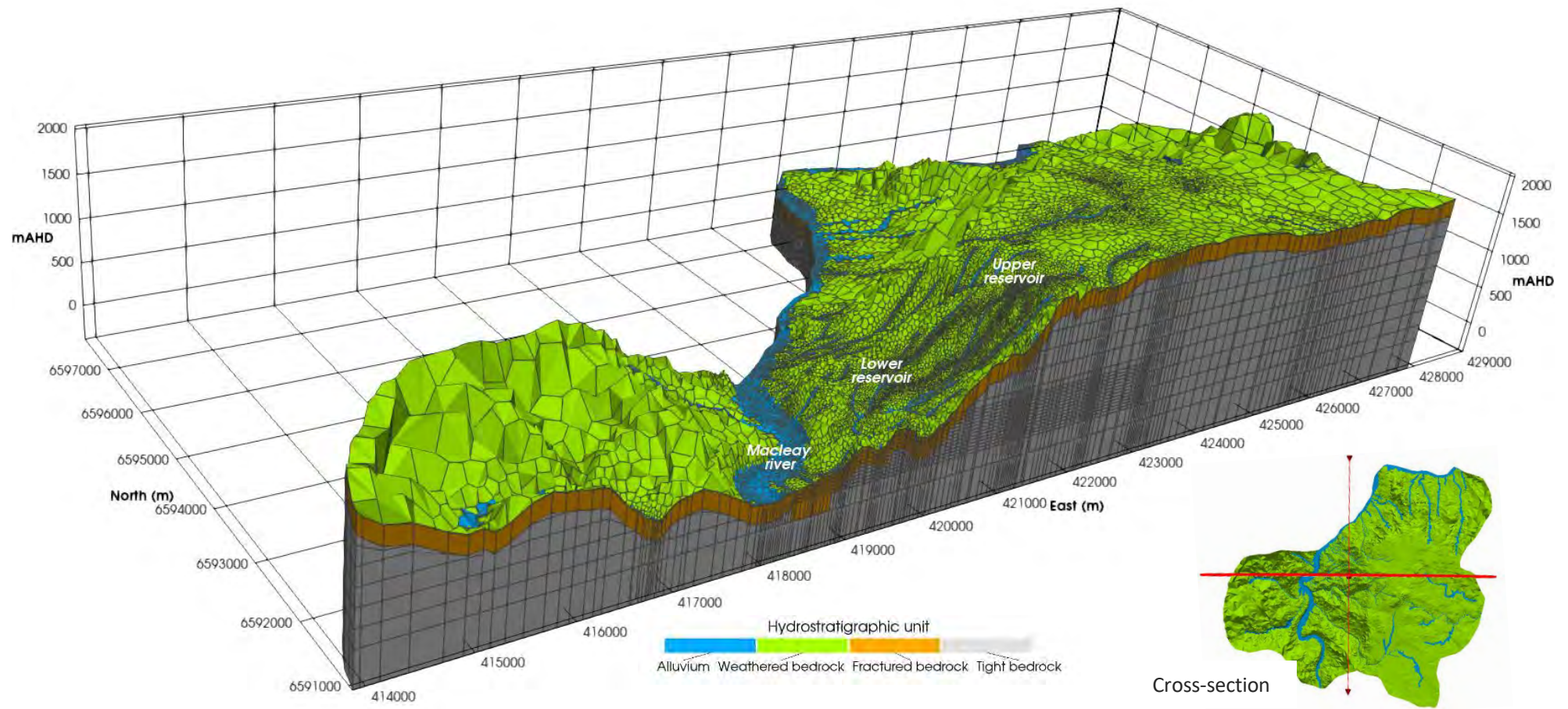
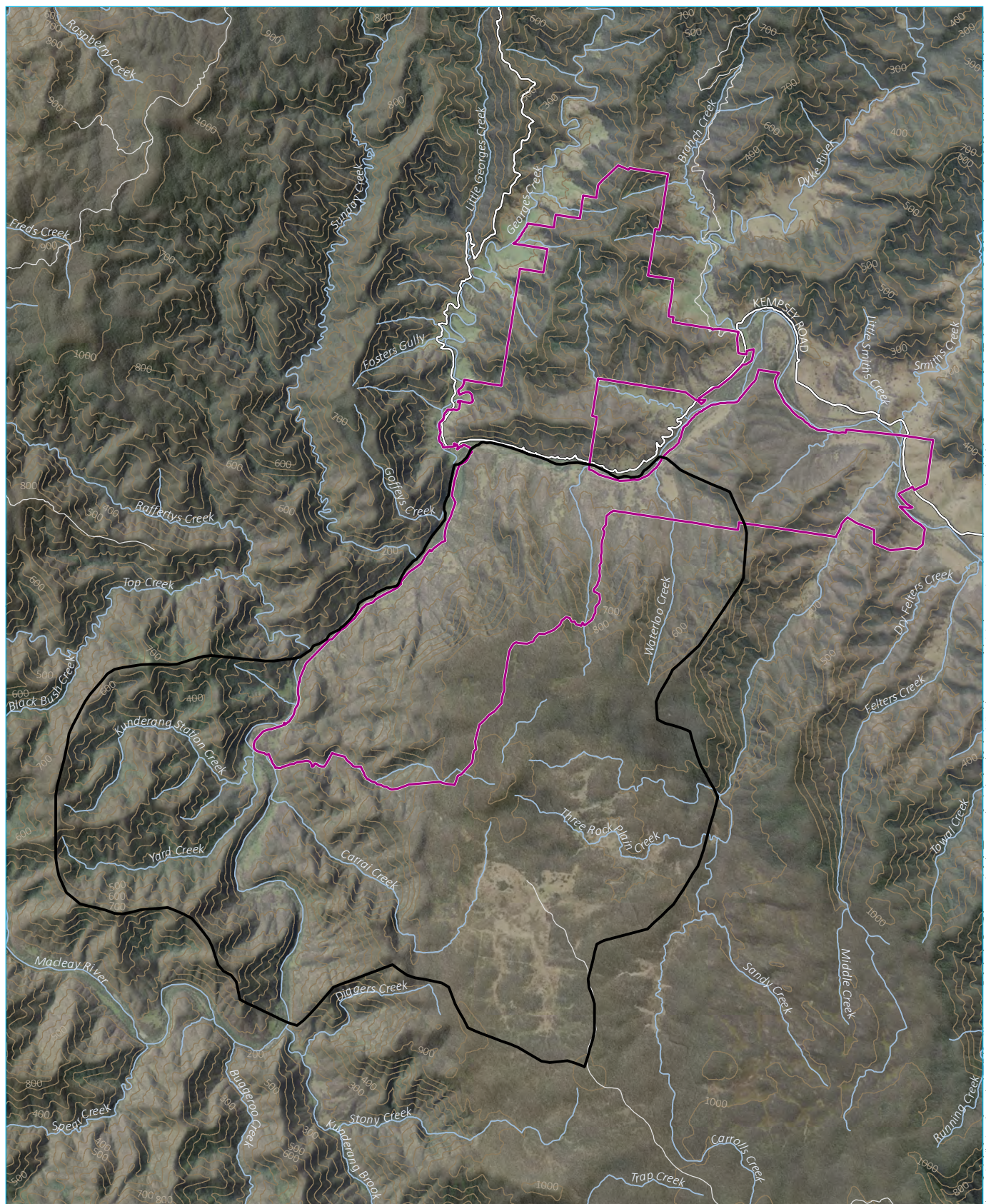


Figure 3.4 Cross section along project alignment showing model layers

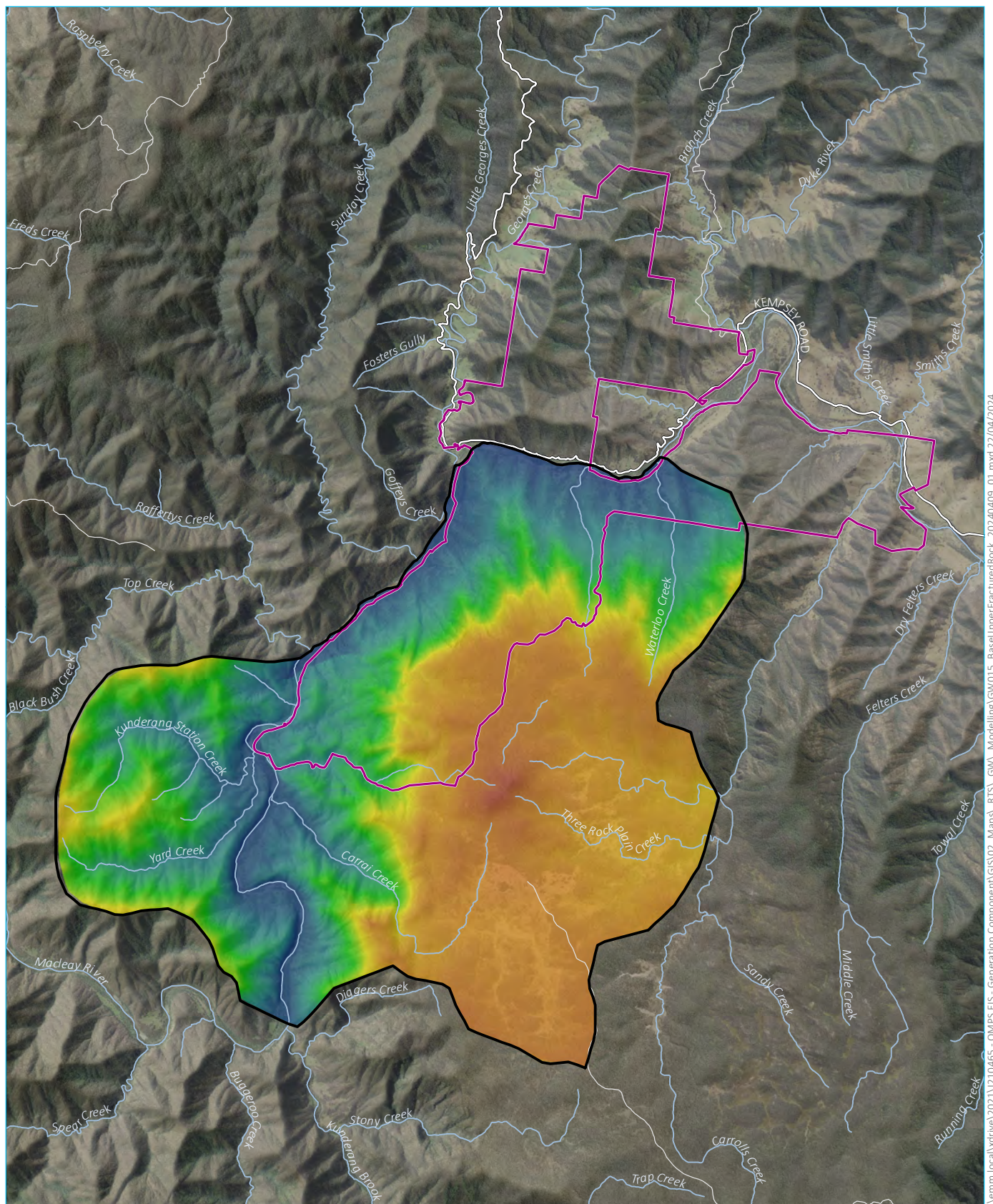


KEY

- Project area
- Model domain
- Topographic contour (50 m interval)
- Existing environment
- Major road
- Minor road
- Named watercourse

Model topography

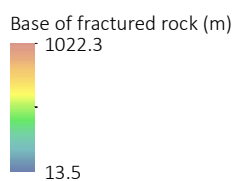
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Groundwater modelling report
OMPS Pty Ltd
Figure 3.5



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

KEY

- Project area
- Model domain
- Existing environment
- Major road
- Minor road
- Named watercourse



Base of the fractured rock unit (layer 2)

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Figure 3.6

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 47 fortnightly stress periods until January 2024 to allow a better dynamic representation of measured responses to climatic stresses when additional bores were installed in early 2022. This is followed by quarterly stress periods; 12 quarterly stress periods continue to simulate average seasonal climate until construction is scheduled to begin in October 2026, and 13 quarterly stress periods were required for predictive simulation of construction through to January 2030. 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 0.05 m.

Transient groundwater level data at the site are 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 2023, with variable rainfall conditions.

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**

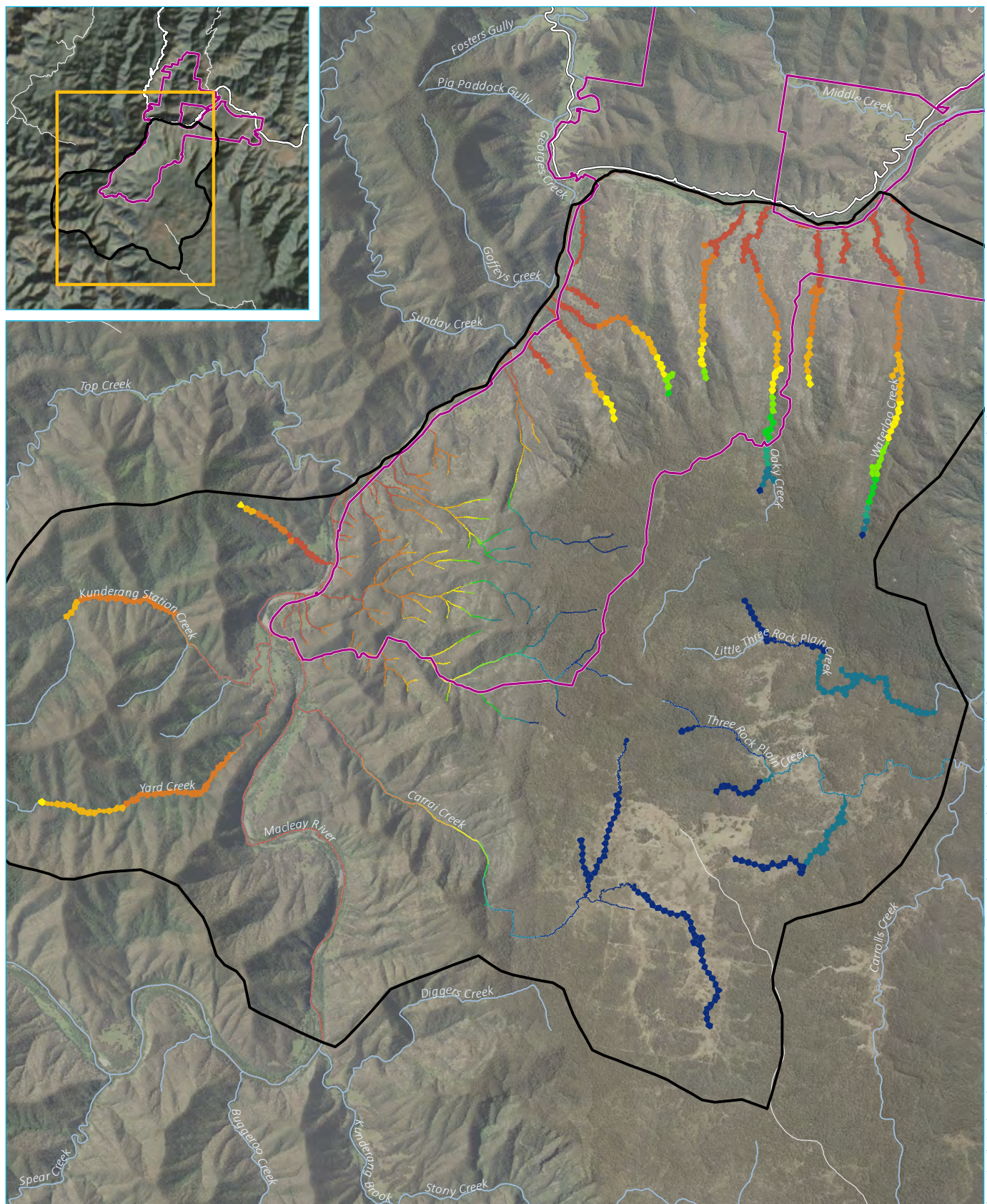
Stress period	Duration	Description
1	120 years	Pseudo steady state stress period run in transient mode to provide numerical stability when varying parameter values during the history-matching process.
2	Steady state	Develops baseline steady state conditions in response to modelled hydraulic properties 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 66	Fortnightly	History-matching period, from January 2022 to January 2024.
67 to 77	Quarterly	Bridging period between history-matching and construction, with average seasonal climate.
78 to 90	Quarterly	Represents Project construction over a period of 3.25 years.
91	1,000 years	Transient simulation of dynamic response to commencement of Project operation.
92	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 (2024); DFSI (2020, 2021); GA (2011, 2020)

KEY

 Project area	River boundary conditions (m AHD)	 500 - 600
 Model domain	 < 200	 600 - 700
 Existing environment	 200 - 300	 700 - 800
 Major road	 300 - 400	 800 - 900
 Minor road	 400 - 500	 > 900
— Named watercourse		

River boundary conditions
used in model domain

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Figure 3.7

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 3.9). 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 970 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 3.9), with initial estimates of 5%, 2% and 25% of rainfall applied across them respectively. Recharge rates within these zones were included in the history-matching process. A zero-recharge zone was applied to 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 3.9) 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 assigned using potential evapotranspiration values.

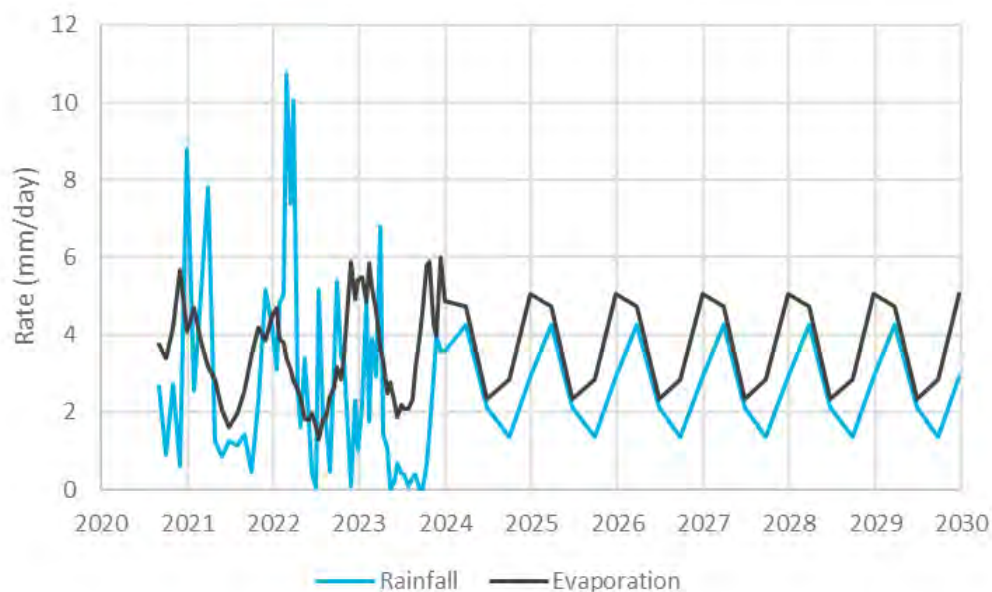
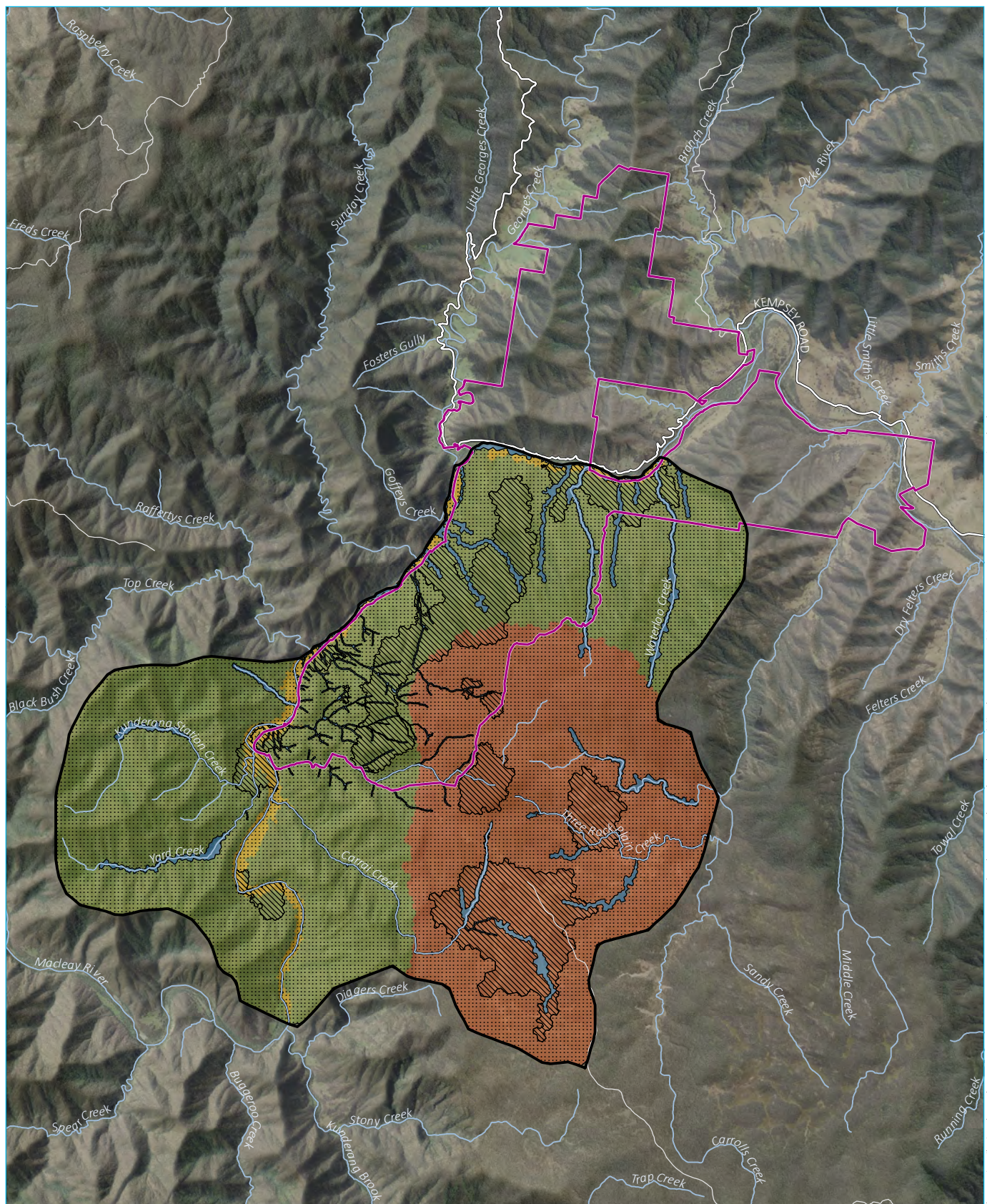


Figure 3.8 Modelled rainfall and evaporation



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

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

Oven Mountain Pumped Hydro Energy Storage Project
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Figure 3.9

3.6.4 Surface water

The major water course within the model domain, the Macleay River, was simulated with the MODFLOW River (RIV) package. Transient river stage, relative to the modelled topography along the river, was assigned as indicated in Figure 3.10 and Figure 3.11, with historic median river level used for the predictive period. To calculate the river levels in Figure 3.10 and Figure 3.11, baseflow separation 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. The $k = 0.90$ regression was applied for calculating river stage elevation.

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 into the creeks from the aquifer where/when the modelled groundwater level reaches the ground surface, but prevents leakage from the creeks 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 creeks 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 creeks are included in the estimated baseflow volumes captured in the model domain.

All river boundary conditions are assigned to layer 1, which represents the weathered and alluvium units.

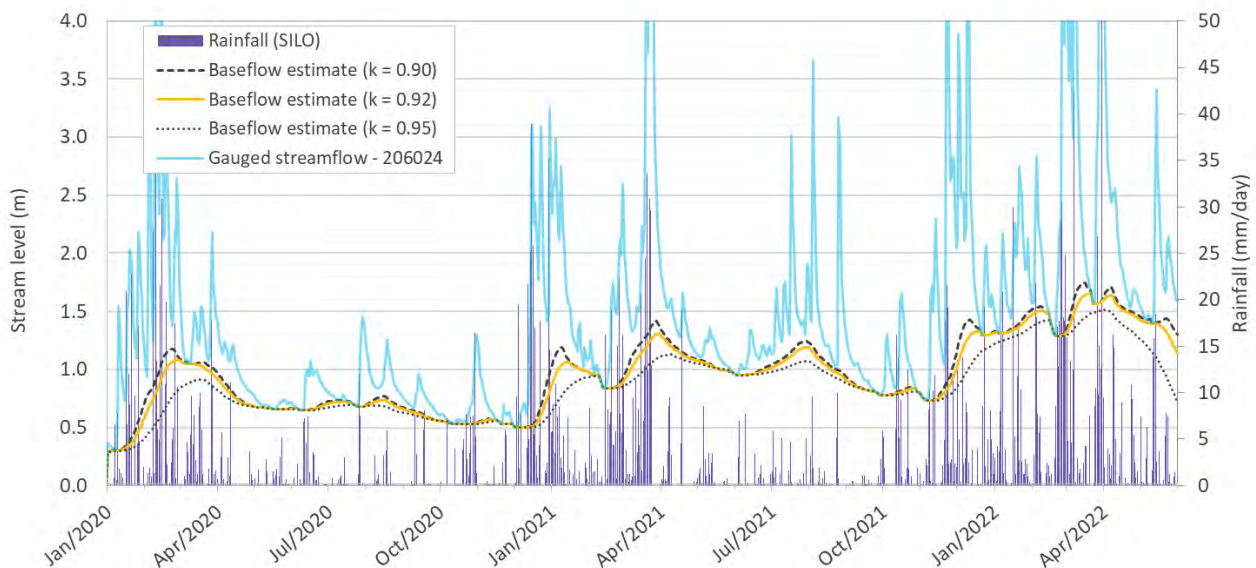


Figure 3.10 Interpreted Macleay River stage (relative to river bottom) with baseflow separation

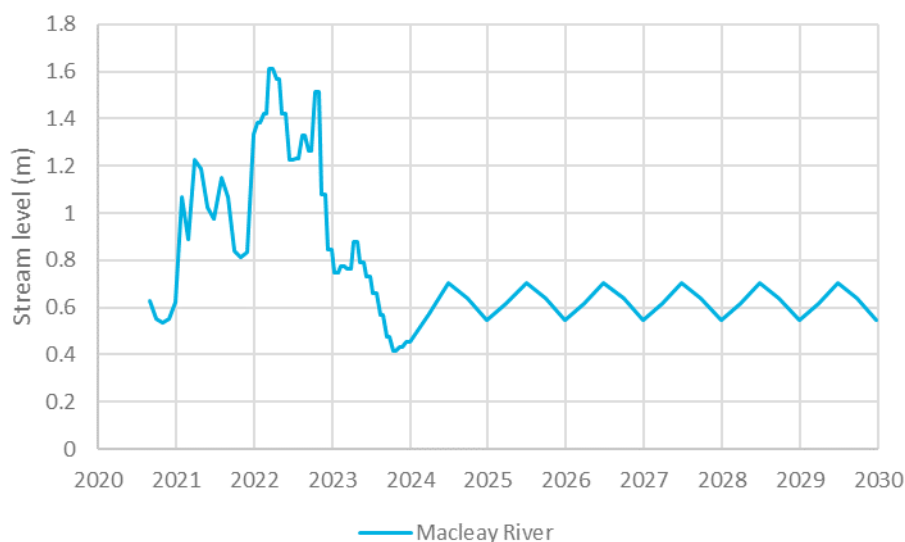


Figure 3.11 Modelled Macleay River stage (relative to river bottom)

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 Attachment A.

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. Beginning at the upper reservoir's base, the upper vertical intake merges into a 641 m long, 6.4-meter-diameter pressure shaft that is concrete-lined. This leads to a concrete-lined, high-pressure headrace tunnel measuring 19 m in length and 6.4 m in diameter, which then splits into concrete-lined bifurcated tunnels. Each 94 m long and 4.5 m in diameter, these tunnels further split into two, forming steel-lined penstock tunnels that are 122 m long with a 2.3 m diameter. The four penstock tunnels connect to the power station's base, comprising the machine hall, IPB galleries, and transformer hall. Exiting the machine hall, four steel-lined draft tube tunnels, each 54 m long and 4.5 m in diameter, begin the tailrace branching. These merge into a steel-lined tunnel, 76.7 m long and 5.5 m in diameter, which in turn connects to a concrete-lined tailrace tunnel that extends 1,434 m with a 6.2 m diameter. A tailrace surge shaft is located 14.5 m from the draft tube merging point. The transformer hall's north side leads to an emergency cable and ventilation tunnel (ECVT), stretching 1,485 m, to ensure safe and efficient access to key infrastructure during construction and operation. This connects to the machine hall via a 210 m long construction adit. Additionally, a main access tunnel (MAT) of about 1,850 m links to the machine hall, with a second tunnel (MAT 2), 270 m long, connecting the MAT to the south side of the transformer hall. A 760 m long tailrace surge shaft ventilation tunnel (TSST) connects the MAT to the tailrace surge shaft. Lastly, a concrete-lined lower intake links the tailrace tunnel's end to the lower reservoir at an elevation of 187 mAH.

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.

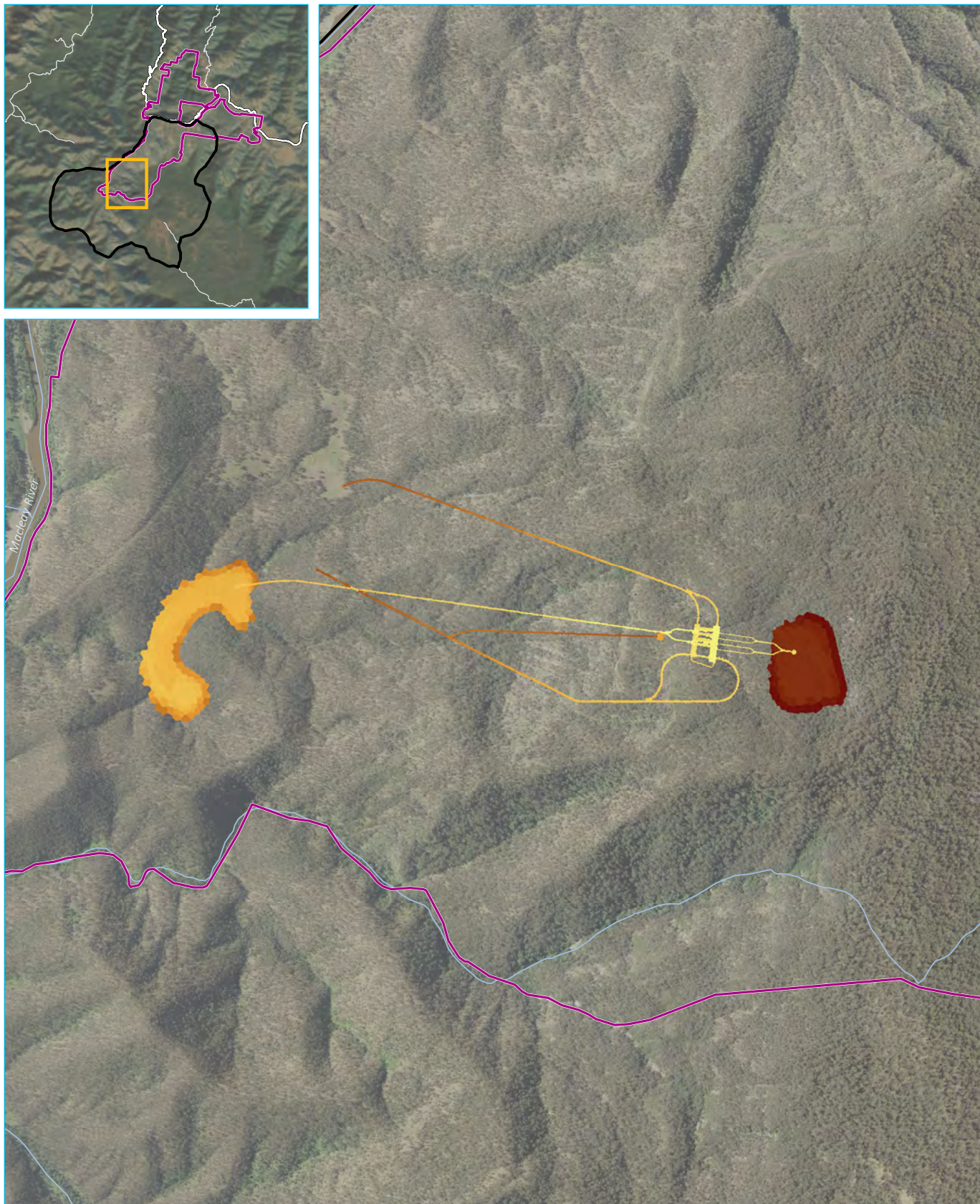
Table 3.5 Construction methods for key project elements

Project element	Construction method
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 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. The upper reservoir is excavated down through bedrock to an elevation of 819 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.
- The ECVT, MAT, MAT2, TSST, and surge shafts 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 high pressure tailrace tunnel, penstocks branching and tailrace branching are simulated with drain boundary conditions during initial excavation and are steel lined very soon after. Steel lined components are simulated with no boundary condition at the end of the construction of each of them. The grey cells in the Figure 3.12 are the components that are to be steel lined.

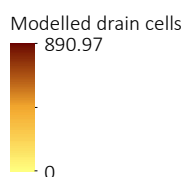


Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

0 0.5 1 km
GDA 1994 MGA Zone 56

KEY

- Project area
- Model domain
- Named watercourse



Modelled drain cells during construction period

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Figure 3.12

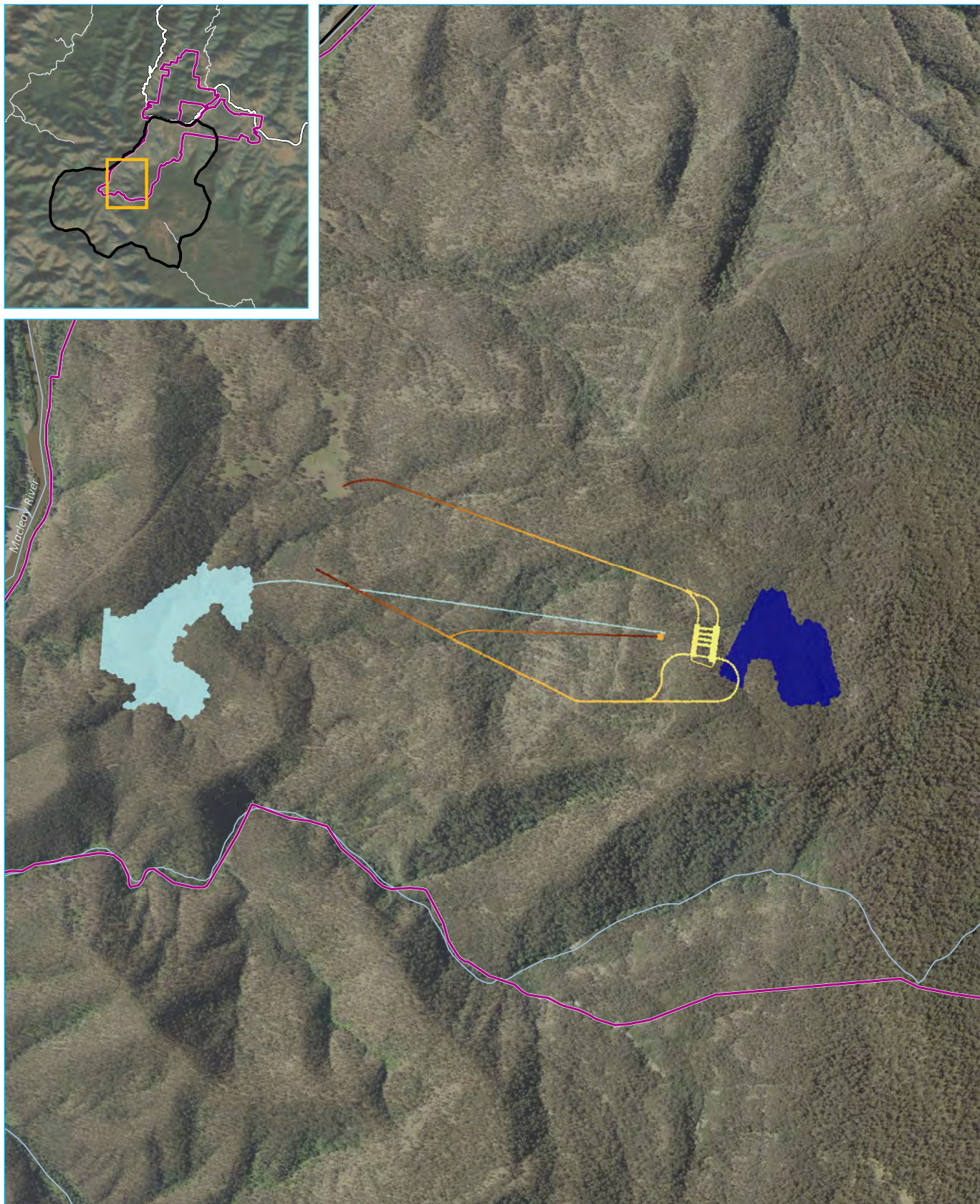
iii Operation boundary conditions

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 mid operating level was adopted (855.5 mAHD at the upper reservoir and 232.5 mAHD at the lower reservoir, see Table 3.6). Water pressure in the 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 3.13.

The design for the headrace high pressure tunnel, the penstock branching and tailrace branching 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	215
Mid operating level	mAHD	855.5	232.5
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 (2024); DFSI (2020, 2021); GA (2011, 2020)

0 0.5 1 km
GDA 1994 MGA Zone 56

KEY

- Project area
- Model domain
- Named watercourse

Modelled drain cells
328
119

Modelled reservoir cells
855.5
232

Modelled drain and general head
boundary conditions during
operation
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Groundwater modelling report
OMPS Pty Ltd
Figure 3.13

4 History-matching

4.1 Approach

PESTPP-IES version 5.0.11 was used to develop a history-matched ensemble of parameter realisations. The realisation with the overall best match to historical measurements is referred to as the base realisation. 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.

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 586 history-matching targets were employed, containing individual head measurements and transient time series head difference targets. The locations of these targets are shown on Figure 4.1. These were comprised of:

- 18 initial head targets from the monitoring bore network
- 13 head targets at points where springs were observed during site visits
- 555 head difference transient targets, defined as the difference between the current and first measured hydraulic head values.

PESTpp-IES 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 at time i , and w is a unitless statistical weighting value.

A weighting scheme was adopted such that:

- both the initial hydraulic head and transient head-change data effectively contributed to the objective function
- monitoring bores with highest reliability with respect to proper monitoring bore construction (MB01A, MB02A, MB02B, MB03A, MB03B, MB04A, MB04B, HA2201, HA2202, HA2203, and BH4A) were given the highest weighting for both initial hydraulic head and transient data
- monitoring bores with the lowest reliability with respect to proper monitoring bore construction (OM1 to OM7) were given a lower weighting for initial hydraulic head and transient data
- springs were given the same weighting as high reliability monitoring bores.

All targets were given a weight of 10, with the exception of 'OM' series bores, which were assigned the following weights:

- OM1: weight 1
- OM2: weight 4
- OM3: weight 4
- OM4: weight 2
- OM5: weight 2
- OM6: weight 1
- OM7: weight 1.

Measurement noise was applied, with the standard deviation of noise set as the inverse of the target weight.

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 initial head and transient head targets – overall, for all data points – 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 • hydrographs comparing measured and modelled heads at individual bores.
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 • boundary condition fluxes are plausible in terms of field observations.

Table 4.1 Minimum history-matching criteria

Objective	Rationale
Acceptance criteria	From a pool of 144 realisations, including the base realisation, 81 were accepted on the basis of their history-matching performance. The accepted realisations were used to conduct the uncertainty analysis. The acceptance criteria is explained in detail in Section 4.1.3.

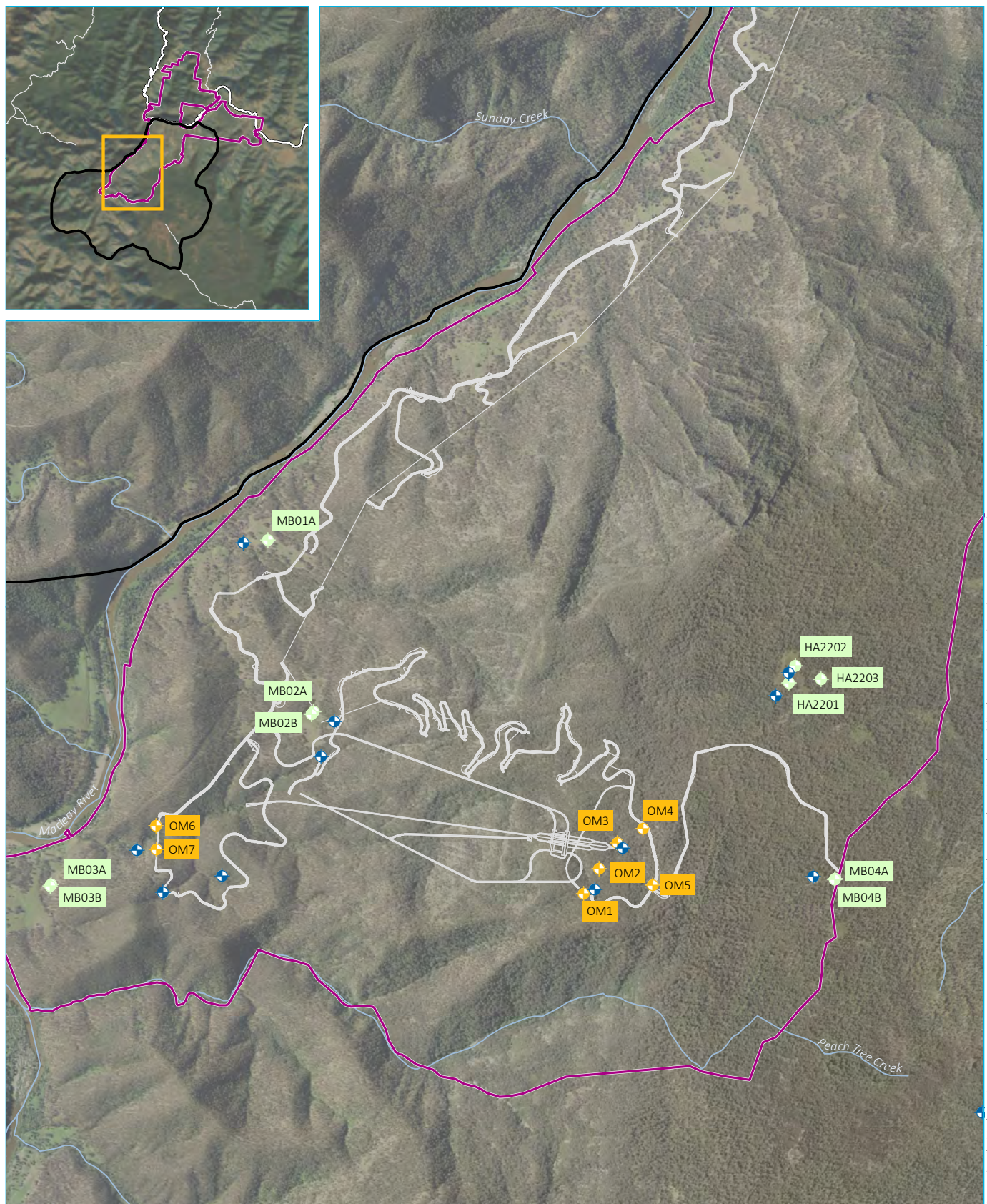
4.1.3 Criteria for realisation acceptance/rejection

A workflow was adopted that holistically incorporates uncertainty analysis in the modelling process, such that probabilistic predictive uncertainty analysis (PUA) could be carried out, aligned with the Type 3 method described in Middlemis and Peeters (2018), i.e. stochastic modelling with Bayesian probability quantification. The parameter ensemble was developed using PESTpp-IES, with realisations filtered from the ensemble based on history-matching performance. PESTpp-IES develops an ensemble of parameters, starting with the conceptual (prior) mean and distribution, and modifying through optimisation iterations.

Following the PESTpp-IES history-matching process, additional rejection sampling was applied to the ensemble to remove any poorly performing realisations that should not be carried forward to predictive modelling. The following steps were employed to identify and reject such realisations:

- For each realisation the median modelled value (across the transient time series) was calculated for each monitoring location.
- For each realisation the absolute difference between the median modelled value and the median target value (for each monitoring location) was calculated.
- With those performance data apply the following rejection criteria:
 - High fidelity bores where DTW < 5 m: HA2201, HA2202, HA2203, MB04A, MB04B – modelled head must be within 3 m of measured.
 - High fidelity bores where 5 m < DTW < 10 m: MB01A, MB03B – modelled head must be within 5 m of measured.
 - High fidelity bores where DTW > 10 m: BH4A, MB02A, MB02B, MB03A – modelled head must be within 10 m of measured.

After applying the rejection criteria, 81 of the total 144 realisations were accepted as the history-matched ensemble.



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

KEY

- | | |
|--|---|
| ▬ Project area | ◆ Bore |
| ▬ Model domain | ◆ High reliability |
| ▬ Existing environment | ◆ Low reliability |
| ▬ Named watercourse | ◆ Spring |

Spatial distribution of history-matching targets

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Figure 4.01

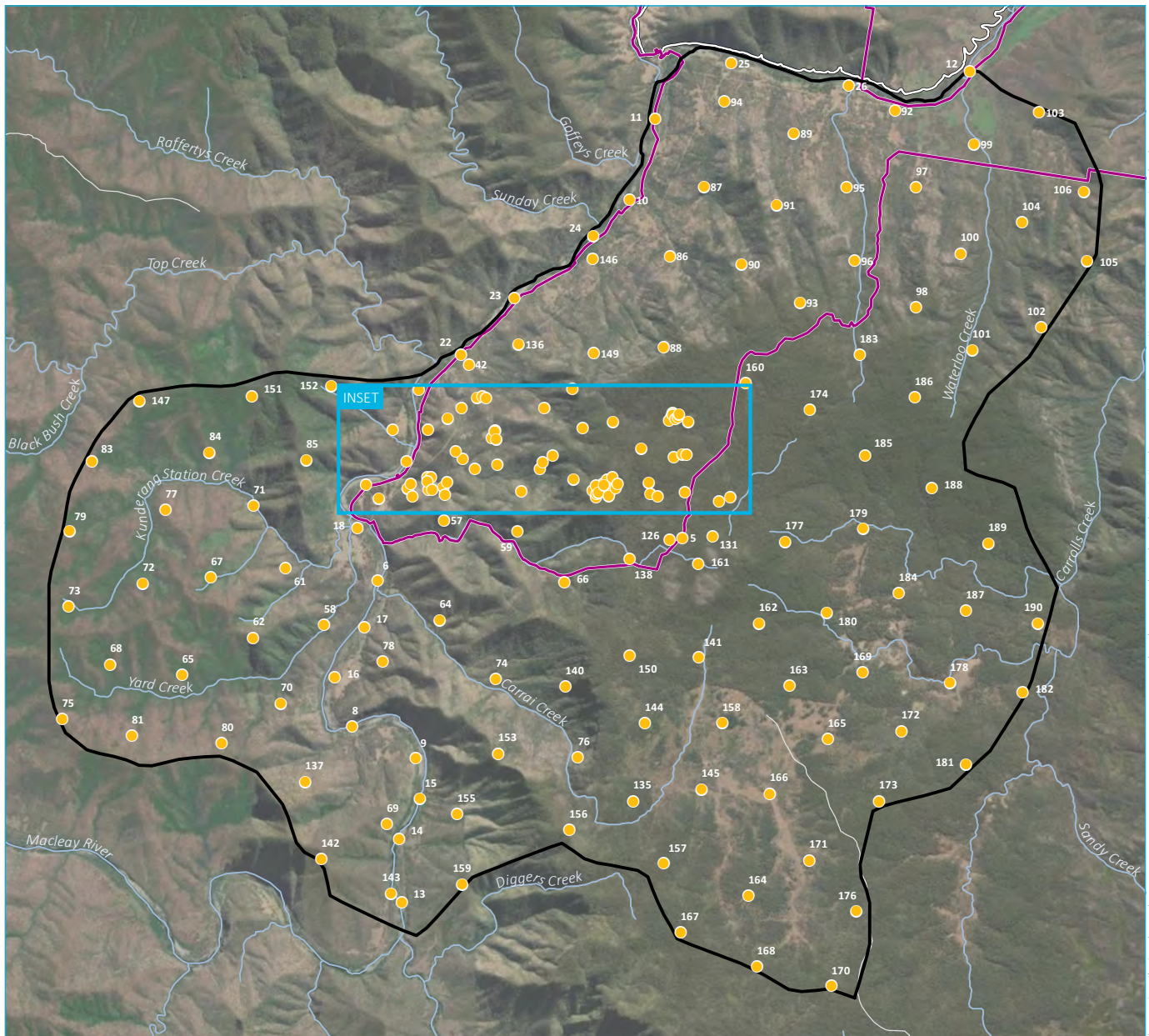
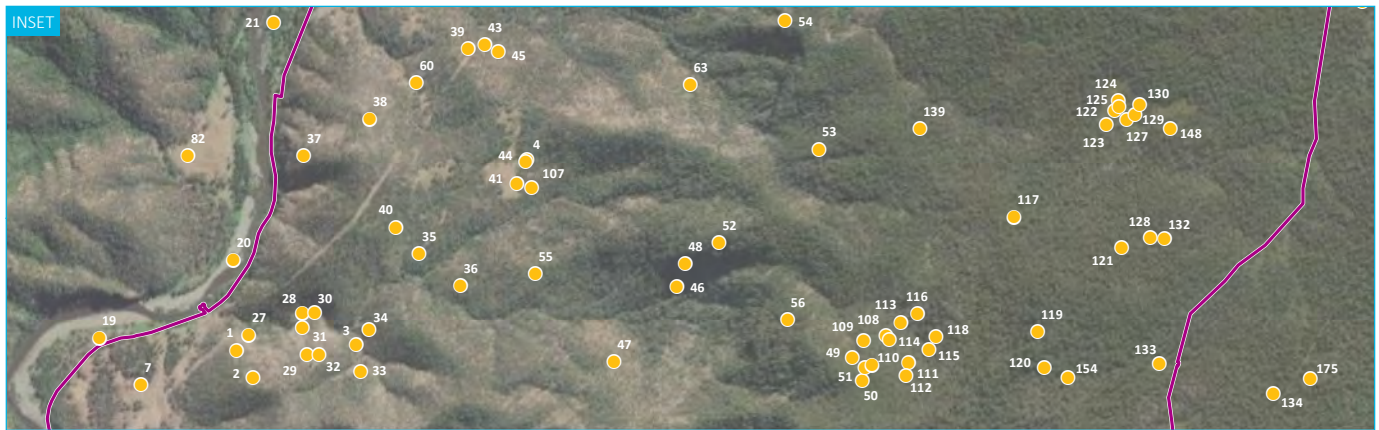
4.1.4 Parameterisation

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. 193 pilot point locations were used, with kriging of parameter values applied per zone:

- four zones for the hydrostratigraphic units; alluvium, weathered bedrock, fractured bedrock, and tight bedrock
- three zones for recharge areas; plateau, escarpment, and alluvium.

The locations of assigned pilot points and relevant monitoring bores are presented in Figure 4.2.



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

KEY

- Project area
- Pilot point
- Model domain
- Existing environment
- Major road
- Minor road
- Named watercourse

Pilot points used for
parameterisation

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Figure 4.2

4.1.5 Prior parameter distributions

Prior parameter distributions provided to PESTpp-IES are presented in Table 4.2. The parameters are log-transformed, with standard deviation representing the spread of conceptual values on a log scale. The minimum and maximum bounds are given as hard limits in PEST, ensuring that modelled properties do not exceed these values. All HSUs were modelled as isotropic.

Table 4.2 **Model prior parameter distributions**

Parameter	Mean	Standard deviation	Minimum	Maximum
Alluvium hydraulic conductivity (m/d)	1×10^1	0.1	1×10^0	1×10^2
Weathered bedrock hydraulic conductivity (m/d)	1.55×10^{-2}	1.55	1×10^{-4}	20
Fractured bedrock hydraulic conductivity (m/d)	3.11×10^{-2}	0.88	1×10^{-5}	5
Tight bedrock hydraulic conductivity (m/d)	1.6×10^{-2}	0.68	1×10^{-5}	0.5
Alluvium specific storage (1/m)	1.1×10^{-5}	1	3.2×10^{-9}	6.0×10^{-3}
Weathered bedrock specific storage (1/m)	1.1×10^{-5}	1	3.2×10^{-9}	6.0×10^{-3}
Fractured bedrock specific storage (1/m)	1.1×10^{-5}	1	3.2×10^{-9}	6.0×10^{-3}
Tight bedrock specific storage (1/m)	1.1×10^{-5}	1	3.2×10^{-9}	6.0×10^{-3}
Alluvium specific yield (-)	0.2	0.4	0.01	0.44
Weathered bedrock specific yield (-)	0.08	0.4	1×10^{-3}	0.44
Fractured bedrock specific yield (-)	0.02	0.5	1×10^{-4}	0.1
Tight bedrock specific yield (-)	3×10^{-4}	0.4	1×10^{-5}	0.01
Plateau recharge (m/d)	1.7×10^{-4}	1.21×10^{-4}	9.25×10^{-6}	5.31×10^{-4}
Escarpment recharge (m/d)	6.81×10^{-5}	5.19×10^{-5}	2.66×10^{-6}	2.66×10^{-4}
Alluvium recharge (m/d)	7.47×10^{-4}	3.87×10^{-4}	3.46×10^{-5}	1.33×10^{-3}

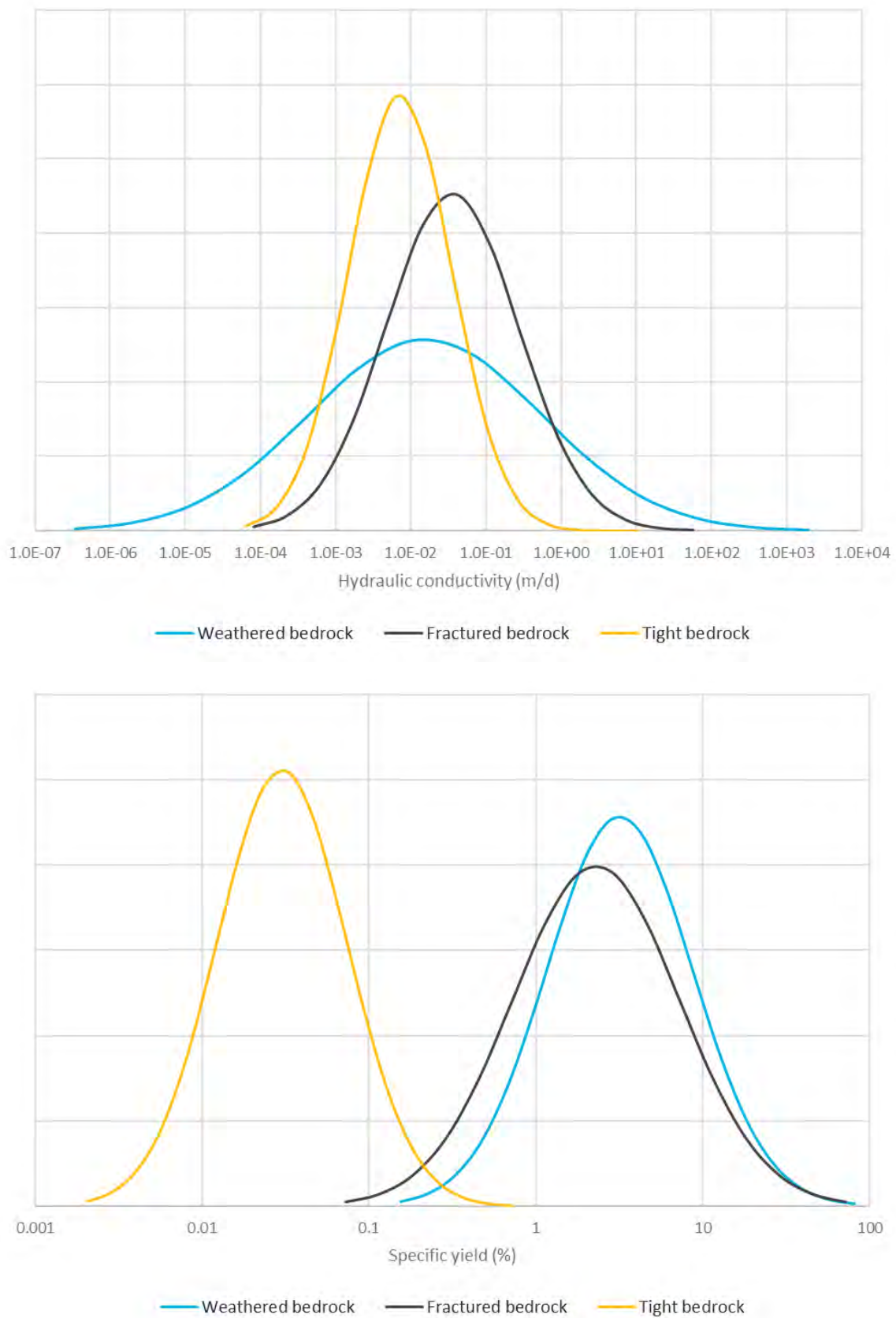


Figure 4.3 Hydraulic conductivity and specific yield conceptual distributions

4.2 Performance

4.2.1 Statistical performance

History-match performance was statistically quantified using SRMS (scaled root mean square) 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
- 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 4.3 and Table 4.4. The overall statistical performance of the model is considered acceptable for the base realisation, 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 4.3 **Model statistics summary – base realisation**

History-matching mode	Entire model	Upper bores (measured head 837–1,033 mAHD)	Lower bores (measured head 155–321 mAHD)
Steady state SRMS	0.60%	1.59%	4.27%
Steady state RMS	5.08 m	3.02 m	7.01 m
Steady state minimum residual	-7.82 m	-5.92 m	-7.82 m
Steady state maximum residual	22.74 m	7.86 m	22.74 m
Transient SRMS	0.71%	1.29%	5.44%
Transient RMS	6.06 m	2.45 m	9.06 m
Transient minimum residual	-7.82 m	-5.92 m	-7.82 m
Transient maximum residual	26.65 m	12.96 m	26.65 m

Table 4.4 **Model statistics summary – ensemble of accepted realisations**

History-matching mode	Entire model	Upper bores (measured head 837–1,033 mAHD)	Lower bores (measured head 155–321 mAHD)
Steady state SRMS	0.64%	2.01%	4.33%
Steady state RMS	5.46 m	3.84 m	7.12 m
Steady state minimum residual	-22.61 m	-22.61 m	-12.25 m
Steady state maximum residual	29.94 m	17.66 m	29.94 m
Transient SRMS	0.77%	1.68%	5.58%
Transient RMS	6.32 m	2.66 m	9.30 m
Transient minimum residual	-10.42 m	-10.42 m	-12.25 m
Transient maximum residual	36.17 m	20.99 m	36.17 m

4.2.2 Hydraulic head

i Steady state

Data from 18 monitoring bores and piezometers and 13 springs were used to evaluate modelled steady state and transient conditions groundwater levels. Scatter plots of modelled against measured steady state hydraulic head are presented in 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
- the overall fit to measured data indicates a generally good match to sitewide groundwater levels and across the various HSUs that are currently monitored.

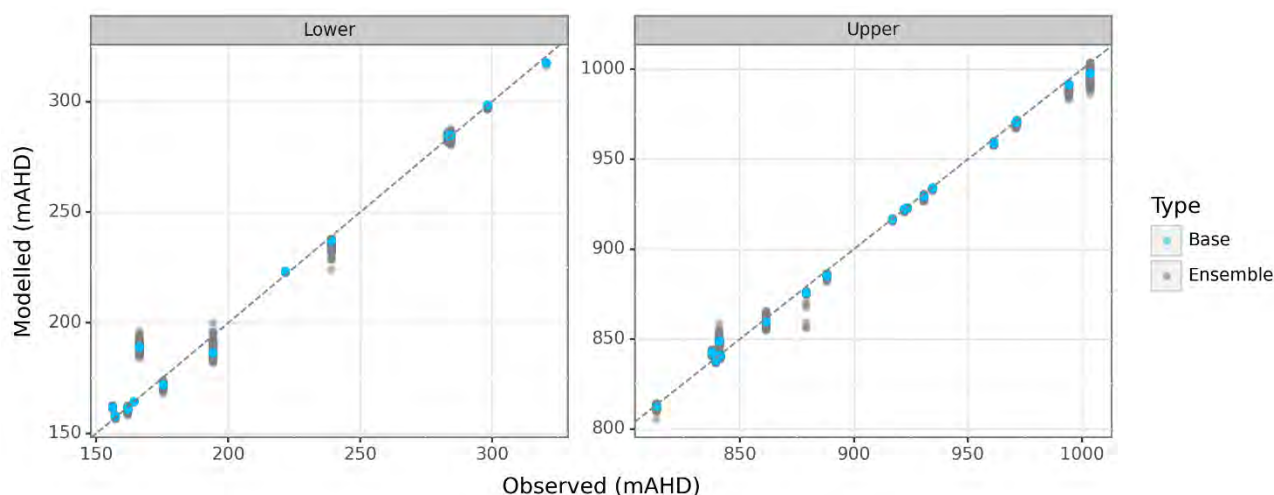


Figure 4.4 Scatter plot of steady state modelled versus measured heads in bores near the lower reservoir and the upper reservoir

A histogram of steady state residuals (modelled head minus measured head) is presented in Figure 4.5 for steady state and all realisations. This figure represents the residual frequency in bands. Of the modelled steady state base realisation heads, 98.49% are within 5 m of measured. For the ensemble, 95.38% are within 5 m.

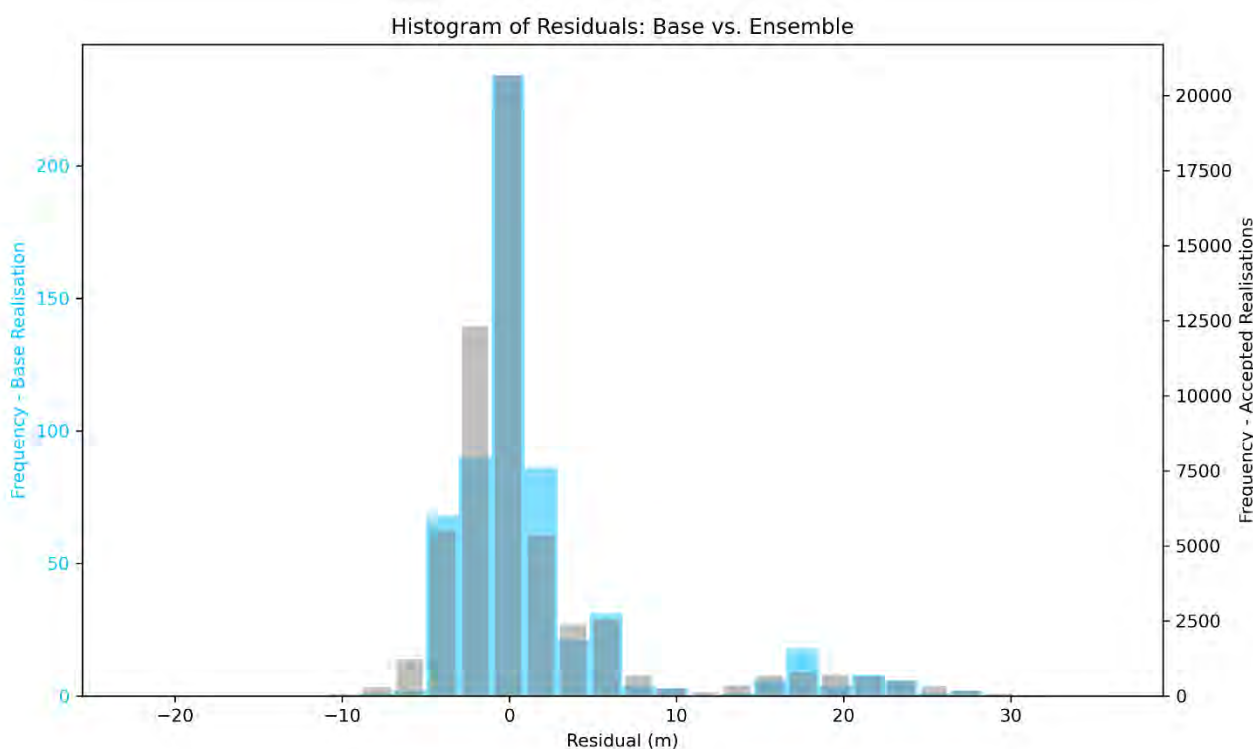


Figure 4.5 Steady state hydraulic head residual distribution for base realisation and ensemble

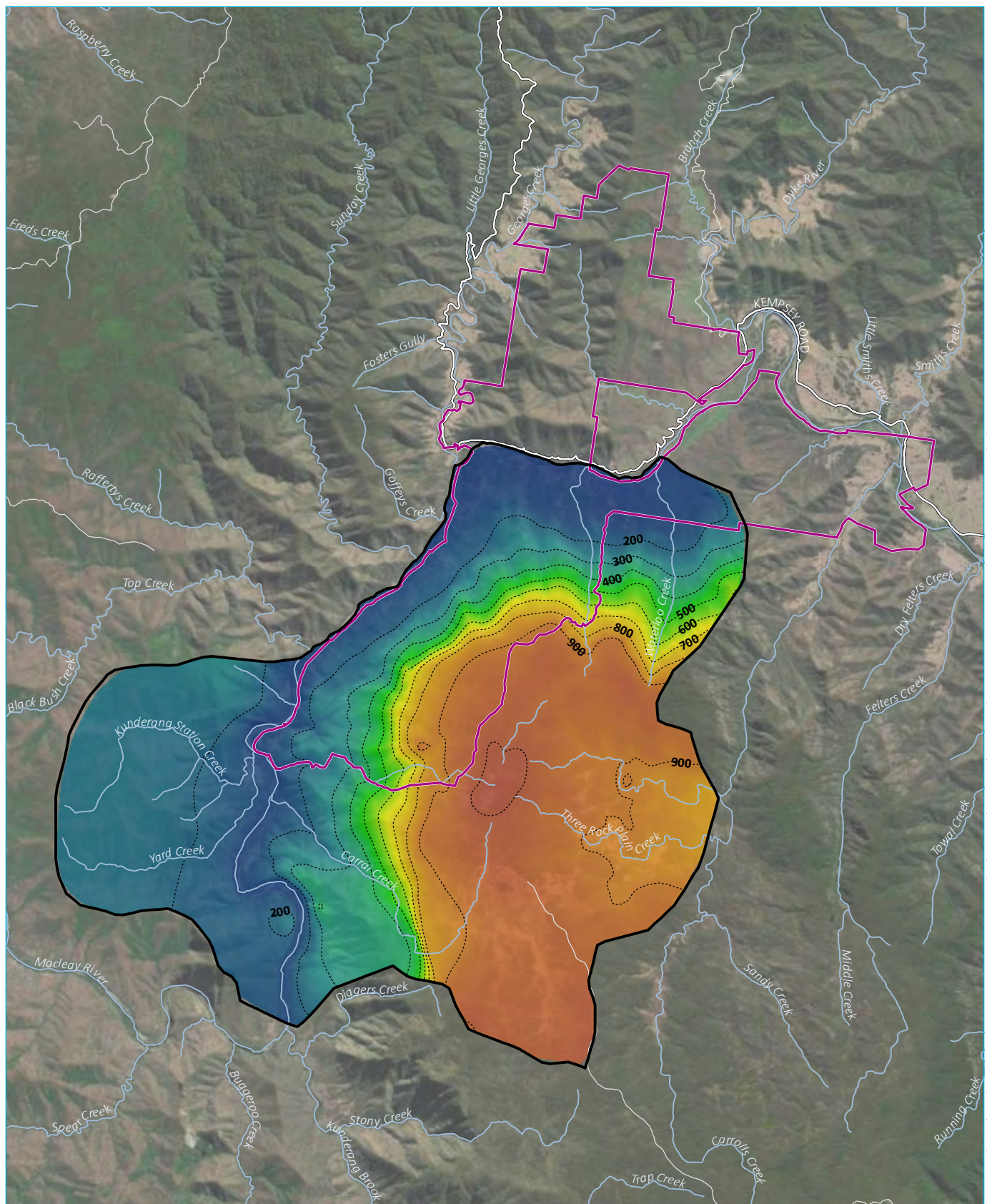
Figure 4.6 displays the simulated steady state watertable elevation. The main factors influencing hydraulic head are the landscape's topography, with the model accurately reflecting the groundwater flow patterns outlined in Section 2.8.2. In the model, groundwater flows predominantly from recharge areas on the plateau and in the western catchment area towards the discharge area along the Macleay River floodplain. The watertable is primarily found within layers of alluvium, colluvium, weathered bedrock, and the layer of 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 hydraulic head in this layer closely matches the watertable shown in Figure 4.6, which is expected since the watertable resides in this layer across most of the model domain.

The residuals from monitoring wells in the upper fractured bedrock are spread out evenly across the area. The largest discrepancies occur where topography changes more sharply in the escarpment area. Water levels simulated on the plateau are generally lower, tending to be lower than measured values. Near the lower reservoir, the magnitude of modelled residuals is greater, displaying a mix of both positive and negative values.

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.

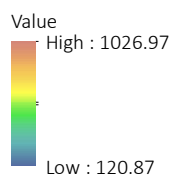
Overall, these three figures represent a reasonable starting condition for groundwater level distribution under baseline steady state conditions.



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

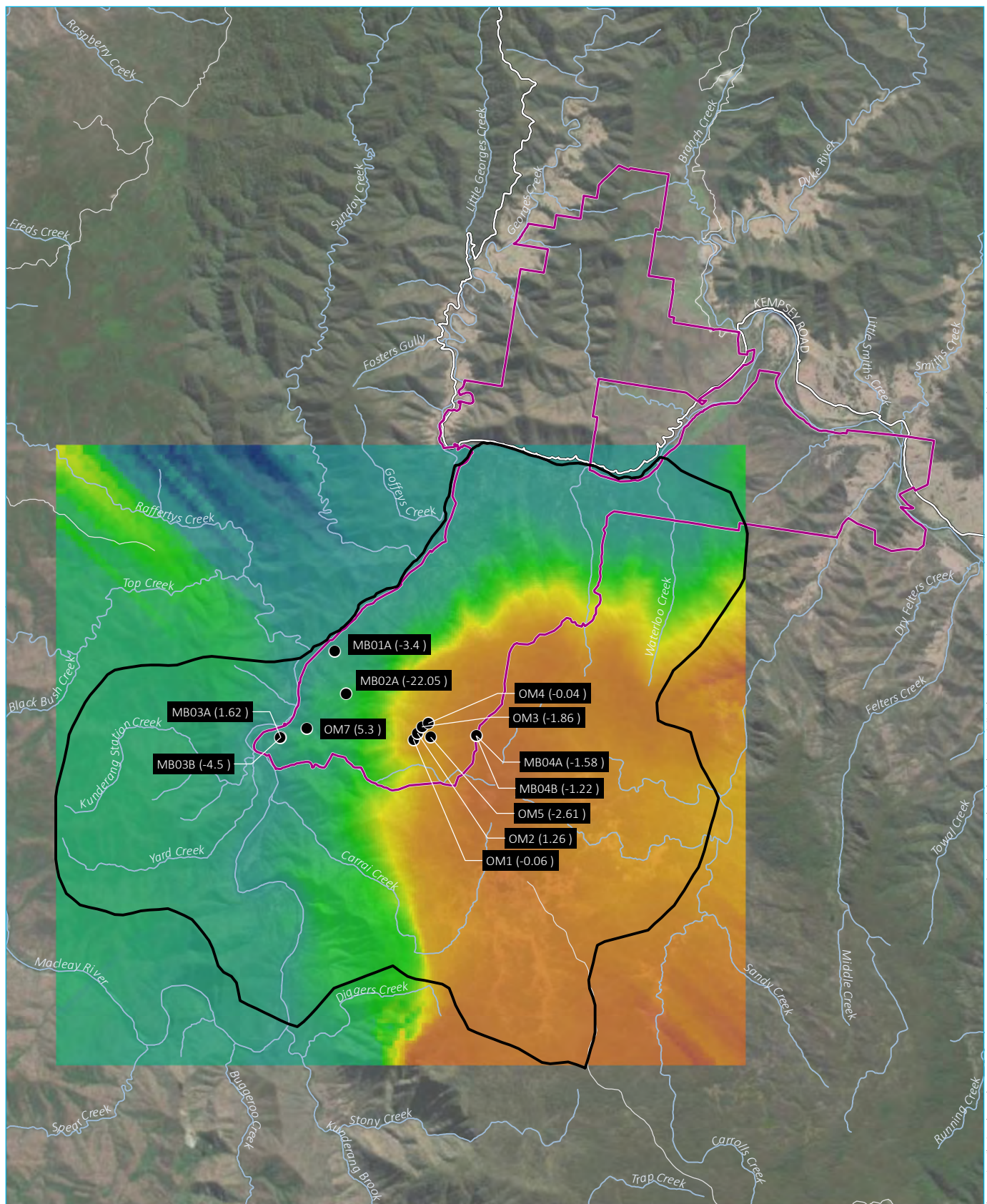
KEY

- Project area
- Model domain
- Modelled water table elevation (mAHD)
- Existing environment
- Major road
- Minor road
- Named watercourse



Modelled steady state water table elevation

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Figure 4.6



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

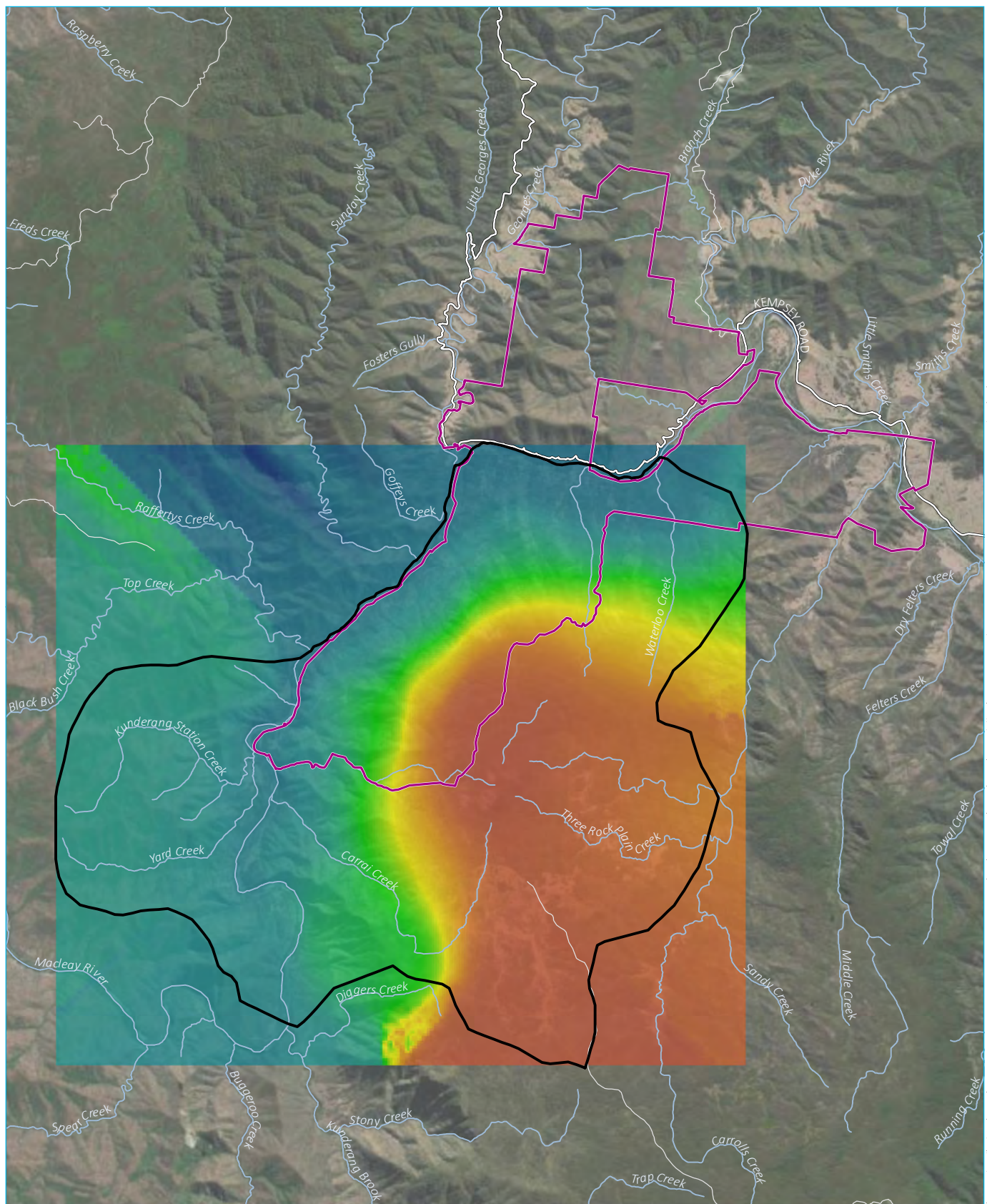
KEY

- ▬ Project area
- Residuals
- ▬ Model domain
- Existing environment
- ▬ Major road
- ▬ Minor road
- ▬ Named watercourse

Value
High : 1140.15
Low : -129.97

Modelled steady state potentiometric surface
and residuals for upper fractured rock

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Figure 4.7



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

0 2.5 5 km
GDA 1994 MGA Zone 56

KEY

- Project area
- Model domain
- Existing environment
- Major road
- Minor road
- Named watercourse

Value
High : 981.311
Low : 18.4463

Modelled steady state potentiometric surface for deeper competent bedrock

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Figure 4.8

ii Transient

Scatter plots of modelled against measured hydraulic head data for the complete history-matching dataset are 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
- there is no systematic bias in under or over-predicting dynamic changes in groundwater levels.

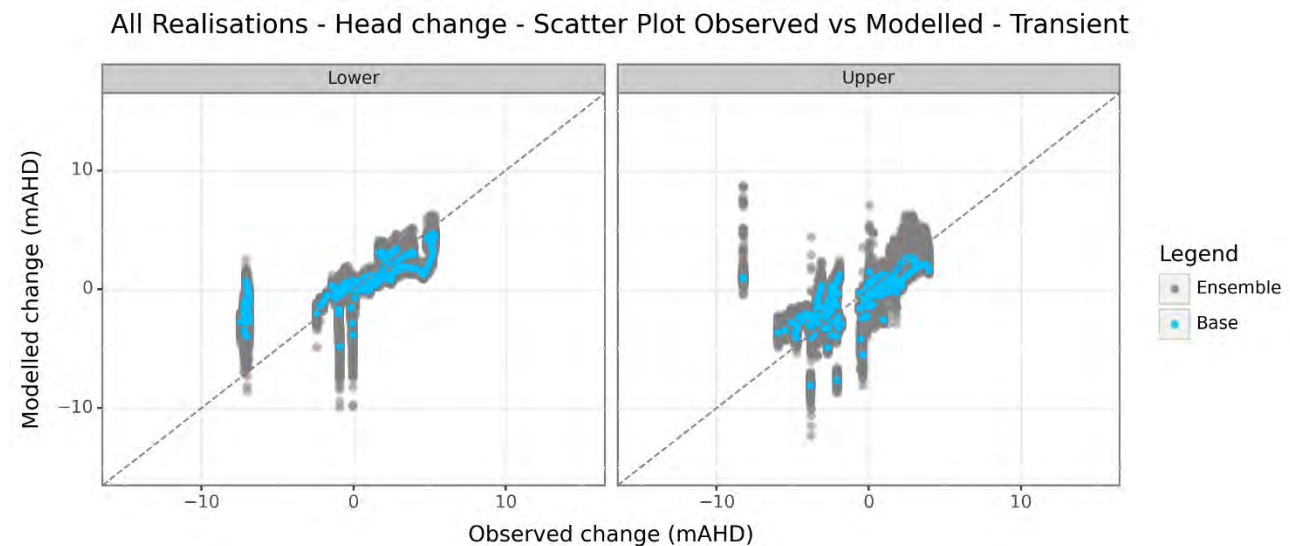


Figure 4.9 Scatter plot of transient hydraulic head change

Hydrographs of modelled and measured head are presented in Figure 4.10 and Figure 4.11. The locations of the bores with respect to the geographic focus areas are presented spatially on Figure 4.12. 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 4.5. 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 4.5 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 1–10 m of measured.	Model predicts timing of seasonality accurately.	Model predicts magnitude of seasonality accurately.	Unable to match to head, but good at capturing seasonality.
OM2	Plateau	Fractured bedrock	Generally within 1–5 m of measured.	Model predicts more seasonality than what was observed.	Model predicts more magnitude of seasonality than what was observed.	Reasonable match to heads and seasonality.

Table 4.5 **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
OM3	Plateau	Fractured bedrock	Generally within 2 m of measured.	Model predicts more seasonality than what was observed.	Model predicts more magnitude of seasonality than what was observed.	Excellent match to heads and reasonable match to seasonality.
OM4	Plateau	Fractured bedrock	Generally within 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 3 m of measured.	Model predicts timing of seasonality accurately.	Model predicts magnitude of seasonality accurately.	Excellent match to heads and reasonable match to seasonality.
MB04B	Plateau	Fractured bedrock	Generally within 2 m of measured.	Model predicts timing of seasonality accurately.	Model predicts magnitude of seasonality accurately.	Excellent match to heads and seasonality (timing and magnitude).
MB04A	Plateau	Residual soil	Generally within 2 m of measured.	Model predicts timing of seasonality very similar to measured.	Model predicts magnitude of seasonality very similar to measured.	Excellent match to heads and seasonality (timing and magnitude).
HA2201	Plateau	Residual soil	Generally within 1 m of measured.	Model predicts timing of seasonality very similar to measured.	Model predicts magnitude of seasonality very similar to measured.	Excellent match to heads and seasonality (timing and magnitude).
HA2202	Plateau	Residual soil	Generally within 2 m of measured.	Model predicts timing of seasonality very similar to measured.	Model predicts magnitude of seasonality very similar to measured.	Excellent match to heads and seasonality (timing and magnitude).
HA2203	Plateau	Residual soil	Generally within 1 m of measured.	Model predicts timing of seasonality very similar to measured.	Model predicts magnitude of seasonality very similar to measured.	Excellent match to heads and seasonality (timing and magnitude).
OM6	Escarpment	Fractured bedrock	Generally within 15 m of measured.	Unable to capture seasonality as there is only one measured head.	Unable to capture seasonality as there is only one measured head.	Unable to match magnitude of heads.

Table 4.5 **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
OM7	Escarpment	Fractured bedrock	Generally within 15–25 m of measured.	Model predicts more seasonality than what was observed.	Model predicts more seasonality than what was observed.	Unable to match magnitude of heads and seasonality, but captures trend.
MB01A	Escarpment	Fractured bedrock	Generally within 1–5 m of measured.	Model predicts timing of seasonality very similar to measured.	Model predicts magnitude of seasonality very similar to measured.	Unable to match heads, but accurate to capture seasonality.
MB02A	Escarpment	Fractured bedrock	Generally within 2.5 m of measured.	Model predicts timing of seasonality very similar to measured.	Model predicts magnitude of seasonality very similar to measured.	Excellent match to heads and seasonality (timing and magnitude).
MB03A	River floodplain	Fractured bedrock	Generally within 6–8 m of measured.	Model predicts timing of seasonality accurately.	Model predicts magnitude of seasonality accurately.	Excellent match to seasonality, but unable to match heads.
MB03B	River floodplain	Fractured bedrock	Generally within 2 m of measured.	Model predicts timing of seasonality very similar to measured.	Model predicts magnitude of seasonality very similar to measured.	Excellent match to heads and reasonable seasonality.
MB02B	Escarpment	Deeper tight bedrock	Within several metres of measured.	Model predicts slightly less seasonality than what was observed.	Model predicts slightly less seasonality than what was observed.	Excellent match to heads and reasonable seasonality.

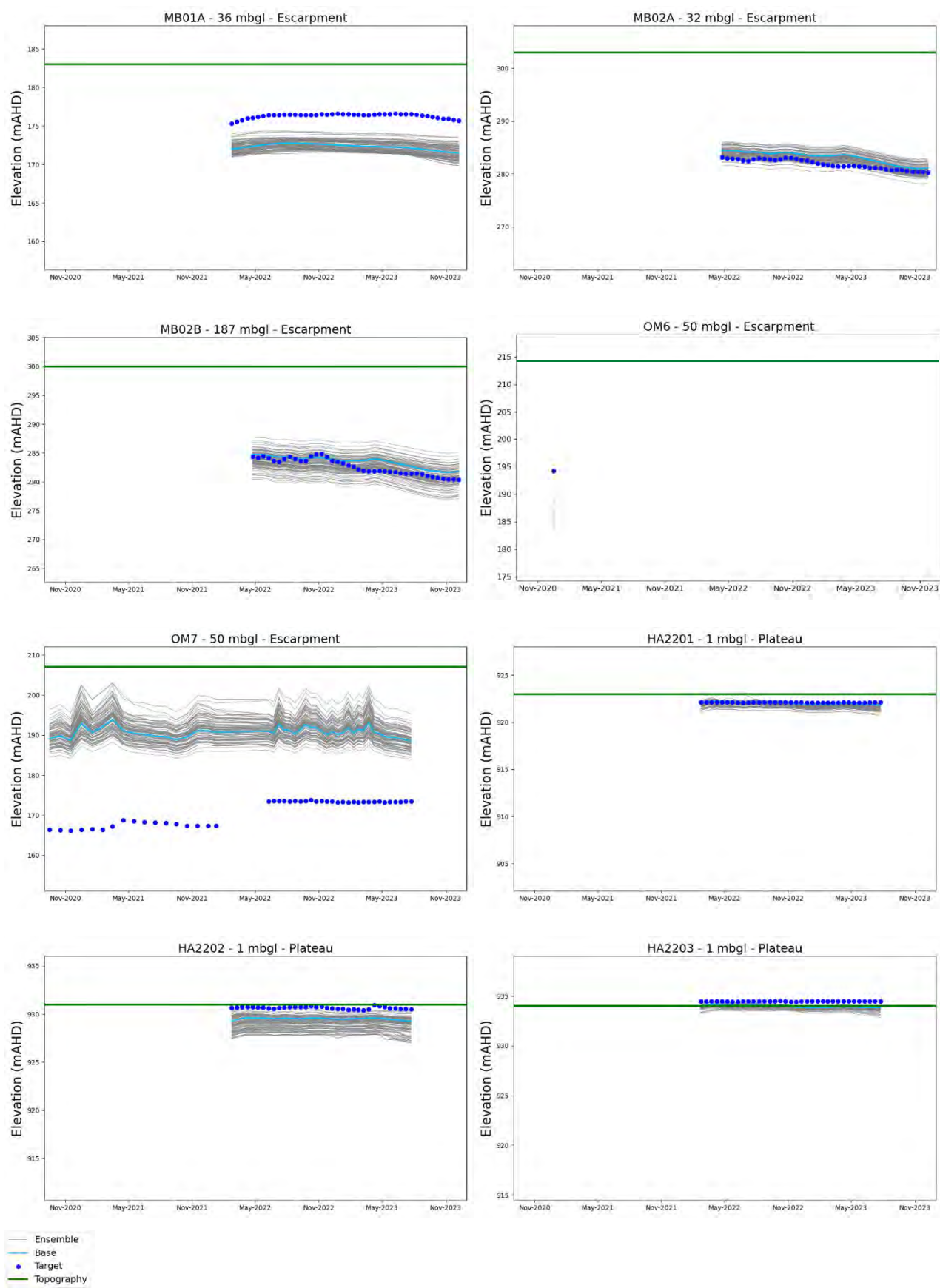


Figure 4.10 Modelled and measured hydrographs over the history-matching period

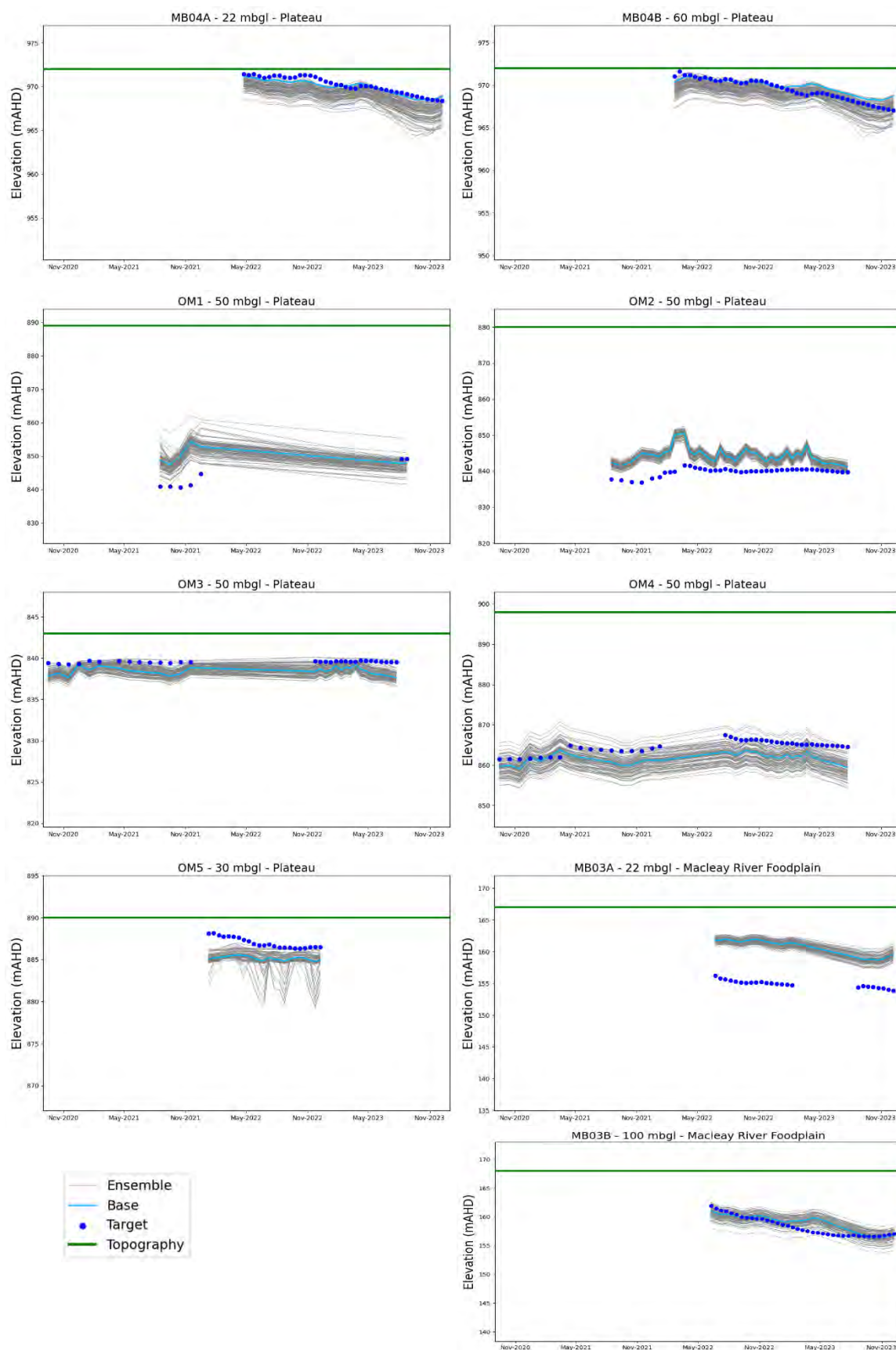


Figure 4.11 Modelled and measured hydrographs over the history-matching period

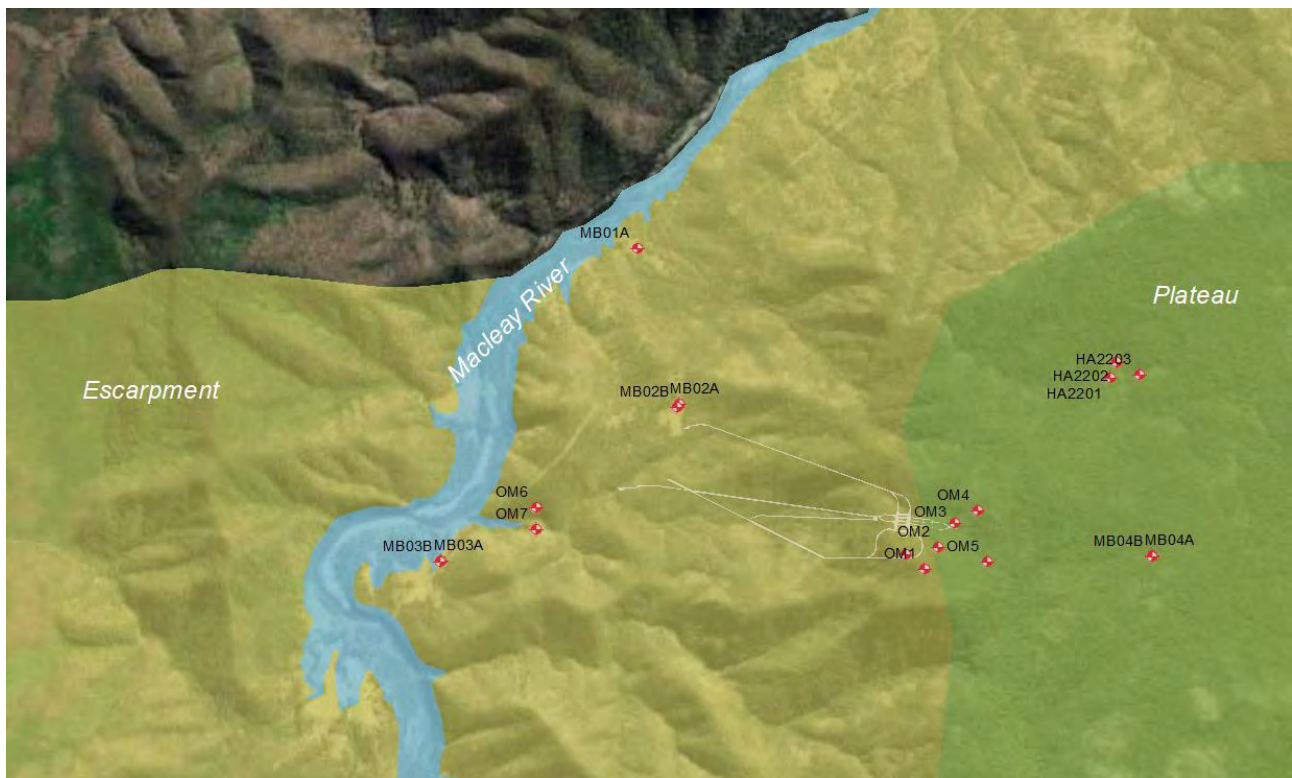


Figure 4.12 Hydrograph monitoring well locations

iii Vertical hydraulic gradient

Vertical hydraulic gradients during the steady-state pre-construction phase, the end of the construction phase, and the steady-state operation phase are depicted in Figure 4.13, Figure 4.14, and Figure 4.15, respectively. Positive values represent a downward gradient (groundwater moves downward), while negative values indicate an upward gradient (groundwater moves upwards).

Across all phases, the hydraulic gradient is generally positive at the western edge of the plateau. This area serves as the primary recharge zone, receiving water mainly through leakage from surface water sources. Conversely, within the rivers, an upward gradient is noticeable. This observation aligns with the conceptual model, which suggests that the aquifer discharges water into the creeks and rivers, thereby constituting the baseflow of the system.

The upward gradient in the rivers indicates that the aquifer actively contributes water to these surface water bodies. This contribution reinforces the idea that the aquifer acts as a feeder to the creeks and rivers. The data from these figures support the understanding that the western edge of the plateau plays a crucial role in recharging the aquifer, while the aquifer, in turn, supports the flow in the creeks and rivers through its baseflow contributions. This relationship highlights the interconnected nature of the groundwater and surface water systems in the area.

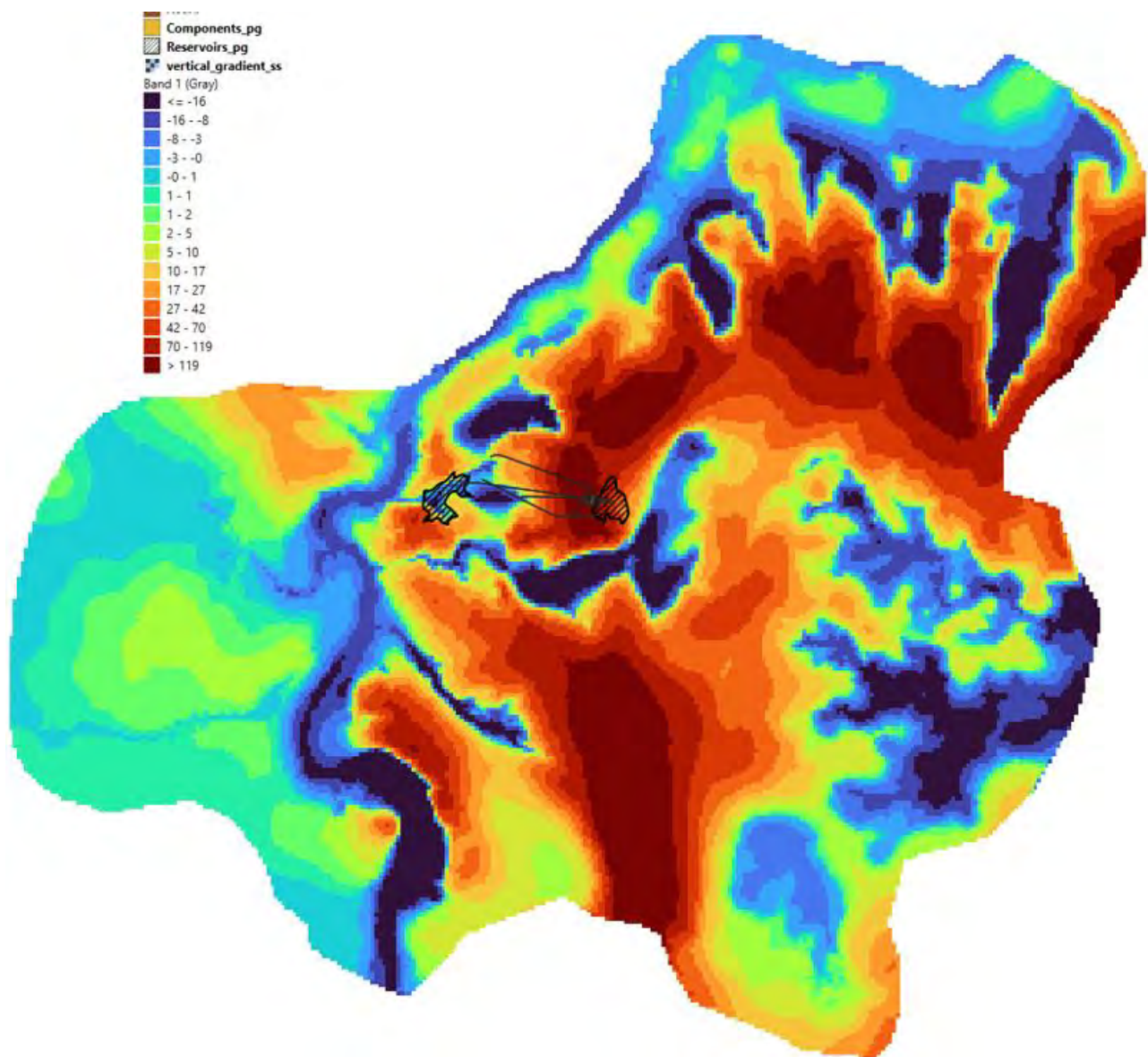


Figure 4.13 Vertical hydraulic gradient at the steady-state pre-construction phase

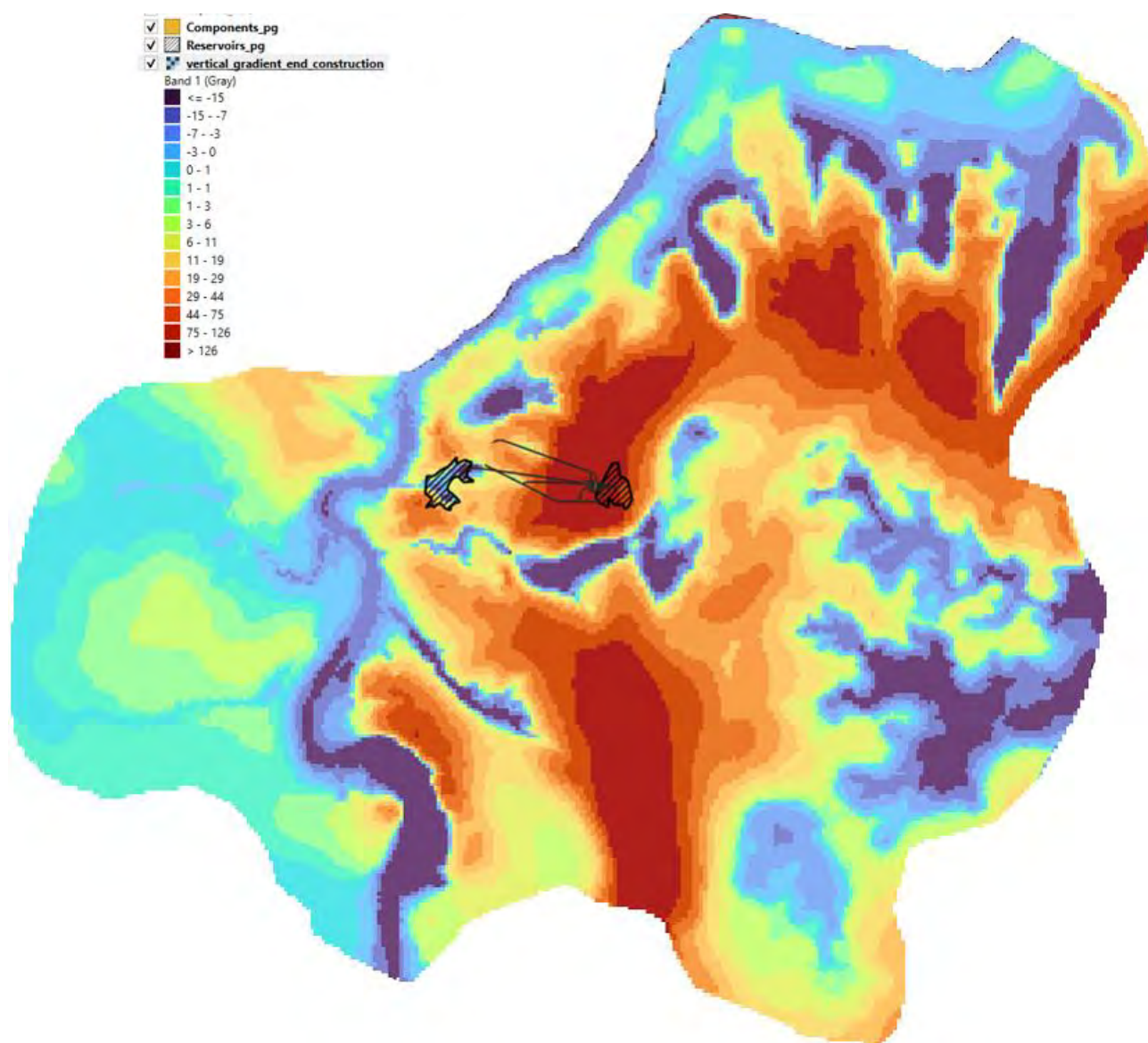


Figure 4.14 Vertical hydraulic gradient at the end of the construction phase

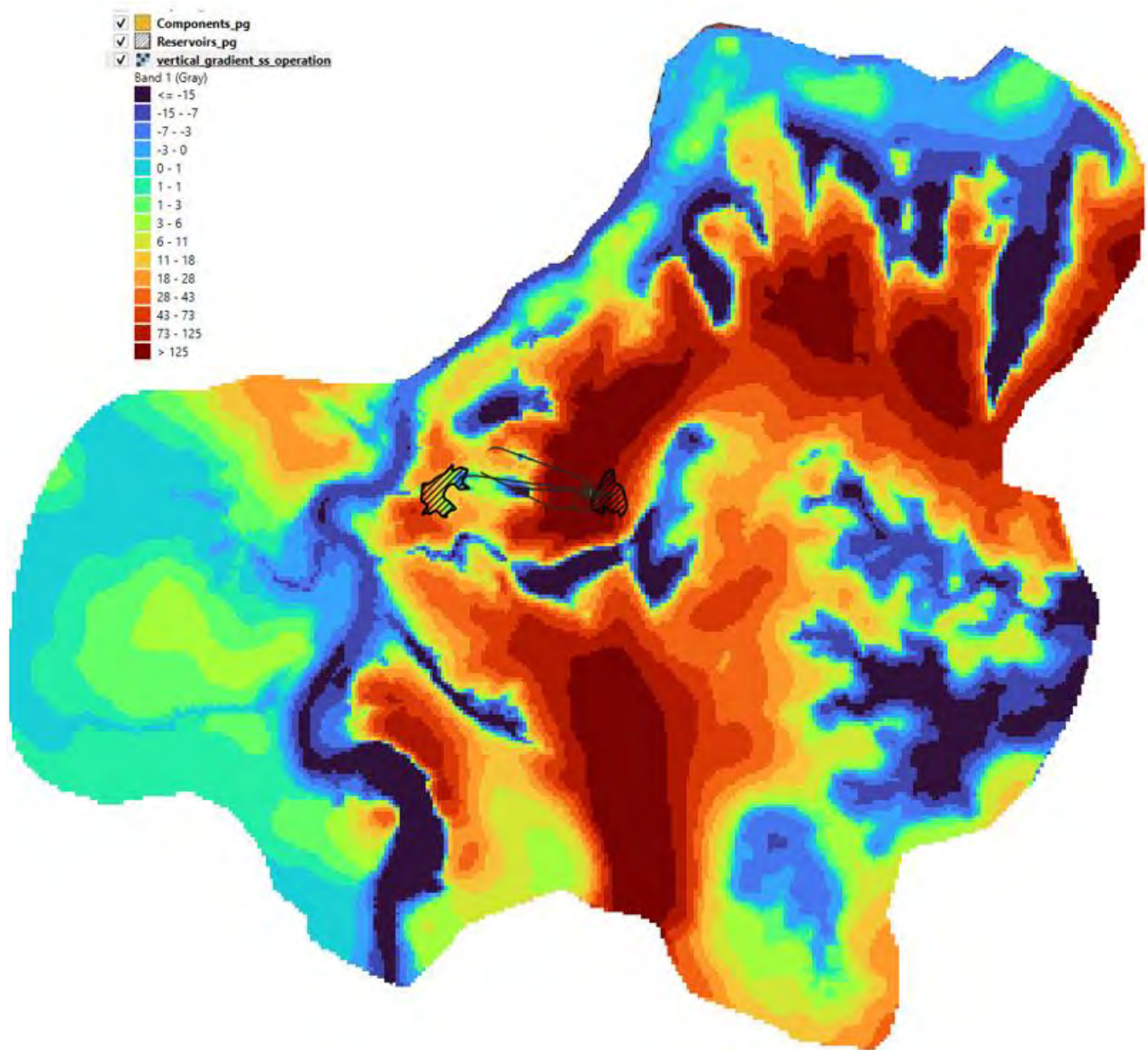


Figure 4.15 Vertical hydraulic gradient at the steady-state operation phase

4.3 Water balance

Table 4.6 presents the modelled water balance for the base realisation steady state stress period. The corresponding transient time series for the history-matching period is shown on Figure 4.16. 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 4.6 Modelled steady state pre-Project water balance

Water balance component	In (ML/d)	Out (ML/d)
Rainfall recharge	27.52	-
Evapotranspiration		13.51
River recharge – Macleay River leakage	0.89	
River recharge – Macleay River other creeks and streams leakage	0.12	
Discharge to rivers – Macleay River baseflow		7.09
Discharge to rivers – Macleay River other creeks and streams baseflow	-	7.94
Total	28.54	28.54
Water balance error		0.00%

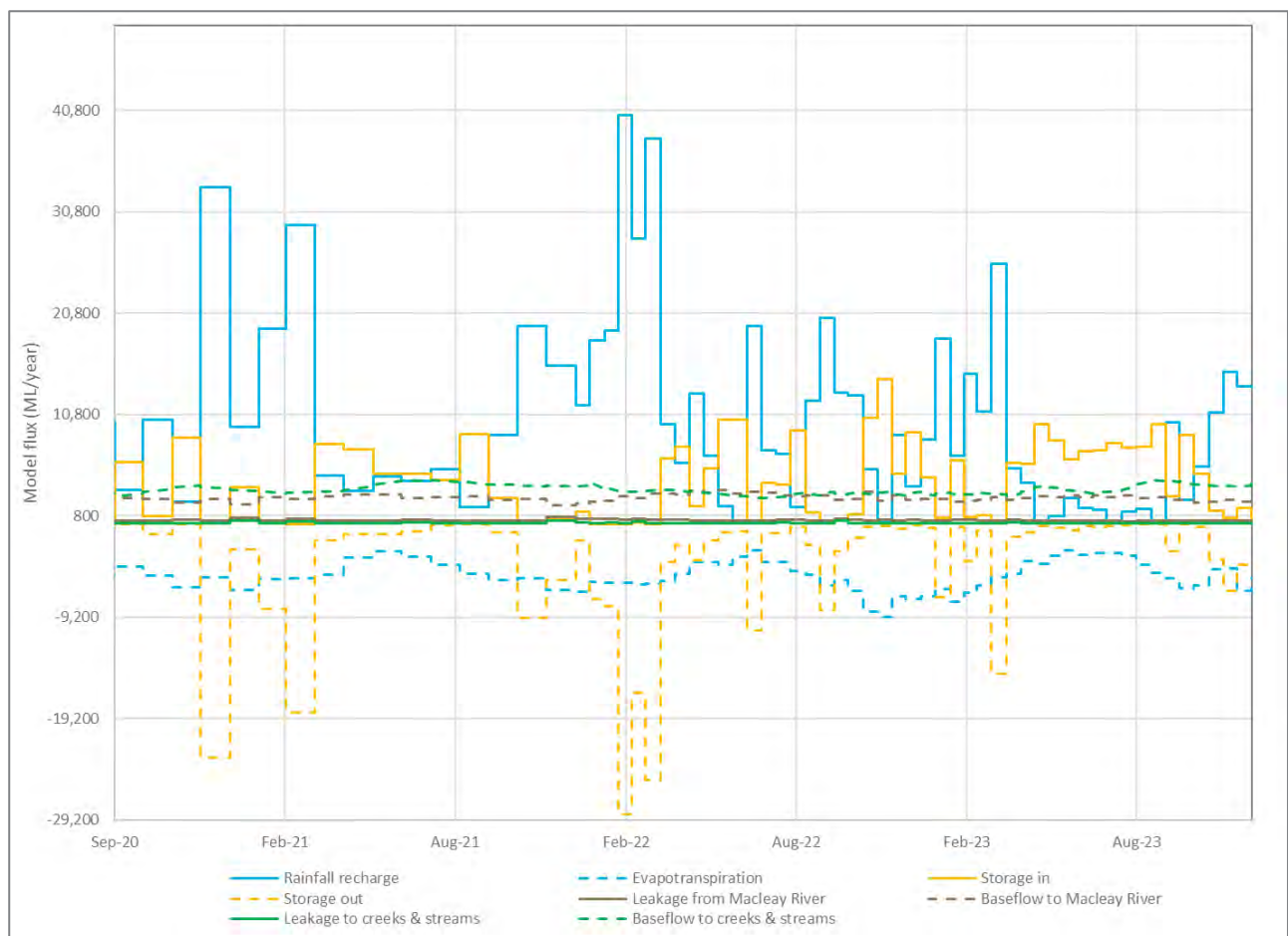


Figure 4.16 Modelled transient water balance over the history-matching period

4.4 Base realisation hydraulic properties

Table 4.7 presents a summary of modelled hydraulic properties resulting from the history-matching process, that are subsequently referred to as the “base realisation” 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 K_h 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 system is isotropic ($K_h = K_v$), 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).

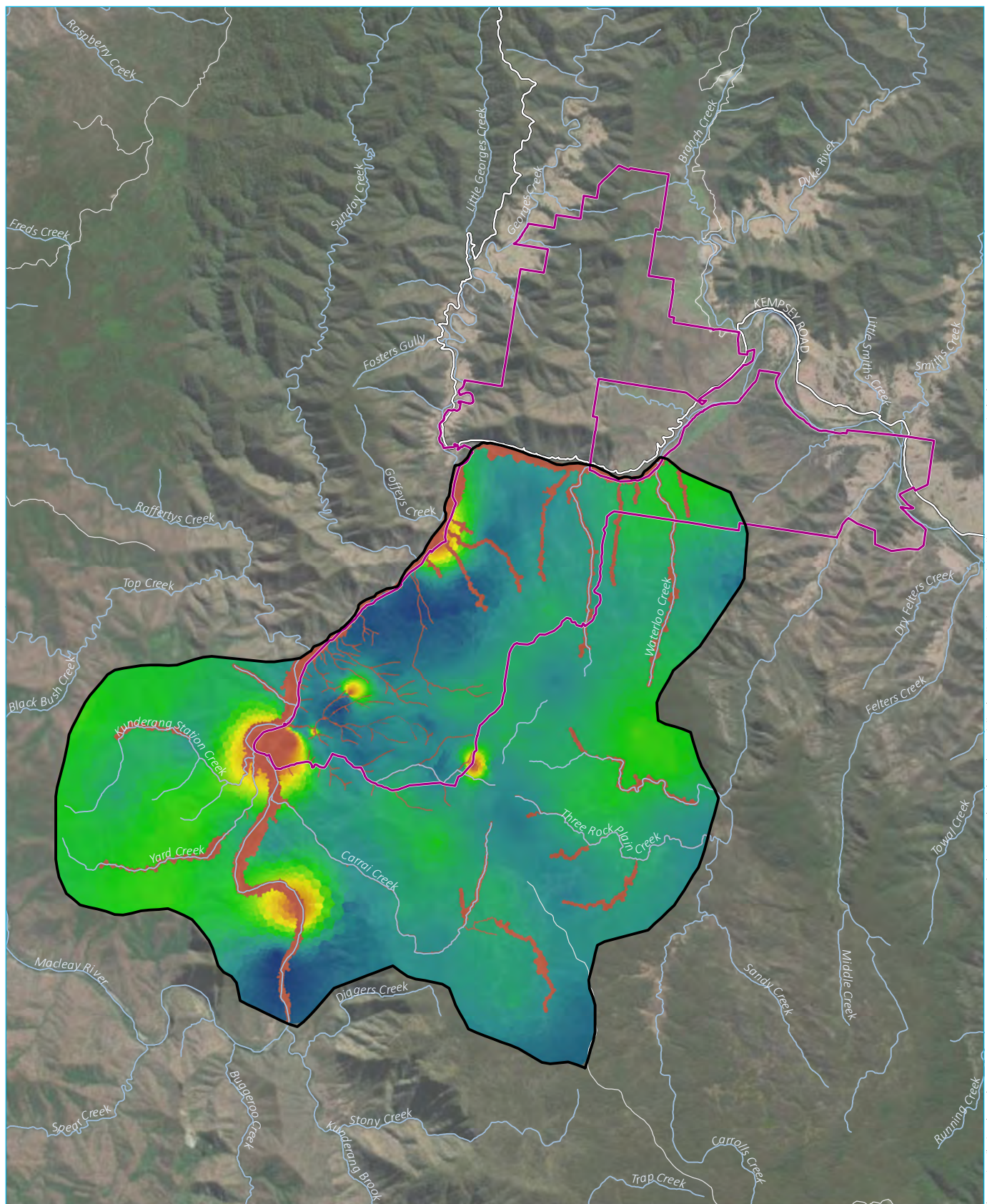
Distributions of spatially variable K_h (m/d) for the alluvium/colluvium/weathered bedrock, the fractured bedrock and the tight bedrock are presented in Figure 4.17 to Figure 4.19, respectively. These figures are presented as a $\log_{10}$ transform of the conductivity to better show variations and since they were history-matched on a log scale.

Table 4.7 **Modelled aquifer properties**

Group	HSU	Kh and Kv (m/d)	Sy (%)	Ss (1/m)
		(P10, P90, mean)	(P10, P90, mean)	(P10, P90, mean)
Base	Alluvium, colluvium	1.99, 9.55, 7.87	5.2×10^{-2} , 0.39, 0.206	7.9×10^{-7} , 1×10^{-4} , 3×10^{-5}
	Weathered bedrock	7×10^{-4} , 1.69, 1.20	2.2×10^{-2} , 0.39, 0.14	3.6×10^{-8} , 4×10^{-5} , 3×10^{-5}
	Fractured bedrock	1×10^{-3} , 0.18, 0.075	3.9×10^{-3} , 0.045, 0.02	1.7×10^{-7} , 1×10^{-5} , 5×10^{-6}
	Tight bedrock	1×10^{-4} , 0.07, 0.03	3.5×10^{-5} , 7×10^{-4} , 3×10^{-4}	4.5×10^{-8} , 1×10^{-4} , 7.8×10^{-5}
Ensemble of accepted realisations	Alluvium, colluvium	1.13, 13.29, 8.41	0.04, 0.44, 0.21	2.9×10^{-7} , 1×10^{-4} , 9×10^{-5} ,
	Weathered bedrock	$4 \times 1 \times 10^{-4}$, 3.26, 1.52	0.016, 0.44, 0.15	3.0×10^{-8} , 7×10^{-5} , 7×10^{-5}
	Fractured bedrock	8×10^{-4} , 0.24, 0.15	3×10^{-3} , 0.63, 0.024	7.9×10^{-8} , 2×10^{-5} , 1×10^{-5}
	Tight bedrock	8×10^{-5} , 0.10, 0.04	2×10^{-5} , 1×10^{-3} , 4×10^{-4}	3.4×10^{-8} , 2×10^{-4} , 1×10^{-4}

Table 4.8 **Modelled recharge zones and rates**

Group	Model recharge zone/ Representative Focus Area	Recharge rate (mm/yr) / Recharge % (% of annual avg rainfall - AAR)		
		P10	P90	Mean
Base	1/Escarpment	15 mm/yr (1.5% of AAR)	86 mm/yr (8.9% of AAR)	39 mm/yr (4.0% of AAR)
	2/Plateau	52 mm/yr (5.4% of AAR)	194 mm/yr (20.0% of AAR)	136 mm/yr (14.0% of AAR)
	3/Alluvium	119 mm/yr (12.3% of AAR)	485 mm/yr (50.0% of AAR)	292 mm/yr (30.1% of AAR)
	4/Model cells containing river boundary conditions	0 mm/yr (0% of AAR)	0 mm/yr (0% of AAR)	0 mm/yr (0% of AAR)
Ensemble of accepted realisations	1/Escarpment	12 mm/yr (1.2% of AAR)	94 mm/yr (9.7% of AAR)	40 mm/yr (4.1% of AAR)
	2/Plateau	49 mm/yr (5.1% of AAR)	193 mm/yr (19.9% of AAR)	135 mm/yr (13.9% of AAR)
	3/Alluvium	96 mm/yr (9.9% of AAR)	485 mm/yr (50.0% of AAR)	296 mm/yr (30.5% of AAR)
	4/Model cells containing river boundary conditions	0 mm/yr (0% of AAR)	0 mm/yr (0% of AAR)	0 mm/yr (0% of AAR)



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

KEY

- Project area
- Model domain
- Existing environment
- Major road
- Minor road
- Named watercourse

Log₁₀ hydraulic conductivity (m/day)

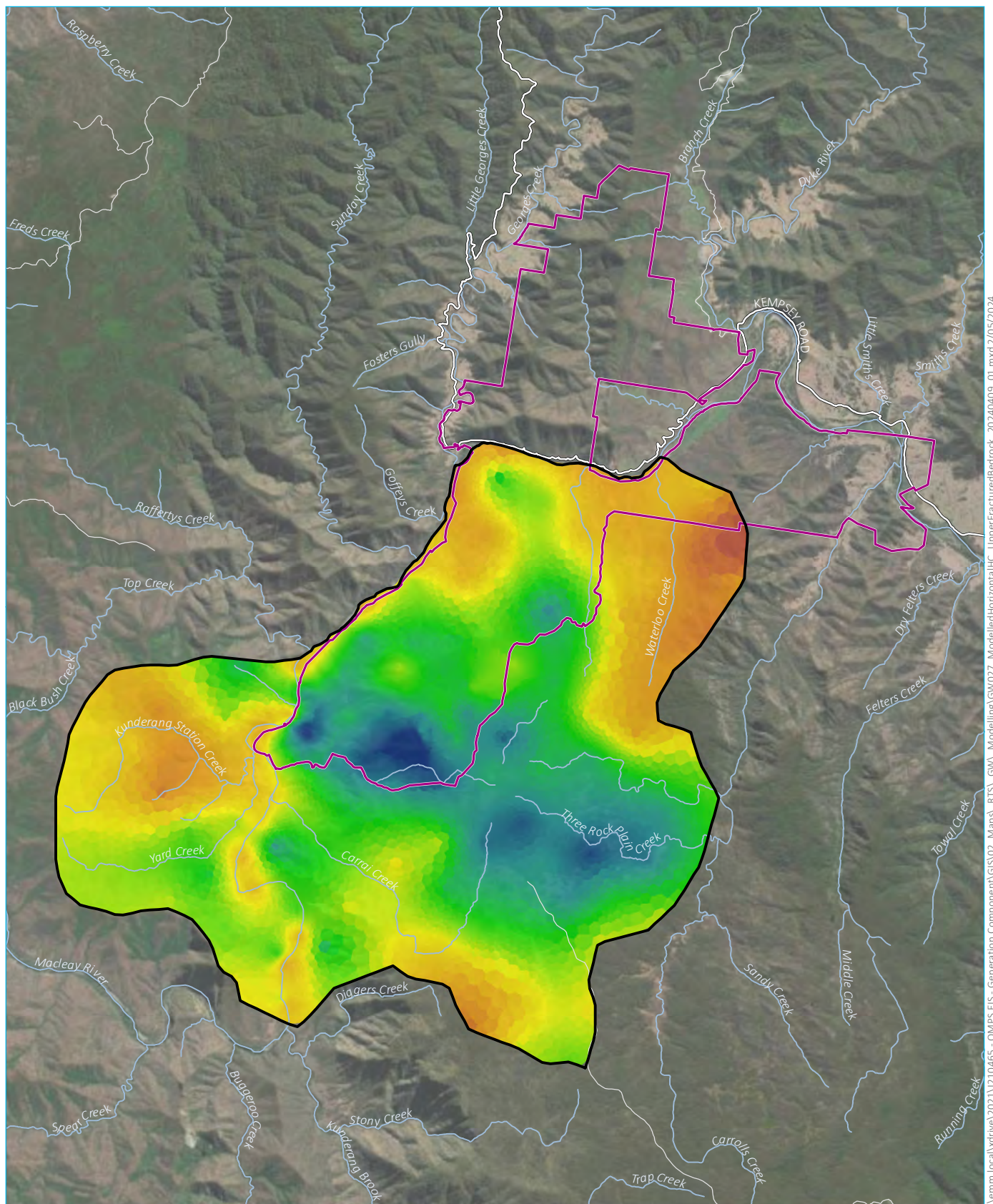
High : 1.24

Low : -2.56

Modelled horizontal hydraulic conductivity of
alluvium, colluvium and residual soil

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd

Figure 4.17



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

KEY

- Project area
- Model domain
- Existing environment
- Major road
- Minor road
- Named watercourse

Log₁₀ hydraulic conductivity (m/day)

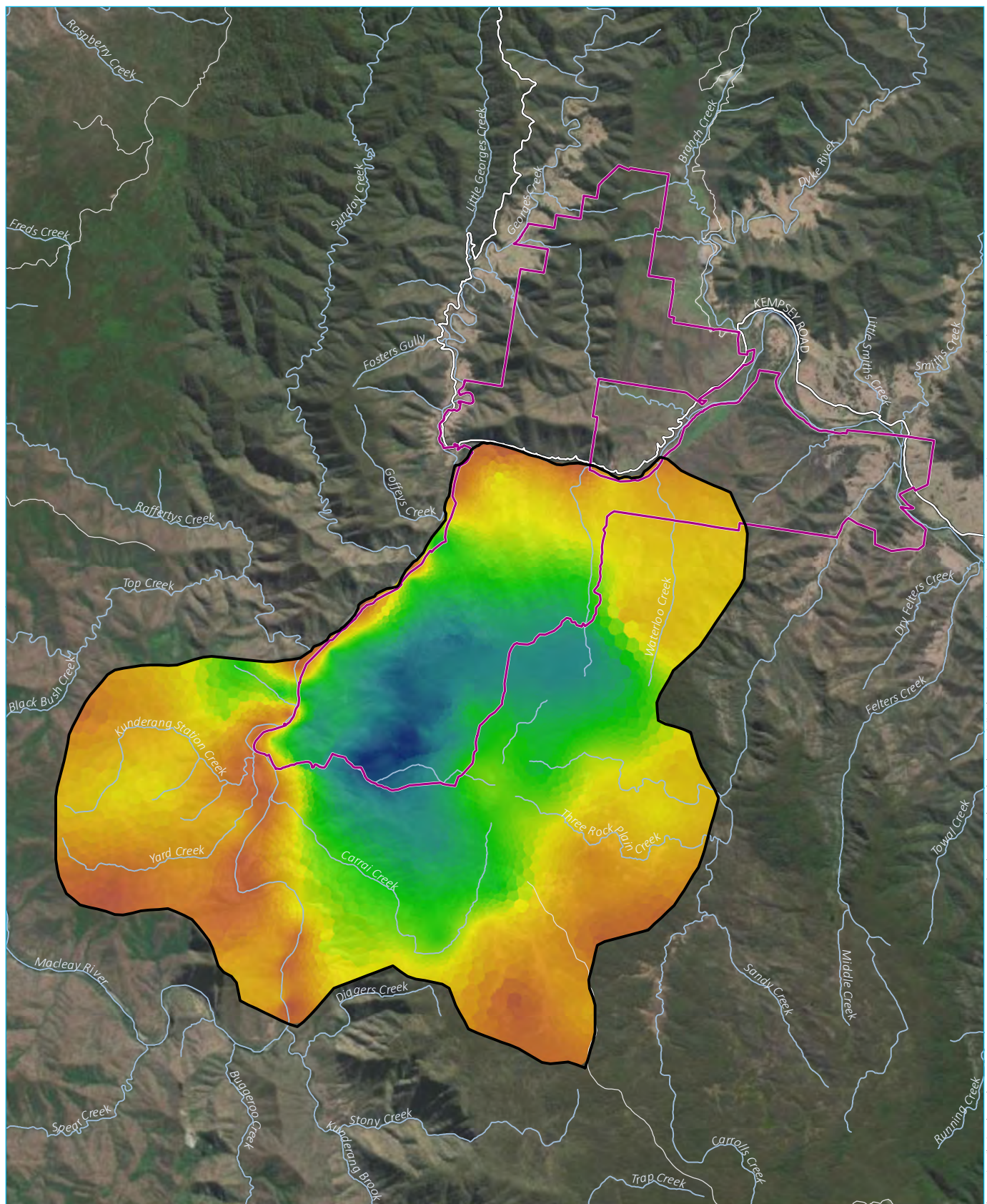
High : -1.0

Low : -2.82

Modelled horizontal hydraulic conductivity of upper fractured bedrock unit

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd

Figure 4.18



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

KEY

- Project area
- Model domain
- Existing environment
- Major road
- Minor road
- Named watercourse

Log₁₀ hydraulic conductivity (m/day)

High : -1.99

Low : -4.24

Modelled horizontal hydraulic conductivity of deeper tight bedrock

Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd

Figure 4.19

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. The ensemble of parameter realisations, including the base realisation, was 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. 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

The accepted ensemble of realisations, following history-matching, was used 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 realisations. Both a null scenario and project scenario were modelled using each accepted realisation. The base realisation model is considered one of these 81 realisations and is differentiated graphically in Section 5.4 for the sake of clarity. The base realisation 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 2026 to January 2030.	Transient followed by steady state.
Penstock tunnels, draft tube merged tunnels, and draft merged tunnels.	MODFLOW drains with stage at invert of tunnel.	No boundary conditions: they are steel lined after their construction.
Bifurcated tunnel, and pressure shaft.	MODFLOW drains with stage at invert of tunnel.	MODFLOW general head boundary adopting pressure of upper reservoir.
Tailrace tunnel and lower intake.	MODFLOW drains with stage at invert of tunnel.	MODFLOW general head boundary adopting pressure of upper reservoir.
ECVT, IPB galleries, machine hall, machine hall construction adit, MAT, MAT2, MH TH egress access, tailrace surge shaft, transformer hall, TSST.	MODFLOW drains with stage at invert of tunnel.	MODFLOW drains with stage at invert of tunnel.
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 realisation water balance

The base realisation model predictions are presented here for:

- groundwater inflows to each component of the project during construction
- river water balances during construction and operation
- 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 inflows to each component of the Project during each quarter of construction are tabulated in Table 5.2 and presented graphically in Figure 5.1. These show that construction of the upper reservoir and the lower reservoir receive between 25% and 66% of the total predicted groundwater inflow for the entire construction schedule. The other main contributors are the MAT, tailrace tunnel and the ECVT that represent between 34% and 73%. Total predicted groundwater inflow is approximately ~79 ML/yr at the beginning of construction (January 2027), then it steadily increases to almost 450 ML/year in April January 2028. From then on inflows fluctuate typically in the range of 360 to 450 ML/yr until the end of the construction period.

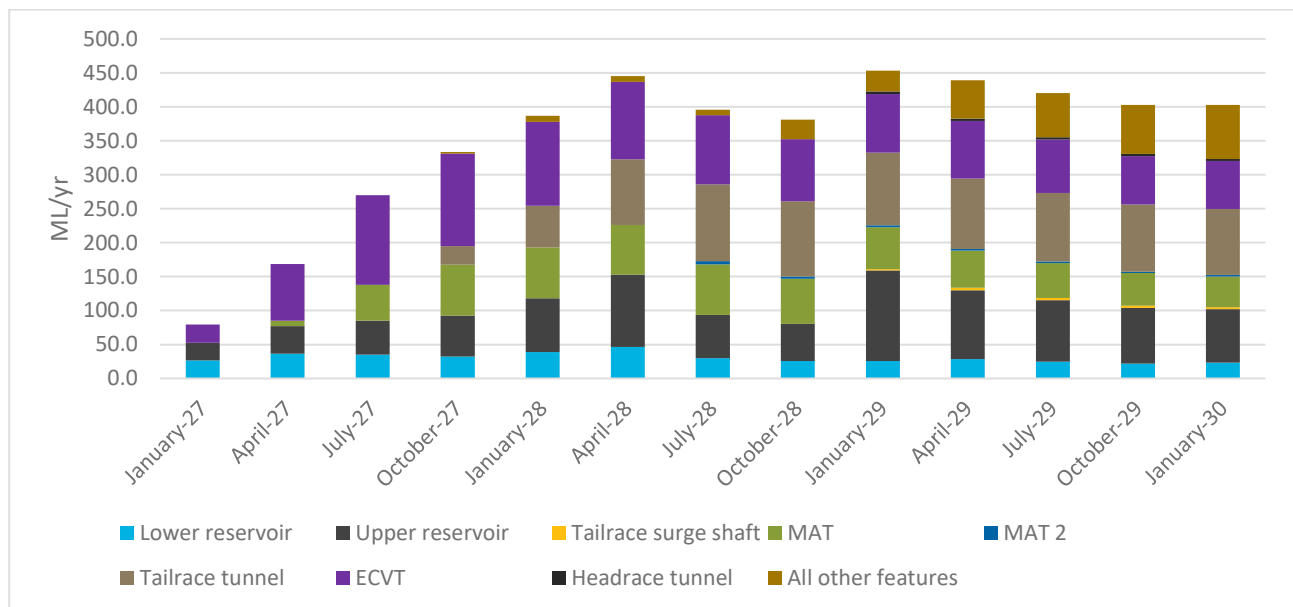


Figure 5.1 Base realisation groundwater inflow to project components during construction

Table 5.2 **Base realisation groundwater inflow to project components during construction**

Project components	January-27	April-27	July-27	October-27	January-28	April-28	July-28	October-28	January-29	April-29	July-29	October-29	January-30
Total	79.3	168.5	269.7	333.5	387.0	445.3	395.7	381.4	453.2	439.1	420.2	402.8	402.7
Lower reservoir	26.5	36.7	35.2	32.3	38.9	46.6	29.8	25.8	25.6	28.8	24.7	21.9	23.4
Upper reservoir	26.1	40.5	50.0	60.3	79.1	106.4	63.6	54.6	133.4	101.3	90.8	82.3	78.6
Tailrace surge shaft	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	3.8	3.3	3.2	3.1
MAT	0.0	7.9	52.8	74.9	75.2	73.2	74.9	66.7	61.9	54.6	51.1	47.9	45.1
MAT 2	0.0	0.0	0.0	0.0	0.0	0.0	4.6	3.3	2.6	2.4	2.4	2.3	2.2
Tailrace tunnel	0.0	0.0	0.0	27.7	61.4	96.6	112.8	110.9	107.2	103.4	101.0	98.8	97.4
ECVT	26.8	83.4	131.7	135.9	123.5	114.1	102.1	91.3	86.2	84.8	78.5	71.3	70.3
Headrace tunnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	3.4	3.3	3.3	3.1
All other features	0.0	0.0	0.0	2.6	9.0	8.4	7.9	28.9	30.7	56.7	65.1	72.0	79.5

5.3.2 Groundwater flow to/from project components during operation

During steady state operation the base realisation predicts 234.6 ML/yr of groundwater take. This includes 173.0 ML/yr of groundwater inflow to excavated project components and 60.7 ML/yr to the two reservoirs. The reservoirs also leak a combined total of 93.8 ML/yr back to the aquifer (i.e. the inflow, ultimately, contributes to throughflow). 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 components	Loss to aquifer	Take from aquifer
Total	93.8	234.6
Lower reservoir	52.1	13.8
Upper reservoir	29.8	46.9
Tailrace surge shaft	0.0	4.7
MAT	0.0	29.8
MAT 2	0.0	2.4
Tailrace tunnel	0.7	36.7
ECVT	0.0	69.1
Headrace tunnel	0.4	0.0
All other features	10.8	30.3

5.3.3 River water balances

Water balances for the Macleay River and surrounding creeks were computed during both the transient construction phase and the steady-state operational phase. These water bodies were categorised based on their location—either within the Macleay Gorges water source or the Macleay Valley water source – and by the direction of water movement (whether as leakage from the river to the aquifer or as baseflow from the aquifer to the river). The resulting water balances for the rivers are depicted in Figure 5.2. In this figure, a negative value indicates a reduction of baseflow or induced leakage.

The data demonstrates that the baseflow from the aquifer to the Macleay River and other creeks is reduced by an average of 50.1 ML/yr during the construction stage, attributed to the excavation work for the lower reservoir in the vicinity. Then, during the operation phase it can be observed that the decrease of this baseflow becomes lower, due to the start of the operation as the cells within the lower reservoir become GHB, which increases the flow towards the other creeks.

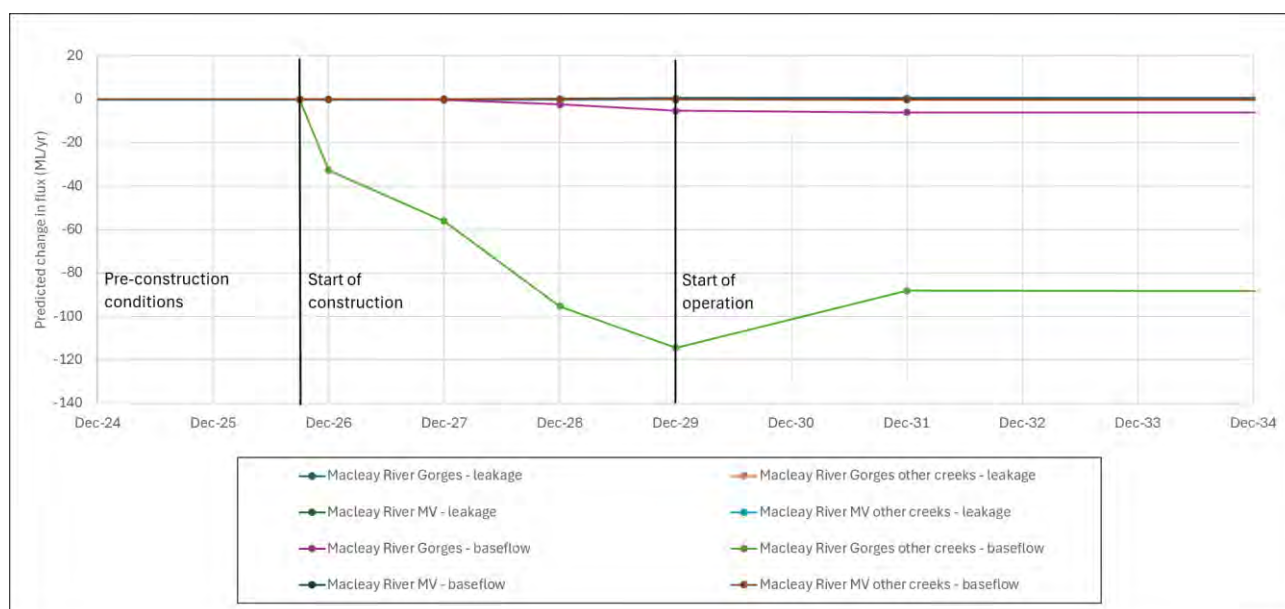


Figure 5.2 River water balance changes during construction and steady state operation comparing null and project scenarios

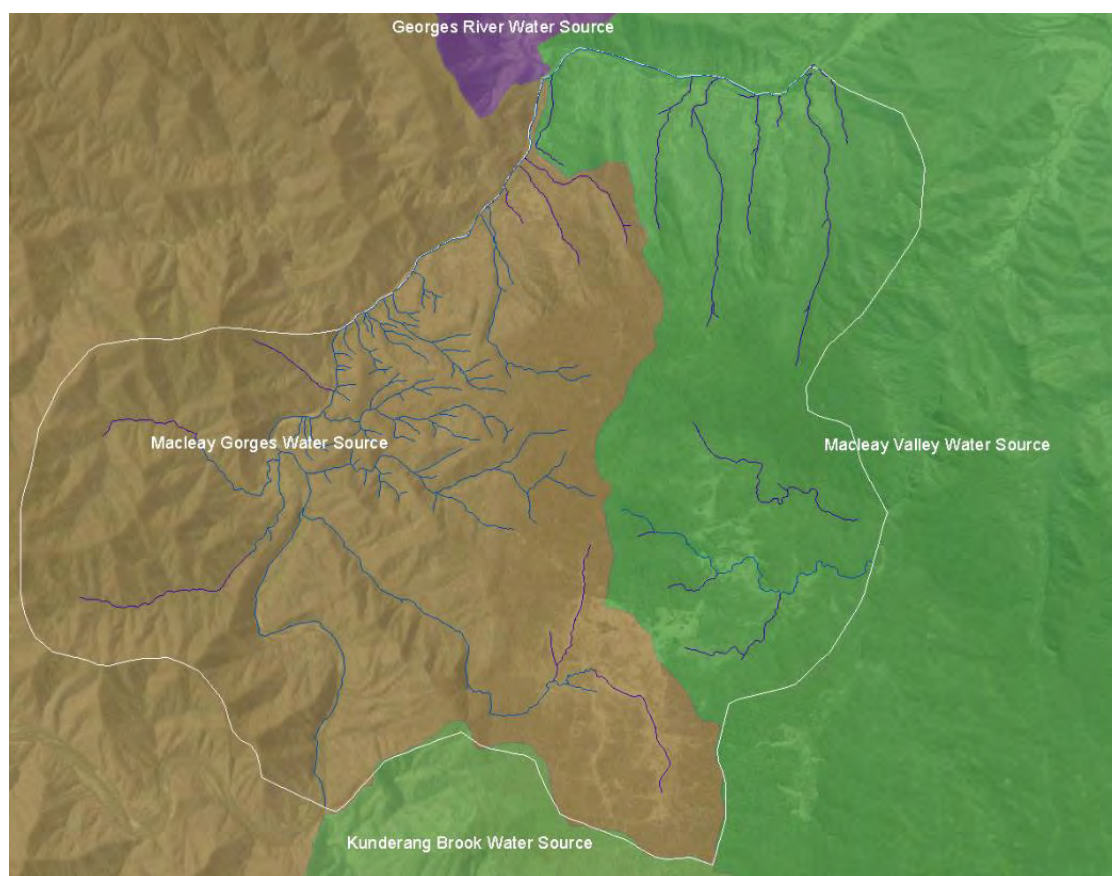


Figure 5.3 Differentiation of river types referred to in Figure 5.2

Figure 5.4 illustrates the modelled river fluxes for the base realisation, along with the percentiles across the ensemble of accepted realisations. In general, the losses from the aquifer to the creeks (baseflow) exceed the inflows into the aquifer. Seasonal fluctuations are also observed. Additionally, the fluxes during the construction and long-term operation periods do not show significant changes compared to the pre-construction conditions.

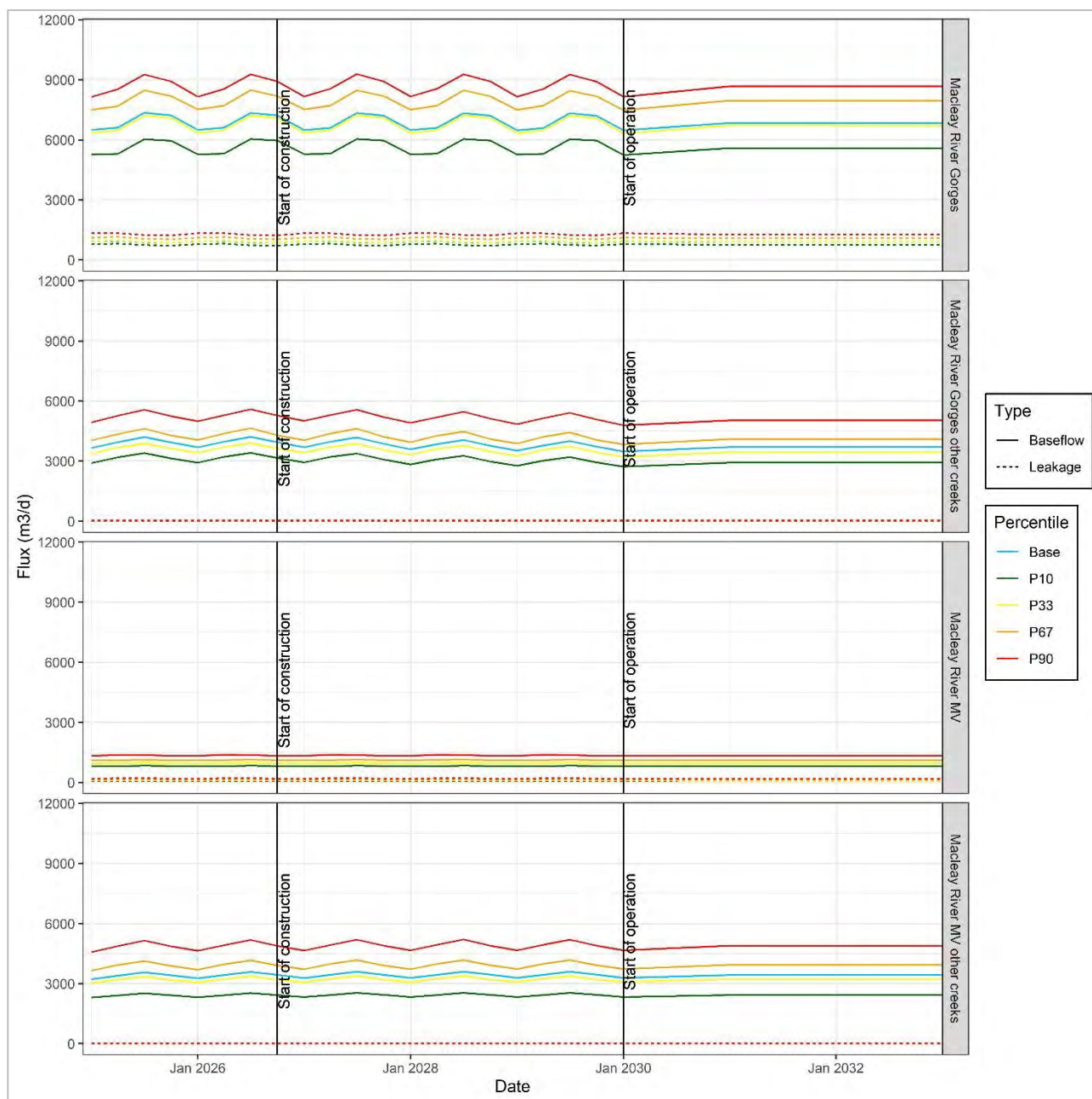


Figure 5.4 River fluxes

5.3.4 Accepted parameter values

After rejecting realisations that did not meet the history-matching acceptance criteria, distributions of the posterior parameter values K_h (which I equal to K_v), S_y , S_s and recharge were analysed. Figure 5.5 to Figure 5.8 present histograms of the distributions of parameter values for the prior (pre-history-matching), posterior (accepted ensemble) and base realisation.

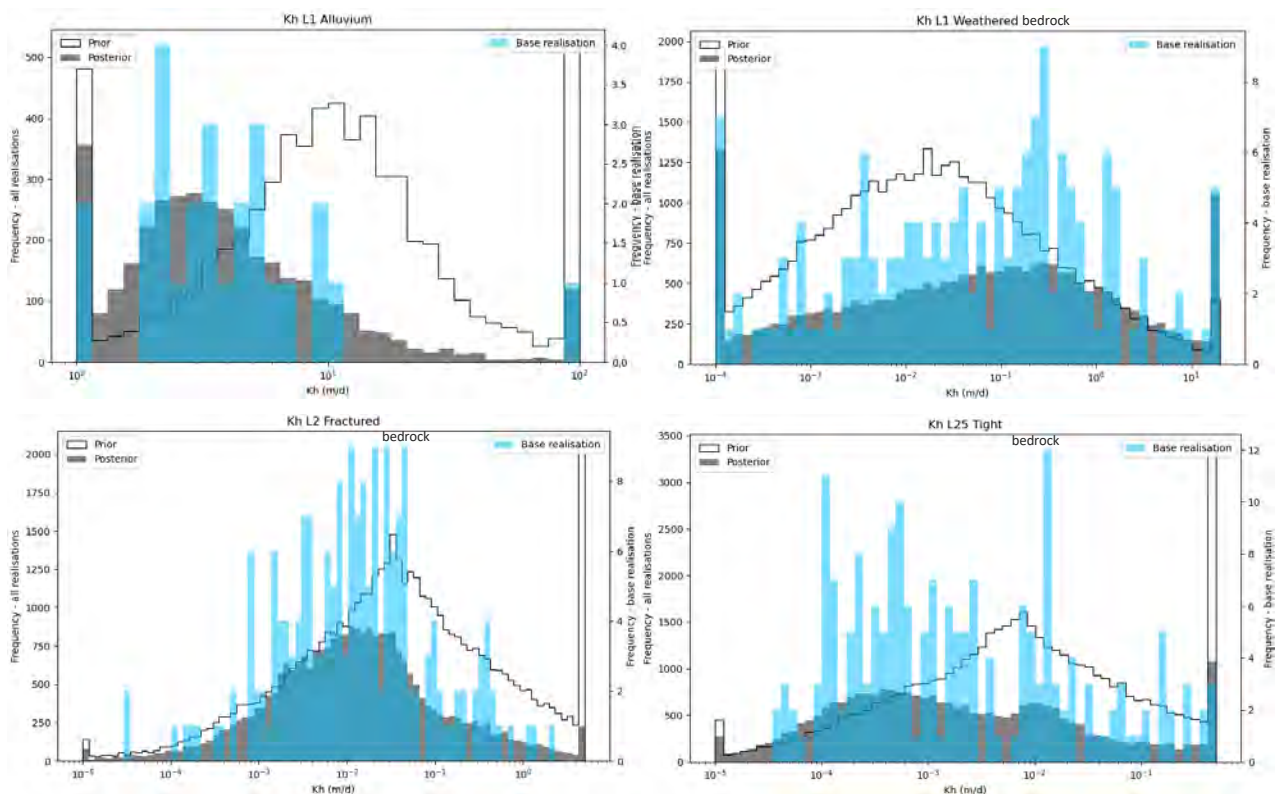


Figure 5.5 Histograms of Kh values

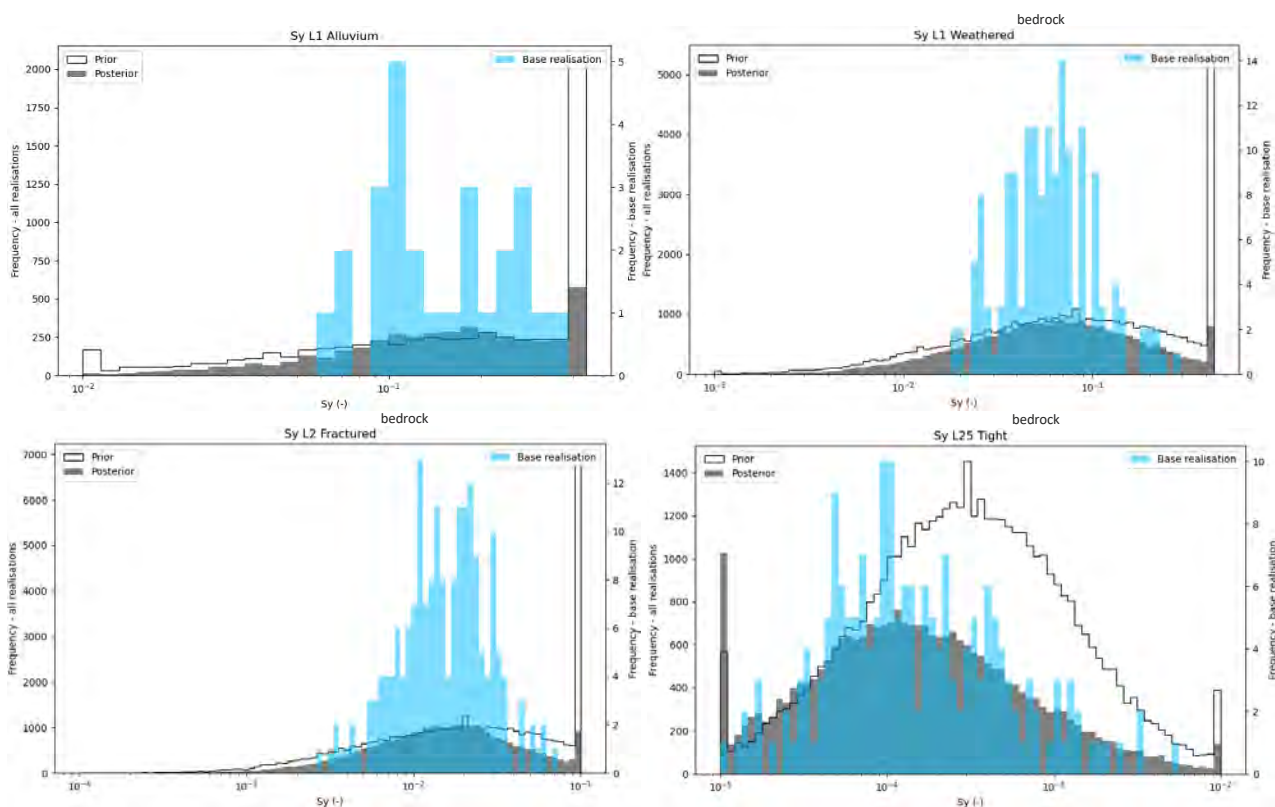


Figure 5.6 Histograms of Sy values

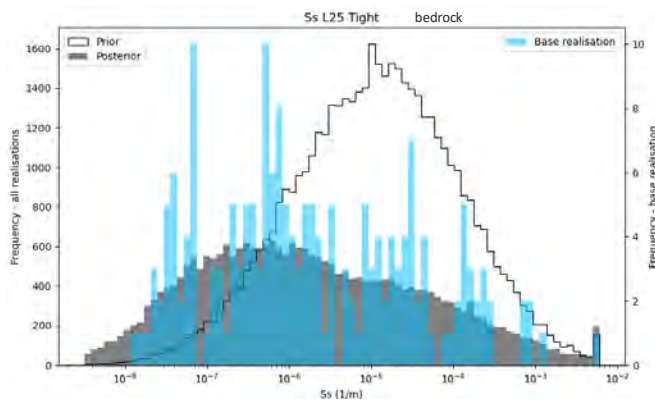


Figure 5.7 Histogram of Ss values

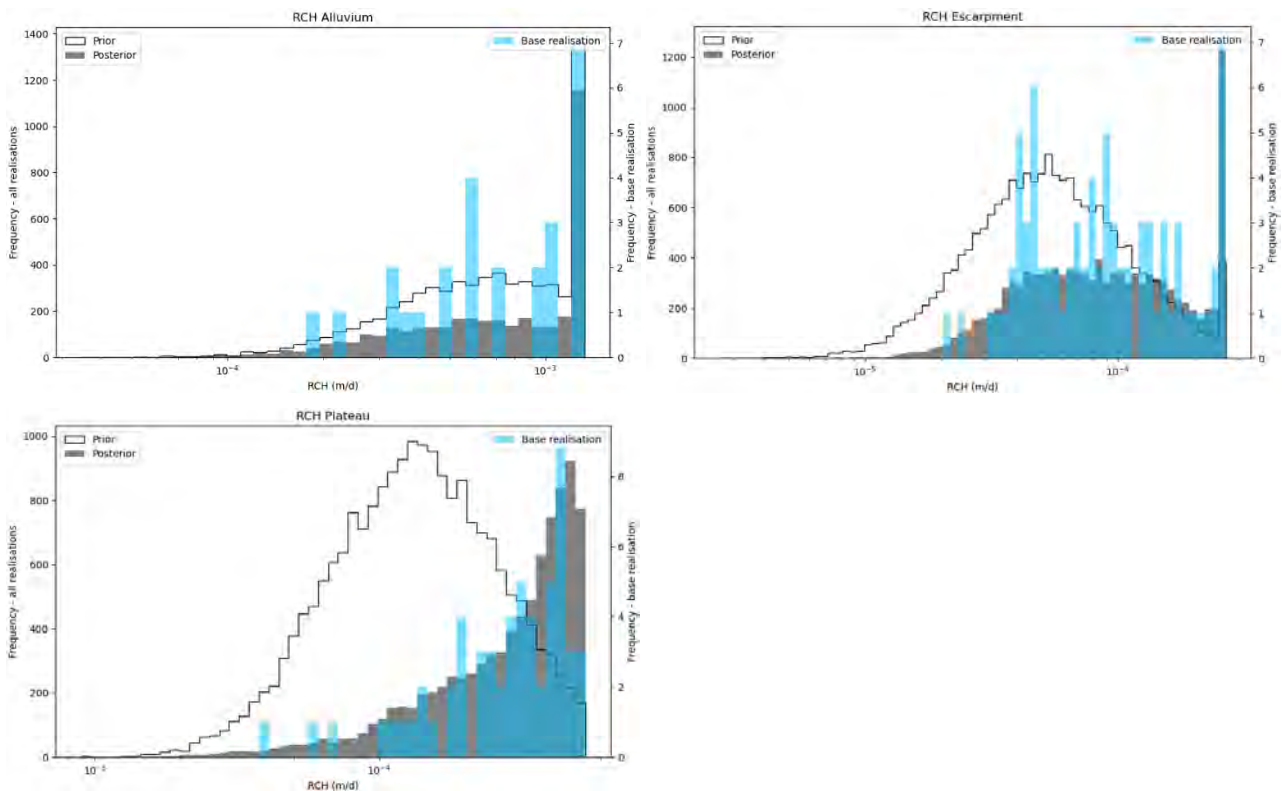


Figure 5.8 Histograms of recharge values

5.4 Results

This section of the report presents probabilistic 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
- water balances for construction and operation (separate to the base realisation water balance presented in Section 5.3).

In this section results for the base realisation are not differentiated from the ensemble of 81 accepted realisations. The base realisation is just one of the plausible realisations within the ensemble for which results are presented as a cohesive set of predictions to understand the predictive uncertainty for the key model outputs described in the dot points above.

5.4.1 Site-wide drawdown/mounding

The drawdown and mounding predicted for the watertable during construction and operation are presented in Figure 5.9 to Figure 5.14. 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 5.4.2 and 5.4.3.

Each of the drawdown and mounding maps presents the likelihood of exceeding a threshold (2 m or 0.2 m) considering all of the accepted model realisations including the base realisation (81 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 (e.g. 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.

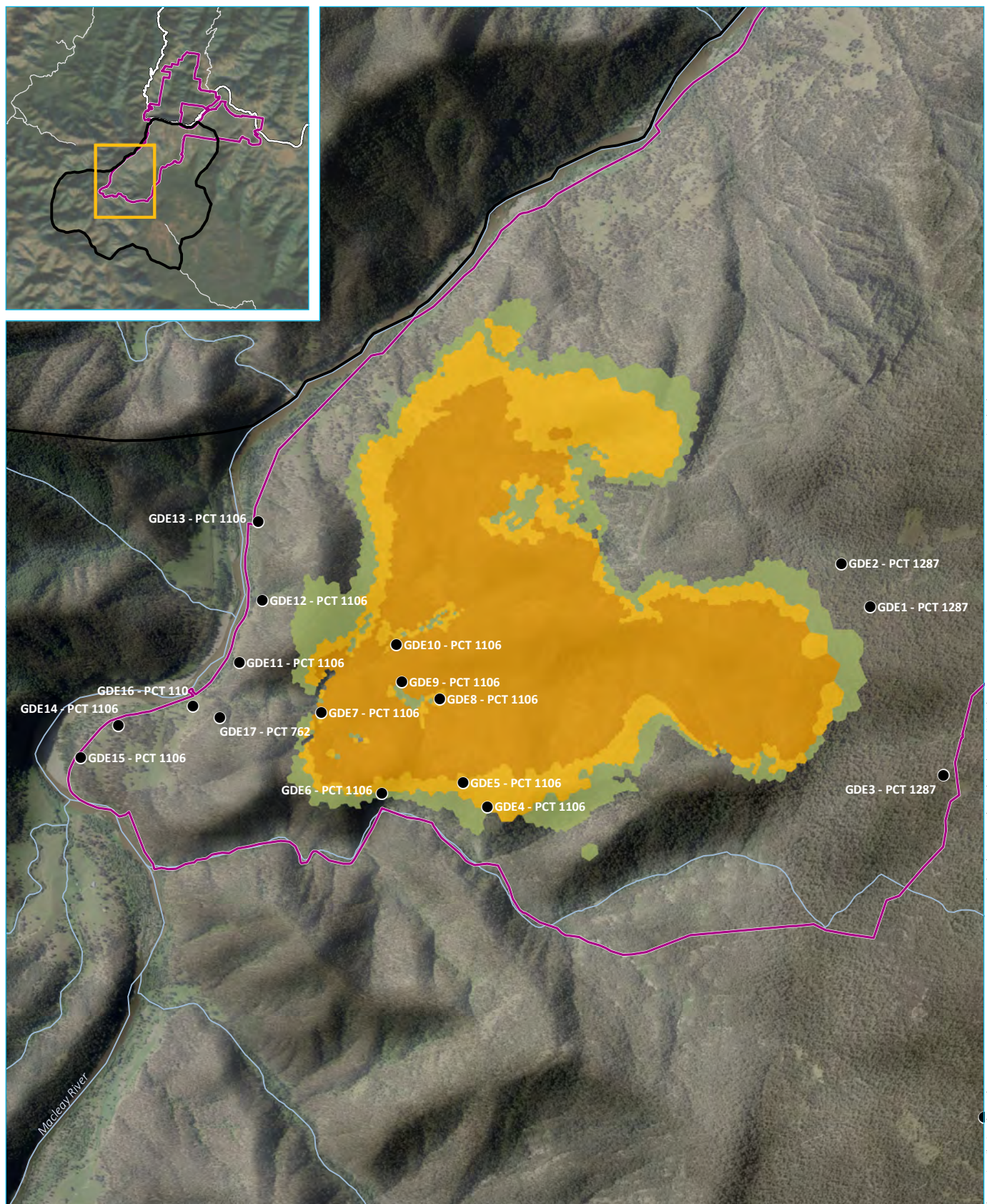
The rationale for the percentile approach to presenting predicted drawdown and mounding is based on Table 2 of Middlemis and Peeters (2018). Those uncertainty guidelines describe the importance of calibrated language and having a consistent and precise language to communicate impacts to decision makers. Table 5.4 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 5.9 to Figure 5.14. Note, on these figures the <P10 band is not shown.

Table 5.4 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:

- At the 2 m threshold (see Figure 5.9), the most significant drawdown occurs during construction when both the upper and lower reservoirs undergo excavation and passive dewatering. Concurrently, the transformer, machine halls, MAT, and MAT2 are excavated and dewatered passively. In contrast, drawdown is considerably reduced during the operational phase of the scheme (see Figure 5.11), when the reservoirs are replenished to their design water levels, and the waterways are pressurised to enable water flow between the reservoirs and through the power station. Operational drawdown is mainly confined to the escarpment area upstream of the lower reservoir, due to ongoing dewatering of the fractured bedrock, which is a consequence of water inflows to the (dry) MAT, MAT2, ECVT, and TSST. The construction-related drawdown at the 2 m threshold predominantly affects areas around the upper reservoir and the escarpment, attributed to the excavation work required to construct the underground tunnels.
- The drawdown during the construction extents at the 0.2 m (see Figure 5.10) threshold span a marginally wider area, primarily concentrated within 250 m of the Project components. Additionally, drawdown extends to three further zones to the south, with the largest located on the plateau on the eastern side of the upper reservoir. However, the modelling during the operation predicts it is unlikely for drawdown to exceed 0.2 m (see Figure 5.12) in these areas. Near the lower reservoir, the area of likely drawdown extends further west, encompassing numerous alluvial areas and creeks.
- During operation, mounding (see Figure 5.13 and Figure 5.14) is primarily confined to areas situated down-gradient from the two reservoirs. This mounding occurs once the reservoirs are filled with water at an elevation that exceeds the pre-development groundwater levels.



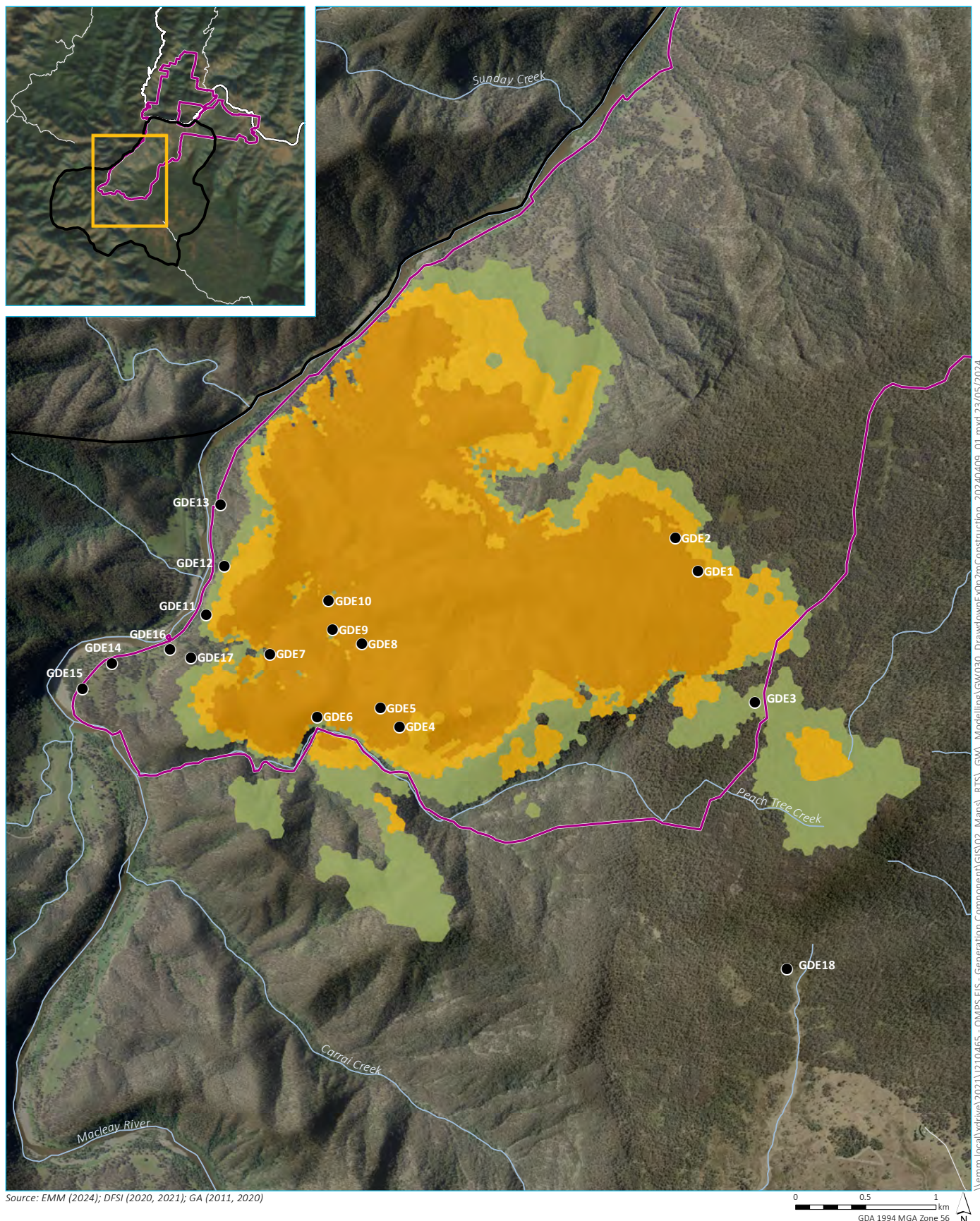
KEY

- | | |
|--|---|
| █ Project area | █ Modelled drawdown |
| ● GDEs | █ Unlikely |
| — Model domain | █ As likely as not |
| — Existing environment | █ Likely |
| — Named watercourse | |

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 5.9

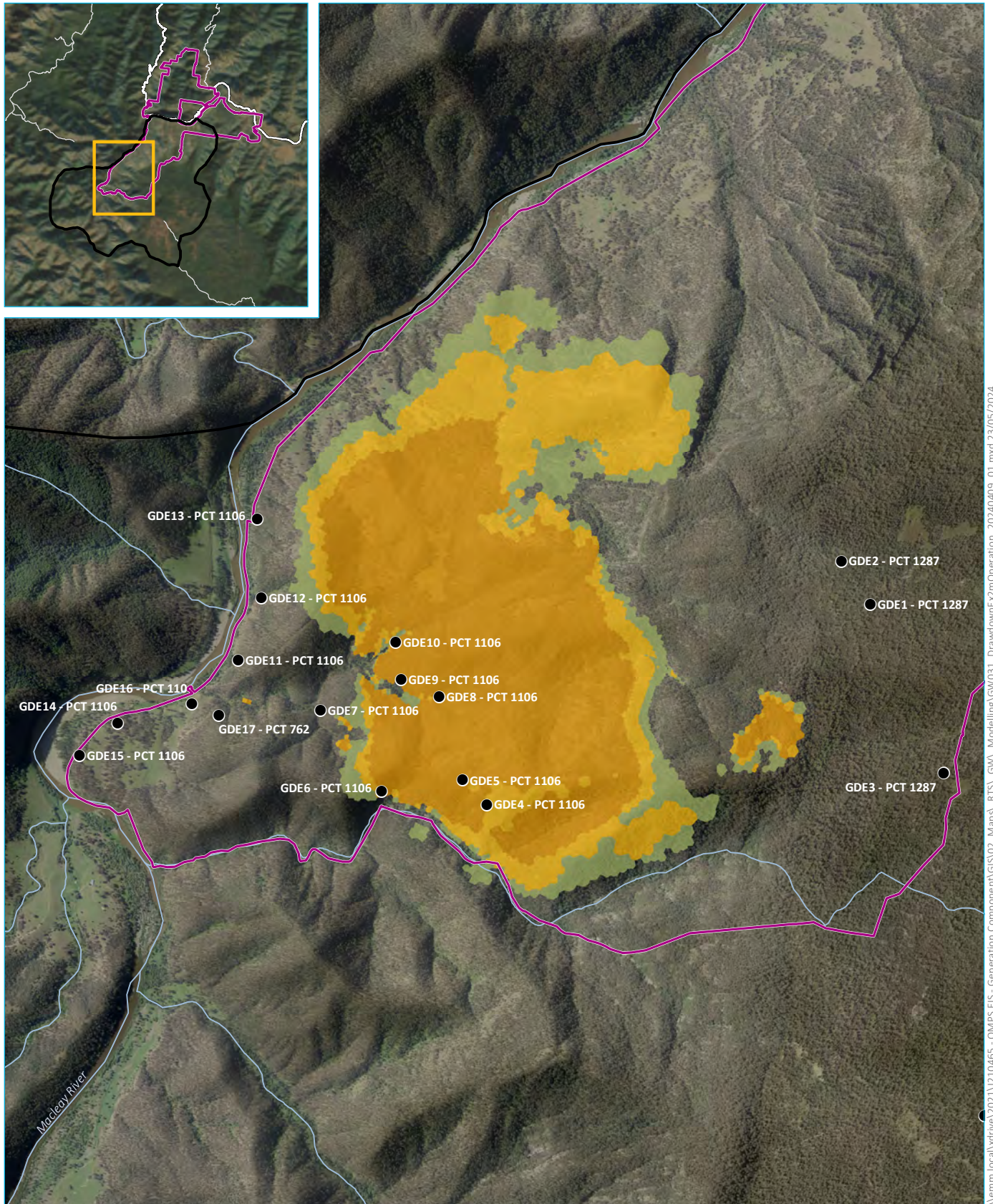


KEY

 Project area	Modelled drawdown
● GDEs	 Unlikely
— Model domain	 As likely as not
Existing environment	 Likely
— Minor road	 Very likely
Existing environment	
— Named watercourse	

Likelihood of watertable drawdown
exceeding 0.2 m at the end of
construction
Oven Mountain Pumped Hydro Energy Storage Project
Groundwater modelling report
OMPS Pty Ltd

Figure 5.10



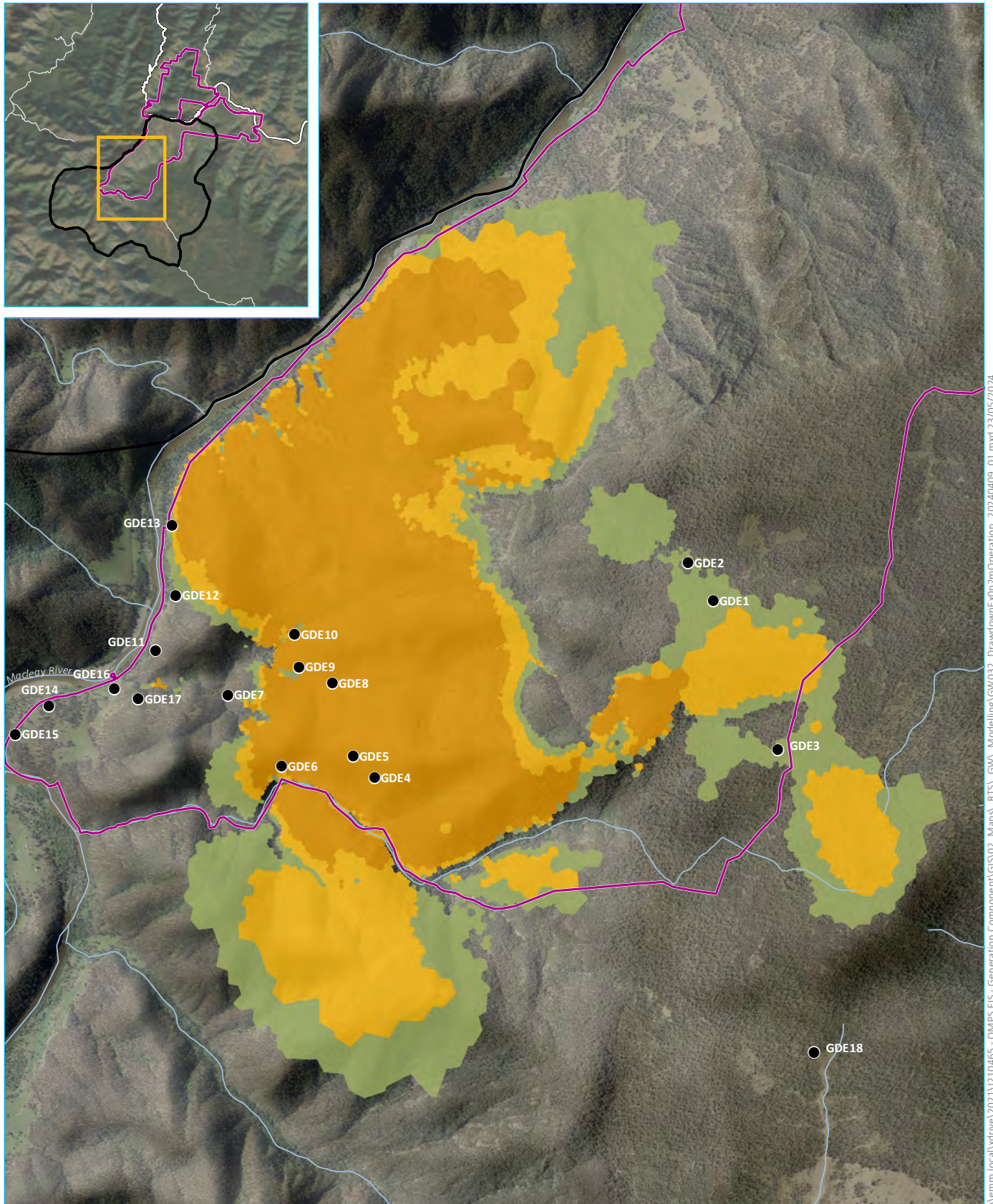
KEY

 Project area	Modelled drawdown
● GDEs	 Unlikely
— Model domain	 As likely as not
Existing environment	 Likely
— Named watercourse	 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 5.11



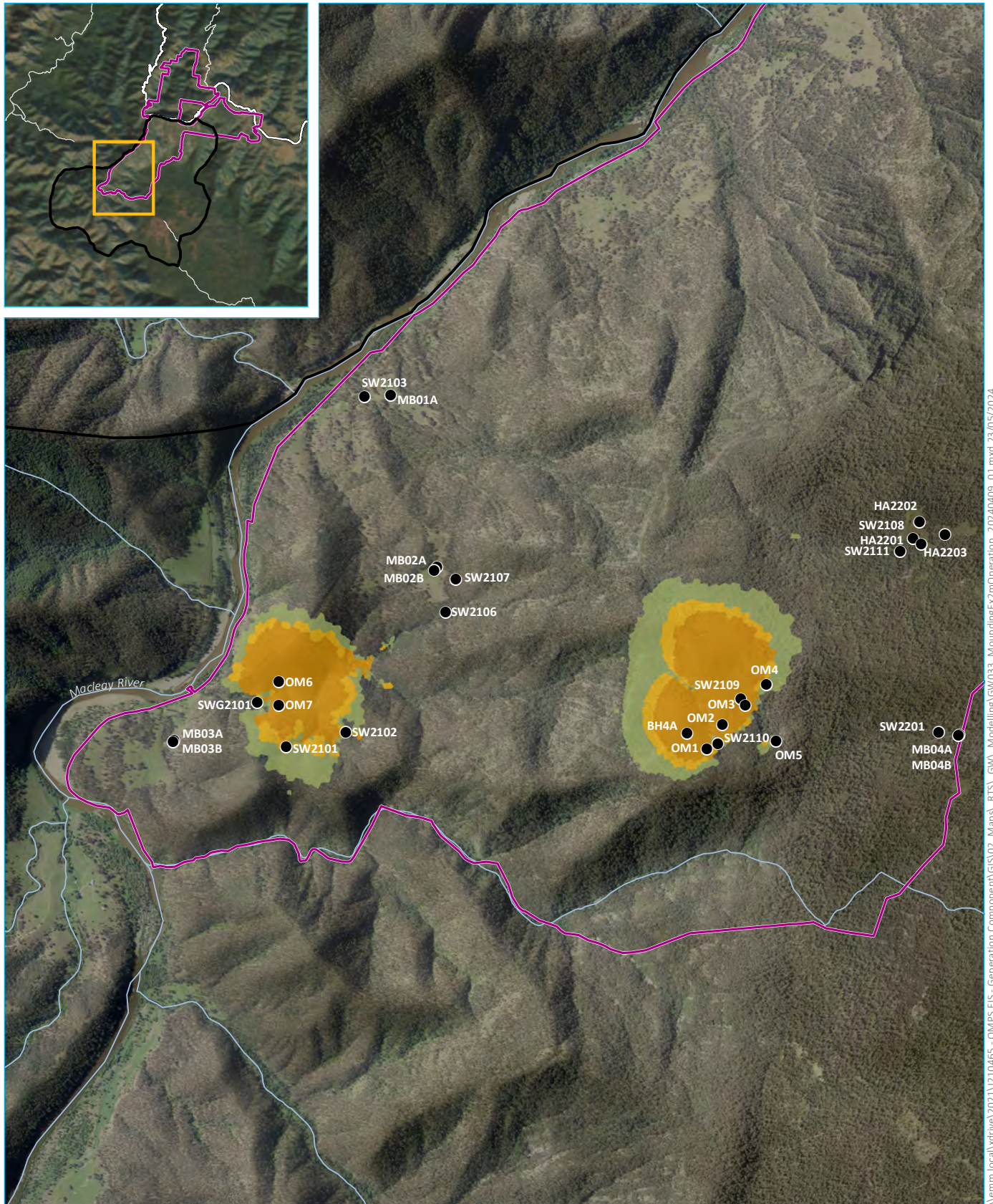
KEY

- █ Project area
- Model domain
- Extraction bore
- Existing environment
- Named watercourse
- █ Modelled drawdown Unlikely
- █ As likely as not
- █ Likely

Likelihood of watertable drawdown exceeding 0.2 m for steady state operation

Oven Mountain Pumped Hydro Energy Storage Project
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Figure 5.12



Source: EMM (2024); DFSI (2020, 2021); GA (2011, 2020)

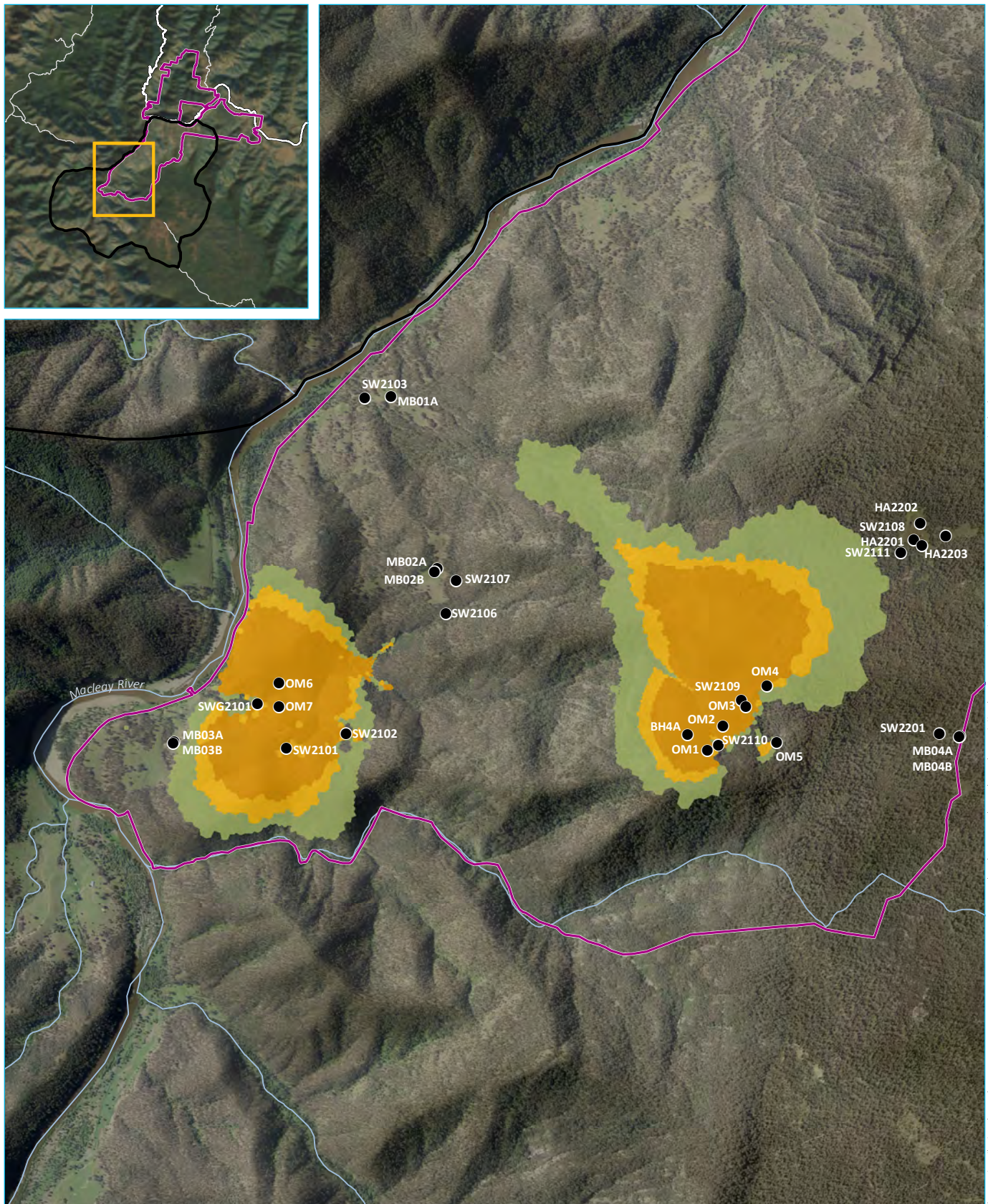
KEY

- | | |
|--|--|
| — Project area | Modelled drawdown |
| — Model domain | Unlikely |
| ● Extraction bore | As likely as not |
| — Existing environment | Likely |
| — Named watercourse | |

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 5.13



KEY

 Project area	Modelled drawdown
 Model domain	 Unlikely
 Extraction bore	 As likely as not
Existing environment	 Likely
 Named watercourse	

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 5.14

5.4.2 Drawdown/mounding at environmental receptors

The complete set of site-specific drawdown and mounding predictions at elected model nodes, representing environmental receptors or water monitoring locations, is presented in Attachment A. Two select sites are presented in Figure 5.15, including the Carrai Waterholes (predicted negligible impact) and OM2 (predicted drawdown during construction and mounding during operation).

Generally, across the 19 designated model nodes representing environmental receptors:

- there is negligible (<0.1 m) drawdown/mounding predicted at six elected model nodes, comprising:
 - the Carrai Waterholes
 - GDE1 and GDE 18 (located near mapped occurrences of PCT1287)
 - GDE14, GDE15 and GDE 16 (located near mapped occurrences of PCT1106)
- there is up to 5 m of drawdown/mounding predicted at seven elected model nodes, comprising:
 - GDE2 and GDE3 (located near mapped occurrences of PCT1287)
 - GDE6, GDE11, GDE12 and GDE13 (located near mapped occurrences of PCT1106)
 - GDE17 (located near mapped occurrences of PCT762)
- there is greater than 5 m of drawdown/mounding predicted at six elected model nodes, comprising:
 - GDE4, GDE5, GDE7, GDE8, GDE9, and GDE10 (located near mapped occurrences of PCT1106).

The context of these changes in groundwater levels in terms of impact is described further in the main body of the GIA report.

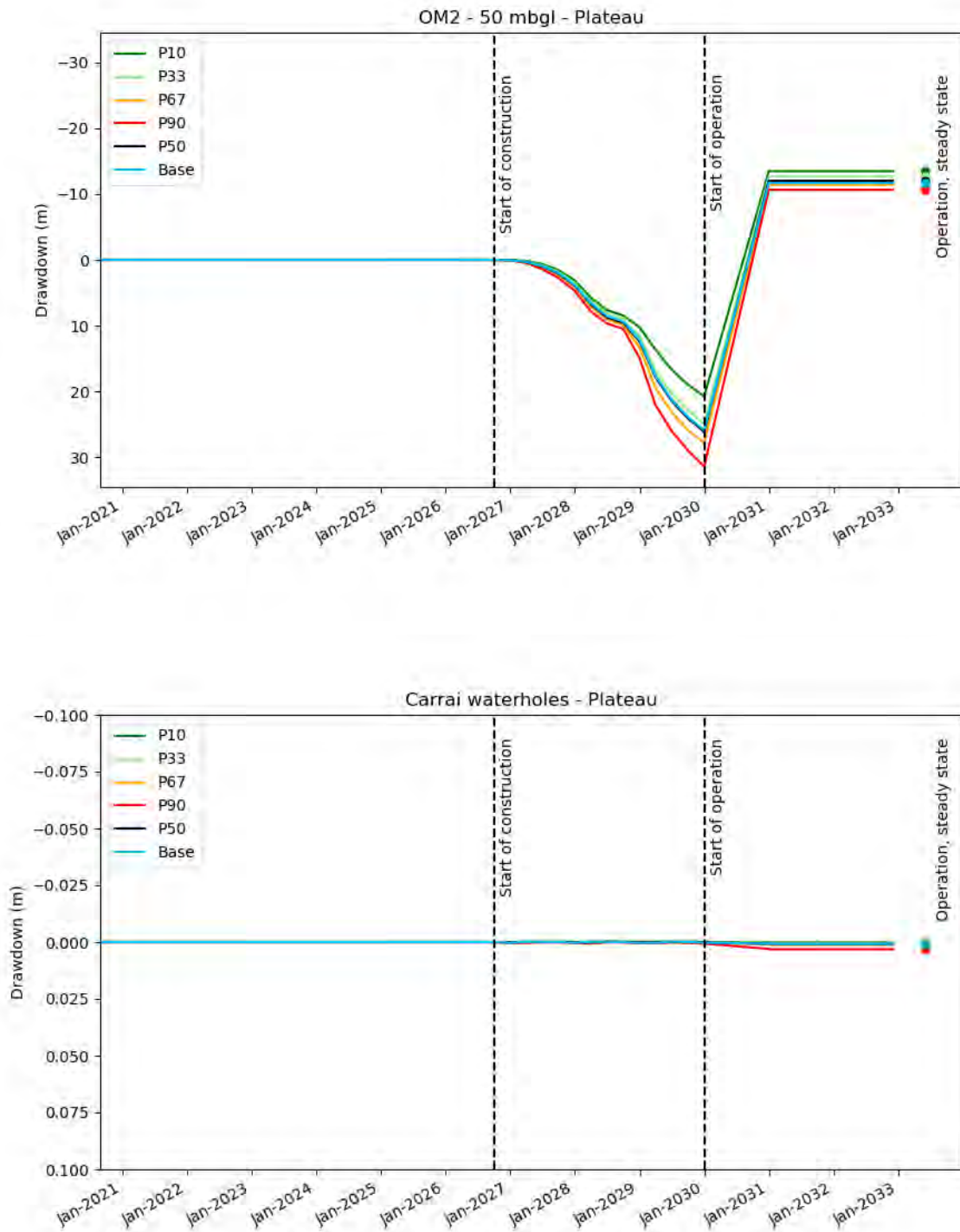


Figure 5.15 Drawdown at select environmental receptors: a) surface water site SWG2101 on the escarpment; and b) GDE site PCT 1287 on the plateau

5.4.3 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 Parrabel Beds. As illustrated in Figure 5.16, there is negligible change (<0.1 m total drawdown/mounding) in groundwater levels predicted at this bore throughout the construction and operation periods.

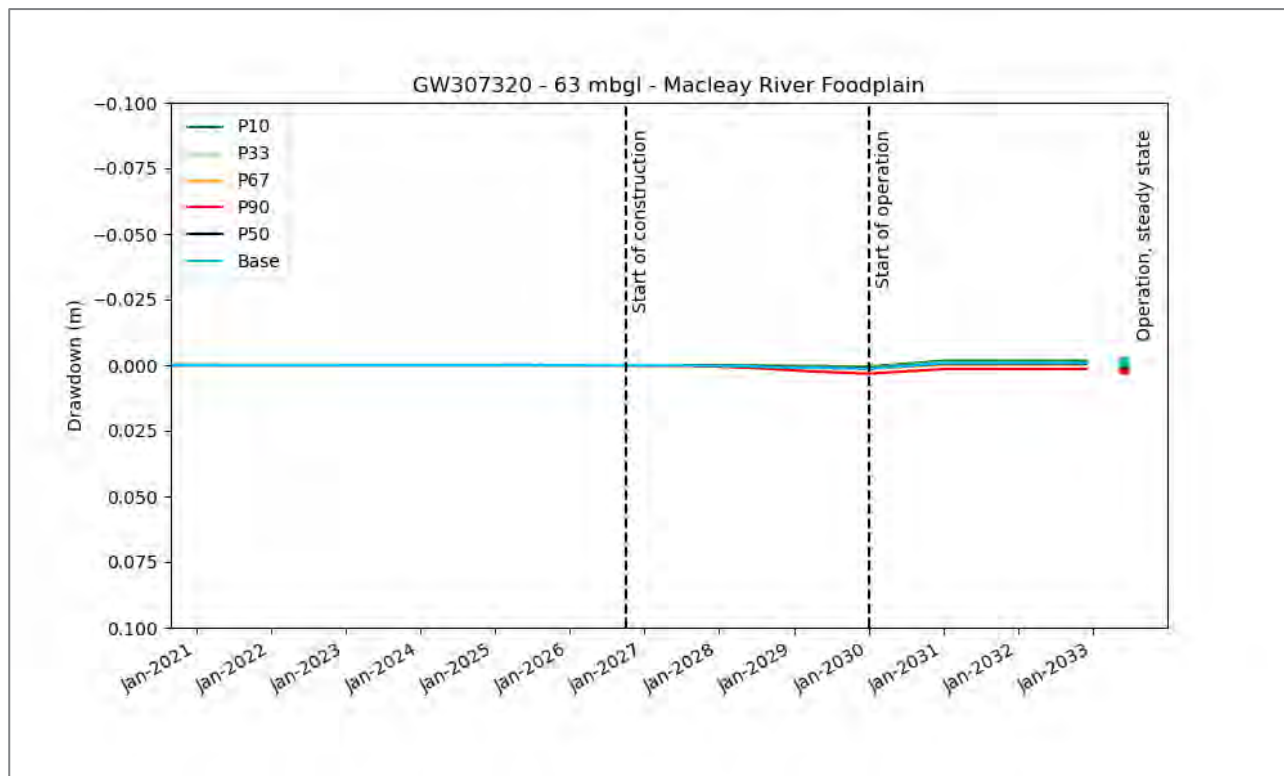


Figure 5.16 Drawdown at third party bore GW307320

5.4.4 Project and environmental water balance

Full project water balances are presented for pre-construction, the end of construction and operation in Table 5.5 to Table 5.7. Results for the other four construction years are documented in Attachment B. The tables present results from the ensemble of 81 realisations and show the probabilistic distribution of each component of the water balance, with the base realisation also separately documented.

The construction timeline is not aligned with water year output times: the water year 2027 balance contains 3 months of construction and 9 months of the transient bridging period prior to construction and the water year 2029 balance contains the 12 months of construction.

The following observations are made with respect to the water balance predictions:

- The base realisation generally sits towards the centre of the probabilistic water balance and the results discussed in Section 0 can be extended to the stochastic predictions.
- It is very unlikely that the groundwater take due to construction will be more than 612 ML in any water year, and it is very unlikely that the take during operation will be more than 324 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, ECVT, MAT and tailrace tunnel.
- During the steady state phase of operation, the reservoirs are filled with water, which provides a net inflow to the aquifer. This results in localised mounding down-gradient of the reservoirs (refer to Section 5.4.1). 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 89 ML/yr.

Table 5.5 Pre-construction steady state water balance (ML/yr)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Entire model domain						
Recharge	In	9,123	9,844	10,468	11,035	10,046
ET	Out	4,072	4,484	4,845	5,217	4,846
Storage in	In	-	-	-	-	-
Storage out	Out	-	-	-	-	-
Macleay gorges SW source						
Macleay River to aquifer	In	275	333	394	462	327
Aquifer to Macleay River	Out	2,151	2,530	2,950	3,203	2,591
All other streams to aquifer	In	6	8	11	15	9
Aquifer to all other streams	Out	1,126	1,292	1,535	1,900	1,402
Macleay valley SW source						
Macleay River to aquifer	In	20	32	45	66	37
Aquifer to Macleay River	Out	324	380	437	512	377
All other streams to aquifer	In					
Aquifer to all other streams	Out	873	1,150	1,405	1,749	1,232

Table 5.6 Construction water balance for water year 2029 (ML)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Entire model domain						
Recharge	In	9,142	9,864	10,490	11,057	10,066
ET	Out	3,991	4,402	4,766	5,141	4,776
Storage in	In	1,896	2,062	2,223	2,369	2,102
Storage out	Out	1,671	1,803	1,957	2,109	1,866
Macleay gorges SW source						
Macleay river to aquifer	In	278	337	398	468	330
Aquifer to Macleay River	Out	2,055	2,470	2,902	3,181	2,515
All other streams to aquifer	In	6	8	11	15	9
Aquifer to all other streams	Out	1,085	1,271	1,509	1,862	1,366
Macleay valley SW source						
Macleay river to aquifer	In	24	36	48	70	41
Aquifer to Macleay River	Out	297	351	408	493	352
All other streams to aquifer	In	0	0	0	0	0
Aquifer to all other streams	Out	888	1,176	1,440	1,795	1,256
Project components						
Overall sum	Out	278.1	277.33	364.77	466.77	610.56
Bifurcated Tunnels	Out	4.4	4.44	8.79	13.75	21.69
Draft Tube Merged Tunnels	Out	0.0	0.00	0.00	0.00	0.00
Draft Tube Tunnels	Out	0.4	0.36	0.54	0.87	1.22
ECVT	Out	52.9	52.89	63.58	79.04	99.90
Headrace Tunnel	Out	1.3	1.35	2.89	4.91	8.18
IPB Galleries	Out	0.6	0.63	0.98	1.52	2.11
Lower intake	Out	1.5	1.53	2.17	3.18	4.58
Lower reservoir	Out	17.29	21.07	25.24	29.16	23.38
Machine hall	Out	2.82	4.51	6.94	9.67	4.98
Machine Hall Construction Adit	Out	2.78	4.40	6.47	9.26	4.91
MAT	Out	36.16	47.71	58.48	72.61	49.65
MAT 2	Out	1.35	2.05	3.18	4.08	2.32
MH TH Egress Access	Out	0.33	0.48	0.74	1.06	0.51
Penstock Tunnels	Out	0.00	0.00	0.00	0.00	0.00

Table 5.6 Construction water balance for water year 2029 (ML)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Pressure shaft	Out	9.30	19.21	31.37	53.90	21.49
Tailrace Surge Shaft	Out	1.90	2.81	4.77	5.98	3.33
Tailrace Tunnel	Out	61.95	84.33	111.32	156.37	100.16
Transformer Hall	Out	0.66	1.04	1.68	2.18	1.21
TSST	Out	12.95	17.39	21.73	26.13	21.43
Upper reservoir	Out	68.66	80.83	91.55	102.54	88.24

Table 5.7 Steady-state operation water balance (ML/yr)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Entire model domain						
Recharge	In	9,123	9,844	10,468	11,035	10,046
ET	Out	4,235	4,641	4,995	5,378	4,996
Storage in	In	-	-	-	-	-
Storage out	Out	-	-	-	-	-
Macleay gorges SW source						
Macleay river to aquifer	In	275	334	396	463	327
Aquifer to Macleay River	Out	2,037	2,448	2,904	3,164	2,497
All other streams to aquifer	In	6	8	11	15	9
Aquifer to all other streams	Out	1,066	1,258	1,494	1,837	1,348
Macleay valley SW source						
Macleay river to aquifer	In	20	32	45	66	37
Aquifer to Macleay River	Out	293	344	403	489	346
All other streams to aquifer	In					
Aquifer to all other streams	Out	885	1,174	1,436	1,786	1,252
Project components						
Overall sum	Out	161.5	204.2	258.6	324	233.2
Bifurcated Tunnels	Out	-	-	-	-	-
Draft Tube Merged Tunnels	Out	-	-	-	-	-
Draft Tube Tunnels	Out	-	-	-	-	-
ECVT	Out	46.8	57.7	75.3	93.8	69.1

Table 5.7 **Steady-state operation water balance (ML/yr)**

Component	Flow direction	P10	P33	P67	P90	Base realisation
Headrace Tunnel	Out	-	-	-	-	-
IPB Galleries	Out	0.5	0.9	1.4	2.0	1.1
Lower intake	Out	0.1	0.1	0.2	0.3	0.2
Lower reservoir	Out	7.7	10.9	15.6	19.6	13.2
Machine hall	Out	4.0	7.1	10.5	16.5	8.4
Machine Hall Construction Adit	Out	2.7	4.5	6.8	10.1	5.4
MAT	Out	23.9	29.6	35.6	46.3	29.8
MAT 2	Out	1.3	1.9	3.3	4.1	2.4
MH TH Egress Access	Out	0.3	0.5	0.9	1.2	0.7
Penstock Tunnels	Out	-	-	-	-	-
Pressure shaft	Out	-	-	-	-	-
Tailrace Surge Shaft	Out	2.3	3.4	6.2	8.6	4.7
Tailrace Tunnel	Out	25.2	31.9	38.8	49.3	36.7
Transformer Hall	Out	0.7	1.1	1.9	2.5	1.4
TSST	Out	9.0	11.4	13.4	16.1	13.2
Upper reservoir	Out	37.0	43.2	48.7	53.6	46.9
Outflow from project components						
Overall sum	In	82.8	89.2	248.1	269.4	89.1
Lower reservoir	In	51.8	53.3	116.6	120.1	52.1
Upper reservoir	In	28.4	30.4	122.3	133.7	29.9
Tailrace	In	0.3	0.5	0.9	1.5	0.7
Pressure shaft	In	2.3	5.0	8.3	14.1	6.4

i Recharge sensitivity

The sensitivity of water balance to recharge during operation is detailed in Table 5.8. The findings illustrate that baseflow to rivers and creeks, along with evapotranspiration, display variations that are almost directly proportional to alterations in recharge. Similarly, outflow from project components shows a proportional variation. Conversely, inflow to project components remains largely unaffected.

Table 5.8 **Water balance sensitivity to recharge**

	Base case	10% recharge increase	10% recharge decrease
Recharge (ML/yr)	10,045	11,041	9,043
Evapotranspiration (ML/yr)	4,996	5,516 (110.4% of base case)	4,482 (89.7% of base case)
Leakage from Macleay River (ML/yr)	373	358 (96.0% of base case)	391 (104.8% of base case)
Baseflow to rivers & creeks (ML/yr)	5,444	5,887 (108.1% of base case)	4,992 (91.7% of base case)
Inflow to project components (ML/yr)	255	251 (98.4% of base case)	260 (102.0% of base case)
Outflow from project components (ML/yr)	234	247 (105.6% of base case)	221 (94.4% of base case)

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)
- 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 Attachment C. Chris's review found that the modelling is fit for purpose and the modelling objectives are satisfied.

7 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 reservoir 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 modelling 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
- 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
- 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 K_h , K_v , S_s and S_y as well as recharge zonation. The ensemble of accepted realisations was deemed to be appropriately history-matched to achieve the stated metrics in Section 4.1 and generally aligns with attributes of a Class 2 model.

Both a null case scenario and project scenario were simulated for an ensemble of 81 stochastic realisations (with each 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 81 realisations (from a pool of 144) 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, MAT2, ECVT, and TSST. The drawdown of the water table spreads from the upper reservoir over the escarpment following an east direction. Likewise, in the lower reservoir area, the drawdown extent to east over the escarpment and creeks.
- The overall drawdown extents at the 0.2 m threshold encompass a marginally wider zone, with the bulk of the drawdown localised within 250 m of the Project components, and a minor extent reaching up to 1.4 km to the northwest. Notably, two new areas of drawdown have been identified to the north and south of the lower reservoir. These areas of drawdown are found along the river valleys, characterised by linear drawdown patterns within the slender alluvial deposits of these valleys. This drawdown is spatially linked to both the upper and lower reservoirs, as well as 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. The pattern of mounding, analogous to drawdown patterns, extends more expansively outward from the upper reservoir, influenced by the gentler hydraulic gradients of the plateau. Conversely, it follows a more linear trajectory along the steep escarpment river valleys located down-gradient from the lower reservoir.
- Across the majority of the 49 environmental receptors, there is negligible change. In 25 of them the change is lower than 0.1 m total drawdown/mounding, there is up to 5 m of drawdown/mounding at six sites, and there is greater than 5 m of drawdown/mounding at 19 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 realisation generally sits towards the centre of the suite of 81 stochastic realisations with respect to water balance and drawdown.
- It is very unlikely that the groundwater take due to construction will be more than 612 ML in any water year, and it is very unlikely that the take during operation will be more than 324 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, MAT, tailrace tunnel, ECVT and TSST. 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 5.4.1). This localised mounding translates to enhanced hydraulic gradients towards the Macleay River and other creeks and an increase of baseflow from the rivers in order to 88.1 ML/yr.

8 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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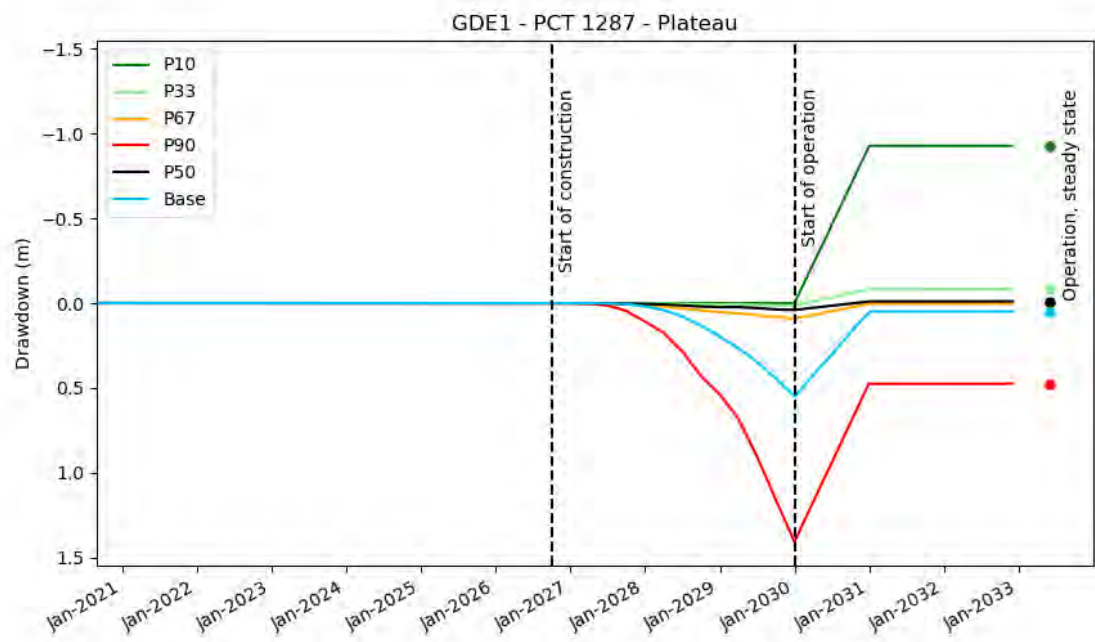
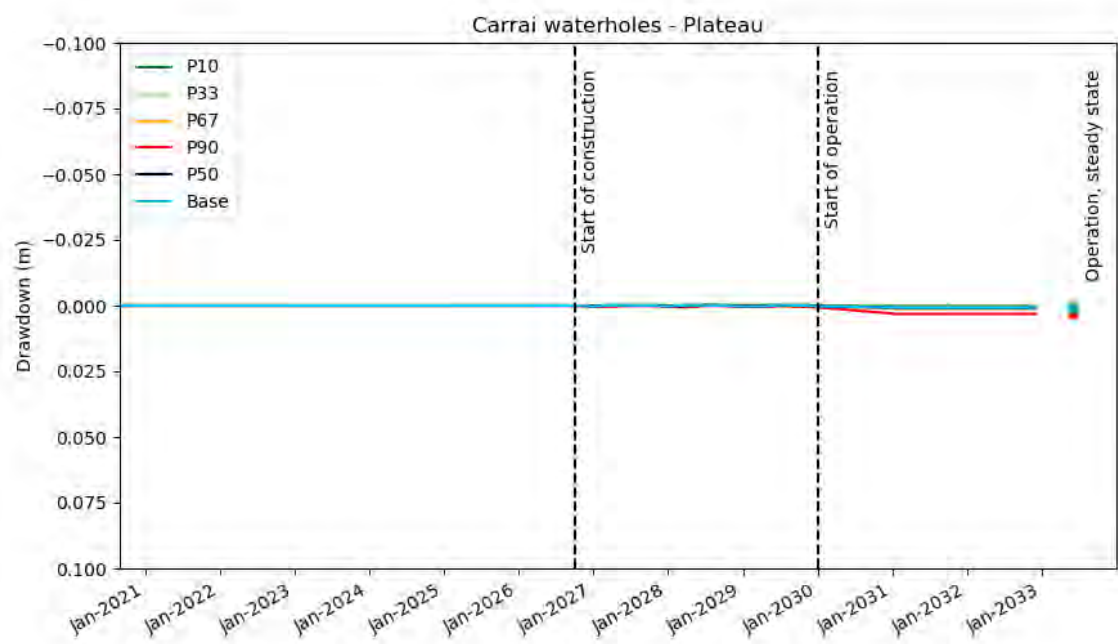
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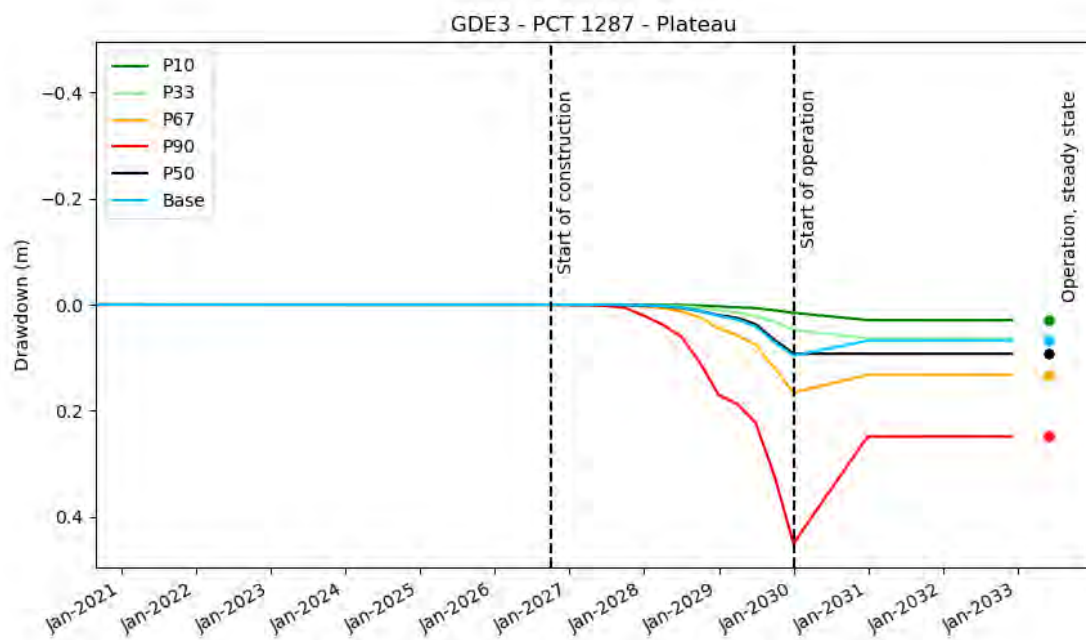
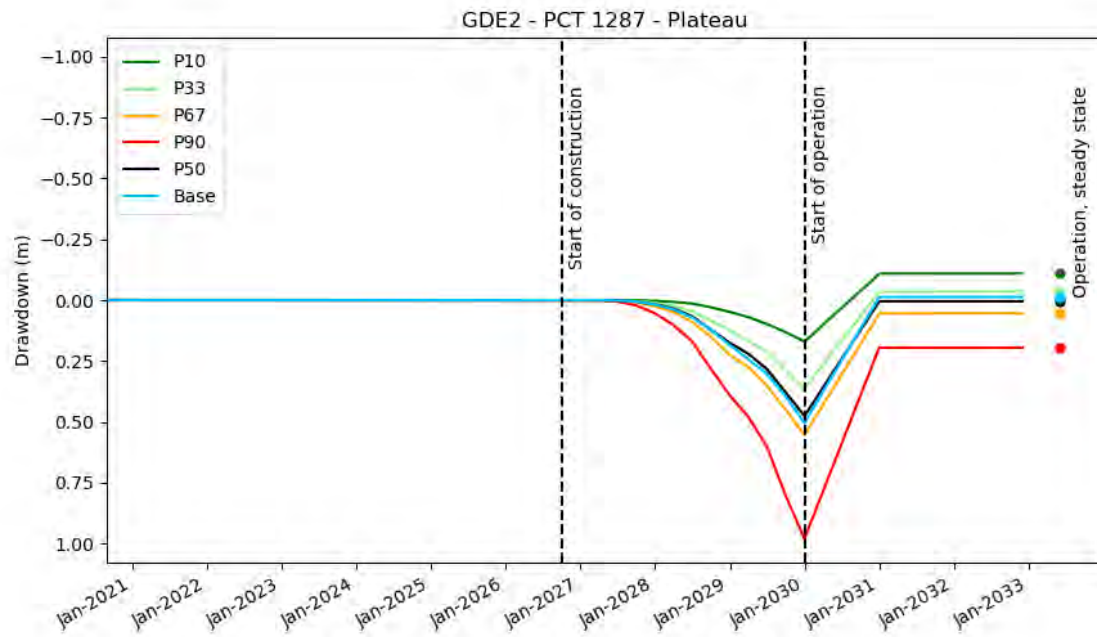
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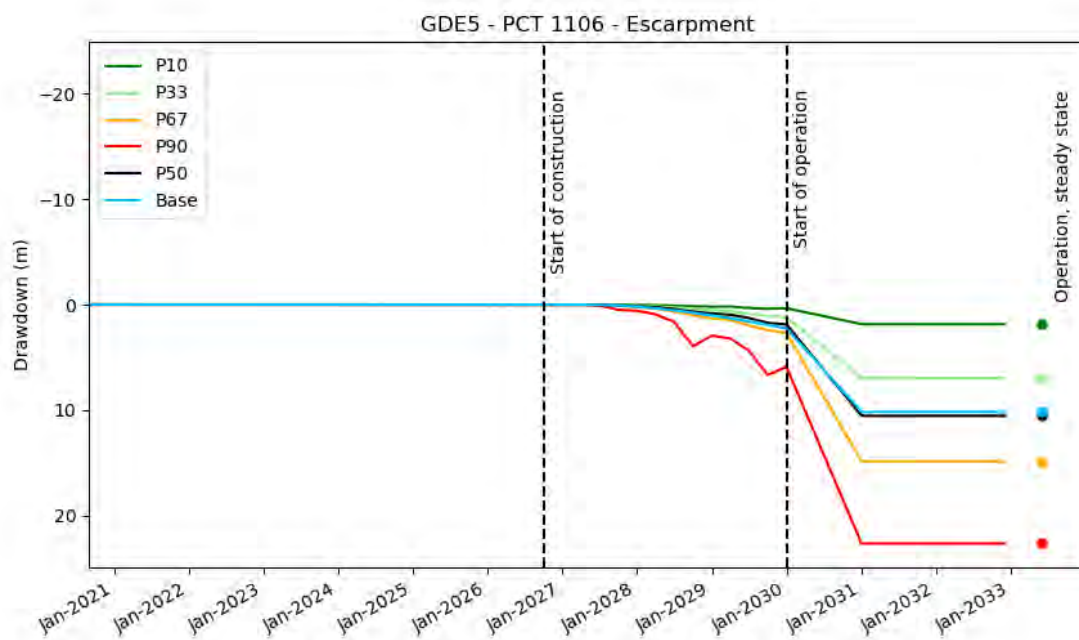
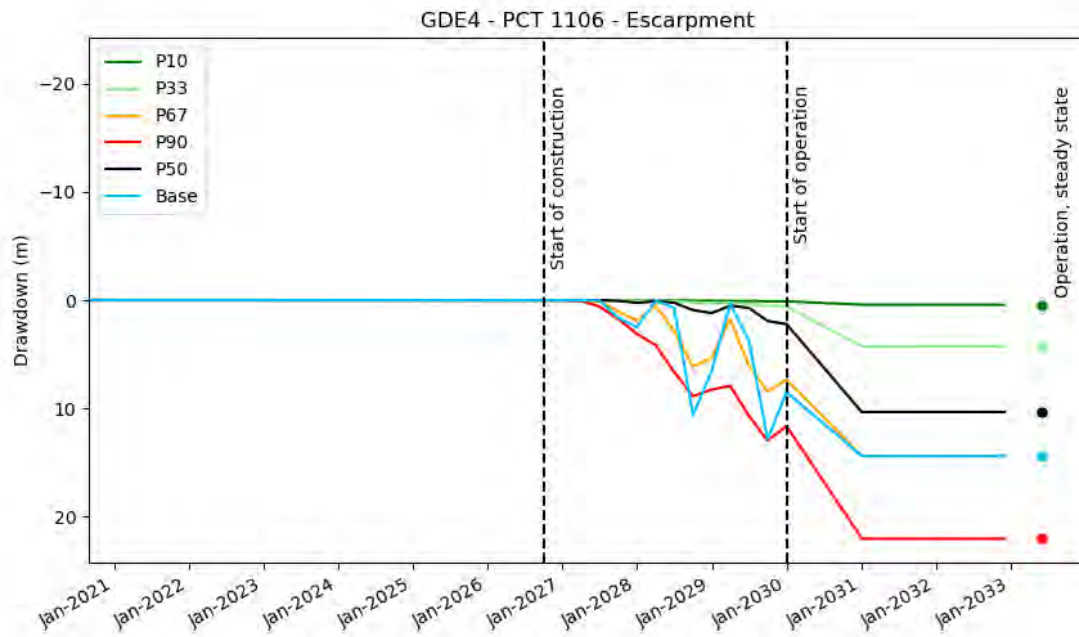
Attachment A

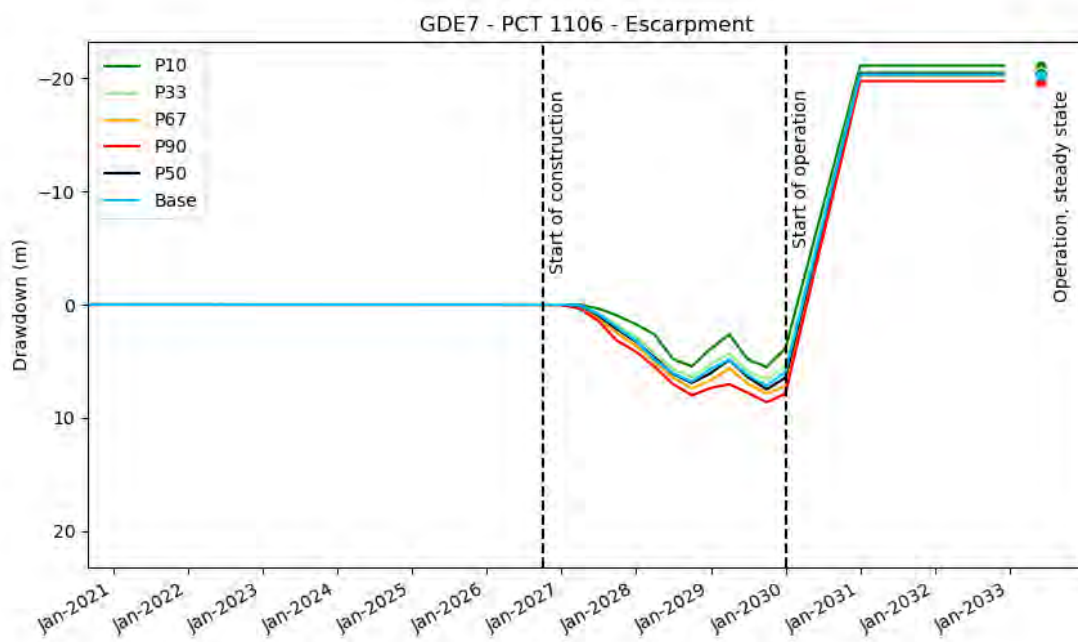
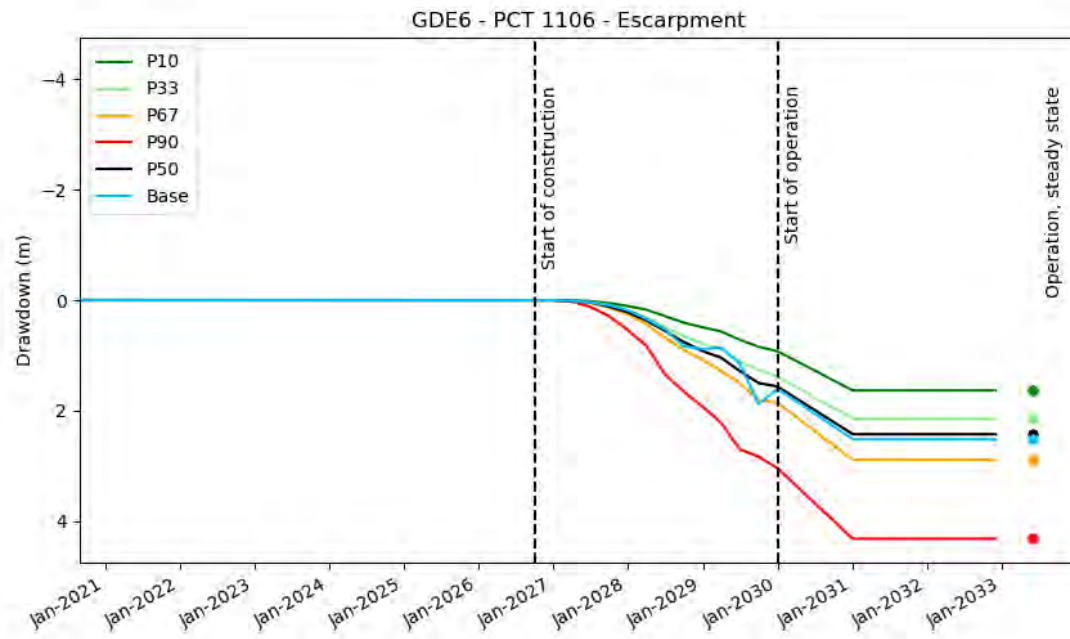
Predicted hydrographs at environmental receptors

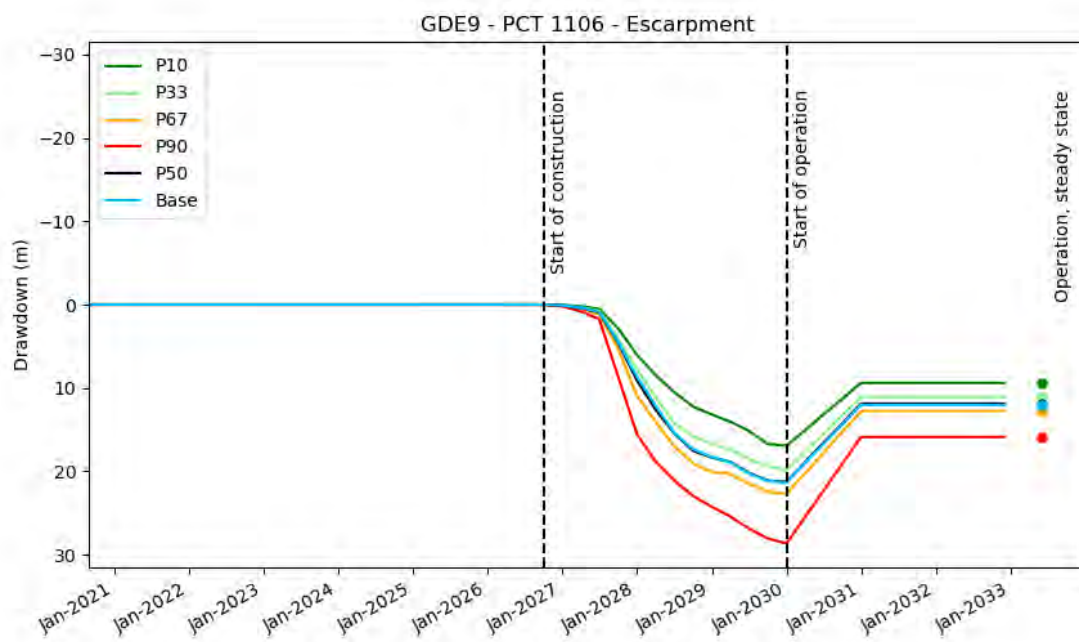
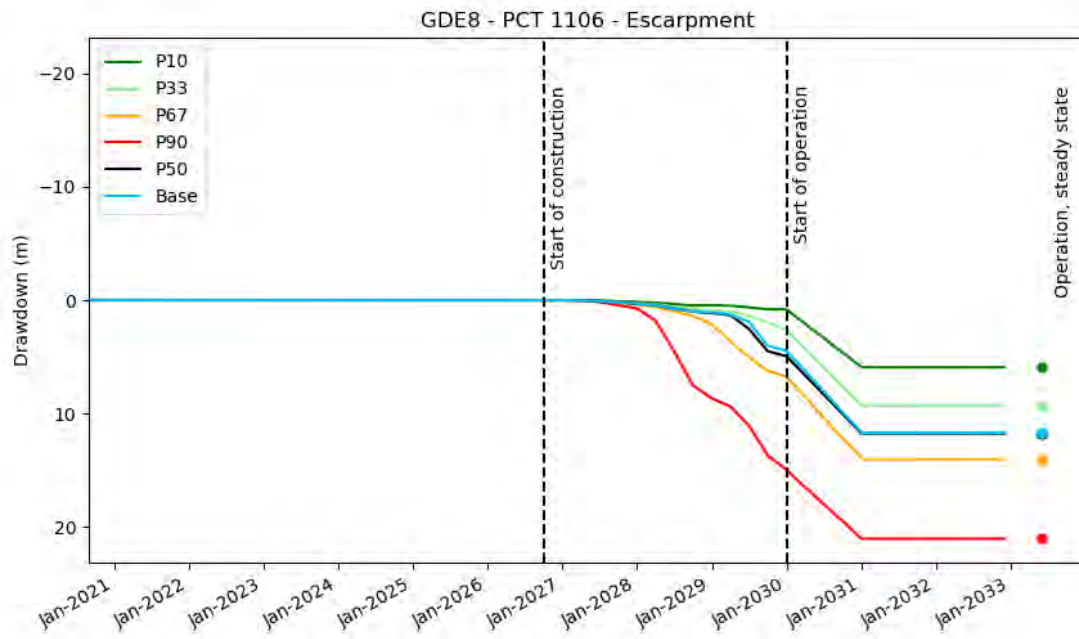
A.1 Predicted hydrographs at environmental receptors

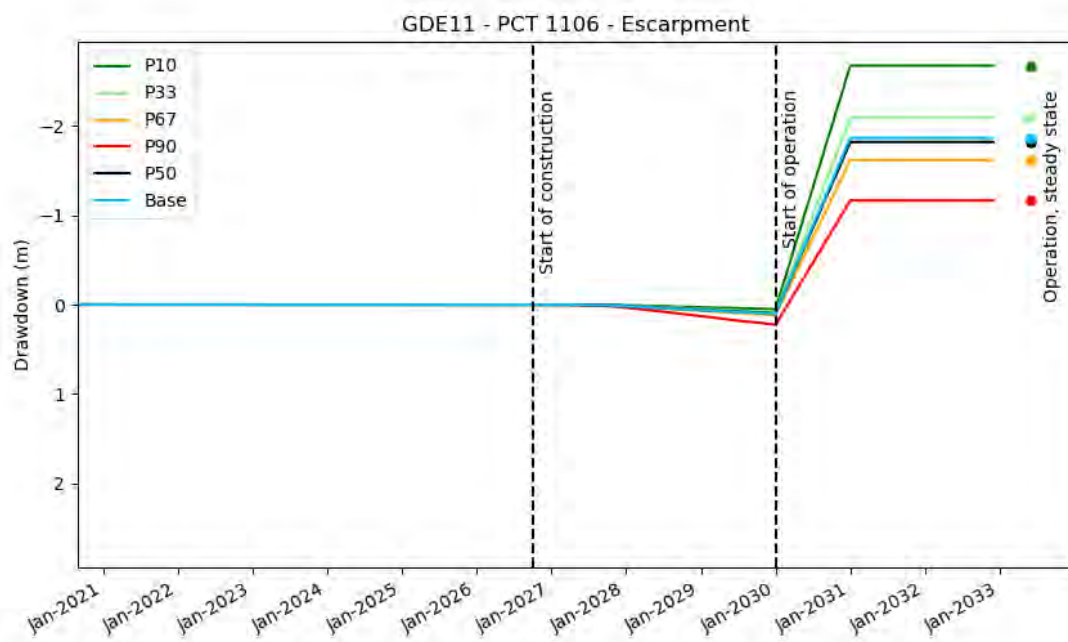
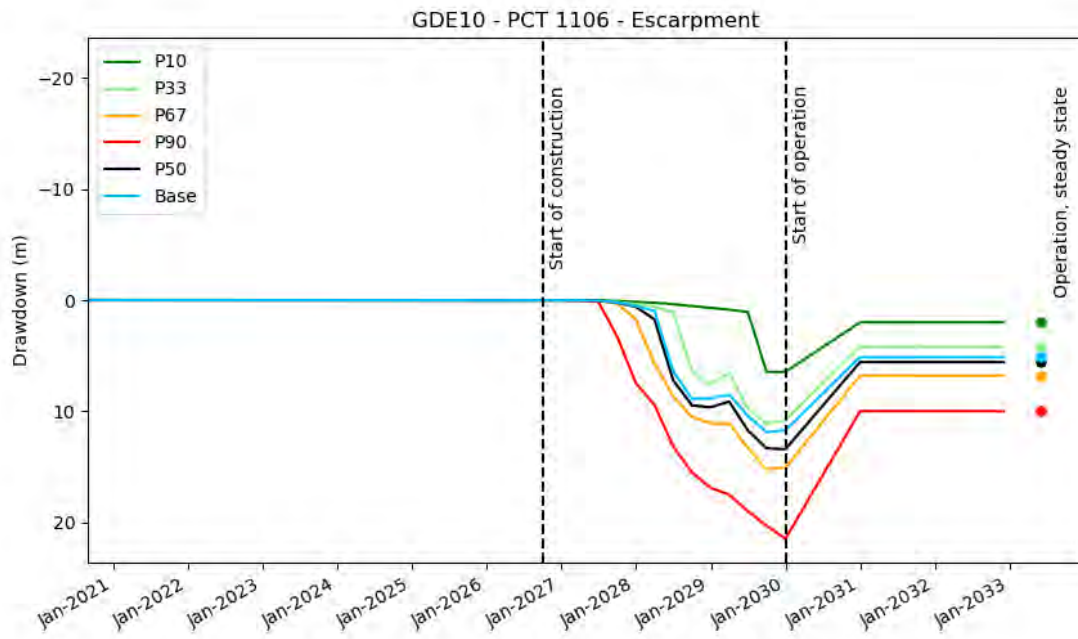


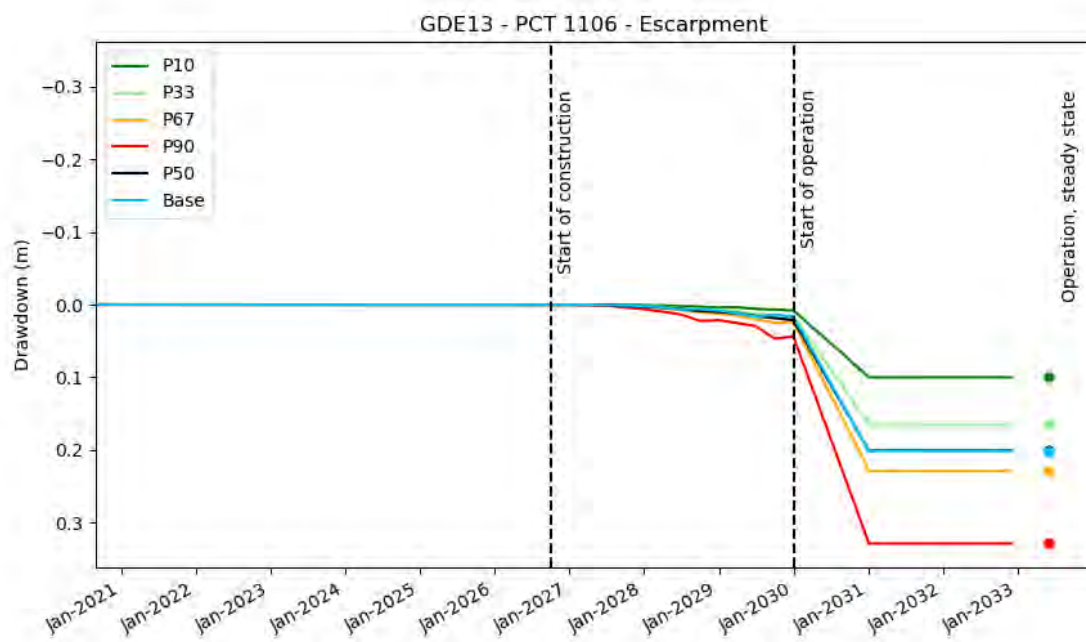
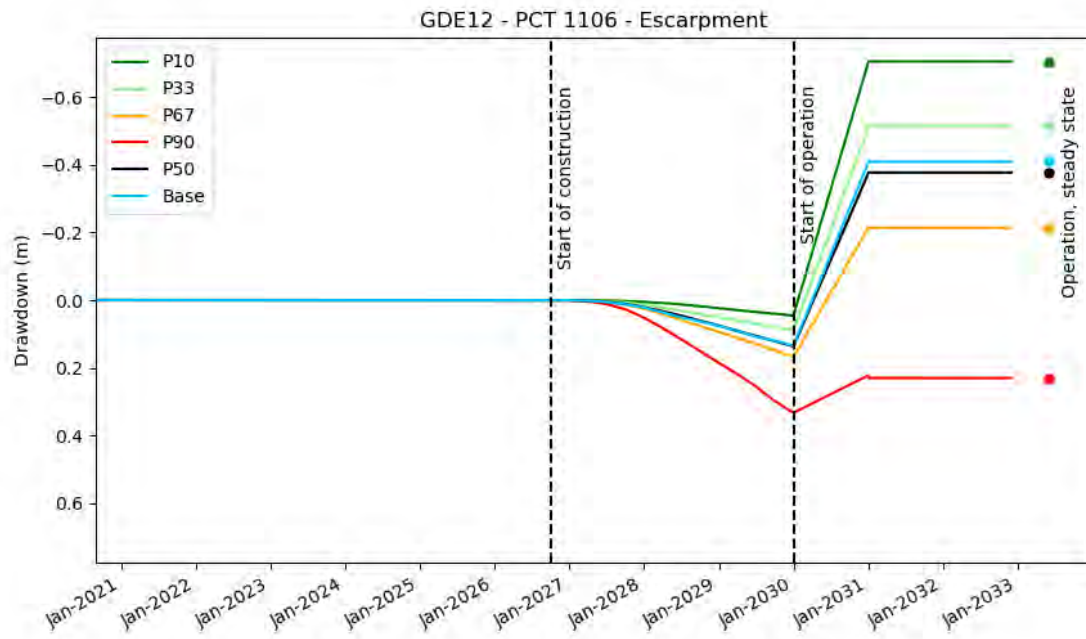


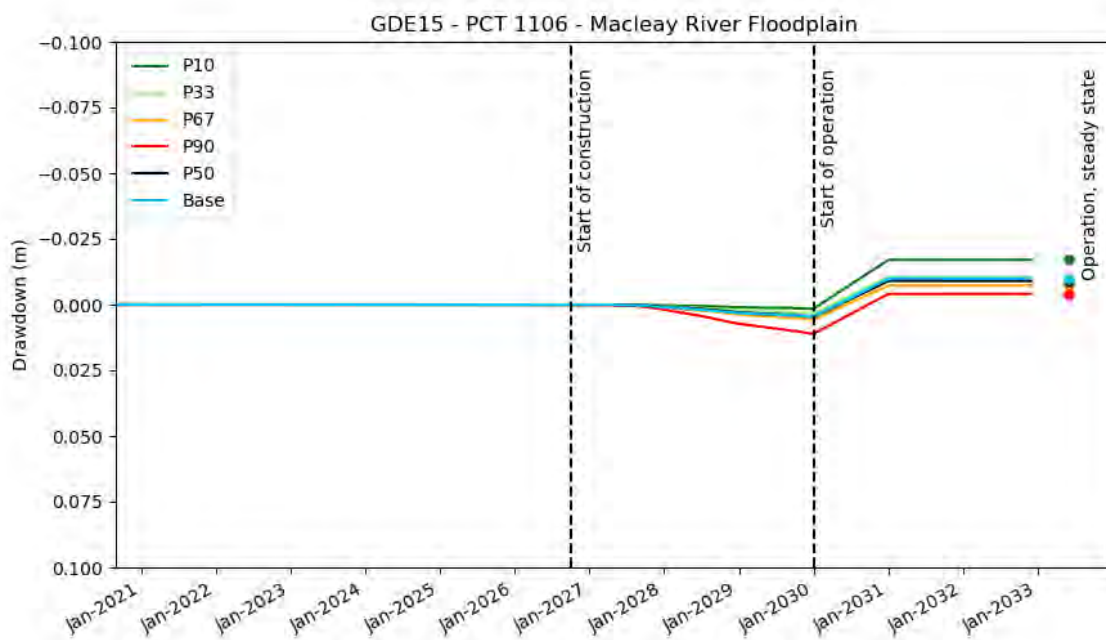
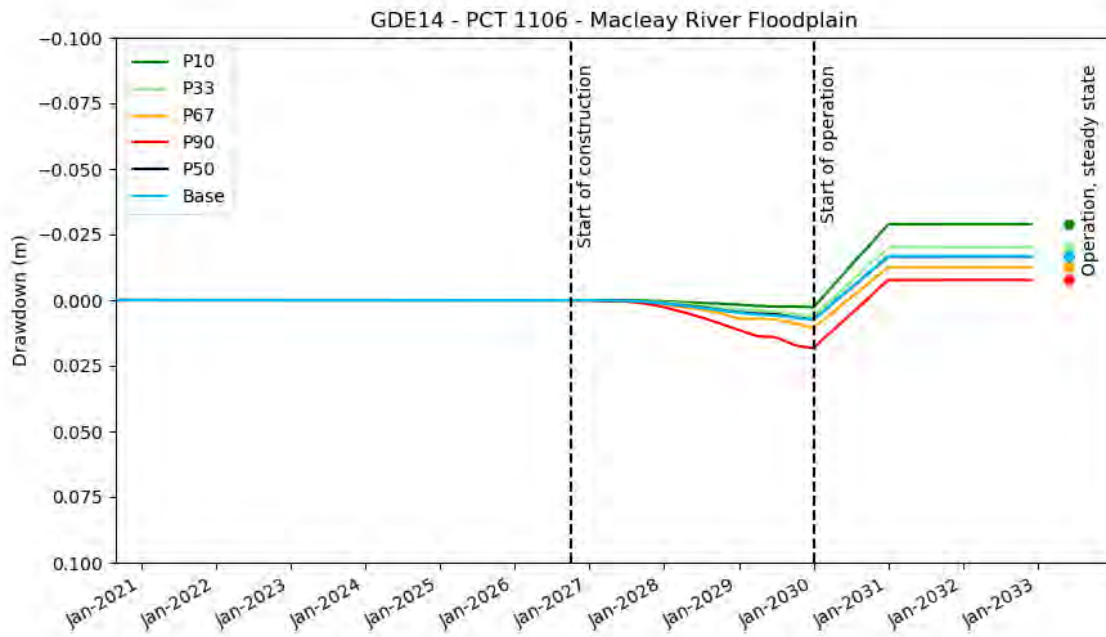


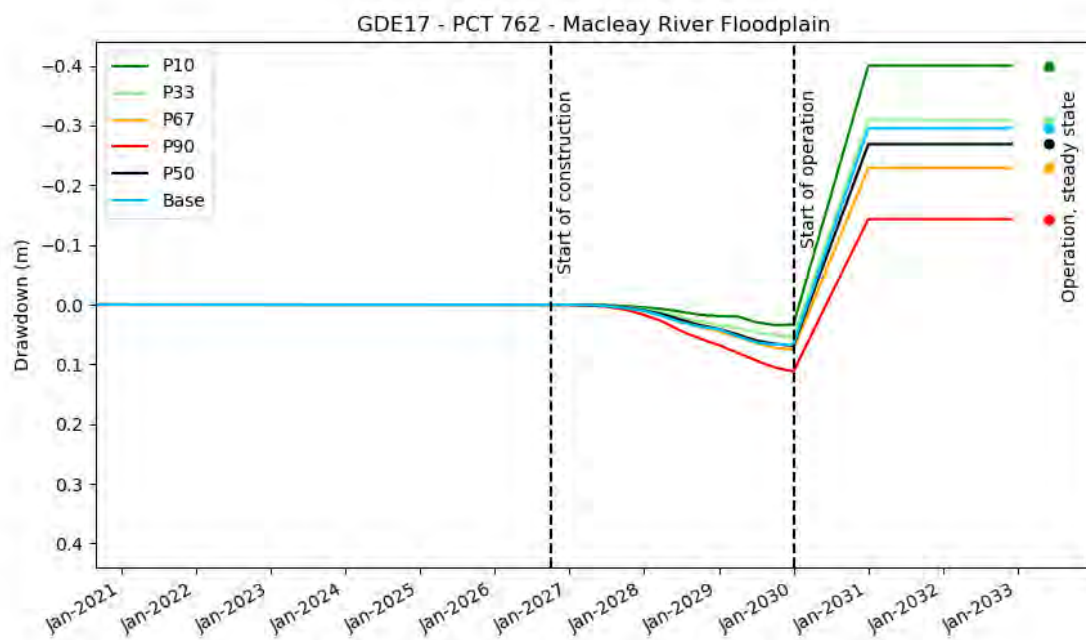
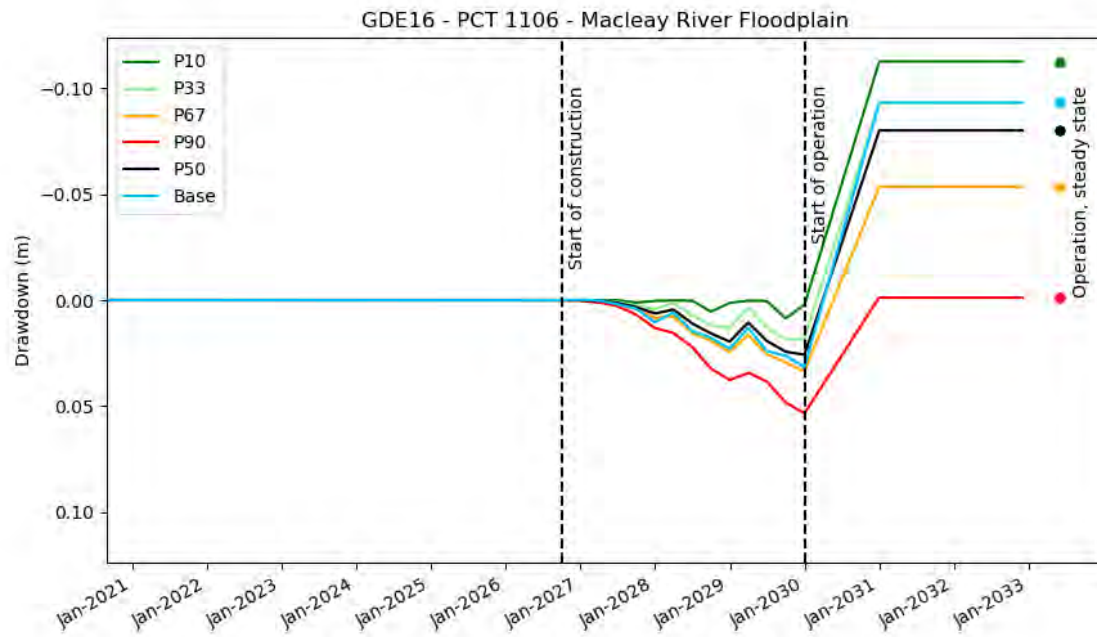


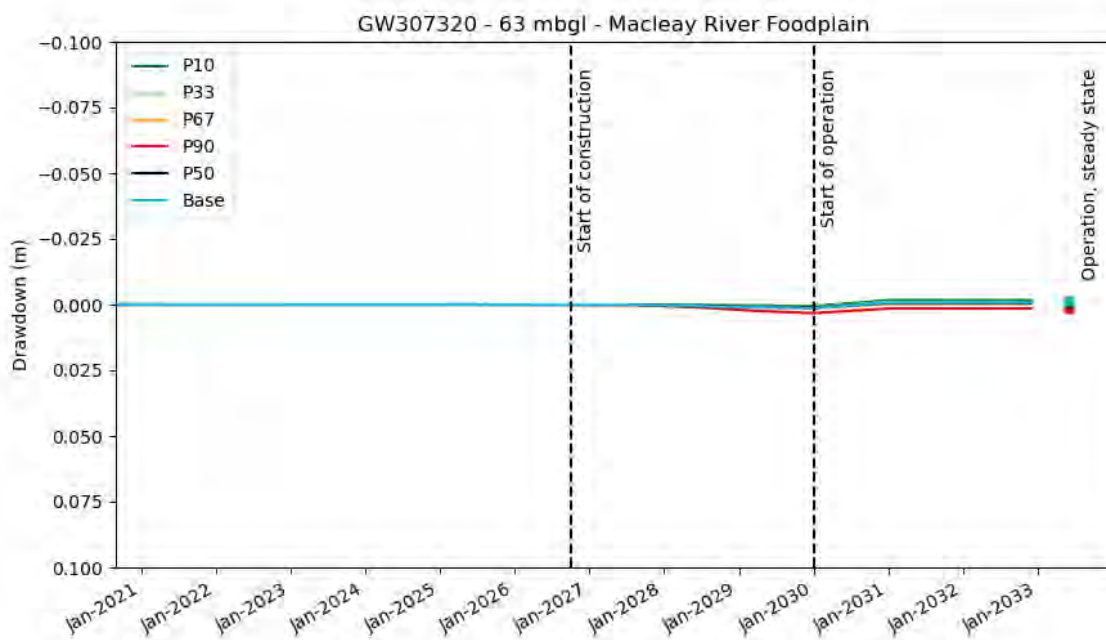
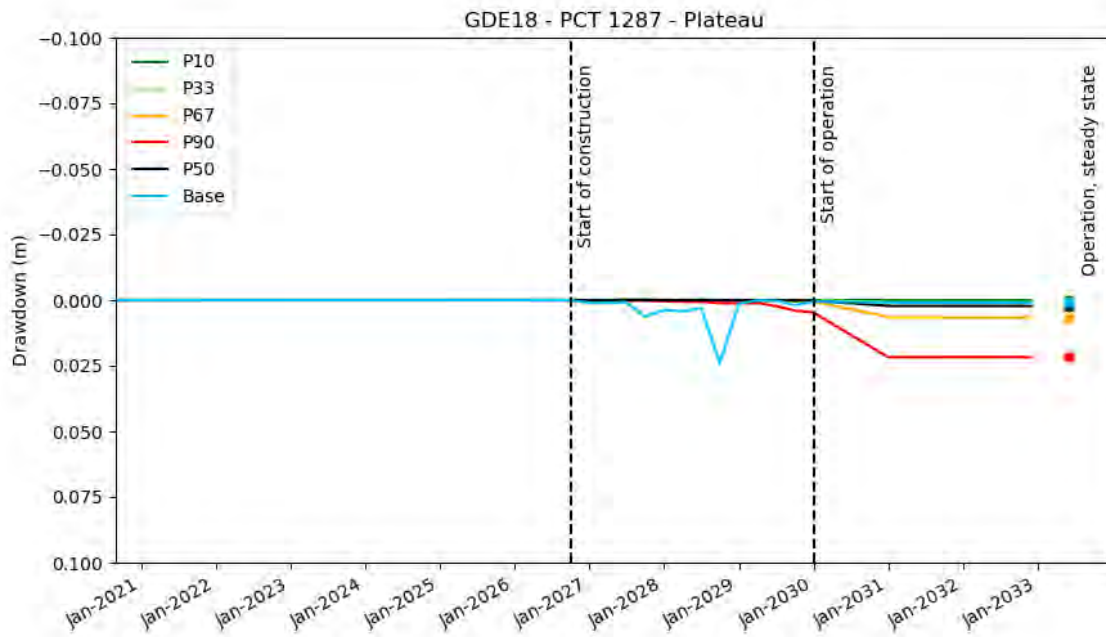


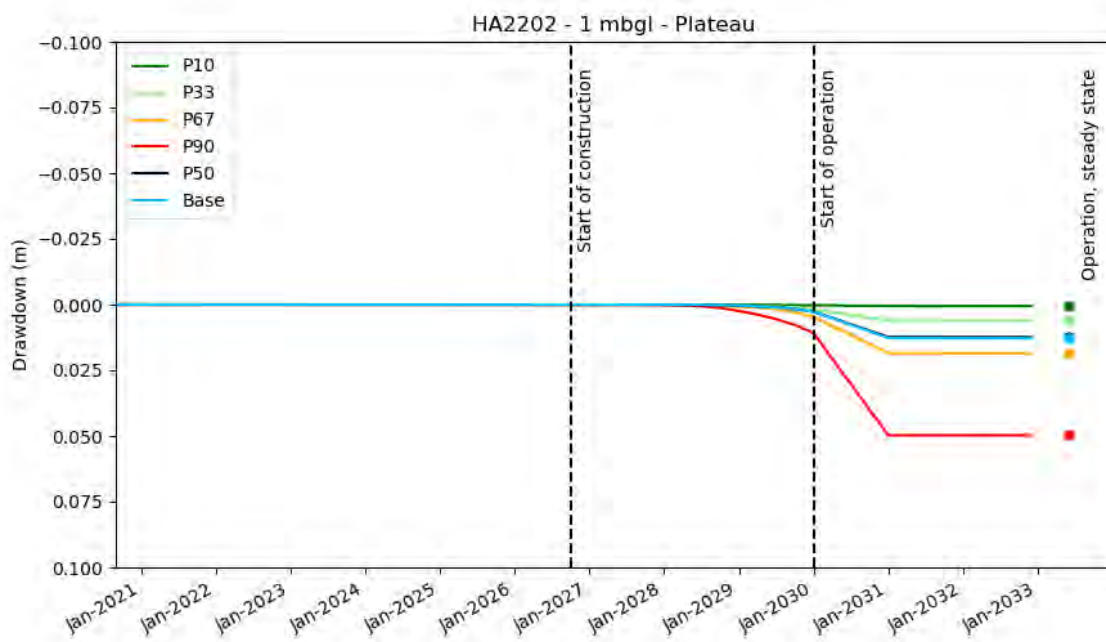
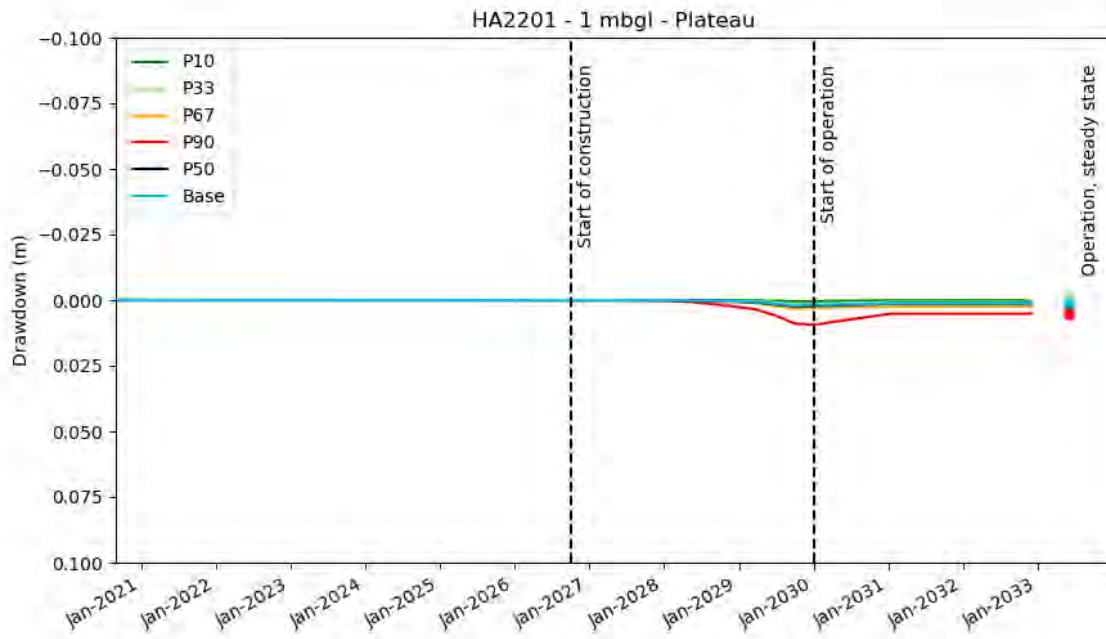


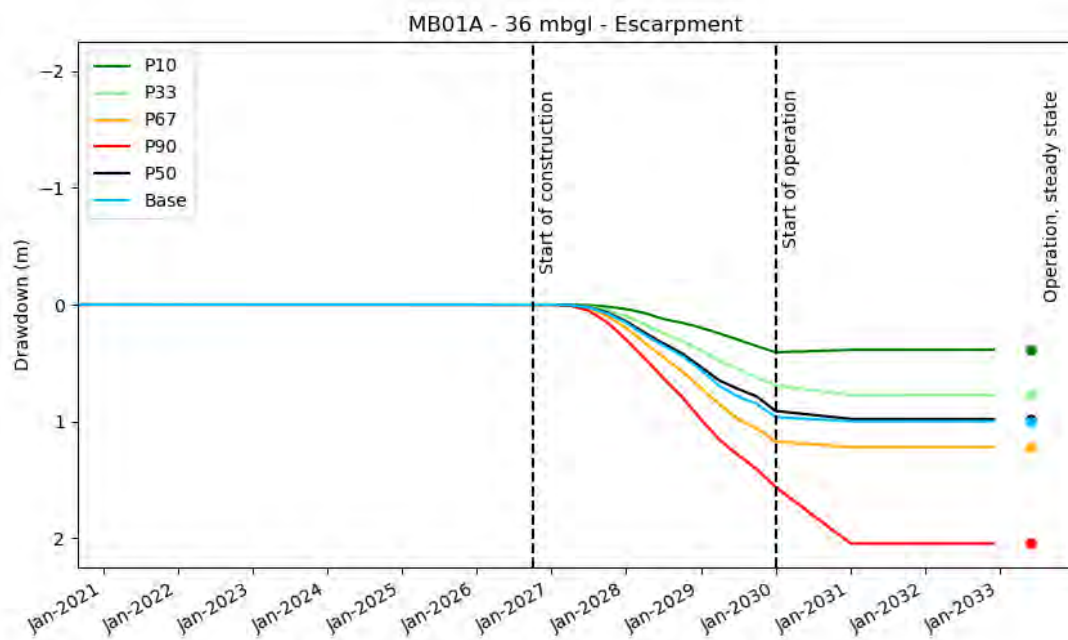
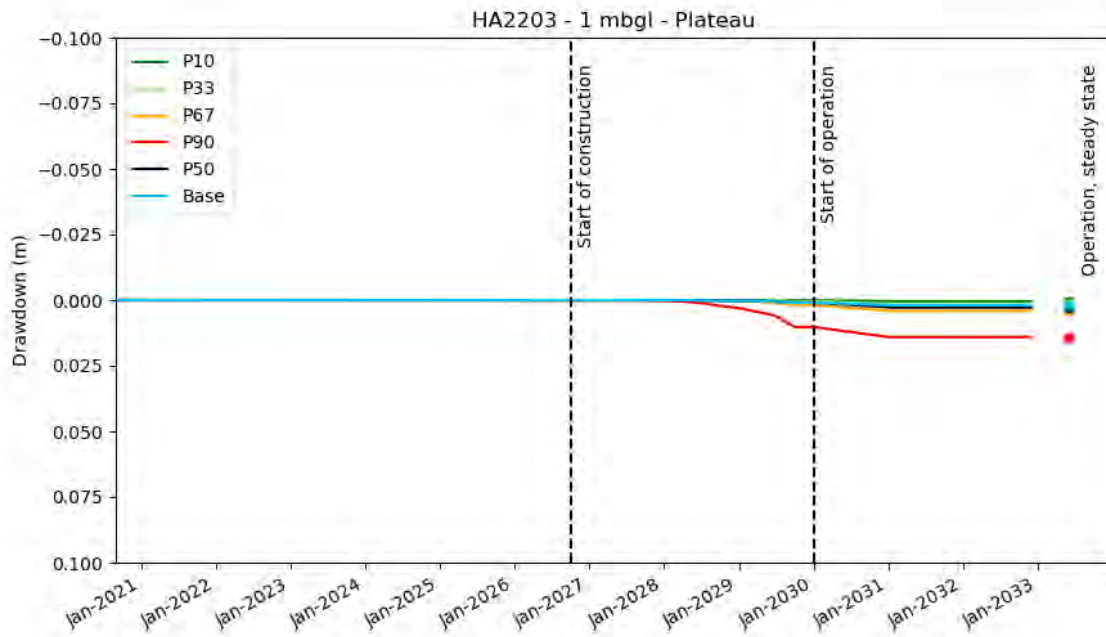


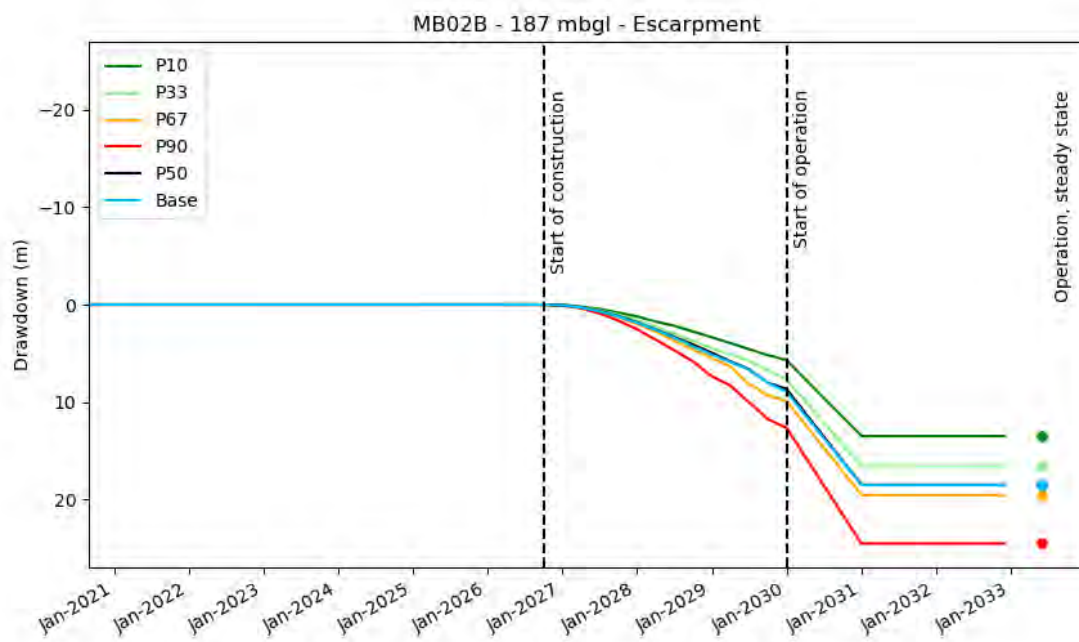
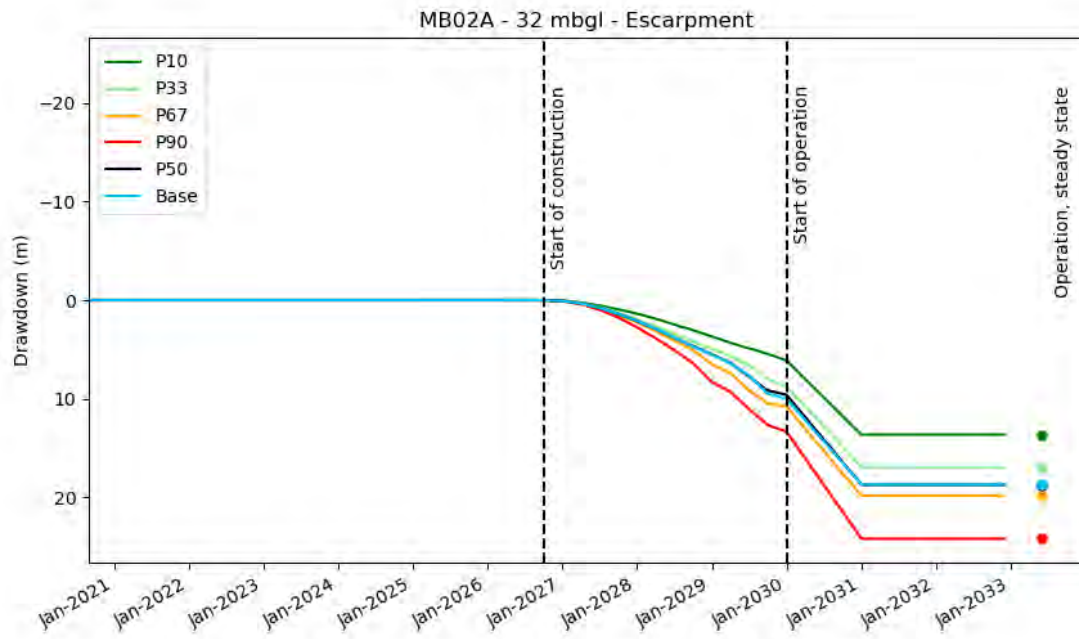


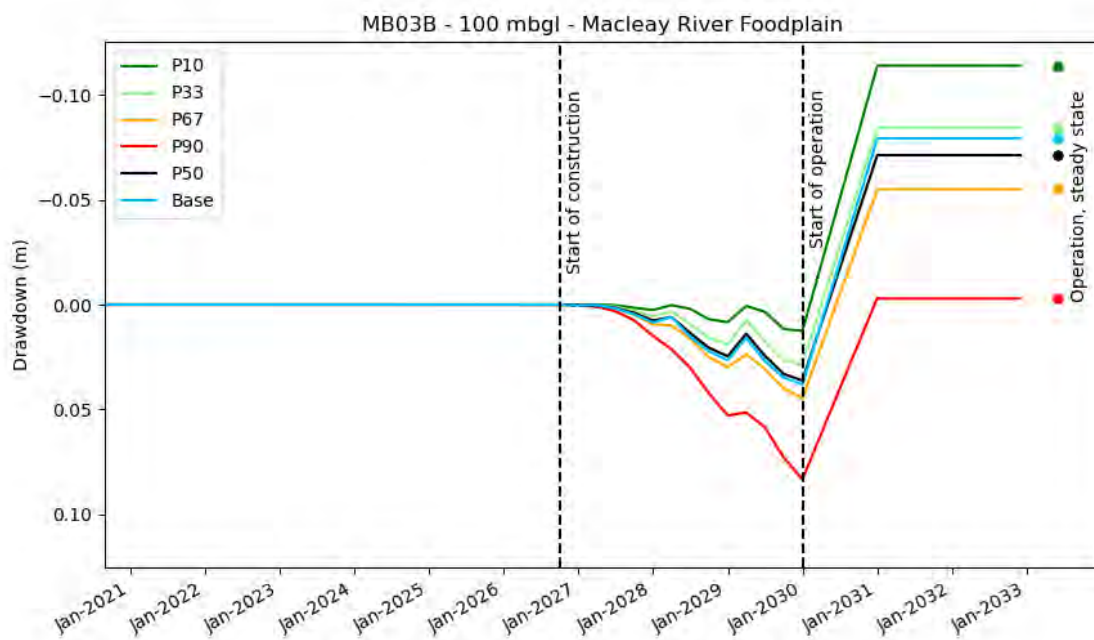
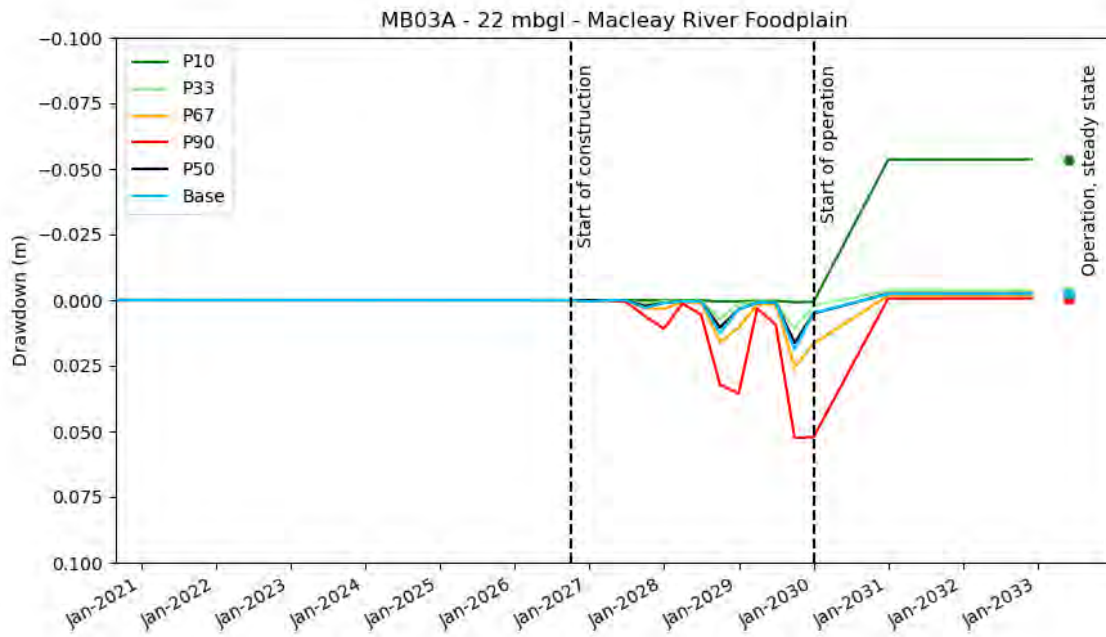


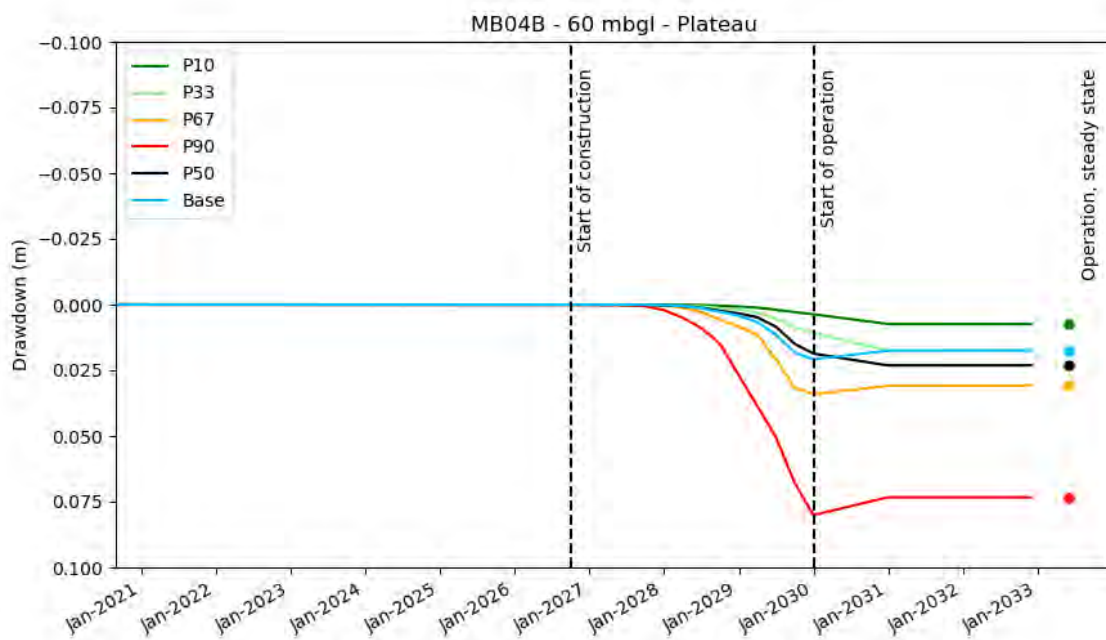
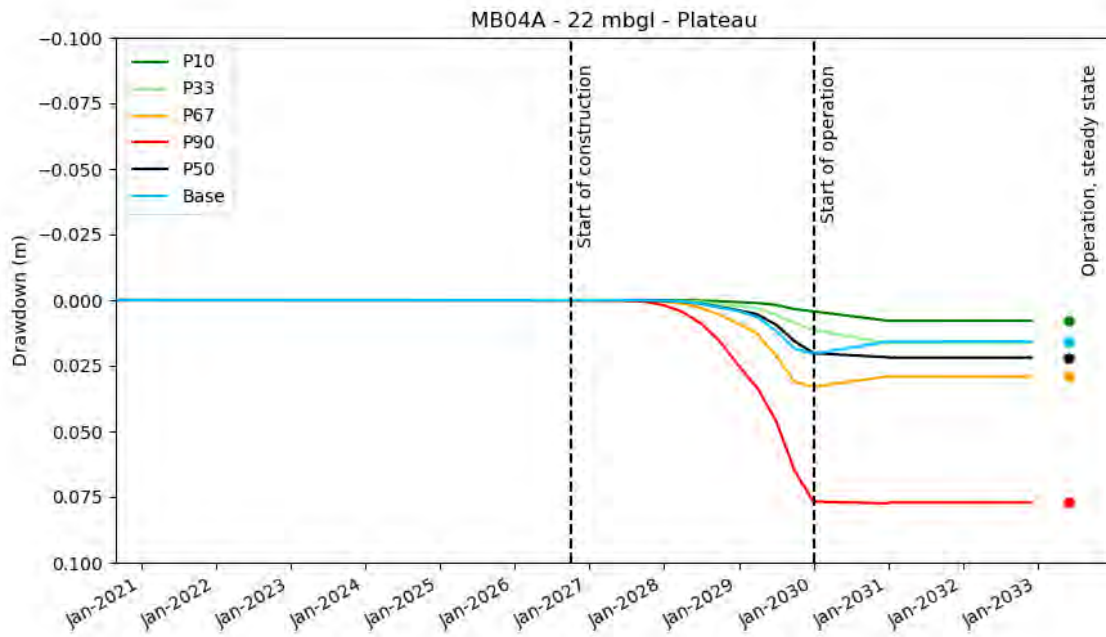


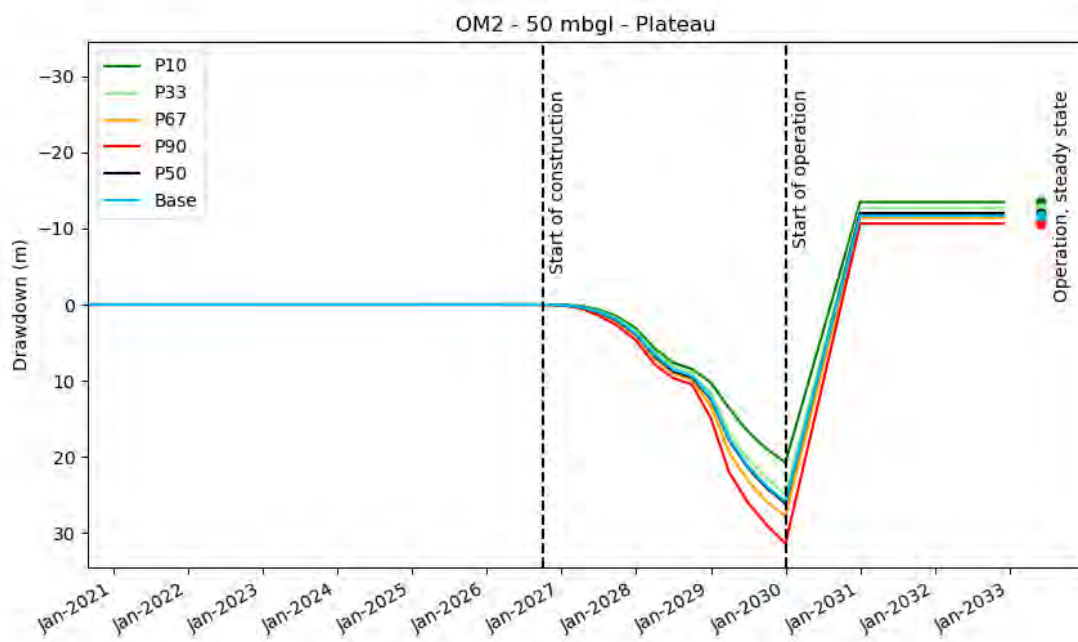
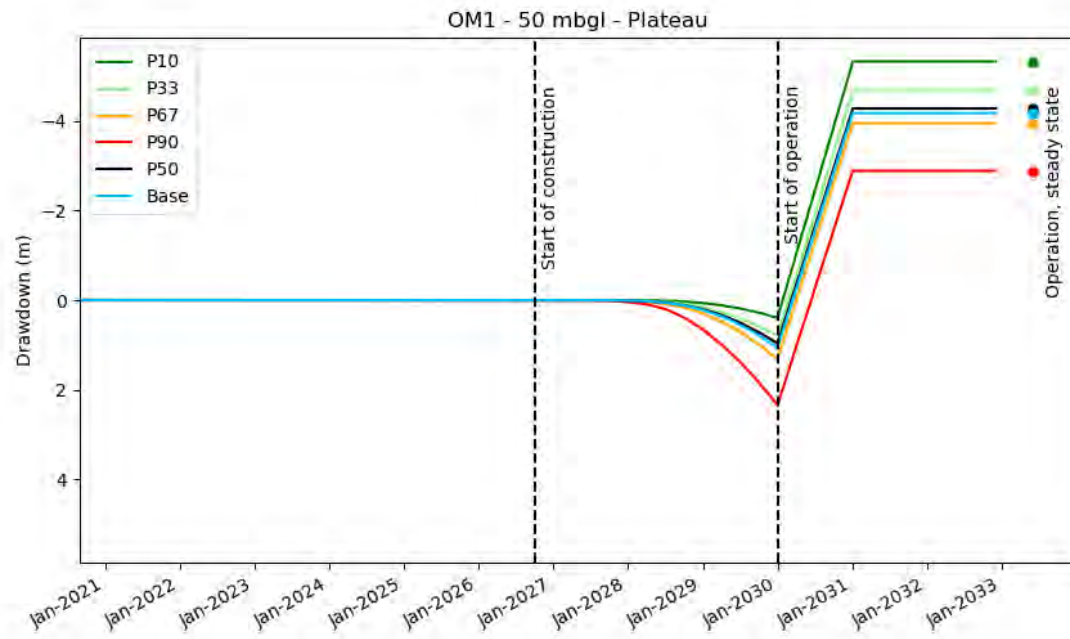


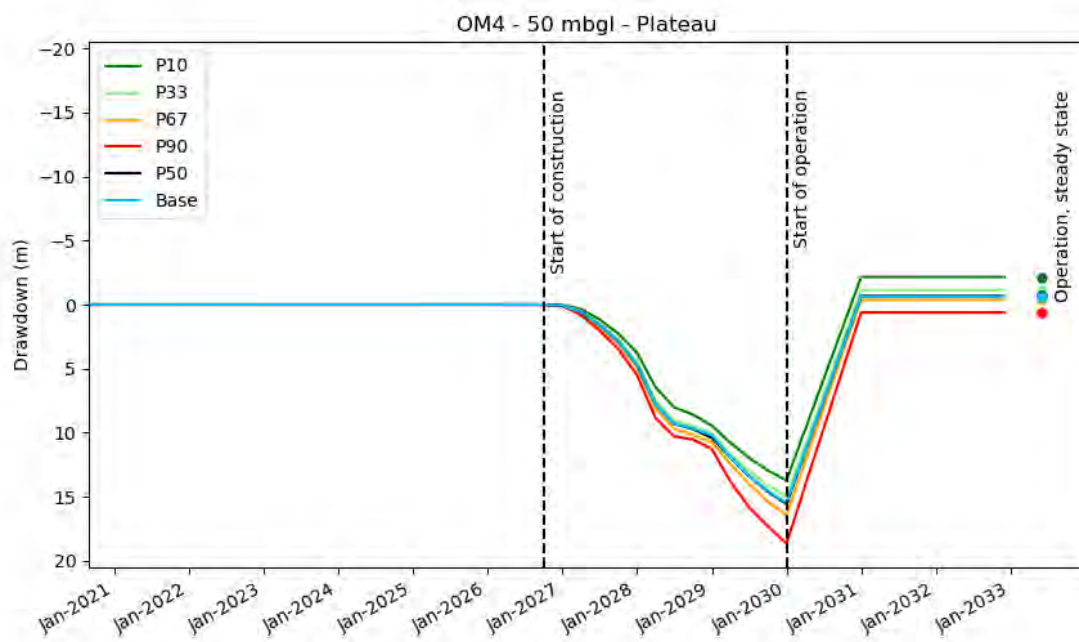
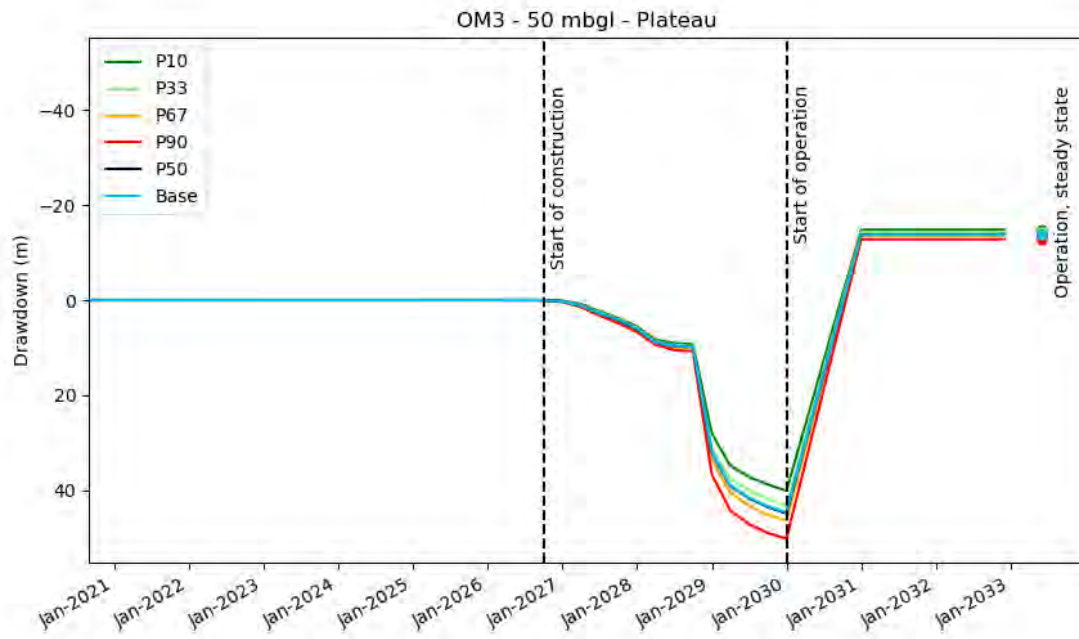


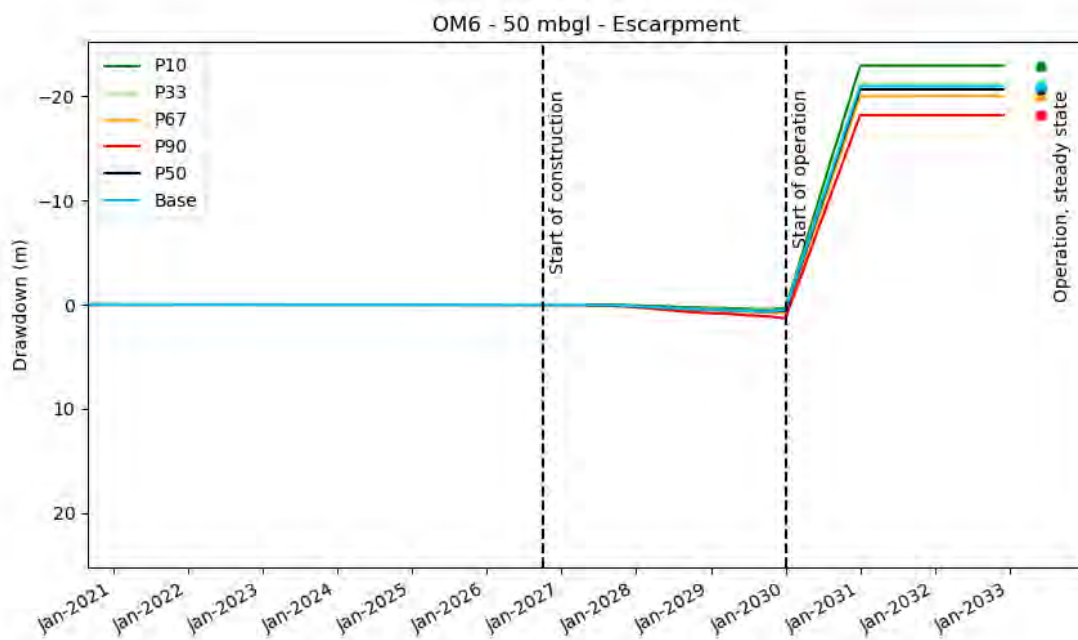
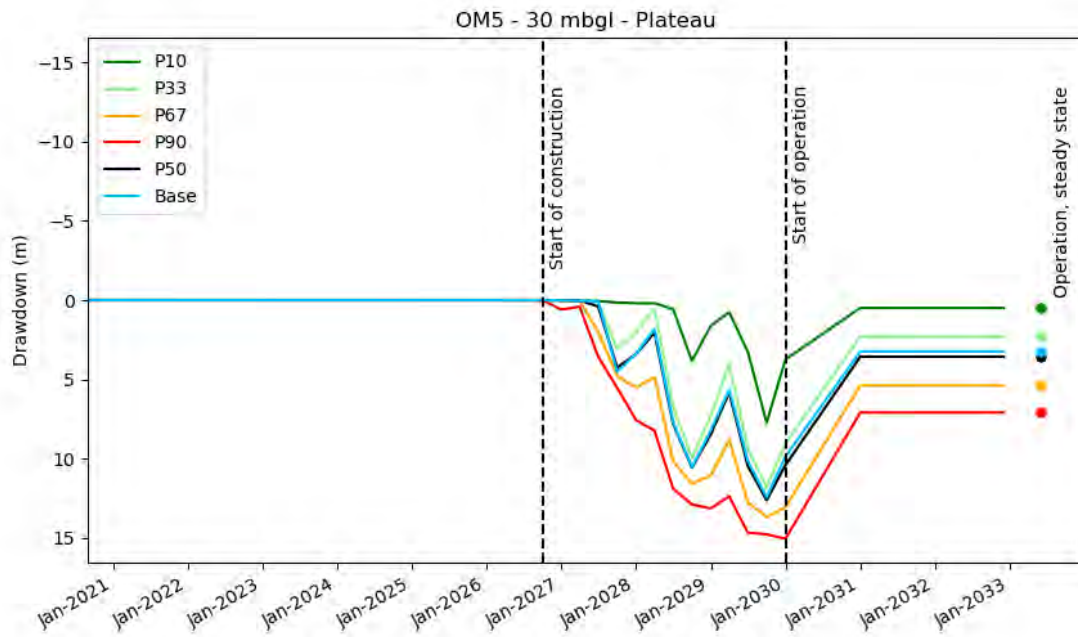


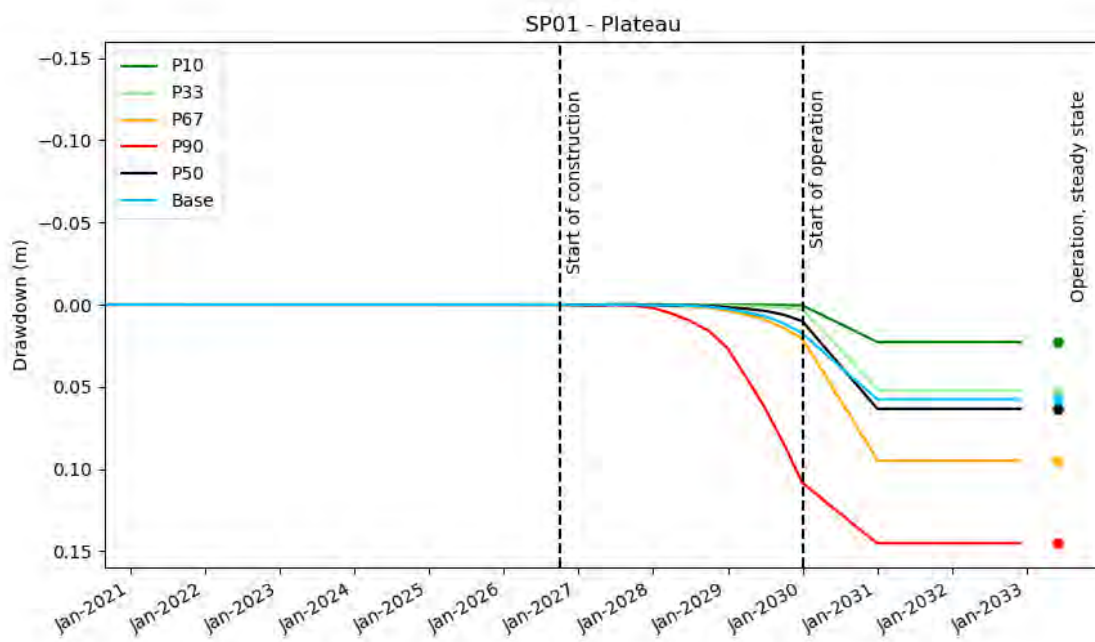
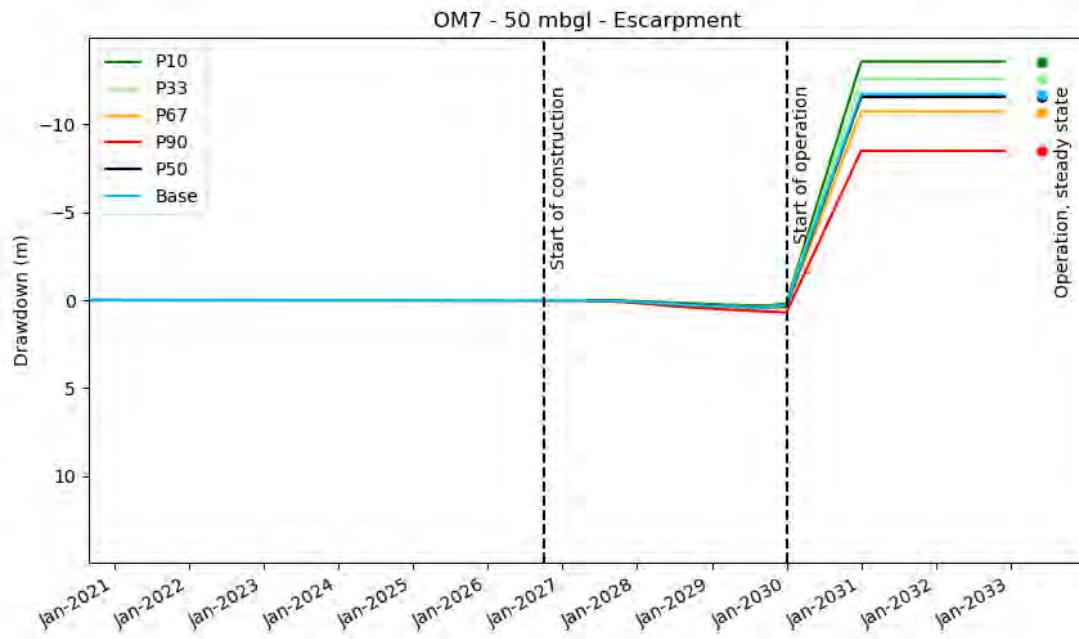


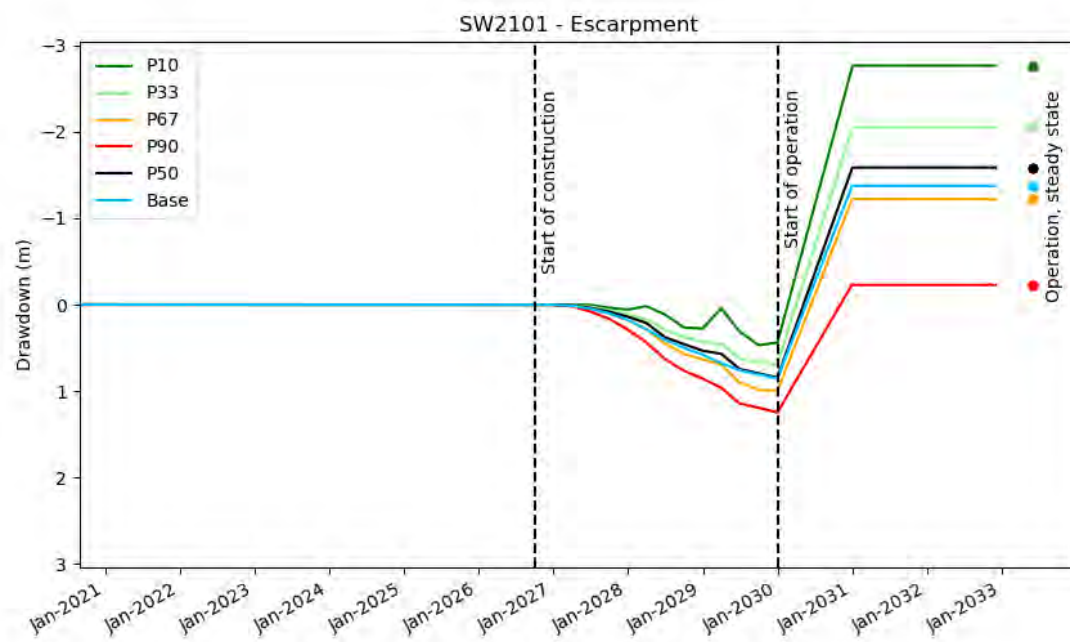
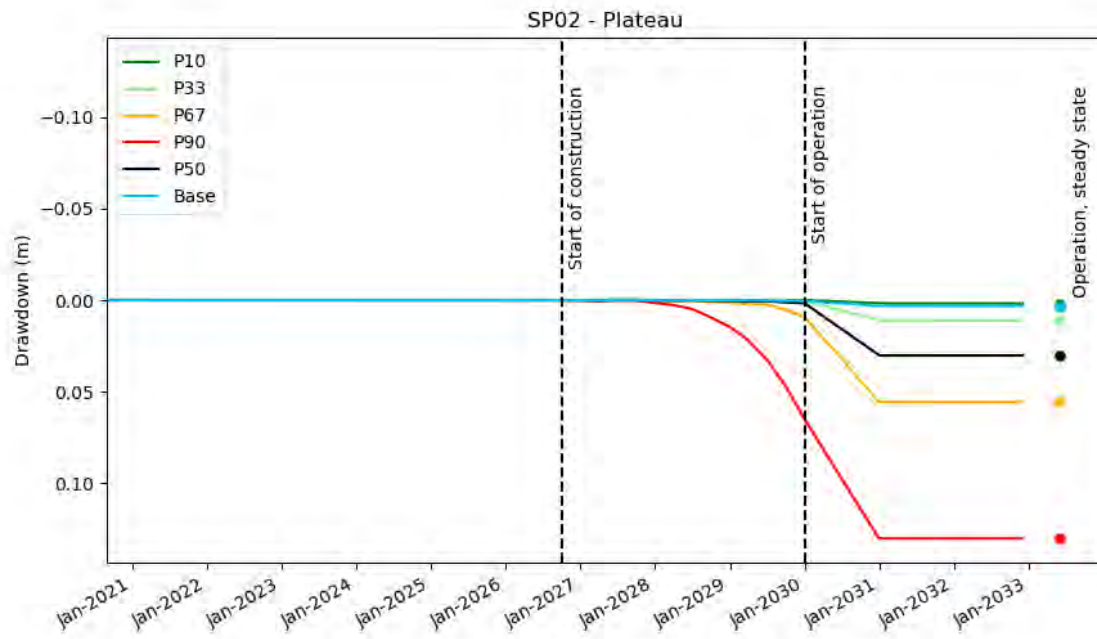


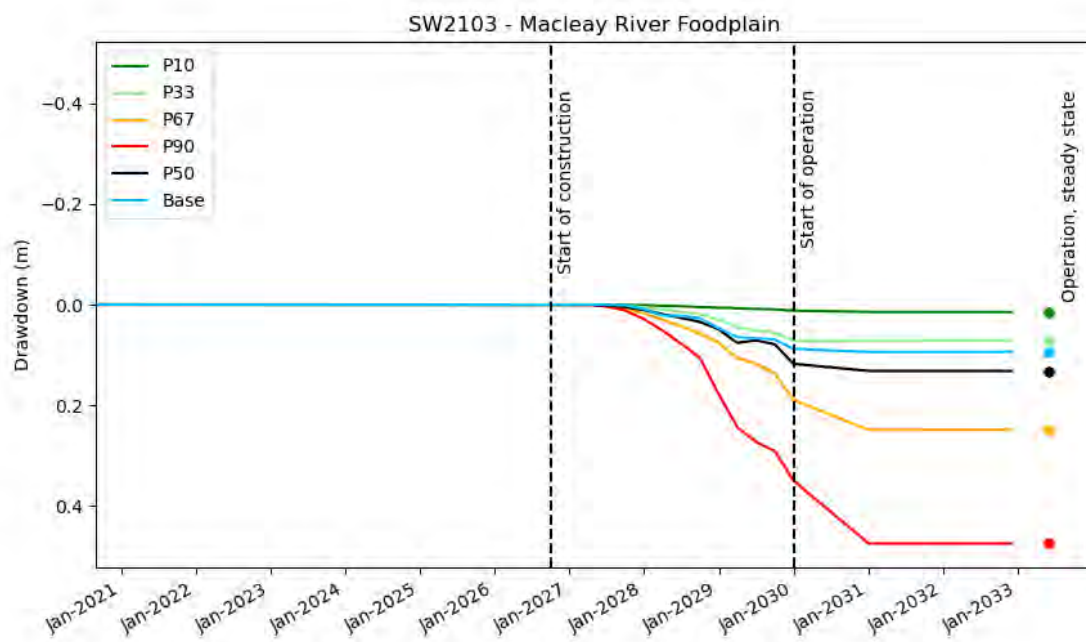
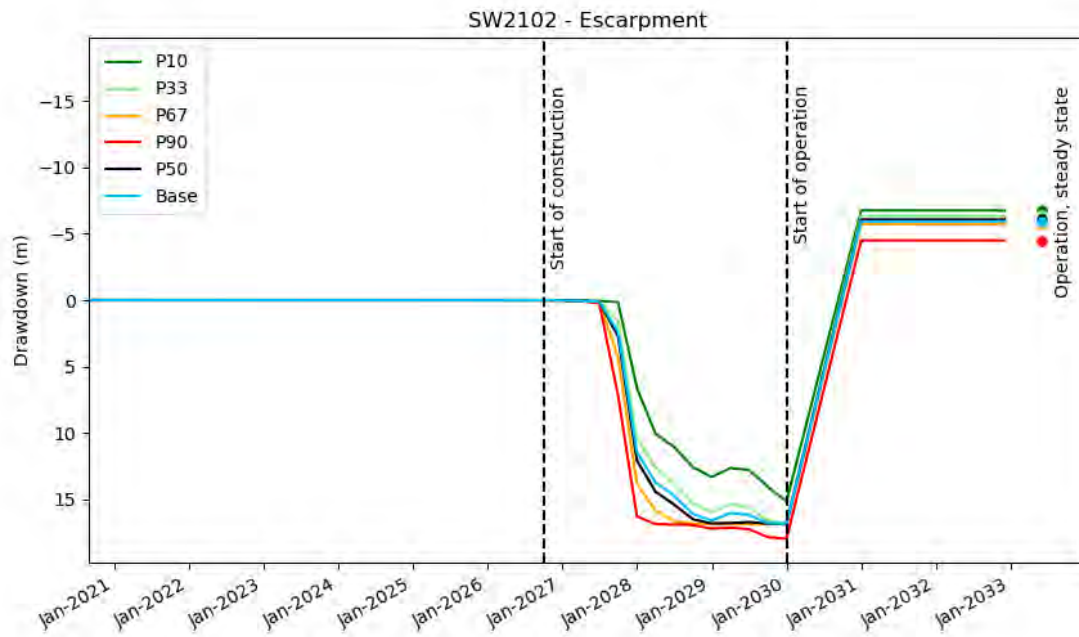


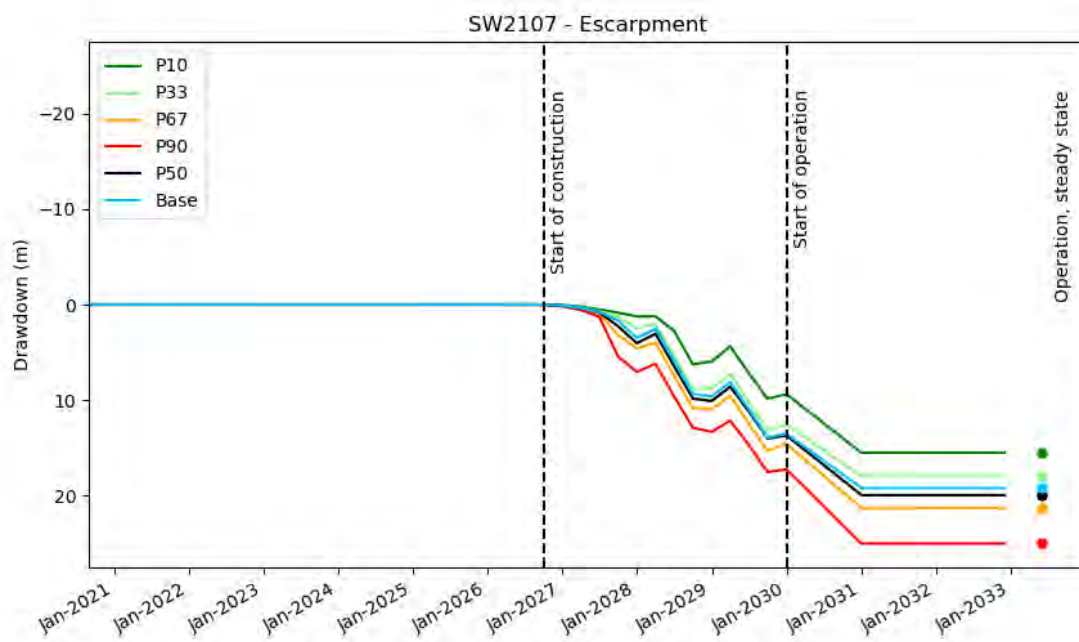
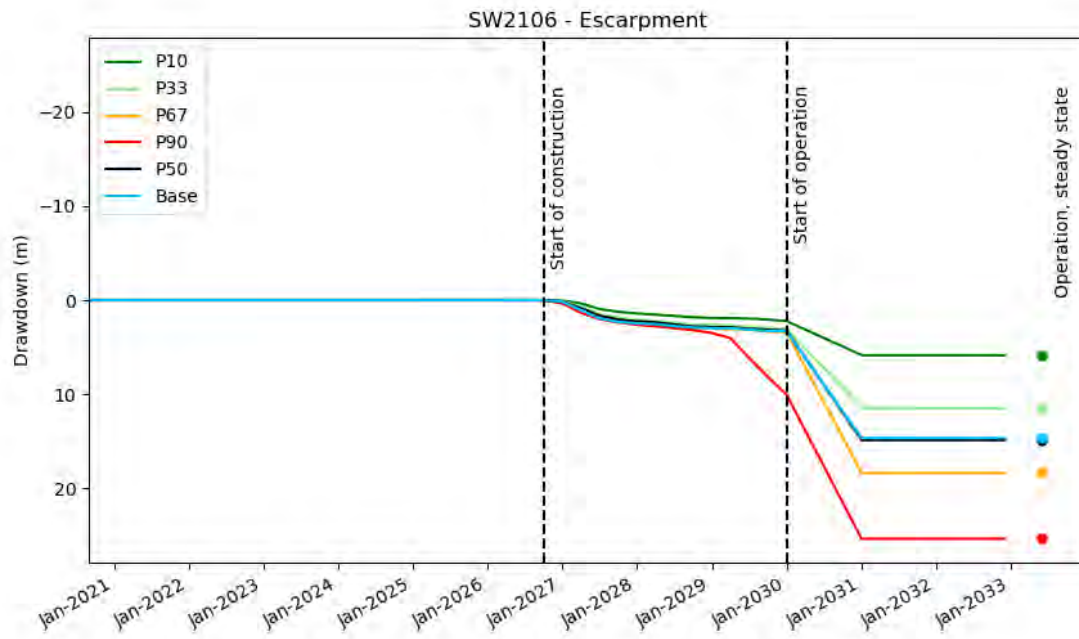


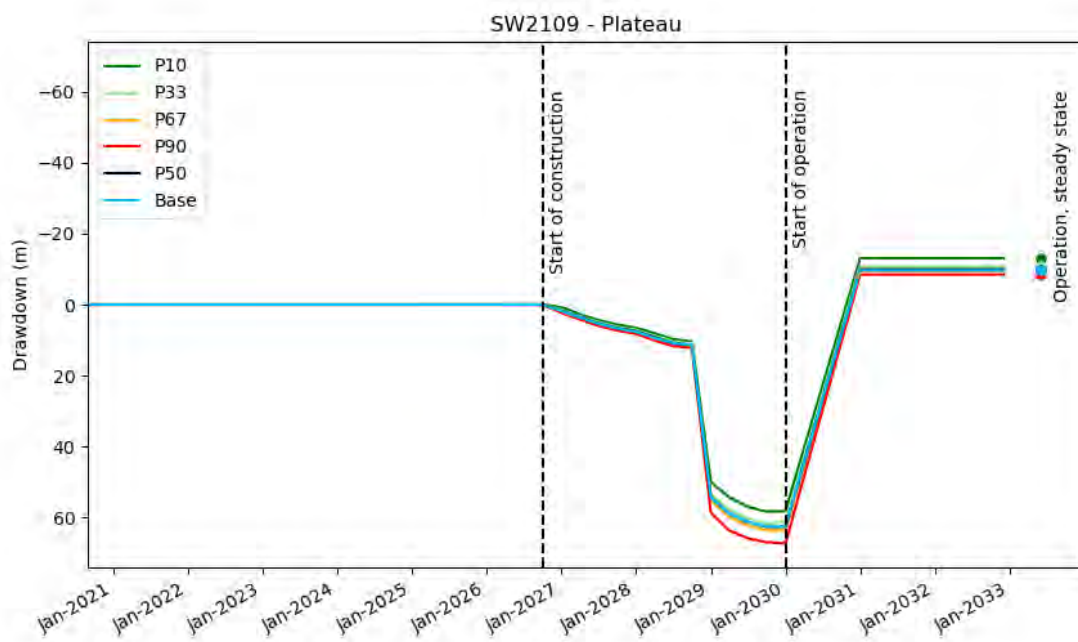
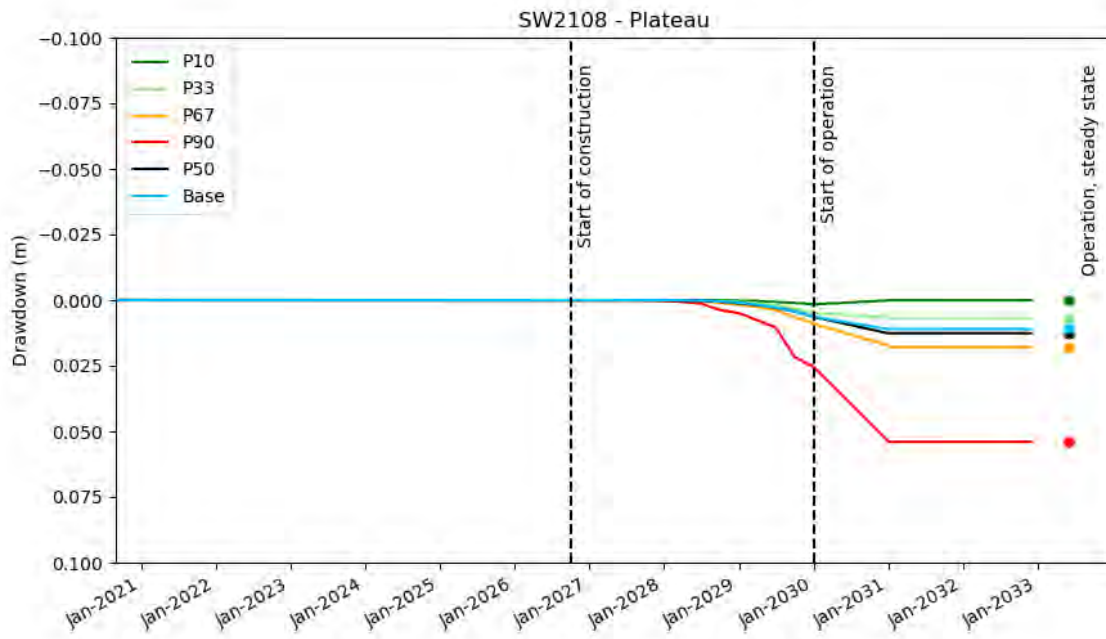


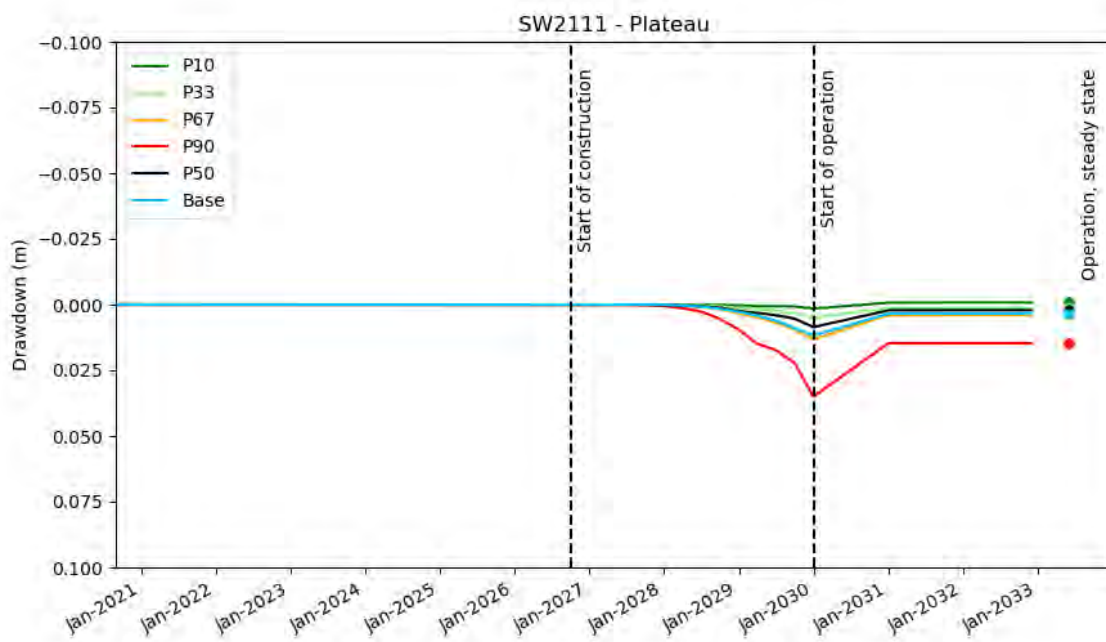
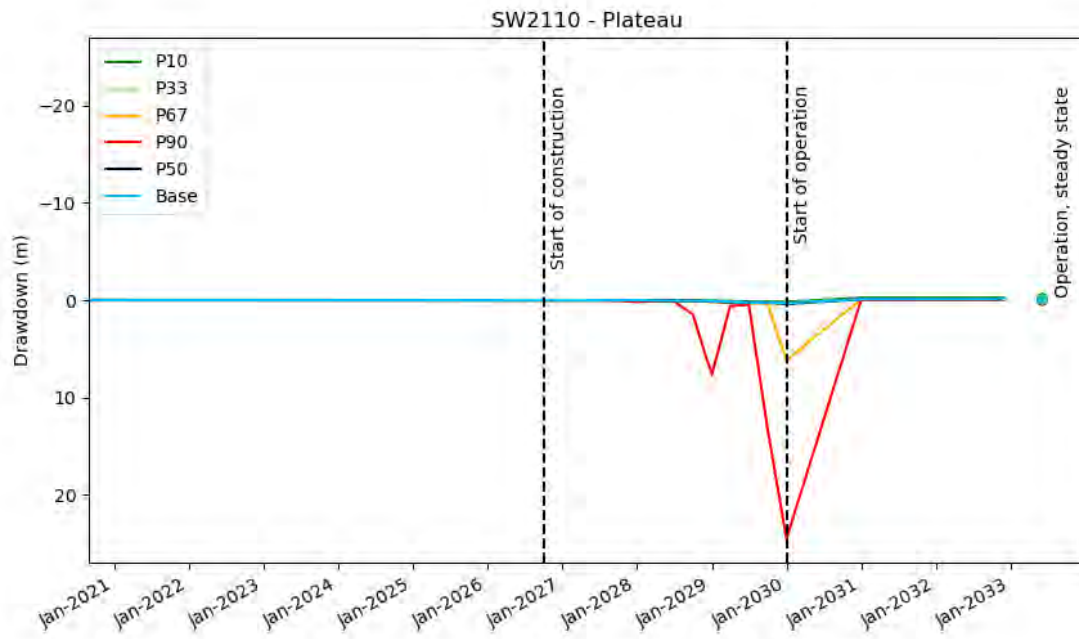


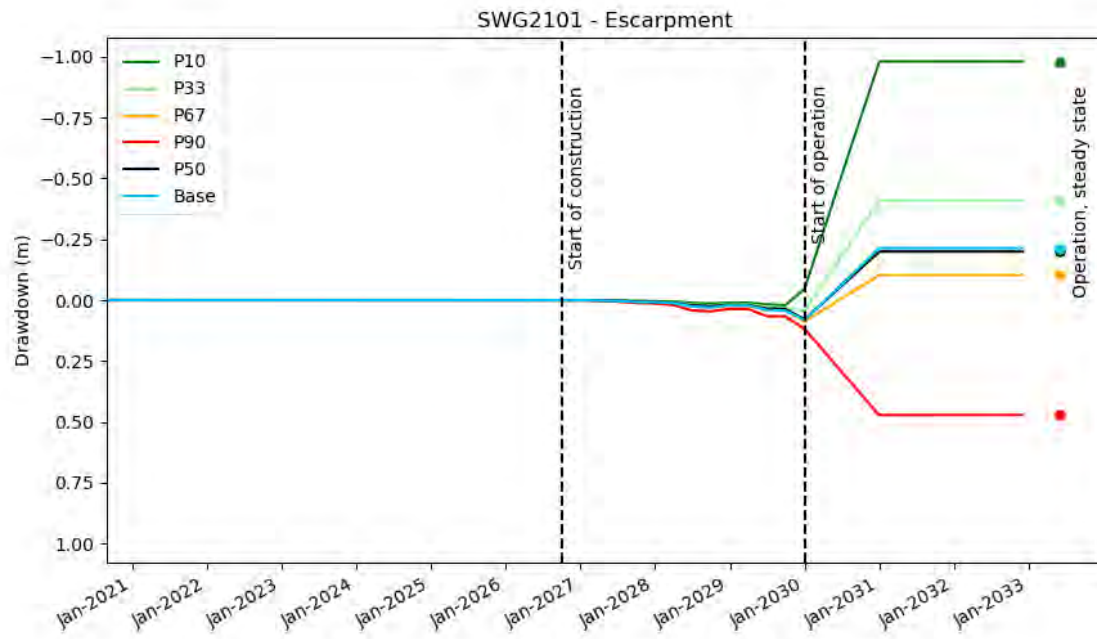












Attachment B

Probabilistic water balances at key times

B.1 Probabilistic water balances at key times

Table B.1 Pre-construction steady water balance (ML/yr)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Entire model domain						
Recharge	In	9,123	9,844	10,468	11,035	10,046
ET	Out	4,072	4,484	4,845	5,217	4,846
Storage in	In	-	-	-	-	-
Storage out	Out	-	-	-	-	-
Macleay Gorges SW source						
Macleay River to aquifer	In	275	333	394	462	327
Aquifer to Macleay River	Out	2,151	2,530	2,950	3,203	2,591
All other streams to aquifer	In	6	8	11	15	9
Aquifer to all other streams	Out	1,126	1,292	1,535	1,900	1,402
Macleay Valley SW source						
Macleay River to aquifer	In	20	32	45	66	37
Aquifer to Macleay River	Out	324	380	437	512	377
All other streams to aquifer	In					
Aquifer to all other streams	Out	873	1,150	1,405	1,749	1,232

Table B.2 Construction water balance for water year 2026 (ML)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Entire model domain						
Recharge	In	10,053	10,848	11,536	12,160	11,070
ET	Out	5,108	5,600	6,028	6,445	6,057
Storage in	In	1,057	1,180	1,298	1,420	1,285
Storage out	Out	1,192	1,330	1,441	1,558	1,330
Macleay gorges SW source						
Macleay river to aquifer	In	286	346	405	484	340
Aquifer to Macleay River	Out	1,936	2,366	2,813	3,120	2,408
All other streams to aquifer	In	6	9	11	15	9
Aquifer to all other streams	Out	1,172	1,350	1,597	1,933	1,446
Macleay valley SW source						
Macleay river to aquifer	In	20	32	44	65	37
Aquifer to Macleay River	Out	294	350	408	502	351
All other streams to aquifer	In	0	0	0	0	0
Aquifer to all other streams	Out	884	1,178	1,451	1,798	1,253
Project components						
Overall sum	Out	52.15	70.87	87.32	110.58	79.34
Bifurcated Tunnels	Out	0.00	0.00	0.00	0.00	0.00
Draft Tube Merged Tunnels	Out	0.00	0.00	0.00	0.00	0.00
Draft Tube Tunnels	Out	0.00	0.00	0.00	0.00	0.00
ECVT	Out	18.52	24.21	29.50	36.63	26.76
Headrace Tunnel	Out	0.00	0.00	0.00	0.00	0.00
IPB Galleries	Out	0.00	0.00	0.00	0.00	0.00
Lower intake	Out	0.00	0.00	0.00	0.00	0.00
Lower reservoir	Out	17.71	23.94	30.18	39.61	26.51
Machine hall	Out	0.00	0.00	0.00	0.00	0.00
Machine Hall Construction Adit	Out	0.00	0.00	0.00	0.00	0.00
MAT	Out	0.00	0.00	0.00	0.00	0.00
MAT 2	Out	0.00	0.00	0.00	0.00	0.00
MH TH Egress Access	Out	0.00	0.00	0.00	0.00	0.00

Table B.2 Construction water balance for water year 2026 (ML)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Penstock Tunnels	Out	0.00	0.00	0.00	0.00	0.00
Pressure shaft	Out	0.00	0.00	0.00	0.00	0.00
Tailrace Surge Shaft	Out	0.00	0.00	0.00	0.00	0.00
Tailrace Tunnel	Out	0.00	0.00	0.00	0.00	0.00
Transformer Hall	Out	0.00	0.00	0.00	0.00	0.00
TSST	Out	0.00	0.00	0.00	0.00	0.00
Upper reservoir	Out	15.91	22.72	27.63	34.34	26.07

Table B.3 Construction water balance for water year 2027 (ML)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Entire model domain						
Recharge	In	9,142	9,864	10,490	11,057	10,066
ET	Out	4,000	4,410	4,775	5,151	4,783
Storage in	In	1,920	2,098	2,269	2,405	2,140
Storage out	Out	1,671	1,804	1,961	2,113	1,868
Macleay Gorges SW source						
Macleay river to aquifer	In	278	336	397	468	330
Aquifer to Macleay River	Out	2,061	2,475	2,908	3,185	2,521
All other streams to aquifer	In	6	8	11	15	9
Aquifer to all other streams	Out	1,129	1,311	1,55	1,90	1,411
Macleay Valley SW source						
Macleay river to aquifer	In	24	36	48	70	41
Aquifer to Macleay River	Out	298	351	408	493	352
All other streams to aquifer	In	0.1	0.2	0.3	0.4	0.2
Aquifer to all other streams	Out	887	1,174	1,439	1,794	1,254
Project components						
Overall sum	Out	197.26	257.22	322.75	407.94	283.12
Bifurcated Tunnels	Out	0.00	0.00	0.00	0.00	0.00

Table B.3 Construction water balance for water year 2027 (ML)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Draft Tube Merged Tunnels	Out	0.00	0.00	0.00	0.00	0.00
Draft Tube Tunnels	Out	0.00	0.00	0.00	0.00	0.00
ECVT	Out	73.01	100.86	130.36	162.84	118.62
Headrace Tunnel	Out	0.00	0.00	0.00	0.00	0.00
IPB Galleries	Out	0.00	0.00	0.00	0.00	0.00
Lower intake	Out	0.00	0.00	0.00	0.00	0.00
Lower reservoir	Out	27.40	33.71	39.73	48.77	32.27
Machine hall	Out	0.00	0.00	0.00	0.00	0.00
Machine Hall Construction Adit	Out	1.56	2.55	3.89	5.36	2.89
MAT	Out	36.13	47.64	61.61	83.71	52.68
MAT 2	Out	0.00	0.00	0.00	0.00	0.00
MH TH Egress Access	Out	0.00	0.00	0.00	0.00	0.00
Penstock Tunnels	Out	0.00	0.00	0.00	0.00	0.00
Pressure shaft	Out	0.00	0.00	0.00	0.00	0.00
Tailrace Surge Shaft	Out	0.00	0.00	0.00	0.00	0.00
Tailrace Tunnel	Out	14.67	19.54	26.13	37.23	22.26
Transformer Hall	Out	0.00	0.00	0.00	0.00	0.00
TSST	Out	0.00	0.00	0.00	0.00	0.00
Upper reservoir	Out	44.49	52.92	61.03	70.02	54.39

Table B.4 Construction water balance for water year 2028 (ML)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Entire model domain						
Recharge	In	9,142	9,864	10,490	11,057	10,066
ET	Out	4,000	4,410	4,775	5,151	4,783
Storage in	In	1,920	2,098	2,269	2,405	2,140
Storage out	Out	1,671	1,804	1,961	2,113	1,868

Table B.4 Construction water balance for water year 2028 (ML)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Macleay Gorges SW source						
Macleay river to aquifer	In	278	336	397	468	330
Aquifer to Macleay River	Out	2,058	2,473	2,905	3,183	2,518
All other streams to aquifer	In	6	8	11	15	9
Aquifer to all other streams	Out	298	351	408	493	352
Macleay Valley SW source						
Macleay river to aquifer	In	24	36	48	70	41
Aquifer to Macleay River	Out	1,098	1,284	1,521	1,876	1,379
All other streams to aquifer	In	0.1	0.2	0.3	0.4	0.2
Aquifer to all other streams	Out	888	1,176	1,440	1,796	1,256
Project components						
Overall sum	Out	286.31	369.54	464.18	593.28	418.79
Bifurcated Tunnels	Out	2.46	4.72	7.77	12.02	5.24
Draft Tube Merged Tunnels	Out	0.34	0.45	0.77	1.04	0.53
Draft Tube Tunnels	Out	0.00	0.00	0.00	0.00	0.00
ECVT	Out	63.38	81.83	103.93	129.86	98.41
Headrace Tunnel	Out	0.36	0.78	1.41	2.38	0.92
IPB Galleries	Out	0.00	0.00	0.00	0.00	0.00
Lower intake	Out	0.38	0.50	0.75	1.05	0.56
Lower reservoir	Out	23.63	29.42	35.27	41.51	31.84
Machine hall	Out	0.55	0.85	1.33	1.82	0.92
Machine Hall Construction Adit	Out	3.72	6.29	9.49	13.19	7.12
MAT	Out	49.92	65.22	79.53	97.70	69.17
MAT 2	Out	1.75	2.49	3.70	4.56	2.63
MH TH Egress Access	Out	0.00	0.00	0.00	0.00	0.00
Penstock Tunnels	Out	1.52	2.45	3.88	5.61	2.68
Pressure shaft	Out	0.47	0.99	1.70	2.89	1.13
Tailrace Surge Shaft	Out	0.30	0.44	0.75	0.95	0.50
Tailrace Tunnel	Out	66.67	89.53	118.53	172.10	106.87
Transformer Hall	Out	0.52	0.74	1.10	1.55	0.79

Table B.4 Construction water balance for water year 2028 (ML)

Component	Flow direction	P10	P33	P67	P90	Base realisation
TSST	Out	0.00	0.00	0.00	0.00	0.00
Upper reservoir	Out	70.36	82.85	94.28	105.05	89.48

Table B.5 Construction water balance for water year 2029 (ML)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Entire model domain						
Recharge	In	9,142	9,864	10,490	11,057	10,066
ET	Out	3,991	4,402	4,766	5,141	4,776
Storage in	In	1,896	2,062	2,223	2,369	2,102
Storage out	Out	1,671	1,803	1,957	2,109	1,866
Macleay gorges SW source						
Macleay river to aquifer	In	278	337	398	468	330
Aquifer to Macleay River	Out	2,055	2,470	2,902	3,181	2,515
All other streams to aquifer	In	6	8	11	15	9
Aquifer to all other streams	Out	1,085	1,271	1,509	1,862	1,366
Macleay valley SW source						
Macleay river to aquifer	In	24	36	48	70	41
Aquifer to Macleay River	Out	297	351	408	493	352
All other streams to aquifer	In	0.1	0.2	0.3	0.4	0.2
Aquifer to all other streams	Out	888	1,176	1,440	1,795	1,256
Project components						
Ovall sum	Out	278.12	366.13	468.25	612.11	416.19
Bifurcated Tunnels	Out	4.44	8.79	13.75	21.69	9.64
Draft Tube Merged Tunnels	Out	0.00	0.00	0.00	0.00	0.00
Draft Tube Tunnels	Out	0.36	0.54	0.87	1.22	0.62
ECVT	Out	52.89	63.58	79.04	99.90	76.23
Headrace Tunnel	Out	1.35	2.89	4.91	8.18	3.28
IPB Galleries	Out	0.63	0.98	1.52	2.11	1.13

Table B.5 Construction water balance for water year 2029 (ML)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Lower intake	Out	1.53	2.17	3.18	4.58	2.40
Lower reservoir	Out	18.08	22.43	26.74	30.70	24.67
Machine hall	Out	2.82	4.51	6.94	9.67	4.98
Machine Hall Construction Adit	Out	2.78	4.40	6.47	9.26	4.91
MAT	Out	36.16	47.71	58.48	72.61	49.65
MAT 2	Out	1.35	2.05	3.18	4.08	2.32
MH TH Egress Access	Out	0.33	0.48	0.74	1.06	0.51
Penstock Tunnels	Out	0.00	0.00	0.00	0.00	0.00
Pressure shaft	Out	9.30	19.21	31.37	53.90	21.49
Tailrace Surge Shaft	Out	1.90	2.81	4.77	5.98	3.33
Tailrace Tunnel	Out	61.95	84.33	111.32	156.37	100.16
Transformer Hall	Out	0.66	1.04	1.68	2.18	1.21
TSST	Out	12.95	17.39	21.73	26.13	21.43
Upper reservoir	Out	68.66	80.83	91.55	102.50	88.24

Table B.6 Steady-state operation water balance (ML/yr)

Component	Flow direction	P10	P33	P67	P90	Base realisation
Entire model domain						
Recharge	In	9,123	9,844	10,468	11,035	10,046
ET	Out	4,235	4,641	4,995	5,378	4,996
Storage in	In	-	-	-	-	-
Storage out	Out	-	-	-	-	-
Macleay gorges SW source						
Macleay river to aquifer	In	275	334	396	463	327
Aquifer to Macleay River	Out	2,037	2,448	2,904	3,164	2,497
All other streams to aquifer	In	6	8	11	15	9
Aquifer to all other streams	Out	1,066	1,258	1,494	1,837	1,348

Table B.6 **Steady-state operation water balance (ML/yr)**

Component	Flow direction	P10	P33	P67	P90	Base realisation
Macleay valley SW source						
Macleay river to aquifer	In	20	32	45	66	37
Aquifer to Macleay River	Out	293	344	403	489	346
All other streams to aquifer	In					
Aquifer to all other streams	Out	885	1,174	1,436	1,786	1,252
Project components						
Overall sum	Out	161.5	204.2	258.6	324	233.2
Bifurcated Tunnels	Out	-	-	-	-	-
Draft Tube Merged Tunnels	Out	-	-	-	-	-
Draft Tube Tunnels	Out	-	-	-	-	-
ECVT	Out	46.8	57.7	75.3	93.8	69.1
Headrace Tunnel	Out	-	-	-	-	-
IPB Galleries	Out	0.5	0.9	1.4	2.0	1.1
Lower intake	Out	0.1	0.1	0.2	0.3	0.2
Lower reservoir	Out	7.7	10.9	15.6	19.6	13.2
Machine hall	Out	4.0	7.1	10.5	16.5	8.4
Machine Hall Construction Adit	Out	2.7	4.5	6.8	10.1	5.4
MAT	Out	23.9	29.6	35.6	46.3	29.8
MAT 2	Out	1.3	1.9	3.3	4.1	2.4
MH TH Egress Access	Out	0.3	0.5	0.9	1.2	0.7
Penstock Tunnels	Out	-	-	-	-	-
Pressure shaft	Out	-	-	-	-	-
Tailrace Surge Shaft	Out	2.3	3.4	6.2	8.6	4.7
Tailrace Tunnel	Out	25.2	31.9	38.8	49.3	36.7
Transformer Hall	Out	0.7	1.1	1.9	2.5	1.4
TSST	Out	9.0	11.4	13.4	16.1	13.2
Upper reservoir	Out	37.0	43.2	48.7	53.6	46.9
Outflow from project components						
Overall sum	In	82.8	89.2	248.1	269.4	89.1
Lower reservoir	In	51.8	53.3	116.6	120.1	52.1
Upper reservoir	In	28.4	30.4	122.3	133.7	29.9

Table B.6 **Steady-state operation water balance (ML/yr)**

Component	Flow direction	P10	P33	P67	P90	Base realisation
Tailrace	In	0.3	0.5	0.9	1.5	0.7
Pressure shaft	In	2.3	5.0	8.3	14.1	6.4

Attachment C

Independent peer review

DATE: 19th July 2024

TO: EMM

Henry Noakes, Itsuo Camargo

FROM: Chris Nicol, Hydrogeologist

RE: Peer review: Oven Mountain Pumped Storage Groundwater Modelling –
2024 update

OUR REF: EMM001/c004_rev0

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 (2024). The reader is referred to EMM (2024) 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 May 2024*” (EMM, 2024). 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. However, this is my second review of groundwater modelling for this project, the first being in 2022 for a first pass modelling effort with a more limited supporting data set. Hence, this 2024 review is informed by that earlier review and associated discussions with EMM. 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 construction-related depressurisation- and mounding-related aquifer stress responses that the model is ultimately used to forecast. Similarly, there are no other historical sources of other types of significant long-term artificial groundwater stress (such as abstraction for urban supply or agriculture). This is a commonly encountered situation and can only be dealt with through targeted ongoing monitoring of stress-responses during and after project construction, with appropriate risk management controls in place.

However, the potential future effects of project-related groundwater 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 modelled nature and magnitude of project-induced changes to the groundwater system are within the range of what I would *qualitatively* expect for a project of this kind in this environment.

The modelling workflow follows current best practice and includes a good assessment of forecast model uncertainty. EMM's report quality is generally high; some suggestions for improvement were provided in Attachment 1. No critical issues were identified by the reviewer in EMM's modelling workflow or application of best practice methods.

The primary issue identified in the modelling relates to the discussion around river / creek impacts on page 95 / Figure 5.2 (see Attachment 1 review checklist item 5.7). The report discusses decreases in flux during construction, and increases during operation, yet all data I can see on Figure 5.2 is positive, and the text on page 95 states "a positive flux indicates a decrease in water flow due to the project's impact". This does not make sense to the reviewer and clarification is warranted.

Related to the above point on river/creek discharge impacts from the project, it could also be useful to present timeseries uncertainty in total river water take, or uncertainty in peak take in any one year, depending on DPE "water take" assessment and reporting expectations.

Other lower priority potential improvements for consideration in reporting and future model updates are provided in Attachment 1 (review checklist).

As an overarching comment on EMM's groundwater modelling for OMPS, the reviewer is of the view that there are no critical issues – on the proviso that the confusion around river/creek impacts discussed above is addressed and explained. On this proviso, I conclude 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 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, Knapp 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.

EMM, 2022. Oven Mountain Pumped Storage Groundwater Modelling. Report prepared for OMPS Pty Limited, November 2022. Version 1 dated 3/11/2022. EMM ref: J210465 RP8

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. *c003_EMM001_NWC2012_Review_Oven_Mountain_2024_update_rev0.xlsx - Review checklist Table 9-2 of the Guidelines (Barnett et al., 2012)*

Review questions	Yes / No / NA 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	Although 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. However, it is acknowledged that there would be (or are) no stress data of direct relevance to the proposed project (construction and operation), or the model outputs required in response to project construction/operation; this is acknowledged by EMM in Table 1.2.				
1.6 Are the planned limitations and exclusions of the model stated?	Yes	A few planned limitations are detailed in section 1.6 in reference to model complexity, and some in section 3.1 and Table 1.2 too. Section 8 includes discussion around identified limitations following the model development and application phases.				
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	Good detail around different sub-units within each geological unit, and how those relate to receptors (eg upland springs and fens).				
2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds	Yes	No critical features missing from EMM's assessment, in my opinion. Whilst there could be localised faulting, there is no evidence of or literature relating to this, according to EMM.				
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	Packer tests, slug tests. But it is noted that there are no data from stresses such as as those that the project is likely to impose; this is however acknowledged by EMM (section 1) and is an issue common to many projects.				
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. The topographic gradient from areas directly affected by project construction and operation is so large that this is unlikely to significantly influence conceptualised or modelled groundwater-related risks arising from the project.				
2.3.3 groundwater usage (pumping, returns etc)	Yes	Not a lot (one farm bore on the western side of the Macleay River, and hence probably at extremely low risk of adverse impact from the project).				
2.3.4 evapotranspiration	Yes					
2.3.5 other?	Yes	Spring discharge and fens. GDE identification and discussion around function.				
2.4 Have groundwater level observations been collected and analysed?	C	Spatially, yes. But in terms of temporal behaviour, only a small selection of hydrographs are presented and roughly analysed (section 2.8.2). No mention of the long term drying trend that appears due to recent low rainfall.				
2.4.1 selection of representative bore hydrographs	C	See above				
2.4.2 comparison of hydrographs	C	See above.				
2.4.3 effect of stresses on hydrographs	C	vaguely...see above				

2.4.4 water table maps/piezometric surfaces?	Yes	Depth and RL, which are both useful
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 around seeps and discrete discharges, but no gaugings - but this is notoriously difficult if not impossible to reliably measure. It is noted that groundwater depths at spring locations were included in the model history match process.
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, which is great. But also by unit and location. There is a good data set now available, and these are well presented and discussed.
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	A potential alternative approach is to use CLNs to simulate construction (shaft/race) features, however this is immaterial given EMM managed to complete the modelling including uncertainty analysis with the chosen approach.
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?	C	However it is noted that the version of usg-transport that is used is not documented.
3.3 Are the spatial domain and discretisation appropriate?	Yes	
3.3.1 1D/2D/3D	Yes	3d
3.3.2 lateral extent	Yes	Covers the flow system and expected area of influence.
3.3.3 layer geometry?	Yes	Sensible approach, if not resulting in a big model!
3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	Yes	More than enough

Document the version of usg-transport you are using. Ensure the executable is kept in the model archives.

3.3.5 Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	Yes	Useful 3d cross section included to make the adopted approach clear. Good stuff.
3.4 Are the temporal domain and discretisation appropriate?	Yes	I like the duration-variable stress period setup as dictated by your data. Good stuff. It is noted that the forecast period is modelled with quarterly stress periods; this is (on face value) fine given the stated modelling objectives are more centred around watertable mounding and drawdown (mapping) and baseflow reductions/increases (which is <i>generally</i> a more time-diffuse process, at least in terms of the adopted "annual take" type of impact assessment, and the relatively low level of risk in this regard that this project is thought to pose).
3.4.1 steady state or transient	Both	Predictive periods use a final SS stress period, which makes sense. And the initial heads SS period is typical and a good approach.
3.4.2 stress periods	Yes	See 3.4 above
3.4.3 time steps?	Yes	Adaptive, fine
3.5 Are the boundary conditions plausible and sufficiently unrestrictive?	Yes	EVT max rate as pan evaporation is arguably too high, but this is likely immaterial to the modelling objectives.
3.5.1 Is the implementation of boundary conditions consistent with the conceptual model?	C	For the history-matching period, somewhat strangely, a filtered baseflow time series is used to define an equivalent "baseflow stage height" (whatever that is) for RIV boundary conditions. This issue was highlighted in my first review of this model. 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 do note that you have ammended the approach in this model revision to use the median historical stage height for the predictive stress periods - which is hydraulically sensible. But I really do wonder why you did not do the same for the historical period? It is a little odd, not to mention unjustified in your report (still!). * Suggest you clarify what "baseflow stage height" is / how it is defined, and conceptually justify it (i.e. how does the adopted approach make hydraulic / conceptual sense? To me, it doesn't on either front. 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). * In your report, clarify river stage interpolation (or not) along the Macleay River (as per the last comment to the left). Related to this, describe how RIVs are assigned to layers. * maybe double check page 62 comment / figure reference noted to left. Another point of note: in my first review of this model, I asked about river stage height variability away from the Macleay River gauge, and you (EMM) replied with: <i>"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"</i>. I suggest that if this still holds, you include it in your report, given its potential importance to model end use. * one final comment: page 62 <i>"The grey cells in the Figure 3.12 are the components that are to be steel lined."</i> - I can't see these in the figure. But I think I worked it out (after some deep reading and rereading of pages 61-64 and comparing figures 3-12 and 3-13) what is meant however re: the steel lined components / construction vs operation boundary conditions. And the model representation of this makes sense to me now. 1. Moderate 2. Moderate 3. Moderate
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	Aside from the Macleay River, but this is a suitable approach in this case.
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?	C	Implicitly, on my reading of the report, because SS (initial heads) recharge rates were adjusted indepently from transient rates.
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	0.05m, ok for a regional model like this.

4. Calibration and sensitivity

4.1 Are all available types of observations used for calibration?	Yes	1. Heads and temporal head differences. Also heads at spring locations, which is more of a conceptual observation - a good approach. 2. Given the topographic head difference and resulting variation in head, a more prudent observation data type than heads (for more effective PEST operation) would be depths below ground, to normalise the data for topography. But this is not a critical issue, just a suggestion for future work.	
4.1.1 Groundwater head data	Yes		
4.1.2 Flux observations	Yes	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 history matching results not being presented/discussed in this regard).	
4.2 Does the calibration methodology conform to best practice?	C	1. Your approach to observation data noise is not quite right / a little risky. This should reflect the standard deviation of measurement error (or at least an estimate of it). Given your weights are numbers like 1, 2, 4 and 10, this would result in measurement error standard deviations of 1m, 0.5m, 0.25m and 0.1m respectively. Hence, assuming a 95% confidence interval, this equates to error ranges of 4.2, 1 and 0.4m respectively (2 SD's about the mean); or for the 99.7%ile potential range that IES could generate in your case: 6.3, 1.5 and 0.6m respectively. The higher end is getting pretty big, especially for shallow bores (...)! This is especially so for head differences, for which error would typically be assumed to be smaller than that for heads. For the higher reliability bores however, I think the range is reasonable. As long as IES could get a decent history-match you are ok however; but this issue could in some cases make pest really struggle to improve phi. And perhaps most importantly, it could potentially result in significant over-estimation of predictive uncertainty - but this is possibly a better position in this case given the lack of data of direct relevance to your forecast types (i.e. response to aquifer stress). 2. But good use of IES - a suitable choice and a good improvement over the earlier modelling effort.	1. In subsequent model history-matching, reconsider the approach to measurement noise. Low
4.2.1 Parameterisation	C	1. It could help the assessment to include Macleay River stage uncertainty, particularly given the unusual RIV stage definition method used (see 3.5.1 above). Consider for future modelling work. 2. Table 4.2 - update plateau/escarpment recharge min/max range (both are currently the same (min?)). Standard deviations for alluvial K and recharge rates seem remarkably low (assuming that the report is correct in stating that these are log space values) - according to my understanding of what you are saying in this table, @ 99.7%ile (6 SDs around the mean), we are talking a range of less than one order of magnitude, so did alluvial K even change much in the history matching? And why is the alluvial K PDF not plotted in Figure 4-3? I am guessing it is very narrow around your prior mean (about 1/7th of your tight bedrock PDF range!). I am also guessing that recharge rates are equally as narrow (less concern conceptually than K, if your prior mean is decent). Alluvial recharge rate prior mean seems high (242mm/year?), but your ranges allow it to go lower, so probably ok (although noting the standard deviation issue just mentioned...resulting in my estimated prior ensemble range of ~130-370mm/year?). Update: * Now I look at table 4.7, I think you are ok - you have decent alluvial K range across the ensemble, according to that (which is a bit weird given the above noted standard deviation...). Table 4.8 also indicates the recharge ranges are reasonable. * Also Section 5.3.4 and figure 5.4 to 5.7 show prior and posterior ranges pdfs / central shifts - and this all looks fine to me. Well done.	2. Update table 4.2 recharge ranges as per left; also address the question re: alluvial ranges/PDF, and any inferred implications (noting the "update" comments to left). 2. Low
4.2.2 Objective function	C	Reasonably well thought out relativities. But also please see #2 in 4.2 re: measurement error above. I like your subdivision of history-match statistics in Table 4.3 and 4.4 - splitting the higher elevation observations out from the lower ones to give a more representative assessment. And I like how you have presented both the filtered and unfiltered ensemble stats - it shows there is not a significant quality bias incurred through your filtering process.	
4.2.3 Identifiability of parameters	No	Whilst useful, its not possible in the traditional sense with the ensemble method (as far as I am aware). However, an informative alternative for the team to consider is plotting the reduction in parameter variance from the prior to the posterior (normalised by the prior range, so 0-->1 values), and possibly the mean shift; with these, one can see which parameters are / are not informed through history matching, and by how much.	Consider prior/posterior variance reduction stats figure described to left. Although your Figures 5.4 to 5.7 and section 5.3.4 roughly do this job, so feel free to ignore me. Low

4.2.4 Which methodology is used for model calibration?	Yes	PESTPP-IES - a good choice and an improvement over the prior modelling effort.
4.3 Is a sensitivity of key model outcomes assessed against?	Yes	
4.3.1 parameters	Yes	
4.3.2 boundary conditions	C	RIV stage could have been included, especially given the unusual "baseflow filtered" stage height approach noted above. But it's probably not a big issue for model end use.
4.3.3 initial conditions	Yes	
4.3.4 stresses	Yes	
4.4 Have the calibration results been adequately reported?	Yes	Significant improvement over the first modelling effort - well done. I like your table 4.5, and your hydrographs. The measurement noise issue I identified above does not appear to be a big issue - great!
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	Consider a quick plot or two of vertical gradients Low
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	Yes	See 4.2.2 above
4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?	Yes	Temporal differences plotted as well as heads. Also a range of stats as per 4.2.2 above
4.5.1 spatially	Yes	Implicitly. Could consider a mean head residual map. Moderate
4.5.2 temporally	Yes	
4.6 Are the calibrated parameters plausible?	Yes	
4.7 Are the water volumes and fluxes in the water balance realistic?	Yes	
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	Including water balances / takes - great.

5.3 Are the assumed climatic stresses appropriate?	Yes	Yes, and water balance sensitivity to recharge is presented; this will suffice in my view for considering climate change impacts on the impact assessment.
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	
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	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.
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?	C	Table 5.1 I think might have a typo re: tailrace GHB being set to <i>upper</i> reservoir head in operation phase - should this not be <i>lower</i> reservoir head, as suggested by figure 3.13 (and this makes more sense to me, noting I am not a hydro engineer)?
5.6 Do the prediction results meet the stated objectives?	Yes	Amend table 5.1 as per left if deemed appropriate. Or amend figure 3.13 as needed. Or clarify and tell me I am wrong. Moderate
5.7 Are the components of the predicted mass balance realistic?	C	1. I cannot make sense of the discussion around river / creek impacts on page 95 / Figure 5.2. There is talk around decreases in flux during construction, and increases during operation, yet all data I can see on Figure 5.2 is positive, and the text on page 95 states "a positive flux indicates a decrease in water flow due to the project's impact". This makes no sense to me. Please clarify. 2. It could be useful to present timeseries uncertainty in total river water take, or even just uncertainty in peak take in any one year, depending on DPE water take needs. 1. Clarify query to left re: page 95 / Figure 5.2. 2. Consider this suggestion, depending on DPE water take needs. 1. High 2. Moderate
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	It is well done - I like the drawdown likelihood maps, and the key forecasts are provided in uncertain terms. This is all done in a clear and consistent manner.
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. And regardless, a range of prediction variances (likelihoods) are presented, which is in my view more useful.
6.3 Are the sources of uncertainty discussed?	Yes	Parameter uncertainty is presented, and the resulting effects on the predictions are presented. Whilst links between the two are not directly made, this is beyond the needs of the modelling.
6.3.1 measurement of uncertainty of observations and parameters	Yes	Noise included on obs. Parameter uncertainties broadly reflect tested and conceptual ranges.
6.3.2 structural or model uncertainty	C	Boundary conditions not included in the uncertainty analysis (aside from recharge); it could be useful in later model revisions to include River boundary uncertainties in the analysis, given its significant role in discharge and impact receptors. Having said that, the main controls on impact will (in my view) be hydraulic conductivity between construction/operational features and receptors, which is covered well.

6.4 Is the approach to estimation of uncertainty described and appropriate?	Yes	Well described, and appropriate. Some might argue that 81 model realisations is a little low, but it is not far below typical industry-applied ensemble sizes (100-200, in my experience). Bigger ensemble sizes can be problematic with larger models because of their run times, and so there are practical limits to what can be achieved. In any case, the presented ranges of key predictions appear to be as wide as might logically be expected.
6.5 Are there useful depictions of uncertainty?	C	1. I really like your drawdown / mounding likelihood maps. Some cross referencing in the text would however be helpful. I think Figure 5.13 title should read "...exceeding 0.2m", not "2m". 2. GDE drawdown timeseries uncertainty will be useful for the GIA / other disciplines / risk assessment. Well done. 1. Regarding your drawdown/mounding maps and discussion, it would be more readable / interpretable if you referred to the relevant figures when making your points / conclusions on page 100. Also consider colouring the mounding maps differently to the drawdown maps - I struggled to work out what the difference between these maps were, which was not helped by the discussion on page 100 not cross referencing the relevant figures... 1. Moderate Also, fix the title of 5.13 (assuming i am correct on this typo)

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	
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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 - noting that this only affects the history-matching period (which is odd in and of itself...).
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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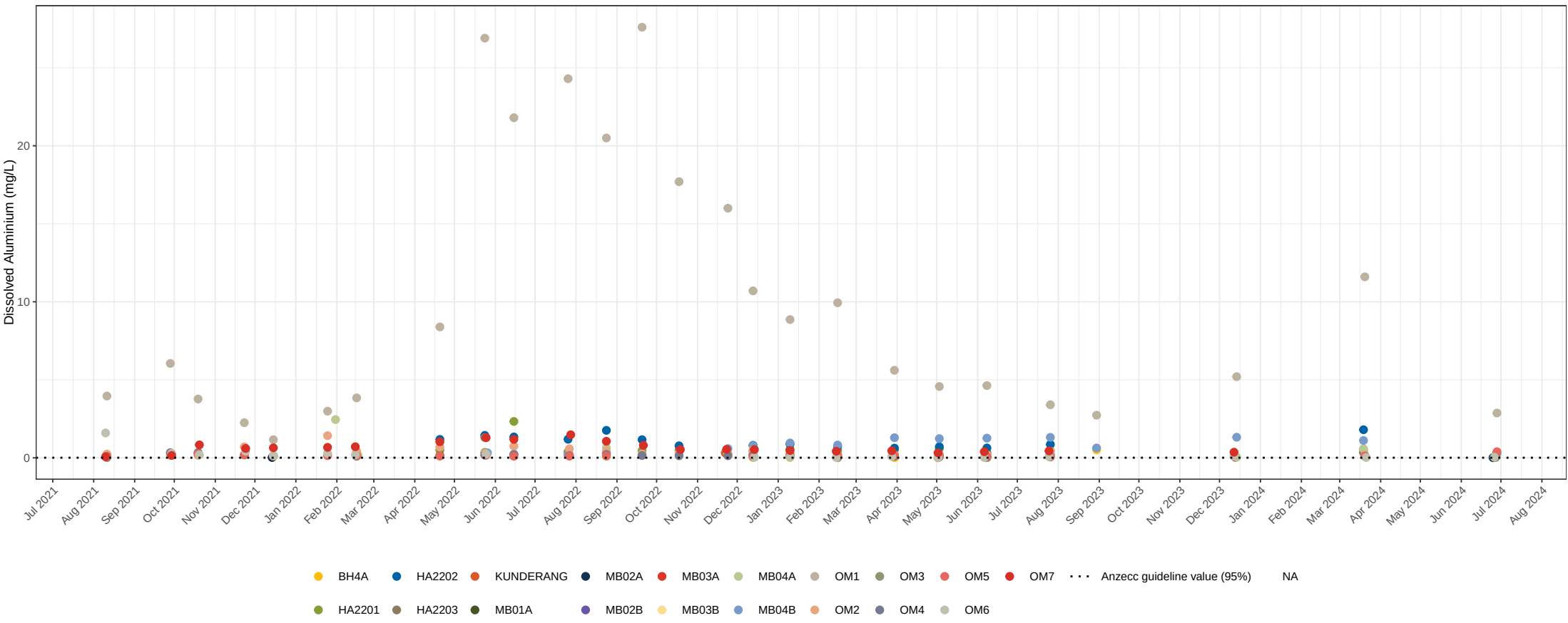
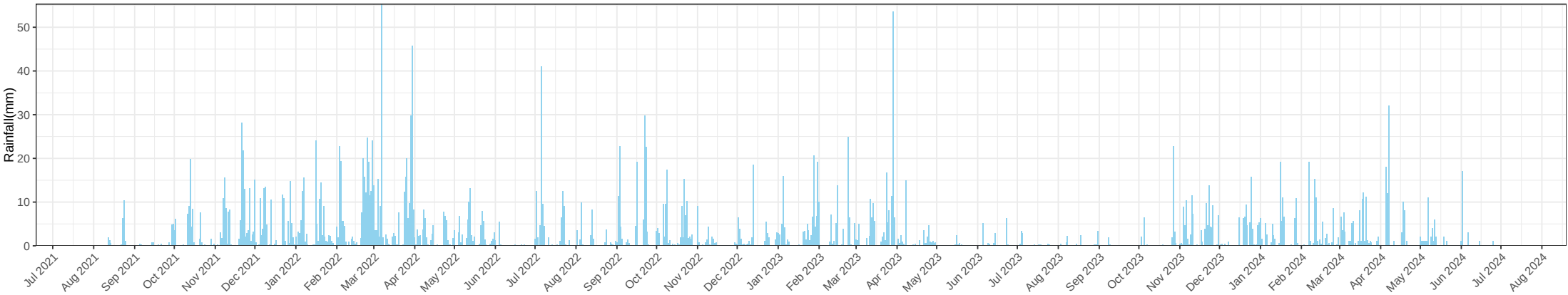
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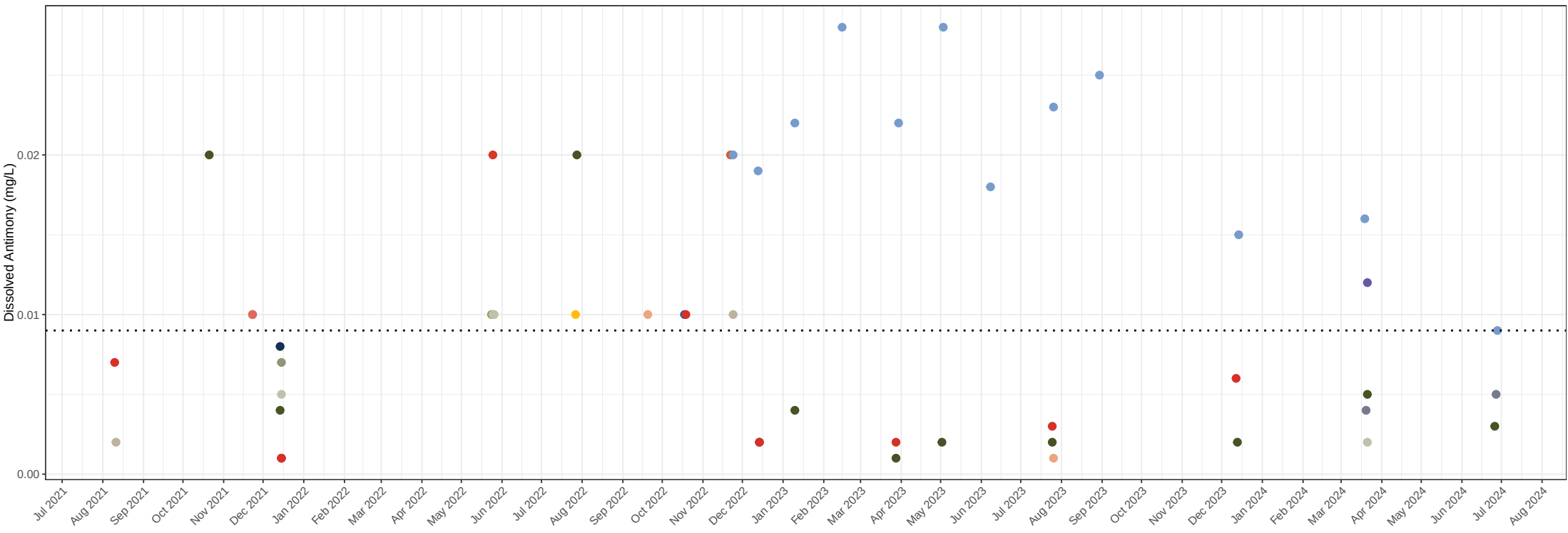
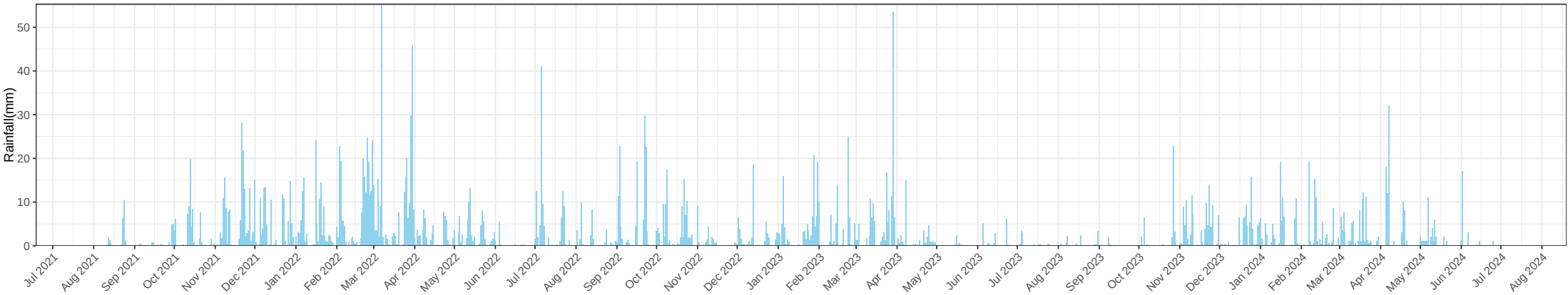
Annexure D

Groundwater chemistry hydrographs (dissolved metals)



Notes
 Rainfall measured at Bellbrook weather station (059122)
<http://www.longpaddock.qld.gov.au/silo>

Dissolved Aluminium (mg/L) groundwater quality times series data
 Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
 Groundwater impact assessment
 Figure D. 1



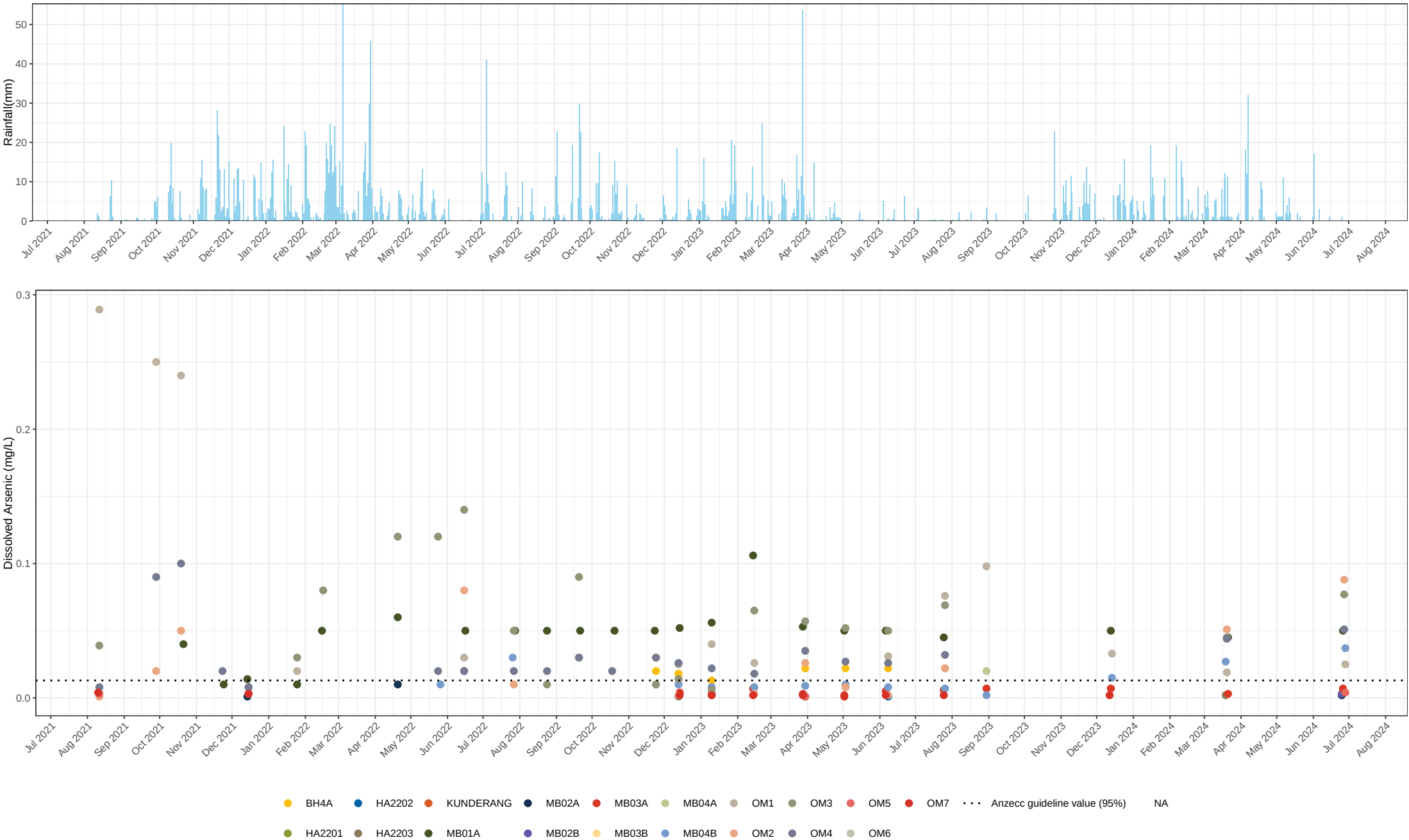
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- HA2202
- KUNDERANG
- MB02A
- MB03A
- MB04A
- OM1
- OM3
- OM5
- OM7
- ...
- Anzecc guideline value (95%)
- NA
- HA2201
- HA2203
- MB01A
- MB02B
- MB03B
- MB04B
- OM2
- OM4
- OM6



Notes
 Rainfall measured at Bellbrook weather station (059122)
<http://www.longpaddock.qld.gov.au/silo>

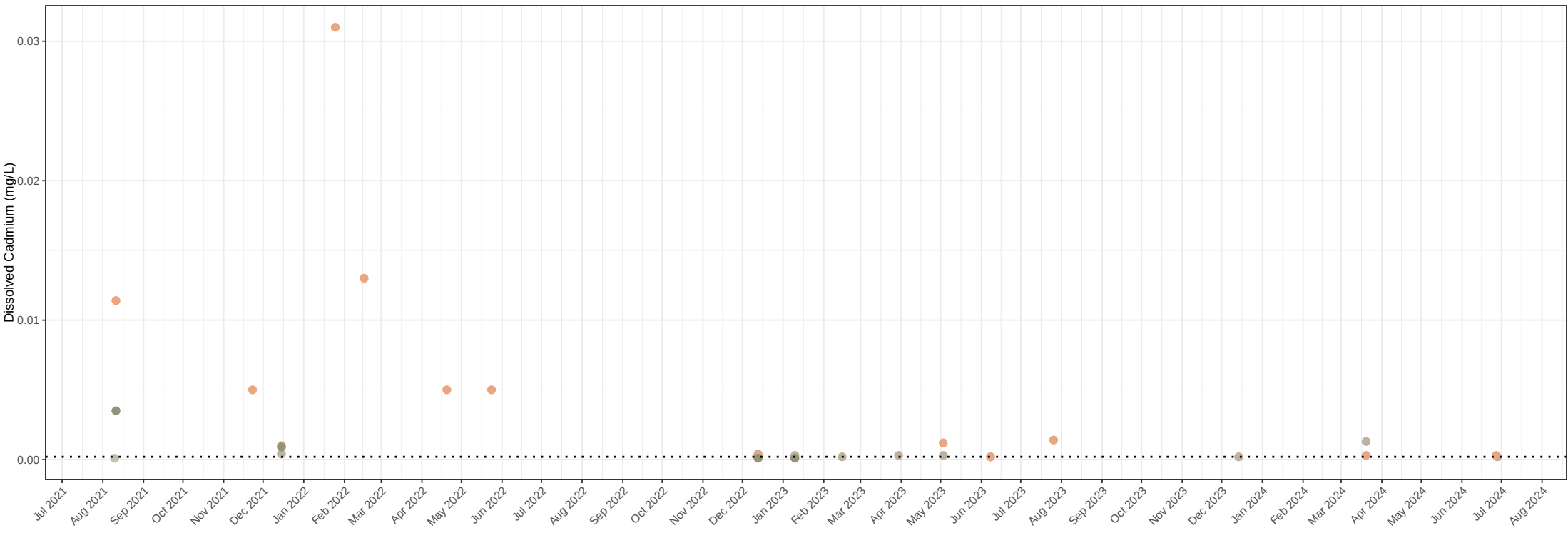
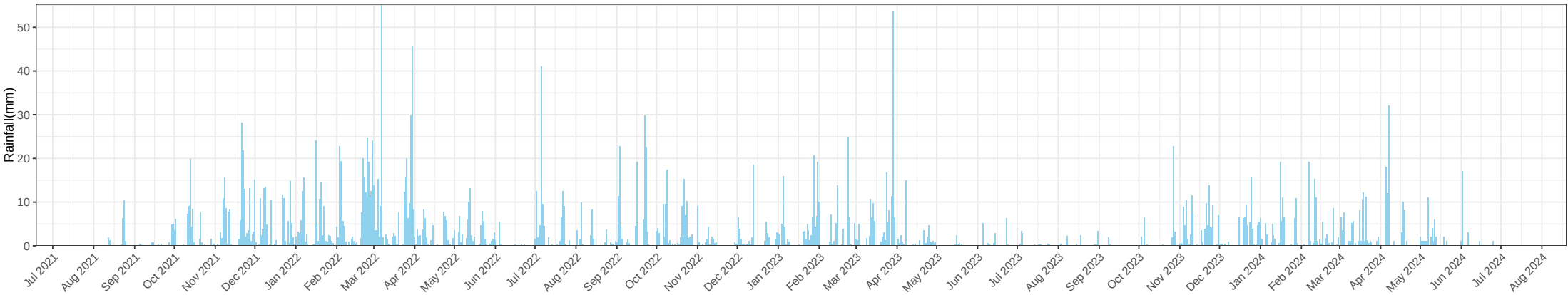
Dissolved Antimony (mg/L) groundwater quality times series data
 Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
 Groundwater impact assessment

Figure D. 2



Notes
Rainfall measured at Bellbrook weather station (059122)
<http://www.longpaddock.qld.gov.au/silo>

Dissolved Arsenic (mg/L) groundwater quality times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Groundwater impact assessment
Figure D. 3

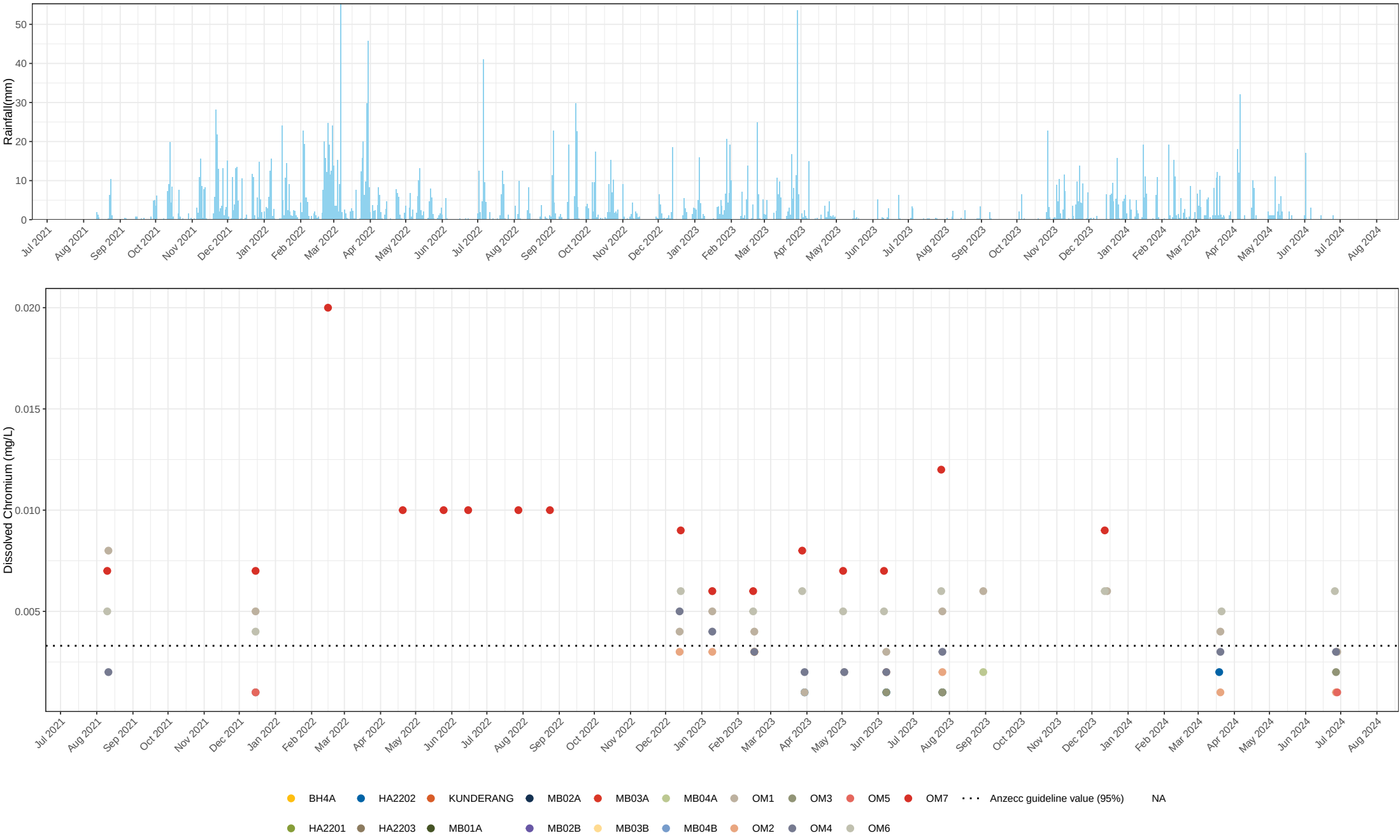


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- MB03A
- MB04A
- OM1
- OM3
- OM5
- OM7
- ...
- Anzecc guideline value (95%)
- NA
- HA2201
- HA2203
- MB01A
- MB02B
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- OM4
- OM6



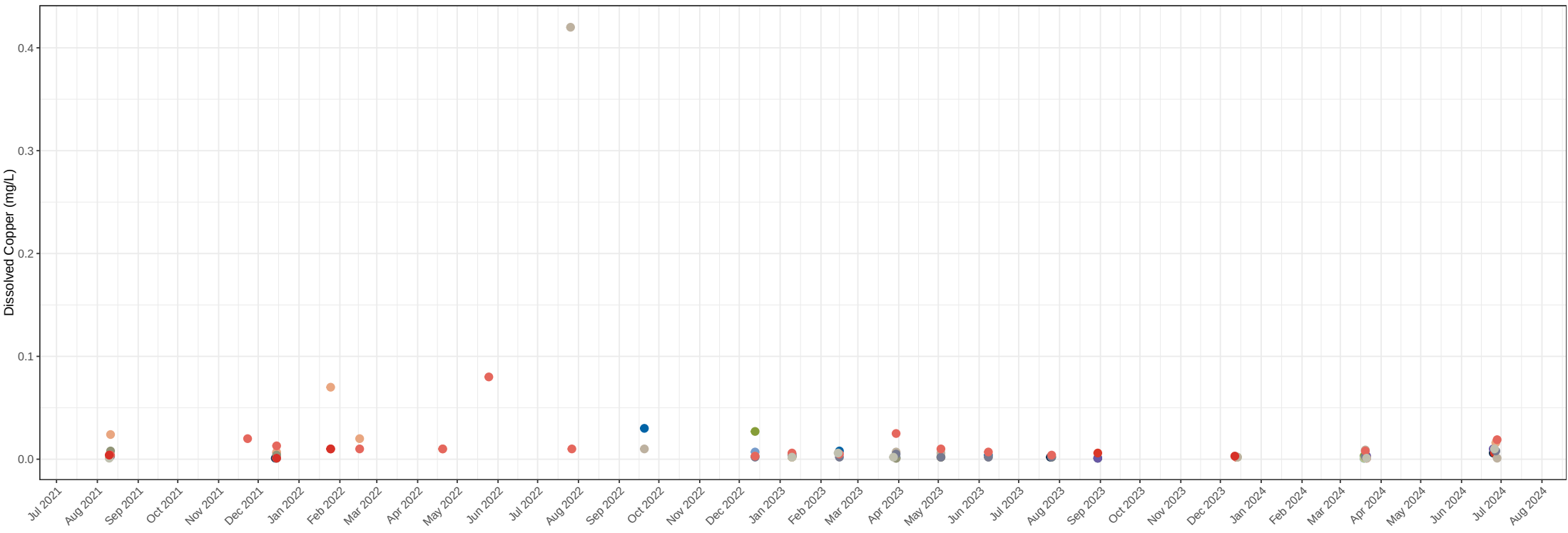
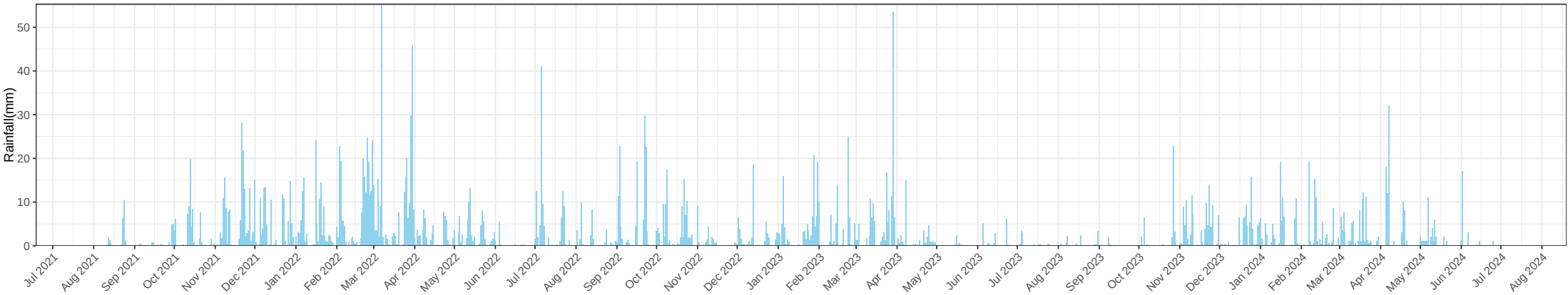
Notes
 Rainfall measured at Bellbrook weather station (059122)
<http://www.longpaddock.qld.gov.au/silo>

Dissolved Cadmium (mg/L) groundwater quality times series data
 Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
 Groundwater impact assessment
 Figure D. 4



Notes
Rainfall measured at Bellbrook weather station (059122)
<http://www.longpaddock.qld.gov.au/silo>

Dissolved Chromium (mg/L) groundwater quality times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Groundwater impact assessment
Figure D. 5



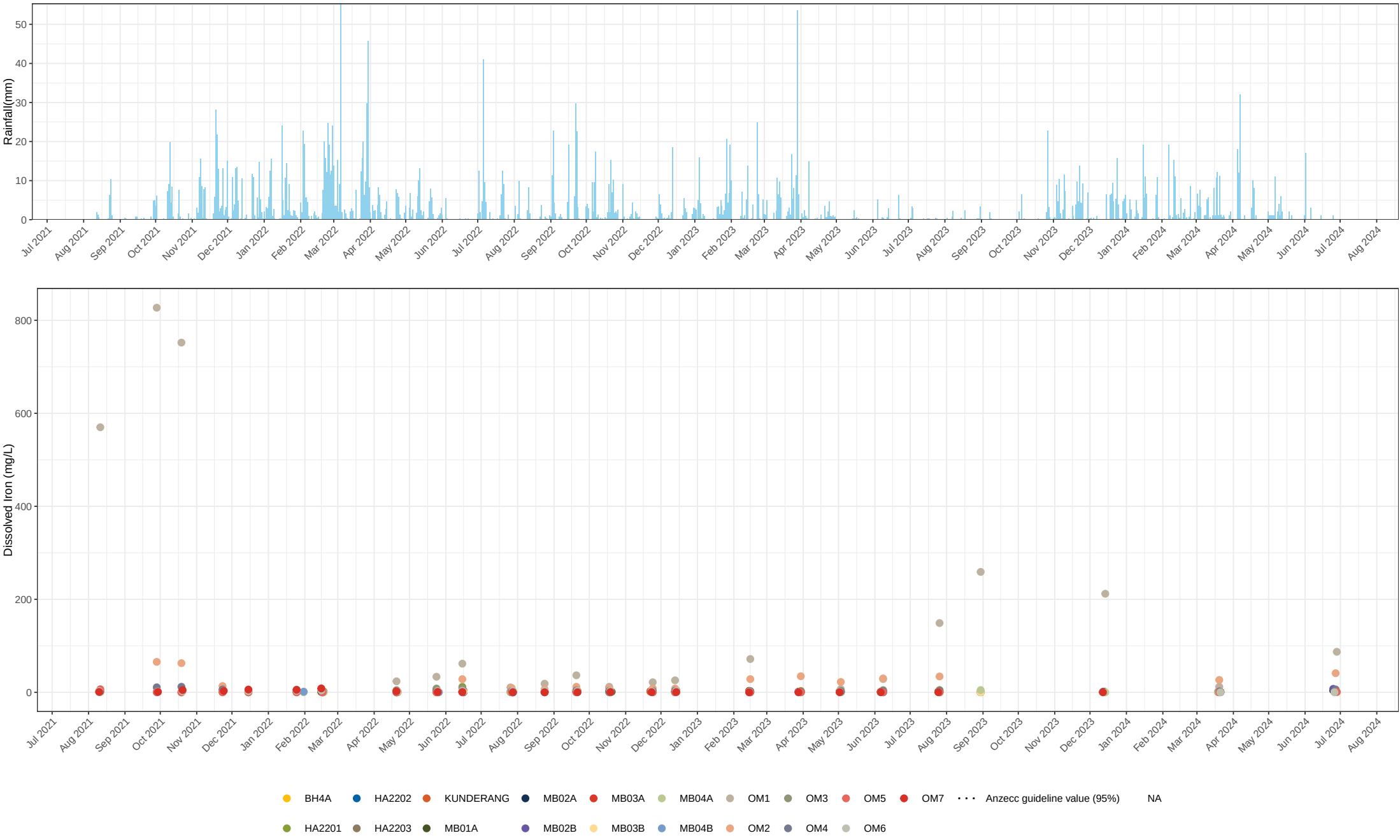
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- MB02A
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- OM1
- OM3
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- Anzecc guideline value (95%)
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- HA2203
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- OM6



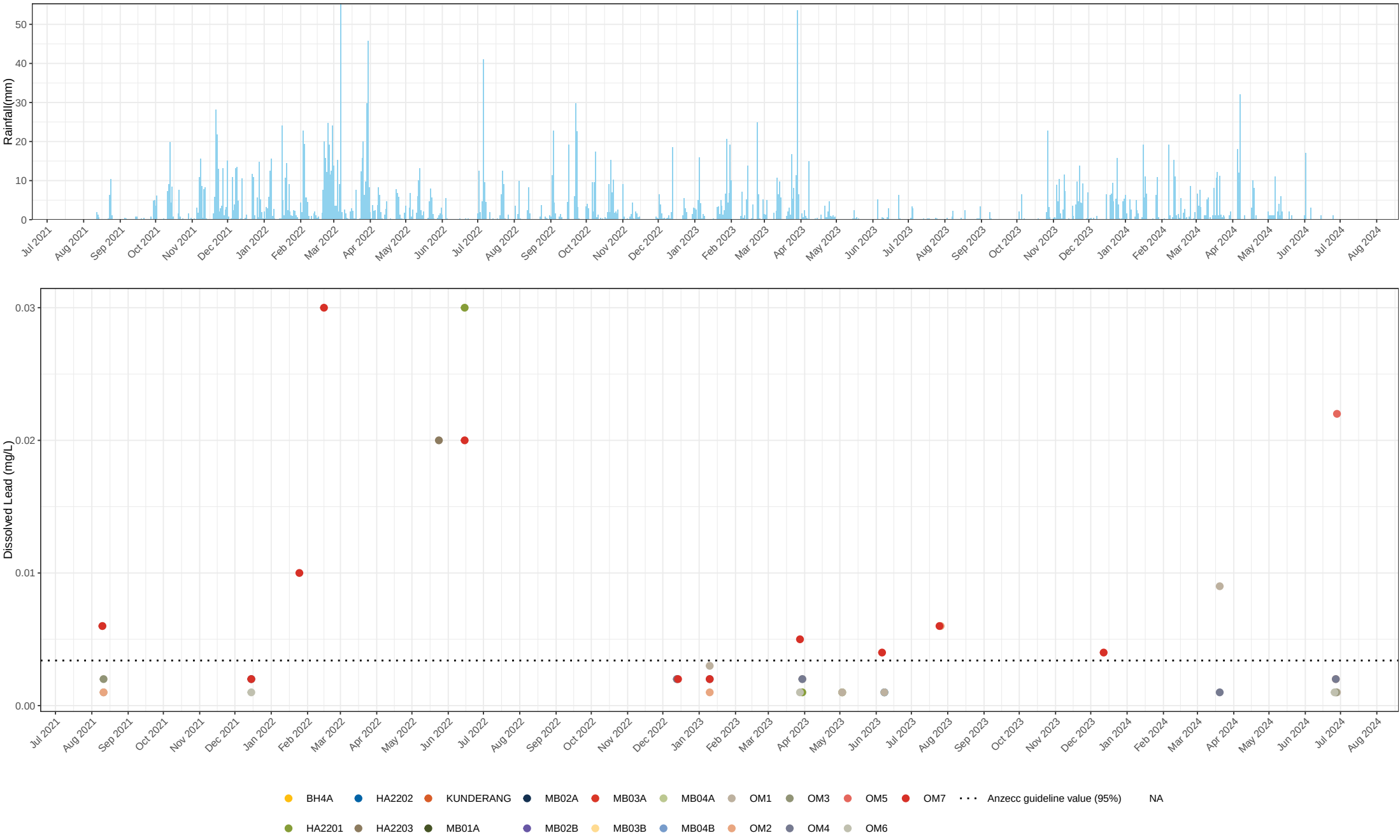
Notes
 Rainfall measured at Bellbrook weather station (059122)
<http://www.longpaddock.qld.gov.au/silo>

Dissolved Copper (mg/L) groundwater quality times series data
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 Groundwater impact assessment

Figure D. 6

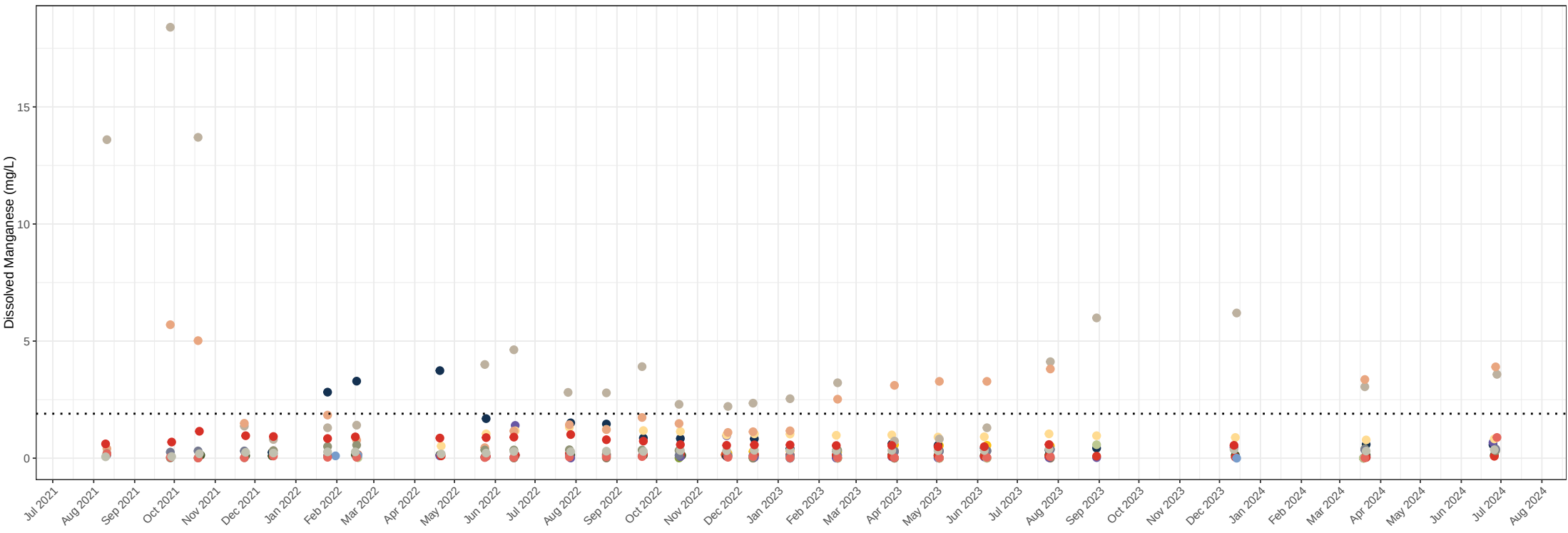
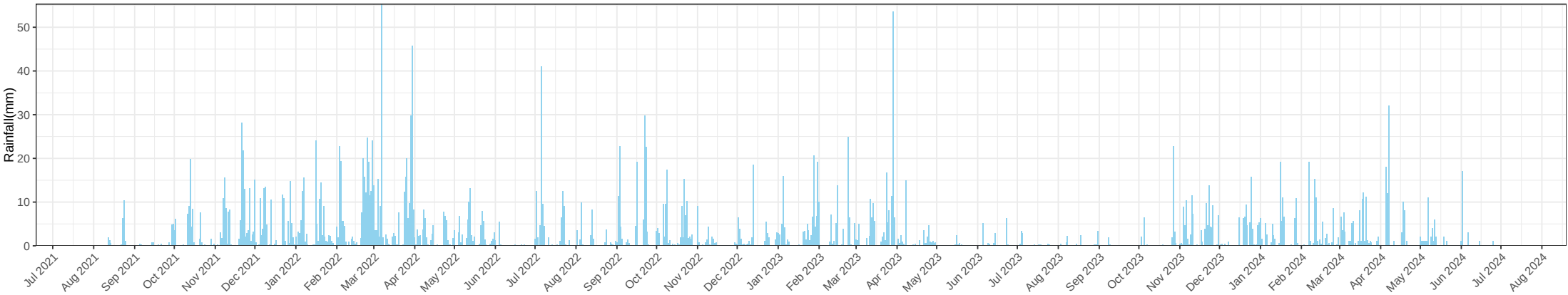


Dissolved Iron (mg/L) groundwater quality times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Groundwater impact assessment
Figure D. 7



Notes
Rainfall measured at Bellbrook weather station (059122)
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Dissolved Lead (mg/L) groundwater quality times series data
Oven Mountain Pumped Hydro Energy Storage – OMPS Pty Ltd
Groundwater impact assessment
Figure D. 8

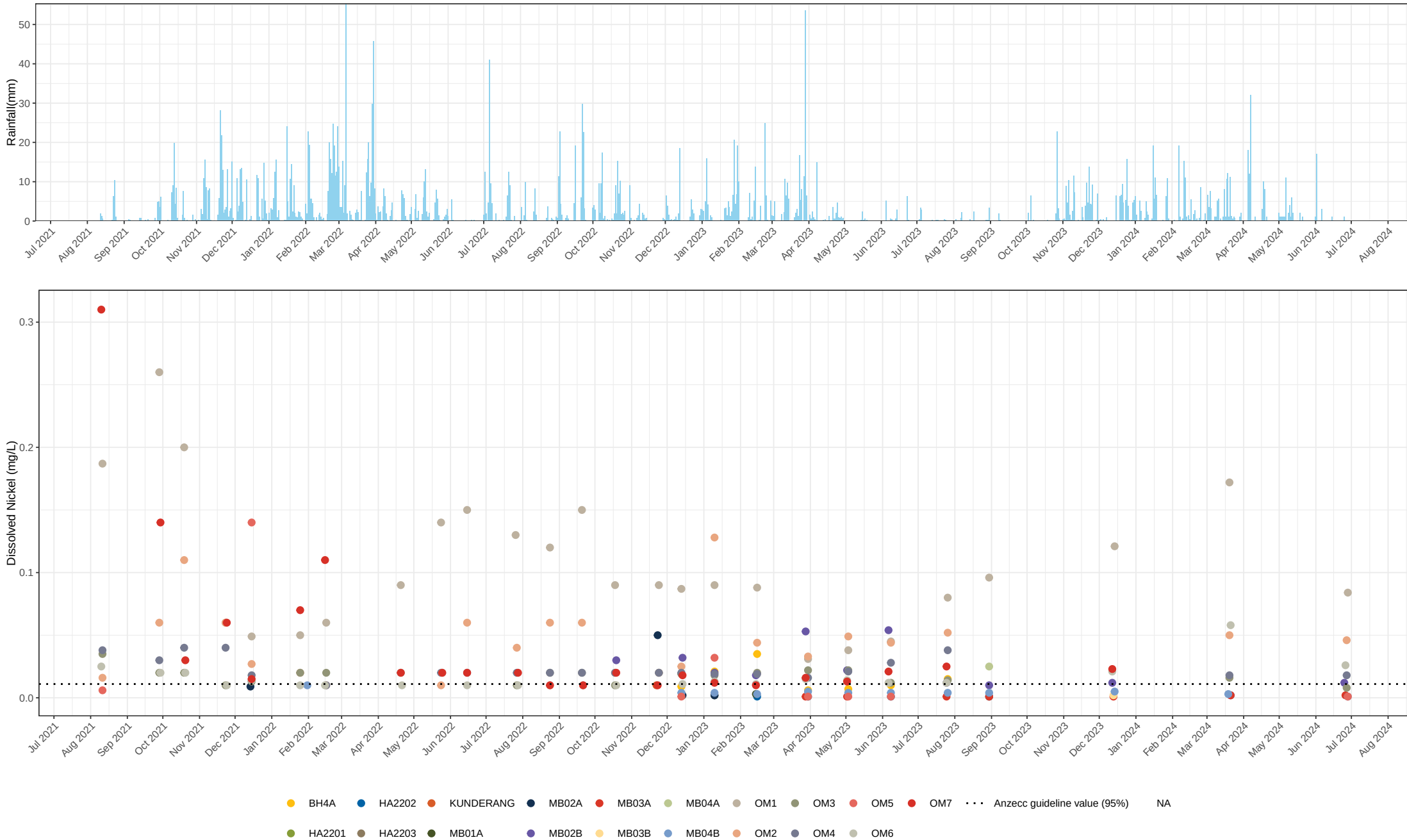


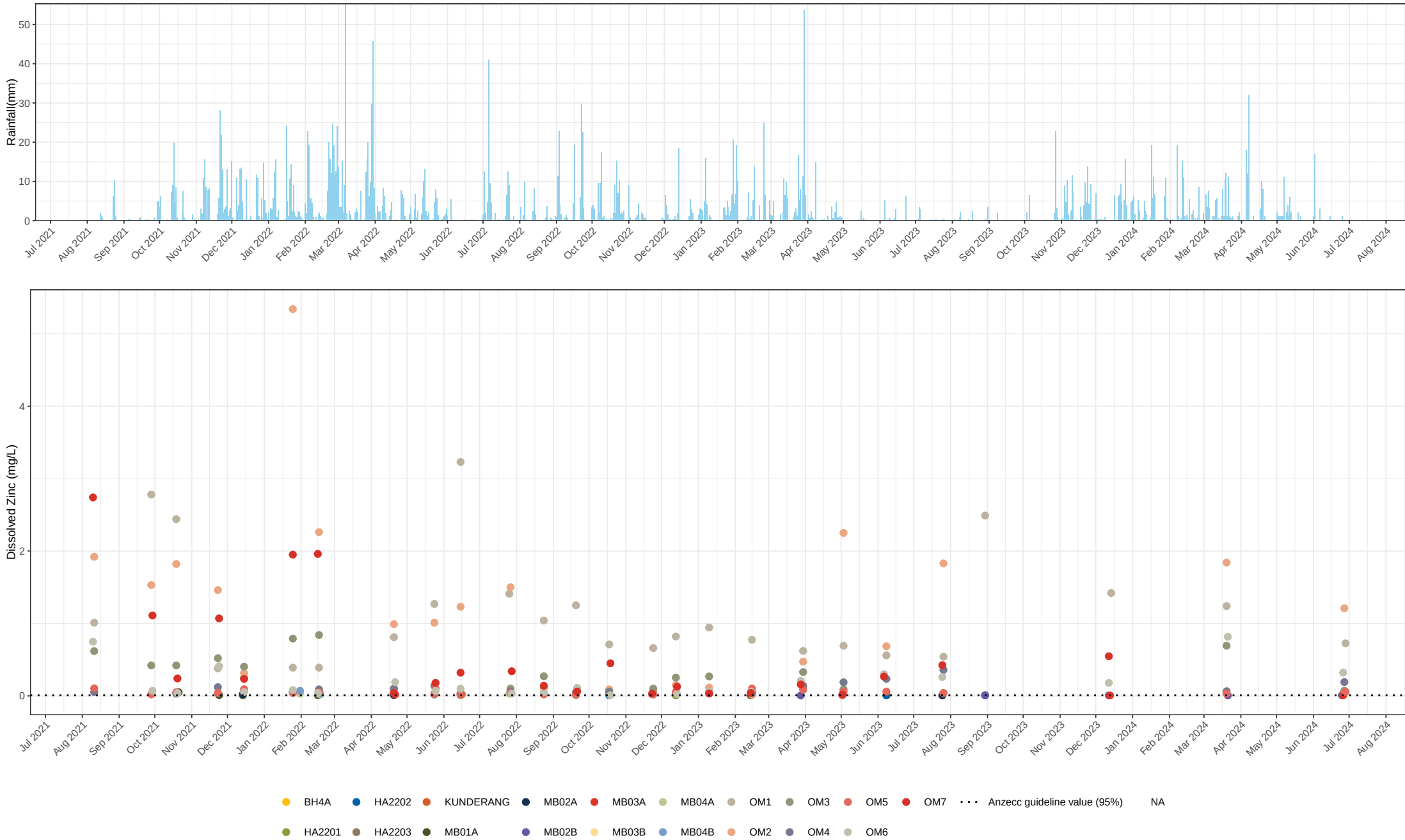
- BH4A
- HA2202
- KUNDERANG
- MB02A
- MB03A
- MB04A
- OM1
- OM3
- OM5
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- Anzecc guideline value (95%)
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- HA2201
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- MB01A
- MB02B
- MB03B
- MB04B
- OM2
- OM4
- OM6



Notes
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Dissolved Manganese (mg/L) groundwater quality times series data
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 Groundwater impact assessment
 Figure D. 9





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