Appendix J. Groundwater impact assessment

Shoalhaven Hydro Expansion Project - Main Works Environmental Impact Statement

SSI-10033

Origin Energy Eraring Pty Ltd

November 2022

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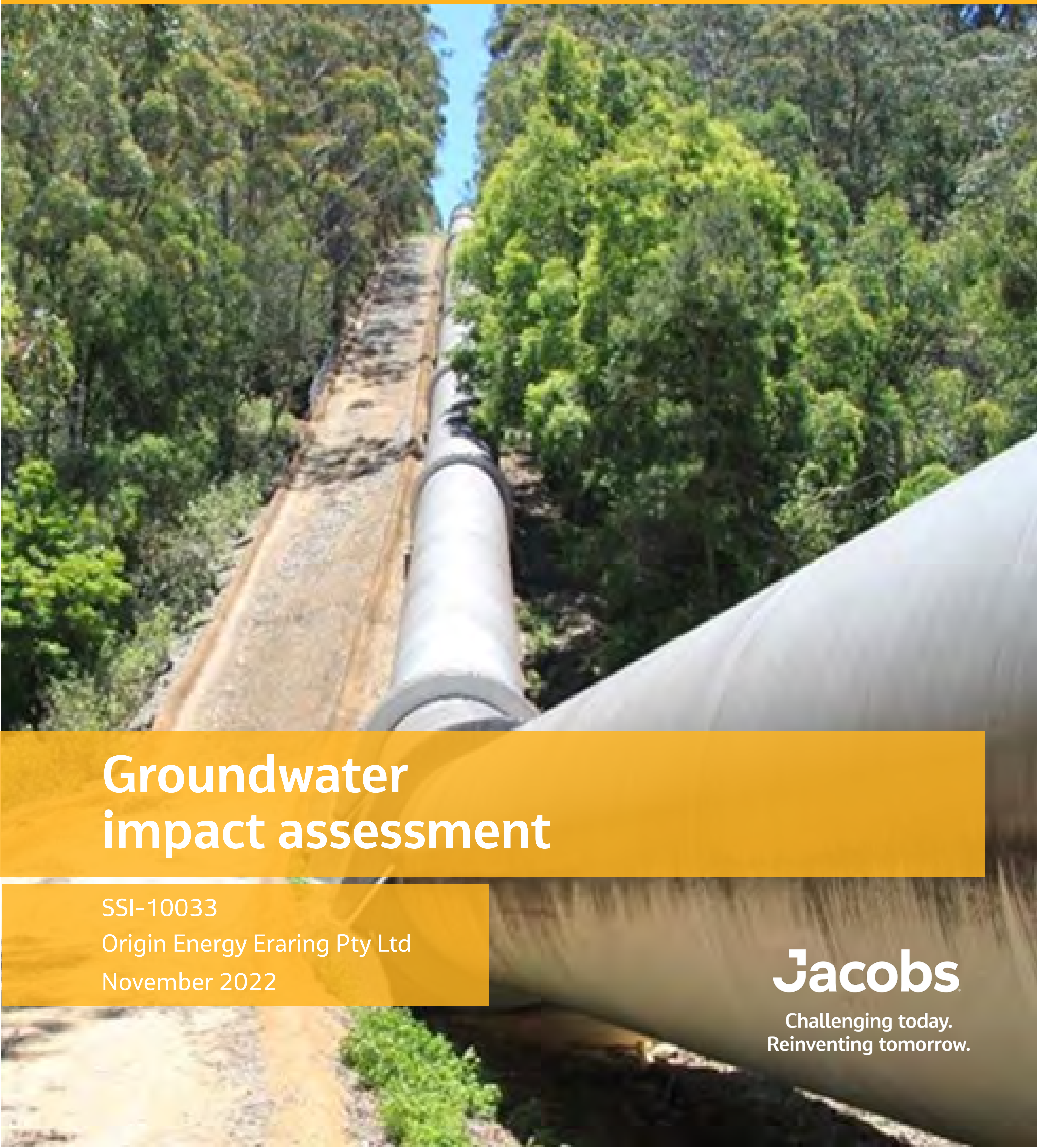
Reinventing tomorrow.

Shoalhaven Hydro Expansion Project - Main Works



Groundwater impact assessment

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Groundwater impact assessment

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Executive summary

Background

Origin proposes to develop the Shoalhaven Hydro Expansion Project, to construct and operate a new pumped hydro power station between the Fitzroy Falls Reservoir and Lake Yarrunga. The Project would pump water up from Lake Yarrunga to Fitzroy Falls Reservoir, consuming energy when it is in less demand. Energy would then be generated through the return of water from Fitzroy Falls Reservoir to Lake Yarrunga when demand for energy increases. The Project would almost double the electricity generation capacity of the existing scheme, providing an approximate additional 235 megawatts (MW) of generation capacity.

Key Project elements interacting with groundwater include a 550 m deep vertical pressure shaft, from the plateau, connecting to a headrace tunnel at depth. The power station will be located in a cavern beneath the plateau and is connected to the inlet / outlet structure at Lake Yarrunga via an almost 3 km long tailrace tunnel. Access, ventilation and egress tunnels decline to the power station from the vicinity of the existing Kangaroo Valley Power Station. A spoil emplacement area is to be established to the east of the Bendeela Pondage.

The Project extends from low elevation areas in the southern extent of the Project area at Lake Yarrunga in Kangaroo Valley to the northern extent of the Project area at the upper plateau near Fitzroy Falls. Elevations across the Project area range between approximately 60 metres (m) AHD at Lake Yarrunga to up to 670 m AHD on the plateau. The plateau continues to the Fitzroy Falls Reservoir. As such, the area can be approximately divided into two distinct areas, the lower study area which spans from the Lake Yarrunga until the base of the escarpment, and the upper study area, which consists of the Fitzroy Falls Reservoir, the plateau and its slopes on both sides

Existing environment

Two main groundwater systems have been identified associated with the Project, these being an upper stratified groundwater system with limited vertical connectivity, and a deeper regional groundwater system. The upper stratified groundwater system is present beneath the elevated plateaus and generally discharges to the escarpments. The regional groundwater system is present beneath the lower study area and is also inferred to extend, at depth, beneath the upper stratified groundwater system.

Groundwater quality is expected to range from relatively fresh at shallow depth and in the vicinity of Lake Yarrunga, to more brackish at depth in the vicinity of the main cavern.

Investigations

Geotechnical investigation has been undertaken for the existing Kangaroo Valley Power Station with more recent drilling and testing conducted as part of the preliminary geotechnical assessment for the current Project. Testing and assessment, relevant to the groundwater assessment, included: hydraulic testing (packer injection testing), laboratory testing of physical rock properties and geochemical testing to assess the acid forming potential of the various formations. Three boreholes have been completed as multilevel vibrating wire piezometers (BH02, BH03 and BH06) for the assessment of pore water pressure, and one bore (BH07) has been completed with a standpipe piezometer.

Predicted inflows

Groundwater inflow to tunnels and caverns have been assessed using both analytical and groundwater modelling techniques.

Inflows to tunnels and underground caverns will be limited by the low permeability of the formations primary permeability and the application of shotcrete as a primary support. Total groundwater inflows are expected to peak at approximately 496 m^3/day, or 5.7 L/s, during construction with average inflows of approximately 274 m^3/day, or 3.2 L/s. During operation, ongoing inflows to drained structures are assessed at approximately 91.5 m^3/day, or 1.06 L/s.

Key identified impacts

During construction, drawdown related to groundwater inflow is not expected to impact on any groundwater dependent ecosystems or other groundwater users; however, dewatering of the tailrace box-cut excavation is expected to be approximately 88% sourced from surface water from Lake Yarrunga. A minor baseflow reduction from the lower reaches of Kings Creek is also possible.

During operation, magnitude of predicted drawdown associated with the drained power station cavern is not expected to detrimentally affect the supply capacity from either water supply work, despite predicted depressurisation and drawdown having the potential to propagate beneath two adjacent groundwater users at a distance of up to 2.2 km from the cavern.

The Project is also assessed as having potential to result in acid rock drainage adjacent to the tailrace excavation and above drained underground structures. Any identified acid rock drainage in the vicinity of the drained structures will ultimately be captured in the dewatering sump located at the lowest level in the underground power station. Captured water will be treated appropriately prior to disposal. Potential acid drainage in the vicinity of the drained structures poses more of a risk to concrete and infrastructure corrosion than a risk to the environment or water quality.

The design of the spoil emplacement area will effectively minimise the risk of potential acid generation and seepage to the environment.

No significant cumulative impacts with respect to groundwater are identified for the Project.

Summary of mitigation measures

Key mitigating measures for the Project include additional investigations during detailed design to further assess the risk of potential acid forming materials.

In the vicinity of the tailrace outlet structure, if the presence of potentially acid forming materials is confirmed in the area of potential drawdown, suitable mitigating measures will be assessed and implemented as required.

For the spoil emplacement area, key mitigating measures will be the emplacement design including lining the emplacement area, encapsulation of potentially acid forming material, mixing of potentially acid forming material with net acid consuming material, or neutralising potential acid forming material with lime. Perimeter drains, to intercept runoff from the spoil emplacement and to intercept shallow seepage, may be also installed with passive treatment options such as limestone rock beds.

Appendix K of the EIS (Spoil management strategy) will be developed to a Spoil Management Plan as part of detailed design and construction planning and identify mitigating and remedial measures in the event that actual acid rock drainage is identified.

Groundwater monitoring, including the installation of additional monitoring locations, is recommended in order to collect additional baseline information and to assess and monitor for potential impacts during construction and operation.

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Appendices

Tables

Figures

Glossary and terms

Term	Definition
ABS	Australian Bureau of Statistics
ACM	Acid consuming potential
AHD	Australian Height Datum
AIP	Aquifer Interference Policy
AnAqSim	Analytic Element Modelling
ANZECC	Australian and New Zealand Environment and Conservation Counci
ARD	Acid Rock Drainage
ATV	Acoustic televiewer
BH	Borehole
BOM	Bureau of Meteorology
DEC	Department of Environment and Conservation
DLWC	Department of Land and Water Conservation
DPI	Department of Primary Industries
EIS	Environmental Impact Statement
EP&A Act	*Environmental Planning and Assessment Act 1979*
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
EPL	Environmental Protection Licence
GDE	Groundwater Dependent Ecosystems
GWh	Gigawatts per hour
HDPE	High Density Poly Ethylene
km	kilometres
m	metres

Term	Definition
mbgl	metres below ground level
µS	micro siemens
mg	milligrams
ML	Megalitres
MW	Megawatts
NAF	Non-acid forming
NAG	Net Acid Generation
NAPP	Net Acid Producing Potential
NEM	National Energy Market
NES matters	matters of National Environmental Significance
NWQMS	National Water Quality Management Strategy
PAF	Potential acid forming
Penstock	Water transfer pipeline and associated infrastructure
POEO Act	*Protection of the Environment Operations Act 1997*
TDS	Total dissolved solids
The Project	The Shoalhaven Hydro Expansion Project
SEARs	Secretary's Environmental Assessment Requirements
Seep/W	Two-dimensional finite element modelling
VWP	Vibrating wire piezometer
WAL	Water Access Licence

1. Introduction

1.1 Project overview

Origin proposes to develop the Shoalhaven Hydro Expansion Project, to construct and operate a new pumped hydro power station on and under the land between the Fitzroy Falls Reservoir and Lake Yarrunga (the Project). The Project would draw on Origin's existing water allocations to pump water up from Lake Yarrunga consuming energy when it is in less demand. Energy would then be generated through the return of water from Fitzroy Falls Reservoir to Lake Yarrunga when demand for energy increases.

The Project would involve almost doubling the electricity generation capacity of the existing scheme, providing an approximate additional 235 megawatts (MW) of generation capacity. The operation of the scheme would respond to the needs of the National Energy Market (NEM) and involving up to one pumping and generation cycle per day. Each generation cycle is anticipated to involve up to 8 hours of generation and 16 hours of pumping, each of which could be divided into shorter durations to best satisfy the needs of the NEM.

The Project location is shown in **Figure 1-1.** An indicative Project layout based on the current reference design is provided in **Figure 1-2** and consists of the construction and operation of:

- Upper scheme components (Upper Scheme) including:
  - Connection to existing upper intake control structure at the southern end of the Fitzroy Canal
  - A surface penstock (water transfer pipeline and associated infrastructure) from the existing Fitzroy Canal control structure to the vicinity of the Existing Scheme surge tank
  - A new surge tank adjacent to the Existing Scheme surge tank
  - A further section of surface penstock, adjacent to the Existing Scheme, from the new surge tank to the high pressure shaft
- Underground works including:
  - Vertical shaft and headrace tunnel connecting to the southern end of Upper Scheme surface penstock to an underground power station
  - An underground power station cavern housing a transformer, reversible motor generator and pump turbine capable of supplying a nominal 235 MW of hydroelectric power
  - Associated access tunnel and multipurpose (egress, ventilation and services) tunnel with an entrance in the vicinity of the existing Kangaroo Valley Power Station
  - A tailrace tunnel, including an underground surge chamber located just downstream of the underground power station, terminating west of the existing Bendeela Power Station on Lake Yarrunga
- Lower scheme surface components (Lower Scheme) including:
  - Lower intake /outlet structure west of the Bendeela Power Station connected to the tailrace tunnel
  - Spoil emplacement facility east of Bendeela Pondage
  - High voltage network connection to existing Kangaroo Valley substation
  - Operational surface infrastructure including administration building, water treatment infrastructure and ventilation building.

The Project would also require ancillary works which may include the carrying out of works to upgrade or construct access roads, spoil disposal sites, utilities infrastructure, construction compounds and construction power and water supply.

Importantly, the Shoalhaven Hydro Expansion Project essentially duplicates the existing scheme and as such, the Project does not propose any new water storages or connections between waterbodies that have not already been utilised for the existing scheme. In addition, no transmission line augmentations are required to receive or distribute electricity from the existing Kangaroo Valley Power Station substation.

A full Project description is provided in Chapter 3 of the Environmental Impact Statement (EIS) EIS. Key components of the Project of relevance to this report are provided in **Section 3.2**.

Legend

- Points of interest
- Indicative Project footprint
- Project location
- NPWS Reserve
- State Forest

0 5 10 km

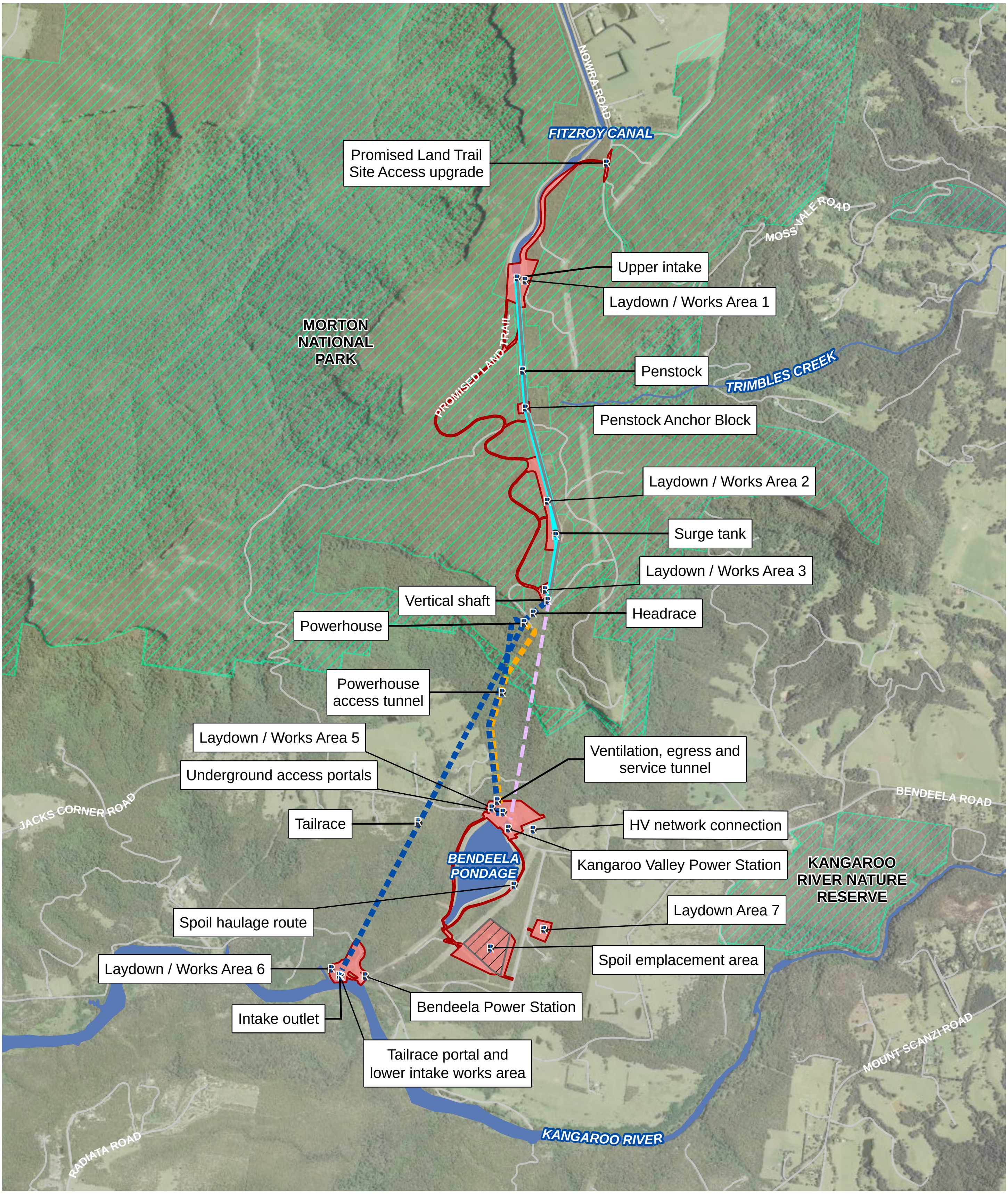
1:300,000 at A4

GDA2020 MGA Zone 56

Data sources

Jacobs 2022
Department of Planning and Environment 2022

Figure 1-1 Project location



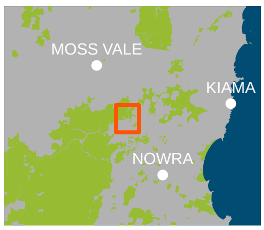
Legend

- Points of interest
- Existing KV tunnel alignment
- Existing scheme pipeline
- Indicative above ground pipeline
- Indicative tunnel alignment
- Indicative access tunnel
- Disturbance area
- Spoil site
- Waterway
- Road
- NPWS Reserve
- Waterbody

0 1 2 km

1:40,000 at A4

GDA2020 MGA Zone 56



Data sources

Jacobs 2022
Department of Planning and Environment 2022
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Figure 1-2 Indicative Project layout

1.2 Project location

The Shoalhaven Hydro Expansion Project is to be carried out in the Wingecarribee and Shoalhaven Local Government Areas (LGAs). Access to the upper portion of the Project on the plateau, for penstock, surge tank and vertical shaft construction would be via the Promised Land Trail. The Promised Land Trail is accessed from Moss Vale Road and traverses both WaterNSW land and the Morton National Park and was constructed as part of the original scheme. Access to the lower portion of the Shoalhaven Hydro Expansion Project within Kangaroo Valley would be via Bendeela Road from Moss Vale Road in the vicinity of the townships of Kangaroo Valley and Barrengarry.

1.3 Secretary's Environmental Assessment Requirements

This assessment forms part of the EIS for the Project. The EIS has been prepared under Division 5.2 of the EP&A Act. This assessment has been prepared to address the Secretary's Environmental Assessment Requirements (SEARs) relating to groundwater and will assist the Minister for Planning to make a determination on whether or not to approve the Project.

Table 1-1 outlines the SEARs relevant to this assessment along with a reference to where these are addressed.

Table 1-1 SEARs relevant to groundwater

Secretary's requirement	Where addressed in this report
Water – including:	
- an assessment of the impacts of the Project on groundwater aquifers and groundwater dependent ecosystems having regard to the NSW Aquifer Interference Policy and relevant Water Sharing Plans;	**Section 2.2.1**, **Section 2.3.1**, **Section 9**
- a detailed site water balance for the Project, including water supply and wastewater disposal arrangements;	Appendix I of the EIS (Surface Water, Hydrology and Geomorphology Technical Report)
- an assessment of whether the Project would have a neutral or beneficial effect on water quality;	An assessment of effects on groundwater quality is provided in **Chapter 9** of this Report
- a strategy to manage spoil.	**Section 7.1**, **Section 11.2.2**

1.4 Structure of this report

The structure and content of this report are outlined in **Table 1-2**.

Table 1-2 Structure and content

Chapter	Description
Chapter 1 Introduction	Outlines key elements of the Project, SEARs and the purpose of this report (this Chapter)
Chapter 2 Legislative and policy context	Provides an outline of the statutory context, including applicable legislation and planning policies
Chapter 3 Assessment methodology	Provides a description of the assessment methodology for this assessment
Chapter 4 Existing environment	Provides a preliminary description of the existing environment including investigations and sources of data
Chapter 5 Hydrogeological conceptual model	Presents an overview of key hydrogeological aspects pertaining to the Project
Chapter 6 Construction schedule	Presents the schedule of key Project aspects during construction pertaining to potential groundwater impacts

Chapter	Description
Chapter 7 Spoil Acid Generation	Present an assessment of acid forming potential of various geological units and associated mitigation methods
Chapter 8 Groundwater Inflow Assessment	Presents the assessment of groundwater seepage to Project tunnels and excavations and summarise the predicted water take associated with Project construction and operation
Chapter 9 Potential impacts	Presents the outcomes of the construction and operational impact assessment including cumulative impacts
Chapter 10 Water Access Licensing Requirements	Presents and assessment of the Project water access licensing requirements for surface water and groundwater and relevant exemptions
Chapter 11 Monitoring and Mitigation measures	Presents the proposed groundwater monitoring and mitigation measures applicable for the Project
Chapter 12 Conclusion	Summarises the findings of this report

2. Legislative and policy context

2.1 Commonwealth legislation

2.1.1 Commonwealth Environment Protection and Biodiversity Conservation Act

The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) prescribes the Commonwealth Government's role in environmental assessment, biodiversity conservation and the management of protected areas and species, population and communities and heritage items.

Impacts on groundwater due to construction and operation of the Project may be relevant under the EPBC Act where groundwater is likely to have a significant impact on 'matters of National Environmental Significance' (NES matters). While the Project could also have an impact on the groundwater environment in terms of groundwater levels and quality, it is found to be unlikely to be to an extent that would affect NES matters.

A referral has been made under the EPBC Act and has been determined to be a controlled activity.

2.1.2 National Water Quality Management Strategy

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

The primary document relevant to the assessment of groundwater risks for the Project is the *Guidelines for Groundwater Quality Protection in Australia* (Australian Government, 2013). This document sets out a high-level risk-based approach to protecting or improving groundwater quality for a range of groundwater beneficial uses (called environmental values), including for aquatic ecosystem protection, primary industries, recreational use, drinking water, industrial water and cultural values.

The guidelines refer to other NWQMS guideline documents for specific water quality objective values. Where the resource requiring protection is a surface water resource with a component of groundwater discharge, the water quality objectives should be applied at the point of discharge. Other NWQMS guideline documents containing specific water quality objectives guideline values that are relevant to the Project include:

- *Guidelines for Managing Risks in Recreational Water* (National Health and Medical Research Council (NHMRC) 2008)
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Australian Government, 2019)
- Australian Drinking Water Guidelines (NHMRC/NRMMC, 2011).

2.2 State legislation

2.2.1 Water Management Act 2000

The *Water Management Act 2000* (NSW) presents the framework for sustainable and integrated water management in NSW and its objectives are as follows:

- To apply the principles of ecologically sustainable development
- To protect, enhance and restore water sources, their associated ecosystems, ecological processes and biological diversity and their water quality
- To recognise and foster the significant social and economic benefits to the State that result from the sustainable and efficient use of water, including—
  - benefits to the environment
  - benefits to urban communities, agriculture, fisheries, industry and recreation
  - benefits to culture and heritage

  - benefits to the Aboriginal people in relation to their spiritual, social, customary and economic use of land and water

- To recognise the role of the community, as a partner with government, in resolving issues relating to the management of water sources
- To provide for the orderly, efficient and equitable sharing of water from water sources
- To integrate the management of water sources with the management of other aspects of the environment, including the land, its soil, its native vegetation and its native fauna
- To encourage the sharing of responsibility for the sustainable and efficient use of water between the Government and water users
- To encourage best practice in the management and use of water.

The primary instruments applied to achieve these objectives are Water Sharing Plans and the NSW Aquifer Interference Policy (NSW Office of Water, 2012).

In general, the *Water Management Act 2000* (NSW) requires:

- A water access licence to take water
- A water supply works approval to construct a work
- A water use approval to use the water.

A water use approval under section 89, a water management work approval under section 90 or an activity approval (other than an aquifer interference approval) under section 91 of the *Water Management Act 2000* are not required for approved State significant infrastructure under Section 5.23 of the EP&A Act.

The Water Management (General) Regulation 2018 (NSW) is the primary regulation instrument under the *Water Management Act 2000* (NSW).

2.2.1.1 Water Sharing Plans

Water sharing plans, following the introduction of the *Water Management Act 2000* (NSW), provide the basis for equitable sharing of surface water and groundwater between water users, including the environment.

For groundwater, the Project lies within the *Sydney Basin South Groundwater Source of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011* (Department of Industry, 2019a). For surface water, the Project lies within the *Shoalhaven Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011* (Department of Industry, 2019b).

2.2.1.2 Water Access licence

Origin Energy currently holds a WAL (no. WAL27432) under the water sharing plan for the Greater Metropolitan Regional Unregulated River Water Source to extract water for the purposes of electricity generation (DPI, 2013a). Under the WAL, Origin must adhere to the conditions outlined within the WAL some of which include volumetric limits for water use between Fitzroy Falls Reservoir and Lake Yarrunga per generation cycle, ensuring the volume of water in Bendeela Pondage does not exceed 880ML, divert water to Lake Yarrunga for the purposes of electricity generation when Fitzroy Falls Reservoir is spilling into Yarrunga Creek. Incidental surface water take resulting from construction of the Project should fall under this existing WAL.

Additional allocation may need to be sought under the Sydney Basin South Groundwater Source of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 for groundwater take during construction and ongoing operation of the Project. An assessment of WAL requirements is provided in **Chapter 10**.

2.2.1.3 Water Supply Work and Water Use

Origin currently holds a Water Supply Works and Water Use Approval under the water sharing plan for the Greater Metropolitan Regional Unregulated River Water Source which authorises them to use and operation the water supply works (DPI, 2013b).

Origin are subject to a number of conditions of approval which are relevant to the operation of this Project including (but not limited to):

- Origin must not interchange water when Cyanobacteria is greater than or equal to 50,000cells/mL *Microcystin aeruginosa* or the biovolume equivalent is greater than or equal to 4mm^3/L for the combined total of all cyanobacteria
- Origin must undertake water quantity monitoring using metering equipment
- Origin must undertake cyanobacteria monitoring at a minimum of weekly between 1 October and 31 May and monthly between 1 June to 30 September at nominated sites and procedures outlined in Attachment 3 and 4 of the Approval).

2.2.2 NSW Water Quality Objectives

The NSW Government has developed Water Quality Objectives that are consistent with the NWQMS and in particular, with the ANZECC 2000 Australian and New Zealand guidelines for fresh and marine water quality. The water quality objectives relate to fresh and estuarine surface waters. Groundwater quality must therefore be maintained to a level that does not degrade any receiving surface water environments.

Mitigation measures for water quality are outlined in **Section 11.2**.

2.2.3 Protection of the Environment Operations Act 1997

The *Protection of the Environment Operations Act 1997* (NSW) (POEO Act) is the key piece of environment protection legislation administered by the NSW Environment Protection Authority. Relevant features of this legislation include protection of the environment policies, integrated environment protection licensing, and regulation of scheduled and non-scheduled activities.

In accordance with Schedule 1 of the Act, the Project falls under a general electricity works over 30 MW, and is therefore classified as a scheduled activity. An environmental protection licence (EPL) will therefore be required.

Kangaroo Valley Power Station and Bendeela Power Station operate under EPL No. 10595. The power stations are currently classed as “Electricity Generation – Generation of electrical power otherwise than from coal, diesel or gas” with a scale of “0 – 250 GWh generated”. The EPL currently has no specific operational water discharge concentration limits, except that the licensee must comply with section 120 of the POEO act, which states there will be “no pollution of waters”.

Under the POEO Act, there is a legal responsibility to ensure that runoff leaving a site meets an agreed water quality standard, including water being discharged from construction sediment basins after storm events, as well as operational discharges. The construction contractor will be responsible for obtaining and complying with an EPL during construction. Following construction, the construction EPL would either be transferred to Origin for operational purposes, a new EPL sought or the existing EPL No. 10595 would be varied as necessary to incorporate any new scheduled activities including any operational discharge requirements.

The design and management of erosion and sediment controls associated with the construction of the Project as well as permanent drainage infrastructure would be confirmed during detailed design to achieve applicable water quality standards.

2.3 Regulatory policies/relevant guidelines

2.3.1 NSW Aquifer Interference Policy

The NSW Aquifer Interference Policy (AIP) is a component of the NSW ‘Strategic Regional Land Use Policy’ and was introduced in September 2012. The AIP defines the regime for protecting and managing impacts of aquifer interference activities on NSW’s water resources and strikes a balance between the water needs of towns, farmers, industry and the environment. It clarifies the requirements for obtaining groundwater extraction licences and the assessment process under the *Water Management Act 2000*.

The *Water Management Act 2000* defines a number of aquifer interference activities including penetration of, interference with and obstruction of water flow within an aquifer. Taking and disposing water from an aquifer are also defined as being aquifer interference activities.

The AIP provides a framework for assessing the impacts of aquifer interference activities on water resources. To assess potential impacts, groundwater sources are categorised as either highly productive or less productive, with sub-categories for alluvial, coastal sands, porous rock, and fractured rock aquifers. For each category there are a number of prescribed minimal impact considerations relating to water table and groundwater pressure drawdown, and changes to groundwater and surface water quality. The Sydney Basin South groundwater source is a porous rock groundwater source and is classified as less productive.

Two levels of minimal impact considerations are specified. If the predicted impacts are less than the Level 1 minimal impact considerations, then these impacts would be considered as acceptable.

The AIP refers to the beneficial use of an aquifer, which is outlined in the *National Water Quality Management Strategy* (NWQMS, 2013); it is noted that within the management strategy the term beneficial use is replaced with environmental value. The beneficial uses include aquatic ecosystems, primary industries (including irrigation and stock drinking water), drinking and industrial water, and cultural and recreational/aesthetic values.

Each beneficial use has a unique set of water quality criteria designed to protect the environmental value of the groundwater resource. Groundwater in the vicinity of the Project is likely to be used by terrestrial ecosystems and primary industries.

An assessment of the Project against the NSW AIP Minimal Impacts Considerations is provided in **Section 9.1.4** and **Section 9.2.4**.

2.3.2 NSW Groundwater Quality Protection Policy

The NSW Groundwater Quality Protection Policy (DLWC, 1998) objectives include the management of groundwater systems such that their beneficial use is maintained, groundwater sources are protected against contamination, groundwater dependent ecosystems are protected, cumulative impacts are recognised and managed, and environmentally degraded areas are rehabilitated.

The following beneficial uses, also referred to as Environmental Values, (in decreasing order of water quality) are adopted by the NSW Groundwater Quality Protection Policy from the National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (ANZECC, 1995):

- Ecosystem protection
- Recreation and aesthetics
- Raw water for drinking water supply
- Agricultural water
- Industrial water.

Specific water quality characteristics are determined on a case-by-case basis with due consideration of existing site conditions and uses within each beneficial class.

Shallow groundwater in the vicinity of the Project is likely to have the most sensitive beneficial use (Ecosystem Protection), whereas deeper groundwater is likely more degraded and only of use for Industrial Water. An assessment of Project impact on beneficial use is included in the NSW AIP Minimal Impacts Considerations (**Section 9.1.4** and **Section 9.2.4**).

2.3.3 NSW Groundwater Dependent Ecosystems Policy and Risk assessment guidelines for groundwater dependent ecosystems

The NSW State Groundwater Dependent Ecosystems (GDE) Policy (Department of Land and Water Conservation, 2002) implements the *Water Management Act 2000* by providing guidance on the protection and management of GDE. It sets out management objectives and principles to:

- Ensure that the most vulnerable and valuable ecosystems are protected
- Manage groundwater extraction within defined limits thereby providing flow sufficient to sustain ecological processes and maintain biodiversity
- Ensure that sufficient groundwater of suitable quality is available to ecosystems when needed
- Ensure that the precautionary principle is applied to protect groundwater dependent ecosystems, particularly the dynamics of flow and availability and the species reliant on these attributes
- Ensure that land use activities aim to minimise adverse impacts on groundwater dependent ecosystems.

The Risk Assessment Guidelines for Groundwater Dependent Ecosystems (DPI Office of Water, 2012) provides the framework for assessing risk to GDE. The Guidelines define GDE as:

> *'Ecosystems which have their species composition and natural ecological processes wholly or partially determined by groundwater.'*

Based on this definition, GDEs explicitly include any ecosystem that uses groundwater at any time or for any duration in order to maintain its composition and condition, and where GDE can rely on groundwater for some or all of their ecological function.

The Guidelines further defines 'High Priority GDE' as ecosystems which are considered high priority for management action and have a high ecological value. High Priority GDEs are identified in the relevant Water Sharing Plans. It is noted that the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 does not identify any High Priority GDE in the vicinity of the Project.

An assessment of potential GDE in the vicinity of the Project is provided in **Section 4.4.2**, with potential impacts during construction and operation assessed in **Section 9.1.2** and **Section 9.2.2**.

2.3.4 Guidelines for the Assessment and Management of Groundwater Contamination

The *Guidelines for the Assessment and Management of Groundwater Contamination* (DEC, 2007) are consistent with the *Contaminated Land Management Act 1999* and the POEO Act, and set out the best-practice framework for assessing and managing contaminated groundwater in NSW. The guidelines consider the assessment, management and remediation of contamination at a site-specific level, and are directed at the polluters or those responsible for cleaning up contamination. These guidelines would become relevant to the Project in the event that construction or operation caused contamination of groundwater that impacted environmental values and required remediation.

3. Assessment methodology

3.1 Study area

The study for the Groundwater Assessment is notionally defined by a 5 kilometre (km) radius from key Project elements of relevance to groundwater (refer **Section 3.2**) including all underground works, the tailrace inlet/outlet structure and the waste rock emplacement area. The extent of the study area is depicted on **Figure 3-1**.

3.2 Key components of the Project of relevance to groundwater

The Project includes the following key structures that have the potential for non-trivial interaction with groundwater:

- Vertical pressure shaft, the intake through which reservoir water runs under pressure
- Headrace tunnel, through which high pressure water runs for generation of power
- Caverns for the underground power station and the transformer hall
- Tailrace tunnel, through which water is conveyed from the underground power station, including the lower intake / outlet works
- Main access tunnel and multi-purpose ventilation and egress tunnel
- Spoil emplacement / stockpiling.

Summary descriptions of these key structures and potential interaction with groundwater are provided in the following sections.

A summary of tunnel and shaft dimensions is provided in **Table 3-1** and cavern and main excavation dimensions is provided in **Table 3-2**.

The locations and layouts of the key Project elements are presented on **Figure 3-2** and **Figure 3-3**. It is noted that the locations and layout of key Project elements as assessed in this technical report are considered to be representative. Any minor changes that may arise during detailed design are not anticipated to materially affect the outcomes of the current assessment.

Table 3-1 Tunnels and shafts summary

Element	Approximate Length (m)	Nominal raw tunnelled diameter (m)	Nominal raw finished lined diameter (m)	Sectional profile
Pressure shaft	547 (vertical)	5.5	3.5	Circular
Headrace tunnel	250	4.8	3.5	Horseshoe
Tailrace tunnel	2965	7.5	5.5	Horseshoe
Main access tunnel	1480	7.5	7.5	Horseshoe
Ventilation and egress tunnel	1505	5.9	5.5	Circular
Surge chamber shaft	90 (vertical)	12	10	Circular

Table 3-2 Caverns and excavations summary

Element	Approximate Length (m)	Approximate Width (m)	Approximate Height / Depth (m)
Main cavern	35	32	65
Transformer cavern	11	14	20
Lower intake / outlet	60	22	23.66

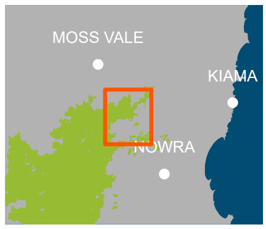
Legend

- Development site
- Study area
- Existing KV tunnel alignment
- Existing scheme pipeline
- Indicative above ground pipeline
- Indicative tunnel alignment
- Indicative access tunnel
- State Forest
- NPWS estate
- Road
- Waterways
- Waterbody

0 2 4 km

1:80,000 at A4

GDA2020 MGA Zone 56



Data sources

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Figure 3-1 Groundwater study area

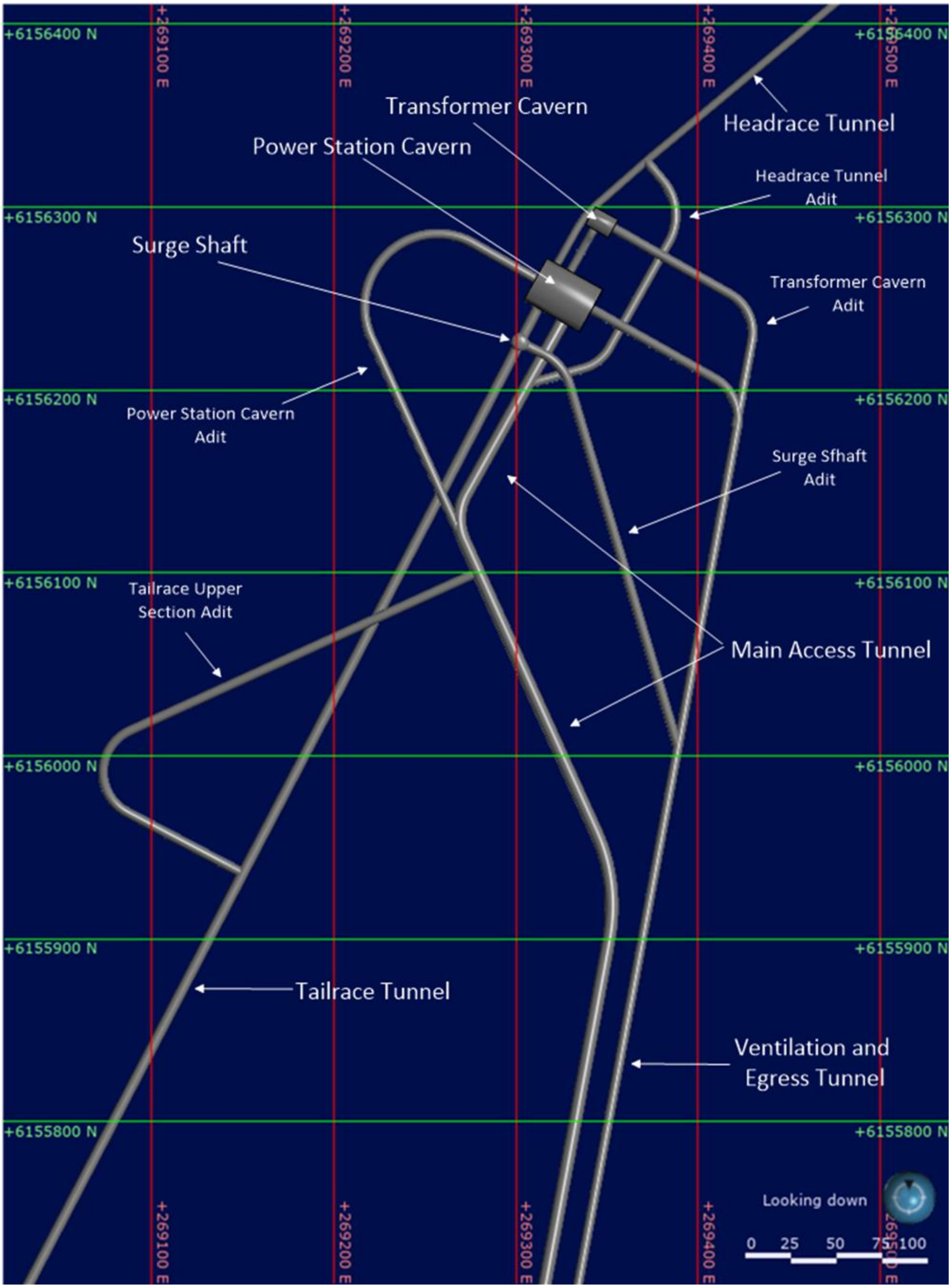


Figure 3-2 Schematic of key Project infrastructure – main cavern

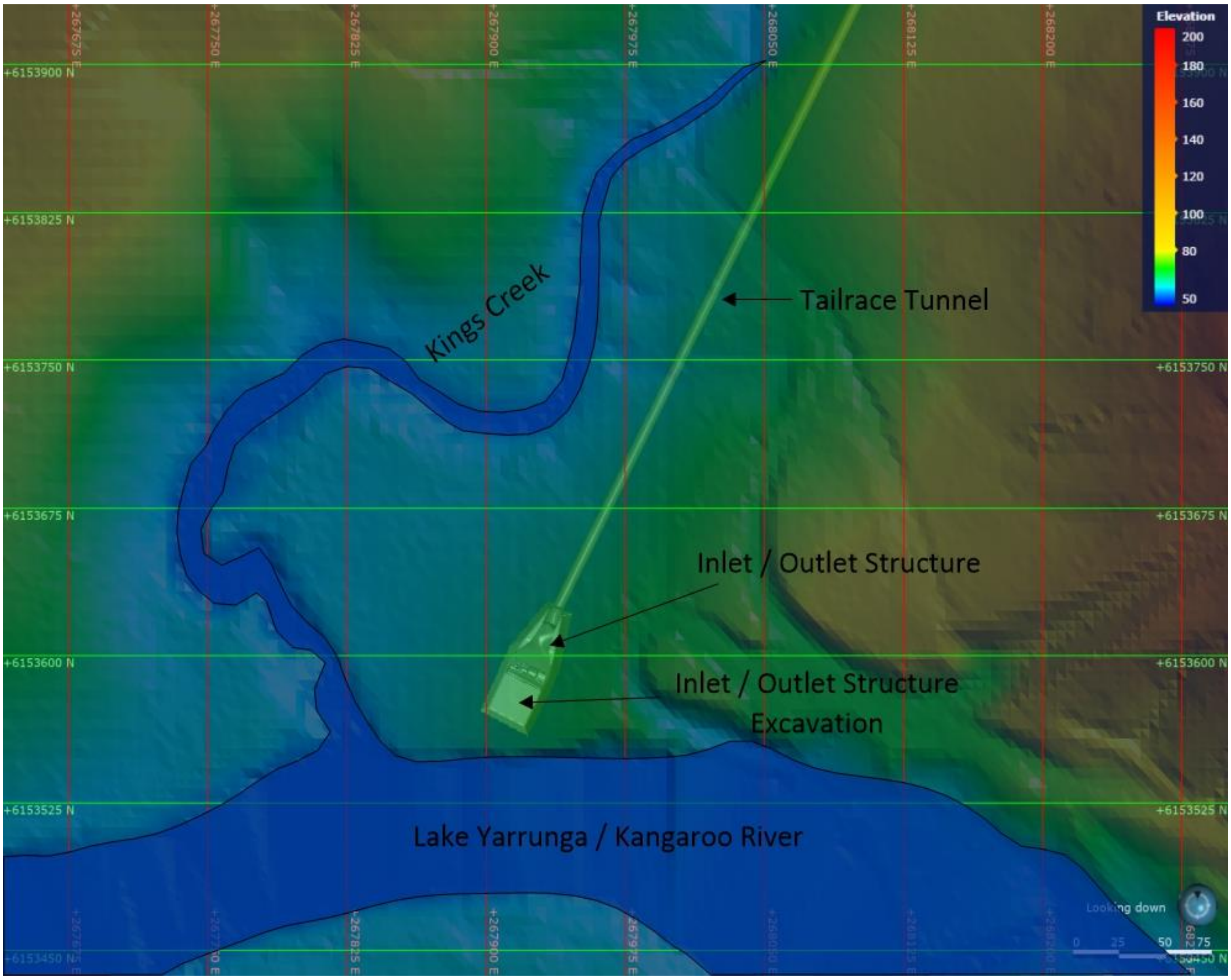


Figure 3-3 Layout of key Project infrastructure – inlet / outlet structure

3.2.1 Tunnelling and excavation

Key groundwater interactions associated with tunnelling and excavation are expected as follows.

3.2.1.1 Headrace shaft

Groundwater interaction associated with the pressure shaft would include:

- The headrace shaft will be open to groundwater inflow during excavation
- It is anticipated that the shaft will be progressively sealed with shotcrete during down reaming, however, some minor groundwater seepage may persist
- The final completed pressure shaft will be fully lined and grouted, and will be undrained.

3.2.1.2 Undrained tunnels

The headrace tunnel and tailrace tunnels will be fully lined and undrained.

Groundwater interaction associated with the undrained tunnels would include:

- A small section of the headrace tunnel will be open to groundwater inflow as excavation progresses
- It is anticipated that the tunnel will be progressively sealed behind the excavation face, however, some minor groundwater seepage may persist
- The final completed headrace tunnel and tailrace tunnel will fully lined and will be undrained.

3.2.1.3 Drained tunnels

The access tunnel and multi-purpose ventilation and egress tunnel, as well as secondary access tunnels and adits will be drained structures.

Groundwater interaction associated with the drained tunnels would include:

- A small section of the tunnels will be open to groundwater inflow as excavation progresses
- Primary support will be progressively placed behind the excavation face and will include the application of strip drains
- Ongoing seepage will occur via the strip drains to prevent excessive hydrostatic pressure
- The final completed tunnels will be permanently drained structures.

3.2.1.4 Power station and transformer caverns

Groundwater interaction associated with the power station and transformer caverns would include:

- The caverns will be open to groundwater inflow as excavation progresses
- Primary support will be progressively placed as the excavations advance
- Strip drains will be installed throughout to provide a continuous drainage system
- Ongoing seepage will occur via the strip drains to prevent build-up of excessive hydrostatic pressure
- The final completed caverns will be permanently drained structures.

3.2.1.5 Lower Tailrace Intake / outlet structure

Groundwater interaction associated with the lower tailrace Intake / outlet structure would include:

- Excavation will proceed below the water table and below the level of Lake Yarrunga dewatering will be required
- Infiltration of surface water through the rock plug from Lake Yarrunga during construction is also likely
- The final completed Intake / outlet structure will be inundated to the level of Lake Yarrunga and no significant ongoing groundwater interaction is anticipated.

3.2.2 Spoil

During tunnelling and excavations there is potential to intercept potentially acid forming rock material. The majority of spoil from the tunnelling, raise-boring and down-reaming operations, and cavern excavations will be transported via the access tunnel and haul roads to a dedicated spoil storage location adjacent to Bendeela Pondage, where it will be treated and managed to acceptable environmental standards by the Contractor.

Groundwater interaction associated with spoil management would include

- With oxidation of potentially acid forming materials there is the possibility of acid leachate generation within the spoil stockpile, and potential for local contamination of shallow groundwater
- Spoil treatment and mitigation measures will minimise the potential for acid leachate generation.

3.3 Assessment methodology

The groundwater assessment for the Project during construction and operation is based on the desktop assessment of prior investigations undertaken for the Shoalhaven scheme and Kangaroo Valley Power Station, as well as the results of preliminary Project geotechnical investigations.

Available data have been applied to characterise the existing hydrogeological environment to facilitate the assessment of potential groundwater seepage to excavations during Project construction, and the long-term response of groundwater to drained underground structures.

Calculation of groundwater inflow rates and seepage to excavations and tunnels, and associated groundwater depressurisation and drawdown, have been assessed via a number of methodologies including:

- Analytic methods – *Goodman et al*. (1965) equation for inflows into tunnels and the Theim and Dupuit-Theim equations for radial flow to a large diameter well (shaft) under confined and unconfined conditions (Fetter, 1988)
  - Applied for the assessment of potential inflows to tunnels and shafts
- Analytic Element Modelling – AnAqSim (Fitts Geosolutions, 2022)
  - For assessment of potential inflows to the inlet / outlet structure excavation, associated groundwater drawdown and potential baseflow reduction to Kings Creek, and for the assessment of groundwater seepage to the main cavern excavations and associated drawdown propagation
- Two-dimensional finite element modelling – Seep/W (Geoslope, 2012)
  - For assessment of potential depressurisation surrounding tunnels and caverns.

Geotechnical characterisation of acid forming potential of spoil from tunnelling and excavations has been applied to assess the potential for acid rock drainage.

Potential impacts with regard to groundwater level and quality have been assessed against the NSW Aquifer Interference Policy and with regard to Neutral or Beneficial Effects of water quality for both the construction and operational phases of the Project.

4. Existing environment

4.1 Climate

Overall, the Project area generally experiences a warm-temperate climate typical of its location in south-eastern Australia, with mild to hot summers and cool-mild winters. More specifically, however, the upper portion of the Project is located in the southern highlands and the lower portion of the Project falls within a valley between Berry Mountain and the Illawarra Escarpment, therefore temperature and rainfall conditions can vary.

Review of data available through BOM Climate Data Online (http://www.bom.gov.au/climate/data/) indicates that the nearest BOM weather stations to the upper and lower portions of the Project area are at Fitzroy Falls (Red Hills) (#68248) and Hampden Bridge (Kangaroo River) (#68181), respectively. The Fitzroy Falls (Red Hills) Weather Station is positioned approximately 5.5 km west of the Project at its nearest point, and Hampden Bridge (Kangaroo River) Weather Station is positioned approximately 5.2 km east of the Project.

The average monthly rainfall for the Fitzroy Falls and Hampden Bridge weather stations, from January 2003 to December 2021 (19 years), was calculated and is summarised in **Table 4-1** and shown in **Figure 4-1**.

Rainfall trends indicate that the region experience highest rainfall in late summer/early autumn (February and March), but also receives significant rainfall in June. Rainfall in upper portion of the Project tends to receive larger amounts of rainfall than the lower portion. This is expected to be due to orographic lift phenomenon whereby rain clouds form above a geographical feature such as a mountain or cliff.

Table 4-1 Average monthly rainfall recorded at Fitzroy Falls and Hampden Bridge

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Fitzroy Falls (mm)	72	173	140	60	69	133	59	79	55	79	111	76	1097
Hampden Bridge (mm)	62	145	118	66	60	91	53	77	38	62	91	58	843

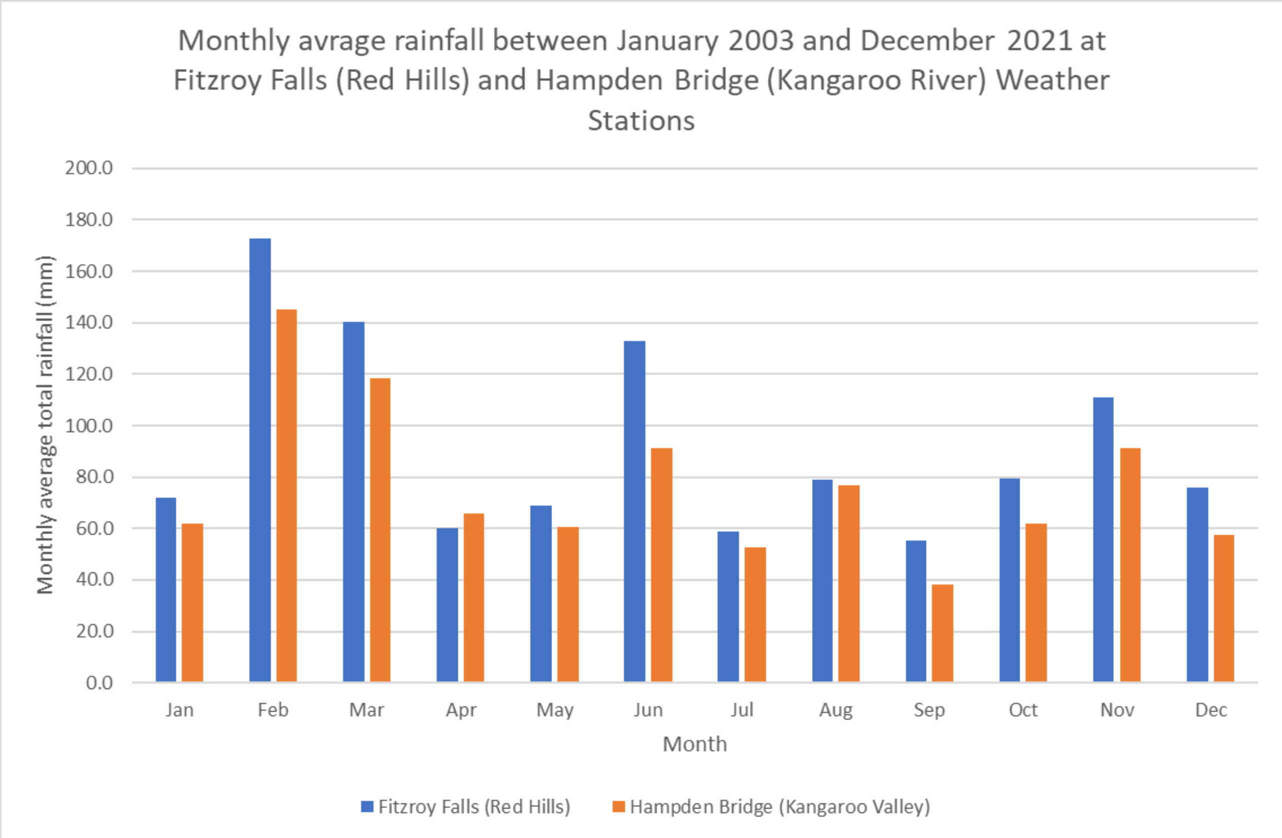


Figure 4-1 Average total monthly rainfall between 2003 and 2021
as recorded by Fitzroy Falls (Red Hills) and Hampden Bridge (Kangaroo River) Weather Stations

The long-term historical rainfall record has been obtained from the SILO Australian climate database (https://www.longpaddock.qld.gov.au/silo/) for grid point 34.75 degrees south and 150.50 degrees north. This location is within Kangaroo Valley approximately 5 km southeast of Bendeela Pondage. Data is for the period January 1900 to June 2022.

Daily rainfall and the long-term cumulative rainfall residual are plotted on **Figure 4-2**. The long-term average annual rainfall (1900 to 2022) for grid point 34.75 degrees south and 150.50 degrees north is approximately 1220 mm.

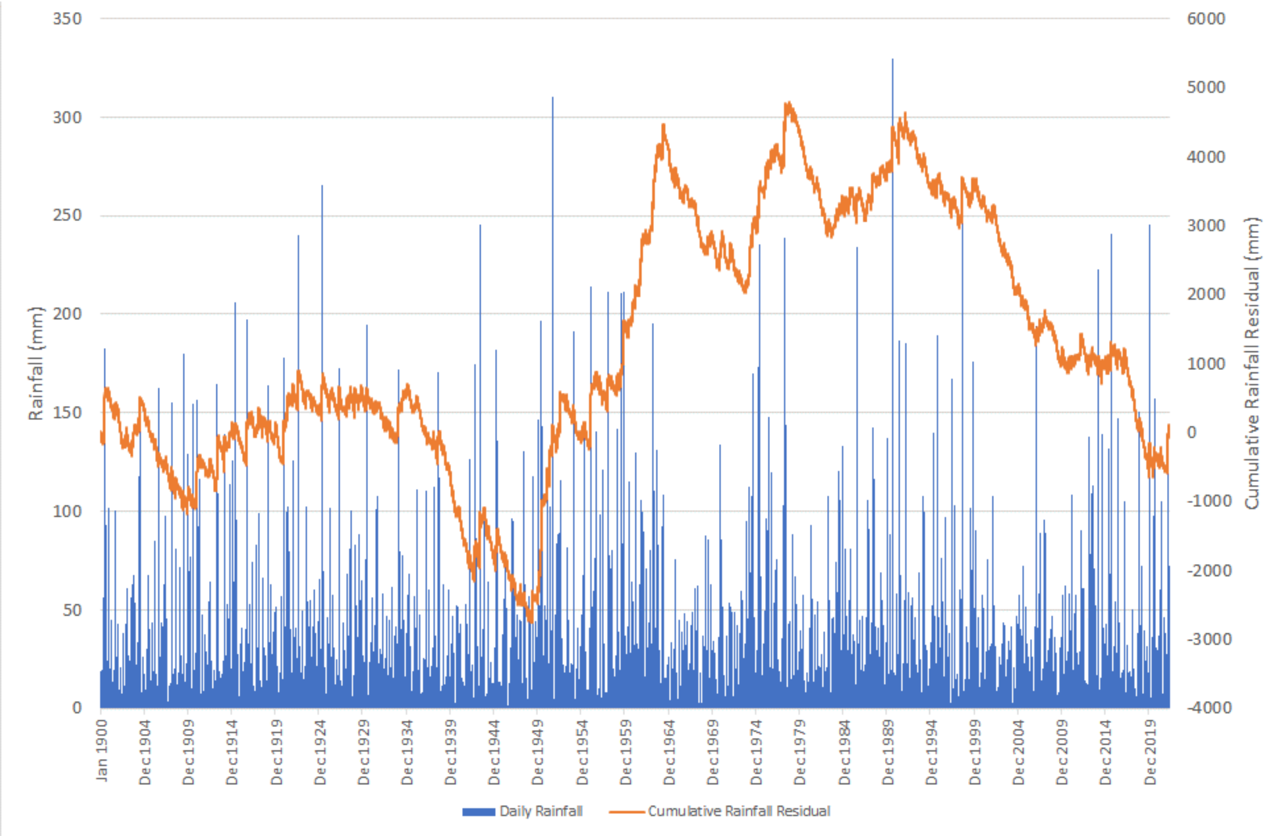


Figure 4-2 Silo rainfall data

4.2 Topography and drainage

The Project extends from low elevation areas in the southern extent of the Project area at Lake Yarrunga in Kangaroo Valley to the northern extent of the Project area at the upper plateau near Fitzroy Falls. Elevations across the Project area range between approximately 60 m AHD at Lake Yarrunga to up to 670 m AHD on the plateau. The plateau continues to the Fitzroy Falls Reservoir. As such, the area can be approximately divided into two distinct areas, the lower study area which spans from Lake Yarrunga until the base of the escarpment (steep rise) and the upper study area, which consists of the Fitzroy Falls Reservoir, the plateau and its slopes on both sides.

4.2.1 Upper study area

The upper study area is largely forested with some small areas of rural farmland on the eastern and northern sides of the Fitzroy Falls Reservoir. There are very little urban or impervious areas with the only significant infrastructure relating to the existing pumped hydro scheme. Existing infrastructure that is present, and extends southward along the upper study area, includes the Fitzroy Falls Reservoir and Canal, the existing surface penstock and easement, surge tank and high pressure shaft.

The Fitzroy Canal connects the Fitzroy Falls Reservoir to the northern extent of the surface penstock on the plateau. There is significant topographic variation along the plateau, in particular, there is a steep slope that dips south from the upper intake control structure to the anchor block at the base of the valley, which is located adjacent to Trimbles Creek. Elevation gradually rises from the anchor block to another high point at the surge tank. From this point, elevation gradually decreases along the slope from the surge tank to the end of the high pressure shaft. Approximately 500 m south of the base of the high-pressure shaft, elevation rapidly decreases, creating a cliff-like topographic feature (the escarpment). At the south-west extent of the plateau there are several drainage lines connecting the top of the escarpment. The headwaters of Kings Creek rise to the west of the plateau and follow the base of the escarpment before turning south and flowing to Lake Yarrunga. Drainage lines also drain west toward Yarrunga Creek which flows west before turning to the south and connecting with Lake Yarrunga. To the south-east of the plateau, drainage lines lead into Nelsons Creek, which also flows into Lake Yarrunga. To the east of the plateau, drainage lines lead into Trimbles Creek which flows east off the escarpment and connect to Millers Creek. Yarrunga Creek forms the main towards the west.

Along the top of the escarpment the man-made Fitzroy Canal connects the Fitzroy Falls Reservoir and the Upper Intake. The plateau is largely flat with a gentle slope towards the edges of the escarpment and away from the canal and as such minimal rainfall runoff will enter the canal.

4.2.2 Lower study area

The lower area beneath the escarpment until Lake Yarrunga and the southern end of the Project area is a mix of vegetation, farmland and built areas relating to the Kangaroo Valley Power Station as well as a small number of houses and farm buildings.

From the base of the escarpment, the area gradually slopes south until an area of flat ground where several farms, the Kangaroo Valley Power Station and Bendeela Pondage are located. The area again slopes south toward Lake Yarrunga. There are two main drainage lines running north to south through the area connecting the escarpment with the Lake Yarrunga. Kings Creek flows on the western side of the Bendeela Power Station as well as a significant, but unnamed drainage line to the east of the power station.

4.2.3 Waterways and waterbodies

Waterways and water bodies are described in detail in the Surface Water, Hydrology and Geomorphology specialist report. The main waterways in the vicinity of the lower scheme, excluding Fitzroy Canal and Fitzroy Fall reservoir, are described in the following sections and are depicted on

Figure 4-3.

4.2.3.1 Lake Yarrunga (downstream) / Kangaroo River (upstream)

Kangaroo River is major waterway that flows in a westerly direction toward Shoalhaven River. The construction of the Tallowa Dam on the waterway at the confluence of Kangaroo River and Shoalhaven River in the 1970’s, has formed Lake Yarrunga. Lake Yarrunga extends from approximately 20 km downstream of the Project area to approximately 4 km upstream of the proposed inlet /outlet structure. At the inlet / outlet structure, the lake is approximately 60 m wide and 10 m deep at its deepest point. The substrate is mostly silty sand.

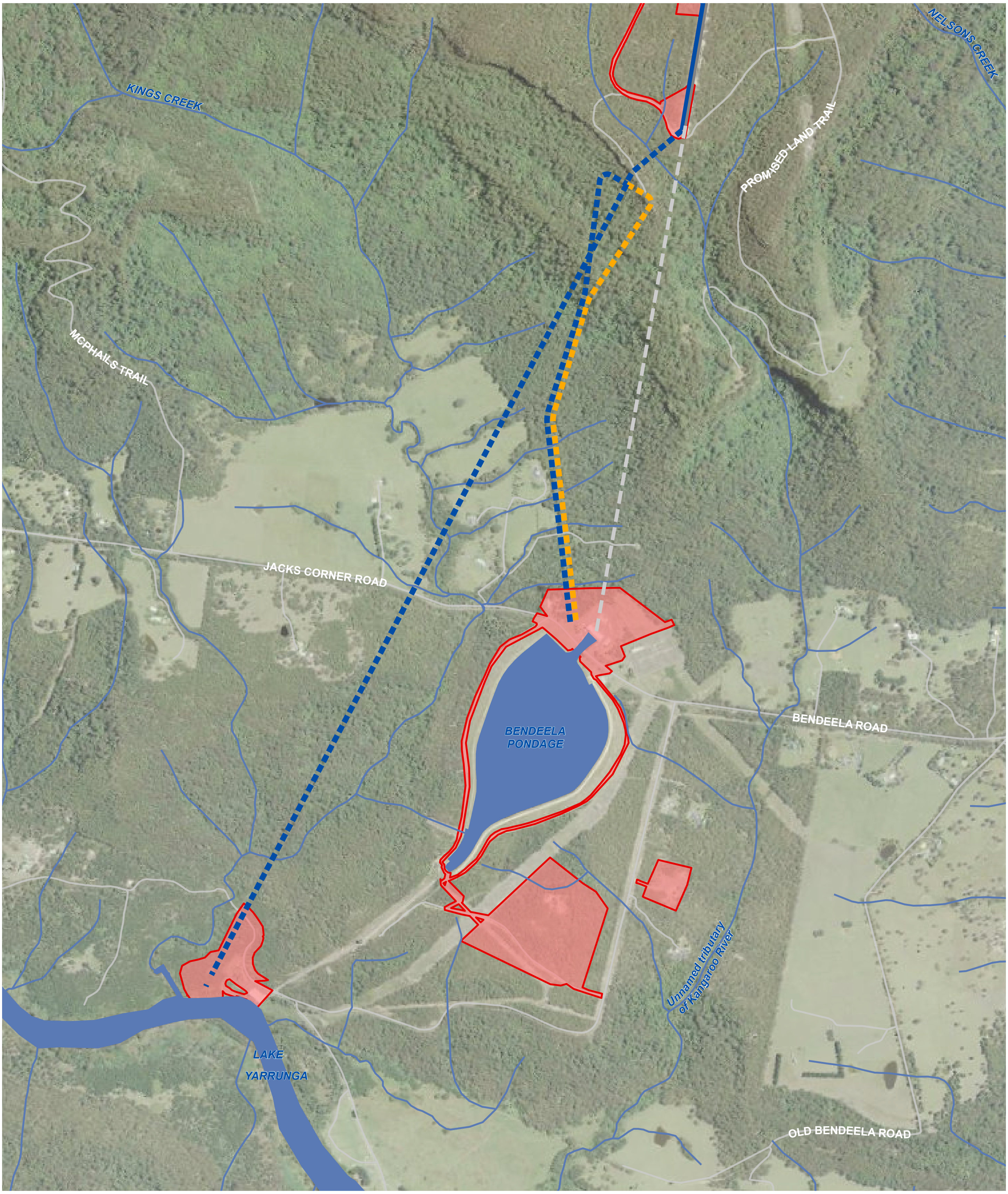
4.2.3.2 Kings Creek

Kings Creek is a perennial, third order stream located immediately west of the Bendeela Pondage, and the Kangaroo Valley and Bendeela Power Stations. The creek flows in a southerly direction, toward Lake Yarrunga, from its headwaters on the escarpment in Morton National Park and has several unnamed, first order tributaries flowing into it. The creek is shallow and has a narrow channel, approximately one to three m wide. The substrate is mostly bedrock with some gravel beds and large boulders along its length.

The lower portion of the creek (below Lower Bendeela Road crossing) becomes inundated from Lake Yarrunga, regularly. Above this road crossing, the creek consists of a series of interconnected rock pools and riffles typically with relatively low flows. A large cliff-like topographic feature is present approximately 0.5 km upstream of the Lower Bendeela Road crossing.

4.2.3.3 Unnamed tributary

An unnamed tributary is a second order, perennial stream located to the east of Bendeela Pondage, and the Kangaroo and Bendeela Power Stations. The unnamed tributary flows generally in a southerly direction toward Lake Yarrunga. The lower portion of the stream forms a wetland environment, and the surrounding area has been cleared of vegetation apart for a small riparian corridor. The upstream section flows through a mix of cleared farmland and densely forested area, as well as under Bendeela Road approximately 800 m east of the Kangaroo Valley Power Station.



Legend

- Existing KV tunnel alignment
- Existing scheme pipeline
- Indicative above ground pipeline
- Indicative tunnel alignment
- Indicative access tunnel
- Construction disturbance area
- Road
- Waterway
- Waterbody

0 0.5 1 km

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Data sources

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Figure 4-3 Key waterways and waterbodies - Lower Scheme

4.3 Geology

The geology in the vicinity of the Project area is shown in **Figure 4-4** and is sourced from the NSW Seamless Geology Geodatabase (Phillips *et al.*, 2015). The geology comprises lithologies of the Southern Coalfields region of the Sydney Basin including the Triassic Hawkesbury Sandstone and Narrabeen Group, and Permian Illawarra Coal Measures and Shoalhaven Group.

A summary of the stratigraphy is included in **Table 4-2**. A lithological description of the units encountered on site during the drilling of BH02 (Jacobs, 2019b) is provided in **Table 4-3** (refer to **Chapter 3** for discussion on site investigations).

Table 4-2 Generalised stratigraphy

Period	Epoch	Group	Formation	Description
Triassic	Middle	Hawkesbury Sandstone		The Hawkesbury Sandstone is composed mainly of quartz-rich sandstone. Some mudstone and shale plies are present within this formation; however, this typically comprises less than 5% of the formation. Deposition is dominated by a braided fluvial deltaic environment.
	Early	Narrabeen Group		The Narrabeen Group is a non-coal-bearing stratigraphic unit composed mainly of quartz-rich sandstone, shale and mudstone units. Deposition was within several different fluvial environments, associated with a relatively slow period of marine transgression.
Permian	Guadalupian	Illawarra Coal Measures		The Illawarra Coal Measures are composed of sandstone, siltstone, claystone and coal. There are also some minor tuff and conglomerate layers, with rare basalt noted within the Southern Coalfield only. The formation of these coal measures occurred in lower delta plain to alluvial fan environments.
		Shoalhaven Group	Broughton Formation	The thick sand and silt units of the Shoalhaven Group were deposited during the early Permian marine transgression. These were deposited in variably low to high energy, fluvial to marine (shelf) environments and mainly comprise sandstone with interbedded shale and mudstone. The shale and mudstone units represent marine influenced deposition, whereas the sandstone units are fluvial to terrestrial in origin. Note: the Budgong Sandstone is not differentiated on the geological map (**Figure 4-4**) and is likely mapped as part of the Broughton Formation.
			Budgong Sandstone	
			Berry Siltstone	
			Nowra Sandstone	
			Wandrawandian Formation	
			Snapper Point Formation	

Table 4-3 Summary of main geological units identified in BH02

Depth (m)		Geological Unit	Summary description
0	74.6	Hawkesbury Sandstone	Sandstone: medium to coarse grained, quartzose, pale brown and pale yellow, distinctly cross-bedded with orange-brown iron oxide staining, frequent dark red ironstone bands and occasional highly weathered seams decomposed to clay and sand.
74.6	93.3	Narrabeen Group	Alternating beds of lithic to feldspathic sandstone, pale brown, medium to coarse grained, and shaley siltstone and claystone, dark grey, sub-horizontal planar laminated; with occasional pebble lenses.

Depth (m)		Geological Unit	Summary description
93.3	117.6	Illawarra Coal Measures	Contains a coal seam 2 m thick: black, massive, brittle; interbedded with dark grey carbonaceous siltstone and fine to medium grained sandstone, grey, with steeply dipping to subvertical joints, mostly undulating, very rough, and clean.
117.6	151.4	Broughton Formation (Upper)*	Grey, fine to medium grained lithic to tuffaceous sandstone, massive; interbedded with dark grey tuffaceous siltstone beds up to 1m thick; distinct horizontal lamination, planar to wavy.
151.4	207.6	Broughton Formation (Lower)*	Grey, fine to medium grained volcaniclastic sandstone, massive, sparsely jointed, with occasional sub-horizontal wavy siltstone lenses and laminations; trace of fine to coarse, subrounded gravel size clasts.
207.6	281.2	Budgong Sandstone	Medium to coarse grained, grey, massive volcaniclastic sandstone; sparsely jointed, with occasional steeply dipping joints, undulating and rough, with iron oxide staining; occasional siltstone bands and thin carbonaceous lenses, wavy and sub-horizontal.
281.2	477.0	Berry Siltstone	Black to dark grey siltstone, wavy to irregular sub-horizontal tight and intact laminations; sparsely jointed, with occasional beds of fine grained silty sandstone, thin calcite-infilled veins, and isolated sub-rounded gravel size clasts.
477.0	511.0	Nowra Sandstone	Medium to coarse grained, massive quartzose sandstone. With occasional thin, wavy sub-horizontal siltstone laminations and conglomerate lenses and beds up to 2 m thick, comprising medium to coarse sub-angular gravel, clast-supported.
511.0	608.8	Wandrawandian Formation	Black to grey siltstone and sandy siltstone, commonly with pebbles; occasional carbonate shell inclusions and dropstones up to 0.5m.
608.8	646.5	Snapper Point Formation	Interbedded quartz-lithic sandstone, fine grained, grey, massive; siltstone, and conglomerate; repeating fining upward sequences grading from conglomerate through quartz -sandstone into siltstone. Occasional carbonate shell inclusions.

4.3.1 Geology along Project alignment

A long section of the tailrace/headrace tunnels and the geological units through which the Project passes are shown in **Figure 4-5**.

The pressure shaft, headrace tunnel and power station cavern lie beneath the plateau, which is underlain by Triassic Age Hawkesbury Sandstone. The pressure shaft passes through all lithologies down to the Snapper Point Formation.

The headrace tunnel and power station cavern are excavated entirely within Snapper Point Formation, while the upper extent of the surge shaft is expected to pass through into the Wandrawandian Formation.

The lower tailrace Intake / outlet structure and the initial tailrace boxcut and tunnel are excavated within the Wandrawandian Formation, with the tailrace tunnel passing into Snapper Point Formation after approximately 250 m. The remainder of the tailrace tunnel is then excavated within the Snapper Point Formation.

4.3.2 Faults

The are no significant structural features such as faults and folds mapped in the vicinity of the Project on the NSW Seamless Geology Geodatabase.

However, faulting was encountered during the investigation and construction stage for the original Kangaroo Valley scheme. Geological mapping from the Kangaroo tunnel and pump house infers an east-west fault encountered in the Kangaroo Pump Station. Jacobs (2019a) noted the expected presence of normal faults with down-throw to the south in the existing Kangaroo tunnel and around the Bendeela Pondage spillway.

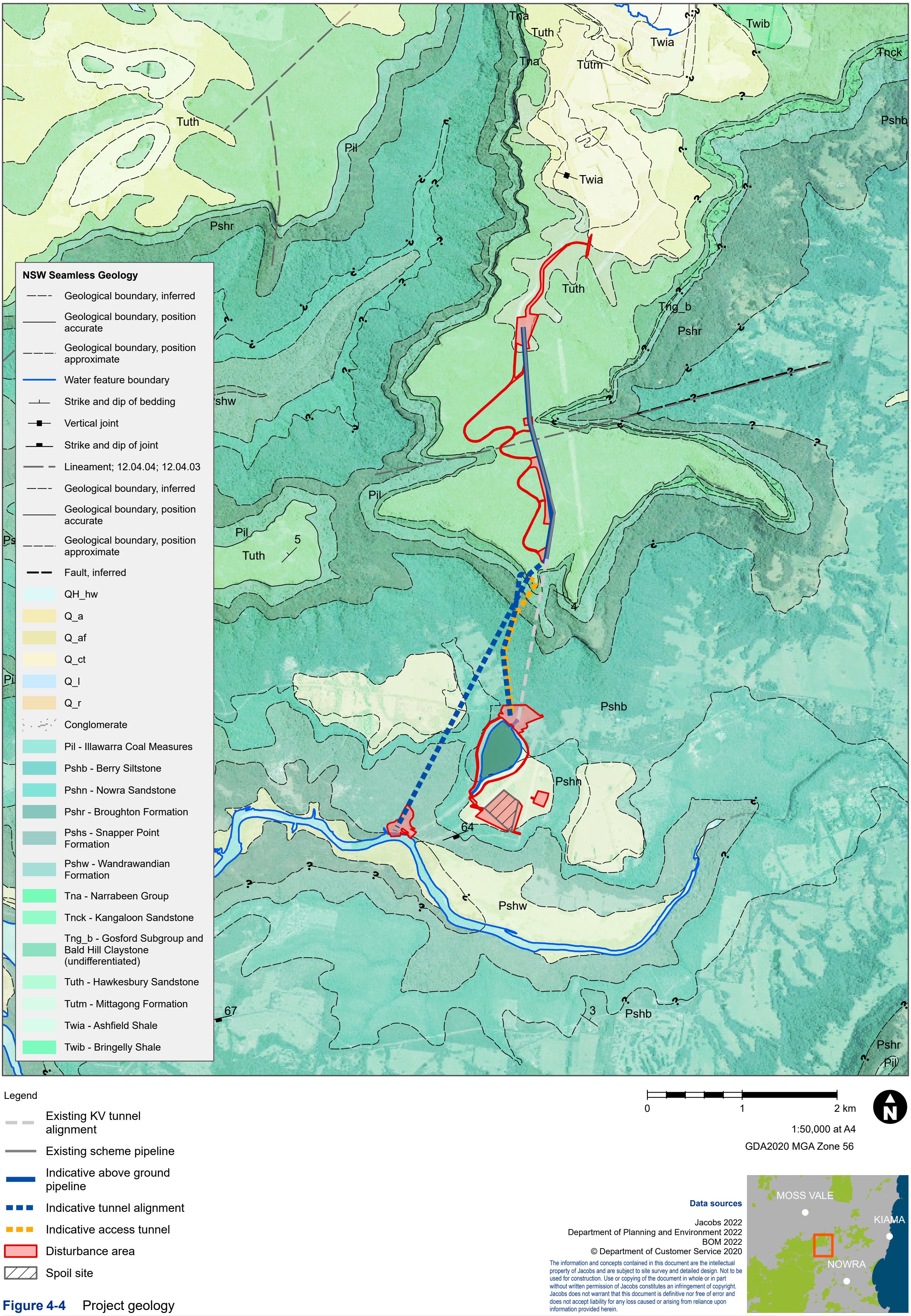
4.4 Regional groundwater system

The regional groundwater system is controlled by topography, areas of recharge and discharge, and the stratigraphic dip of the geological units.

Groundwater systems beneath the upper plateau and above the escarpment (i.e., above approximately 250 m AHD in the vicinity of the Project) are likely to have a limited catchment area and possess discrete saturated horizons. Geological units at these elevations are expected to have potentially discontinuous hydraulic connection with each other, and with the units below the escarpment. Groundwater flow beneath the upper plateau is expected to be towards the escarpments, with partial discharge at the escarpments and cliff faces, particularly at the interfaces between geological units of contrasting vertical hydraulic conductivity. Steep vertical hydraulic gradients are likely to be present in the vicinity of the escarpment due to discharge at seepage faces.

Below the escarpment (i.e., below approximately 250 m AHD in the vicinity of the Project), a deeper regional groundwater system is expected to be present. The NSW Department of Mines Wollongong Geological Sheet 1:250,000 (1966) indicates that the regional stratigraphic dip is generally eastwards in the vicinity of the Project. This suggests that the regional groundwater flow is toward the escarpment and the Project area, which is consistent with topography and regional flow towards the major drainage lines in the Project area.

In the lowland areas, a similar flow regime is expected, with additional localised influence by shallow discharge towards Lake Yarrunga and Kangaroo River.



Data sources

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Figure 4-4 Project geology

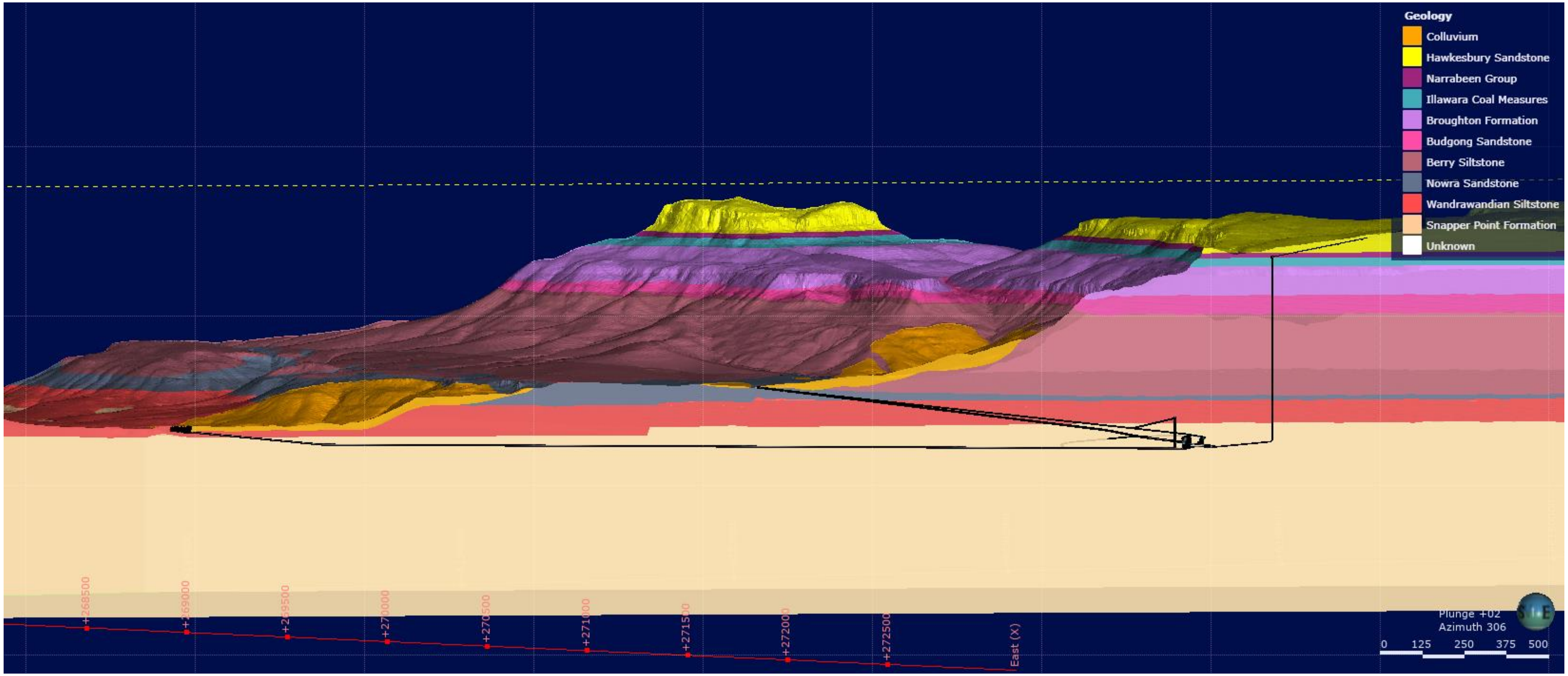


Figure 4-5 Alignment geology – Leapfrog geological model

4.4.1 Registered groundwater works

A search of the WaterNSW-registered groundwater bores within approximately 5 km of the Project area was undertaken (https://realtimedata.waternsw.com.au), with additional bore data sourced from the Australian Groundwater Explorer (http://www.bom.gov.au/water/groundwater/explorer/map.shtml).

The groundwater works locations are presented on **Figure 4-6** and are classified according to the recorded purpose of the bore. The works are summarised as follows:

- There are approximately 53 groundwater works within 5 km of the Project (works classified as abandoned or non-functional are excluded). Of these works:
  - 26 bores are recorded as being for water supply
  - 4 bores are recorded as being for irrigation
  - 1 bore is recorded as “other”
  - 22 bores are recorded as being for monitoring, and are associated with the Kangaroo Valley power station.
- There is only one bore within 2 km of the proposed excavations and tunnelling and this bore is located to the south of the Lake Yarrunga.
- Reported bore yields for these bores range from 0.1 L/s to 26 L/s, with an average yield of 3.8 L/s.

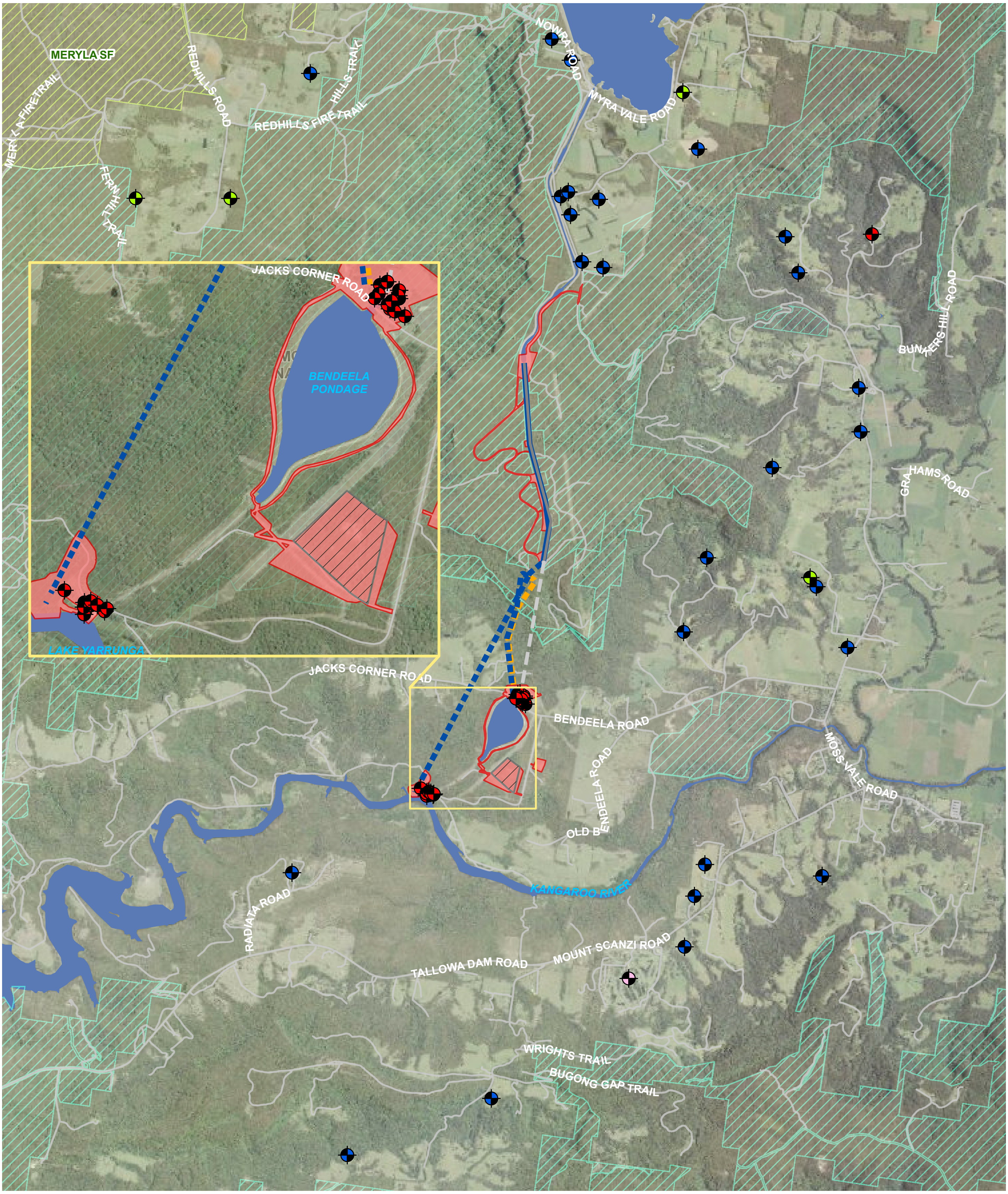
Water level data has also been sourced for these groundwater works, where available and is summarised in **Table 4-4**.

Based on the available water level information, groundwater levels at the Project area are expected to be as follows:

- Approximately 25 m to 100 m below ground level in the highland areas and upper steep escarpment slopes
- Approximately 10 m to 50 m below ground level in the mid-slope areas underlain by Berry Siltstone
- Approximately 5 m to 20 m below ground level close to the valley area adjacent to Lake Yarrunga.

This equates to groundwater elevations of between approximately 530 m AHD and 630 m AHD beneath the plateau, around approximately 175 m AHD in the vicinity of the Bendeela Pondage, reducing to 75 m AHD in areas adjacent to Lake Yarrunga.

Further discussion on site specific groundwater levels is provided in **Section 4.6.6**.



Legend

Bore

- Irrigation
- Monitoring
- Water Supply
- Other
- Existing KV tunnel alignment
- Existing scheme pipeline
- Indicative above ground pipeline
- Indicative tunnel alignment
- Indicative access tunnel
- Project area
- Spoil site
- Road
- State Forest
- NPWS Reserve
- Waterbody

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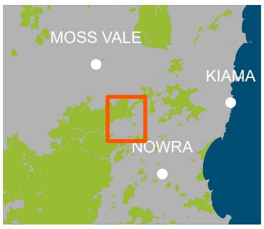

Data sources

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Figure 4-6 WaterNSW-registered bores in vicinity of Project

Table 4-4 Available water level data in vicinity of the Project

Bore ID	MGA Easting	MGA Northing	Estimated Ground Surface Elevation (mAHD)	Bore Depth (mbgl)	Geology Encountered in the Water Bearing Zone	Screen Interval (mbgl)	Groundwater level (mbgl)
GW052042	269985	6160149	671	54	Sandstone	3 to 53 (open hole)	40
GW072257	271253	6151675	133	30	Blue shale & sandstone	10 to 30 (open hole)	18
GW100210	268862	6149799	322	116	Sandstone	Open hole	60
GW101462	270563	6151284	161	72	Sandstone (10-72)	7 to 10, 10 to 72 (open hole)	6
GW101591	271241	6155570	131	60	Shale and sandstone	Unknown	15
GW103623	270244	6160079	671	56	Sandstone	38 to 53	24
GW106468	267080	6149098	188	60	Siltstone	Open hole >24	22
GW106689	273269	6155377	99	30	Siltstone	Open hole >18	12
GW106743	272883	6156130	161	30	Decomposed siltstone and sandstone	16 to 28	10
GW107627	266396	6152592	210	54	Sandstone and shale bands	29 to 54	10

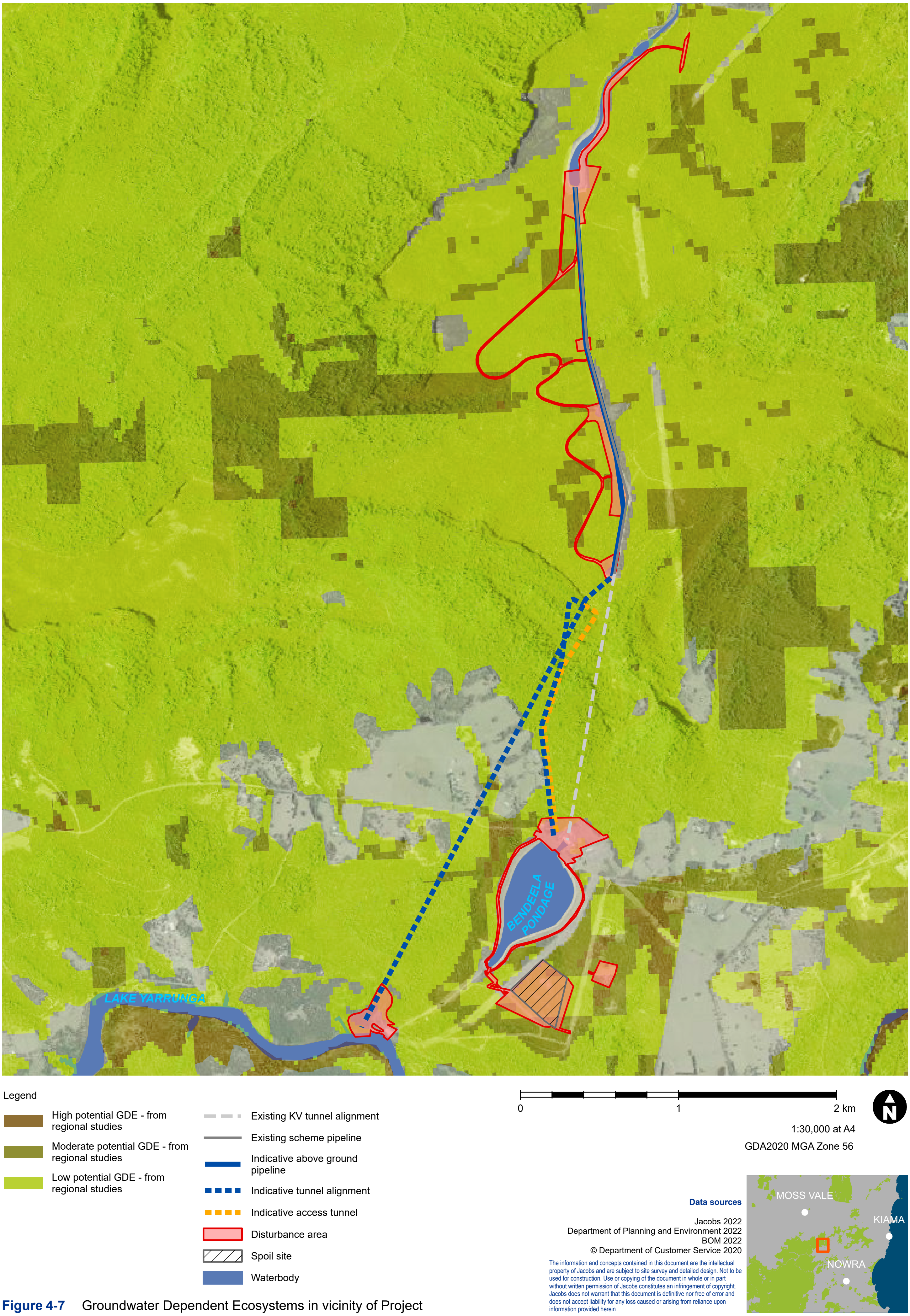
4.4.2 Groundwater dependent ecosystems

The Bureau of Meteorology's (BOM's) GDE Atlas identifies the following terrestrial (vegetation) ecosystems that potentially rely on groundwater in the vicinity of the Project area:

- Shoalhaven Hanging Swamps of high potential reliance and Shoalhaven Sandstone Forest of low and moderate potential on the upper slopes and plateau
- Escarpment Foothills Wet Forest low potential reliance on the mid-slopes and escarpment
- Coastal Warm Temperate Rainforest of low to moderate potential reliance on the mid-slopes and escarpment
- Warm Temperate Layered Forest of low to high potential reliance, and Southern and Turpentine Forest of moderate potential on the lower slopes, in the vicinity of Bendeela Pondage and the lower reaches of Kings Creek
- Southern Turpentine Forest of moderate potential reliance in the vicinity of Lake Yarrunga and Bendeela Pondage
- Riverbank Forest of moderate potential reliance in the vicinity of Kangaroo River and the lower reaches of Kings Creek.

The GDE Atlas also identifies Lake Yarrunga, located immediately downstream of the Project area, as an aquatic GDE with moderate potential reliance on groundwater. These GDE are shown in **Figure 4-7**.

The Water Sharing Plan does not identify any high priority GDE in the vicinity of the Project.



Data sources

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Figure 4-7 Groundwater Dependent Ecosystems in vicinity of Project

4.5 Previous site investigations

4.5.1 Kangaroo Valley Power Station

The Kangaroo Valley Power Station headrace tunnel was constructed to 5 metre diameter horseshoe profile by drill and blast, driven from the power station end through Berry Siltstone. Primary support was provided with shotcrete and steel sets as required depending on rock conditions encountered but for the most part only limited support was provided. The tunnel was advanced over a length of length of 1480 m during the period 18 April 1973 to the15 May 1974. The inclined 300 m deep pressure shaft was also constructed by drill and blast methods from the top down. On completion of both the shaft and tunnel, a 3.6 m ID steel lining and backfill concrete was installed as the final stage of the works (Jacobs, 2019a).

4.5.1.1 Water levels

SMEC (1972) reported water levels form 16 completed holes drilled for the Shoalhaven Scheme. The water levels were measured at irregular intervals following completion. The range in observed water levels are summarised in **Table 4-5**. Hole locations are shown on **Figure 4-9**.

Table 4-5 Shoalhaven Scheme water levels

Bore	Inclination (degrees from horizontal)	Hole Depth (m)	Indicative water level range (mbgl)
KPS10	90	67.06	39 to 43
KPS11	90	50.29	23 to 35
KPS12	90	47.24	8 to 14
KPS13	45	91.44	28.3 to 29
KPS14	45	76.2	29.7 to 31.8
KPS16	43	84.81	8.2 to 8.9
KPS17	45	45.72	24 to 25.5
STPL2	90	30.02	28 to 29
STPL3	60	48.77	33.8 to 37.2
STPL4	90	60.53	35 to 41
STPL5	90	35.05	30 to 32
STPL6	90	91.29	77 to 78
STPL7	90	24.38	18 to 20
STPL8	90	106.81	75 to 77
ST1	90	67.06	39 to 43

The water levels provided in **Table 4-5**, are mostly generally indicative of a shallow, potentially perched, groundwater system. It is noted that water levels are measures in an open drillhole and as such are a composite level of any groundwater systems intersected by the hole. A number of holes are noted as being inclined and in these cases the measured depths have been converted to an equivalent vertical depth.

4.5.1.2 Packer Testing

Geotechnical investigations for the Kangaroo Valley Power Station included the drilling of approximately 25 investigation holes in the vicinity of power station, headrace tunnel, and in the vicinity of Bendeela Pondage and tailrace.

Hydraulic test data (packer testing) for 133 borehole packer (Lugeon) tests carried out in 18 boreholes across the original scheme investigation are available for the Hawkesbury Sandstone, Narrabeen Group, Illawarra Coal Measures, Berry Siltstone, Nowra Sandstone, and Wandrawandian Formation (Jacobs, 2019a). Test data are not available for the Snapper Point Formation. A summary of the testing results is provided in **Table 4-6**.

These data indicate that the horizontal hydraulic conductivity of the tested rock units ranges from approximately 0.2 m/day to less than 1×10^{-3}m/day.

- 45 of the tests are reported as returning a value of zero lugeons, indicating that no significant flow to the formation was recorded. For these tests, for the purposes of statistical analysis, the zero lugeon value was substituted with a value equivalent to 0.5 times the lowest practical value that is considered obtainable with older packer testing equipment (0.1 L or 1.1x10-3 m/day)
- The Hawkesbury Sandstone had the greatest range and highest hydraulic conductivity value, followed by the Illawarra Coal Measures
- The Illawarra Coal Measures had the highest average and geometric mean hydraulic conductivity values
- The Narrabeen Group had the lowest average hydraulic conductivity, although only two tests were undertaken with identical results
- The Nowra Sandstone had the lowest geometric mean hydraulic conductivity.

Table 4-6 Kangaroo Valley Power Station hydraulic testing summary

Lithology	Number of tests	Hydraulic Conductivity (m/d)			
		Min	Max	Average	Geometric Mean
Hawkesbury Sandstone	13	0.0034	0.7301	0.7267	0.1264
Narrabeen Group	2	0.0022	0.0022	0.0000	0.0022
Illawarra Coal Measures	3	0.0056	0.6178	0.6121	0.2303
Berry Formation	67	0.0006	0.3594	0.3589	0.0477
Nowra Sandstone	19	0.0006	0.2583	0.2578	0.0148
Wandrawandian Formation	29	0.0006	0.1011	0.1005	0.0319

4.5.1.3 Water Quality

SMEC (1972) reported water levels from two holes (KPS11 and KPS12) drilled for the Shoalhaven Scheme. The resulting water quality data are presented in **Table 4-7**. Hole locations are shown on **Figure 4-9**.

KPS11 and KPS12 are located approximately 280 m north and 320 m northeast of the Kangaroo Valley Power Station, respectively, and are drilled to depths of approximately 50 m and 47 m. KPS11 is drilled through Berry Siltstone and Nowra sandstone, while KPS12 is drilled through colluvium and Berry Siltstone.

The water quality from KPS11 and KPS12 is indicative of bicarbonate dominant water with elevated calcium and magnesium. Calcium carbonate groundwater is typically associated with recharging groundwater but could also be indicative of an abundance of carbonate minerals in formation.

Table 4-7 Shoalhaven Scheme groundwater quality

Analyte	KPS11	KPS12
pH	7.4	7.5
TDS (mg/L)	420	500
Sodium (mg/L)	34	32
Potassium (mg/L)	2	4
Calcium (mg/L)	34	55
Magnesium (mg/L)	15	28
Chloride (mg/L)	70	95

Analyte	KPS11	KPS12
Sulphate (mg/L)	135	70
Carbonate (mg/L)	0	0
Bicarbonate (mg/L)	320	590

4.5.1.4 Faulting

SMEC (1972) noted the presence of numerous small faults and two larger faults. One normal fault was mapped north of the Kangaroo Valley Power Station with a throw of approximately 15 m (upwards to the north) and another fault was noted in the base of the power station excavation with a vertical off set of approximately 0.3 metres.

The locations of these faults in section are shown on **Figure 5-2**.

4.5.1.5 Dykes

Excavations in the Kangaroo Valley Power Station area revealed the presence of two basic dykes (SMEC, 1972). The dykes were noted as being completely weathered to clay in the excavations.

4.5.1.6 Tunnel Inflows

Jacobs (2019a) provide a summary observed groundwater during tunnel excavation of the Kangaroo headrace tunnel. The tunnel is excavated primarily through Berry Siltstone, with some minor fault displaced intersection of Nowra Sandstone in the floor of the tunnel in the lower tunnel section (approximate chainage 70 m to 240 m).

Ground conditions were generally noted as fair to very good. More detail on the geology intersected and rock mass classification is provided in Jacobs, 2019a.

For the most part, the tunnel was generally dry, with only two minor zones of inflow associated with faulting:

- From chainage 66 m to 81 m inflows seeping from the invert at rate of about 0.10 to 0.19 m^3/day (0.001 to 0.002 L/s) were observed, associated with a thick clay infilled fault zone, dipping 45° towards approximately 210°, with approximately 10 m of displacement (downthrow to the south)
- From chainage 230 to 238, inflows of 150 to 230 litres per hour were recorded, associated with a major fault dipping 47° towards 189°, with thickness of 1 metre and infill comprising highly weathered rock, and with displacement of approximately 1 metre (downthrow to the south)
- Damp walls were observed and minor water drips near a fault at approximately chainage 934 m
- Damp walls were recorded from chainage 1388 m to the terminus at 1480 m.

Total inflows were therefore relatively low with a maximum seepage of approximately 5.7 m^3/day (0.07 L/s).

4.5.2 Bendeela Pondage

During a review into the feasibility of expanding the Bendeela Pondage, GHD (2017) noted the presence of an east-west trending fault located in the channel leading to the Bendeela pipeline control structure in the area downstream of the pondage. The magnitude of displacement along the fault was not defined but suggest the sense of movement was an upthrow in the north at surface, where Berry Siltstone comprised of siltstone, shale and fine-grained sandstone was exposed, and a down throw to the south where medium to coarse grained Nowra Sandstone and slightly clayey sandstone was exposed.

WaterNSW currently undertake monitoring of groundwater levels and pore pressure in the embankments for the pondage. WaterNSW provided groundwater level monitoring data from 2014 to 2017 for 13 monitoring bores located around the Bendeela Pondage (WaterNSW, 2018). The locations are shown **Figure 4-8**. Groundwater levels are generally stable over the monitoring period, and average recorded levels are provided in **Table 4-8**. The indicative elevation of Bendeela Pondage stage height is approximately 182 m AHD.

The recorded groundwater levels are relatively shallow and close to ground surface. It is considered likely that these levels are influenced by groundwater seepage from the Bendeela Pondage. Elevated water levels are observed at WT1 adjacent to the power station tailrace and at WT8 along the western embankment. Water level lows are observed at WT2 along the eastern embankment and at WT9 and WT10 on the north-western embankment.

While the elevated water levels are likely to represent points of focussed seepage from the Pondage, the alignment between WT2 and WT9/WT10, broadly aligns with the inferred dominant faulting orientation and may indicate a zone of enhanced deeper infiltration.

The presence of Bendeela Pondage in the vicinity of the tailrace tunnel requires consideration of seepage inflow impacts from the tunnels during construction and in the long-term.

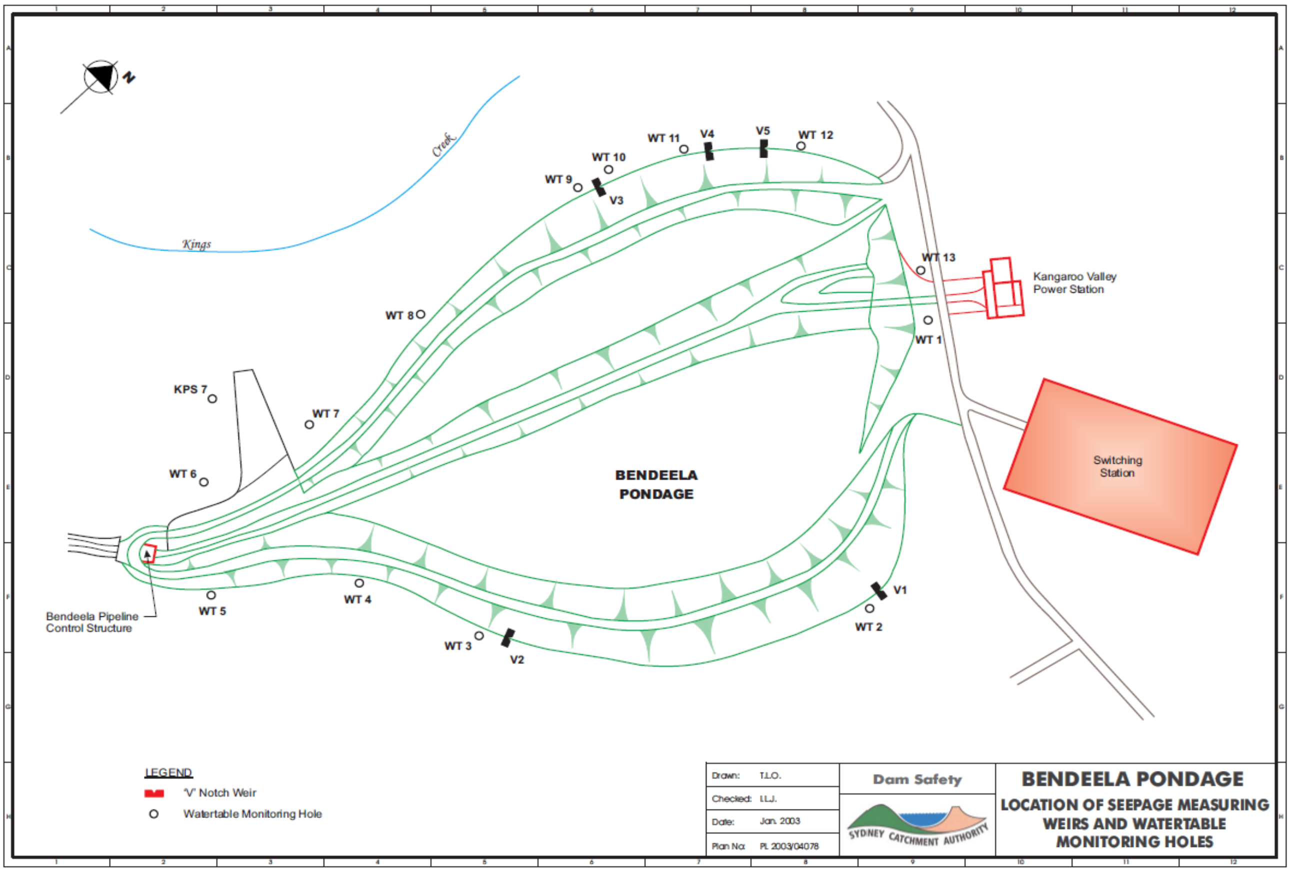


Figure 4-8 WaterNSW groundwater monitoring locations in the vicinity of Bendeela Pondage

Table 4-8 Average groundwater levels in the vicinity of Bendeela Pondage (2014 to 2017)

Bore	Average Groundwater Elevation (m AHD)
WT1	182
WT2	165
WT3	170
WT4	170
WT5	173
WT6	170
WT7	173

Bore	Average Groundwater Elevation (m AHD)
WT8	177
WT9	168
WT10	168
WT11	170
WT12	174
WT13	173

4.6 Current site investigations

4.6.1 Investigation drill holes

As part of the preliminary geotechnical investigations, four geotechnical drill holes (BH02, BH03, BH06 and BH07) were completed with associated geotechnical and hydraulic testing (Jacobs, 2019b). The holes provide valuable data on formation geotechnical and hydraulic properties. Hole locations are shown on **Figure 4-9**.

Full details of the geotechnical investigation programme are provided in the Preliminary Geotechnical Investigations Factual Report (Jacobs, 2019b).

Summary geology for drillhole BH02 is already provided in **Table 4-3**. Summary geology for the remaining drillholes is provided in **Table 4-9**, **Table 4-10** and **Table 4-11**.

The drillholes have been subject to geophysical logging, packer testing and have been equipped as vibrating wire piezometer installations (BH02, BH03 and BH06) and with a standpipe monitoring bore at BH07.

Table 4-9 Summary of main geological units identified in BH03

Depth (m)		Geological Unit	Summary description
0	27.0	Nowra Sandstone	Medium to coarse grained, massive quartzose sandstone. Alternating beds of siltstone and sandstone. Occasional conglomerate horizons up to about 200 mm thick, comprising fine to coarse grained subrounded quartz gravel.
27.0	143.0	Wandrawandian Formation	Dark grey siltstone and sandy siltstone, indistinctly laminated, commonly with subrounded pebbles; occasional bioturbation and carbonate shell fragments.
143.0	247.1	Snapper Point Formation	Repeating fining upward sequences grading from conglomerate through quartz -sandstone into siltstone.

Table 4-10 Summary of main geological units identified in BH06

Depth (m)		Geological Unit	Summary description
0	2.0	Residual Soil	Fine grained yellow-brown sand; dry and loose.
2.0	35.6	Wandrawandian Formation	Dark grey siltstone and sandy siltstone, indistinctly laminated, commonly with subrounded pebbles; occasional bioturbation and carbonate shell fragments.
35.6	90.6	Snapper Point Formation	Repeating fining upward sequences grading from conglomerate bands up to 200mm thick, through quartzose sandstone into siltstone.

Table 4-11 Summary of main geological units identified in BH07

Depth (m)		Geological Unit	Summary description
0	2.8	Fill	Clayey sand, brown, with some fine to medium gravel, rootlets, and brick fragments.
2.8	4.9	Colluvium	Sandstone boulders larger than 200 mm, fine to coarse gravel and cobbles of sandstone and siltstone.
4.9	5.9	Residual Soil	Sandy clay, medium plasticity, grey mottled red-brown, with fine to medium sandstone gravel; firm grading to stiff; moist.
5.9	25.0	Wandrawandian Formation	Black to dark grey siltstone, massive to indistinctly laminated; occasional bioturbation and gravel bands.
25.0	60.7	Snapper Point Formation	Quartz-lithic sandstone, fine grained, grey; occasional conglomerate bands up to 0.5m thick, trace shell fragments; alternating between indistinctly laminated and massive.

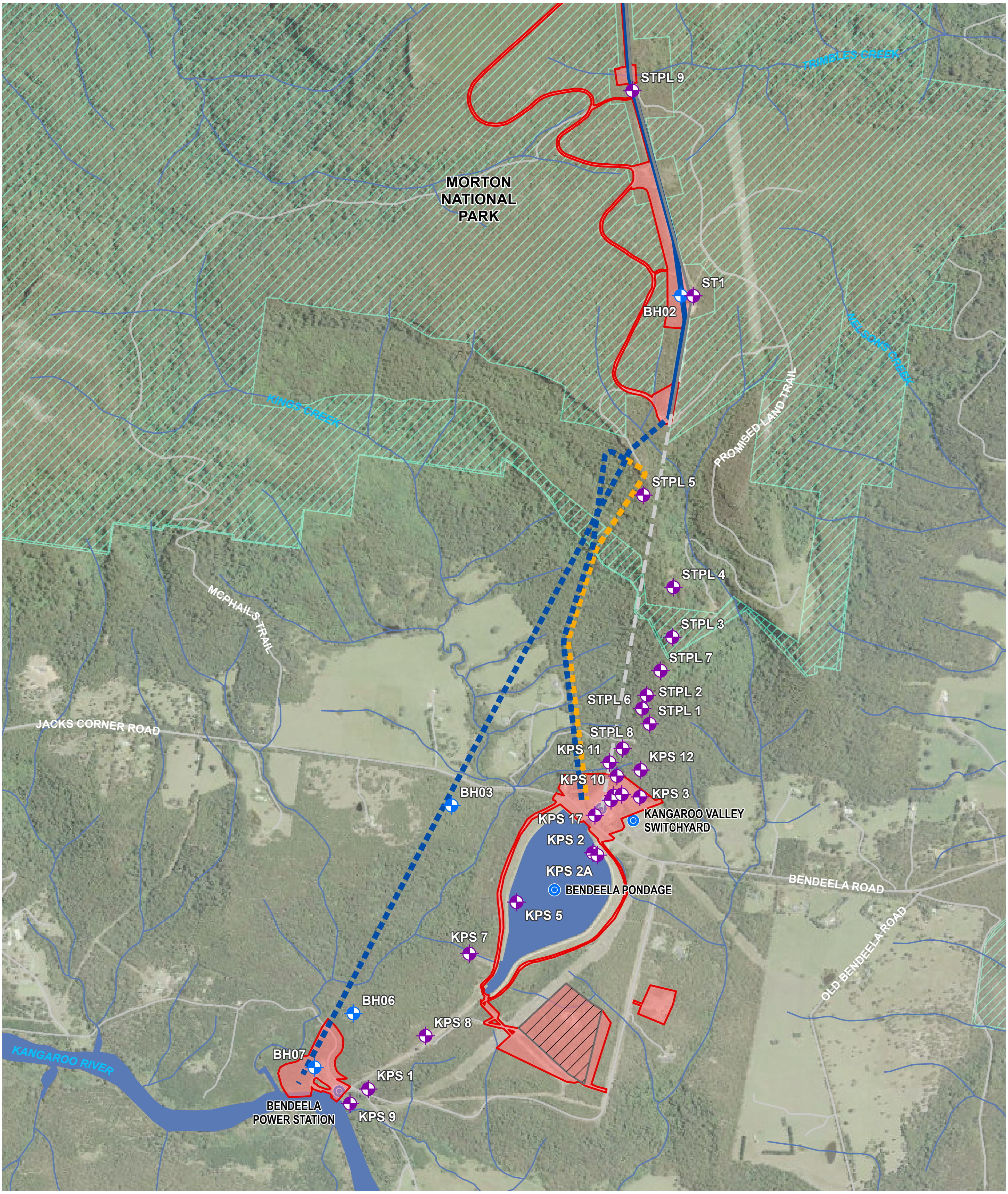
4.6.2 Structural deformation

The Geological and Geotechnical Desktop Review (Jacobs, 2019a) predicted a steeply dipping normal fault, dipping towards south and striking east-west, occurring the vicinity of BH03. This fault was mapped by SMEC and CSIRO (1974) as part of the Kangaroo Power Station tunnel investigations. Although BH03 encountered zones of moderately to highly fractured rock between about 118 m and 213 m depth, there was no definitive single horizon of steeply dipping fault gouge. The results are consistent with drilling through the margins of a wider fault damage zone, with multiple intersections of minor fault splays associated with fractures ranging from sub horizontal bedding shears infilled with clay or gouge, and some steeply dipping joints with no clay infill or gouge.

In-situ stress testing undertaken on BH02, BH03 and BH06 (SCT, 2019), indicates that there is considerable local variation in stress orientation and magnitude at some of the test sites that are interpreted to be the result of local geological faulting and topographic effects (such as valley unloading, valley closure, etc).

4.6.3 Packer testing

Lugeon testing (packer injection testing) was undertaken at selected depths in each borehole. The injection test initially comprised single packer tests completed at intervals as the drill hole advanced. However, as each test required the drill hole to be flushed with clean water to remove drilling fluids and drilling fluid filter cake that had formed on the borehole walls, as well as being time consuming, subsequent water losses during drilling also resulted. Subsequent testing then changed to utilising a straddle packer system once the hole had been drilled to total depth.



Legend

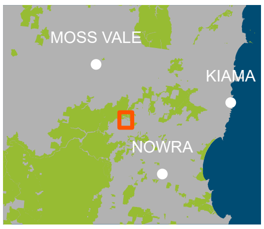
Geotechnical drill holes

- Current
- Historic
- Points of interest
- Existing KV tunnel alignment
- Existing scheme pipeline
- Indicative above ground pipeline
- Indicative tunnel alignment
- Indicative access tunnel
- Disturbance area
- Spoil site
- Waterway
- Road
- NPWS Reserve
- Waterbody

0 0.5 1 km

1:22,500 at A4

GDA2020 MGA Zone 56



Data sources

Jacobs 2022
Department of Planning and Environment 2022
© Department of Customer Service 2020

Figure 4-9 Geotechnical investigation site locations

A total of 47 Lugeon tests were completed over the four drillholes. Full results and analysis for each packer test are provided in Appendix C of the Preliminary Geotechnical Investigations Factual Report (Jacobs, 2019b). Packer testing results for each drillhole are summarized in **Table 4-12** to **Table 4-15**, with a combined summary of test results presented in **Table 4-16**.

Table 4-12 Summary of packer test results for BH02

Packer Setup	Depth (m)		Geological Unit	Maximum flow (L/min)	Hydraulic Conductivity (m/day)
	From	To			
Single	24.4	32.4	Hawkesbury Sandstone	1.3	2.07E-03
Single	54.4	62.4	Hawkesbury Sandstone	0.6	9.50E-04
Single	84.4	92.4	Narrabeen Group	0.5	7.60E-04
Single	90.4	98.4	Illawarra Coal Measures	61.1	1.21E-01
Double	108.4	114.8	Illawarra Coal Measures	51.8	6.31E-02
Single	126.4	134.4	Broughton (Upper)	32.8	4.06E-02
Double	132.4	138.8	Broughton (Upper)	16.2	1.47E-02
Double	156.4	162.8	Broughton (Upper)	0.2	1.10E-04***
Double	180.4	186.8	Broughton (Lower)	77.2	4.92E-02
Double	204.4	210.8	Budgong Sandstone	0.2	1.56E-04
Double	228.4	234.8	Budgong Sandstone	0.5	3.20E-04
Double	255.4	261.8	Budgong Sandstone	0.3	1.12E-04
Double	279.4	285.8	Berry Siltstone	56.4	2.94E-02
Double	327.4	333.8	Berry Siltstone	0.3	1.10E-04***
Double	375.4	381.8	Berry Siltstone	0.3	1.47E-04
Double	423.4	429.8	Berry Siltstone	0.3	1.47E-04
Double	471.4	477.8	Berry Siltstone	90.0*	5.79E-02
Double	504.4	510.8	Nowra Sandstone	120.0*	7.69E-02
Double	531.4	537.8	Wandrawandian Formation	0.6	3.02E-04
Double	558.4	564.8	Wandrawandian Formation	0.8	4.41E-04
Double	582.4	588.8	Wandrawandian Formation	0.8	2.25E-04
Double	609.4	615.8	Snapper Point	0.4	1.10E-04***
Double	633.4	639.8	Snapper Point	47.2	2.76E-02

NOTE: * - Denotes tests where it was not possible to fill the drill string due to apparent high permeability test interval

*** - The lower practical limit of quantification for packer testing with modern equipment is approximately 0.01L or $1.1X10^{-4}$ m/day. Values calculated as lower than this have been substituted with the value of $1.1X10^{-4}$ m/day.

Table 4-13 Summary of packer test results for BH03

Packer Setup	Depth (m) From	To	Geological Unit	Maximum flow (L/min)	Hydraulic Conductivity (m/day)
Single	9.0	17.6	Nowra Sandstone	51.6*	3.46E-01
Single	26.0	36.7	Wandrawandian Formation	43.4	1.04E-01
Single	36.7	45.7	Wandrawandian Formation	50.0	1.38E-01
Double	109.6	116.0	Wandrawandian Formation	60.0*	9.50E-02
Double	127.6	134.0	Wandrawandian Formation	54.4*	7.17E-02
Double	139.6	146.0	Wandrawandian Formation	43.6*	5.53E-02
Double	162.1	168.5	Snapper Point	51.6*	5.96E-02
Double	163.6	170.0	Snapper Point	51.1*	1.10E-04
Double	181.6	188.0	Snapper Point	59.4*	6.83E-02
Double	184.6	191.0	Snapper Point	61.8**	1.04E-01
Double	214.6	221.0	Snapper Point	10.7	1.21E-02
Double	235.6	242.0	Snapper Point	28.0	2.85E-02
Double	238.6	245.0	Snapper Point	82.9	1.12E-01

NOTE: * - denotes tests where it was not possible to fill the drill string due to apparent high permeability test interval
** gas leak noted during rod filling; aborted.

Table 4-14 Summary of packer test results for BH06

Packer Setup	Depth (m) From	To	Geological Unit	Maximum flow (L/min)	Hydraulic Conductivity (m/day)
Double	13.9	20.9	Wandrawandian Formation	0.2	1.12E-04
Double	22.9	29.3	Wandrawandian Formation	51.4*	3.97E-01
Double	40.9	47.3	Snapper Point	Undetectable**	n/a
Double	61.9	68.3	Snapper Point	Undetectable**	n/a
Double	79.9	86.3	Snapper Point	Undetectable**	n/a

NOTE: * - denotes tests where it was not possible to fill the drill string due to apparent high permeability test interval
** - no significant flow: Flow meter tested on surface and found to be in good working order; inferred very tight, low hydraulic conductivity ground conditions

Table 4-15 Summary of packer test results for BH07

Packer Setup	Depth (m) From	Depth (m) To	Geological Unit	Maximum flow (L/min)	Hydraulic Conductivity (m/day)
Single	12.7	21.7	Wandrawandian Formation	60.0*	1.04
Single	16.7	24.7	Wandrawandian Formation	5.7	4.49E-02
Single	24.4	32.4	Snapper Point	57.0	3.72E-01
Single	27.7	36.7	Snapper Point	0.1	2.76E-04
Single	36.7	45.7	Snapper Point	1.6	7.34E-03
Single	51.7	60.7	Snapper Point	1.0	3.80E-03

NOTE: * - denotes tests where it was not possible to fill the drill string due to apparent high permeability test interval

Table 4-16 Shoalhaven hydraulic testing summary

Lithology	Number of tests	Hydraulic Conductivity (m/d)			
		Min	Max	Average	Geometric Mean
Hawkesbury Sandstone	2	0.0010	0.0021	0.0011	0.0015
Narrabeen Group	1	0.0008	0.0008	0.0008	0.0008
Illawarra Coal Measures	2	0.0631	0.1210	0.0579	0.0920
Broughton Formation	4	0.0001	0.0492	0.0491	0.0262
Budgong Sandstone	3	0.0001	0.0294	0.0293	0.0099
Berry Siltstone	5	0.0001	0.0579	0.0578	0.0117
Nowra Sandstone	2	0.0769	0.3456	0.2687	0.2112
Wandrawandian Formation	11	0.0001	1.0368	1.0367	0.1717
Snapper Point	17	0.0001	0.3715	0.3715	0.0534

Hydraulic conductivity depth profiles from the packer testing are provided on **Figure 4-10** and **Figure 4-11** along with summary lithological profiles.

BH02 is located on the plateau, approximately 500m north of the vertical shaft, and penetrates the full geological sequence that the shaft will encounter.

BH03, BH06 and BH07 are located along the tailrace alignment and include packer testing in the Wandrawandian Formation, in which the initial box cut and tunnelling will commence, and in the Snapper Point Formation, through which the bulk of the tailrace tunnel and power station cavern will be excavated. BH03 also include one packer test in the Nowra Sandstone.

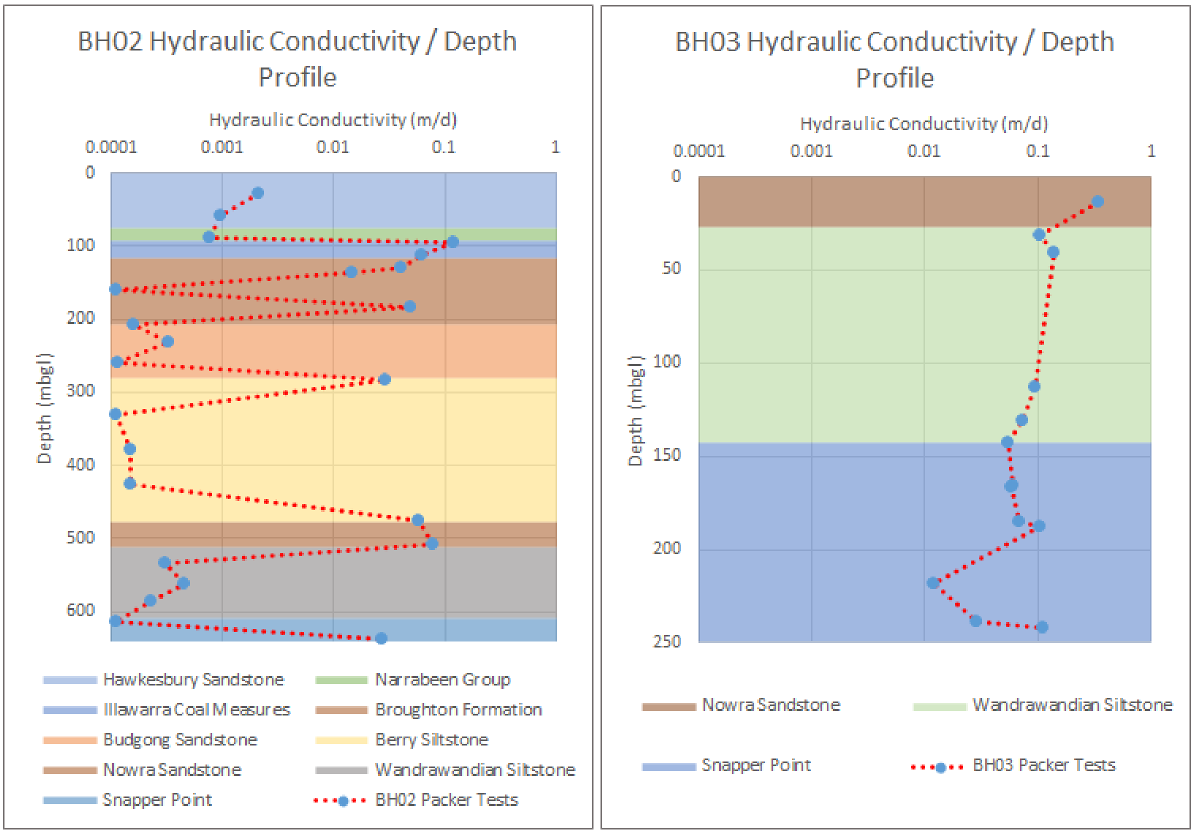


Figure 4-10 BH02 / BH03 - Hydraulic conductivity depth profiles

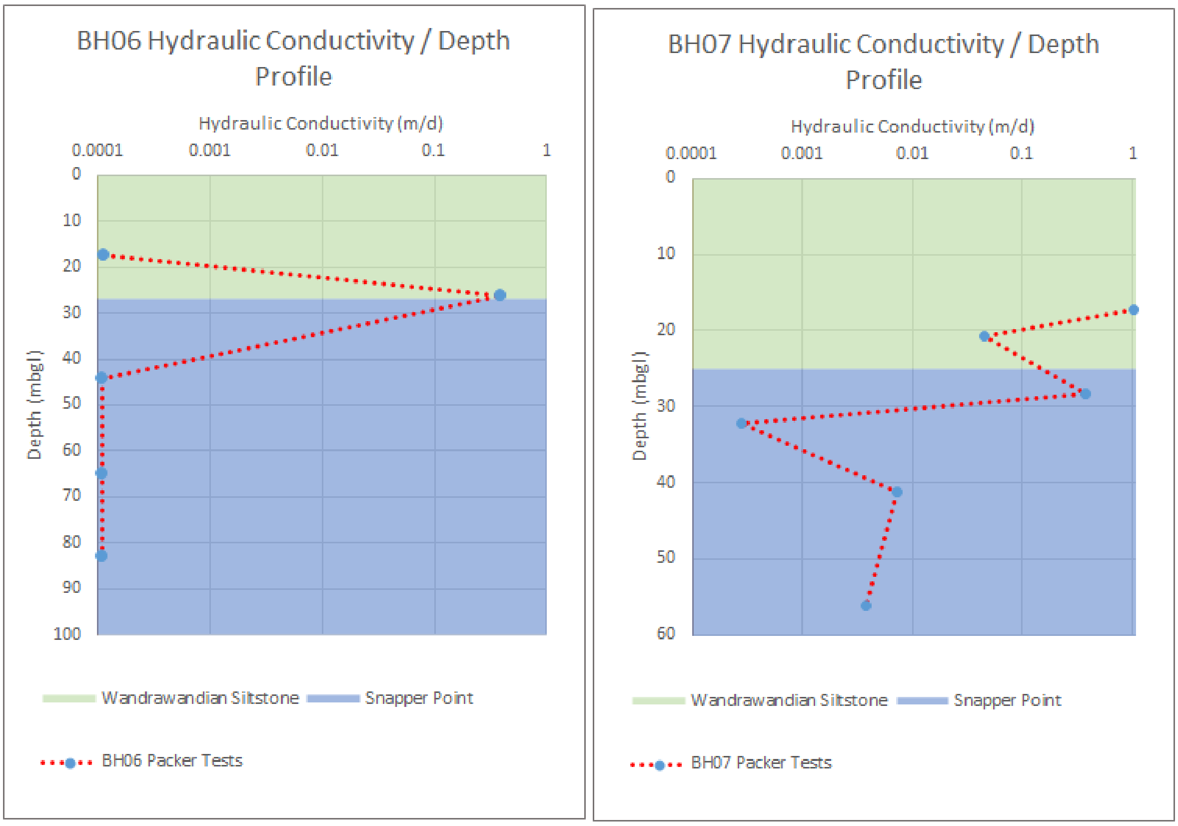


Figure 4-11 BH06 / BH07 - Hydraulic conductivity depth profiles

Below the Narrabeen Group, packer test results from BH02 display two distinct groups of results. One group ranges from approximately 0.0001 to 0.0004 m/day and is considered to be representative of the bulk formation. The second group shows elevated hydraulic conductivity in the range 0.015 to 0.121 m/day. This group is largely associated with lithological contacts and is likely representative of enhanced permeability along bedding planes. Results within the shallower Hawkesbury Sandstone and Narrabeen Group sit between these two permeability groups and are considered to be representative of the elevated bulk hydraulic conductivity in these formations.

Results from BH06 and BH07 broadly follow the same pattern as BH02. At BH06, results were generally low (at or below the lower limit of quantification) with one elevated result (approximately 0.4 m/day) associated with the contact between the Wandrawandian Formation and the Snapper Point Formation. At BH07, results were more evenly distributed (approximately 0.0003 to 1.0 m/day) without such an apparent bi-modal distribution. Results from the upper 30 m, however, are elevated with respect to those below 30 m.

At BH03, a distinctly different hydraulic conductivity depth profile is apparent. All of the packer testing results for BH03 are consistently elevated, ranging from approximately 0.012 to 0.346 m/day. BH03 is located in the vicinity of faulting that has been mapped in the Kangaroo Valley Power Station headrace tunnel. In addition to permeability associated with bedding joints, fault induced fracturing is also considered to be increasing the overall hydraulic conductivity observed at BH03.

With the exception of the shallow results at BH07, no significant variation of hydraulic conductivity with depth is apparent.

4.6.4 Formation porosity

As part of the geotechnical investigations, 81 core samples were subjected to a range of laboratory testing including assessment of porosity. Details of the testing, including laboratory results, are presented in the Preliminary Geotechnical Investigations Factual Report (Jacobs, 2019b) and are summarised by geological unit in **Table 4-17**. As the porosity has been calculated from the bulk and dry density, the results can be considered to be a close approximation of the effective porosity of the formation, while specific yield (drainable porosity) is likely to be somewhat lower. From studies conducted in the Sydney metropolitan area and elsewhere in the Sydney Basin, Tammetta and Hewitt (2004) suggest that a specific yield of between 0.01 and 0.02 (1% to 2%) is reasonable for typical Hawkesbury Sandstone.

Table 4-17 Summary of rock porosity results by geological unit

Geological Unit	Rock Porosity (%)			
	Count	Min.	Max.	Average
Hawkesbury Sandstone	2	17.3	19.2	18.3
Narrabeen Group	2	12.3	14.9	13.6
Illawarra Coal Measures	3	8.1	28.6	19.6
Broughton Formation (Upper)	2	6.6	9.1	7.9
Broughton Formation (Lower)	2	8.3	12.0	10.2
Budgong Sandstone	6	7.9	14.1	10.8
Berry Siltstone	8	2.8	9.2	6.3
Nowra Sandstone	10	7.1	15.1	10.9
Wandrawandian Formation	22	4.0	14.0	6.2
Snapper Point	24	3.5	12.0	8.4

Elevated average porosity is observed in the Illawarra Coal Measures, Hawkesbury Sandstone and Narrabeen Group. Porosity These results are considered to be representative of the nature of the sandstone of the formations, including the Illawarra Coal Measure where two of the three samples were sandstone. Elevated secondary porosity with coal seams is also likely due to fracturing and cleat development.

The lowest average porosities were from the dominantly siltstone formations including the Wandrawandian Formation, Berry Siltstone, Upper Broughton Formation and Snapper Point Formation.

4.6.4.1 Secondary porosity

An assessment of secondary porosity development resulting from open fracturing has been undertaken from the results of the acoustic televiewer (ATV) logging. Details of the ATV logging and other geotechnical investigations are provided in the geotechnical factual report (Jacobs, 2019b).

The ATV survey provides an ultrasound pseudo-3D image of the borehole wall, based on the intensity and travel time of an acoustic pulse; the results can be used to carry out structural logging of the discontinuities and breakouts.

The ATV interpretation provides an assessment of the discontinuities (joints and fractures), including aperture width, and ranks them in the following fracture ranking:

- Major open joint/fracture
- Minor open joint/fracture
- Partially open joint/fracture
- Filled joint/fracture
- Drilling induced fracture.

An assessment of porosity for the various formation has been made by calculating the cumulative aperture widths (void spaces for fracture ranking 1, 2, and 3) in each drill hole. Results are summarised in **Table 4-18**.

Table 4-18 Indicative secondary / fracture porosity

Geological Unit	BH02	BH03	BH06	BH07
Total depth (m)	616.1	212.67	77.45	37.07
Cumulative fracture aperture (m)	1.70	1.75	0.59	0.19
Average / bulk	0.28%	0.82%	0.76%	0.50%
Hawkesbury Sandstone	0.26%	-	-	-
Narrabeen Group	0.44%	-	-	-
Illawarra Coal Measures	0.00%	-	-	-
Broughton Formation	0.03%	-	-	-
Budgong Sandstone	0.07%	-	-	-
Berry Siltstone	0.30%	-	-	-
Nowra Sandstone	0.00%	-	-	-
Wandrawandian Formation	0.94%	0.70%	0.50%	1.43%
Snapper Point	0.05%	0.96%	0.90%	0.44%

The results in **Table 4-18** indicate that the secondary porosity due to fracturing is generally very low compared to the primary porosity presented in **Table 4-17** and as such fracturing is not expected to add significantly to the groundwater storage component of the formations. The fractures would however add to the overall permeability of the formations as, although relatively small, the hydraulic conductivity of an open fracture will be orders of magnitude greater than the surrounding rock mass.

4.6.5 Formation specific storage

It is possible to derive values for specific storage from rock strength data, including Young's Modulus, also known as the modulus of elasticity, and Poisson's Ratio. Young's Modulus is a measure of the stiffness of a solid material, while Poisson's Ratio is a measure of lateral expansion divided by axial compression under load.

Specific storage is determined as the product of rock compressibility and the unit weight of water, where rock compressibility is a function of Poisson's Ratio and Young's Modulus.

Poisson's Ratio and Young's Modulus have been determined from laboratory testing of core samples that were undertaken for the preliminary geotechnical investigations (Jacobs, 2019b). The testing is undertaken on intact core samples and the resultant values of specific storage are of the intact rock mass and do not take into account any fractures or discontinuities. As such, the values derived are indicative of the minimum likely values for the bulk formation.

The determination of specific storage has been undertaken by applying the average values of Poisson's Ratio and Young's Modulus for each lithology type to derive a representative specific storage value for the formation. Results are presented in **Table 4-19**.

Table 4-19 Assessment of specific storage

Geological Unit	No. Samples	Average Youngs Modulus (GPa)	Average Poisson's ratio	Rock Compressibility (LT2/m)	Calculated Specific Storage (m-1)
Broughton Formation (Lower)	2	5.3	0.2	1.64E-07	1.61E-06
Budgong Sandstone	2	23.4	0.4	2.36E-08	2.31E-07
Berry Siltstone	5	17.7	0.5	7.03E-09	6.90E-08
Nowra Sandstone	5	12.4	0.6	8.65E-08	8.48E-07
Wandrawandian Formation	10	13.8	1.6	6.80E-07	6.67E-06
Snapper Point	13	11.6	0.6	9.16E-08	8.98E-07

4.6.6 Groundwater levels

Project specific water level data is available from a standpipe monitoring bore installed in BH07 and from multi-level vibrating wire piezometer (VWP) installations in BH02, BH03 and BH06.

BH07 was completed using 50 mm ND PVC casing, with a 9 m slotted interval from 51.7 m to 60.7 mbgl. The bore annulus was packed over the screened interval using coarse quartz sand from 50.7 m to 60.7 m, followed by a 3 m bentonite plug to 47.7 m. The remaining annulus was grouted back to ground surface. BH07 is screened within the Snapper Point Formation.

A summary of the VWP installation depths are provided in **Table 4-20**.

Table 4-20 Vibrating wire piezometer details

Hole ID	Hole Depth	VWP Installation Depth (m)	VWP Installation RL (mAHD)	Formation
BH02	646.5	105	527	Illawarra Coal Measures
		310	322	Berry Siltstone
		380	252	Berry Siltstone
		450	182	Berry Siltstone
		480	152	Nowra Sandstone
BH03	250	140	37	Wandrawandian Formation
		170	7	Snapper Point
		205	-28	Snapper Point
BH06	90	39	30	Snapper Point
		68	1	Snapper Point
		84	-15	Snapper Point

4.6.6.1 Hydrographs

Groundwater level and piezometric hydrographs are provided on **Figure 4-12** to **Figure 4-15**.

BH07

The hydrograph for BH07 is provided on **Figure 4-12**. Following installation, the water level at BH07 showed a steady decline until a marked increase in January 2020 of almost 3 m. This increase coincides with a significant rainfall event, after which water levels have remained relatively stable at around 56 mAHD (approximately 12 mbgl). Subsequent rainfall events have not resulted in similar increases in water levels. Available stage elevation data for Lake Yarrunga (Kangaroo River at BPS) sourced from Water NSW online database (https://realtimedata.waternsw.com.au/water.stm) are also plotted. The hydrograph shows a close correlation between BH07 and Lake Yarrunga water levels and indicates that water levels -are more strongly influenced by lake water levels than by rainfall infiltration.

BH06

The hydrograph for the BH06 VWP sensors is provided on **Figure 4-13**. Similar to BH07, all three VWP sensors display a general decline in piezometric pressure following installation, with a stepped increase in piezometric pressure following the January 2020 rainfall event. The response is strongest in the deeper sensors and diminishes with decreasing depth. The water levels show a strong correlation to level in Lake Yarrunga, despite BH06’s location approximately 380 m from the lake. The stronger response at depth and diminished response to subsequent rainfall events indicates that similar to BH07, the BH06 groundwater fluctuations are more strongly driven by lake water levels than by rainfall recharge.

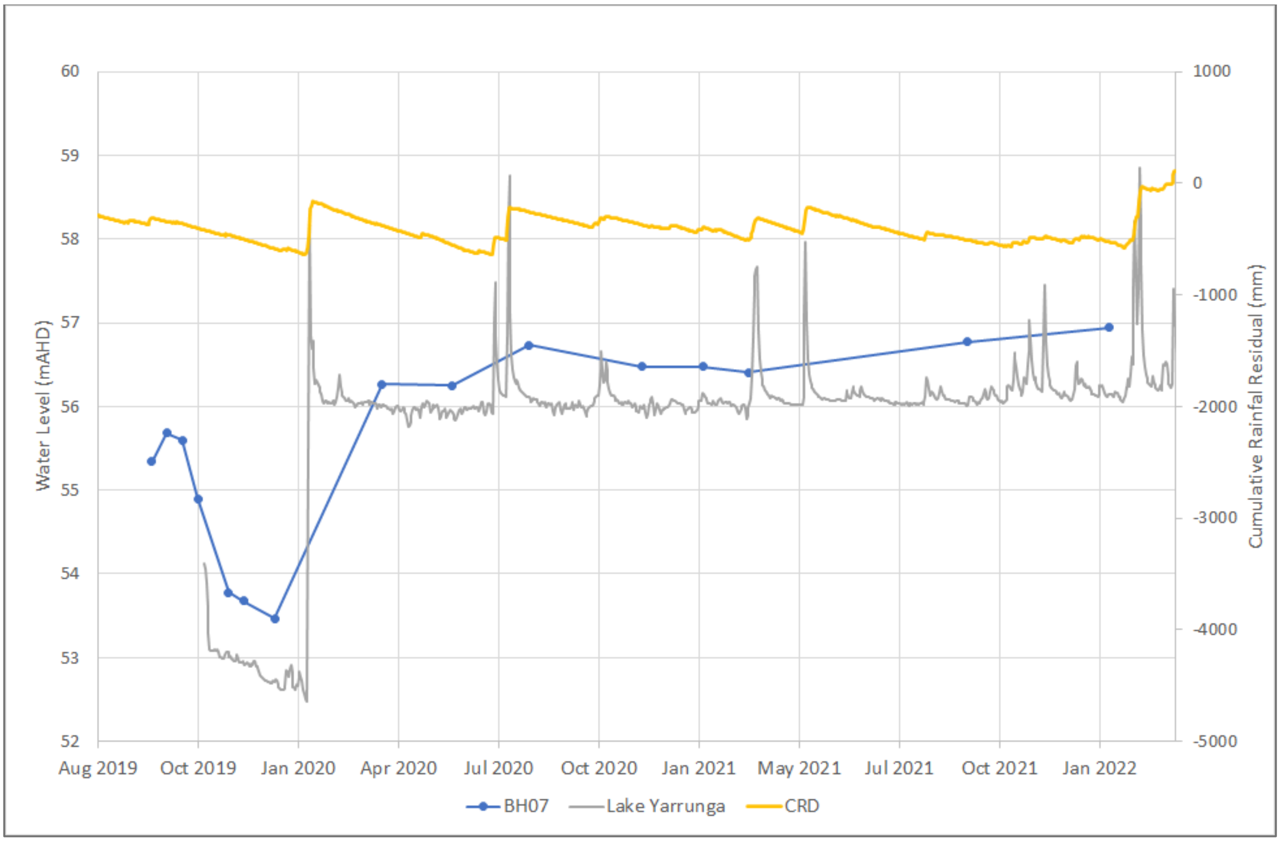


Figure 4-12 BH07 hydrograph

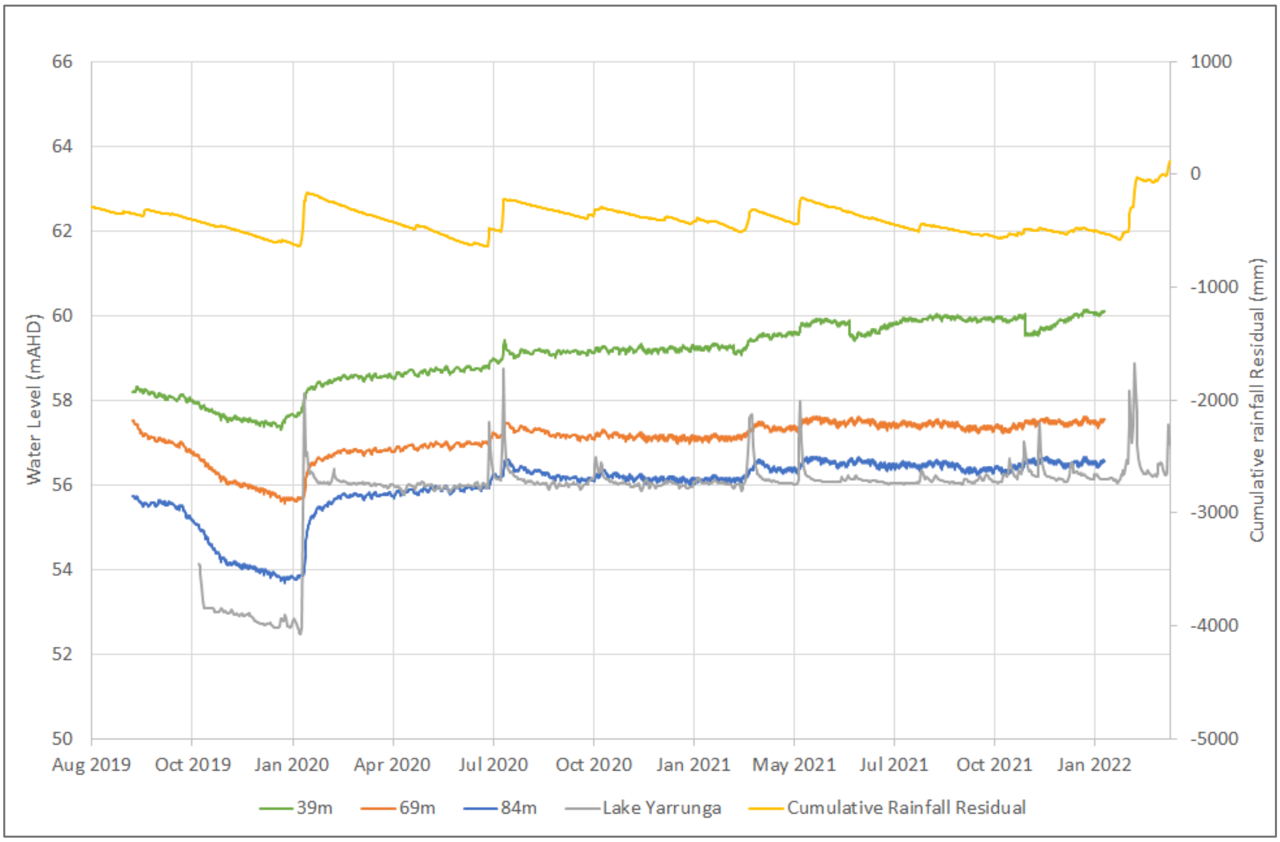


Figure 4-13 BH06 hydrograph

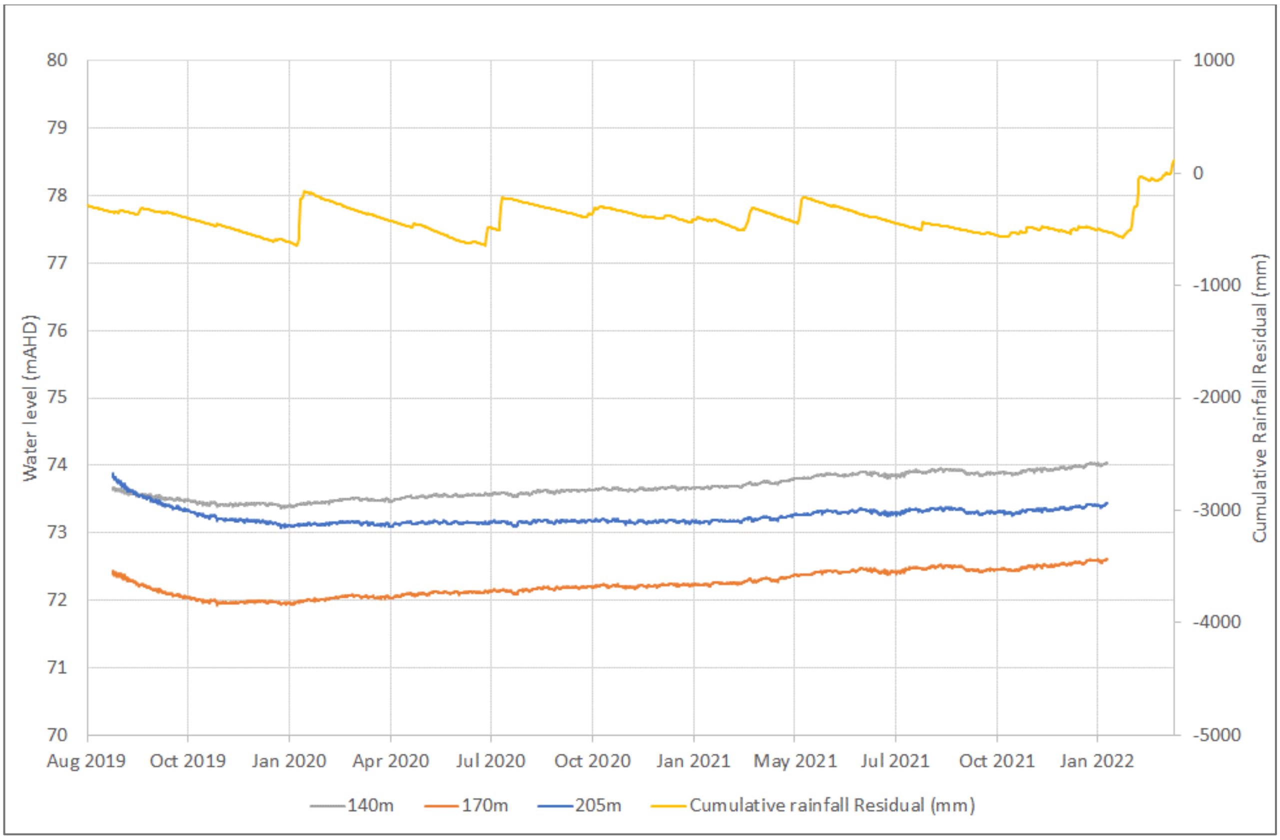


Figure 4-14 BH03 hydrograph

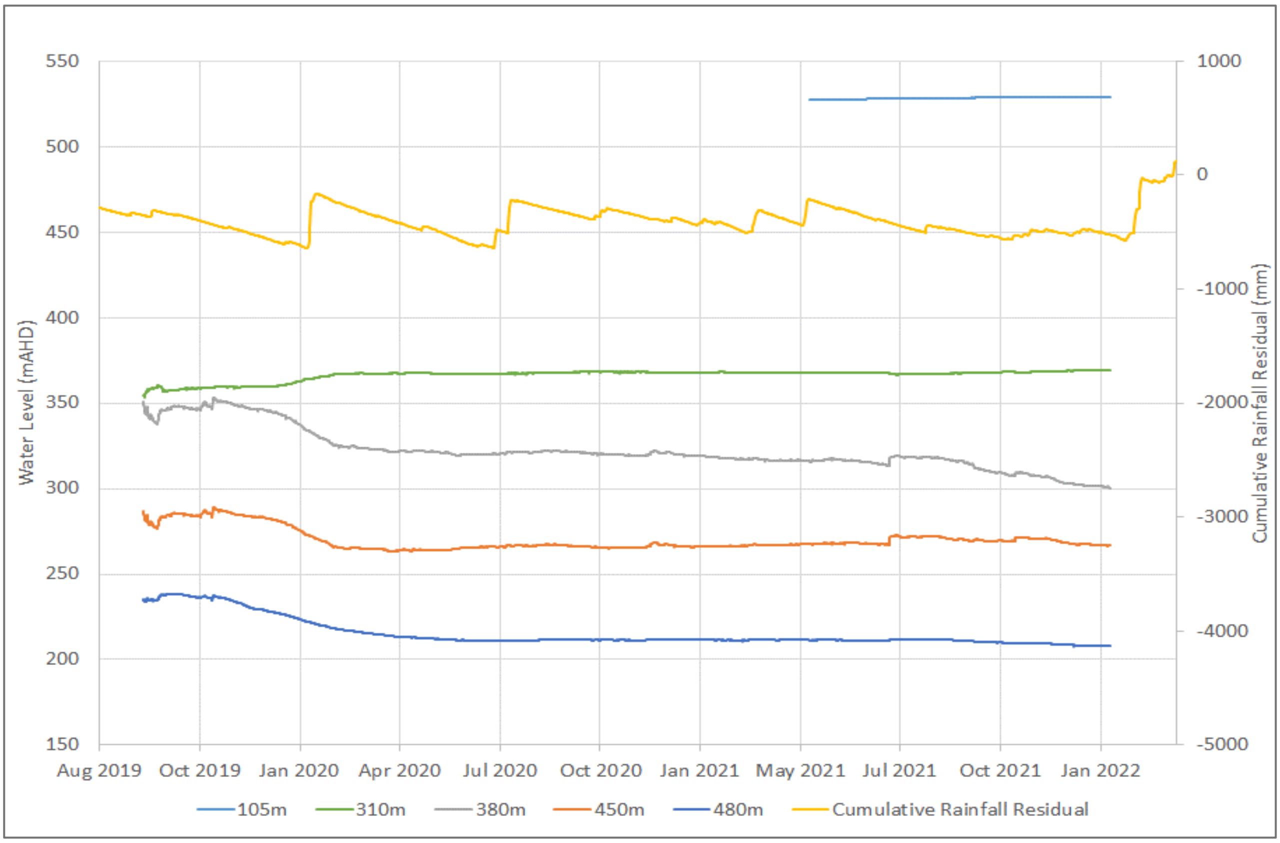


Figure 4-15 BH02 hydrograph

BH03

The hydrograph for the BH03 VWP sensors is provided on **Figure 4-14**. All three VWP sensors generally display a similar trend of early pressure decline transitioning to gradual increase in pressure after January 2020. The trend is broadly similar to that observed at BH06 but significantly muted, and it is noted that the piezometric heads are of the order of 15 m above lake level and BH03 is located over 1350 m from Lake Yarrunga. No significant response is observed to individual rainfall events and the response is, therefore, considered to be a broader scale catchment response to a significant recharge event. BH03 is also located approximately 390 m northwest of Bendeela Pondage.

Some settling in, or equilibration of the grouted VWP to the surrounding formation, is also noted. The 205 m sensor initially displays the greatest head prior to declining and displaying different trend to the 140 m and 170 m sensors. From January 2021 all three sensors display a relatively parallel trend, with the 207 m sensor piezometric head midway between those of the 140 m and 170 m sensors.

BH02

The hydrograph for the BH02 VWP sensors is provided on **Figure 4-15**. The VWP sensors generally show different sets of trends.

The shallowest sensor, at 105 m, located near the base of the Illawarra Coal Measures was unsaturated until May 2021 after which it displays a slow increase in head, similar to the next deepest sensor at 310 m.

Sensors at 380 m and deeper display an initial elevated piezometric pressure with subsequent decline. It is not clear if this is the result of the sensors “settling in” or if it is a lagged response to the early decline observed at BH03.

The 380 m and 450 m sensors show similar fluctuations, including a stepped increase in pressure in July 2021 and subsequent decline in pressure. The rate of decline is greater in the shallower 380 m sensor. The response in the deepest 480m sensor is more subdued, but it also displays a gradual decline from July 2021. This is contrary to the increasing piezometric pressures observed at BH03.

4.6.6.2 Hydrostatic profiles

Hydrostatic profiles for the three VWP installations are presented on **Figure 4-16** and **Figure 4-17**.

The hydrostatic profiles plot the VWP sensor depth (as mbgl) against the piezometric head (m) above the sensor. The profiles provide an indication of vertical hydraulic gradients and the connectedness, or otherwise, between the formations and the VWP sensors. In addition to the hydrostatic profile, the vertical error bars represent the hydrostatic head at each sensor.

In isotropic porous media, there should be a uniform increase in head with depth below the water table, that is, a 1:1 ratio of depth to head. This is shown on the hydrostatic profiles as the indicative hydrostatic lines (Hydrostatic and Hydrostatic 2). These hydrostatic lines are provided for comparison of the slope of the curve plotted by the hydrostatic profiles.

On **Figure 4-16**, the hydrostatic profile for BH03 plots more or less parallel to the hydrostatic line, indicating that the formations, in which the sensors are installed, are hydraulically connected and there is no significant vertical hydraulic gradient apparent. The hydrostatic profile for BH06 is similar but not quite parallel with the hydrostatic line. For BH06 the hydrostatic profile is slightly steeper than the hydrostatic line indicating a slight downwards vertical gradient.

On **Figure 4-17**, the hydrostatic profile for BH02, is considerably different, although notably it is also over a much greater depth range. The hydrostatic profile for BH02 is near vertical indicating a strong downwards vertical gradient. However, it also suggests that the formations, in which the sensors are installed, are not directly hydraulically connected. This would be indicative of a sequence of vertically stacked and separate hydrostratigraphic units. The exception to this may be between the sensors at 380 m and 450 m within the Berry Siltstone. While there is still a strong downwards vertical gradient between these two sensors they may still at least be partially hydraulically connected.

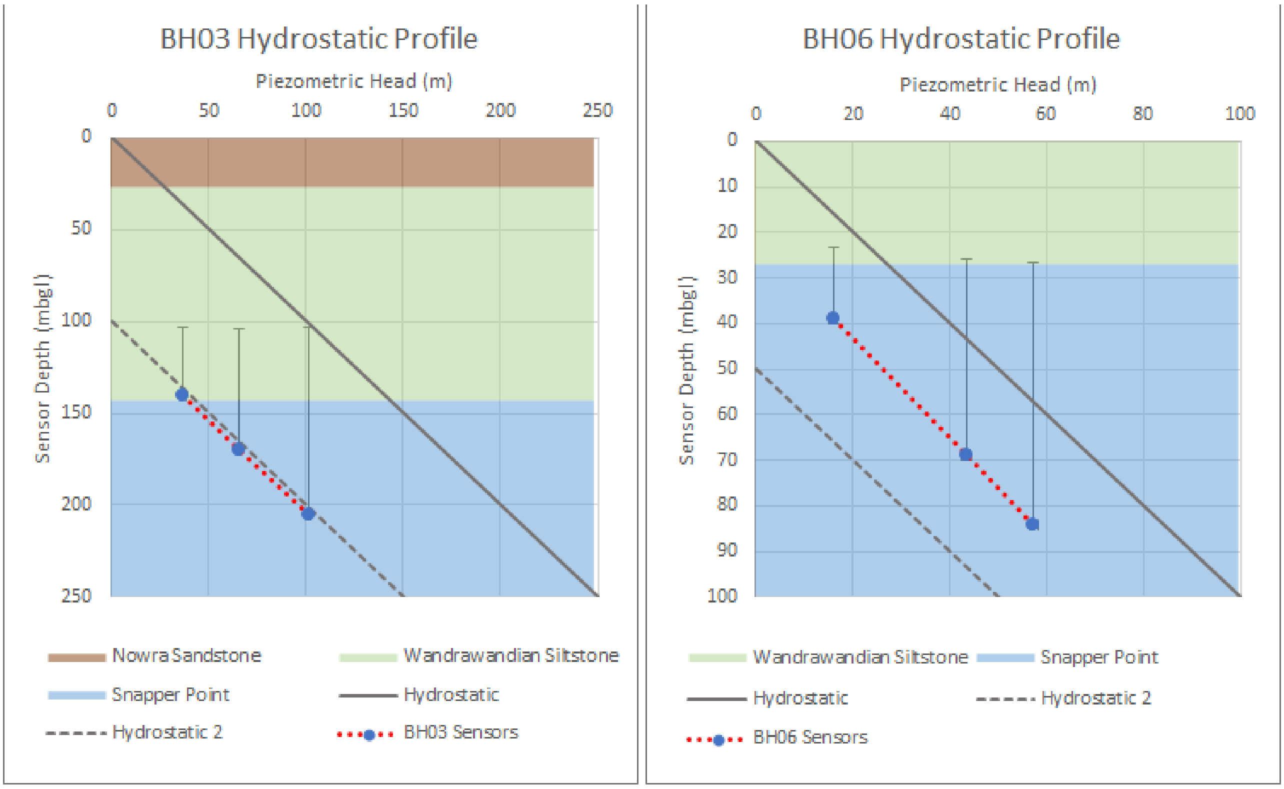


Figure 4-16 BH03 / BH06 hydrostatic profiles

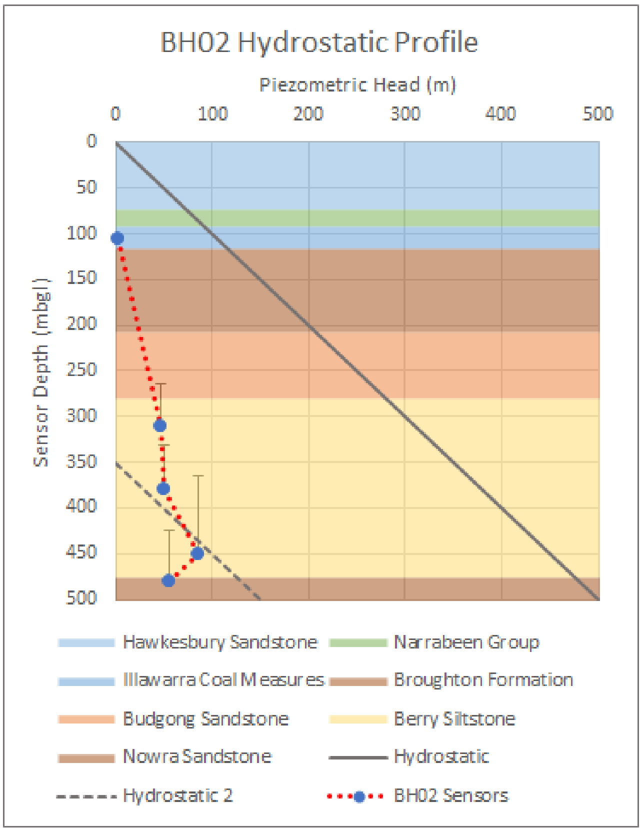


Figure 4-17 BH02 hydrostatic profile

4.6.7 Potential acid forming materials

Potential acid forming (PAF) sediments or rocks are typically formed in reducing environments such as anoxic swamp conditions, deeper marine settings and are also associated with coal measure rocks. The fine grained Permian sedimentary rocks of the Shoalhaven sequence are known to pose a high risk of acid generation (Bridgeman, 2017).

There is a relatively high risk of encountering PAF rock in the Berry Siltstone and the Wandrawandian Formation. This is because these two units were deposited in more anoxic, lower offshore marine environments. The relatively high carbonate content within the Berry Sitstone and possibly also within the Wandrawandian Formation may provide some buffering effect reducing the acid forming potential on oxidation.

The Snapper Point Formation was predominantly deposited within a shallow marine environment, above storm wave base and thus should be largely non-acid forming (NAF). It should be noted that the environment of deposition of the Snapper Point Formation is more variable and according to Tye (1995), there are fourteen depositional environments of which only one depositional environment (facies) reflects a low energy anoxic swamp environment, such as the finer grained more offshore units of the Berry Siltstone and Wandrawadian Formation.

As part of the geotechnical investigations (Jacobs, 2019b), 47 rock core samples were tested for acid-generating potential. The sample intervals were based on a background review of acid rock potential for each of the geological units occurring across the Project area. The review considered the depositional environments of the different geological units, and previous evidence of acid rock on past projects.

Table 4-21 summarises the number of acid rock tests per borehole. The testing methods are based on AMIRA international (2002) Acid Rock Drainage (ARD) test handbook (Smart et al., 2002).

Table 4-21 Summary of geochemical acid rock testing

Geological Unit	Number of Acid Rock Tests				
	BH02	BH03	BH06	BH07	Total
Illawarra Coal measures	4				4
Berry Siltstone	16				16
Nowra Sandstone	1	1			2
Wandrawandian Formation		5	3	5	13
Snapper Point		4	6	2	12

The acid rock test suite included two classification methods for assessing acid generating potential:

- Classification based on Net Acid Generation, pH and Net Acid Producing Potential
- Classification based on Net Acid Producing Potential (based on total sulphur; does not include actual acidity) including acid consuming (neutralising) materials.

Table 4-22 summarises the results per geological unit. Both classification systems show general agreement with respect to the number of PAF samples.

The results show that PAF rock occurs in the Illawarra Coal Measures, Berry Siltstone, Wandrawandian Formation, and Snapper Point Formation. However, over all of the formations tested, the number of samples displaying net acid consuming potential (ACM) exceeded the number of samples with acid forming potential by approximately 60%.

Of the formations not sampled, these being Hawkesbury Sandstone, Narrabeen Group, Broughton Formation and Budgong Sandstone, the depositional environment are generally considered to be inconsistent with deposition of potentially acid forming sediments. These formations are therefore considered to be non-acid forming (NAF).

Table 4-22 Summary of acid rock potential

Geological Unit	Classification 1 (NAG pH)*				Classification 2 (NAPP, total sulphur)*			
	NAF	PAF	UC	UC-NAF	ACM	NAF	PAF	PAF-LC
Illawarra Coal measures	1	3			1		3	
Berry Siltstone	10	6			10		5	1
Nowra Sandstone	1		1		1			1
Wandrawandian Formation	4	5	3	1	6	2	5	
Snapper Point	8	3	1		8		3	1
Total	24	17	4	1	26	2	16	3

* Classification: NAG – Net acid generation, NAF – non-acid forming, PAF – potential acid forming, UC – uncertain, UC-NAF – uncertain to non-acid forming, NAPP – Net acid producing potential, ACM – acid consuming potential, PAF-LC – potentially acid forming, low capacity.

4.7 Regional mining

Groundwater assessments undertaken for nearby Southern Coalfields mining projects include:

- Hume Coal Project – located approximately 28 km to the northwest (EMM, 2017)
- Dendrobium Coal Mine – located approximately 43 km to the northeast (Watershed Hydrogeo, 2022)
- Tahmoor Colliery – located approximately 52 km to the north-northwest (Hydrosimulations, 2018).

Coal mining in the vicinity of the Project targets economic seams within the Illawarra Coal Measures, as such, the available data is only relevant to the upper 120 m of the pressure shaft, beneath the plateau. Key data on formation hydraulic properties is summarised in the following sections.

4.7.1 Hydraulic conductivity

4.7.1.1 Hawkesbury Sandstone

For Hume Coal, EMM (2017) reported a broad range of hydraulic conductivity values ranging several orders of magnitude from 0.0001 m/day to 10 m/day with a typical vertical anisotropy (Kv/Kh) of 0.1. In the calibrated groundwater model, Coffey (2016) adopted values ranging from 0.005 m/day to 0.6 m/day and a broad vertical anisotropy ranging from 0.0017 to 0.2.

Hydrosimulations (2018) noted that hydraulic conductivity within the Hawkesbury Sandstone was generally at least one or two orders of magnitude higher than in the other, deeper units. Calibrated hydraulic conductivity in the groundwater model ranged from 0.04 m/day to 0.18 m/day, with a vertical anisotropy of 0.002 to 0.004.

For Dendrobium, Watershed HydroGeo (2022) reported a mean hydraulic conductivity of 0.014 m/day for the Hawkesbury Sandstone, typically ranging between 0.0001 m/day and 0.1 m/day with some extreme (higher and lower) values. A trend of diminishing hydraulic conductivity with depth was also noted.

4.7.1.2 Narrabeen Group

Coffey (2016) adopted a value of 0.005 m/day to represent the Narrabeen Group and other interburden formations. A vertical anisotropy of 0.2 was also adopted.

Hydrosimulations (2018) adopted calibrated hydraulic conductivity values for various units in the Narrabeen Group ranging from 0.0001 m/day to 0.085 m/day, with a strong vertical anisotropy ranging from 0.0001 to 0.0087.

Watershed HydroGeo (2022) reported a mean hydraulic conductivity for various units in the Narrabeen Group ranging from 0.003 m/day to 0.0165 m/day. A trend of diminishing hydraulic conductivity with depth was also noted.

4.7.1.3 Illawarra Coal Measures

The hydraulic conductivity of the Illawarra Coal Measures is typically higher than the surrounding formations, particularly in coal seams where cleat development enhances hydraulic conductivity. EMM (2017) report measured values of between 0.02 m/day and 0.9 m/day at the Hume Coal Project; however, for the calibrated groundwater model significant lower values of 0.005 m/day to 0.0001 m/day were adopted with a 1:1 vertical isotropy.

Hydrosimulations (2018) noted that at Tahmoor, coal permeability tends to lie between 0.0001 m/day and 0.001 m/day. In the groundwater model calibrated hydraulic conductivity values ranged from 0.0001 m/day to 0.0007 m/day, with vertical anisotropy ranging from 0.0005 to 0.023.

Watershed HydroGeo (2022) reported a mean hydraulic conductivity for various units in the Illawarra Coal Measures ranging from 0.003 m/day to 0.0165 m/day.

4.7.1.4 Shoalhaven Group

Coffey (2016) adopted a value of 0.0001 m/day to represent the Shoalhaven Group at Hume Coal, with a vertical isotropy of 1. At Tahmoor, Hydrosimulations (2018) adopted a calibrated hydraulic conductivity in the groundwater model of 0.0001 m/day with a vertical anisotropy of 0.01, considerably lower than that applied at Hume Coal.

4.7.2 Faults

At Tahmoor, faults have been observed to act as both hydraulic barrier and conduits to groundwater flow, with large hydraulic gradients noted across the Nepean Fault. The Nepean Fault was also found to be more permeable than the surrounding formation with observed water inflows to the mine to be higher than normal at a point where the mine workings intersected the fault zone (Hydrosimulations, 2018). However, the intersection of other faults by mining has not produced notable additional water inflows. Hydrosimulations (2018) reported that most of the faults in the area acted as barriers to flow, possibly due to the presence of gouge or mineralisation within the fault zone.

At Dendrobium, investigations into the Elouera Fault (Watershed HydroGeo, 2022) comprising a broad damaged zone between 8 and 31 m thick, found that permeable zones were discontinuous on a scale of tens of m and the fault does not form a continuous conduit to groundwater flow.

4.7.3 Water quality

Indicative groundwater quality, as total dissolved solids (TDS), of the Hawkesbury Sandstone and Illawarra Coal Measures has been obtained from regional mining studies. Water quality in the Hawkesbury Sandstone is generally relatively good, ranging from 80 mg/L TDS at Dendrobium (Watershed Hydrogeo, 2022) to a median value of approximately 500 mg/L TDS at Tahmoor (Hydrosimulations, 2018) and in the range 350 mg/L to 700 mg/L TDS at Hume Coal (EMM, 2017). Parsons Brinckerhoff (2013) report and average value of for groundwater in the Hawkesbury Sandstone of 380 mg/L TDS at the Camden Gas project.

Water quality of the Illawarra Coal Measures ranged from being similar to that in the Hawkesbury Sandstone to marginally worse. Mine inflows at Dendrobium, were reported to have elevated salinity ranging from 800 µS/cm to 3,000 µS/cm (approximately 500 µS/cm to 1800 mg/L TDS). At Hume Coal, water quality in the Illawarra Coal Measures was comparable with that in the Hawkesbury Sandstone, typically ranging 350 mg/L to 700 mg/L TDS, with a maximum of 1750 mg/L. At the Camden Gas Project water quality of the Illawarra Coal Measures was significantly worse, with an average TDS of 11,000 mg/L and a range of 3,200-27,500 mg/L.

5. Hydrogeological conceptual model

5.1 Groundwater occurrence

Based on the available information, the Project area can be classified into two key hydrogeological systems. Beneath the elevated plateau, there is a highly stratified groundwater system comprising numerous discrete and stacked, and poorly connected groundwater systems. There is insufficient data to determine whether there is continuous saturation beneath the upper water table, or if unsaturated zones and multiple phreatic surfaces exist, such as immediately below significant siltstone/mudstone horizons. This is undoubtedly the case in proximity to the escarpment, where seepage faces will result in localised drainage and phreatic surfaces, but is unknown away from the influence of the seepage faces.

Notwithstanding, in the event that there is continuous saturation, this would be the result of a catchment scale response time over millennia and for the purposes of the relatively short Project construction phase the system would act as a series of discrete and disconnected groundwater systems, with the maximum head at any one point of the vertical shaft, headrace tunnel of cavern equivalent to that of the nearest equivalent depth VWP. In addition to the partial saturation of the uppermost VWP sensor at BH02, there is also likely to be a shallower perched aquifer (or number of perched aquifers) in the weathering profile of the Hawkesbury Sandstone.

Beneath the lower lying areas, the available data are indicative of continuous saturation beneath the water table and more hydraulically connected formations, at least insofar as the depth of the current investigations and the Project development. Perched aquifers are also likely in the upper weathered horizons of the Nowra Sandstone and Wandrawandian Formation.

5.2 Groundwater recharge and discharge

Direct rainfall recharge is likely to occur to outcropping and sub-cropping formations of the uppermost geological unit on the elevated plateau area and on the lower lying area below the plateau. Enhanced recharge from rainfall and runoff is likely due to colluvial accumulations at the base of the escarpment.

A small component of vertical infiltration through the geological sequence is also possible.

Recharge estimates to Hawkesbury Sandstone from regional studies range from 1.4% to 6.5% of long-term average annual rainfall (Hydrosimulations, 2018). Recharge rates for finer grained formations, will likely be lower.

Discharge for formations exposed in the escarpment (Hawkesbury Sandstone to Berry Siltstone) will be via seepage faces along the escarpment outcrop. For deeper formations (Wandrawandian Formation and Snapper Point Formation) discharge will be to the regional drainages, and locally to Kangaroo River/Lake Yarrunga.

5.3 Groundwater levels and flow

Interpreted groundwater levels and flow directions in the vicinity of the Project are shown in plan view on **Figure 5-1** and in section view on **Figure 5-2**.

Groundwater flow in the Project area will be significantly influenced by topography. Beneath the plateau, and for areas above approximately 250 mAHD, groundwater flow direction is expected to be generally towards the seepage faces along the escarpments. Beneath approximately 250 mAHD groundwater flow will still be influenced by topography but less influenced by the escarpment seepage faces. Groundwater flow will be more influenced by regional drainages such as Kangaroo River. In the vicinity of the Project this is generally inferred to be to the south-southwest.

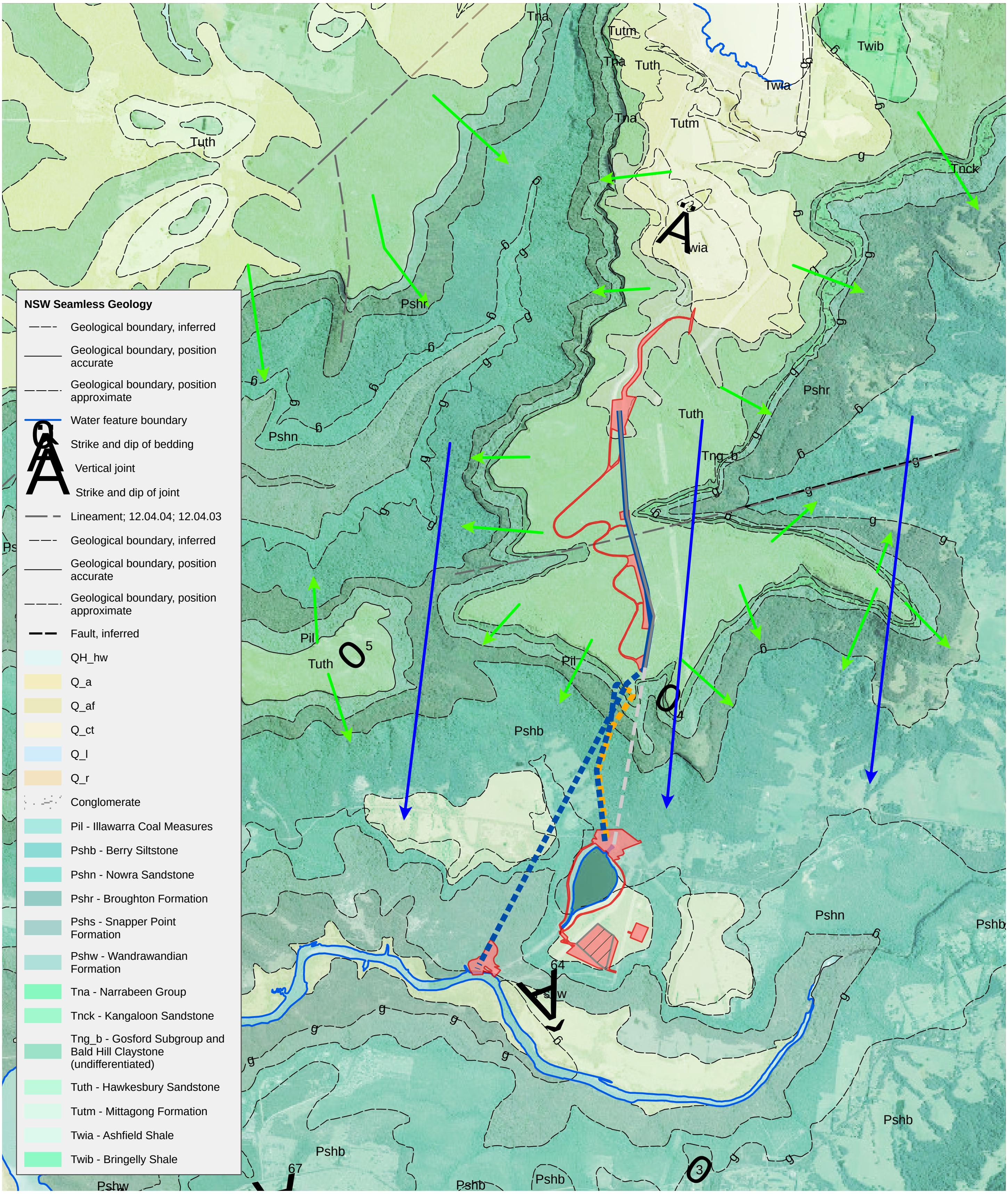
Water levels observed at BH03, BH06 and BH07 (**Figure 5-2**) indicate a fairly uniform hydraulic gradient of approximately 0.014 m/m towards Lake Yarrunga.

The lowest VWP sensor installed in BH02, at the contact between the Berry Siltstone and Nowra Sandstone, has a pore water pressure of approximately 56 m head, despite being approximately 480 mbgl. While there is currently no water level data for the Wandrawndian Siltstone and Snapper Point Formation in the vicinity of the power station cavern, there is also no reason to assume that the stratified nature of the groundwater system does not continue through these formations. However, for the purposes of this assessment, it is assumed that at the location of the power station cavern, the Wandrawandian and Snapper Point Formations are fully saturated. This would equate to a head of approximately 145 m above the lowest invert of the power station. Extrapolation of the hydraulic gradient from BH07 to BH03 would indicate groundwater levels at the power station of the order of 120 m above invert, so this is considered to be a conservative assumption.

The influence of the faults on water levels is not known. There is potential that, despite presenting as a zone of increased hydraulic conductivity, the major faults may also act as barriers to groundwater flow in the fault planes. This may result in stepped change in water levels across the faults as indicated on **Figure 5-2**.

Table 5-1 Project water levels

Project Element	Indicative head above invert (m)	Comment
Box Cut	Approx. 13 m to 14m	Based on water levels at Lake Yarrunga and BH07.
Tail Race - outlet structure to fault zone	13 m to 80 m	Approx. 13 m below BH07 water level at outlet structure to 80 m below BH03 water level.
Tailrace fault zone	Approx. 95 m	80 m to 85 m below BH03 water level, potential step change across fault.
Tailrace - fault zone to cavern	Approx. 110 m to 150 m	Based on similar hydraulic gradient to lower section and full saturation of the Wandrawandian and Snapper Point Formations at power station.
power station cavern	Approx. 145 m	Based on full saturation of the Wandrawandian and Snapper Point Formations beneath Nowra Sandstone.
Surge shaft	Approx. 135 m	Based on full saturation of the Wandrawandian and Snapper Point Formations beneath Nowra Sandstone.
Access tunnel	Variable up to 120 m	Maximum heads approaching the power station cavern. Variable heads in stratified groundwater system above the Wandrawandian Formation.
Ventilation tunnel	Variable up to 110 m	Maximum heads approaching the power station cavern. Variable heads in stratified groundwater system above the Wandrawandian Formation.
Headrace tunnel	120 m to 135 m	Based on full saturation of the Wandrawandian and Snapper Point Formations beneath Nowra Sandstone.
Vertical shaft	Variable up to 110 m	Based on full saturation of the Wandrawandian and Snapper Point Formations beneath Nowra Sandstone and variable pore pressure above Nowra Sandstone as indicated by BH02. The average head excluding the uppermost sensor is approximately 70 m.



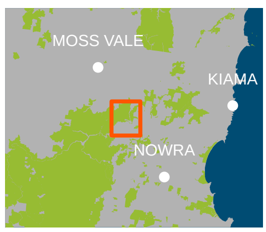
Legend

Upper stacked groundwater system
Lower regional groundwater system
Existing KV tunnel alignment
Existing scheme pipeline
Indicative above ground pipeline
Indicative tunnel alignment
Indicative access tunnel
Project area
Spoil site

0 1 2 km

1:50,000 at A4

GDA2020 MGA Zone 56



Data sources

Jacobs 2022
Department of Planning and Environment 2022
© Department of Customer Service 2020

Figure 5-1 Groundwater flow directions

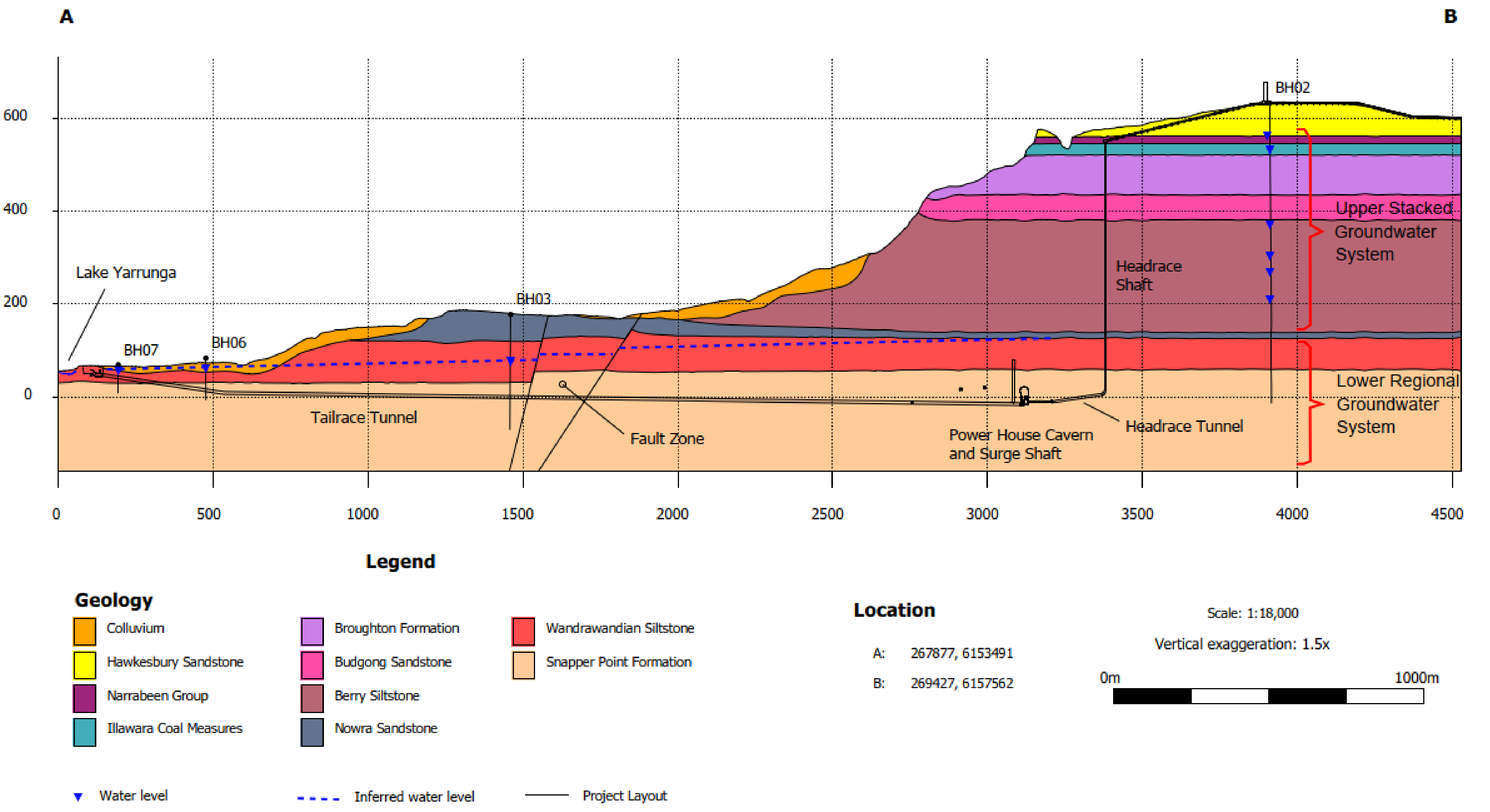


Figure 5-2 Inferred groundwater elevations

5.4 Groundwater quality

Groundwater quality for the Project is expected to range from relatively fresh through to brackish.

SMEC (1972) showed that shallow groundwater in the vicinity of the Kangaroo Valley Power Station was of the order of 420 mg/L to 500 mg/L TDS. Water quality is anticipated to reduce with depth, however, for the deeper tunnelling and cavern depths there is currently no water quality data available.

Beneath the plateau, water quality within the Hawkesbury Sandstone is expected to be good and commensurate with regional water quality for the formation, typically less than 500 mg/L TDS. Groundwater quality is also likely to deteriorate with depth beneath the plateau, however, the proximity to the escarpments is expected to have a beneficial effect on water quality, with enhanced recharge and discharge processes and reduced residency time. Where regionally the Illawarra Coal Measure are known to have highly variable and degraded water quality, given the proximity and exposure in the escarpments in the vicinity of the Project, water quality is not anticipated to deteriorate below approximately 1500 mg/L to 1800 mg/L. Deeper formations beneath the plateau area, that are not subject to recent recharge and discharge processes, may have groundwater of a more deteriorated quality.

The presence of PAF materials has potential to further degrade water quality and groundwater inflows to excavations. However, the rapid application of primary support (shotcrete) will reduce the potential for oxidation and acid formation and subsequent acid leachate.

It is noted that all groundwater seepage to excavations will be managed by appropriate collection, treatment and disposal to prevent contamination of the environment and meet with relevant discharge criteria.

5.5 Groundwater – surface water interaction

Other than infiltration of rainfall recharge, key groundwater – surface water interactions in the vicinity of the Project are expected to be as follows.

5.5.1 Escarpment seepage faces

Groundwater seepage is expected along the contact surfaces of low permeability siltstones and mudstones that outcrop on the escarpment and lower slopes. Seepages are expected to be of low volume but are likely to support localised ecological communities including hanging swamps. The Project is not anticipated to change this interaction.

Baseflow to drainage lines

Minor groundwater seepage is likely to provide a component of baseflow to drainages such as Kings Creek and the un-named drainage line east of Bendeela Pondage, on the lower slopes of the escarpment and within the lower Project area. As with the escarpment seepage faces, seepage is expected to be along the contact surfaces of low permeability siltstones and mudstones that outcrop in the drainage lines. The Surface Water, Hydrology and Geomorphology specialist report describes Kings Creek, above the influence of Lake Yarrunga, as comprising a sequence of interconnected pools and riffles. Field observations during a site visit conducted on the 19^{th} and 20^{th} February 2019 noted very little flow in Kings Creek. January and February 2019 recorded below average rainfall with less than half of the long-term average rainfall falling in January 2019 and only approximately 17% of the long-term average rainfall falling in February 2019. The low flow suggests that these small drainages are more reliant on catchment interflow than on groundwater seepage, although ongoing groundwater seepage may be the source of the small flows observed.

As the seepage is inferred to be along the contact surfaces of low permeability siltstones and mudstones, the Project is not anticipated to change this interaction.

Baseflow to Lake Yarrunga/Kangaroo Creek

Kangaroo River and Lake Yarrunga are inferred to be a major regional point of discharge for groundwater.

As indicated by the hydrograph for monitoring bore BH07 (**Figure 4-12**), there is also a component of groundwater recharge that occurs associated with high lake water levels. This is likely to be a bank storage effect where high lake levels result in short term recharge to groundwater, but where the overall net flow is groundwater discharge to the lake.

Excavation of the tailrace box-cut adjacent to Lake Yarrunga is expected to induce a component of leakage from the lake, including the lower reaches of Kings Creek that are influenced by the lake. However, as the lake is effectively acting as a constant head boundary, there will be no measurable effect on lake water levels.

Seepage from Bendeela Pondage

Shallow groundwater monitoring in the embankment of Bendeela Pondage (**Section 4.5.2**) indicates that seepage is occurring and resulting in localised groundwater mounding. Given the low vertical hydraulic conductivity, deep recharge from the mounding is not anticipated and the mounding is likely to dissipate laterally, possibly contributing to seepage to Kings Creek and the un-named tributary to the east of the Pondage. However, the possibility for enhanced permeability along the BH03 fault zone and deeper infiltration is also noted.

5.6 Representative hydraulic conductivity

A statistical summary of formation hydraulic conductivity values is provided in **Table 5-2**. Representative hydraulic conductivity values are discussed for respective Project elements.

Table 5-2 Hydraulic conductivity statistical summary

Geological unit	Depth range (m)	Average hydraulic conductivity (m/day)	Geometric mean hydraulic conductivity (m/day)
Hawkesbury Sandstone	All	0.0845	0.0292
Narrabeen Group	All	0.0014	0.0013
Illawarra Coal Measures	All	0.1486	0.0605
Broughton Formation	All	0.0262	0.0033
Budgong Sandstone	All	0.0002	0.0002
Berry Formation	0-200	0.0366	0.0024
Berry Formation	>200	0.0194	0.0011
Nowra Sandstone	All	0.0302	0.0007
Wandrawandian Formation	0-200	0.0698	0.0108
Wandrawandian Formation	>200	0.0003	0.0003
Snapper Point	All	0.0533	0.0074

5.6.1 Shotcrete and concrete linings

Following rock bolting and injection grouting (if required), primary support of tunnels and excavation will be completed by the application of shotcrete. Shotcrete permeability is typically very low and of the order of 1×10^{-4} to $1\text{x}10^{-6}$ m/day. Permeability can vary depending on the application (dry mix vs wet mix) and composition. Very low permeability values can be managed by the addition of silica fume (mircosilica) to reduce porosity and permeability, and increase strength and durability, and also from the inclusion of fibre (fibre reinforced shotcrete). Micro fibres (< 0.3mm diameter) help to reduce shrinkage cracking, while macro fibres (>0.3 mm diameter) are considered to be structural fibres and help prevent cracking and crack propagation. The application of shotcrete as primary support can therefore provide an effective low permeability barrier to groundwater seepage.

Permanent concrete liners provide an even more effective low permeability barrier. Greater thickness and more uniform and consistent application results in a barrier that is effectively impermeable as far as groundwater seepage and interactions are concerned.

For the purposes of groundwater assessment, a conservative hydraulic conductivity value of 1×10^{-4} m/day (0.0001 m/day) has been adopted for tunnels and caverns following primary support application. This is only marginally lower than the lowest representative formation hydraulic conductivity of 2×10^{-4} m/day for the Budgong Sandstone.

It is assumed that groundwater seepage through full concrete liners is negligible and as such, is not assessed.

5.6.2 Pressure shaft

Packer testing completed at BH02 and ST1 are considered to be representative for the location of the vertical pressure shaft.

For the Hawkesbury Sandstone the geometric mean hydraulic conductivity value from both BH02 and ST1 is 0.029 m/day.

Below the Hawkesbury Sandstone, the bi-modal hydraulic conductivity values apparent at BH02 (**Figure 4-10**) are considered to provide a reasonable representation of both the primary formation hydraulic conductivity and the secondary bedding plane/fracture hydraulic conductivity for these formations.

The geometric mean of BH02 data below the Hawkesbury Sandstone is considered to be representative for the assessment of uncontrolled inflows applicable to the pilot hole and raise bore drilling, and for the down reamed shaft. The geometric mean hydraulic conductivity from BH02 below the Hawkesbury Sandstone is approximately 0.002 m/day.

Assuming that fracture treatment (grouting) is undertaken as excavation progresses, then only the lower hydraulic conductivity group, representative of primary permeability, would apply. The geometric mean of the inferred primary hydraulic conductivity ground for BH02 is approximately 0.0002 m/day and would be further reduced to approximately 0.0001 m/day following the application of primary support as the shaft is advanced.

5.6.3 Headrace, cavern and tailrace (excluding fault zone)

The headrace tunnel and caverns are entirely excavated within the Snapper Point Formation with upper 20 m of the surge chamber excavated into the overlying Wandrawandian Formation. The tailrace tunnel is excavated within the Snapper Point Formation and Wandrawandian Formation. The geometric mean hydraulic conductivity values for these formations are as follows:

- Wandrawandian Formation, 0 to 200m – 0.0108 m/day
- Wandrawandian Formation, below 200m – 0.0003 m/day
- Snapper Point Fm. – 0.0074 m/day.

Both the Wandrawandian and Snapper Point Formations appear to show a bimodal hydraulic conductivity, with the geometric mean of all data for the Wandrawandian Formation similar to that of the Snapper Point Formation (0.008 m/day).

Following ground improvement and primary support application, the representative hydraulic conductivity for post control groundwater inflow to the headrace and tailrace tunnels would be similar to the pressure shaft at 0.0002 m/day for improved ground and 0.0001 m/day after application of primary support.

The power station cavern will be a drained structure, with strip drains placed behind the shotcrete lining to reduce the build-up of water pressure, as such the representative hydraulic conductivity will be between the primary formation hydraulic conductivity (0.0003 m/day) and the shotcrete hydraulic conductivity (0.0001 m/day). A value of 0.0002 m/day has, therefore, been adopted for the drained structures.

5.6.4 Tailrace – fault zone

Elevated hydraulic conductivity values at BH03 and KPS2A are considered to be representative for the assessment of uncontrolled inflows to excavations through the BH03 fault zone. The geometric mean hydraulic conductivity of all data from BH03 and is approximately 0.044 m/day.

Testing data for BH03 indicate that the elevated hydraulic conductivity values are consistent throughout the depth of the hole and are associated with significantly elevated frequency of open fracturing. BH03 has an average of 1.4 open fractures per metre compared to BH02, BH06 and BH07 with an average of 0.12 to 0.2 open fractures per metre (Jacobs, 2019b).

Following ground improvement and primary support application, the representative hydraulic conductivity for post control groundwater inflow to the tailrace tunnel in the fault zone would be similar to that in un-faulted ground at 0.0002 m/day for improved ground and 0.0001 m/day after application of primary support.

5.6.5 Access tunnel and ventilation and egress tunnel

The access tunnel and ventilation and egress tunnel commence excavation at surface in the Berry Formation before proceeding through Nowra Sandstone and Wandrawandian Formation, ending in Snapper Point formation at the main cavern.

Auxiliary adits will also be excavated to provide access to the top of the surge shaft (for top-down excavation) and to bypass the main caverns to allow excavation of the headrace tunnel.

The first 200 m to 300 m of the access tunnel and ventilation and egress tunnel declines are also likely to intersect the BH03 fault zone at relatively shallow depths, and may be subject to elevated hydraulic conductivity.

Within the fault zone, hydraulic conductivity is likely to be significantly elevated. Shallow hydraulic conductivity values (>50m) at BH03 have a geometric mean of 0.17 m/day. It is noted, however, that previous testing in the area does not indicate particularly elevated hydraulic conductivity values.

The access tunnel and ventilation and egress tunnel will be drained structures, with strip drains placed behind the shotcrete lining to reduce the build-up of water pressure, as such the representative hydraulic conductivity will be between the primary formation hydraulic conductivity and the shotcrete hydraulic conductivity. A value of 0.00015 m/day has therefore been adopted for the drained structures.

5.6.6 Tailrace box-cut

For the box-cut adjacent to Lake Yarrunga, hydraulic conductivity data from BH07 and nearby KPS1 are considered to be representative. Both bores indicate a trend of decreasing hydraulic conductivity with depth, with the trend more defined at BH07.

Geometric mean hydraulic conductivity by depth are as follows:

- 0 to 30m – 0.173 m/day
- below 30m – 0.011 m/day.

It is anticipated that the excavation sides will be battered and without primary support, other than in the vicinity of the tailrace outlet structure.

5.6.7 Vertical hydraulic conductivity

Vertical hydraulic conductivity for the Project has not been measured, however the highly stratified system, as indicated at BH02, is indicative of a strong vertical anisotropy that is likely controlled by massive (unfractured) fine grained siltstone and mudstone units.

For regional mining studies in the Hawkesbury Sandstone, Narrabeen Group and Illawarra Coal Measures (**Section 4.7**), vertical hydraulic conductivity values are typically one to three orders of magnitude lower than horizontal hydraulic conductivity. The following Kv:Kh anisotropies are considered to be representative, and conservative for the purposes of groundwater assessment:

- For the bulk of the alignment including vertical shaft, caverns and tunnels with a depth of cover greater than 200m – Kv/Kh = 0.01
- For tunnels and excavations with a depth of cover less than 200m – Kv/Kh = 0.1
- For the BH03 fault zone - Kv/Kh = 1.

However, it is noted that within the fault zone there was still a distinct separation of shallow water levels in the vicinity if the Kangaroo Valley Power Station and Bendeela Pondage and those observed in BH03.

6. Indicative Construction schedule

The indicative construction schedule is summarised in **Table 6-1** for key Project tunnels and excavations. The schedule is considered indicative only and is provided for assessing total potential groundwater take from concurrent work fronts and for input into the Project water balance (refer to the Surface Water, Hydrology and Geomorphology specialist report).

Excavation activities will likely commence with the box-cut for the tailrace inlet / outlet structure followed by commencement of the tailrace tunnelling. The box-cut excavation is anticipated to be completed over approximately two months; however, the excavation will require dewatering until removal of the rock plug prior to commissioning, an anticipated duration of approximately 48 months.

Tunnelling for the ventilation and egress, access, and tailrace tunnels will then commence, with the main tunnelling work completed at end of construction month 18. For all tunnelling works, primary support comprising rock bolting and shotcrete application is expected to follow behind the excavation front. The assumed rate of advance for the purposes of this assessment is of the order of 3 m/day to 4 m/day (100 m/month).

The tailrace tunnel is anticipated to be excavated concurrently on two work fronts with a total duration of approximately 21 months. Final concrete lining of the tailrace tunnel is assumed to lag behind excavation and primary support by approximately 18 months.

Access and bypass adits in and around the power station cavern area, including the headrace tunnel are anticipated to be excavated during months 16 to 30. Lining of the headrace tunnel is assumed to lag approximately six months behind excavation and primary support.

Excavation of the power station cavern is expected to commence around month 20 or 21, with an anticipated duration of nine months.

Excavation of the headrace shaft would commence following completion of the headrace tunnel, with an anticipated duration of approximately six months. For the purposes of this assessment the durations of the different phases are estimated as follows:

- Pilot hole drilling – two weeks
- Raise boring – six weeks
- Down-reaming – four months.

The steel lining and grouting of the headrace shaft is expected to lag behind the down-reaming by approximately five to eight months.

The surge chamber excavation is expected to commence at the end of month 30, with an anticipated duration of six months. Concrete lining will commence following completion of excavation.

Table 6-1 Indicative construction schedule for key tunnelling and excavation components

Project element	Total Duration (months)	Construction Month															
		1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36	37-39	40-42	43-45	46-48
Tunnels and excavations - primary support																	
Lower intake	48	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Ventilation and egress tunnel	14		■	■	■	■	■										
Access tunnel	19		■	■	■	■	■	■	■								
Tailrace tunnel - Workfront 1	21			■	■	■	■	■	■	■	■						
Tailrace tunnel - Workfront 2	12						■	■	■	■	■						
Power station adit	3						■	■									
Headrace shaft adit	3							■	■								
Headrace tunnel	1								■								
Power station tunnel	5								■	■	■						
Surge chamber adit	3										■						
Power station cavern	9							■	■	■	■						
Headrace shaft	6									■	■						
Surge chamber	6											■	■				
Final linings																	
Tailrace tunnel lining - Workfront 1	15										■	■	■	■			
Tailrace tunnel lining - Workfront 2	15										■	■	■	■			
Headrace tunnel lining	3											■					
Headrace shaft lining	7											■	■	■			
Surge chamber lining	2													■			

7. Spoil acid generation

Indicative volumes of spoil produced per geological formation have been assessed from the geological model and are summarised in **Table 7-1**. **Table 7-2** summarises the average and cumulative net acid producing potential for all samples per geological unit.

The Wandrawandian Formation is indicated to be predominantly potentially acid forming, whereas the Nowra Sandstone is indicated to be non-acid forming. The Illawarra Coal Measures, Berry Siltstone and Snapper Point Formation are indicated to be overall net acid consuming.

The overall net acid producing potential of all samples tested (sum of all results as kg H2SO4/t) is strongly negative (-161 kg H2SO4/t), indicating the overall acid consuming potential of the combined samples.

Table 7-1 Spoil volumes per geological formation

Geological Unit	Volume excavated (m^3)	Percentage of total excavation volume
Hawkesbury Sandstone	17,222	5.8%
Narrabeen Group	180	0.1%
Illawarra Coal Measures	564	0.2%
Broughton Formation	1,916	0.6%
Budgong Sandstone	1,262	0.4%
Berry Siltstone	14,575	4.9%
Nowra Sandstone	27,900	9.4%
Wandrawandian Formation	55,105	18.6%
Snapper Point	177,326	59.9%

Table 7-2 Net acid forming potential

Geological Unit	Number of samples	Average Net Acid Producing Potential (kg H_2SO_4/t)	Cumulative Net Acid Producing Potential (kg H_2SO_4/t)	Classification
Illawarra Coal Measures	4	-3.3	-13.3	Net acid consuming material
Berry Siltstone	16	-9.0	-143.3	Net acid consuming material
Nowra Sandstone	2	-0.3	-0.6	Non-acid forming material
Wandrawandian Formation	13	9.2	119.2	Potential acid forming material
Snapper Point	12	-10.3	-123.2	Net acid consuming material

Based on the volumes and classifications in **Table 7-1** and **Table 7-2**, volumes of indicated non-acid forming material (NAF), net acid consuming material (ACM) and potential acid forming material (PAF) are as follows:

- NAF – 48,481 m^3 (16.4%)
- ACM – 192,464 m^3 (65%)
- PAF – 55,105 m^3 (18.6%).

While not necessarily representative of the entire volume of rock that will be excavated, the sampling and analysis of potentially acid forming materials undertaken to date indicates that the potential volume of acid forming materials are manageable and comprise less than 20% of the overall volume of material to be excavated.

Furthermore, material with net acid consuming potential is indicated to comprise the bulk of the excavated material and can be used for mixing with potential acid forming materials in the spoil emplacement to neutralise the acid forming potential.

7.1 Spoil management

As indicated above, and based on current available testing results, the spoil material is indicated to be dominated by net acid consuming materials. Notwithstanding, there is the possibility that greater volumes of potentially acid forming material may be excavated than is indicated by the existing data.

Mitigation measures for the handling, stockpiling and long-term emplacement of potentially acid forming material will be put in place and will be outlined in the Acid Rock Drainage Management Plan of the Construction Environmental Management Plan.

Potential mitigation measure may include:

- Additional investigations to be undertaken as part of detailed design to further refine and characterise the spoil acid forming potential
- Development of a Spoil Management Plan
- HDPE lining of the PAF containment areas
- Encapsulation of potentially acid forming materials within the spoil emplacement area
- Mixing of potentially acid forming material with net acid consuming material, as available
- Dosing and neutralisation with lime, dependant on availability of net acid consuming material
- Collection and treatment of potential seepage and runoff.

8. Groundwater inflows and dewatering

During construction, groundwater inflows will occur to the excavated structures. During operation, the drained structures (access tunnel, caverns and multi-purpose ventilation tunnel) will experience ongoing groundwater seepage.

Groundwater seepage and inflow will result in depressurisation and groundwater level drawdown in the rock surrounding these structures. This has the potential to result in environmental impacts, including loss of groundwater contributions to surface waters and GDE, loss of groundwater access at groundwater supply bores, and ground settlement due to ground depressurisation.

Inflows and potential impacts have been assessed through a combination of analytical calculations, analytic element groundwater modelling (AnAqSim [Fitts Geosolutions, 2022]) and two-dimensional finite element groundwater modelling (Seep/W [Geostudio, 2021]).

The modelling considered groundwater levels consistent with those noted in **Section 5.3**, a recharge of 4% of mean annual rainfall, where applicable, horizontal hydraulic conductivity values and horizontal to vertical hydraulic conductivity ratios as noted in **Section 5.4**.

An overview of the AnAqSim and Seep/W modelling approaches is provided in **Appendix A** and **Appendix B**.

8.1 Construction

Groundwater inflows to individual Project elements are discussed in **Section 8.1.1** to **Section 8.1.5** with a summary of total construction groundwater take provided in **Section 8.1.6**.

8.1.1 Headrace shaft

Groundwater inflows to the headrace shaft have been assessed progressively using the modified Dupuit-Thiem equation (Fetter, 1998). Given the stratified nature of the groundwater system a layered (stacked) aquifer system comprising 5 layers, each 120 m in thickness and comprising a 60 m thick confined aquifer with a head of 100 m, has been applied.

The maximum groundwater inflow to the headrace tunnel during construction is estimated to be approximately 15.7 m^3/day (1.34 L/s).

8.1.2 Tunnels

Inflows to tunnels have been assessed though the application of analytical equations for unsteady flows and steady state flows to a tunnel (Goodman *et al.*, 1965).

The unsteady state equation has been applied to assess short term inflows at the excavation face and unlined tunnel immediately behind the excavation face, while longer term inflows through the primary supported tunnel were calculated using the steady state equation.

Inflows have been assessed for a number of intervals along the tunnel development and are then interpolated for the intervening tunnel sections.

For simplicity, a uniform rate of advance of 3.5 m/day has been assumed for all tunnels. It is also assumed that tunnel excavations will be open to inflow through formation primary permeability following excavation until primary support and shotcreting are emplaced. A lag of 5 days (17.5 m) has been assumed between initial excavation and application of primary support to allow sufficient working room behind the excavation face.

Seepage though primary support, or via strip drains, as appropriate, has then been assessed. Ongoing inflows consider the cumulative tunnel length as the tunnel is advanced.

Tailrace tunnel

Groundwater inflow to the tailrace tunnel excavation will start to increase progressively once the tunnel is initiated from the inlet /outlet structure excavation and will reach a maximum the deepest point of the tunnel in the vicinity of the power station cavern. Groundwater inflows through the unsupported formation are estimated to peak at approximately 6.3 m^3/day (0.07 L/s).

Seepage through the supported tunnel will progressively increase with increasing length of primary supported tunnel, before diminishing as the final concrete liner is emplaced. The maximum cumulative seepage from both work fronts is estimated at 59.3 m^3/day (0.69 L/s).

The maximum expected groundwater inflow for the tailrace tunnel, including excavation face inflows and primary support seepage, is approximately 66.4 m^3/day (0.77 L/s).

It is noted that it is assumed that elevated permeability through the fault zone will be managed via ground improvement ahead of the advancing tunnel.

Headrace tunnel

Excavation of the headrace tunnel commences at the depth of the main cavern with only minor variation in elevation (approximately 20 m).

Groundwater inflows through the unsupported formation are estimated at approximately 6.3 m^3/day (0.07 L/s).

Seepage to the supported tunnel will progressively increase with increasing length of primary supported tunnel, before diminishing as the liner is emplaced. The maximum cumulative seepage is estimated at 5.47 m^3/day (0.06 L/s).

Access tunnel and ventilation and egress tunnel

The assessment of groundwater inflows to the access tunnel and ventilation and egress tunnel considers two aquifer systems. As the tunnels decline from surface, it is assumed that the formation(s) above the Wandrawandian Formation are continuously saturated and hydraulically connected, with heads increasing with increasing depth of cover. As the tunnels advance into the Wandrawandian Formation and Snapper Point Formations, a unform head of 100 m has been applied.

Maximum groundwater inflows through the unsupported formation are estimated at approximately 3.4 m^3/day (0.04 L/s) for both the access tunnel and ventilation and egress tunnel.

Seepage to the supported and drained tunnels will progressively increase with increasing length tunnel. The maximum cumulative seepage is estimated at 61.2 m^3/day (0.71 L/s) for the access tunnel, and 53.5 m^3/day (0.62 L/s) for the ventilation and egress tunnel.

As the tunnels are drained structures these seepage rates will endure for the life of the tunnels.

Secondary tunnels / adits

The secondary access tunnels and adits have not been assessed individually. Groundwater inflows have been assessed based on cumulative length and average depth and head conditions.

Groundwater inflows through the unsupported formation are estimated at approximately 3.4 m^3/day (0.04 L/s) and the maximum cumulative seepage to the supported tunnels is estimated at 26.2 m^3/day (0.30 L/s).

8.1.2.1 Depressurisation

SEEP/W modelling of the tailrace tunnel was undertaken at two locations, with one model assessing the access and ventilation and egress tunnels (**Figure B-1** in **Appendix B**).

Tailrace Model 1 is located approximately 470 m north of Lake Yarrunga adjacent to BH06. Results are shown on **Figure 8-1**. At this location water levels at BH06 are below the level of Kings Creek and no groundwater contribution to base flow is expected from the regional groundwater system. Some seepage from perched or stratified groundwater may occur but is not expected to be affected by the Project.

Depressurisation propagation around tailrace is shown to spread out laterally with limited vertical propagation due to the strong vertical anisotropy.

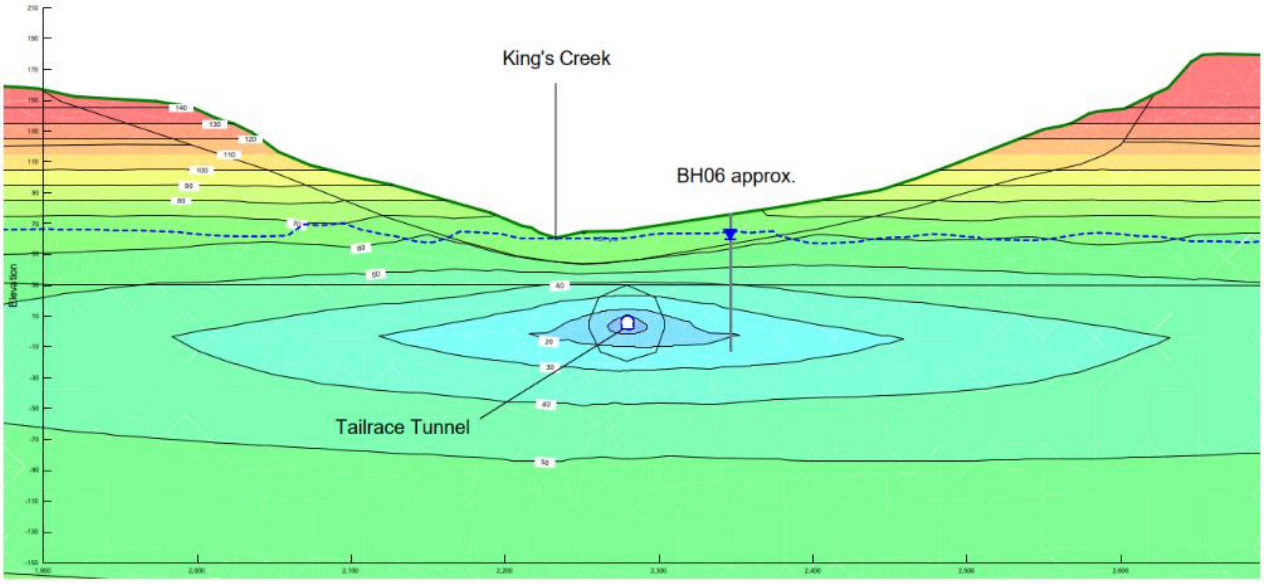


Figure 8-1 Tailrace Model 1

Tailrace Model 2 is located the vicinity of the BH03 fault zone and Bendeela Pondage. Results are shown on **Figure 8-2**. At this location water levels at BH03 are substantially below the level of Kings Creek and indicate a strong hydraulic gradient with seepage from Bendeela Pondage.

Depressurisation propagation around the tailrace is limited at this location due to the elevated hydraulic conductivity in the vicinity of the fault zone.

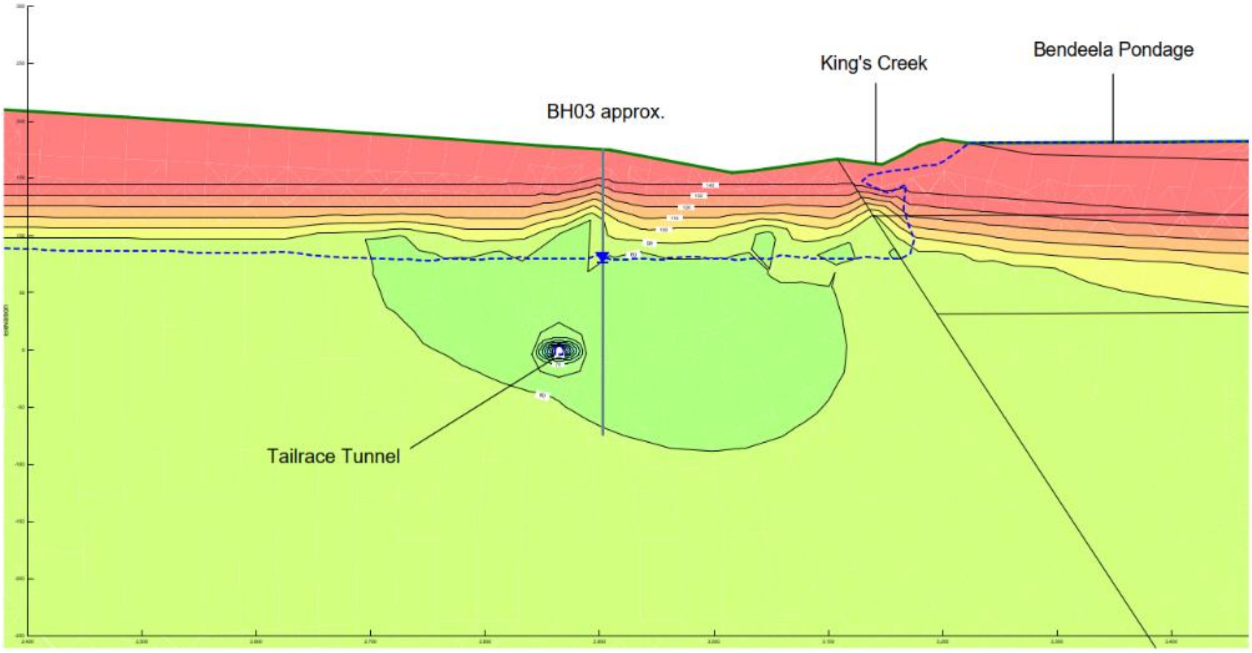


Figure 8-2 Tailrace Model 2

The access tunnel and ventilation and egress tunnel model section is located approximately midway between the portal and the power station cavern. Modelling predicts a drawdown of approximately 20m above the tunnels steady state with no significant propagation of depressurisation.

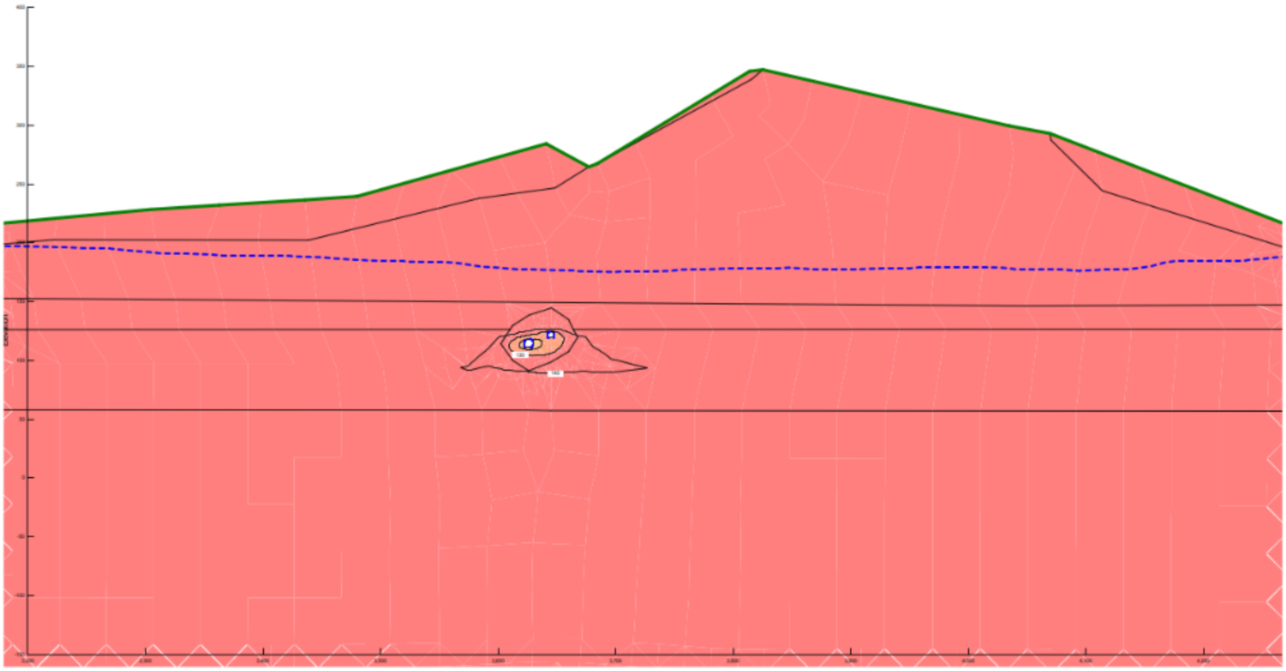


Figure 8-3 Access tunnel and ventilation and egress tunnel model

8.1.3 Surge chamber shaft

The surge chamber shaft will be excavated from top down with primary support applied progressively as the excavation advances downwards. The final lining will be installed on completion of the excavation and primary support.

Inflows are expected to reach a maximum of approximately 14.8 kL/day (0.17 L/s).

8.1.4 Caverns

Power station cavern

Groundwater inflow to the power station cavern and associated drawdown have been assessed in AnAqSim (Fitts GeoSolutions, 2022).

Modelling assumed a maximum depth of excavation of -16 mAHD. Pre-excavation water levels assumed full saturation, of the Wandrawandian and Snapper Point Formations with a confined head of approximately 125 m AHD in the vicinity of the cavern. Formation hydraulic conductivity was based on testing results from BH02 as discussed in **Section 5.6.3**. Bulk formation hydraulic conductivity was assumed to be consistent with that representative hydraulic conductivity in the Snapper Point Formation and Wandrawandian Formation (0.008 m/d). A halo of improved ground, approximately 10 m thick, has been incorporated surrounding the cavern surrounding the cavern at a hydraulic conductivity of 0.0002 m/d. Groundwater drawdown and inflow to the excavation were assessed in transient modes.

Groundwater seepage to the cavern via the progressively applied drained lining is predicted to progressively increase over the nine months of excavation, peaking at approximately 45.2 kL/day (0.51 L/s). Ongoing inflows are expected to stabilise at approximately 36.6 kL/day (0.42 L/s).

8.1.4.1 Depressurisation

Dewatering and depressurisation resulting from drainage to the caverns has been assessed in both AnAqSim and Seep/W (**Appendix A** and **Appendix B**).

Predicted drawdown in the confined Wandrawandian and Snapper Point Formations resulting from drainage to the caverns at end of construction is provided in plan view on **Figure 8-4** and in section view on **Figure 8-5**. Predicted Drawdown, as defined by the 1 m drawdown contour, is expected to propagate up to 1100 m from the cavern area. Drawdown at the caverns is predicted to be of the order of up to 80 m but is expected to be constrained within the Wandrawandian and Snapper Point Formations.

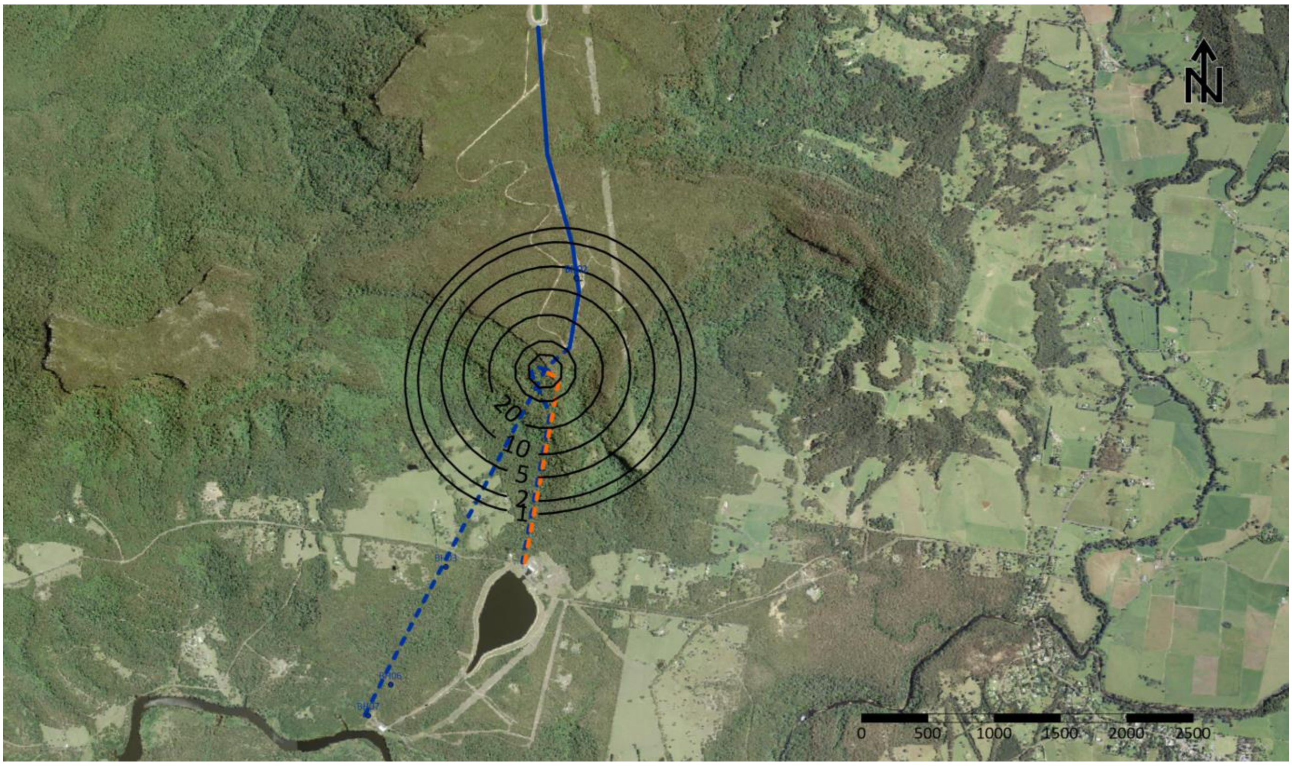


Figure 8-4 Cavern drainage drawdown contours (m) – end of construction
Aerial imagery source: MinView (https://minview.geoscience.nsw.gov.au/).

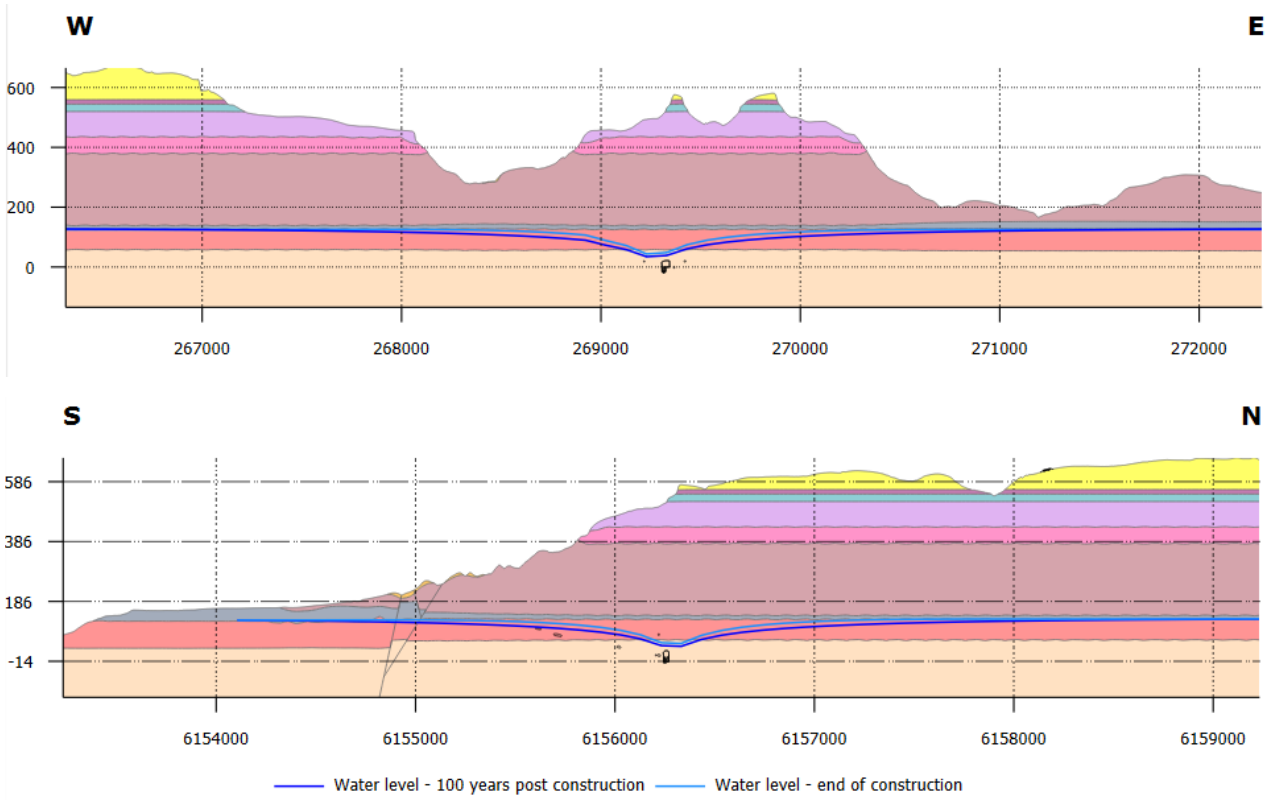


Figure 8-5 Cavern drawdown propagation (AnAqSim) – N-S and E-W sections

8.1.5 Box cut

Groundwater inflow to the outlet structure box-cut have been assessed in AnAqSim (Fitts GeoSolutions, 2022).

Modelling assumed a maximum depth of excavation of 42.75 mAHD, approximately 14 m below the water table. Pre-excavation water levels were based on observed water levels at BH03, BH06 and BH07, and formation hydraulic conductivity based on testing results from BH07, as discussed in **Section 5.6.6**. Lake Yarrunga elevation was set to 56 mAHD. Groundwater drawdown and inflow to the excavation were assessed in steady state.

Predicted steady state inflows to the full excavation are 136 m^3/day (1.57 L/s). It is expected that the excavation would take approximately 2 months to complete, and that inflows would increase progressively as the excavation is advanced below the water table. The box-cut will be required to be dewatered for a period of approximately 48 months.

It is noted that this assessment is conservative and assumes that no ground improvement, such as grouting, is applied to restrict groundwater entry to the excavation.

8.1.5.1 Groundwater drawdown

The predicted steady state drawdown resulting from the box-cut dewatering is shown on **Figure 8-6**. Drawdown is expected to propagate a maximum of approximately 380 m to the north and 440 m to the northeast of the excavation. Drawdown is attenuated at the south and west at Lake Yarrunga. The maximum drawdown at the excavation is of the order of 14 m.

At steady state, following the initial depletion of groundwater storage within the cone of drawdown, approximately 88% of the inflows are assessed as being sourced from Lake Yarrunga and the lower reaches of Kings Creek that are influenced by the lake.

There is also potential that the lower reaches of Kings Creek, above the influence of Lake Yarrunga and below the break in slope (approximately 60 m/AHD), may be subject to groundwater baseflow from the regional water table. It is assumed that above the break in slope, the stratified nature of the formation would restrict vertical drawdown propagation.

The AnAqSim model calculates the pre-excavation baseflow contribution to the lower reaches of Kings Creek to be of the order of 18.1 m^3/day (0.21 L/s), reducing to 5.95 m^3/day (0.07 L/s) following excavation, a reduction of 12.12 m^3/day (0.14 L/s). While this represents a potentially significant reduction in baseflow contribution to this lower reach of the stream (approximately 67%), the creek at this point is likely to be more reliant on runoff and flows from the upstream catchment and the baseflow contribution is considered to be only a minor component of the total stream flows. Given the observed bedrock substrate this is also considered to be a very conservative assessment.

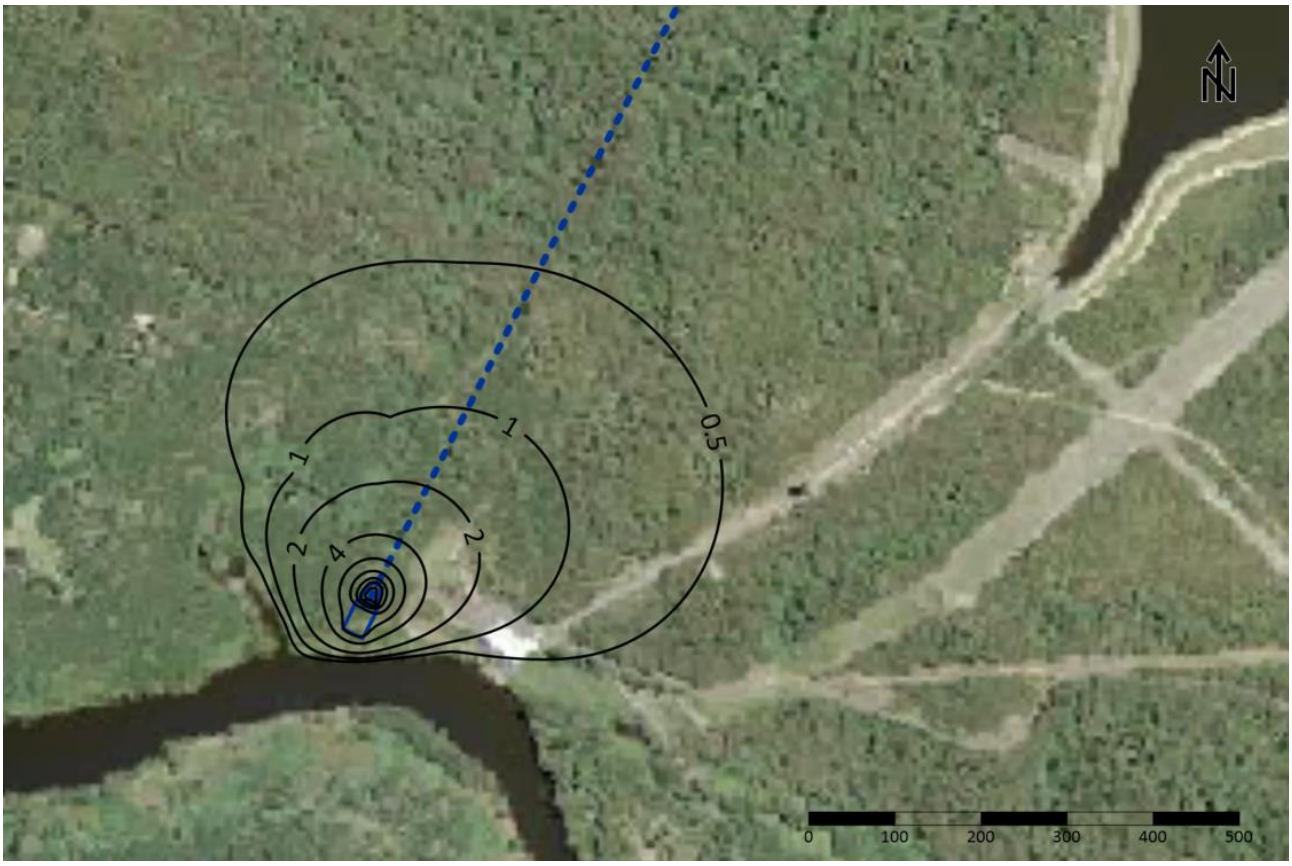


Figure 8-6 Box-cut dewatering – predicted drawdown contours (m)
Aerial imagery source: MinView (https://minview.geoscience.nsw.gov.au/).

8.1.6 Total construction groundwater take

The total estimated groundwater take during construction from the individual Project elements is presented in **Figure 8-7**.

Groundwater inflows are predicted to increase steadily, peaking at 15,131 m^3/month (15.13 ML/month) after two years of construction.

The total predicted groundwater take is estimated at 426.7 ML, averaging approximately 106.7 ML per annum or 3.6 L/s.

Overall, the predicted groundwater inflows are considered to be conservative with respected to the inflows observed during the excavation of the Kangaroo Valley headrace tunnel of 5.7 m^3/day (0.07 L/s) (**Section 4.5.1.6**) and with consideration for the larger scale of the Project.

It is possible that short term inflows may exceed predictions where fractured ground or more permeable formations are encountered. Where inflow volumes are problematic remedial measures such as grouting would be employed.

8.1.7 Water quality

Groundwater inflows to tunnels and excavations are likely to range in quality from relatively fresh, in the vicinity of the outlet structure box-cut and shallow tunnelling operations, to brackish at depth in the vicinity of the main cavern. While no quantitative data is available, an upper limit of the order of 2,500 mg/L is considered reasonable; however, it is also noted that more deteriorated water quality is also possible.

The box-cut for the inlet/outlet structure will be excavated in Wandrawandian, which is noted as being potentially acid forming. The box-cut will require dewatering for the duration of construction and there is potential for the oxidation of potentially acid forming materials in the zone of drawdown, which could result in acid drainage entering the excavation and dewatering system.

Similarly, in the vicinity of the main cavern and other drained structures, where these structures are excavated within or beneath Snapper Point Formation, there is potential for the oxidation of potentially acid forming materials in the zone of drawdown that could result in acid drainage entering the excavation and dewatering system.

As hydraulic gradients will be directed towards the points of drainage, there will be no migration of deteriorated water quality away from the Project. Potential acid drainage in the vicinity of the drained structures poses more of a risk to concrete and infrastructure than it does a risk to the environment of water quality.

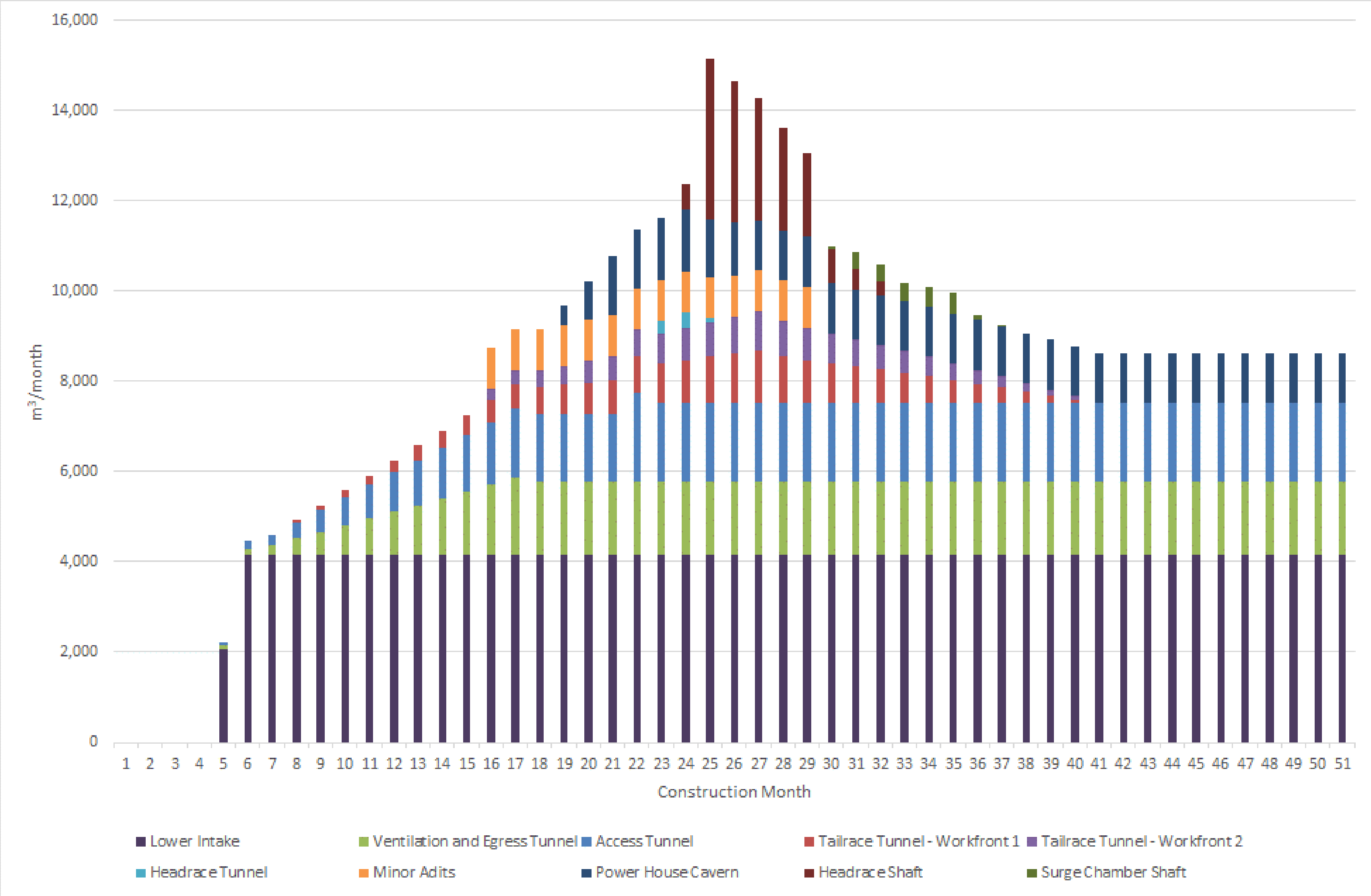


Figure 8-7 Total predicted construction groundwater take

8.2 Operation

Ongoing groundwater take during operation will be limited to seepage through the drained structures, namely the access tunnel and ventilation and egress tunnel and the power station cavern. It is noted that the lower reaches of the access tunnel and ventilation and egress tunnel will be influenced by depressurisation around the power station cavern and, as such, the calculated inflows have been halved to account for this.

Predicted ongoing seepage to each of these structures are as follows:

- Access tunnel – 28.5 m^3/day (0.33 L/s)
- Ventilation and egress tunnel – 26.8 m^3/day (0.31 L/s)
- Power station cavern – 36.2 m^3/day (0.42 L/s).

The ongoing, operational, seepage is therefore estimated to be of the order of 91.5 m^3/day (1.06 L/s), equivalent to approximately 33.4 ML per annum.

8.2.1 Depressurisation

Dewatering and depressurisation resulting from drainage to the caverns has been assessed in both AnAqSim and Seep/W.

Predicted drawdown in the confined Wandrawandian and Snapper Point Formations resulting from drainage to the caverns at 100 years following construction is provided in plan view on **Figure 8-8** and in section view on **Figure 8-5**.

Predicted Drawdown, as defined by the 1m drawdown contour, is expected to propagate up to 2,200 m to the east and west the cavern area, 1,900 m to the south and 2,800 m to the north.

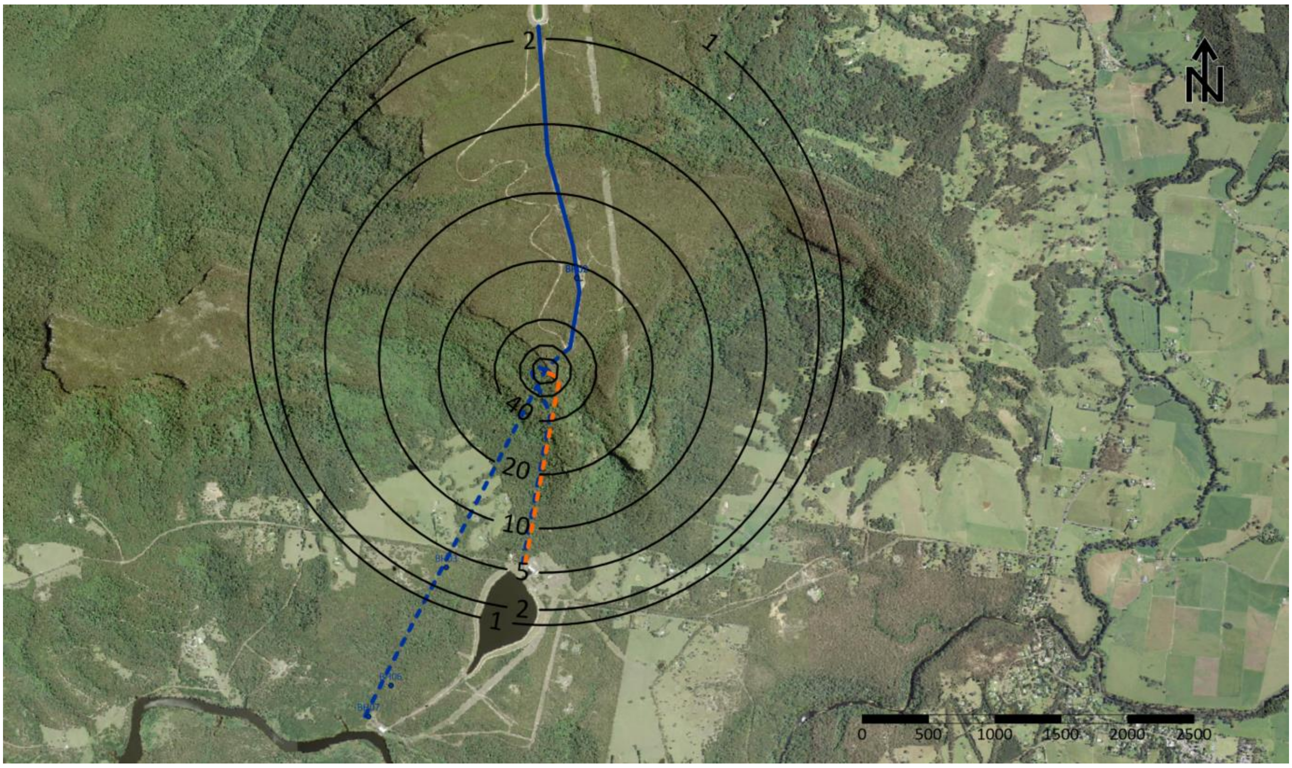


Figure 8-8 Cavern seepage drawdown (m) – end of construction
Aerial imagery source: MinView (https://minview.geoscience.nsw.gov.au/).

8.2.2 Water quality

Ongoing seepage to drained structures within or underlying Snapper Point Formation has potential for the oxidation of potentially acid forming materials in the zone of drawdown, which could result in acid drainage entering the excavation and dewatering system. As hydraulic gradients will be directed towards the points of drainage, there will be no migration of deteriorated water quality away from the Project.

Dewatering of the outlet structure box-cut will cease prior to the end of construction. The rock plug between the excavation and Lake Yarrunga will be removed and the inlet/outlet structure and tailrace allowed to fill to the level of Lake Yarrunga.

If potentially acid forming materials have oxidised during the construction dewatering phase, as the oxidised materials are re-wet as water levels recover, there is potential for short term acid drainage to occur until water levels have fully recovered and flushed the oxidised material.

It is noted that the natural rate of groundwater throughflow to the lake and flooded inlet/outlet structure will be very low in relation to the volume of stored water and any observable effects are expected to be negligible.

Groundwater monitoring will be in place for the construction dewatering phase with appropriate management and mitigation measures, as outlined in the Construction Environmental management Plan (CEMP) and spoil management strategy, should acid drainage be identified.

8.3 Dewatering management

Management and monitoring of dewatering and associated potential impacts will be managed via the implementation of a Dewatering Management Plan to be developed as part of detailed design and construction planning.

Inflows to underground tunnels and excavations during construction will be collected in dewatering sumps and pumped to construction drainage water holding ponds located near the access and tailrace drive portals.

The primary water treatment process will be determined by the construction contractor but is expected to at least include settling ponds or tanks, and a pH dosing system to neutralise acidity if required.

Collected groundwater will be prioritised for re-use in either dust suppression, under-ground tunnelling and excavations, or concrete batching as required and will be treated to the appropriate quality prior to re-use.

Discharge to environment of surplus water may also be required and the water will be treated to the appropriate discharge criteria prior to discharge as required. A construction water balance detailing anticipated discharge volumes is presented in Appendix I of the EIS (Surface water quality, hydrology and geomorphology impact assessment).

Ongoing seepage to drained structures during operation will be collected in a dewatering sump located at the lowest level in the underground power station. Seepage water will be treated, before being discharged to the tailrace.

As part of detailed design, a Construction Soil and Water Management Plan (CSWMP) will be prepared for the Project. The CSWMP will outline appropriate water quality criteria for discharge and re-use onsite.

9. Potential impacts

9.1 Construction

9.1.1 Groundwater users

Groundwater drawdown and depressurisation at end of construction in relation to groundwater users and GDE are shown on **Figure 9-1**.

There are no known groundwater users within the predicted areas of groundwater drawdown and depressurisation during construction. As such, the Project construction will not result in impacts to other groundwater users.

9.1.2 Groundwater dependant ecosystems

The are no high priority GDEs in the vicinity of the Project and no high potential GDEs mapped within the predicted areas of groundwater drawdown.

Groundwater drawdown at the water table associated with the outlet structure box-cut excavation is predicted to propagate beneath areas mapped as low potential GDE as shown on **Figure 9-1**.

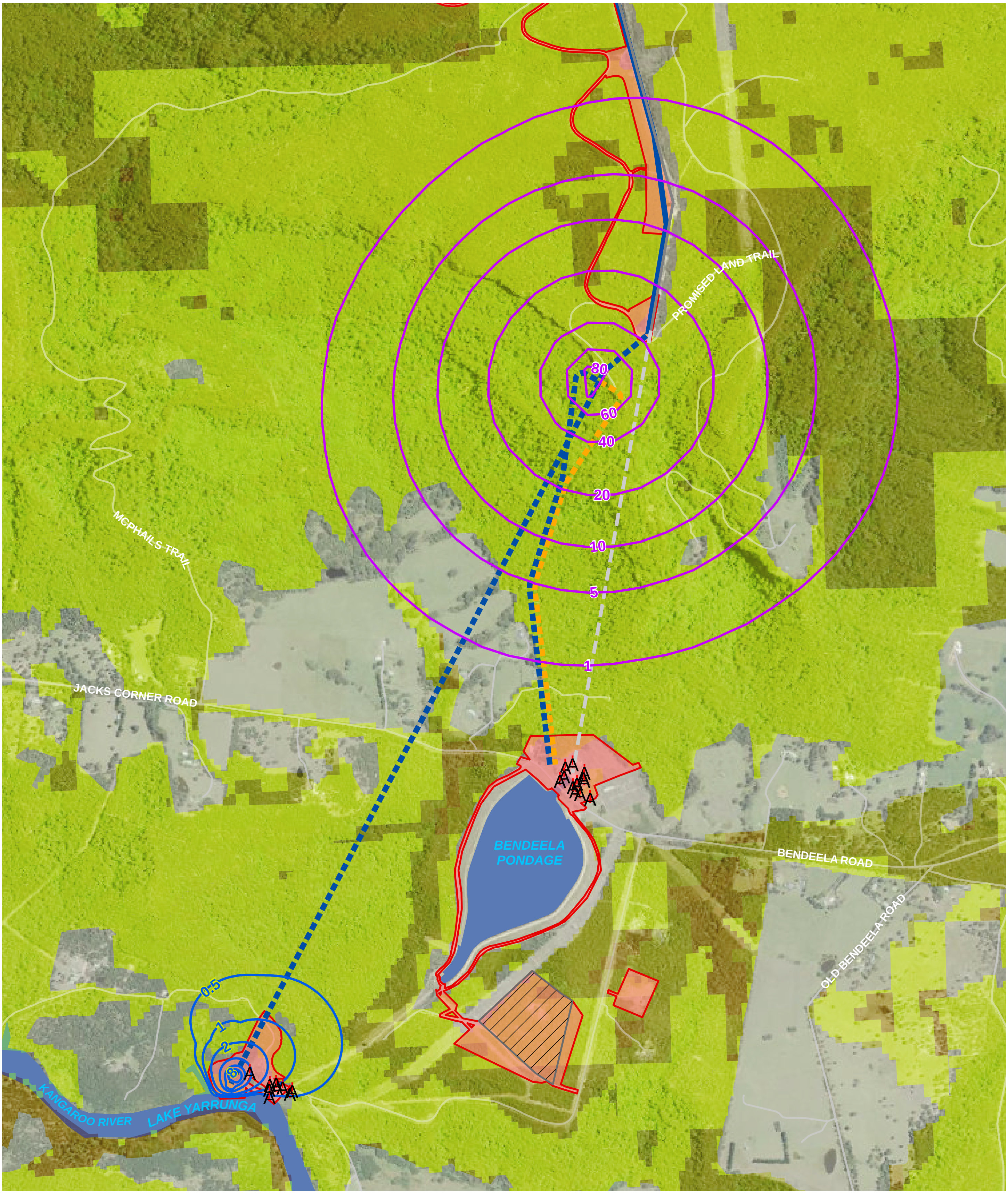
Drawdown and depressurisation associated with the drained caverns, while propagating beneath an area mapped as medium potential GDE, is constrained to the Wandrawandian and Snapper Point Formations and is well below the potential GDE. As such the Project will not result in impacts to GDEs.

9.1.3 Water quality

The Project is not expected to result in any detrimental change to groundwater quality.

Potential acid drainage in vicinity of spoil emplacement and outlet structure excavation will be monitored and managed in accordance with the Project CEMP and Spoil Management Plan.

With respect to potential groundwater discharges, the Project is not anticipated to result in any detrimental changes to catchment water quality. All controlled groundwater discharges will be treated to suitable quality prior to being discharged. As such, Project construction is considered to meet with the requirement for Neutral or Beneficial Effect on catchment water quality with regards to groundwater.



Legend

Bore

- Monitoring
- Water table drawdown contours (m)
- Confined drawdown contours (m)
- High potential GDE - from regional studies
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies
- Existing KV tunnel alignment
- Existing scheme pipeline
- Indicative above ground pipeline
- Indicative tunnel alignment
- Indicative access tunnel
- Disturbance area
- Spoil site
- Waterbody

0 0.4 0.8 km

1:20,000 at A4

GDA2020 MGA Zone 56

Data sources

Jacobs 2022
Department of Planning and Environment 2022
BOM 2022
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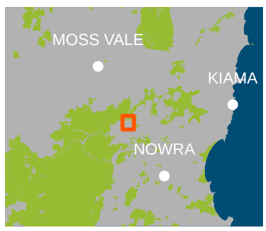

Figure 9-1 Predicted drawdown at end of construction

9.1.4 NSW Aquifer Interference Policy

An assessment of the Project construction phase against the NSW AIP Minimal Impact Considerations for less productive porous and fractured rock groundwater sources is provided in **Table 9-1**.

Project construction meets with the Level 1 Minimal Impact Considerations.

Table 9-1 Minimal Impact Considerations - construction

Less Productive Porous and Fractured Rock Groundwater Source

Minimal Impact Consideration	Response
Water Table 1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m 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; or A maximum of a 2 m decline cumulatively at any water supply work.	Meets level 1 consideration. No decline in water level due to the Project is predicted at any high priority groundwater dependent ecosystem, culturally significant site or water supply work.
Water Pressure 1. A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work	Meets level 1 consideration. No decline in water pressure due to the Project is predicted at any water supply work.
Water Quality 1. (a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity; and (b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. (c) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply".	Meets level 1 consideration. (a) The Project is not anticipated to result in a change to the beneficial use category of the groundwater source. (b) & (c) There are no highly connected surface water sources in the vicinity of the Project.

9.2 Potential operational impacts

9.2.1 Groundwater users

Groundwater drawdown and depressurisation during operation (100 years following construction) in relation to groundwater users and GDE are shown on **Figure 9-2**.

Drawdown propagation from the drained caverns is predicted to encroach beneath two registered groundwater works, GW101249 and GW101591, both bores are recorded as being for water supply purposes.

Predicted drawdown beneath GW101249 is approximately 1.12 m, and beneath GW101591 is approximately 1.3 m.

GW101249 is recorded as being 1 m deep. The bore is inferred to be installed at the location of a natural seepage resulting from the stratified groundwater system or in an alluvial channel and is unlikely to be detrimentally affected by the predicted drawdown.

GW101591 is recorded as being 60 m deep. Review of the leapfrog geological model indicates that GW101591 is likely to be installed within the Berry Siltstone to approximately 30 m depth and then within the Wandrawandian Formation to 60 m depth. It is therefore considered possible that some drawdown may be experienced at the bore. However, the magnitude of the predicted drawdown is unlikely to detrimentally impact on the supply capacity of the bore.

9.2.2 Groundwater dependant ecosystems

There are no high priority groundwater dependant ecosystems in the vicinity of the Project and no high potential GDEs mapped within the predicted areas of groundwater drawdown.

Drawdown and depressurisation associated with the drained caverns, while propagating beneath an area mapped as medium potential GDE, is constrained to the Wandrawandian and Snapper Point Formations and is well below the potential GDE. As such the Project will not result in impacts to GDE.

9.2.3 Water quality

Operation of the Project is not expected to result in any significant change to groundwater quality.

Potential acid drainage in vicinity of spoil emplacement and outlet structure excavation during operation will be monitored and managed in accordance with the Project Operational Environmental Management Plan and Spoil Management Plan.

With respect to potential groundwater discharges, the Project is not anticipated to result in any detrimental changes to catchment water quality. All controlled groundwater discharges will be treated to suitable quality prior to discharge. As such, Project construction is considered to meet with the requirement for Neutral or Beneficial Effect on catchment water quality with respect to groundwater.

Legend

Bore

- Monitoring
- Water Supply
- Confined drawdown contours (m)
- High potential GDE - from regional studies
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies
- Existing KV tunnel alignment
- Existing scheme pipeline
- Indicative above ground pipeline
- Indicative tunnel alignment
- Indicative access tunnel
- Disturbance area
- Spoil site
- Waterbody

0 0.6 1.1 km

1:27,500 at A4

GDA2020 MGA Zone 56

Data sources

Jacobs 2022
Department of Planning and Environment 2022
BOM 2022
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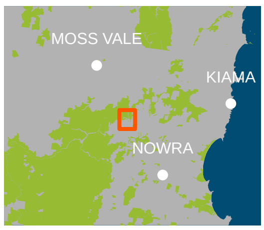

Figure 9-2 Predicted drawdown after 100 years

9.2.4 NSW Aquifer Interference Policy

An assessment of the Project operational phase against the NSW AIP Minimal Impact Considerations for less productive porous and fractured rock groundwater sources is provided in **Table 9-2**.

Project operation meets with the Level 1 Minimal Impact Considerations.

Table 9-2 Minimal Impact Considerations - operation

Less Productive Porous and Fractured Rock Groundwater Source

Minimal Impact Consideration	Response
Water Table 1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m 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; or A maximum of a 2m decline cumulatively at any water supply work.	Meets level 1 consideration. No decline in water level due to the Project is predicted at any high priority groundwater dependent ecosystem, culturally significant site or water supply work.
Water Pressure 1. A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2m decline, at any water supply work	Meets level 1 consideration. No decline in water pressure in excess of 2 m due to the Project is predicted at any water supply work.
Water Quality 1. (a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity; and (b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. (c) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply".	Meets level 1 consideration. (a) The Project is not anticipated to result in a change to the beneficial use category of the groundwater source. (b) & (c) There are no highly connected surface water sources in the vicinity of the Project.

9.3 Cumulative impacts

Potential groundwater related impacts for the Project during construction and operation are not considered to be significant and are restricted to the vicinity of the Project. The potential for cumulative impacts with other aquifer interference activities within the area is therefore unlikely.

10. Water access licensing requirements

Under the Water Management (General) Regulation 2018 (NSW Government, 2018), the Project is exempt of requiring a water access licence for the take of water in relation to the generating of electricity; however, water access licences will likely be required for groundwater and surface water take relating to construction and for the ongoing take of water during operation.

The total groundwater take during construction is predicted to be of the order of 426.7 ML, peaking at 195.1 ML during the third year of construction.

Of this groundwater take, approximately 88% of the inflows to the tailrace box-cut excavation (i.e. approximately 49.6 ML) are assessed as being sourced from Lake Yarrunga and the lower reaches of Kings Creek.

For construction, the water access licensing volumes are assessed at:

- 49.6 ML from the Shoalhaven Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011
- 145.5 ML from the Sydney Basin South Groundwater Source of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011.

During operation, ongoing seepage to the drained structures are assessed at:

- 33.4 ML from the Sydney Basin South Groundwater Source of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011.

11. Monitoring and mitigation

11.1 Water level

11.1.1 Tailrace box-cut excavation

Groundwater level monitoring is recommended in the vicinity of the tailrace box-cut excavation to assess the groundwater response to dewatering and to assess potential drawdown propagation in the vicinity of Kings Creek, above the reaches that are influenced by Lake Yarrunga.

Existing bore BH07 and the vibrating wire piezometer installation at BH06 should be monitored and may indicate some response to dewatering. However, it is also recommended that at least two additional shallow monitoring bores are installed and located between the excavation and Kings Creek.

11.1.2 Power station cavern depressurisation

Dewatering and depressurisation in the vicinity of the drained power station cavern has potential for long-term propagation and encroachment on existing groundwater users. While the predicted drawdown is not anticipated to be detrimental to the supply capacity of the affected groundwater bore, the actual magnitude and extent of drawdown during construction and operation should be assessed so that any potential impacts can be identified and addressed.

Existing vibrating wire piezometer installations at BH02 are installed above the Wandrawandian and Snapper Point Formations and are unlikely to be directly influenced by depressurisation in the Snapper Point Formation in the vicinity of the power station. Vibrating wire piezometer installations at BH03, while installed in the Snapper Point Formation are likely too far away from the power station to be utilised as an effective monitoring location.

Proposed borehole, BH09, will be drilled into the location of the power station cavern. Installation of multi-level vibrating wire piezometers will provide valuable data on the vertical propagation of dewatering.

It is recommended that a bore census be undertaken for the potentially affected bores (GW101249 and GW101591) to assess current status and use, and the potential for monitoring water levels.

11.2 Water quality

11.2.1 Tailrace box-cut excavation

Groundwater quality in the vicinity of the tailrace box-cut will be monitored during construction dewatering and through the early stages of operation as water levels rebound.

Existing monitoring bore BH07 is screened too deep to act as an effective water quality monitoring bore (51.7 m to 60.7 mbgl) for the identification of acid drainage and it is recommended that two additional shallow monitoring bores are installed prior to construction commencing. The bores should be screened from the current water table to below the depth of predicted drawdown.

Potential mitigating measures should be assessed during detailed design, including, but not limited to:

- Additional investigations in the vicinity of the box-cut excavation to characterise potential acid forming material and quantify risk of acid rock drainage occurring
- Development of Acid Rock Drainage Management Plan that identifies remedial measures in the event that actual acid rock drainage is identified.

11.2.2 Spoil emplacement area

Groundwater quality in the vicinity of the spoil emplacement area should be monitored during construction and through the early stages of operation to assess for potential seepage of acid rock drainage from acid forming materials within the spoil emplacement. A Spoil management strategy is presented as Appendix K of the EIS and will be developed in to a Spoil Management Plan as part of detailed design and construction planning.

Potential mitigating measures for the prevention of acid drainage will be assessed during detailed design. Potential mitigating measures may include, but are not limited to:

- HDPE or similar lining of a dedicated PAF emplacement area
- Encapsulation and capping of potential acid forming materials to prevent ingress of water and leachate generation
- Neutralisation / buffering of potential acid forming materials by mixing with net acid consuming materials or by dosing with lime
- Perimeter drains to intercept runoff from the spoil emplacement and to intercept shallow seepage. Drain may be installed with passive treatment options such as limestone rock beds.

11.3 Summary of mitigation measures

Mitigation measures for potential groundwater related issues and impacts associated with the Project are summarised as follows on **Table 11-1**.

Table 11-1 Summary of mitigation measures

Reference	Impact	Mitigation measure	Timing
GW01	Groundwater monitoring	Groundwater monitoring, including the installation of additional monitoring locations, will be undertaken to collect additional baseline information and to assess and monitor for potential impacts during construction and operation. Also refer to GW02 and GW03.	Pre-construction/ Construction/ Operation
GW02	PAF forming materials	The Spoil management strategy (Appendix K of the EIS) will be developed to a Spoil Management Plan as part of detailed design and construction planning and identify mitigating and remedial measures in the event that actual acid rock drainage is identified.	Pre-construction/ Construction
GW03	Dewatering	A Dewatering Management Plan (DWMP) will be prepared in conjunction with the Construction Environmental Management Plan. The DWMP will outline responsibilities, controls and procedures to mitigate potential environmental impacts associated with temporary construction dewatering and ongoing operational dewatering.	Pre-construction/ Construction/ Operation
GW04	Groundwater discharge	In conjunction with the DWMP, discharge of groundwater will be managed in accordance with the Construction Soil and Water Management Plan (CSWMP). Refer to the Surface Water, Hydrology and Geomorphology technical report mitigation measure SW06 for more detail on mitigation of construction discharges.	Pre-construction/ Construction/ Operation

12. Conclusion

A groundwater assessment has been completed for the Shoalhaven Hydro Expansion Project.

Two main groundwater systems were identified associated with the Project, including an upper stratified groundwater system with limited vertical connectivity, and a deeper regional groundwater system. The upper stratified groundwater system is present beneath the elevated plateaus and discharges to the escarpments.

Key Project elements interacting with groundwater include a 550 m deep vertical pressure shaft connecting to a headrace tunnel at depth. The power station is located at depth and is connected to the inlet / outlet structure at Lake Yarrunga, via a an almost 3 km long tailrace tunnel. Access and ventilation and egress tunnels decline to the power station from the vicinity of the existing Kangaroo Valley Power Station. A spoil emplacement area is to be established to the east of the Bendeela Pondage.

Inflows to tunnels and underground caverns will be limited by the low permeability of formation primary permeability and the application of shotcrete as a primary support. Total groundwater inflows are expected to peak at approximately 496 m^3/day, or 5.7 L/s, during construction with average inflows of approximately 274 m^3/day, or 3.2 L/s. During operation, ongoing inflows to drained structures are assessed at approximately 91.5 m^3/day, or 1.06 L/s.

During construction, drawdown related to groundwater inflow is not expected to impact on any groundwater dependent ecosystems or other groundwater users, however dewatering of the tailrace box-cut excavation is expected to be approximately 88% sourced from surface water from Lake Yarrunga. A minor baseflow reduction from the lower reaches of Kings Creek is also possible.

During operation, the magnitude of predicted drawdown associated with the power station cavern is not expected to detrimentally affect the supply capacity from either water supply, despite predicted depressurisation and drawdown having the potential to propagate beneath two adjacent groundwater users at a distance of up to 2.2 km from the cavern.

Excavations are likely to produce spoil with potential to develop acid rock drainage. Dewatering in the vicinity of the tailrace box-cut excavation also has potential to result in the oxidation of potential acid forming materials. Potential acid forming materials will be encapsulated within the spoil emplacement area to minimise the potential for acid leachate and seepage.

In the event that actual acid rock drainage does occurs, management and remedial measures are available to mitigate potential environmental impacts and will be detailed in an Acid Rock Drainage Management Plan.

Assessment of the Project against the NSW Aquifer Interference Policy – Minimal Impact Considerations indicates that the Project meets with the Level 1 - Minimal Impact Considerations and, as such, has an acceptable (negligible) level of impact. Similarly, with suitable mitigation measures in place the Project also meets with the Neutral of Beneficial Effect requirement for the drinking water catchment.

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Appendix A. Groundwater Modelling – AnAqSim

A.1 Introduction

An analytic element groundwater flow model has been developed to assess groundwater inflow and drawdown associated with surface and underground excavation for the Shoalhaven Hydro Expansion Project.

A.2 Adopted model type and program

The groundwater flow model has been developed in the Fitts Geosolutions software package, AnAqSim (v2022-2). AnAqSim is an analytic element modelling package for modelling groundwater flow in porous media. The analytic element method is a mathematical approach to solving groundwater flow equations that results in exact solutions and does not require discretization of areas or volumes throughout the model domain. AnAqSim superposes analytic solutions for individual model elements (such as wells, river segments, and area source/sinks) to yield a composite solution consisting of equations for head and discharge as functions of location and time.

A.3 Model set up

Two groundwater flow models have been developed. One model was developed to assess dewatering requirements for the tailrace box-cut excavation and potential impacts to Kings Creek (tailrace box-cut model) and the other model was developed to assess inflows to the main caverns and resulting drawdown propagation.

A.3.1 Tailrace box-cut model

The tailrace box-cut model incorporates two layers, an upper confined/unconfined layer representing the Wandrawandian Formation and a lower confined layer representing the Snapper Point Formation. The model extents and boundary conditions are shown on **Figure A-1**.

Model layers and hydraulic properties are summarised in **Table A-1**.

Table A-1. Model layers and hydraulic properties

Layer	Formation	Domain type	Porosity	Storativity	Specific Yield	Kh (m/day)	Kv upper (m/day)	Kv lower (m/day)
1	Wandrawandian	confined/ unconfined	0.1	0.001	0.05	0.17	0.01	0.01
2	Snapper Point	confined	0.05	0.0001	0.01	0.011	0.001	0.001

Boundary Conditions

Boundary conditions for the tailrace box-cut model are shown on **Figure A-1** and are summarised as follows:

- No flow boundaries are applied along the eastern and western model boundaries. These boundaries are approximately parallel to the regional groundwater flow direction
- A specified head boundary is applied along the northern model boundary. Heads are consistent with water levels observed at BH03 and are set at 75 mAHD in Layer 1 and 73 mAHD in Layer 2
- A specified head boundary is applied along the southern model boundary representing Lake Yarrunga and the inundated lower section of Kings Creek. Head is set at 56 mAHD in Layers 1 and 2
- A river boundary is applied in layer one to represent the lower reaches of Kings Creek. River depth is assumed to range from 0.2 to 0.5 m. Bed conductance is based on the hydraulic conductivity of the underlying formation and ranges from 0.02 to 0.05 m^2/day
- For the prediction model the base of the box-cut excavation water simulated by an internal specified head line boundary consistent with the base of excavation.

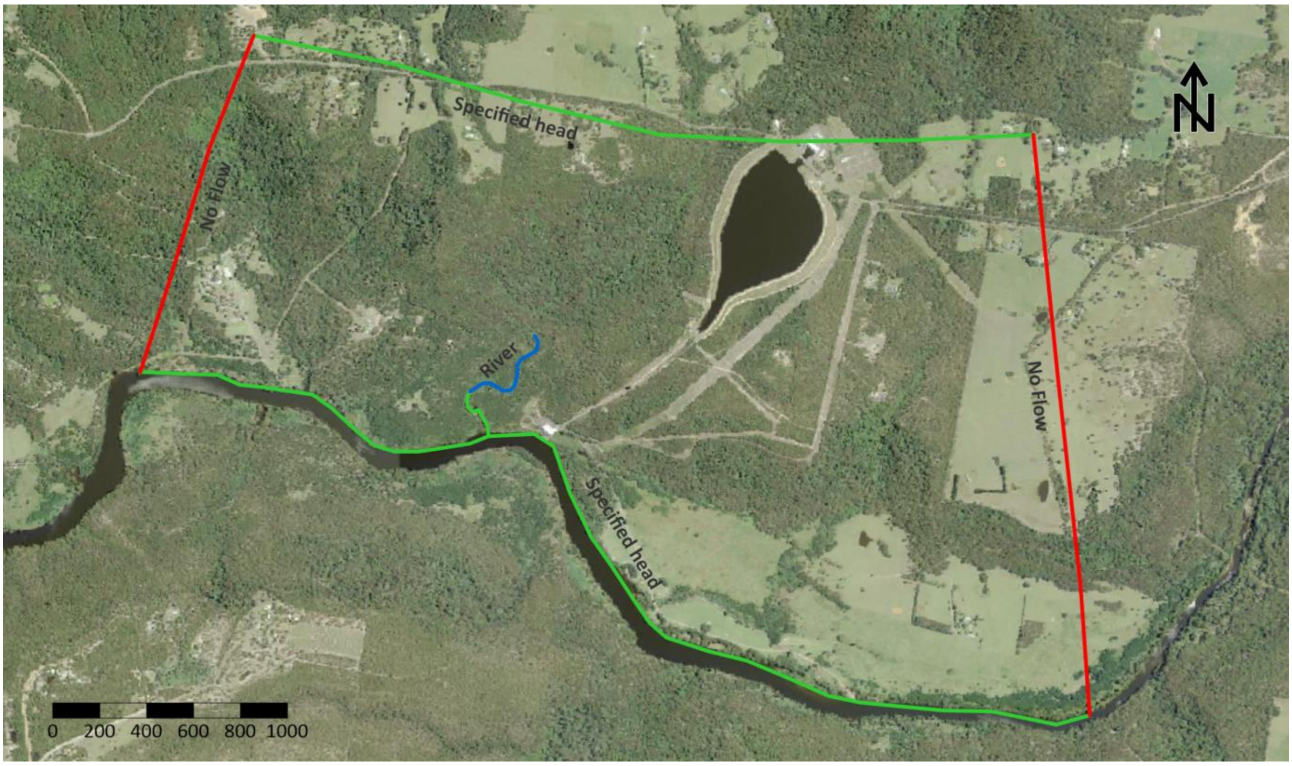

Figure A-1 Tailrace box-cut model - domain and boundary conditions
Aerial imagery source: MinView (https://minview.geoscience.nsw.gov.au/).

Calibration

The tailrace box-cut model was calibrated in steady state to observed heads at BH03, BH06 and BH07.

No recharge was applied to the model. During calibration the specified head of Lake Yarrunga was lowered to achieve a reasonable representation of observed water level at BH06 and BH07.

Calibrated water level contours are shown on **Figure A-2**, with modelled and observed water levels plotted on **Figure A-3**.

Prediction model

For the prediction model the tailrace box-cut model was run in steady state with specified head boundaries applied to simulate the base of the excavation.

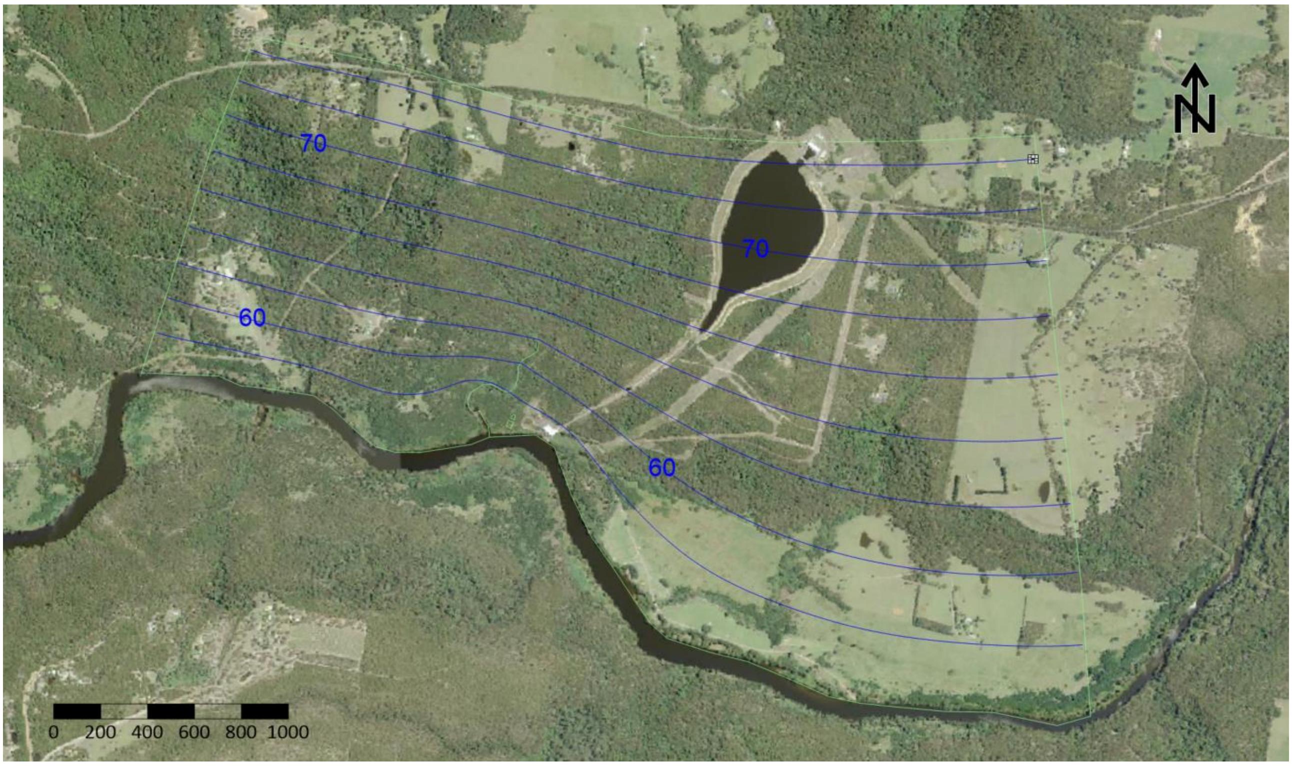

Figure A-2 Tailrace box-cut model – calibrated steady state water levels (mAHD)
Aerial imagery source: MinView (https://minview.geoscience.nsw.gov.au/).

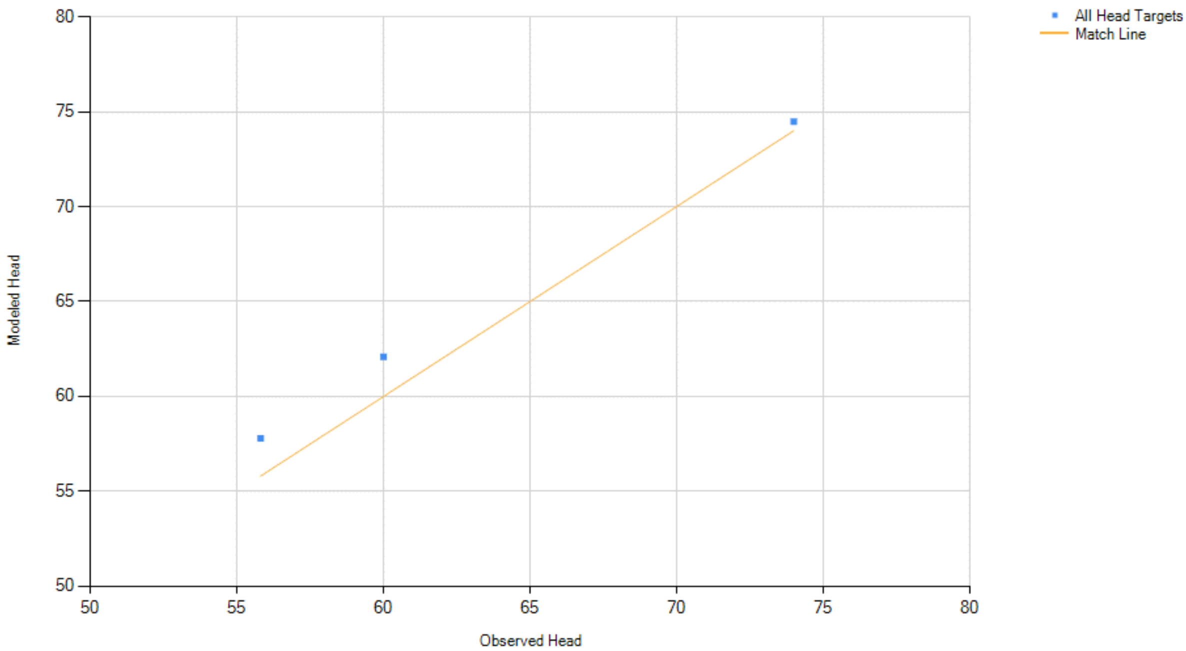

Figure A-3 Tailrace box-cut model – calibration scatter plot

Results

Steady state groundwater inflows to the excavation are predicted to be approximately 135.86 m3/day (1.57 L/s). It is anticipated that inflows will progressively increase as the excavation is advanced below the water table reaching the steady state inflows at full excavation.

Steady state water levels with the simulated excavation dewatering are provided on **Figure A-4** with calculated drawdown contours shown on **Figure A-5**.

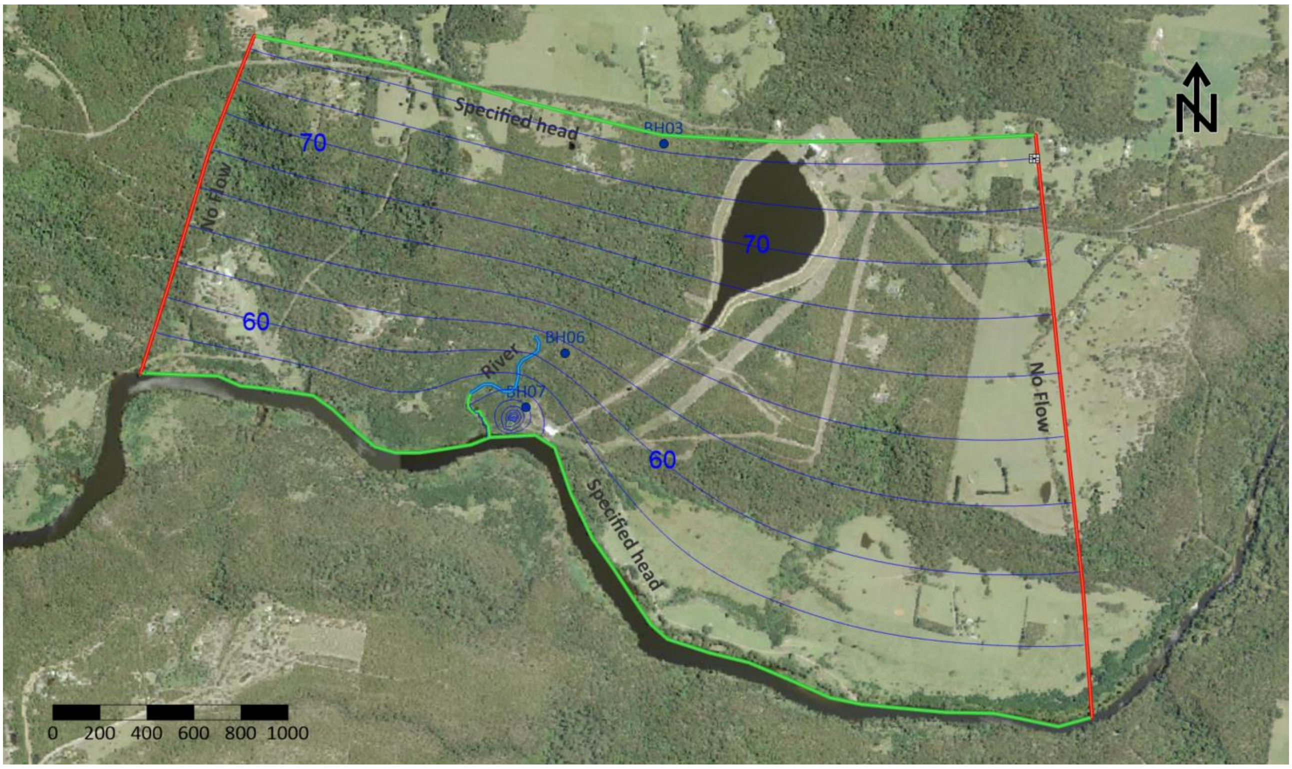

Figure A-4 Tailrace box-cut model – excavation dewatering steady state water levels (mAHD)
Aerial imagery source: MinView (https://minview.geoscience.nsw.gov.au/).

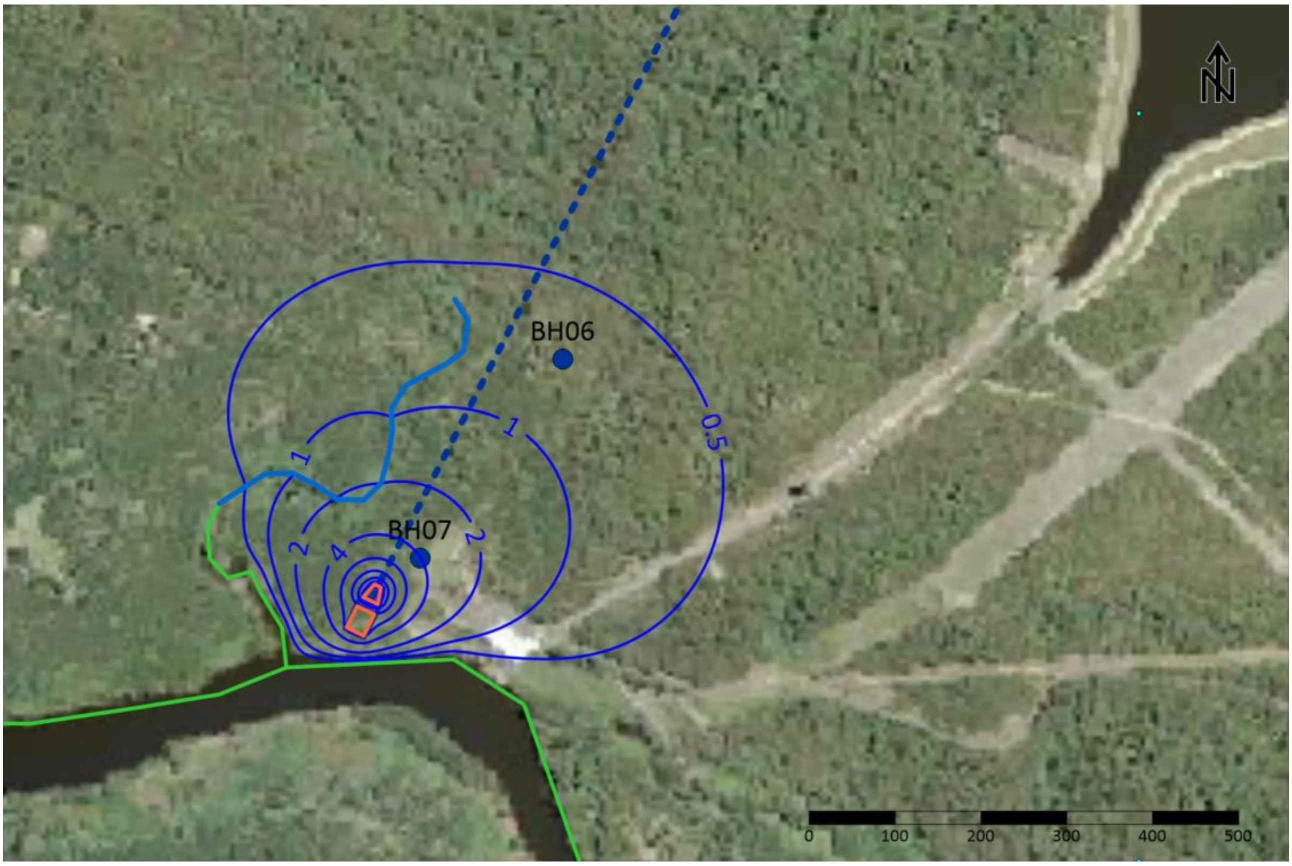

Figure A-5 Tailrace box-cut model – excavation dewatering drawdown contours (m)
Aerial imagery source: MinView (https://minview.geoscience.nsw.gov.au/).

A.3.2 Cavern model

The cavern model incorporates a single confined layer, approximately 200 m thick, representing the Wandrawandian and Snapper Point Formations at depth. The model incorporates a circular head specified, uniform gradient boundary with a diameter of approximately 20 km. The average model head was set at 125 mAHD with a uniform flow gradient of 0.001 to the south. Model extents and steady state water levels are shown on **Figure A-1**.

Model hydraulic properties are summarised in **Table A-2**.

Table A-2 Model layers and hydraulic properties

Layer	Formation	Domain type	Porosity	Storativity	Specific Yield	Kh (m/day)	Kv upper (m/day)	Kv lower (m/day)
1	Wandrawandian / Snapper Point	confined	0.1	0.0001	0.05	0.0003	0.000003	0.000003

A.3.2.1 Boundary conditions

Boundary conditions for the cavern model are summarised as follows:

- An external specified head, uniform gradient boundary was applied.
- For the prediction model the progressive top-down excavation of the cavern was simulated by an internal specified head line boundary consistent with the base of excavation at three-monthly increments. Specified heads were:
  - Stress Period 1 to 10 mAHD
  - Stress Period 2 to 0 mAHD

- Stress Period 3 to -16 mAHD.

A.3.2.2 Calibration

The cavern model was established with a head of approximately 125 mAHD in the vicinity of the caverns, as such calibration was not undertaken.

A.3.2.3 Prediction model

For the prediction model the cavern model was run in transient mode with specified head boundaries applied to simulate the base of the excavation, with excavation progressively advancing from top down over the nine-month excavation period. Model stress periods are summarised in **Table A-3**.

Table A-3 Model stress periods

Stress period	Duration	Time steps	Step multiplier	Purpose
1	90 days	4	1.5	Progressive cavern excavation
2	90 days	4	1.5	Progressive cavern excavation
3	90 days	4	1.5	Progressive cavern excavation
4	36500 days	4	1.5	Long-term water level response

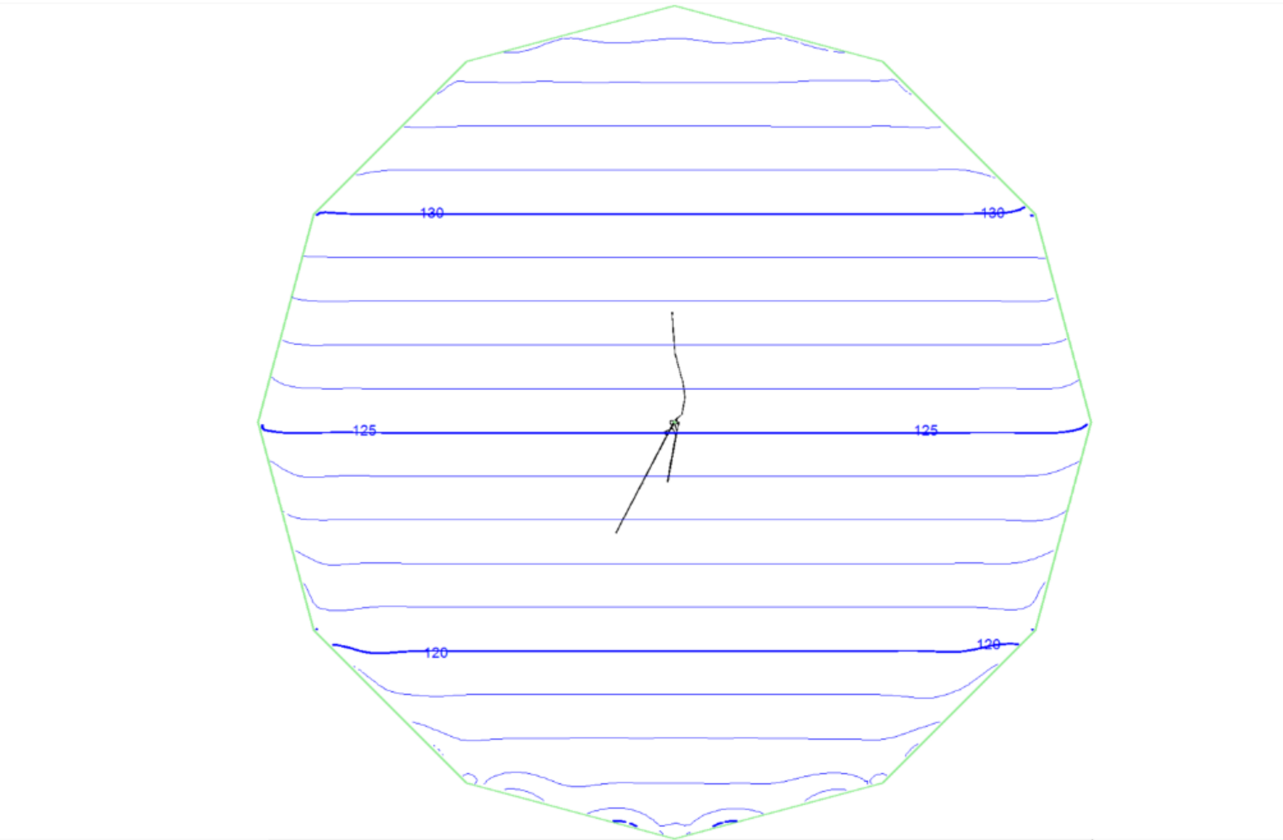

Figure A-6 Cavern model – model extent and steady state water levels (mAHD)

A.3.2.4 Results

Transient groundwater inflows to the caverns are presented on **Figure A-7**. Inflows are predicted to peak at approximately 45.6 m3/day (0.53 L/s). It is anticipated that inflows will progressively increase as the excavation is advanced. Long-term inflows settle out at approximately 36.1 m3/day (0.42 L/s).

Predicted drawdowns at end of construction and 100 years post construction are presented on **Figure A-8** and **Figure A-9**.

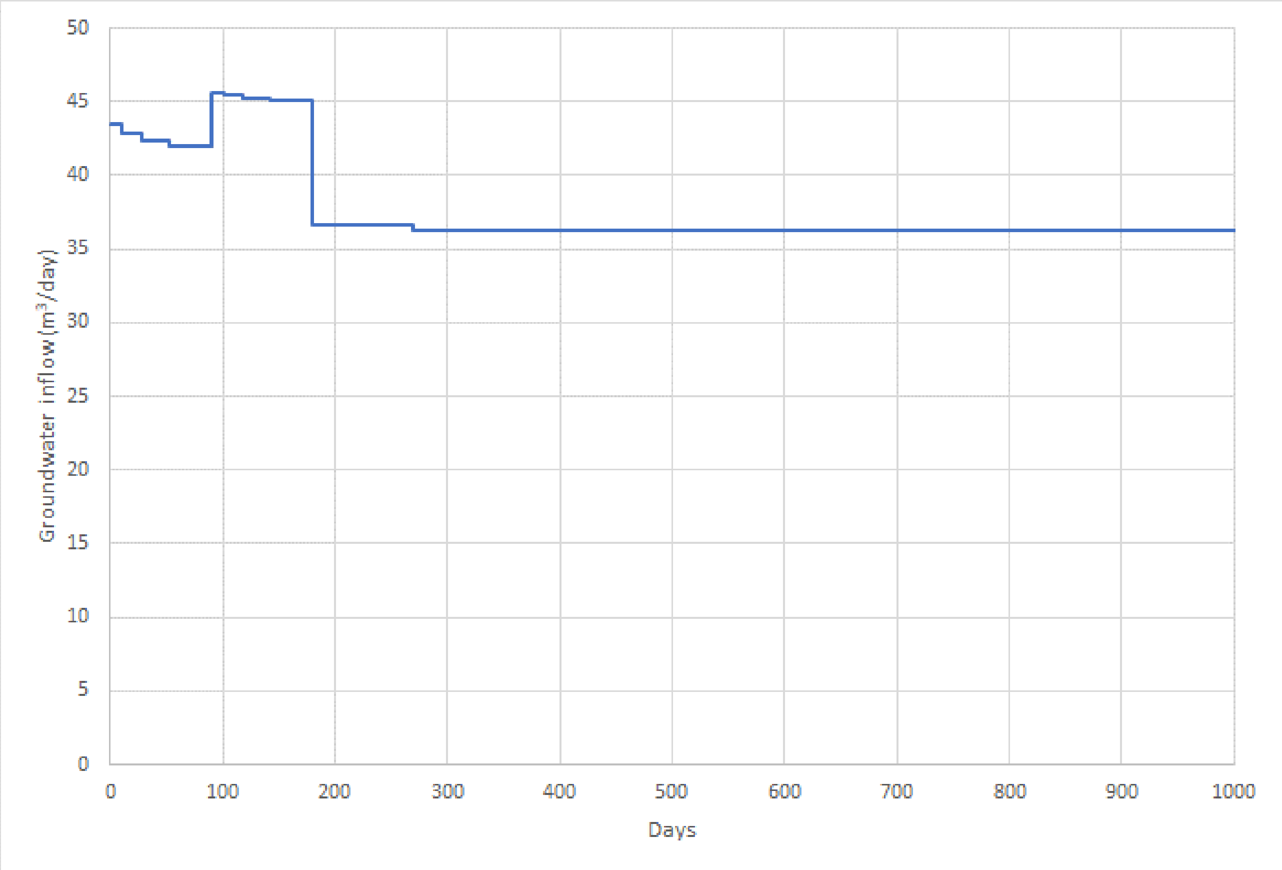

Figure A-7 Cavern model – discharges to internal specified head line boundaries

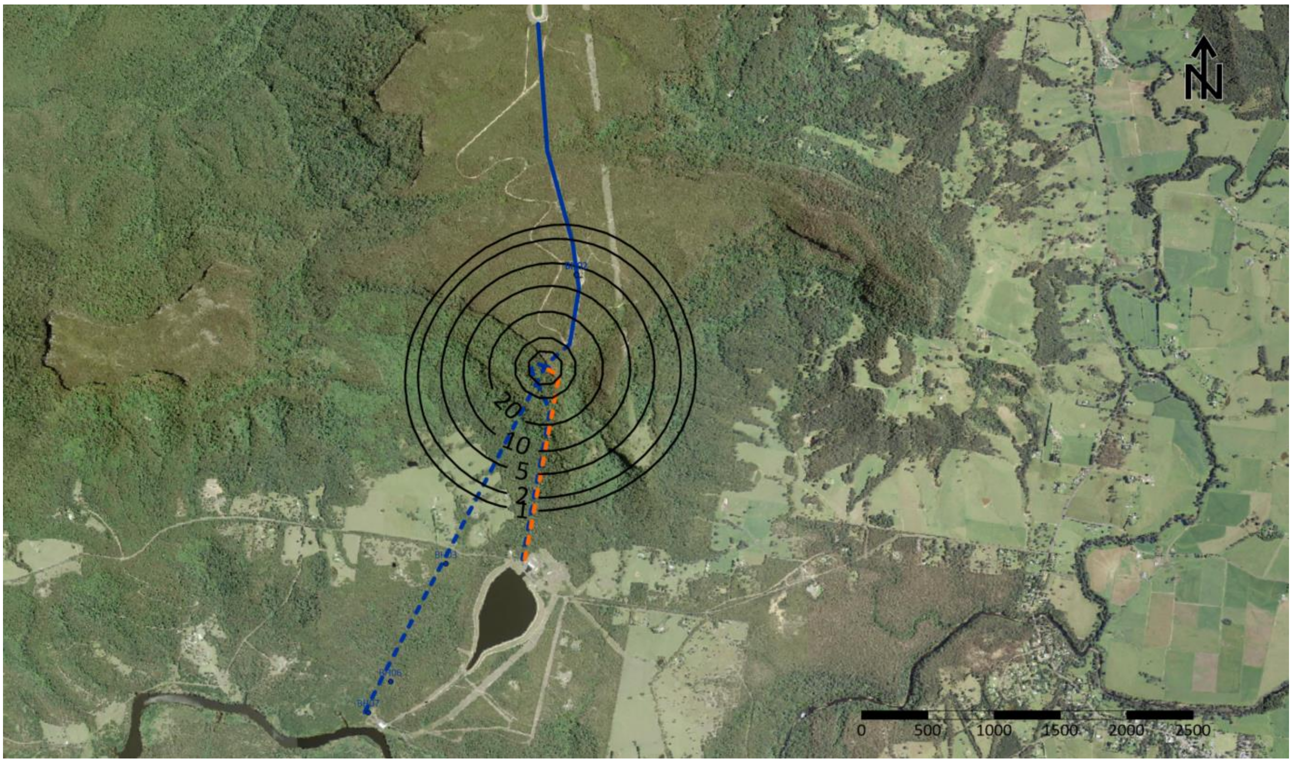

Figure A-8 Cavern model – Predicted drawdown at end of construction (m)
Aerial imagery source: MinView (https://minview.geoscience.nsw.gov.au/).

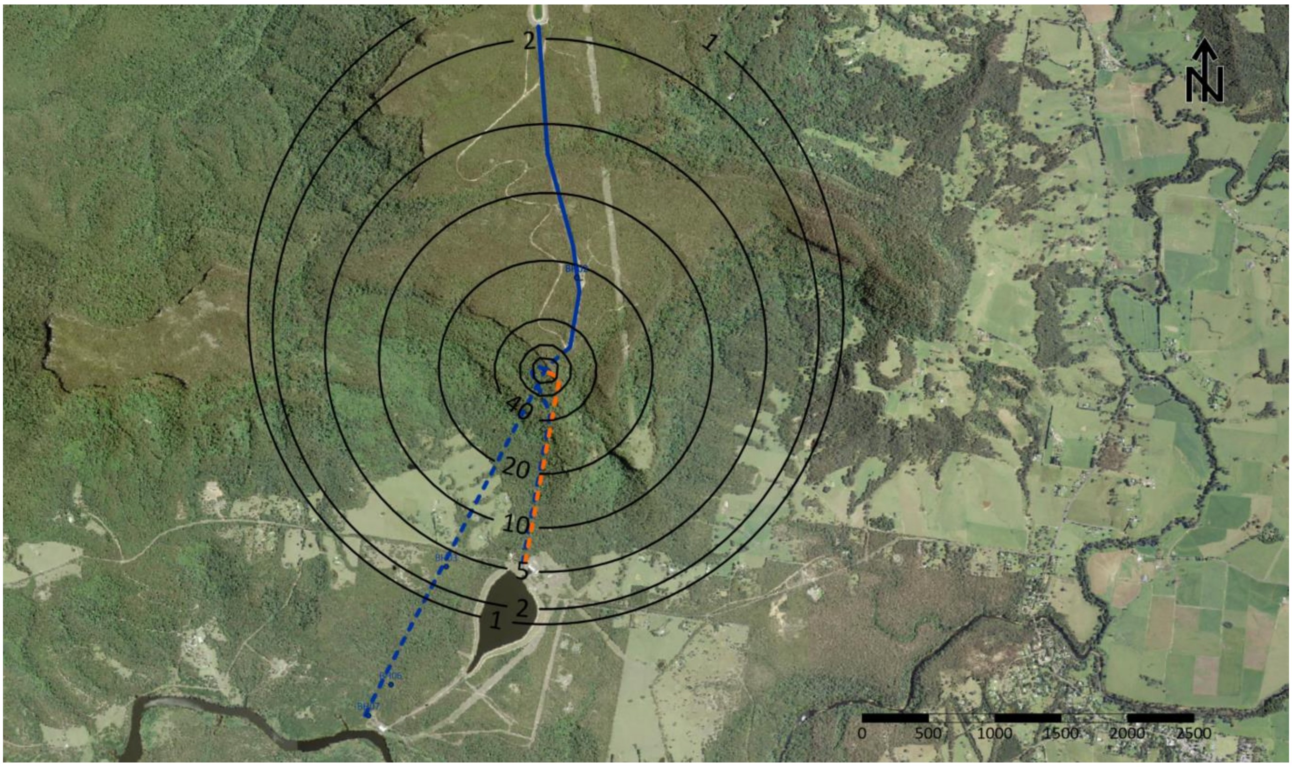

Figure A-9 Cavern model – Predicted drawdown at 100 years post construction (m)
Aerial imagery source: MinView (https://minview.geoscience.nsw.gov.au/).

Appendix B. Groundwater Modelling – SEEP/W

B.1 Introduction

Numerical groundwater flow models have been developed in support of the Shoalhaven Hydro Expansion Project. The modelling objectives were primarily to assess propagation of groundwater level drawdown and depressurisation resulting from groundwater seepage to excavations. Given that groundwater seepage (inflows) to tunnels and excavations has been assessed through other means (refer **Chapter 8** of the main report) and SEEP/W cannot account for radial inflows, quantification of inflows was not a primary objective of the modelling exercise.

B.2 Adopted model type and program

The groundwater flow model has been developed in the Geostudio software package, SEEP/W (v2019). SEEP/W is a finite element modelling package for modelling groundwater flow in porous media. Two-dimensional cross section style models were developed.

B.3 Model set up

Modelling using SEEP/W involved the 2D simulation of groundwater conditions in the areas around proposed drainage and access structures associated with the Shoalhaven Hydro Expansion Project. The five models either simulated conditions under steady state conditions, or transiently for the period of structure construction. The modelling assessment focused on changes in hydraulic head due to groundwater seepage to the Project elements and included a null case model (no Project elements) and a Project case model (including tunnels or caverns as relevant).

Geologic sections, sourced from the Leapfrog geological model (IS392600-3DMODEL_UPDATED LAYOUT-VB-17062022) were used as the basis for each scenario. Predictive scenarios adopted for this study are summarized below in **Table B-1**.

Section locations are shown on **Figure B-1**. It is noted that the NW-SE trending sections are more or less perpendicular with the inferred regional groundwater flow direction (refer **Section 5.3** of the main report).

Table B-1 Summary of predictive modelling scenarios

ID	Section Name	Orientation	Model Type	Model Duration
Model 1	Main Cavern 1	SW-NE	Steady-State	-
Model 2	Main Cavern 2	NW-SE	Steady-State	-
Model 3	Tailrace 1	NW-SE	Transient	18 Months
Model 4	Tailrace 2	NW-SE	Transient	18 Months
Model 5	Tailrace / Access	NW-SE	Steady-State	-

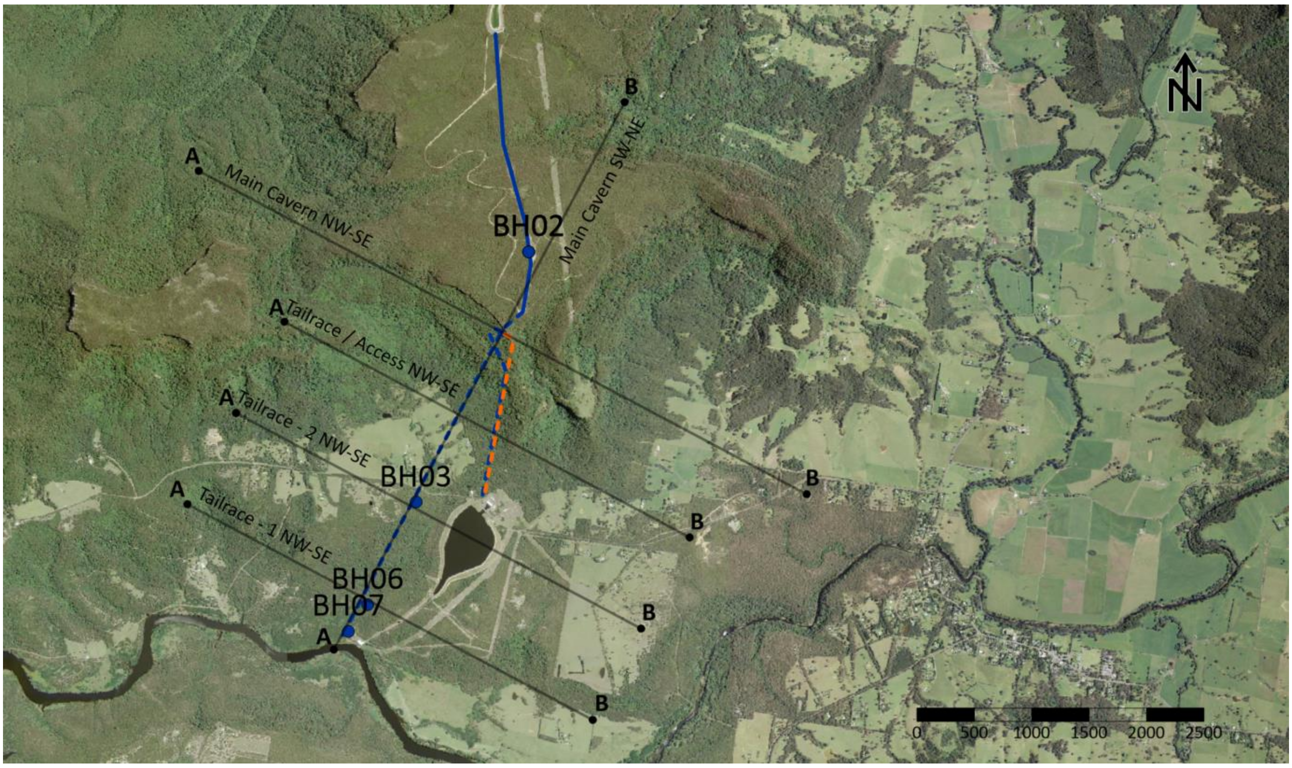

Figure B-1 Modelled section locations

Aerial imagery source: MinView (https://minview.geoscience.nsw.gov.au/).

B.3.1 Model layers

All geological units are represented in the model and are based on the Leapfrog geological model. The geologic units and associated hydraulic conductivity values defined for all models are as depicted below in **Figure B-2**. The geology of Model 1 is displayed as an example in **Figure B-3**.

B.3.2 Flow mode

Both saturated and unsaturated flow conditions were simulated.

B.3.3 Model parameters

Hydrogeological parameters applied in the models are provided on **Figure B-2**. Ky'/Kx' referred to on **Figure B-2** is the vertical hydraulic conductivity to horizontal hydraulic conductivity ratio. Hydrogeological parameters are discussed in detail in **Section 4.6** and **Section 5.6** of the main report.

Color	Name	K-Function	Ky'/Kx' Ratio
	1. Hawkesbury Sandstone	0.029 m/day	0.1
	2. Narrabeen Group	0.002 m/day	0.1
	3. Illawara Coal Measures	0.002 m/day	0.1
	4. Broughton Formation	0.002 m/day	0.1
	5. Budgong Sandstone	0.002 m/day	0.1
	6. Berry Siltstone	0.002 m/day	0.01
	7. Nowra Sandstone	0.002 m/day	0.01
	8. Wandrawandian Siltstone	0.0003 m/day	0.01
	9. Snapper Point Formation	0.0003 m/day	0.01
	C. Fault Zone	0.044 m/d	1

Figure B-2 Geologic units used across all model domains

B.3.4 Mesh resolution

A mesh resolution ranging from 4 m to 40 m was applied in the models, with refinement to finer grid in the vicinity of Project elements.

B.3.5 Boundary conditions

Boundary conditions adopted in modelling included:

- External constant head – applied to simulate observed or expected head conditions in the vicinity of the Project elements of interest, including Lake Yarrunga (Model 1) and Bendeela Pondage (Model 4)
- Recharge - was applied across all modelled sections and was estimated to at 4% of average annual rainfall, equivalent to approximately 0.134 mm/day. Recharge was applied uniformally across the surface of all models for the duration of the modelled period
- Internal potential seepage face - applied around tunnels and caverns to simulate seepage to excavations and dewatering.

B.3.6 Model calibration

Each model was calibrated to observed or expected groundwater head conditions, using measured heads from groundwater wells, where available, and known surface water features along the length of each section. A summary of initial head conditions assigned to each model section is displayed below in **Table B-2** below.

Table B-2 Summary of initial head conditions for base case scenarios

ID	Scenario	Upgradient Heads	Downgradient Heads
Model 1	Main Cavern – SW-NE	Approx. 150m head on cavern location	Lake Yarrunga – 56mAHD
Model 2	Main Cavern – NW-SE	Calibrated for 150m head on cavern location	
Model 3	Tailrace 1	Callbrated to heads at BH06 – approximately 60m AHD	
Model 4	Tailrace 2	Bendeela Pondage – 182m AHD	BH03 –74m AHD
Model 5	Tailrace / Access	Callbrated to heads at STPL 2 – approx 250m AHD	

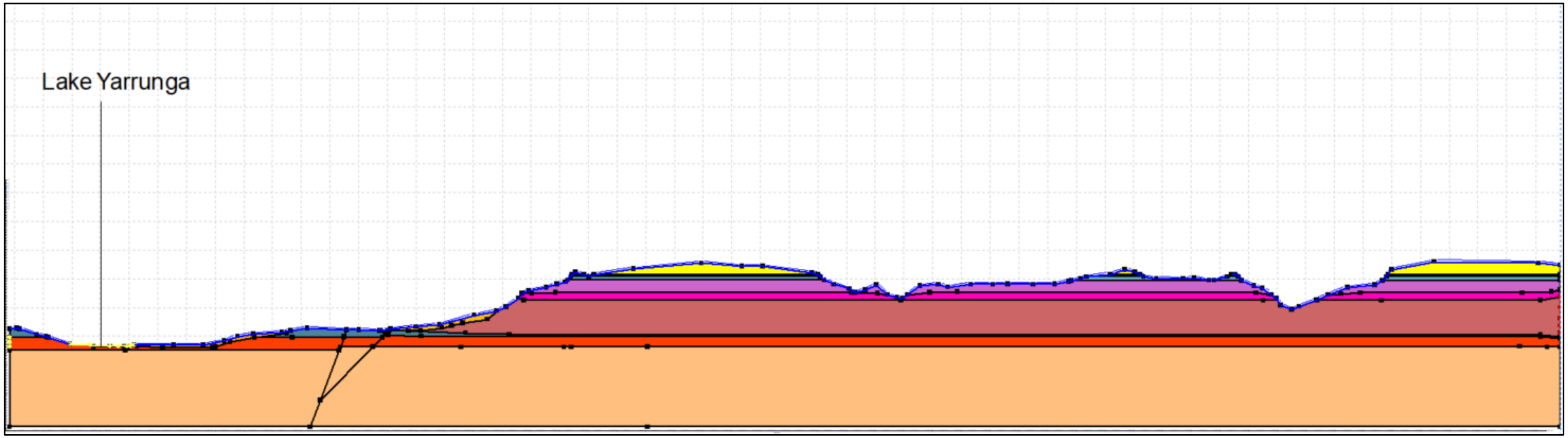

Figure B-3 Geology and geometry of Model 1 null case

B.3.7 Predictive models

The proposed Project elements (tunnels and caverns) were incorporated into the relevant model geometry to assess the impacts of the development on groundwater conditions in the region (Project case model). As an example, Model 1 geometry with proposed power station and transformer caverns added for the Project case model is shown below in **Figure B-4**.

All Project case scenarios incorporate a halo of improved ground surrounding the cavern or tunnel to replicate the grouting of fractures such that groundwater flow to the cavern or tunnel is via primary formation permeability only.

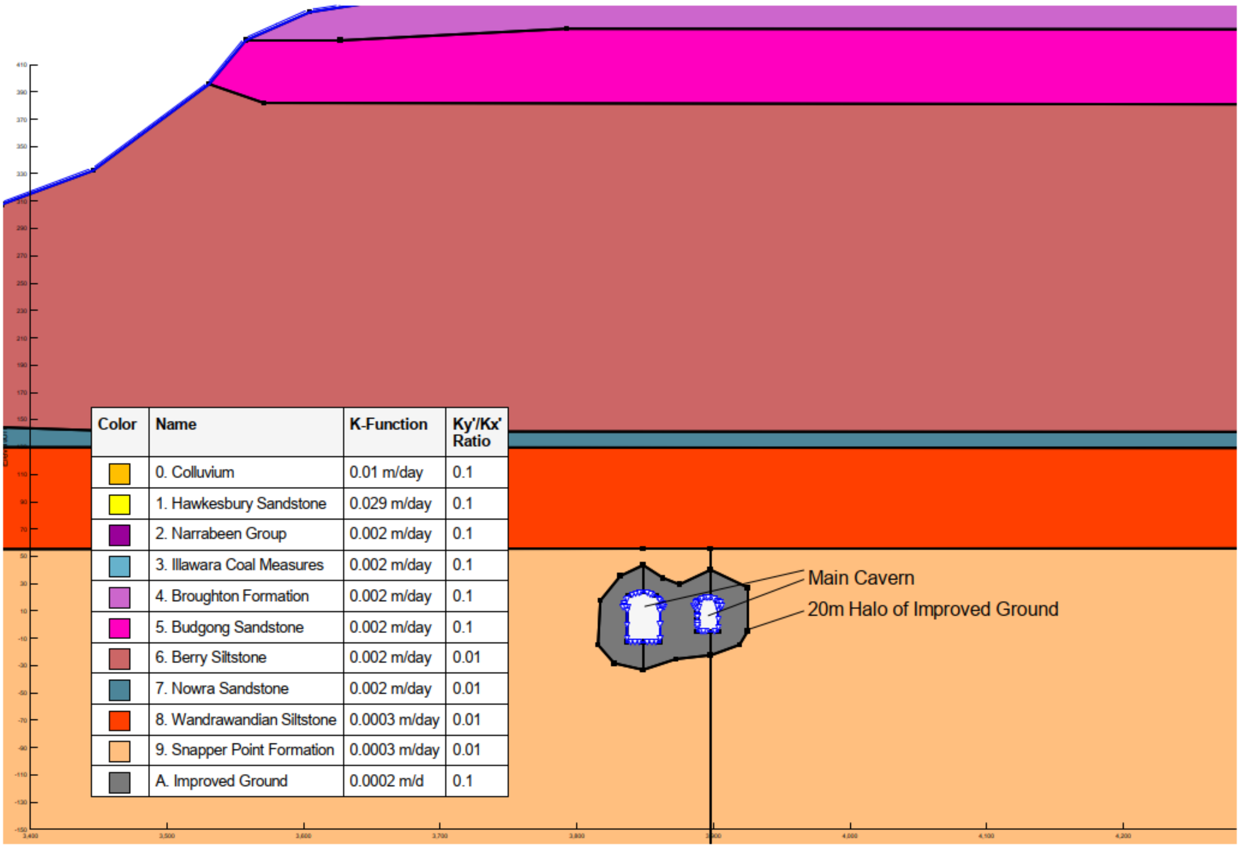

Figure B-4 Model 1 Geometry with proposed Project caverns

B.4 Results

B.4.1 Model 1 - main cavern SW-NE

Model 1 of the main caverns was modelled in steady state mode and as such is likely a conservative estimate of the potential long-term response of the groundwater system to ongoing seepage to the drained structure. Given the low horizontal hydraulic conductivity and very low Kv/Kh ratio, groundwater response times and time required to reach equilibration are likely to be of the order of hundreds of years.

Null case and Project case modelled heads are shown on **Figure B-5** and **Figure B-6**.

B.4.1.1 Change in hydraulic head

Simulated steady state heads for Model 1 null case are shown on **Figure B-5**. The water table in the null case section was modelled at approximately 145 mAHD, or 155 m above the main cavern floor such that the entire Wandrawandian and Snapper Point Formations are saturated.

The modelled Project case heads are shown on **Figure B-6** with indicated heads of the order of 80 to 120 m above the main cavern floor, equivalent to drawdown of approximately 35 to 75 m under steady state conditions. Depressurisation is centred on the inverts of the caverns with a zone of desaturation developing and extending down gradient (south) from the caverns.

Saturation above the caverns is maintained by the limited vertical propagation and downwards seepage from overlying strata.

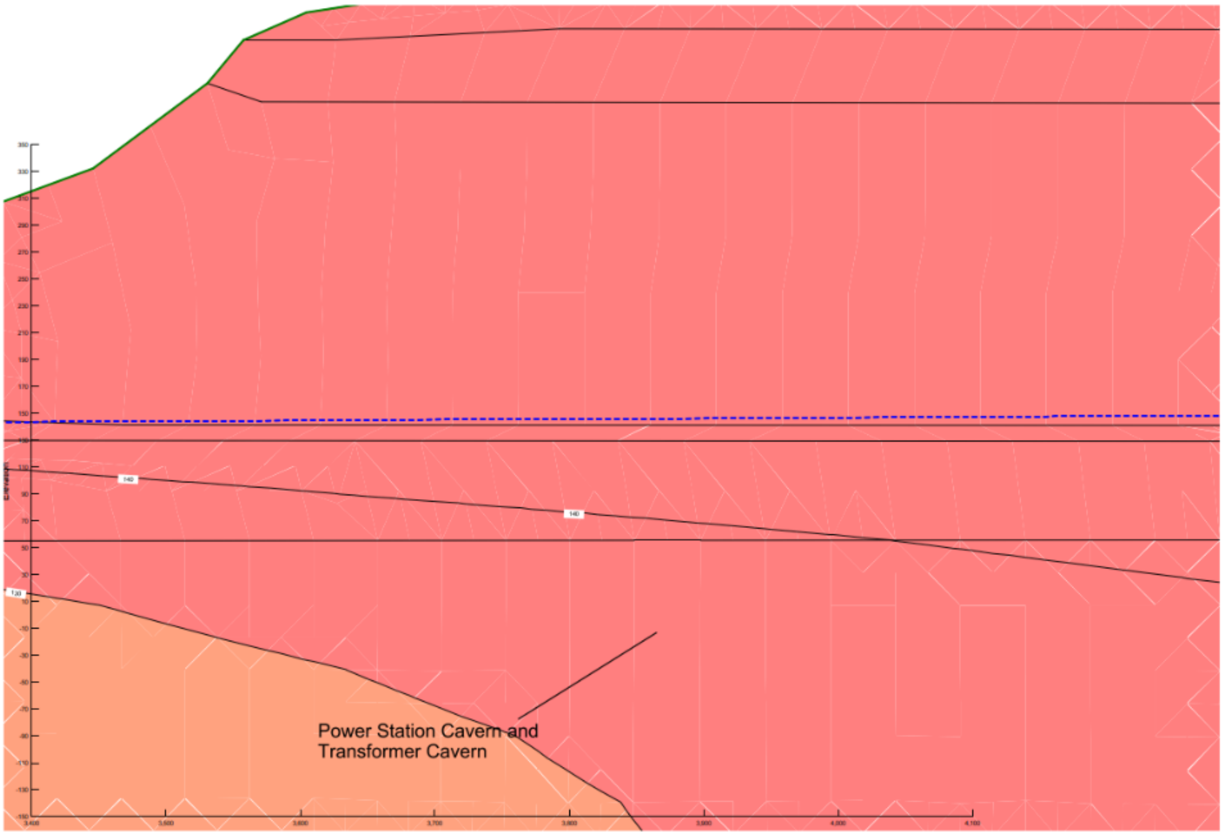

Figure B-5 Model 1 total head – null case

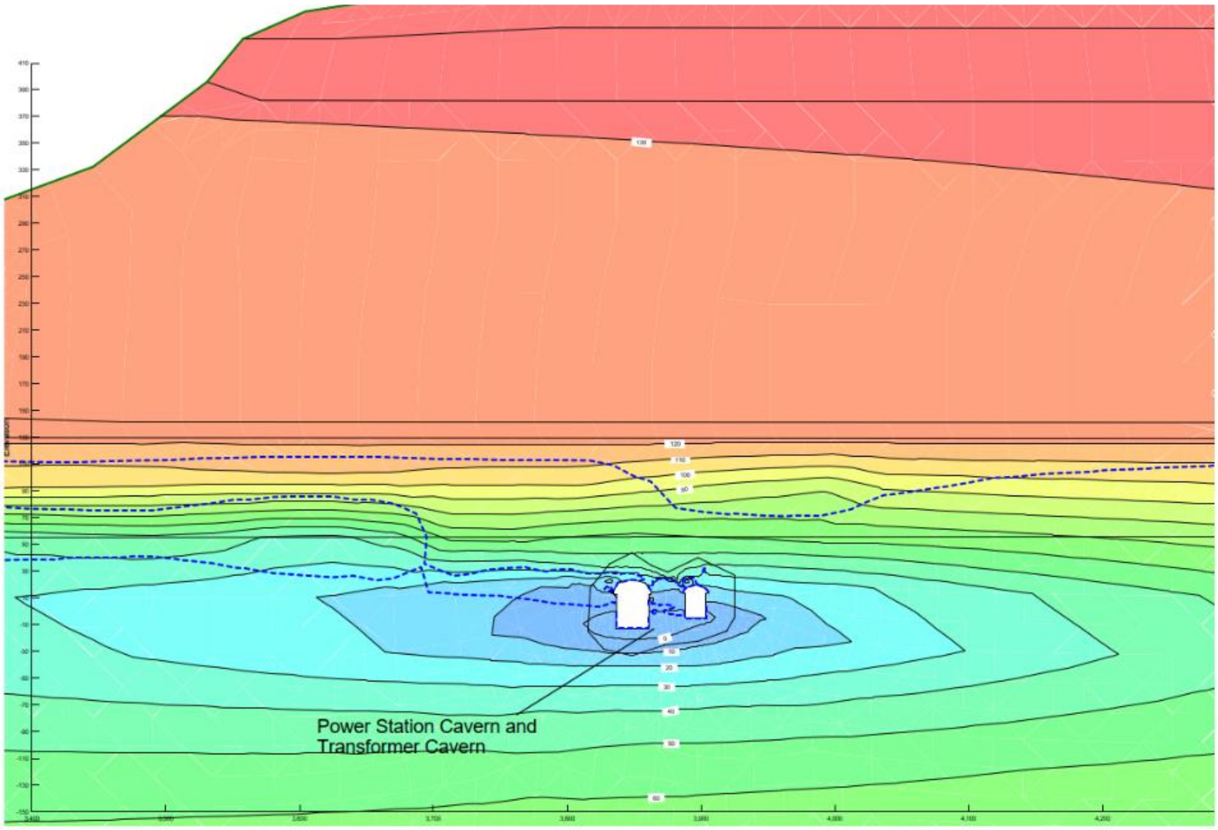

Figure B-6 Model 1 total head – Project case

B.4.2 Model 2 – main cavern NW-SE

Model 2 of the main caverns was modelled in steady state mode and as such is a conservative estimate of the potential long-term response of the groundwater system to ongoing seepage to the drained structures. Given the low horizontal hydraulic conductivity and very low Kv/Kh ratio, groundwater response times and time required to reach equilibration are likely to be of the order of hundreds of years. Model 2 is also aligned approximately perpendicular to the inferred regional groundwater flow direction and as such has limitations with respect to replicating regional groundwater flow.

Null case and Project case modelled heads are shown on **Figure B-7** and **Figure B-8**.

Change in hydraulic head

Simulated steady state heads for Model 2 null case are shown on **Figure B-7**. The water table in the null case section was modelled at approximately 140 mAHD, or 150 m above the main cavern floor such that the entire Wandrawandian and Snapper Point Formations are saturated.

Depressurisation is centred on the inverts of the caverns with a small zone of desaturation developing above the main cavern (**Figure B-8**). Saturation above the caverns is maintained by the limited vertical propagation and downwards seepage from overlying strata.

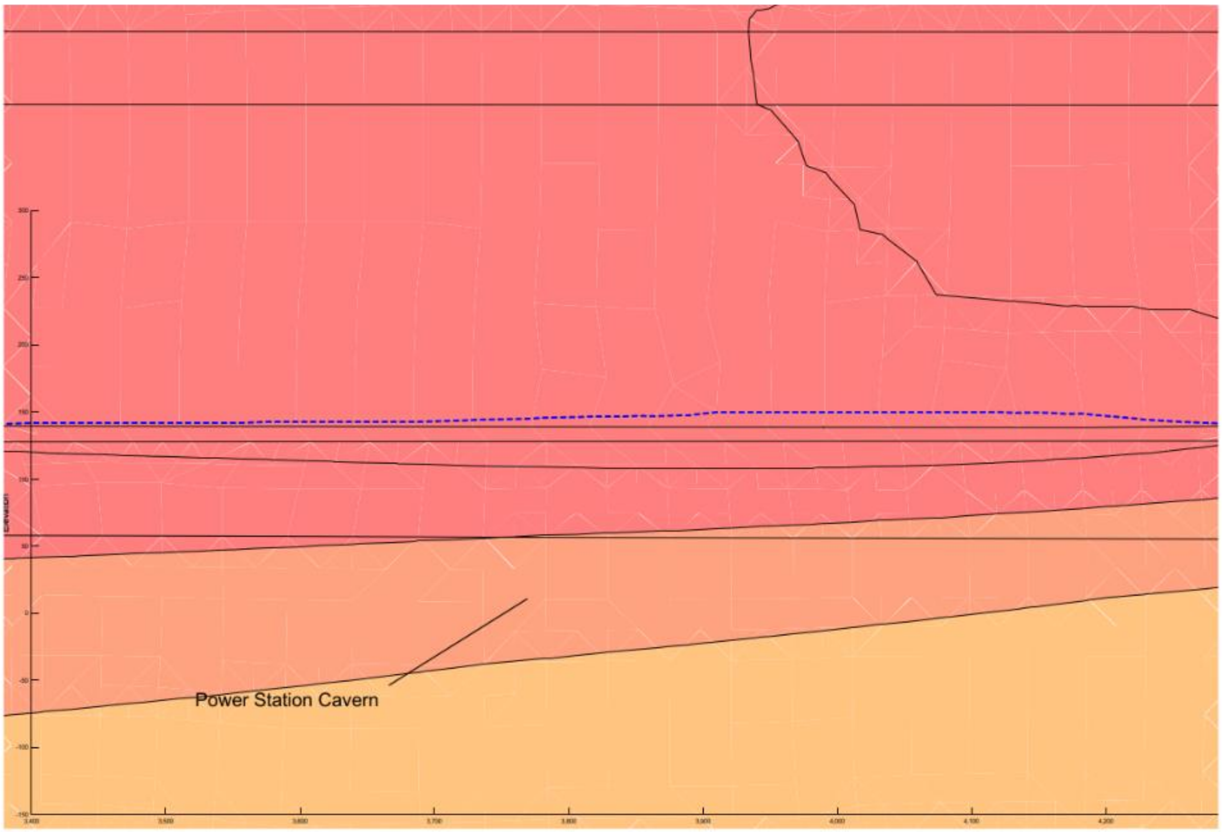

Figure B-7 Model 2 total head – null case

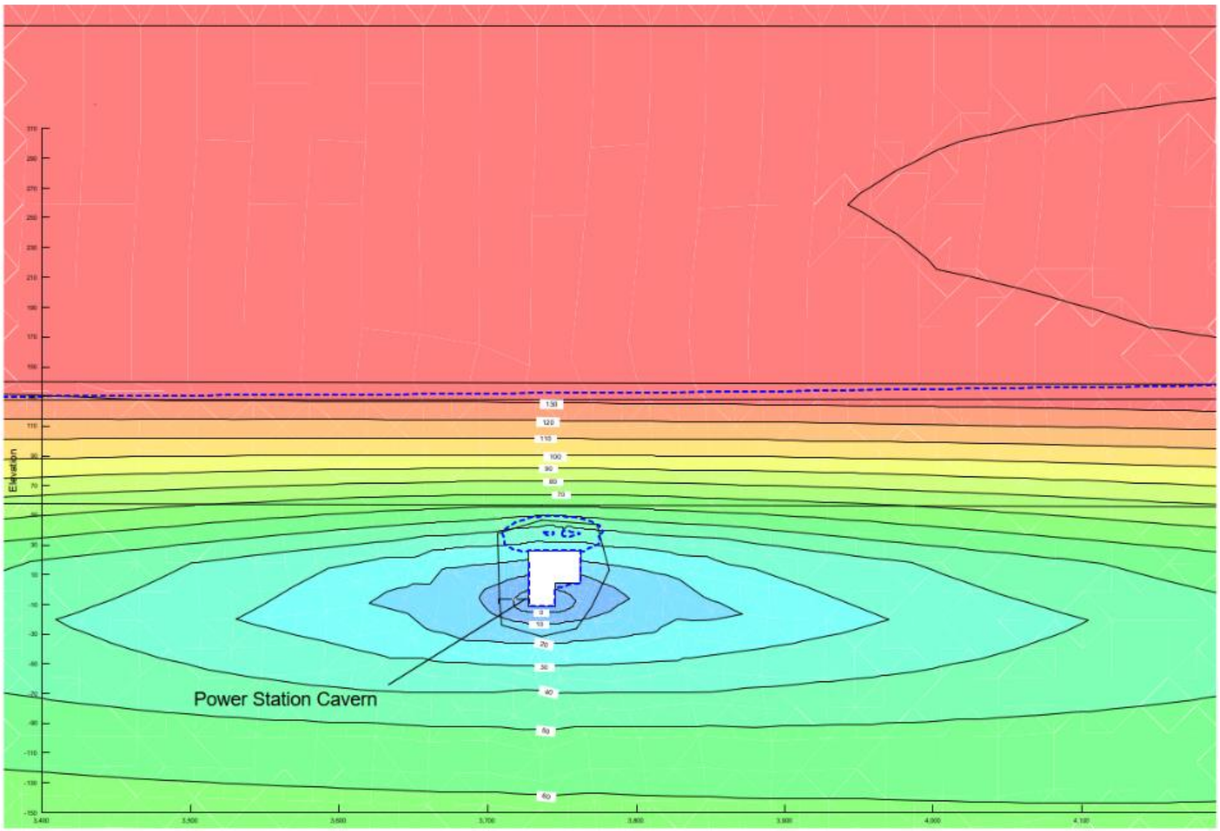

Figure B-8 Model 2 total head – Project case

B.4.3 Model 3 - Tailrace 1

Model 3 simulates the lower end of the tailrace approximately 470 m north of Lake Yarrunga. Model 3 Project case was run in transient mode to simulate the lag between initial excavation and application of primary support, and the final lining of the tunnel, a lag time of approximately 18 months.

Model 3 is aligned approximately perpendicular to the inferred regional groundwater flow direction and as such has limitations with respect to replicating regional groundwater flow. Null case and Project case modelled heads are shown on **Figure B-9** and **Figure B-10**.

Changes in hydraulic head

The simulated water table for the pre-development model is at an elevation of approximately 66 mAHD in the area above the tailrace. The pre-development groundwater levels indicate the potential for seepage and baseflow contribution to Kings Creek. However it is noted that the maximum water level from BH06, located adjacent to the alignment and approximately 30m off-section is of the order of 60 mAHD and is below the level of Kings Creek at this location. Therefore no baseflow contribution from the regional water table is anticipated at this location.

The water table elevation predicted from the Project case model above the main cavern structures, after an 18-month period, is at an elevation of approximately 60 mAHD, equivalent to a drawdown of approximately 6 m. Following the lining of the tailrace tunnel, full recovery of groundwater levels is anticipated.

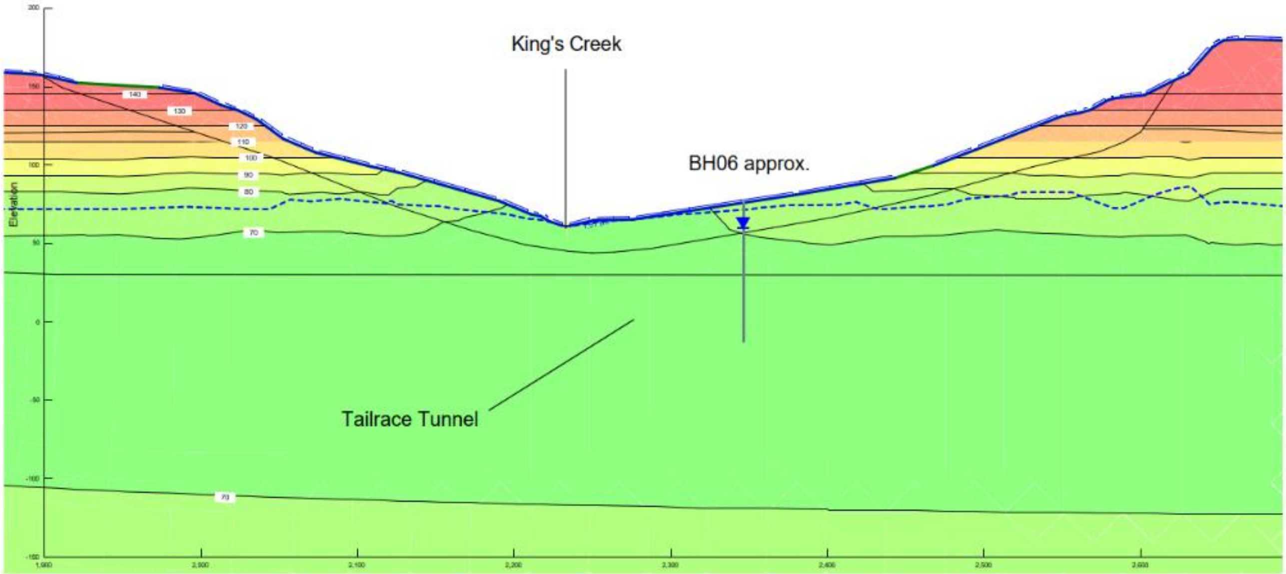

Figure B-9 Model 3 total head – null case

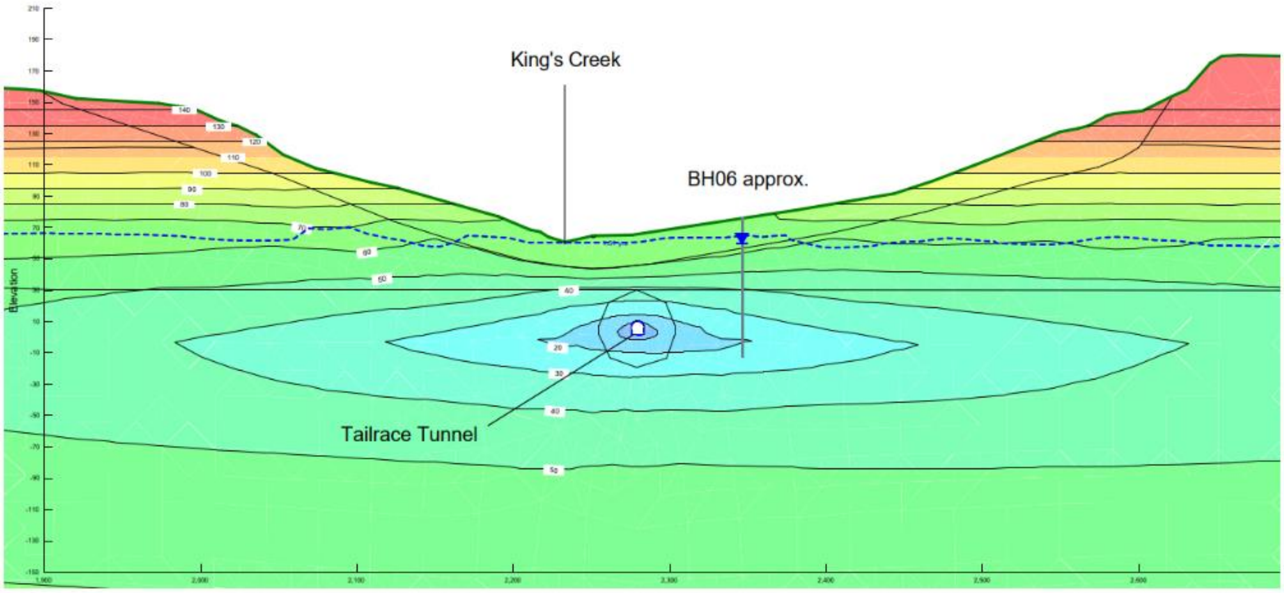

Figure B-10 Model 3 total head – Project case

B.4.4 Model 4 - Tailrace 2

Model 4 simulates the groundwater conditions at the tailrace tunnel in the vicinity of the BH03 fault zone and Bendeela Pondage. Model 4 Project case was run in transient mode to simulate the lag between initial excavation and application of primary support, and the final lining of the tunnel, a lag time of approximately 18 months.

Model 4 is aligned approximately perpendicular to the inferred regional groundwater flow direction and as such has limitations with respect to replicating regional groundwater flow. Base case and Project case modelled heads are shown on **Figure B-11** and **Figure B-12**.

Changes in hydraulic head

The water table in the null case section was modelled at approximately 80 mAHD over the tailrace structure. Observed upper water levels at BH03, located approximately 30 m east of the alignment and approximately 50m off-section is of the order of 74 mAHD. This is considerably below the level of Kings Creek and represents a significant hydraulic drop from the seepage and mounding in the vicinity of Bendeela Pondage.

The water table modelled by the predictive scenario indicates no significant drawdown after an 18-month period. This is inferred to be due to the significant contrast between the tunnel primary support and halo of improved ground, and the elevated hydraulic conductivity and storage within the fault zone.

No influence on either Kings Creek or Bendeela Pondage is indicated.

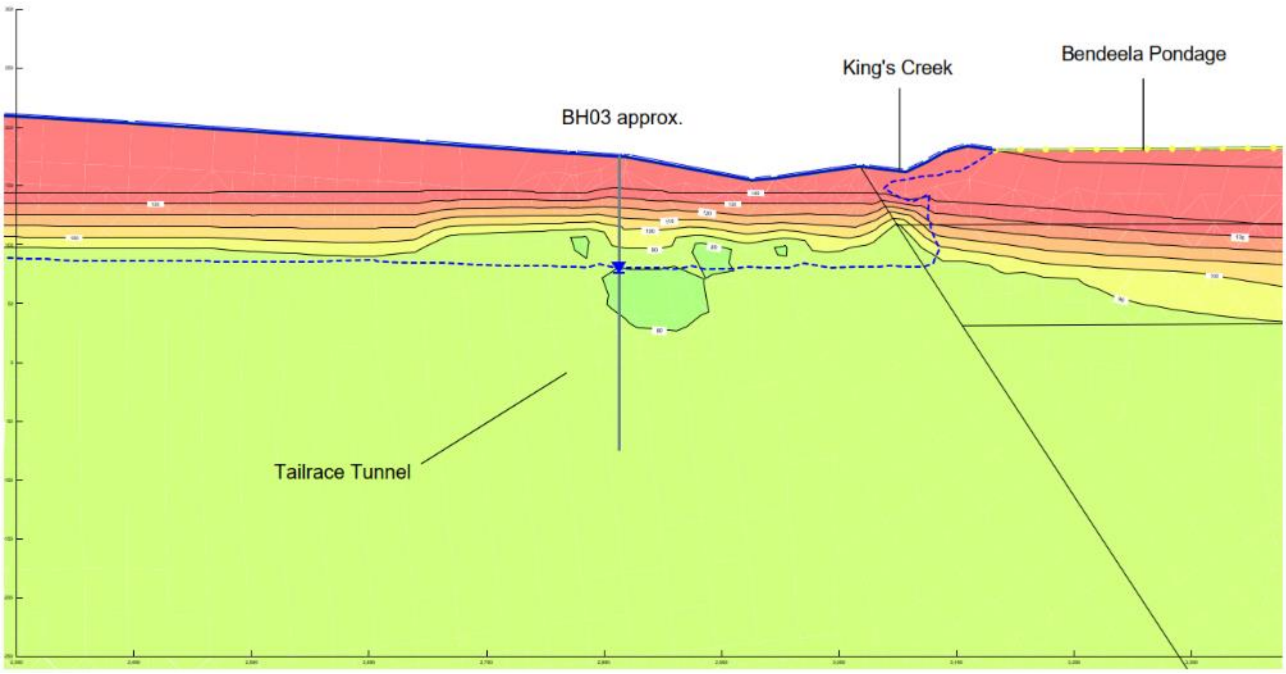

Figure B-11 Model 4 total head – null case

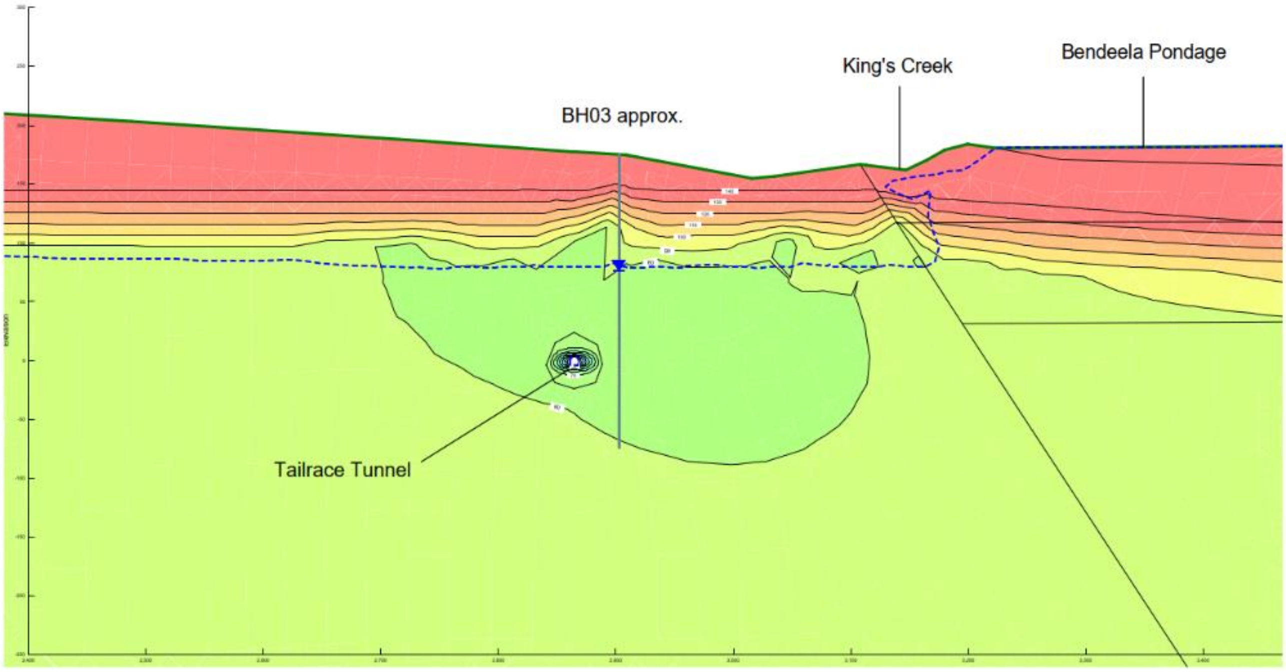

Figure B-12 Model 4 total head – Project case

B.4.5 Model 5 – access tunnels

Model 5 simulates the groundwater conditions at the access tunnel and ventilation and egress tunnel approximately midway between the portal and the power station cavern. Model 4 was run in steady state to simulate long-term seepage to the drained structures.

Model 5 is aligned approximately perpendicular to the inferred regional groundwater flow direction and as such has limitations with respect to replicating regional groundwater flow. Base case and Project case modelled heads are shown on **Figure B-13** and **Figure B-14**.

Change in hydraulic head

The water table in the base case section was modelled at 220 mAHD above the main cavern structures.

The steady state water table predicted from the Project case model above the access structures is approximately 200 mAHD, equivalent to a drawdown of approximately 20 m under steady state conditions.

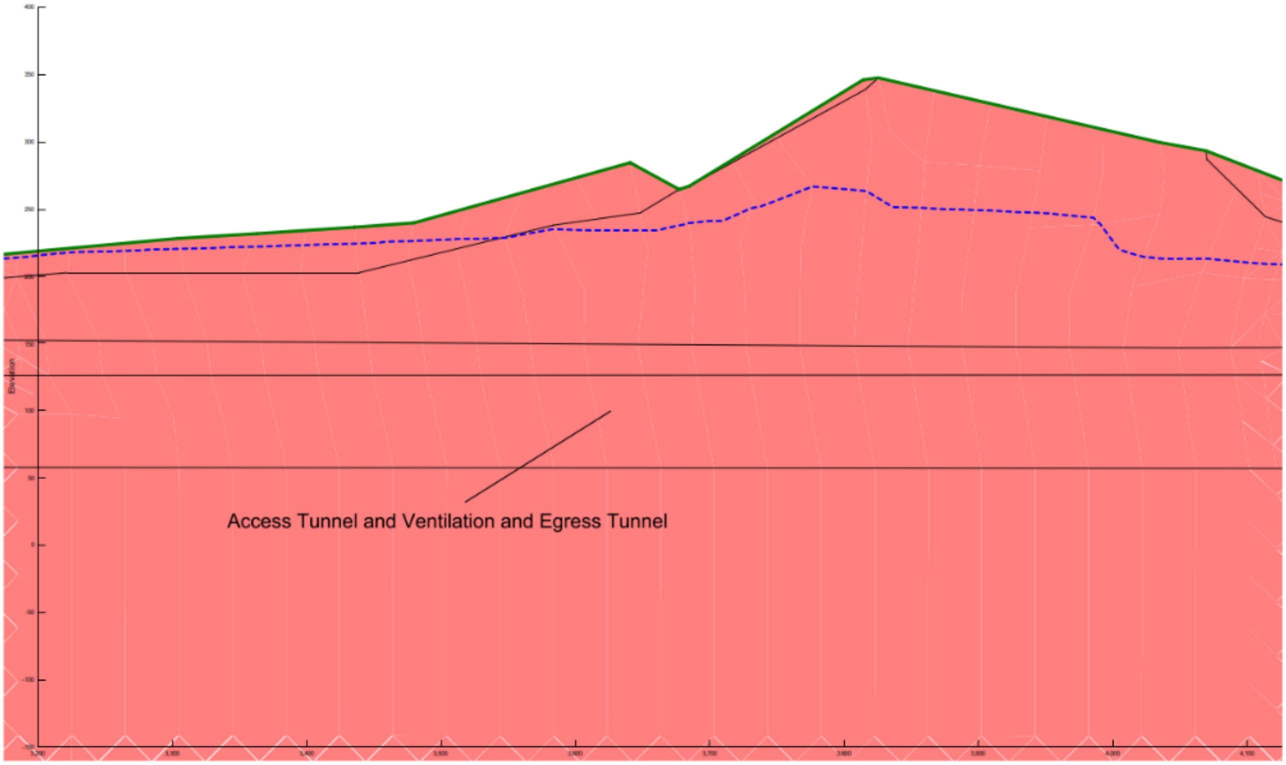

Figure B-13 Model 5 total head – null case

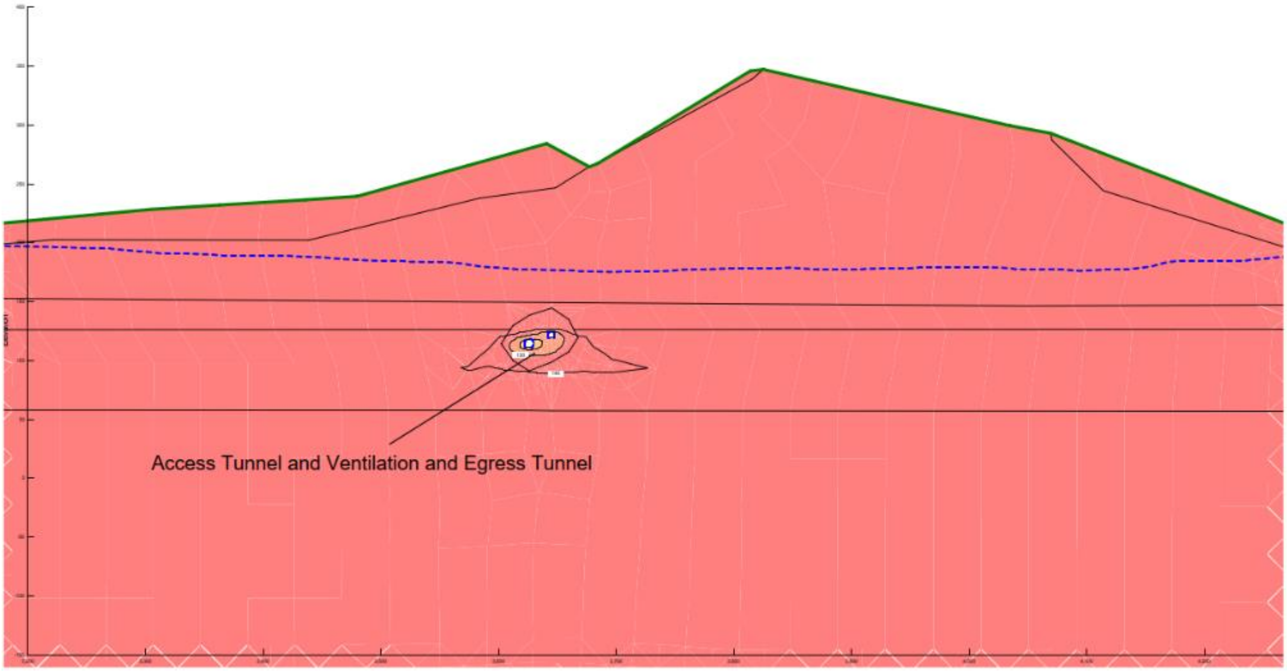

Figure B-14 Model 5 total head – Project case