Appendix I
Groundwater

Great Western Highway Blackheath to Little Hartley

Appendix I - Technical report - Groundwater

Client: Transport for NSW

ABN: 18 804 239 602

Prepared by

AECOM Australia Pty Ltd
Level 21, 420 George Street, Sydney NSW 2000, PO Box Q410, QVB Post Office NSW 1230, Australia
T +61 2 8008 1700 www.aecom.com
ABN 20 093 846 925

18-Jan-2023

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Glossary and abbreviations

Term	Description
ADWG	Australian Drinking Water Guidelines
AIP	Aquifer Interference Policy
ANZECC	Australian and New Zealand Environmental Conservation Council
ANZG	Australia and New Zealand Guidelines
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ASR	Acid Sulfate Rock
ASRMP	Acid Sulfate Rock Management Plan
ASSMP	Acid Sulfate Soil Management Plan
ASSMAC	Acid Sulfate Soils Management Advisory Committee
AWS	Automated Weather Station
BC Act	Biodiversity Conservation Act 2016 No 63
BoM	Bureau of Meteorology
BTEXN	Benzene, Toluene, Ethylbenzene, Xylenes and Naphthalene
CBD	Central Business District
CCTV	Closed Circuit Television
CEMP	Construction Environment Management Plan
CLM Act	Contaminated Land Management Act 1997
CRD	Cumulative Rainfall Departure
CoPC	Contaminant of Potential Concern
DPE	NSW Department of Planning and Environment
DPE Water	NSW Department of Planning and Environment Water
EC	Electrical Conductivity
EIS	Environmental Impact Statement
EP&A Act	Environmental Planning and Assessment Act 1979
EPB	Earth Pressure Balance
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
EPL	Environment Protection Licence
GA	Geoscience Australia
GDEs	Groundwater Dependent Ecosystems
GWV	Groundwater Vistas v.8 format
LGA	Local Government Authority
LLS	Local Land Services
LTAAEL	Long-term Average Annual Extraction Limit
mAHD	metres Australian Height Datum
mbgl	metres below ground level

Term	Description
ML	Megalitres
NSW	New South Wales
NSW EPA	New South Wales Environment Protection Authority
NSW WQO	NSW Water Quality Objectives
NWQMS	National Water Quality Management Strategy
OCPs	Organochlorine Pesticides
OPPs	Organophosphorus Pesticides
PAHs	Polycyclic Aromatic Hydrocarbons
PASR	Potential Acid Sulfate Rock
PFAS	Per- and Poly-Fluoralkyl Substances
POEO Act	Protection of the Environment Operations Act 1997
REF	Review of Environmental Factors
SEARs	Secretary's Environment Assessment Requirements
SVOCs	Semi-volatile Organic Compounds
SWMP	Surface Water Management Plan
TBM	Tunnel Boring Machine
TDS	Total Dissolved Solids
THPSS	Temperate Highland Peat Swamps on Sandstone
Transport	Transport for New South Wales
TRH	Total Recoverable Hydrocarbons
VOCs	Volatile Organic Compounds
VWP	Vibrating Wire Piezometer
WAL	Water Access Licence
Water Act	NSW Water Act 1912
WM Act	NSW Water Management Act 2000
WSP	Water Sharing Plan
WTP	Water Treatment Plant

Executive summary

Project overview

Transport for NSW (Transport) is seeking approval under Division 5.2, Part 5 of the NSW Environmental Planning and Assessment Act 1979 (EP&A Act) to upgrade the Great Western Highway between Blackheath and Little Hartley (the project).

The project would comprise the construction and operation of new twin tunnels around 11 kilometres in length between Blackheath and Little Hartley, and associated surface road upgrade work for tie-ins to the east and west of the proposed tunnel portals.

Construction of the project is expected to take around eight years. Subject to planning approval, construction is planned to commence in 2024 and be completed by late 2031; however, the project would be open to traffic by 2030.

The majority of the project would be located below ground generally along or adjacent to the west of the existing Great Western Highway between around Blackheath and Little Hartley.

Construction of the project would include:

- site establishment and enabling works
- tunnel portal construction
- tunnelling and associated works
- surface road upgrade works
- operational infrastructure construction and fit-out, including construction of operational environmental controls
- finishing works, testing, and commissioning.

Purpose of this technical report

This groundwater technical report is one of a number of technical documents that forms part of the EIS. The purpose of this technical report is to provide a groundwater impact assessment which addresses the Secretary's Environment Assessment Requirements (SEARs). This technical report provides an assessment of the groundwater impacts associated with the construction and operation of the project and recommended management measures to minimise these impacts.

Methodology

The methodology applied to assessment of potential impacts on the groundwater system arising from the project include:

- characterisation of the existing environment including climate, topography, geology, and groundwater resources, including groundwater occurrence, quality, use, and groundwater dependent ecosystems (GDEs)
- review of similar assessments and previous tunnelling projects in the region
- dedicated field investigations including drilling, permeability testing, monitoring bore installation, and water level and quality monitoring
- development of a conceptual hydrogeological model
- development of a three-dimensional numerical groundwater flow model to simulate tunnelling and provide predictions of groundwater inflows and drawdown propagation. The groundwater modelling approach is consistent with the Australian Groundwater Modelling Guidelines (Barnett et al, 2012) and has undergone an independent third-party review by a suitably qualified person
- assessment of potential groundwater impacts to satisfy the minimal impact considerations of the NSW Aquifer Interference Policy (AIP) and to address groundwater related issues raised in the SEARs

- assessment of potential cumulative impacts through identification and review of other projects in the area
- development of mitigation and management measures to address the impacts identified for both construction and operation of the project
- recommendations for monitoring and management of identified impacts and risks, including validation of mitigation measures as appropriate.

Existing environment

- the construction footprint is proposed immediately adjacent to the Greater Blue Mountains World Heritage Area (GBMA) at Blackheath and Soldiers Pinch. This project was therefore assessed under the World Heritage significance criteria and National Heritage significance criteria
- the project would be generally aligned beneath the existing Great Western Highway, which is located along a ridge line. Numerous creeks and gullies traverse or extend from the Great Western Highway and connect as tributaries of rivers on both sides of the project corridor. Those on the southern and western side of the existing Great Western Highway feed into the Coxs River and those in the northern and eastern side of the Great Western Highway feed into the Grose River. Parts of the Coxs River catchments potentially affected by the project lie within Sydney's drinking water catchment
- the project lies within both the Sydney Basin Blue Mountains and the Sydney Basin Coxs River Groundwater Sources, regulated under the Groundwater Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011
- the project would tunnel through various lithostratigraphic units deposited during the middle Triassic to middle Permian periods and includes predominantly sandstone overlying the Illawarra Coal Measures
- sensitive receptors relevant to groundwater within the project area include groundwater users and groundwater dependent ecosystems (GDEs), including the high priority Temperate Highland Peat Swamps on Sandstone, which are at various locations between Blackheath and Little Hartley.

Assessment of impacts

The proposed construction methodology and project design has sought to minimise groundwater impacts, including:

- the use of tunnel boring machines (TBMs) to excavate the twin tunnels which lines the tunnels with precast concrete segments with an impermeable casing/membrane that minimises groundwater inflows to negligible rates as the TBMs progress
- tanking of the tunnel cross-passages and upper-section of the mid-tunnel access shaft upon construction completion.

Construction

The key potential construction phase groundwater impacts without mitigation identified in this assessment include:

- groundwater users may be impacted. Bore water levels may decrease at up to around 23 registered water supply bores located within the extent of groundwater drawdown due to dewatering required for tunnelling that intersects groundwater along the project. Two registered water supply bores have a maximum predicted drawdown of greater than two metres
- groundwater drawdown resulting in potential baseflow impacts to hanging swamps (classified as a THPSS GDE) located west of the project footprint (between the mid-tunnel caverns and Blackheath portals), due to the construction of the tunnel and cross-passages (prior to being tanked) and the mid-tunnel caverns, adit and access shaft
- groundwater drawdown resulting in potential for increased risk of contaminated groundwater migration, where areas of environmental interest (AEI) for contamination has been identified
- ground settlement impacts to buildings and structures due to tunnelling activities.

Operation

The twin tunnels and the cross-passages would be tanked by the end of the construction phase and the mid-tunnel access shaft and the adit would be infilled at the end of construction. Therefore, during the project's operational phase, groundwater inflows and drawdown impacts related to those features would cease (apart from minor leaks within the tunnels and cross-passages).

Groundwater flows and drawdown impacts during operation would be associated with the permanently drained features of the project, allowing long-term groundwater inflows to these features. Drained features include the portals at Blackheath and Little Hartley, and the mid-tunnel caverns.

The key potential operational phase groundwater impacts without mitigation identified in this assessment include:

- groundwater drawdown resulting in potential baseflow reductions at creeks, including Greaves Creek at Blackheath (predicted to be up to around 18%), and potential for impacts on THPSS GDEs
- groundwater drawdown resulting in potential baseflow impacts to hanging swamps (classified as a THPSS GDE) west of the project footprint (between the mid-tunnel caverns and Blackheath portals) due to the permanently drained mid-tunnel caverns
- groundwater drawdown resulting in potential for increased risk of contaminated groundwater migration, where areas of environmental interest (AEI) for contamination has been identified.

Management of impacts

The numerical groundwater model will be updated and refined as additional information from geotechnical and hydrogeological investigations, groundwater monitoring programs and further design development becomes available. Where a marked reduction in baseflow (groundwater contribution to surface water) is predicted due to construction of the project, design responses and/or other mitigation will be implemented, particularly for potential baseflow loss to surface water resources around the Blackheath portal. Design responses could include the review of tanked or drained infrastructure elements, pre-grouting of cross-passages and/or the treatment and discharge of treated groundwater into the affected creeks to address baseflow reductions.

Potential loss of groundwater available to existing groundwater users due to the project will be monitored during construction an operation (for a period of up to 24 months). This would include a baseline assessment of each of the registered groundwater bores predicted to have drawdown impacts greater than two metres. In accordance with the NSW AIP, if drawdown at registered bores is found to exceed two metres during construction and the initial stage of operation of the project, then measures will be taken to 'make good' the impact.

Additionally, the CEMP will be implemented to manage potential impacts to groundwater due to contaminant migration from AEIs.

Groundwater inflows collected from the drained underground infrastructure will be treated at three water treatment plants during construction (Blackheath, Soldiers Pinch and Little Hartley) and one during operation of the project at Little Hartley, prior to discharge. All surface water leaving the site will be treated and managed in accordance with Managing urban stormwater: soils and construction (the Blue Book) to ensure no dirty water will be released into drainage lines and/or waterways.

An updated assessment of potential ground settlement as a consequence of tunnel construction activities will be carried out based on the final design for the project, to confirm that acceptance criteria for settlement will not be exceeded for buildings/ structures, heritage items and other sensitive buildings, or critical infrastructure.

Ground settlement monitoring will be carried out during tunnel construction activities to confirm that settlement predictions are not exceeded. Where monitoring data identifies an exceedance, or potential for an exceedance, of the acceptance criteria for settlement, additional mitigation measures will be identified, which may include design and construction measures, monitoring and/ or reparatory works to affected buildings, structures or infrastructure.

1.0 Introduction

1.1 Project context and overview

The Great Western Highway is the key east-west road freight and transport route between Sydney and Central West New South Wales (NSW). Together, the Australian Government and the NSW Government are investing more than $4.5 billion towards upgrading the Great Western Highway between Katoomba and Lithgow (the Upgrade Program). Once upgraded, over 95 kilometres of the Great Western Highway will be two lanes in each direction between Emu Plains and Wallerawang.

The Upgrade Program comprises the following components:

- Great Western Highway Upgrade – Medlow Bath (Medlow Bath Upgrade): upgrade and duplication of the existing surface road corridor with intersection improvements and a new pedestrian bridge (approved).
- Great Western Highway East – Katoomba to Blackheath (Katoomba to Blackheath Upgrade): upgrade, duplication and widening of the existing surface road corridor, with connections to the existing Great Western Highway east of Blackheath (approved).
- Great Western Highway Upgrade Program – Little Hartley to Lithgow (West Section) (Little Hartley to Lithgow Upgrade): upgrade, duplication and widening of the existing surface road corridor, with connections to the existing Great Western Highway at Little Hartley (approved).
- Great Western Highway Blackheath to Little Hartley: construction and operation of a twin tunnel bypass of Blackheath and Mount Victoria and surface road works for tie-ins to the east and west of the tunnel (the project).

The components of the Upgrade Program are shown in Figure 1-1.

Transport for NSW (Transport) is seeking approval under Division 5.2, Part 5 of the *Environmental Planning and Assessment Act 1979* (NSW) (EP&A Act) to upgrade the Great Western Highway between Blackheath and Little Hartley (the project).

The project would comprise the construction and operation of new twin tunnels around 11 kilometres in length between Blackheath and Little Hartley, and associated surface road upgrade work for tie-ins to the east and west of the proposed tunnel portals.

The project would be located around 90 kilometres northwest of the Sydney CBD and located within the Blue Mountains and Lithgow Local Government Areas (LGA).

The majority of the project would be located below ground generally along or adjacent to the west of the existing Great Western Highway between around Blackheath and Little Hartley.

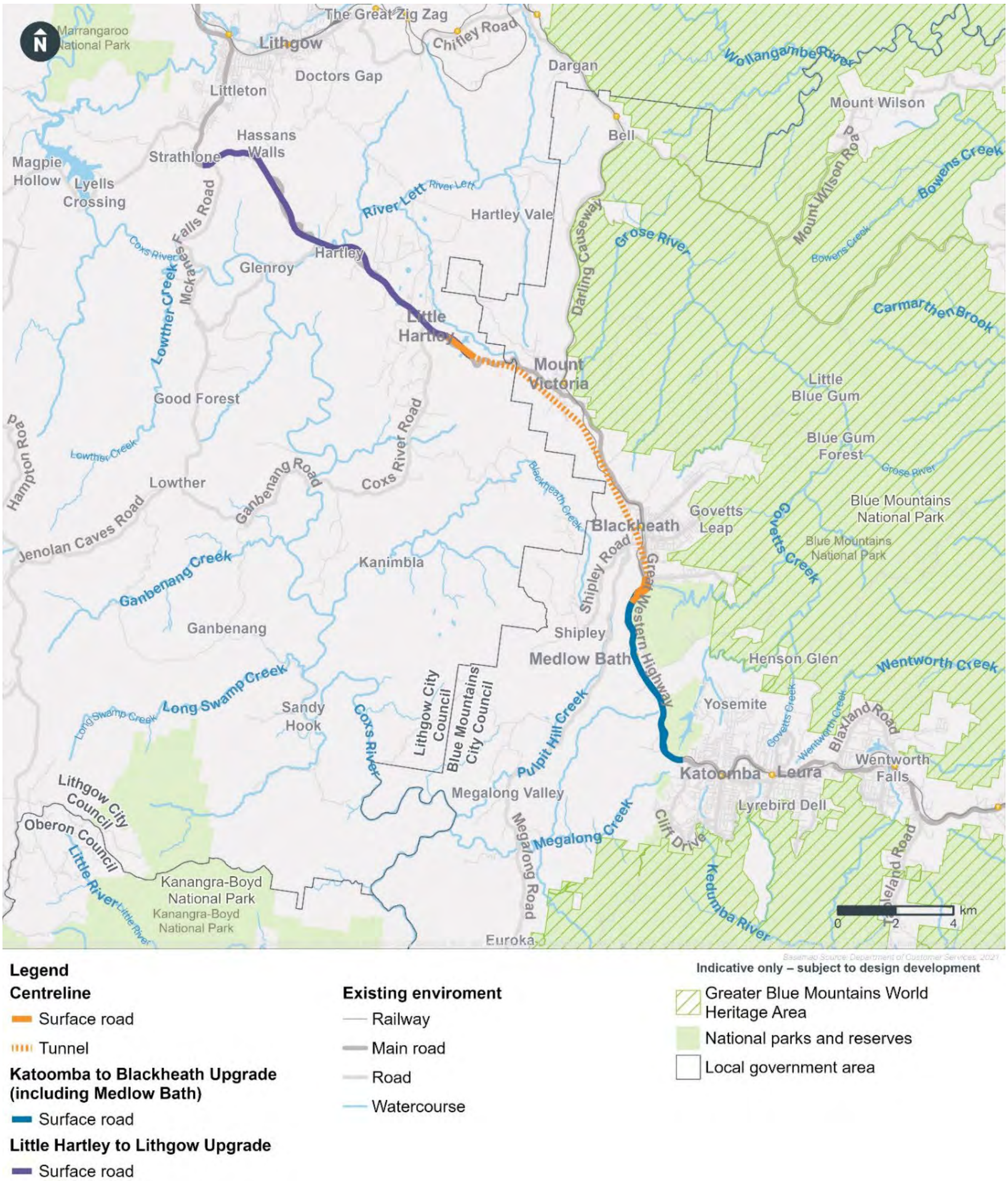


Figure 1-1 The Great Western Highway Upgrade Program

1.2 The project

1.2.1 Key components of the project

Key components of the project are summarised in Table 1-1 and shown in Figure 1-2. These components are described in more detail in Chapter 4 (Project description) of the environmental impact statement (EIS).

The indicative operational configuration of the surface road network at Blackheath and Little Hartley is shown in Figure 1-3 and Figure 1-4.

Subject to approval, the project is anticipated to be open to traffic in 2030.

Table 1-1 Key components of the project

Key project component	Summary
Tunnels	Twin tunnels around 11 kilometres in length between Blackheath and Little Hartley, connecting to the upgraded Great Western Highway at both ends. Each tunnel would include two lanes of traffic and road shoulders and would range in depth from just below the surface near the tunnel portals, to up to around 200 metres underground at Mount Victoria.
Surface work	Surface road upgrade work would be required to connect the tunnels and surface road networks south of Blackheath and at Little Hartley. The twin tunnels would connect to the surface road network via: • mainline carriage ways and on- and off-ramps at the Blackheath portal, located adjacent to the existing Great Western Highway and south of Evans Lookout Road • mainline carriageways at the Little Hartley portal, located adjacent to the existing Great Western Highway at the base of the western escarpment below Victoria Pass and southwest of Butlers Creek.
Operational infrastructure	Operational infrastructure that would be provided by the project include: • a tunnel operations facility adjacent to the Blackheath portal • in-tunnel ventilation systems including jet fans and ventilation ducts connecting to the ventilation facilities • one of two potential options for tunnel ventilation currently being investigated, being: • ventilation design to support emissions via ventilation outlets • ventilation design to support emissions via portals • water quality infrastructure including sediment and water quality basins, an onsite detention tank at Blackheath and a water treatment plant (WTP) at Little Hartley • fire and life safety systems, emergency evacuation and ventilation infrastructure and Closed Circuit Television • lighting and signage including variable message signs and associated infrastructure such as overhead gantries.
Utilities	Key utilities required for the project would include: • a new electricity substation at Little Hartley to facilitate the construction and operational power supply • a new pipeline between Little Hartley and Lithgow to facilitate construction and operational water supply • other utilities connections and modifications, including electricity substations in the tunnel
Other project elements	The project would also include: • integrated urban design initiatives • landscape planting.

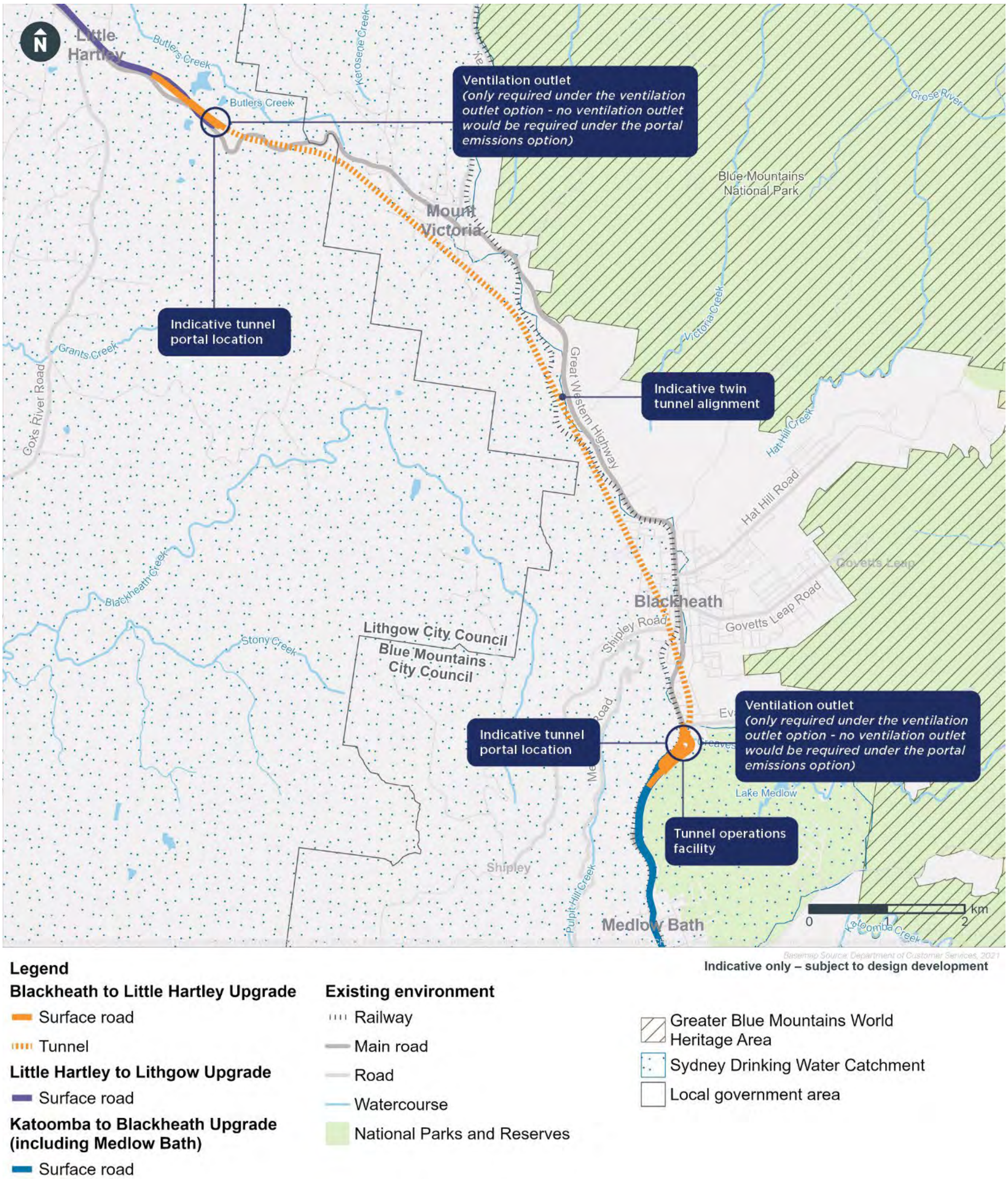


Figure 1-2 Overview of the project

Figure 1-3 Indicative operational configuration at Blackheath

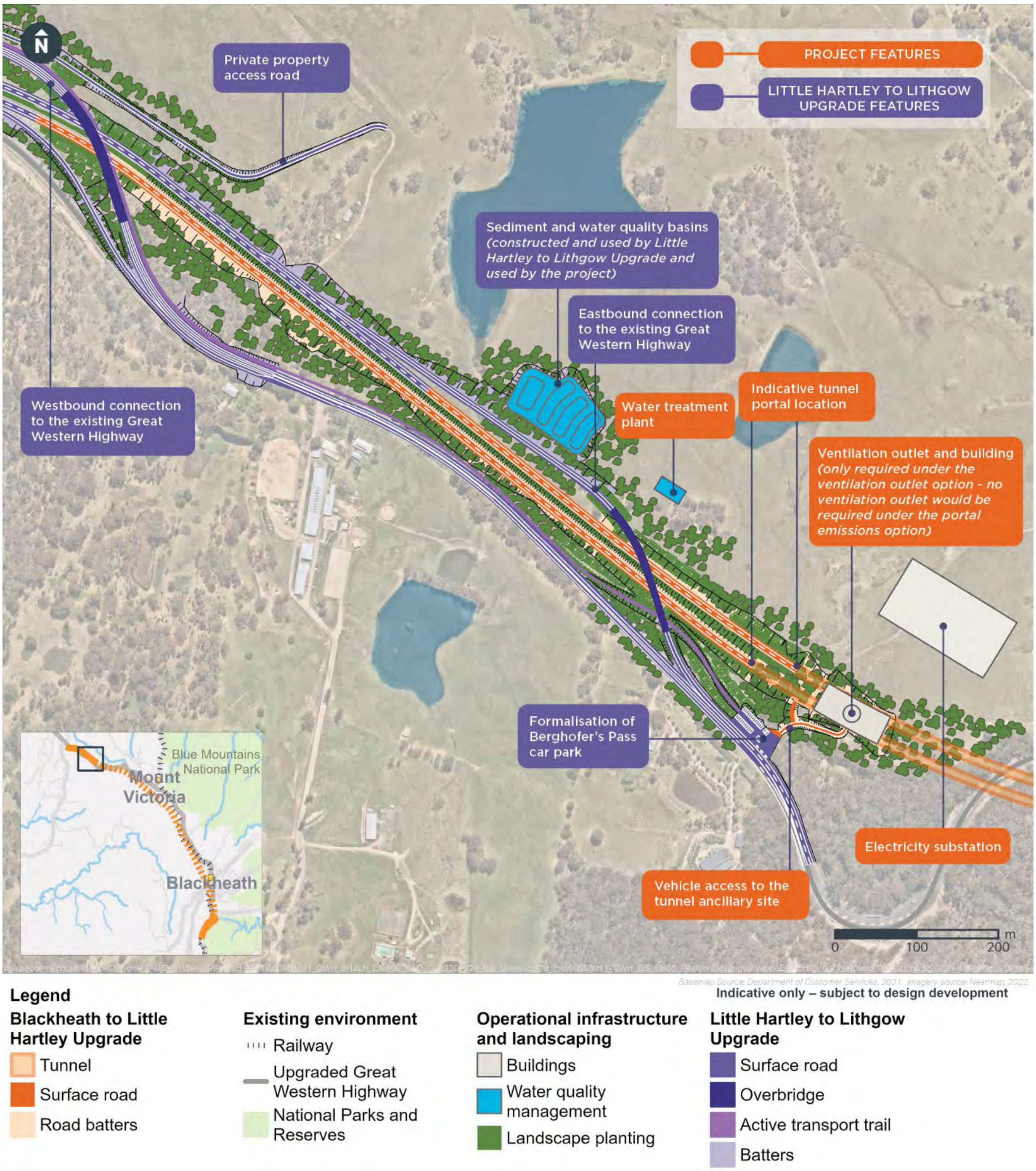


Figure 1-4 Indicative operational configuration at Little Hartley

1.2.2 Project construction

Construction of the project would include:

- site establishment and enabling works
- tunnel portal construction
- tunnelling and associated works
- surface road upgrade works
- operational infrastructure construction and fit-out, including construction of operational environmental controls
- finishing works, testing, and commissioning.

These activities are described in more detail in Chapter 5 (Construction) of the EIS.

The indicative construction footprint for the project is shown in Figure 1-5 to Figure 1-7, including construction site layout and access arrangements.

Construction of the project is expected to take around eight years. Subject to planning approval, construction is planned to commence in 2024 and be completed by late 2031; however, the project would be open to traffic by 2030.

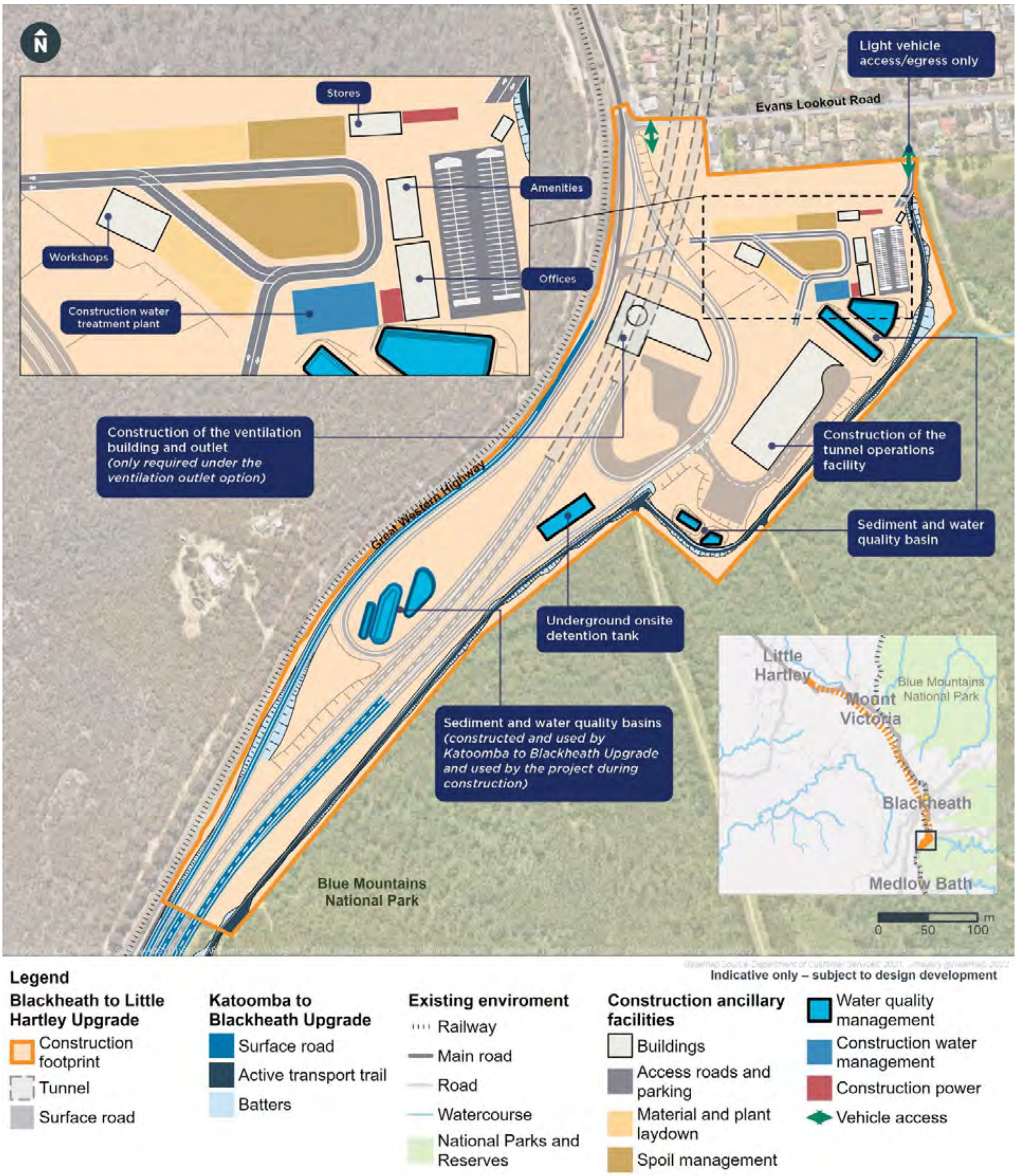


Figure 1-5 Indicative construction footprint at Blackheath

Figure 1-6 Indicative construction footprint at Soldier's Pinch

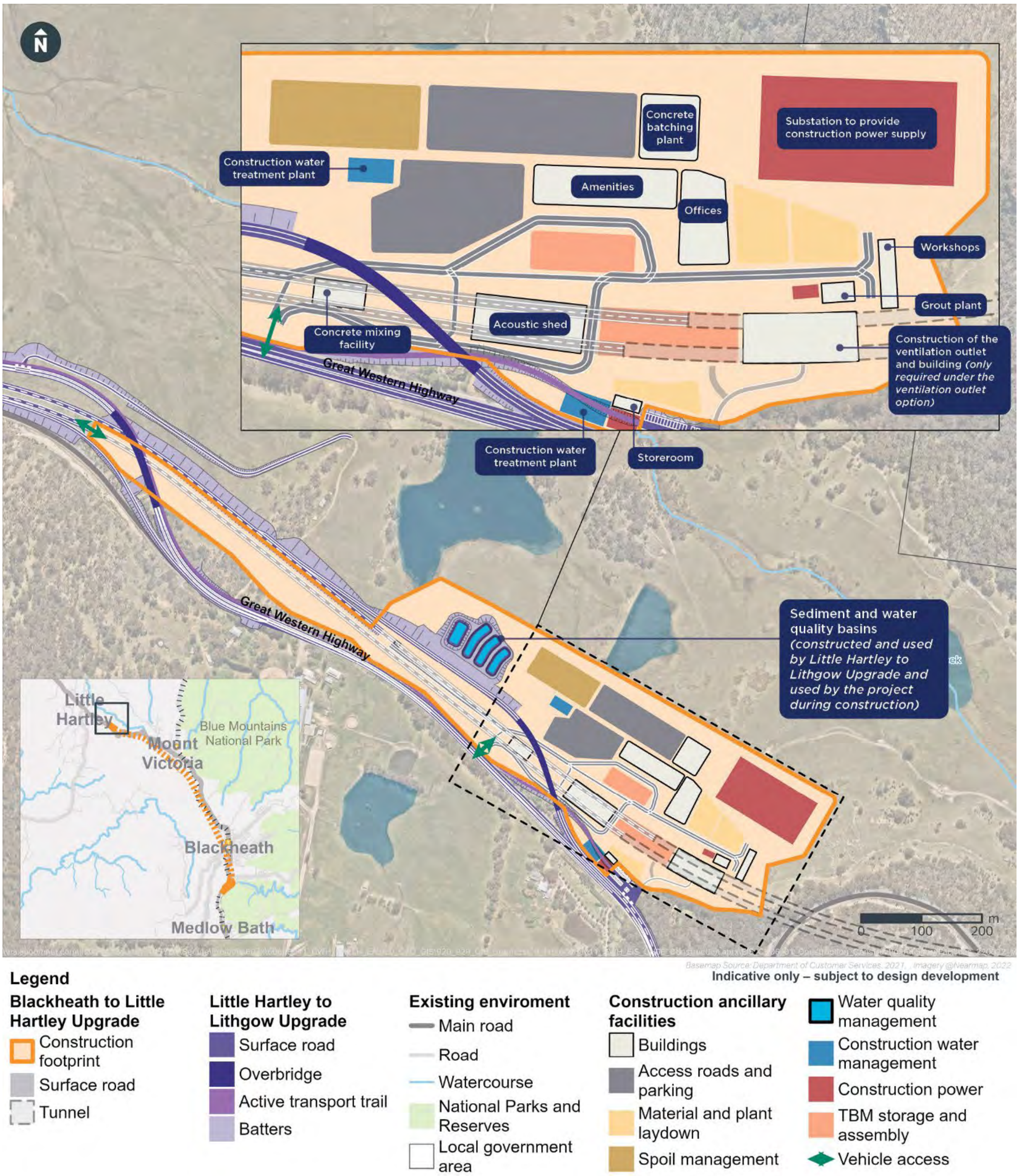


Figure 1-7 Indicative construction footprint at Little Hartley

1.2.3 Baseline environment

The Katoomba to Blackheath and Little Hartley to Lithgow Upgrades adjoining the project to the east and west respectively would be under construction when construction of the project commences (refer to Figure 1-8). To minimise environmental impacts, parts of the Katoomba to Blackheath Upgrade and Little Hartley to Lithgow Upgrade construction footprints would be used to support construction of the project.

As a result, the following activities will be undertaken at the construction sites as part of the Katoomba to Blackheath and Little Hartley to Lithgow Upgrades:

- vegetation would be cleared
- topsoil would be levelled and compacted
- site access tracks would be established
- water quality controls such as water quality and sediment basins would be installed.

The environmental impacts associated with these works have been assessed as part of the Katoomba to Blackheath Upgrade and the Little Hartley to Lithgow Upgrade.

The construction footprint for these projects are shown in Figure 1-9 and Figure 1-10 and form the baseline environment considered at Blackheath and Little Hartley for this EIS.

No work is proposed at Soldier's Pinch as part of the Katoomba to Blackheath Upgrade or the Little Hartley to Lithgow Upgrade and therefore the existing environment forms the baseline environment for this EIS.

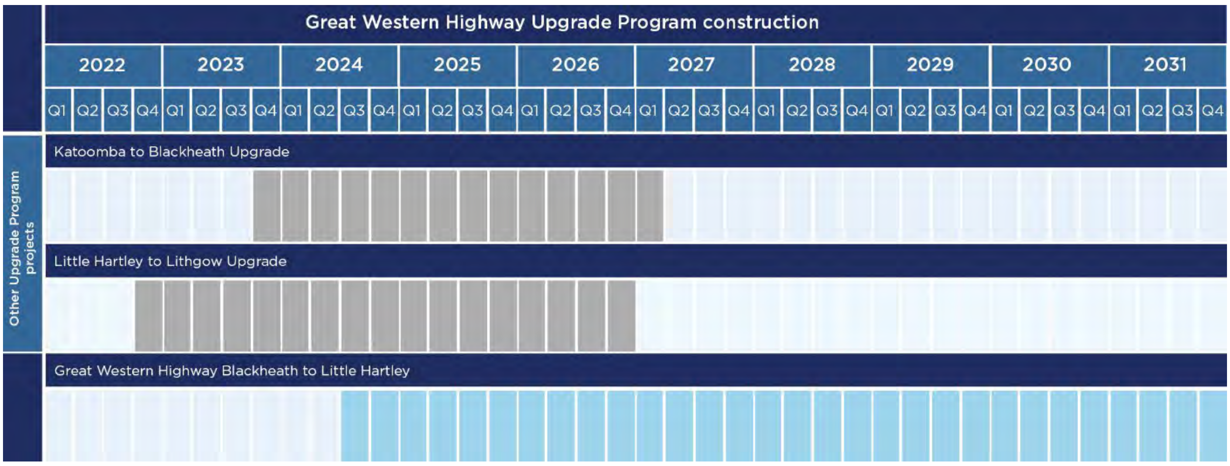


Figure 1-8 Great Western Highway Upgrade Program construction

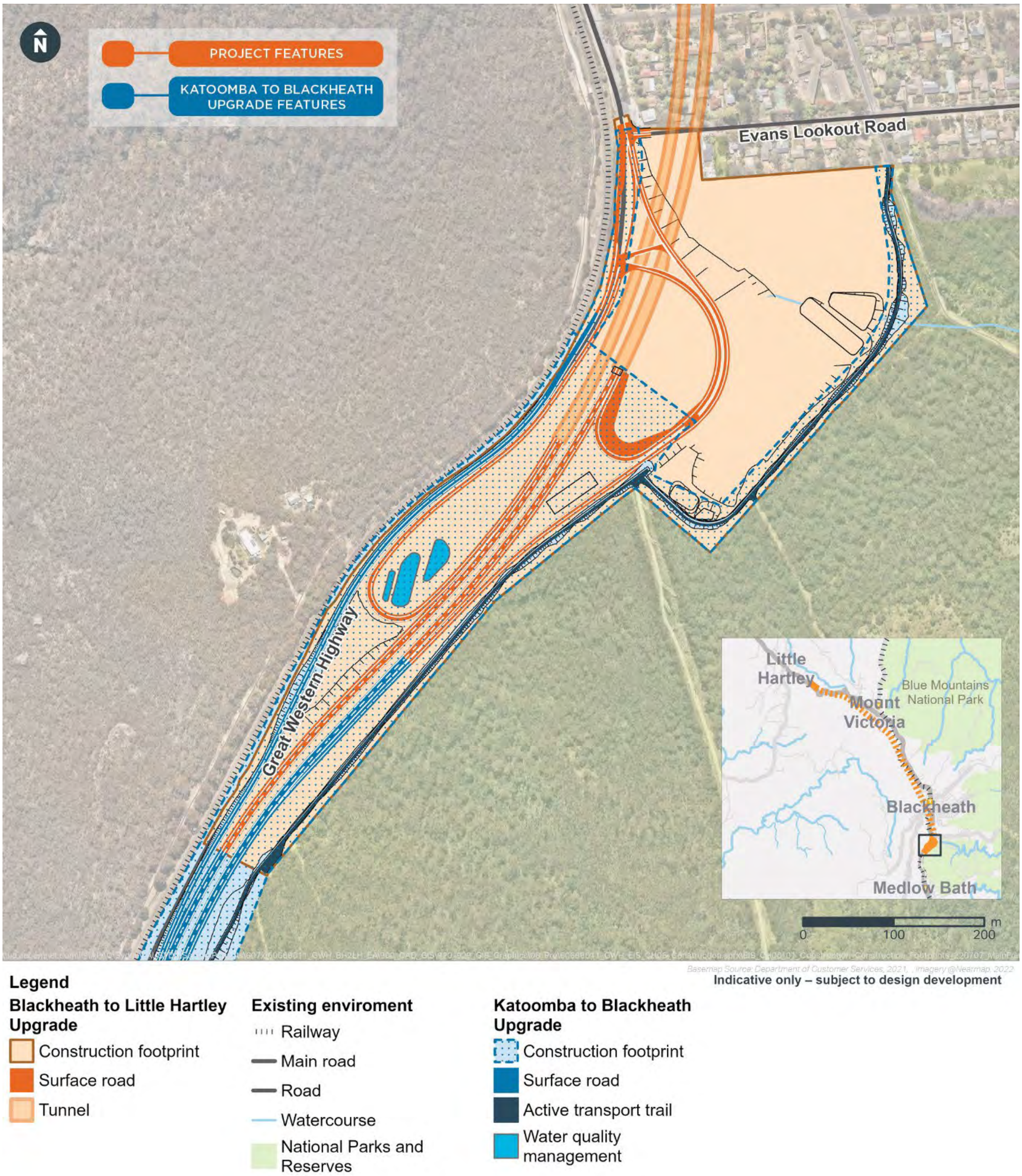
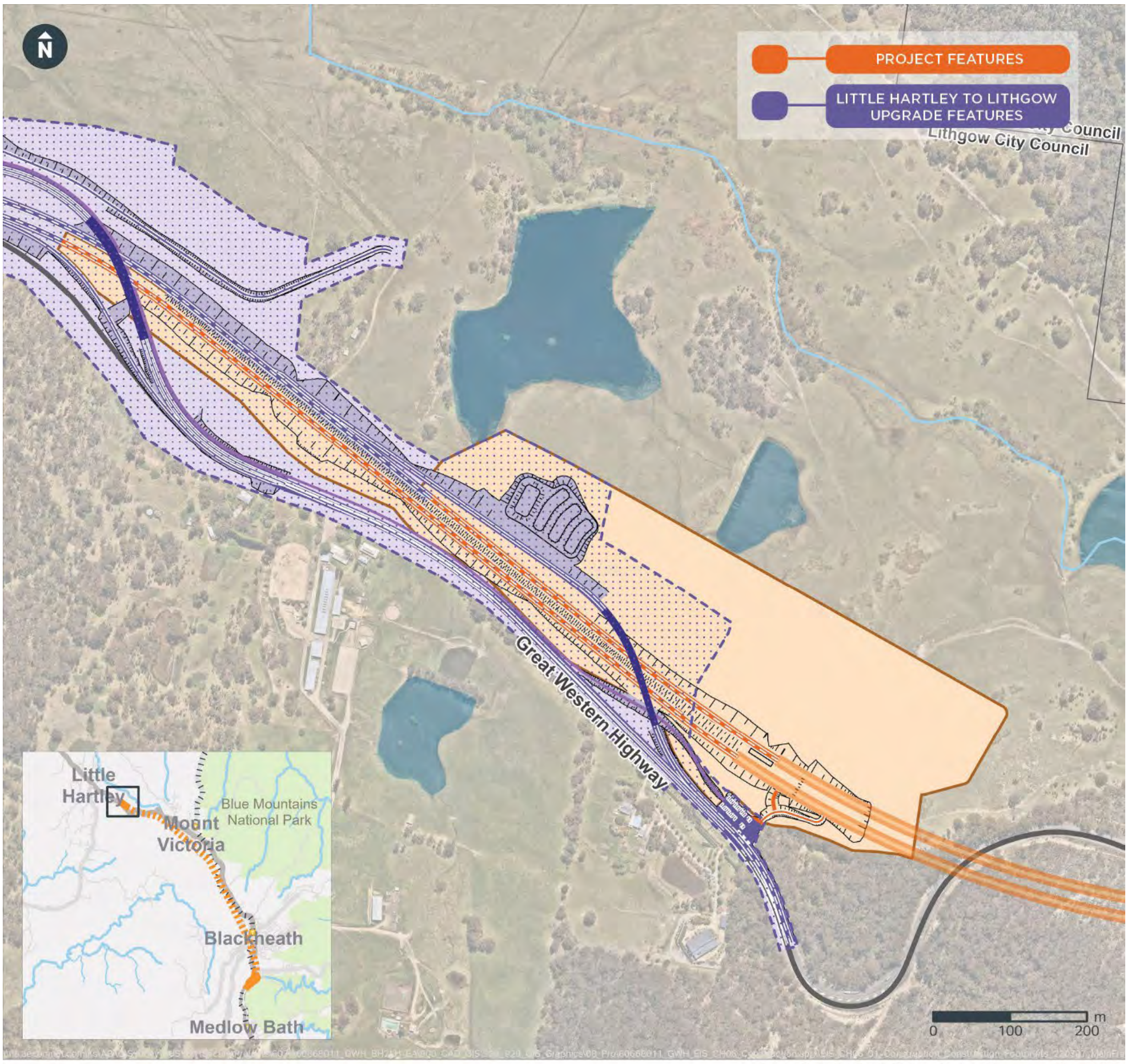


Figure 1-9 Baseline environment at Blackheath



Indicative only – subject to design development

Legend

Blackheath to Little Hartley Upgrade
- Construction footprint
- Surface road
- Tunnel

Existing enviroment
- Main road
- Road
- Watercourse
- National Parks and Reserves
- Local government area

Little Hartley to Lithgow Upgrade
- Construction footprint
- Surface road
- Overbridge
- Active transport trail

Figure 1-10 Baseline environment at Little Hartley

1.2.4 Other project specific aspects

The key elements of the project that would intersect groundwater include:

- the twin tunnels would be constructed using two tunnel boring machines (TBMs) launched from the Little Hartley construction footprint, tunnelling eastbound on an uphill gradient to the Blackheath construction footprint
- cross-passages linking the two mainline tunnels, located at around 120 metre intervals. Investigations are ongoing in relation to cross-passage design and consultation is ongoing with relevant stakeholders regarding opportunities to reduce the number of cross-passages required for the project while meeting fire and life safety requirements.
- tunnel portals located at Blackheath and Little Hartley
- caverns, a shaft, and an adjoining adit, would be constructed at around the mid-point of the twin tunnels. These would support TBM refurbishment, including cutterhead maintenance and replacement, and to allow for the provision of maintenance and breakdown bays incorporated into the tunnel design.

For further information, refer to Section 4.2 and Section 5.1 for construction and operation design elements, respectively, that have potential to impact groundwater.

1.3 Purpose of this report

This groundwater technical report is one of numerous technical documents that form part of the EIS. The purpose of this technical report is to provide a groundwater impact assessment which addresses the requirements outlined in Section 1.3.1. This technical report provides an assessment of the of the groundwater impacts associated with the construction and operation of the project.

1.3.1 Assessment requirements

The Secretary's environmental assessment requirements (SEARs) issued by the NSW Department of Planning and Environment (DPE) which relate to groundwater, and where these requirements are addressed in this technical report, are outlined in Table 1-2.

Table 1-2 Secretary's environmental assessment requirements – groundwater

Secretary's Environmental Assessment Requirements (SEARs) - Groundwater		
17. Water - Hydrology		
Desired performance outcome	**Requirement**	**Addressed**
Long term impacts on surface water and groundwater hydrology (including drawdown, flow rates and volumes) are minimised. The environmental values of nearby, connected and affected water sources, groundwater and	1. Describe (and map) the **existing hydrological regime** for any surface and groundwater resources (including reliance by users and for ecological purposes or by groundwater dependent ecosystems) likely to be impacted by the project, including stream orders, as well as the location of all proposed intake and discharge locations.	A description and maps of groundwater resources (hydrological regime) is presented in Section 3.5 of this report. Refer to Section 3.3 of this report and Appendix J (Technical report - Surface water and flooding) of the EIS, for a description of waterways and catchments. Refer to Section 3.7 of this report and Appendix H (Technical report - Biodiversity) of the EIS, for a description on groundwater dependent ecosystems.
	2. Provide a detailed **construction and operational** water balance for ground	A simulated regional groundwater balance is included in the

Secretary's Environmental Assessment Requirements (SEARs) - Groundwater		
dependent ecological systems including estuarine and marine water (if applicable) are maintained (where values are achieved) or improved and maintained (where values are not achieved). Sustainable use of water resources. Consideration of tunnel boring methods to minimise groundwater drawdown impacts and dewatering's.	and surface water including the volume, frequency and quality of discharges at proposed intake and discharge locations, and confirmation that any water supply needs can be sourced from an appropriately authorised and reliable supply, including the source of the supply	numerical groundwater model report (Annexure B). Water management and disposal information for construction and operational phase of the project is included in Section 4.5.8 and Section 5.4.8, respectively. Refer to Appendix J (Technical report - Surface water and flooding) of the EIS, for a detailed water balance and further information regarding proposed water intake and discharge locations.
	3. Surface and groundwater hydrological impacts of the construction and operation of the project and any ancillary facilities (both built elements and discharges) in accordance with the current guidelines, including: a. natural processes within rivers and wetlands that affect the health of fluvial and riparian systems b. impacts to downstream water-dependent fauna and flora c. impacts from any permanent and temporary interruption of groundwater flow including the extent of drawdown, barriers to flows, implications for groundwater dependent surface flows, waterfalls, hanging swamps, other ecosystems and species, groundwater users, and the potential for settlement d. changes to environmental water availability and flows, both regulated/licensed and unregulated/rules-based sources e. direct or indirect increases in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses, and destabilisation of escarpment features f. measures for minimising the effects of proposed stormwater and wastewater management during construction and operation on natural hydrological attributes (such as volumes, flow rates, management methods and re-use options) and on the conveyance capacity of existing stormwater	Potential groundwater hydrological impacts are described in Section 4.0 (construction) and Section 5.0 (operation). Refer to Appendix J (Technical report - Surface water and flooding) of the EIS, for surface water impacts. Refer to Appendix H (Technical report – Biodiversity) of the EIS, for impacts to groundwater dependent ecosystems and other ecological receptors.

Secretary's Environmental Assessment Requirements (SEARs) - Groundwater		
	systems where discharges are proposed through such systems g. water take (direct or passive) from all surface and groundwater sources with estimates of annual volumes during construction and operation.	
	4. Identify any requirements for **baseline monitoring** of hydrological attributes through the use of groundwater pump testing and other hydrogeological testing to assess regional impacts on aquifers, including open hole monitoring bores along and perpendicular to the tunnel alignment, to assess the existing regional hydrogeology, potential groundwater extraction impact area. The results of the baseline monitoring must be included in the EIS	The data requirements for baseline monitoring are listed in Section 2.1.10. Baseline monitoring data used to inform the EIS is described in Section 2.3.5 and Section 3.5. Requirements for additional pre-construction baseline monitoring are described in Section 7.2.
	5. Identify design approaches to minimise or prevent **drainage of groundwater** through the use of tunnel excavation/boring methods	Design elements of the project that influence groundwater is summarised in for the construction phase in Section 4.2, and during the operational phase in Section 5.1.
	6. A series of **detailed geological cross sections** and long sections of the underground tunnel, these include: a. schematic sections reflecting the detailed geology as recorded in the geological drillhole logs, relative position of the investigation drill holes, groundwater intersections, groundwater dependent ecosystems elevations plus the proposed tunnel, and b. emphasis on those locations where the tunnel rises to the surface, has connections to immersed tunnel sections, or intersects zones of high concentration of discontinuities c. perpendicular sections at a regular spacing, developed on the basis of the geology d. details on the locations of faults and geological changes and e. mapped on the sections conceptual three-dimensional block model for the tunnel(s) demonstrating the relationship of the tunnel(s) to existing landforms (including surrounding cliffs,	Geological information is presented in Section 3.4. Three-dimensional block models which illustrate the tunnels relationship with the existing landforms, groundwater levels and groundwater dependent ecosystems are included in Section 3.7 and Section 3.10. Detailed geological cross-sections are included in Section 3.10. A long section is attached in Annexure A.

Secretary's Environmental Assessment Requirements (SEARs) - Groundwater		
	valleys, waterways), groundwater levels and groundwater dependent ecosystems.	
	7. A schematic of the **hydrogeological conceptual model** must include geology units, known geological structures, proposed tunnel alignment, relevant monitoring bores and their relative depths, with groundwater levels and groundwater dependent ecosystems. The model must be developed in consultation with the Department of Planning and Environment (DPE) Water	The hydrogeological conceptual model is described in Section 3.10. Consultation with DPE Water has occurred throughout the groundwater impact assessment process.
	8. Assessment of **groundwater impacts** must be undertaken using a numerical model (steady state/transient). The model should be in a form that can be made available to DPE Water to access along with the data used for model construction and predictions	The numerical groundwater modelling report is attached in Annexure B. Modelling was conducted in MODFLOW-USG-Transport v1.9.0 (MODFLOW USG) software, and available in Groundwater Vistas v.8 (GWV) format, an accessible format for DPE Water access. Consultation with DPE Water has occurred throughout the preparation of the groundwater impact assessment process. Potential construction impacts on groundwater resources are presented in Section 4.0 and operational impacts are presented in Section 5.0.
	9. Details of the proposed **groundwater monitoring** to identify construction and operational impacts including changes to groundwater levels, impacts on groundwater dependent ecosystems and volume of groundwater discharges	The proposed groundwater monitoring program is detailed in Section 7.2.
18. Water Quality		
Desired performance outcome	**Requirement**	**Addressed**
The project is designed, constructed and operated to protect the NSW Water Quality Objectives where they are currently being achieved,	1. Water quality impacts, including: a. stating the ambient NSW Water Quality Objectives (NSW WQO) and environmental values for the receiving waters relevant to the project, including the indicators and associated trigger values or criteria for the identified environmental values in	Groundwater quality impacts during construction are described in Section 4.5.6 and water management and discharge/disposal is discussed in Section 4.5.8. Groundwater quality impacts during operation are described in Section

Secretary's Environmental Assessment Requirements (SEARs) - Groundwater		
and contribute towards achievement of the Water Quality Objectives over time where they are currently not being achieved, including downstream of the project to the extent of the project impact including estuarine and marine waters (if applicable).	accordance with the Australia & New Zealand Guidelines (ANZG) for Fresh & Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government b. identifying and estimating the quality and quantity of pollutants that may be discharged and the degree of impact that any discharge(s) may have on the receiving environment, including consideration of all pollutants that pose a risk of non-trivial harm to human health and the environment c. identifying the rainfall event that the water quality protection measures will be designed to cope with d. the significance of any identified impacts including consideration of the relevant ambient water quality outcomes e. demonstrating how construction and operation of the project will, to the extent that the project can influence, ensure that: • where the NSW WQOs for receiving waters are currently being met they will continue to be protected • where the NSW WQOs are not currently being met, activities will work toward their achievement over time. f. justifying, if required, why the WQOs cannot be maintained or achieved over time g. demonstrating that all practical measures to avoid or minimise water pollution and protect human health and the environment from harm are investigated and implemented	5.4.6 and water management and discharge/disposal is discussed in Section 5.4.8. Refer to Appendix J (Technical report - Surface water and flooding) of the EIS.

1.3.2 Agency engagement

During preparation of the EIS, DPE Water, including in its function as the regulatory and manager of groundwater resources in New South Wales, was engaged in relation to the groundwater impact assessment method adopted for the project, including:

- in April 2022, an initial briefing on the project, an overview of the conceptual hydrogeological model (CHM) that was developed for the project, discussion of the approach to developing a numerical hydrogeological model, and an outline of planned geotechnical investigations
- also in April 2022, discussion of the objectives and modelling approach for the numerical hydrogeological model for the project
- in July 2022, briefing on the development and calibration of the numerical hydrogeological model for the project.
- Further details of engagement with agencies are provided in Chapter 7 (Community and stakeholder engagement) of the EIS.

2.0 Assessment methodology

2.1 Relevant guidelines and policies

This section presents relevant legislation, guidelines and policies governing the management and assessment of groundwater. These relevant legislative documents are summarised in Table 2-1.

Table 2-1 Relevant legislation, policies and guidelines

Relevant legislation, policies and guidelines
Legislation and policies
• NSW Groundwater Policy Framework Document 1997 - NSW Groundwater Quantity Management Policy - NSW Groundwater Quality Protection Policy - NSW Groundwater Dependent Ecosystems Policy • Water Act 1912 (NSW) and Water Management Act 2000 (NSW) - NSW Water Sharing Plans • NSW Aquifer Interference Policy (DPI, 2012) • Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (Cth)
Guidelines
• National Water Quality Management Strategy. - Australian and New Zealand Guidelines (ANZG) for Fresh and Marine Water Quality (ANZG, 2018) - Australian Drinking Water Guidelines (NHMRC/NRMMC, 2011, revised in September 2022) • NSW Water Quality Objectives (DEC, 2006) • Risk assessment Guidelines for Groundwater Dependent Ecosystems (Serov et al, 2012) • Australian Groundwater Modelling Guidelines (Barnett et al., 2012) • Minimum groundwater modelling requirements for Major Projects in NSW (DPE, 2022a) • Guidelines for the Assessment and Management of Groundwater Contamination (DEC, 2007) • Minimum requirements for pumping tests on water bores in NSW (DPIE, 2019) • National Environment Protection (Assessment of Site Contamination) Measure (NEPC, 2003) • Approved Methods for the Sampling and Analysis of Water Pollutants in NSW (DECC, 2008) • Guidelines for Groundwater Documentation for SSD/SSI Projects (DPE, 2022b)

Key legislation, policies and guidelines are further detailed in the following sub-sections.

2.1.1 NSW Groundwater Policy Framework Document 1997

The groundwater policy framework document is used to provide ecologically sustainable management guidance about groundwater resources, so they can sustain environmental, social and economic uses for the people of NSW. The policy is divided into three components:

- NSW Groundwater Quantity Management Policy - this policy is designed to maintain and protect groundwater quantity using the following principles that are implemented under the Water Management Act 2000 (NSW) (WM Act) and the AIP:
  - maintain total groundwater use within the sustainable yield of the aquifer from which it is withdrawn
  - groundwater extraction shall be managed to prevent unacceptable local impacts
  - all groundwater extraction for water supply is to be licensed
- NSW Groundwater Quality Protection Policy - this policy is designed to maintain and protect groundwater quality with the aims of slowing, halting or reversing any degradation in the quality of groundwater resources and to minimise risks to the groundwater environment from potentially polluting activities.

- NSW Groundwater Dependent Ecosystems Policy - this policy is designed to protect valuable ecosystems that rely on groundwater to survive, maintain the biophysical functions and preserve these ecosystems for the resources of future generations. Furthermore, the policy provides practical guidelines that can be used as tools to suit a specific need based on a given groundwater dependent ecosystem or environment.

2.1.2 Water Act 1912 and Water Management Act 2000

Groundwater in NSW is managed by DPE Water under the *Water Act 1912* (NSW) (Water Act) and the *Water Management Act 2000* (NSW) (WM Act). The WM Act is gradually replacing the planning and management frameworks in the Water Act although some provisions of the Water Act remain in operation. The WM Act regulates water use for rivers and aquifers where water sharing plans (WSPs) have commenced, while the Water Act continues to operate in the remaining areas of the State. As identified in Section 2.1.2.1 below, a WSP for the area within which the project is located has started and therefore the WM Act applies.

If an activity results in a net loss of either groundwater or surface water from a source covered by a WSP, then an approval and/or licence is required. The WM Act requires:

- a water access licence (WAL) to take water
- a water supply works approval to construct a work
- a water use approval to use the water.

It is noted: Under Schedule 4, Part 1, clause 2 of the Water Management Regulation 2018 (WM Regulation), road authorities are exempt from the need for a WAL in relation to water required for road construction and road maintenance. The WM Regulation is the primary regulation instrument under the WM Act. The exemption does not include water take from aquifer interference activities and Transport must still satisfy the requirements of licensing set out in the Greater Metropolitan Region WSP and satisfy the approval requirements of the NSW Government DPI Office of Water Aquifer Interference Policy (AIP).

2.1.2.1 NSW Water Sharing Plans

WSPs are the main tool in the WM Act to allocate and provide water for the environmental health of rivers and groundwater systems, while also providing licence holders access to water. WSPs define the rules for how water is allocated and have been developed under the WM Act for all water sources in NSW. The aims of the WSPs are to:

- clarify the rights of the environment, basic landholders, town water suppliers and other licensed users
- define the long-term average annual extraction limit (LTAAEL) for water sources
- set rules to manage the impacts of extractions
- facilitate the trading of water between users.

The Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 (the Groundwater WSP) (NSW Government, 2011) covers 13 groundwater sources in eastern NSW. The project lies within both the Sydney Basin Blue Mountains and the Sydney Basin Coxs River Groundwater Sources (as shown on Figure 2-1), regulated under the Groundwater WSP.

The Groundwater WSP contains provisions for allocation of water to construction projects through a volume of ‘unassigned water’ or through the ability to purchase an entitlement where groundwater is available under the long-term average annual extraction limit (LTAAEL). Water available under the LTAAEL, which could be partially reduced by groundwater inflows to the project during construction is summarised in Table 2-2.

Table 2-2 Calculated water available under the LTAAEL

Groundwater Source	LTAAEL (ML/year)	Megalitres of entitlement (unit shares)	Approximate number of existing licences	Water available under the LTAAEL (ML/year)
Sydney Basin Blue Mountains	7,039	138	13	6,901
Sydney Basin Coxs River	17,108	6,926	12	10,182

DPE Water released the Draft Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2023 (DPE, 2022c). The draft 2023 plan proposes to amalgamate the Sydney Basin Blue Mountains, Sydney Basin Coxs River and Sydney Basin Richmond Groundwater Sources into the Sydney Basin West Groundwater Source, recognising the continuous nature of aquifers (different to surface water catchments), geological and geographical similarities between the areas. Approval assessments will continue to manage the risk of local extraction pressure within the groundwater sources.

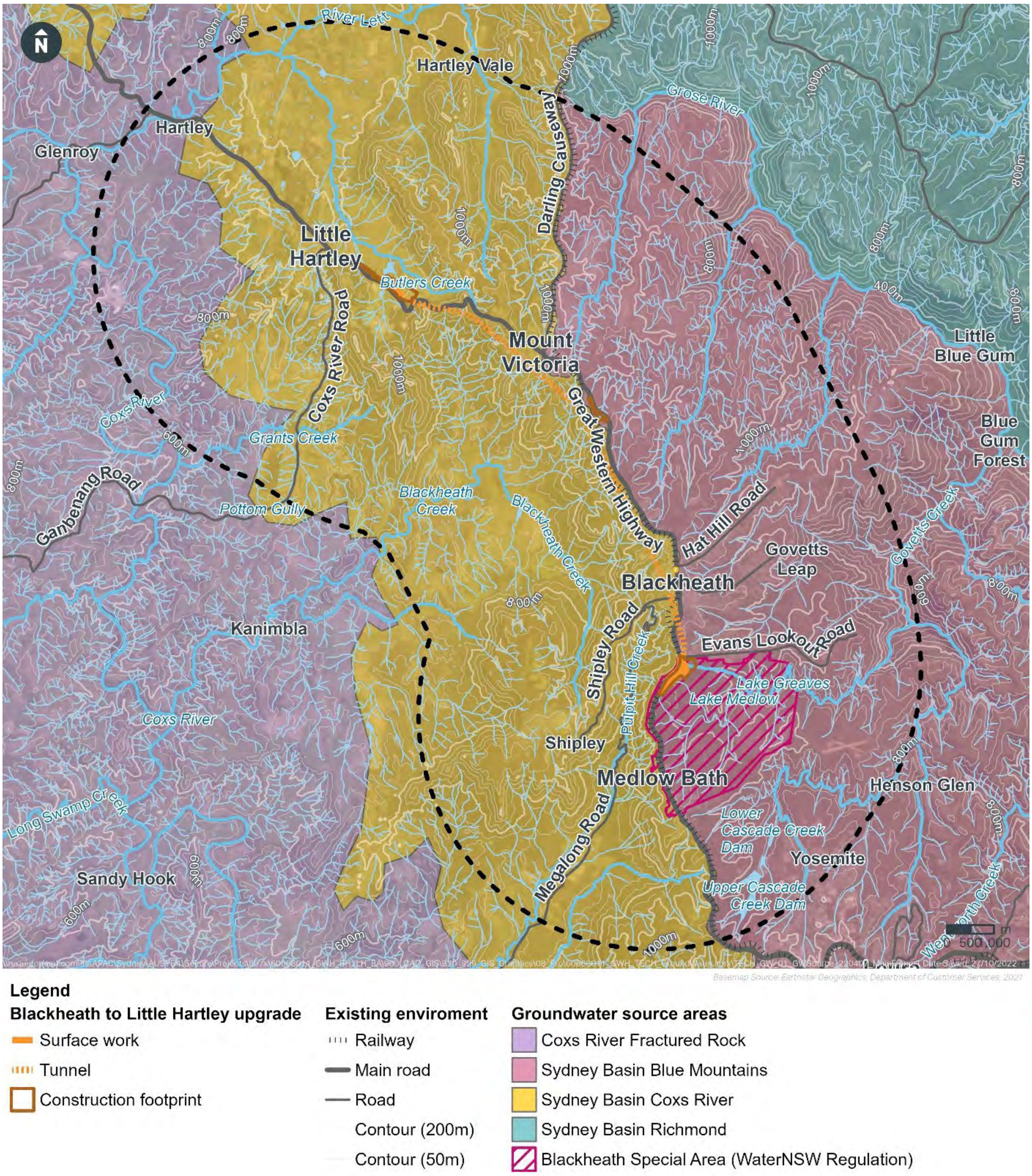


Figure 2-1 Water Sharing Plan groundwater sources areas

2.1.3 NSW Aquifer Interference Policy

The AIP (NSW Government, 2012) explains the process of administering water policy under the WM Act for activities that interfere with the aquifer. The AIP outlines the assessment process and modelling criteria that DPE Water apply to assess aquifer interference projects.

This assessment process and modelling criteria have been adopted for this groundwater impact assessment. Minimum impact considerations required under the AIP, for example, have been assessed for the project and are outlined in Section 8.2 of this report. Key components of the AIP are:

- an activity must address minimal impact considerations in relation to the water table, groundwater pressure and groundwater quality

- where the actual impacts of an activity are greater than predicted, planning measures must be put in place ensuring there is sufficient monitoring.

2.1.4 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act) deals with matters of national environmental significance. Actions that have or are likely to have a significant impact[1] on a matter of national environmental significance require approval from the Commonwealth Minister for the Environment. Of the nine matters of national environmental significance outlined within the EPBC Act, the following are generally of more relevance to groundwater:

- listed threatened species and ecological communities
- wetlands of international importance (listed under the Ramsar Convention)
- a water resource, in relation to coal seam gas development and large coal mining development.

Potential impacts on listed threatened species and ecological communities are assessed in detail in Appendix H (Technical report - Biodiversity) of the EIS, and where impacts relate to groundwater dependent ecosystems, in Section 4.5.4 (construction impacts) and Section 5.4.4 (operational impacts) of this report.

There are no Ramsar wetlands in proximity to the project, and the project does not involve coal seam gas or large coal mining development.

2.1.5 National Water Quality Management Strategy

The National Water Quality Management Strategy (NWQMS) aims to provide a nationally coordinated framework to facilitate water quality management for the productive and sustainable use of Australia's waters. The NWQMS provides national guideline documents and policy which relate to the protection of surface water and groundwater resources for local implementation.

The main document for groundwater under the NWQMS is the Guidelines for Groundwater Protection in Australia which sets out a risk-based approach to protecting or improving groundwater quality. The environmental value of groundwater is used to define values or uses of the water resource based on established water quality criteria for each value as outlined in the ANZG for Fresh and Marine Water Quality (ANZG, 2018) and the ADWG (NHMRC/NRMMC, 2011, revised in September 2022). Environmental Values outlined in the guidance include:

- aquatic ecosystems (those which are to some degree dependent on groundwater to maintain the ecosystem health, i.e., groundwater dependent ecosystems (GDEs)
- primary industry (irrigation and general water uses, stock drinking water, aquaculture, and human consumers of aquatic foods)
- recreation and aesthetics
- drinking water
- industrial water
- cultural and spiritual values.

Guideline water quality criteria for the environmental values of aquatic ecosystems, primary industry, recreation, and aesthetics and drinking water set out in the ANZG for Fresh and Marine Water Quality (ANZG, 2018) and are used in this technical report for comparative purposes against available groundwater quality data.

[1] A 'significant impact' is an impact which is important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the environment which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts. You should consider all of these factors when determining whether an action is likely to have a significant impact on matters of national environmental significance.

2.1.6 NSW Water Quality Objectives

The NSW Government has developed WQO that are consistent with the NWQMS, and, with the ANZG for Fresh and Marine Water Quality (ANZG, 2018). 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.

2.1.7 Risk Assessment Guidelines for Groundwater Dependent Ecosystems 2012

The Risk Assessment Guidelines (Serov *et al.*, 2012) are used to manage land and water use activities that pose a potential threat to groundwater dependent ecosystems. The document aims to:

- define GDE types
- support the requirements of the WM Act
- determine the risk of an activity to the ecological value of an aquifer and associated GDEs
- provide management strategies for aquifers and identified GDEs using the Risk Matrix Approach.

2.1.8 Australian Groundwater Modelling Guidelines

The Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012) are intended as a reference document for groundwater modellers, project proponents (and model reviewers), regulators, community stakeholders and model software developers who may be involved in the process of developing a model and/or modelling studies. The objective of the guidelines is to promote a consistent and sound approach to the development of groundwater flow and solute transport models in Australia. This approach should progress through a series of interdependent stages with frequent feedback loops to earlier stages: planning; conceptualisation; model design and construction; model calibration; predictive scenarios; and model reporting.

The guidelines suggest that the model review process should be carried out in a staged approach, with separate reviews taking place after each reporting milestone (i.e., after conceptualisation and design, after calibration and sensitivity and at completion).

2.1.9 Guidelines for the Assessment and Management of Groundwater Contamination

These guidelines are consistent with the *Contaminated Land Management Act 1999* (CLM Act) and the *Protection of the Environment Operations Act 1997* (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 specific site level, and are directed at the polluters or those responsible for cleaning up contaminant plumes.

These guidelines would become relevant to the project where groundwater with poor water quality is found within the modelled construction or operation phase groundwater drawdown extents, such that it could result in contaminated groundwater migration towards the project.

2.1.10 Guidelines for groundwater documentation for SSD/SSI Projects

The main objective of the guidelines (DPE, 2022b) is to clarify and inform the requirements for groundwater assessment and documentation required for State significant development (SSD) and State significant infrastructure projects (SSI) in NSW to demonstrate if the activity can operate and be compliant with the principles and objects of the WM Act and requirements describe within the NSW groundwater policy documents.

For projects that are expected to intercept the water table, the proponent must ensure that the project meets the following data requirements:

- sufficient groundwater (and related surface water) data are available to:
    - define baseline conditions
    - describe the CHM
    - assess the potential changes to groundwater and surface water resources due to future operations.

- a minimum of two years of baseline monitoring data is typically required to capture two seasonal cycles2 (AIP requirement)
- any publicly available data for longer historical periods across the region and within the same groundwater source(s) are considered and referenced in the groundwater impact assessment.

2.2 Key assumptions

The key assumptions relied on in the development of this report include:

- predictions of project related groundwater inflows and associated groundwater level and resource depletion impacts are based on the groundwater model assumptions outlined in Section 4.2 and 5.1
- the existing environment has been characterised based on project specific data and other data available in the public domain, with resulting interpretations considered to reasonably represent the existing environment and the potential impacts associated with the project
- this groundwater assessment considers field investigation data available at the time of writing. Groundwater data will continue to be collected as part of ongoing design development.

2.3 Methodology

2.3.1 General

The methodology applied to assessment of potential impacts on the groundwater system arising from the project include:

- characterisation of the existing environment including climate, topography, surface water features, geology, and groundwater resources, including groundwater occurrence, recharge and discharge processes, quality, use, and GDEs
- review of similar assessments and previous tunnelling projects within similar geologies in NSW
- dedicated field investigations including drilling, permeability testing, monitoring bore installation, and water level and quality monitoring
- development of a CHM(s)
- development of a three-dimensional numerical groundwater flow model to simulate the assumed tunnelling and construction features and provide predictions of groundwater inflows and drawdown propagation. The groundwater modelling approach is consistent with the Australian Groundwater Modelling Guidelines (Barnett *et al*, 2012) and has undergone an independent third-party review by a suitably qualified person
- assessment of potential groundwater impacts to satisfy the minimal impact considerations of the AIP and to address groundwater assessment requirements identified in the SEARs
- assessment of potential cumulative impacts through identification and review of other projects in the area
- development of mitigation and management measures to address the potential impacts identified for both construction and operation of the project
- recommendations for monitoring, including validation of mitigation measures as appropriate.

The specific methodologies used for these components of the methodology are described in the following sections.

[2] It will not always be possible or practical to collect two years of baseline monitoring data, for example, where land access constraints limit data collection. This constraint and data gap should be considered as part of a risk assessment and data gap analysis, and a plan put in place for future monitoring. Any assumptions made due to the data gap should be communicated and checked as the project develops.

2.3.2 Groundwater study area

The 'groundwater study area' that was used to inform the groundwater impact assessment included a five-kilometre buffer around the project's construction footprint. This buffer area was identified based on findings of preliminary groundwater modelling carried out as part of design development.

2.3.3 Desktop assessment

The desktop assessment involved a review of the existing groundwater resources across the groundwater study area to assess the likely and potential impacts of the project on groundwater flow and quality during construction and operation.

Relevant data was collected to inform on existing groundwater conditions across the project area. Sources included:

- the Bureau of Meteorology's (BoM) Australian Groundwater Explorer (BoM, 2022a) and the WaterNSW Real Time Data online database (WaterNSW, 2022a) for groundwater level and quality data at registered groundwater bores
- the NSW Water Register (WaterNSW, 2022b) for data on existing groundwater users, including WAL holders and stock and domestic users
- the National Atlas of Groundwater Dependent Ecosystems (BoM, 2022b) to identify the location and groundwater dependence of surface water systems and vegetation
- the NSW Environmental Protection Agency (EPA) list of contaminated sites notified to the EPA www.epa.nsw.gov.au/your-environment/contaminated-land/notification-policy/contaminated-sites-list
- temperature and rainfall data from gauging stations within the vicinity of the project area, from the BoM, Climate Data Online website (BoM, 2022c)
- modelled evapotranspiration data for regions within the project area, from the BoM Australian Landscape Water Balance website (BoM, 2022d)
- the NSW EPA Contaminated Land Record.

Publicly available maps were also used, including geological, topography, drainage, and soil maps.

2.3.4 Review of previous studies

A range of previous investigation and construction projects provided geological and hydrogeological data useful for the groundwater study area, from the following projects:

- Great Western Highway Upgrade - Katoomba to Little Hartley
- Great Western Highway Upgrade - Mount Victoria to Lithgow.

2.3.5 Field assessment

Results and interpretation of the geotechnical and hydrogeological field work relevant to this groundwater assessment, as well as 2021 and 2022 groundwater monitoring data from existing project monitoring sites, are presented in Section 3.0. Groundwater monitoring bore locations are shown in Figure 2-2 to Figure 2-4.

2.3.5.1 Geotechnical investigations

Geotechnical investigations for the project commenced in 2021, which to date has included:

- drilling of 27 vertical boreholes to depths up to 210 metres below ground level
- packer testing at 20 boreholes over 99 selected depth intervals

- installation 12 vibrating wire piezometers3 (VWPs) within four boreholes and installation of six standpipes
- two hand-auger bores converted to standpipes within identified GDE locations.

Geotechnical and hydrogeological field work is ongoing, and will inform further design development for the project.

Additional geotechnical and hydrogeological field work planned for the project includes:

- drilling of 49 vertical boreholes to depths up to 245 metres below ground level
- packer testing in 23 boreholes over 211 selected depth intervals
- installation of 19 standpipes, and 55 VWPs within 24 boreholes at various depth intervals
- 16 hand-auger bores converted to standpipes within identified swamp locations.

In consultation with government agencies the scope of geotechnical investigations was refined to include additional standpipes to verify the VWP potentiometric pressure data. The scope for the current investigation was amended, as follows:

- VWPs were originally scoped to be installed at 16 borehole locations within identified swamps. These VWP borehole locations are now scoped to be converted to standpipes. This also allows for groundwater quality monitoring of the swamps.
- an additional ten standpipes are to be installed to spatially cover the range of hydrostratigraphic units within the study area. These standpipes are scoped to be installed close to already proposed VWP bores at similar depths to provide verification of the nearby VWP pressure data, and to provide additional groundwater quality data.

It is noted that the VWPs allow for the evaluation of water pressure changes, related to dewatering, whereas the standpipes will facilitate groundwater level and quality monitoring. The combination of groundwater monitoring methods will allow for the validation of numerical groundwater model predictions.

The locations of the completed and proposed boreholes and groundwater monitoring locations (standpipes and VWPs) for the project are shown on Figure 2-2 to Figure 2-4. Lithological and bore completion logs for boreholes and constructed standpipe installations are provided in Annexure C, and summarised in Table 2-3 and Table 2-4, respectively.

Table 2-3 Groundwater standpipes already installed to support design development

Bore ID	Date installed	Bore depth (mbgl)[4]	Screen interval (mbgl)[4]	Screened formation
BH500	20/09/2021	34.81	22-25	Banks Wall Sandstone
BH500 A	22/09/2021	39.11	22-23	Banks Wall Sandstone
BH502	31/08/2021	89.44	29.70-35.70	Banks Wall Sandstone
BH505 A	30/03/2021	53	21-24	Banks Wall Sandstone
BH505 B	30/03/2021	83	40-46	Burra-Moko Head Sandstone
BH507	04/05/2021	210	49-55	Burra-Moko Head Sandstone
BH622	14/10/2021	42.50	24-27	Illawarra Coal Measures

[3] VWPs include vibrating wire transducer inside the piezometer which converts water pressure to a frequency signal via a diaphragm, a tensioned steel wire, and an electromagnetic coil. The transducer is constructed so that a change in water pressure on the diaphragm causes a change in the tension of the wire. These changes facilitate the assessment of water pressure changes over time.
[4] metres below ground level

Bore ID	Date installed	Bore depth (mbgl)[4]	Screen interval (mbgl)[4]	Screened formation
GC1	20/12/2021	0.75	0.25-0.75	Greaves Creek Swamp
GC2	20/12/2021	0.80	0.30-0.80	Greaves Creek Swamp

Table 2-4 Vibrating wire piezometers already installed to support design development

Bore ID	Date installed	Number of VWPs	Installation depth (mbgl) [4]	Installation elevation (mAHD)[5]	Formation VWP installed within
BH501	18/05/2021	2	33.5 49.0	1021.5 1006.0	Upper Banks Wall Sandstone Lower Banks Wall Sandstone
BH501A	19/05/2021	3	109.0 124.0 170.0	946.0 931.0 885.0	Lower Banks Wall Sandstone Mount York Claystone Lower Burro-Moko Head Sandstone
BH504	20/05/2021	3	47.0 50.0 85.0	985.0 982.0 947.0	Lower Banks Wall Sandstone Mount York Claystone Lower Burro-Moko Head Sandstone
BH505	21/05/2021	4	26.5 36.0 86.0 117.0	1008.5 999.0 949.0 918.0	Lower Banks Wall Sandstone Mount York Claystone Lower Burro-Moko Head Sandstone Lower Burro-Moko Head Sandstone

[5] metres above Australia Height Datum

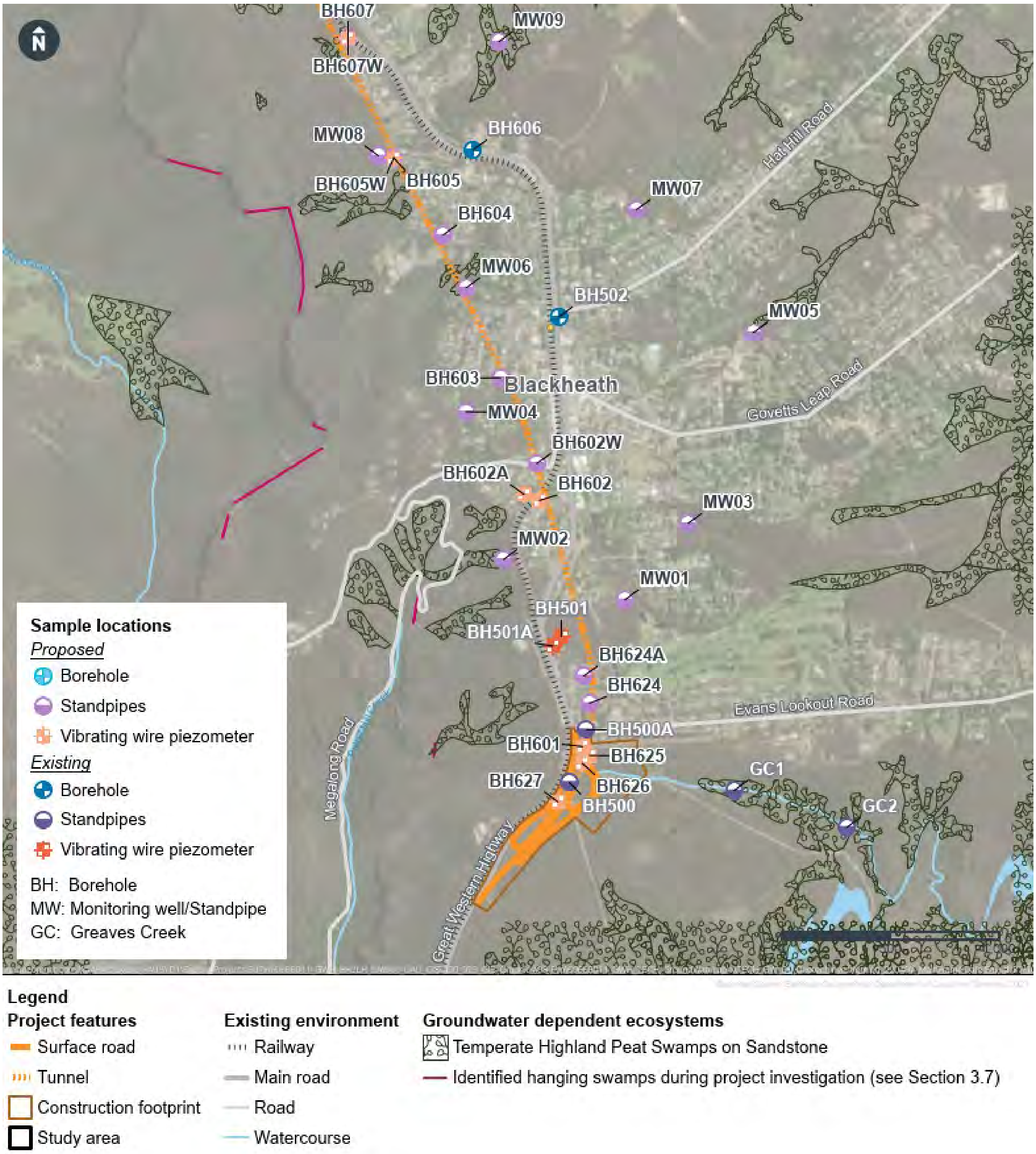


Figure 2-2 Geotechnical investigation and groundwater monitoring bore locations – map 1 of 3

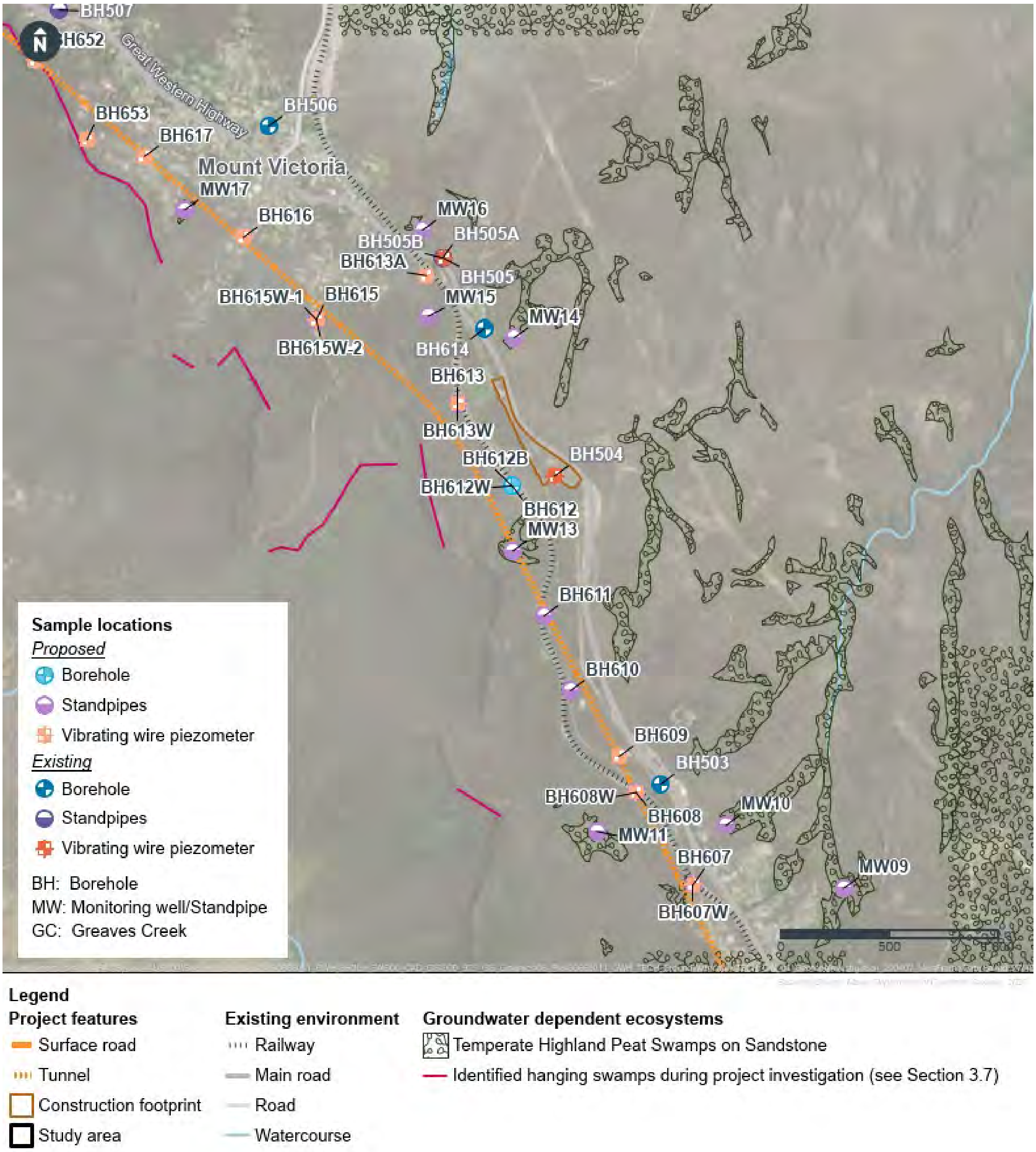


Figure 2-3 Geotechnical investigation and groundwater monitoring bore locations – map 2 of 3

Figure 2-4 Geotechnical investigation and groundwater monitoring bore locations - map 3 of 3

2.3.5.2 Groundwater level and quality monitoring data

Manual groundwater level measurements were collected in 2021 during the initial geotechnical investigation carried out for the project (Transport for NSW, 2022b) at standpipes BH500, BH500A, BH505A, BH505B, BH507, BH622, GC1, and GC2. At the time of writing this report, a full year of transient VWP water pressure data was compiled, between 25 May 2021 and 16 May 2022.

Baseline groundwater level and groundwater quality data collected from bores within the groundwater study area is presented in Section 3.5.2 and Section 3.5.5, respectively.

2.3.5.3 Hydraulic testing

As detailed in Table 1-2 of Section 1.3.1, the SEARs require baseline monitoring of hydrological attributes through the use of groundwater pumping tests and other hydrogeological testing to describe the aquifer hydraulic parameters and assess the project's regional impacts on hydrostratigraphic units.

To this end, regional impacts to groundwater resources have been assessed through the consideration of the available hydraulic testing dataset, which included packer tests (spatially and with depth) completed during previous investigations and the current investigation.

2.3.6 Groundwater modelling

Predictive numerical groundwater modelling was used to assess potential effects and impacts that tunnel construction and operation may have on the hydrogeological environment and hydraulically connected surface water features around the project area.

The model utilised the MODFLOW-USG-Transport V1.9.0 modelling software package[6], which is considered industry-standard software, having been used for many impact assessment models and for a variety of applications (mining, civil and construction, contaminant transport) in NSW.

Additionally, Groundwater Vistas (GWV) was utilised as a pre-processor and as a repository for data to allow DPE Water access, as per a requirement of the SEARs (Section 1.3.1).

Predictive groundwater modelling outputs were produced for a scenario where the construction staging was flexible (i.e., excavation of more 'drained' features simultaneously, specifically the cross-passages for which there is likely the most flexibility in construction scheduling). The flexible schedule simulation provided a more conservative (potentially higher impact to groundwater) scenario.

Due to uncertainty when simulating a complex hydrogeological system, which can include knowing exact and spatial variation of hydraulic properties (such as permeability and porosity) for a given aquifer, a set of plausible parameters are modelled. Each of these sets of plausible model parameters is a model 'realisation'. The project modelling used a set of 300 realisations in a stochastic[7] fashion to simulate the project area and the project.

The predictions from each realisation were analysed to estimate the approximate frequency of inflow or drawdown. For model predictions, the 300 realisation results are presented as:

- the 5th percentile, which represents a 'likely best case' (Note – this limited impact assessment result(s) was excluded from the impact assessment)
- the 50th percentile (median), which represents the central or 'likely' or base value
- the 95th percentile, which represents the 'likely worst case'.

Thus, to allow for uncertainty and ensure a robust impact assessment the 50th percentile and 95th percentile groundwater ingress and water level drawdown predictions were included in the groundwater impact assessment. Reporting of model development, construction, and calibration, plus outputs is included in Annexure B – Numerical Groundwater Modelling Report.

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[6] Panday, S., 2022; USG-Transport Version 1.9.0: Transport and Other Enhancements to MODFLOW-USG, GSI Environmental, Feb 2022 http://www.gsi-net.com/en/software/free-software/USGTransport.htm
[7] Stochastic - having a random probability distribution or pattern that may be analysed statistically but may not be predicted precisely.

2.3.7 Impact assessment

The methodology for assessment of potential impacts upon groundwater arising from the project included the following:

- characterising the existing local and regional hydrogeological conditions and identifying sensitive groundwater receptors
- characterising the project and its potential intersection with the surrounding groundwater environment
- development of a CHM, including recharge and discharge mechanisms
- based on the CHM and field information, assessing impacts on groundwater receptors through predictive groundwater modelling, in line with the AIP and other relevant legislation and policies (as outlined in Section 8.0)
- qualitatively discussing identified impacts, due to the construction and operation of the project, as needed to clarify the presence or absence of those impacts
- qualitatively discussing any projects identified as contributing to potential cumulative impacts as needed to clarify the presence or absence of those impacts, including the Katoomba to Blackheath Upgrade (including Medlow Bath Upgrade) and the Little Hartley to Lithgow Upgrade projects.

2.3.8 Ground surface settlement assessment

A ground movement assessment has been carried out to identify infrastructure such as buildings (including heritage items), railways and utilities that may be affected by potential ground movement associated with the project. Ground movement refers to a localised lowering of the ground level typically associated with either:

- immediate settlement caused by the tunnel excavation and tunnel convergence. These settlements have been estimated and are based on a semi-empirical method which utilises two-dimensional finite element analysis to back calculated key parameters for use with a gaussian settlement curve
- long-term settlement resulting from groundwater drawdown. These settlements are based on one-dimensional compression resulting from a change in effective vertical stress caused by groundwater drawdown within compressible soil layers.

An assessment of ground movement due to immediate settlement was undertaken using two-dimensional finite element analysis. This assessment analysed the full tunnel alignment except for the settlements associated with the construction access shaft at Soldiers Pinch. The 2D finite element model was developed and analysed several locations to predict surface settlements due to volume loss.

The settlement assessment methodology included:

- calculation of the zone of influence for settlement and identification of buildings located in areas where maximum settlement levels are exceeded (see Table 2-5)
- calculation of the maximum slope of ground and maximum settlement for the identified buildings. These values were compared against criteria specified in conditions of approval for recent large tunnel projects in NSW
- numerical modelling and structural assessment for those buildings that exceed the settlement criteria or have an assessed damage category that exceeds ‘slight’ (see Table 2-5).

Table 2-5 Settlement criteria (adopted from recent large tunnel projects in NSW)

Beneath structure / facility	Maximum settlement	Maximum angular distortion	Maximum equivalent strain
Buildings - Low or non-sensitive properties (i.e. < 2 levels and carparks)	30 mm	1:350	0.1%

Beneath structure / facility	Maximum settlement	Maximum angular distortion	Maximum equivalent strain
Buildings - High or sensitive properties (i.e. > 3 levels and heritage items)	20 mm	1:500	0.1%
Roads and Parking areas	40 mm	1:250	-
Parks	50 mm	1:250	-

Table 2-6 Building damage category and corresponding tensile strain limits (Mair et al, 1996; Rankin, 1988)

Damage category	Description	Maximum building settlement	Maximum building slope
0	Negligible	<10 mm	<1:500
1	Very slight	10 mm	<1:500
2	Slight	50 mm	1:200
3	Moderate	75 mm	1:50
4-5	Severe to very severe	>75 mm	>1:50

3.0 Existing environment

This section provides a summary of the existing environment along and adjacent to the project corridor, as relevant to the assessment of potential groundwater impacts. It includes details of climate and weather, topography, drainage and surface water resources, geology, hydrogeology, and groundwater users (human and ecological).

The construction footprint is proposed immediately adjacent to the Greater Blue Mountains World Heritage Area (GBMA) at Blackheath and Soldiers Pinch. This project was therefore assessed under the World Heritage significance criteria and National Heritage significance criteria in Appendix M (Technical report - Non-Aboriginal heritage) as part of the Statement of significance.

3.1 Climate and rainfall

The Australian BoM operates several automated weather stations (AWS) within and adjacent to the groundwater study area that have been used to inform this impact assessment, including:

- Mount Victoria (Selsdon Street) (063056) – data available from January 1872 to December 1990.
- Mount Boyce AWS (063292) – data available from June 1994 to present.
- Little Hartley (Roscommon) (063270) – data available from July 1994 to April 2022.
- Blackheath (Wombat Street) (063295) – data available from July 1996 to present.
- Katoomba (Farnells Road) (063039) – data available from December 1885 to present.

The locations of these weather stations relative to the project and the groundwater impact assessment study area are shown on Figure 3-1.

3.1.1 Temperature

Mean monthly maximum temperatures recorded at Mount Boyce (June 1994 to January 2022) and at Katoomba (January 1907 to January 2022) (refer to Figure 3-2) show that the region is typical of a cool temperate mountain climate. Snow and/or sleet is common during the winter months.

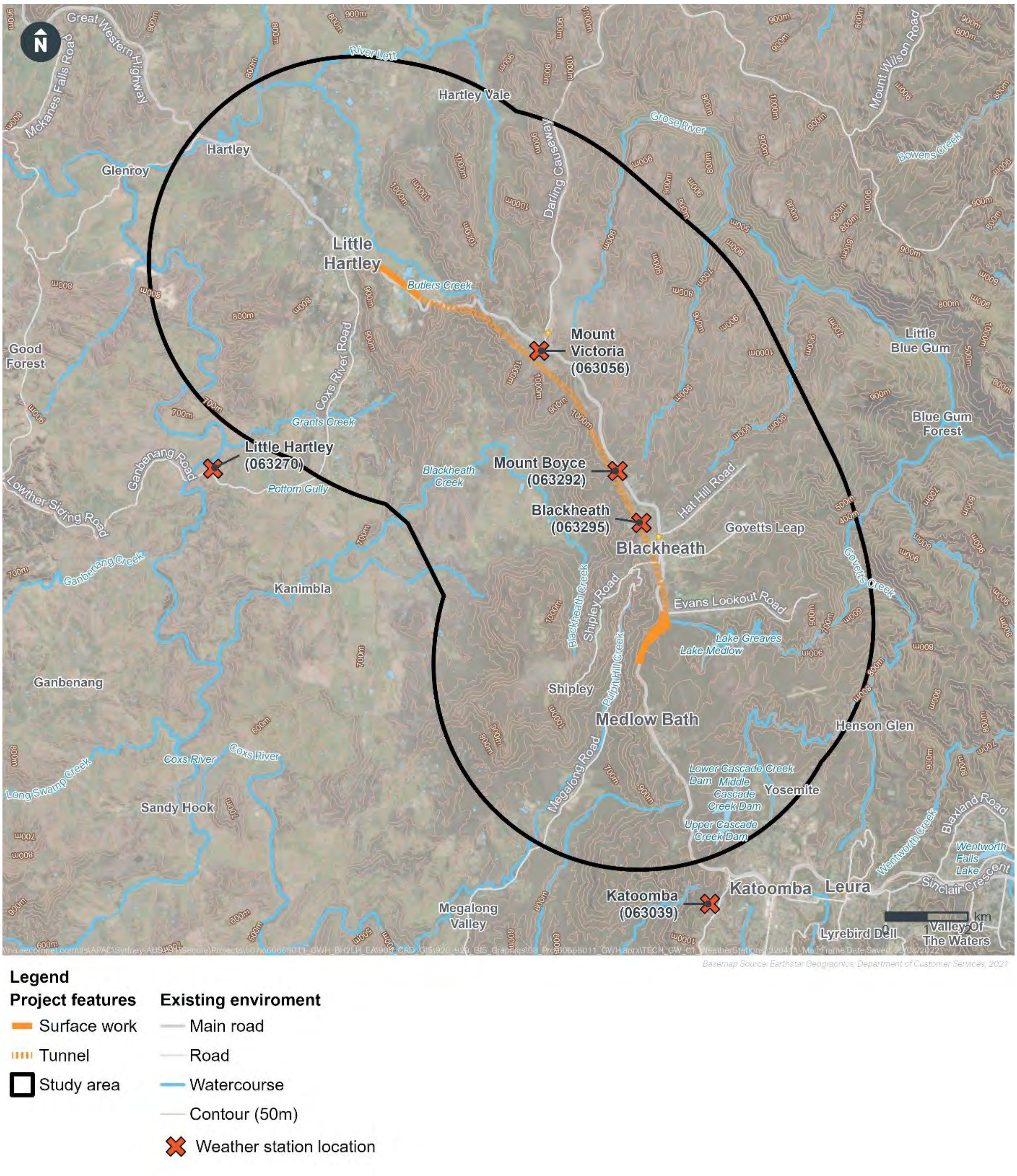

Figure 3-1 BoM weather station locations within and adjacent to the groundwater study area

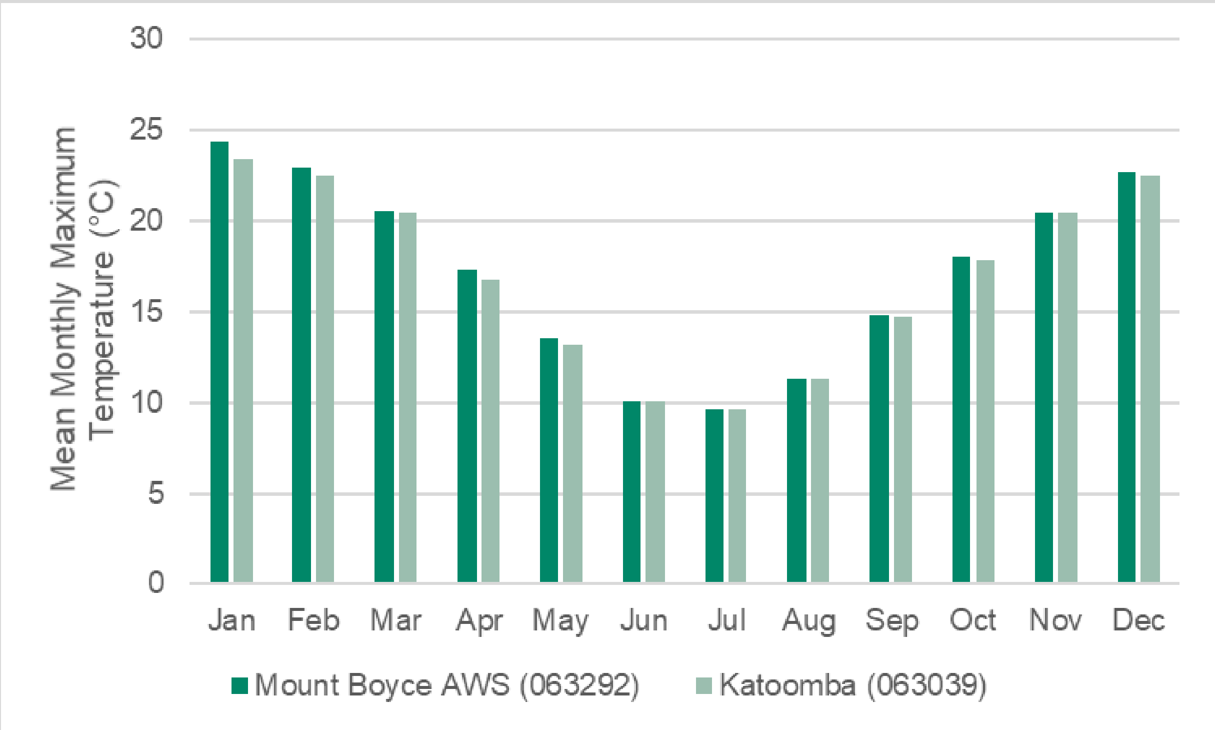

Figure 3-2 Mean monthly maximum temperatures at Mount Boyce AWS and Katoomba

3.1.2 Rainfall

Available mean monthly rainfall data for five BoM AWS used in the groundwater impact assessment are summarised in Table 3-1. Rainfall data for weather stations located at higher elevations on the ridge line (Katoomba, Blackheath, Mount Victoria, and Mount Boyce) typically have higher mean annual rainfall (between 1005.9 mm and 1407.6 mm) than the weather station located in the valley at Little Hartley (712.4 mm).

Rainfall data for weather stations located at higher elevations on the ridge line (Katoomba, Blackheath, Mount Victoria, and Mount Boyce) typically have higher mean annual rainfall (between 1005.9 mm and 1407.6 mm) than the weather station located in the valley at Little Hartley (712.4 mm).

Table 3-1 Mean monthly rainfall (mm) for selected BoM weather stations

Station	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Katoomba	162.2	179.1	172.1	120.3	99.2	117.9	81.6	78.6	71.1	92.0	110.0	121.6	1407.6
Blackheath	125.6	171.3	144.1	72.6	52.5	84.3	45.8	53.7	49.2	73.7	116.6	100.3	1130.0
Mount Victoria	117.1	121.0	110.3	90.0	79.4	90.9	72.0	66.8	62.1	77.7	81.7	91.9	1062.5
Mount Boyce	117.6	138.8	133.5	62.8	53.7	75.3	44.5	56.5	53.6	68.7	104.8	85.9	1005.9
Little Hartley	77.0	76.1	65.7	41.0	35.6	48.9	37.9	47.7	45.3	41.5	75.2	60.7	712.4

Notes:

BoM Katoomba AWS (Farnells Road), No.063039 – data between 1886 to December 2021

BoM Blackheath AWS (Wombat Street), No.063295 – data between 1996 to December 2021

BoM Mount Victoria AWS (Selsdon Street), No. 063056 – data between 1872 to December 1990

BoM Mount Boyce AWS, No.063292 – data between 1994 to December 2021

BoM Little Hartley AWS (Roscommon), No.063270 – data between 1994 to December 2021

Annual rainfall records were used to calculate rainfall residuals and the cumulative rainfall departure (CRD) for the Katoomba (Farnells Road) weather station, as shown on Figure 3-3. The rainfall residual is a measure of the accumulated deficit or surplus of rainfall at a particular time, relative to average rainfall. The CRD from normal, measures the accumulated departure of precipitation from a mean defined for a period of time. CRD plots were not generated for other BoM weather stations because they generally have a short period of available rainfall data. The annual rainfall for Katoomba (Farnells Road) weather station, showing the long-term average annual rainfall as a trend line, is presented on Figure 3-4.

The CRD curve and long-term patterns in rainfall show that the region was subject to relatively wet years prior to 1895 followed by a relatively dry period until the late 1940s. The period between the late 1940s and 1980s was a relatively wet period and was followed by a relatively dry period. In the last couple of years (2021-2022), rainfall has been above the long-term average. Overall, the CRD plot indicates that rainfall has been variable with significant drought and wet periods since the late 1880s.

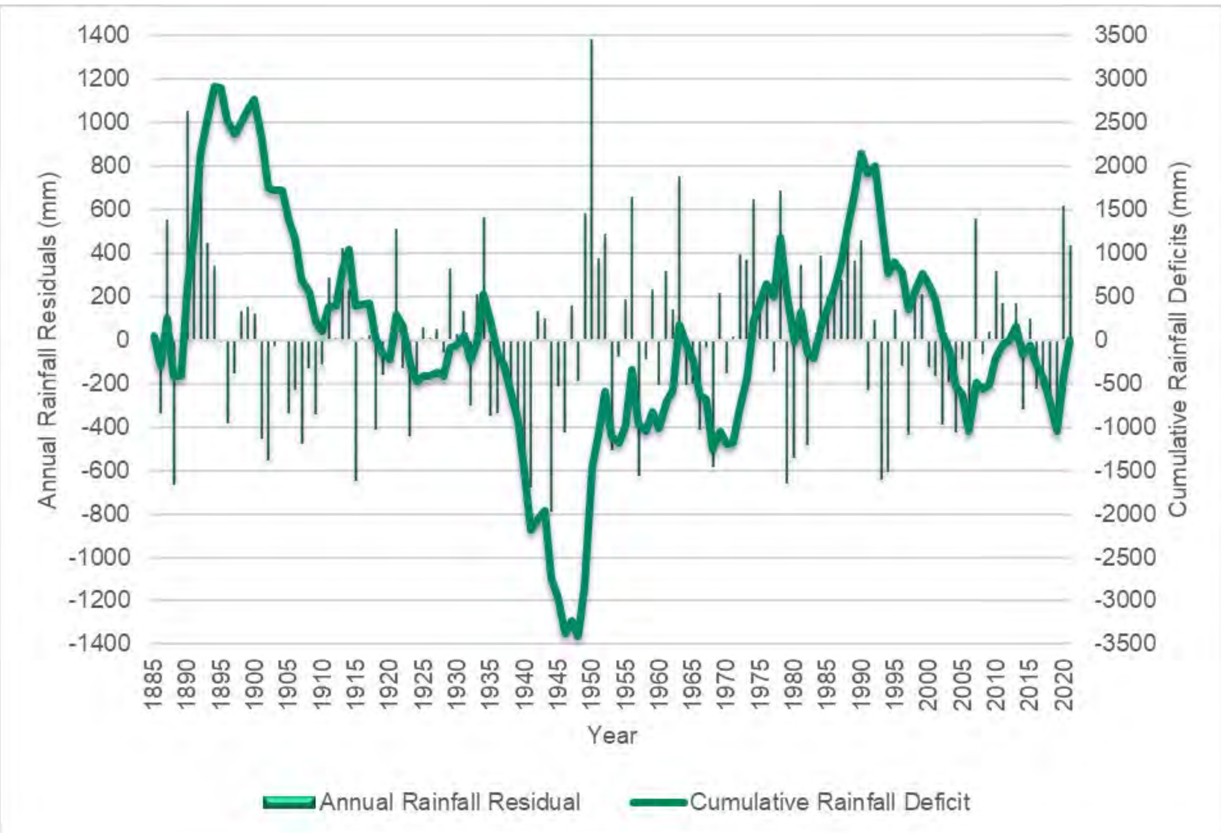

Figure 3-3 Annual rainfall residuals and CRD for Katoomba (Farnells Road) weather station

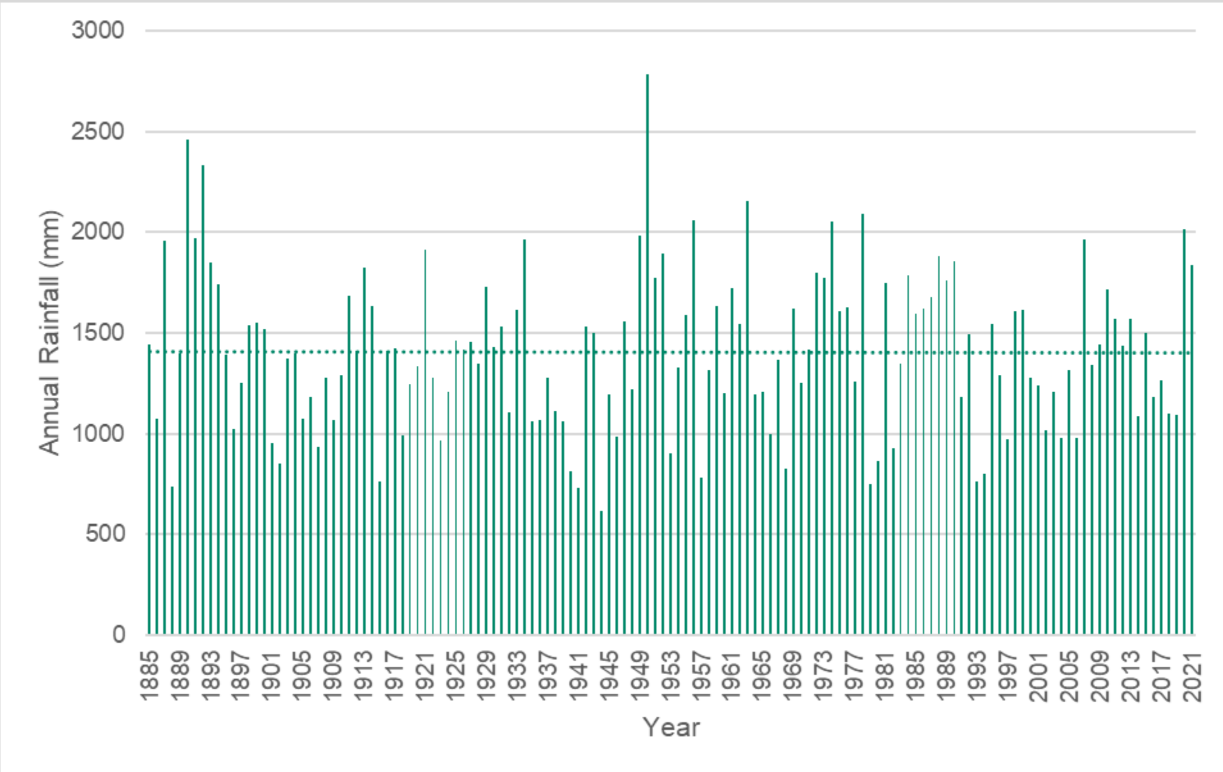

Figure 3-4 Annual rainfall and long term annual average rainfall for Katoomba (Farnells Road) weather station

3.1.3 Evaporation and evapotranspiration

Evaporation data are used to reflect to the loss of water through evaporation from an open water surface (such as a lake or dam). Evapotranspiration data are applied to the loss of water from land surfaces and vegetation.

Evaporation data has been measured at the weather stations used in this groundwater impact assessment. However, pan evaporation mapping published by the BoM (refer to Figure 3-5) indicates that the total average annual evaporation in the region in which the project would be located is between 1,400 mm and 1,600 mm.

Evapotranspiration data is also published by the BoM through its Australian Landscape Water Balance website (BoM, 2022c). Monthly modelled landscape actual evapotranspiration data published by the BoM for Blackheath, Mount Victoria and Little Hartley regions is summarised in Table 3-2. For all three regions, evapotranspiration is generally highest during the summer months with the highest evapotranspiration rates shown during December. The lowest evapotranspiration is during the winter months, with June showing the lowest rate of evapotranspiration. Evapotranspiration is greater in regions of higher elevation on the ridge line (Blackheath and Mount Victoria) when compared to Little Hartley located at a lower elevation within a valley.

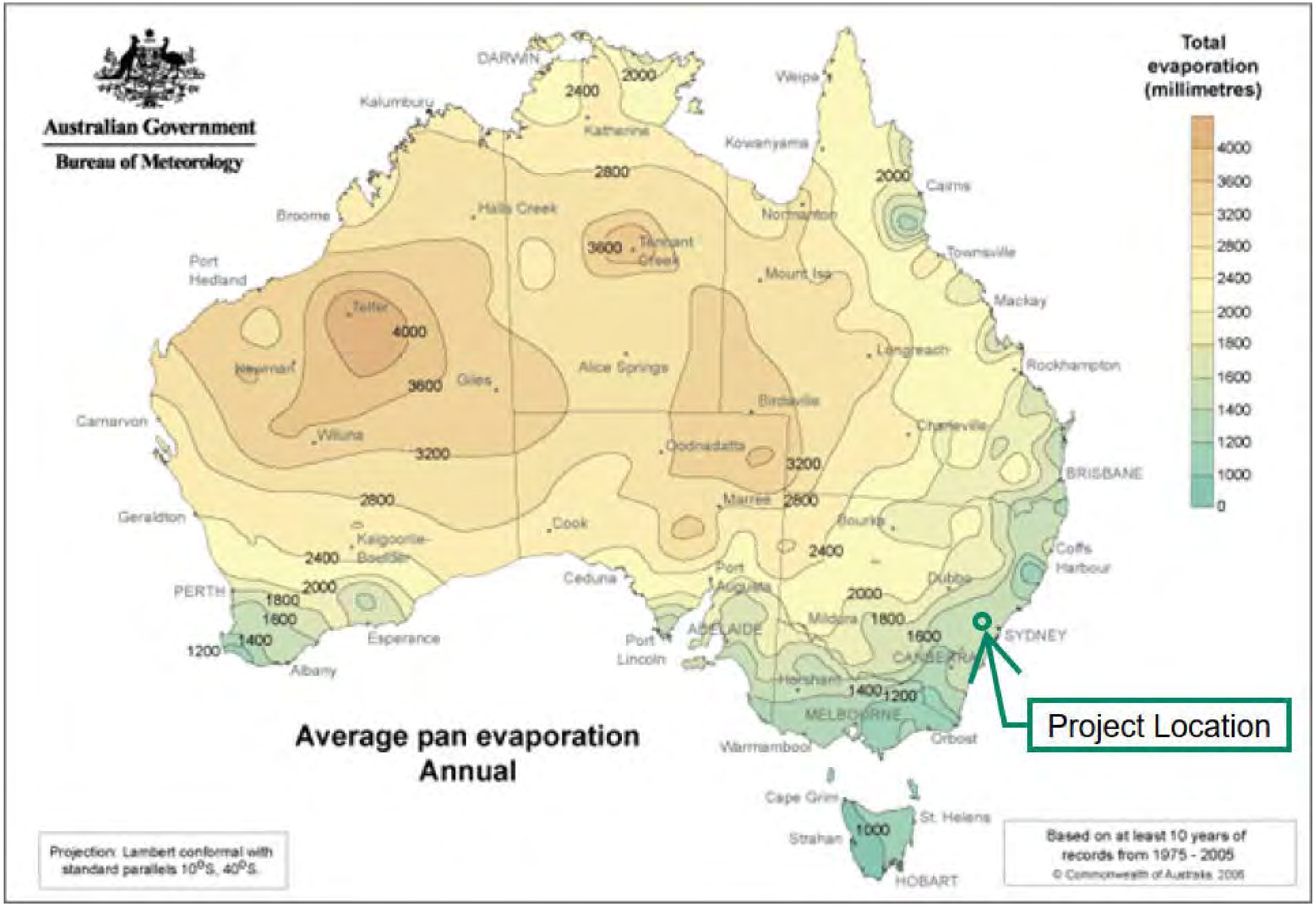

Figure 3-5 Average annual evaporation (BoM, 2006)

Table 3-2 Monthly modelled landscape actual evapotranspiration data (mm) for 2021

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
Blackheath	111.95	91.11	100.02	61.27	45.02	31.84	34.27	48.07	59.7	84.55	80.95	113.80	862.55
Mount Victoria	110.93	90.27	93.70	62.38	44.77	31.82	35.27	49.48	59.59	80.32	78.99	119.42	856.94
Little Hartley	98.78	80.84	78.14	58.47	40.01	28.74	32.35	46.45	57.30	70.51	69.00	113.70	774.29

Figure 3-6 and Figure 3-7 compare the total monthly rainfall recorded at the Blackheath and Little Hartley weather stations in 2021, respectively, compared with evapotranspiration data from the BoM for those sites in the same year. Blackheath, located on the ridge line, predominantly had months where rainfall exceeded evapotranspiration rates, including the summer months when evapotranspiration rates are highest.

Total annual rainfall (1,786 mm) at Blackheath was far greater than the annual evapotranspiration rates (863 mm).

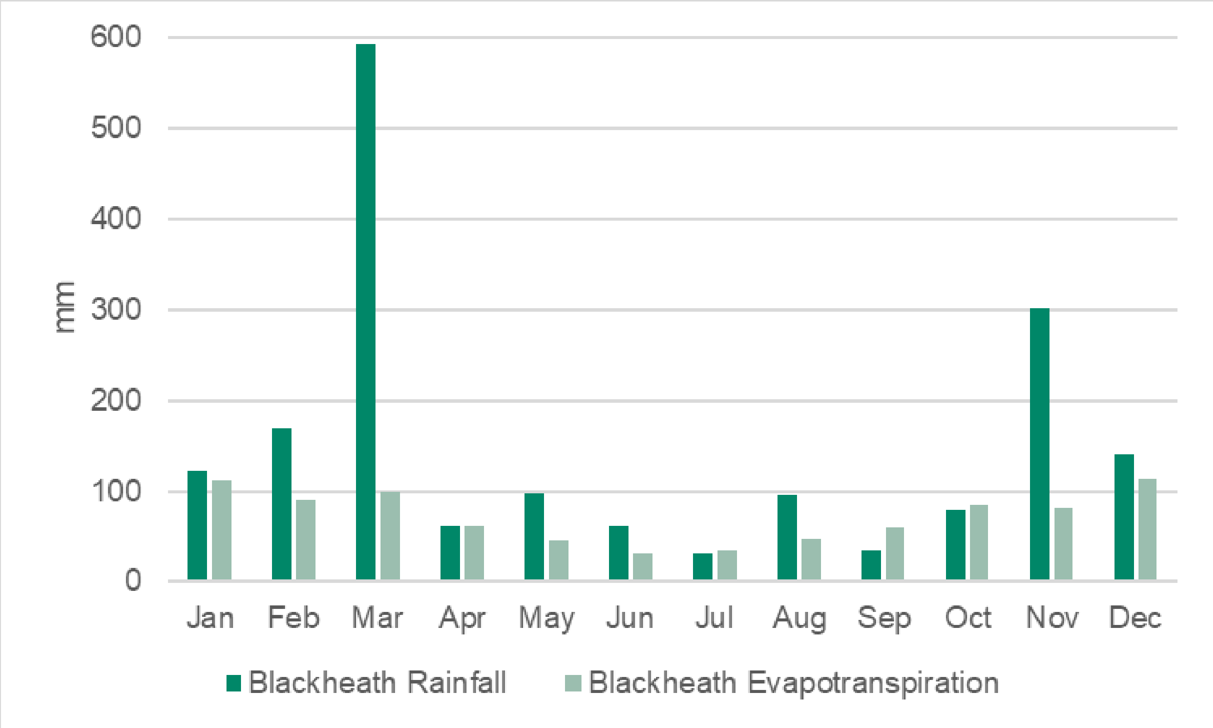

Figure 3-6 2021 rainfall data compared with evapotranspiration data for Blackheath (BoM)

Little Hartley, located at a lower elevation within the valley predominately had months where evapotranspiration rates exceeded total monthly rainfall. Total annual rainfall (875 mm) was only slightly greater than the total annual evapotranspiration rates (774 mm).

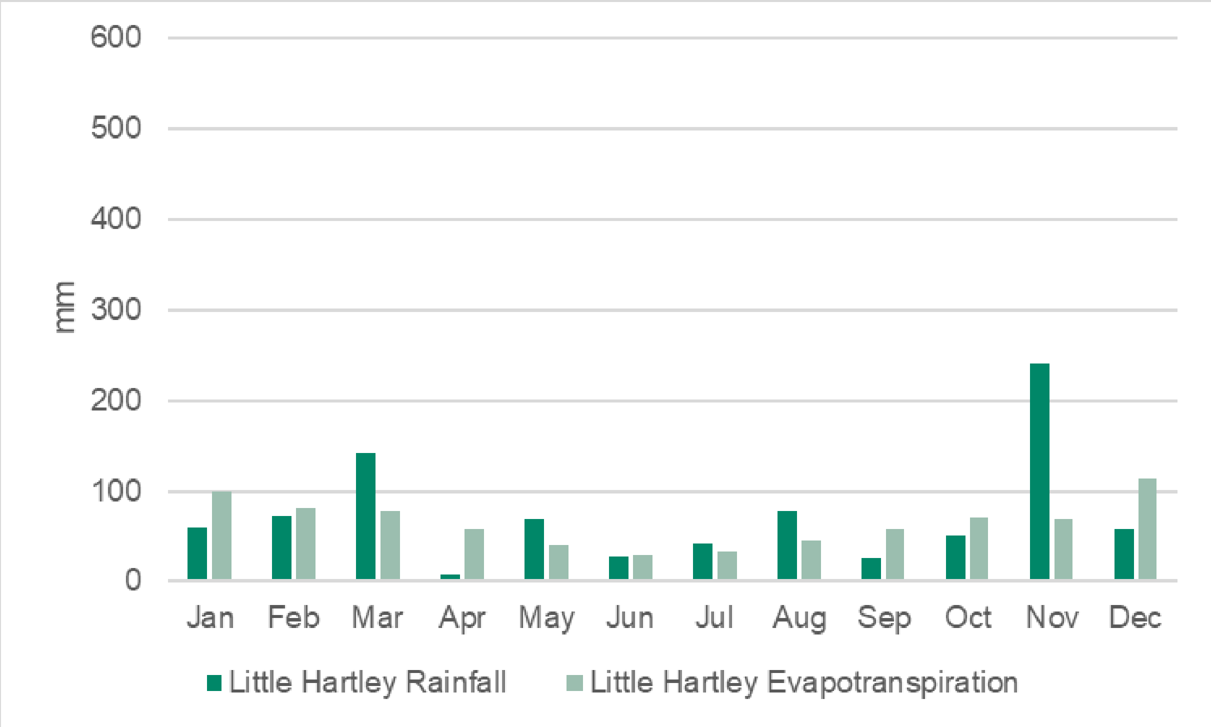

Figure 3-7 2021 rainfall data compared with evapotranspiration data for Little Hartley (BoM)

3.2 Topographical setting and drainage

The project would be generally aligned beneath the existing Great Western Highway, which is located along a ridge line as seen in Figure 3-8. The lands to the east are generally similar or higher elevation and lands to the west follow a moderately steep slope down towards the Megalong Valley. There are numerous mountain peaks on both sides of the project corridor, including Mount Boyce to the west and Mount Victoria to the north. The lands closest to the western and eastern ends of the project are the lowest and flattest and the land with greatest elevation, around 1,000 to 1100 metres above Australian Height Datum (mAHD), are located near Mount Victoria.

Numerous creeks and gullies traverse or extend from the Great Western Highway and connect as tributaries of rivers on both sides of the project corridor. Those on the southern and western side of the existing Great Western Highway feed into the Coxs River and those in the northern and eastern side of the Great Western Highway feed into the Grose River.

3.3 Surface water features and catchments

3.3.1 Hawkesbury-Nepean Catchment

The project would be located within the wider Hawkesbury-Nepean River catchment. The Hawkesbury River and its tributaries are over 470 km long and the Hawkesbury-Nepean River Catchment has an area of around 22,000 km^2. Runoff from all areas of the project would ultimately drain to the Hawkesbury River via one of two different drainage pathways and sub-catchments (Grose River and Coxs River water catchments) (refer to Figure 3-8)

Parts of the Coxs River catchments potentially affected by the project lie within Sydney's drinking water catchment, which is described in the following section. The Grose River Catchment does not lie within Sydney's drinking water catchment.

3.3.2 Sydney's drinking water catchment

The project would be located along and close to the boundary between the Coxs River and Grose River water catchments (refer to Figure 3-8). The project tunnels would be located beneath the ridge line that separates the two catchments, while surface works at Blackheath would be located predominantly in the Grose River catchment and the surface works at Little Hartley in the Coxs River catchment.

The project would be located at the top of Sydney's drinking water catchment (Coxs River), which drains to Lake Burragorang and Warragamba Dam to the south. The majority of the project would pass under the catchment area in tunnels, with construction activities at Soldiers Pinch comprising the only surface works in the Coxs River catchment. Surface works at Blackheath would be within a protected drinking water catchment (Grose River) used to supply water to Blue Mountains townships through a series of smaller local reservoirs. Protected drinking water catchments are shown on Figure 3-8.

The location of the existing Great Western Highway between Blackheath and Little Hartley along a ridge line means that it is intersected by relatively few watercourses. Key among these are Victoria Brook Creek and Boyce Gully, which are both first order streams. Other watercourses close to the existing Great Western Highway and the project corridor include Victoria Creek, Hat Hill Creek and Popes Glen Creek (tributaries of Grose River to the north and east) and Wilsons Gully, Fairy Bower Creek and Centennial Glen Creek (tributaries of Coxs River to the south and west).

Further information regarding surface water is detailed in Appendix J (Technical report - Surface water and flooding) of the EIS.

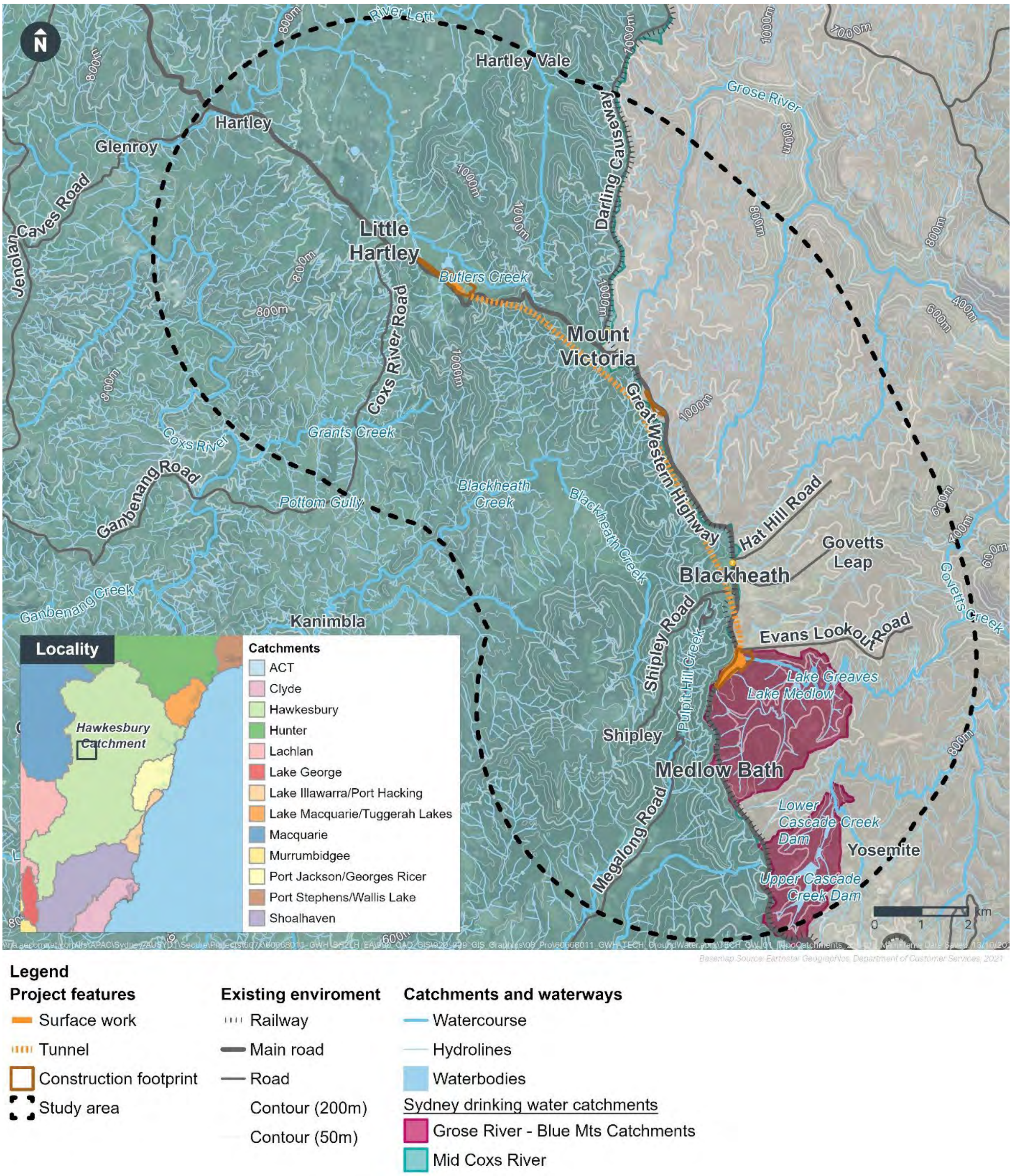

Figure 3-8 Topographic setting, surface water features and drinking water catchments

3.4 Geology

The mapped geology within the project area is shown in Figure 3-9 and summarised in Table 3-3. According to geological maps (Katoomba 1:50,000 Geological Map (Goldbery R. and Bembrick C.S., 1996) and the NSW Seamless Geology dataset (Colquhoun *et al*., 2022)), the bedrock along the project corridor includes the Narrabeen Group, Illawarra Coal Measures, and Shoalhaven Group. There are intrusive units of the Kanimblan cycle of the Lachlan Orogen located at the western end of the groundwater study area, however, the project does not intercept these intrusive units.

Geological cross sections and a long section through the project footprint are attached in Annexure A.

3.4.1 Unconsolidated sediments

The soils along the majority of the project corridor are characterised as Kandosol which is described as dissected sandstone plateau of moderate to strong relief with sandstone pillars, ledges and slabs – level to undulating ridges, irregularly benched slopes, steep ridges, cliffs, canyons and narrow sandy valleys. Soils are on areas of gentle to moderate relief, include acid yellow leached sand and siliceous sand, and sometimes these soils contain ironstone gravel.

The soils along the north-western portion of the project corridor (Little Hartley) are characterised as Sodosol which is described as dissected plateau. The soils on undulating ridge crests are hard acidic yellow mottled soils.

Further information regarding soil landscapes and associated erosion hazards is included in Appendix K (Technical report - Contamination) of the EIS.

3.4.1.1 Acid sulfate soils

The majority of land along and around the project corridor is classified as C – extremely low probability of acid sulfate soil occurrence (1-5 per cent chance of occurrence with occurrences in small, localised areas).

At the western end of the project corridor, near Little Hartley, land is classified B – low probability of acid sulfate soil occurrence (6-70 per cent chance of occurrence).

Table 3-3 Bedrock geology within the project area

Age	Group	Sub-group	Formation	Formation thickness (metres)	General description
Early to Middle Triassic	Narrabeen Group (Tna)	Grose Sub-group (Tnr)	Banks Wall Sandstone (Tnrb)	Up to 115	Quartzose to quartz-lithic sandstone. Numerous claystone lenses and ironstone bands. Dominant outcropping unit within the project area. Includes the Wentworth Falls Claystone Member (typically 3 to 4.5 m thick).
			Mount York Claystone (Tnrb)	Up to 13	Single claystone bed or several claystone beds split by narrow sandstone units.
			Burra-Moko Head Sandstone (Tnru)	30 to 112 thickens eastward.	Quartzose to quartz-lithic sandstone with irregular pebbly bands. Thin lenticular shaly units frequently occur. Includes the Unnamed Claystone Member (maximum 3 m thick).
Early Triassic Late Permian		-	Caley Formation (Tnac)	27 to 46	Siltstone, shale, claystone and fine-grained sandstone.
Middle Permian	Illawarra Coal Measures (Pil)	Wallerawang Sub-group (Piw)	Farmers Creek Formation (Piwf) and Gap Sandstone (Piwg)	0.3 to 12	Coal, claystone, sandstone, band chert, torbanite.
		Charbon Sub-group (Pih)	State Mine Creek Formation (Pihs), Watts Sandstone (Pihw), Denman Formation (Pwjd), Glen Davis Formation (Pihg), Newnes Formation (Pihn), Irondale Coal (Pihi), Long Swamp Formation (Pihl)	1.2 to 27	Claystone, siltstone, sandstone, torbanite.
		Cullen Bullen Sub-group (Pib)	Lidsdale Coal (Pibl), Blackmans Flat Formation (Pibb), Lithgow Coal (Pibi), Marangaroo Formation (Pibm)	0.9 to 16	Coal, quartz-lithic sandstone, conglomerate.

Age	Group	Sub-group	Formation	Formation thickness (metres)	General description
		Nile Sub-group (Pin)	Gundangaroo Formation (Ping) Coorongooba Creek Sandstone (Pinc), and Mount Marsden Claystone (Pinm)	5 to 25	Lithic sandstone, siltstone, shale, coal, torbanite with the lower formation consisting of limestone, dolomite, claystone and siltstone.
	Shoalhaven Group (Psh)	-	Berry Siltstone (Pshb)	Up to 210	Sandy micaceous siltstone. Boulder-bearing beds are common.

Notes: Geological information was extracted from geological maps and referenced from Bembrick (1983), Bembrick (1980), Bembrick and Holland (1972), Goldbery (1969), and Yoo et al. (2001)

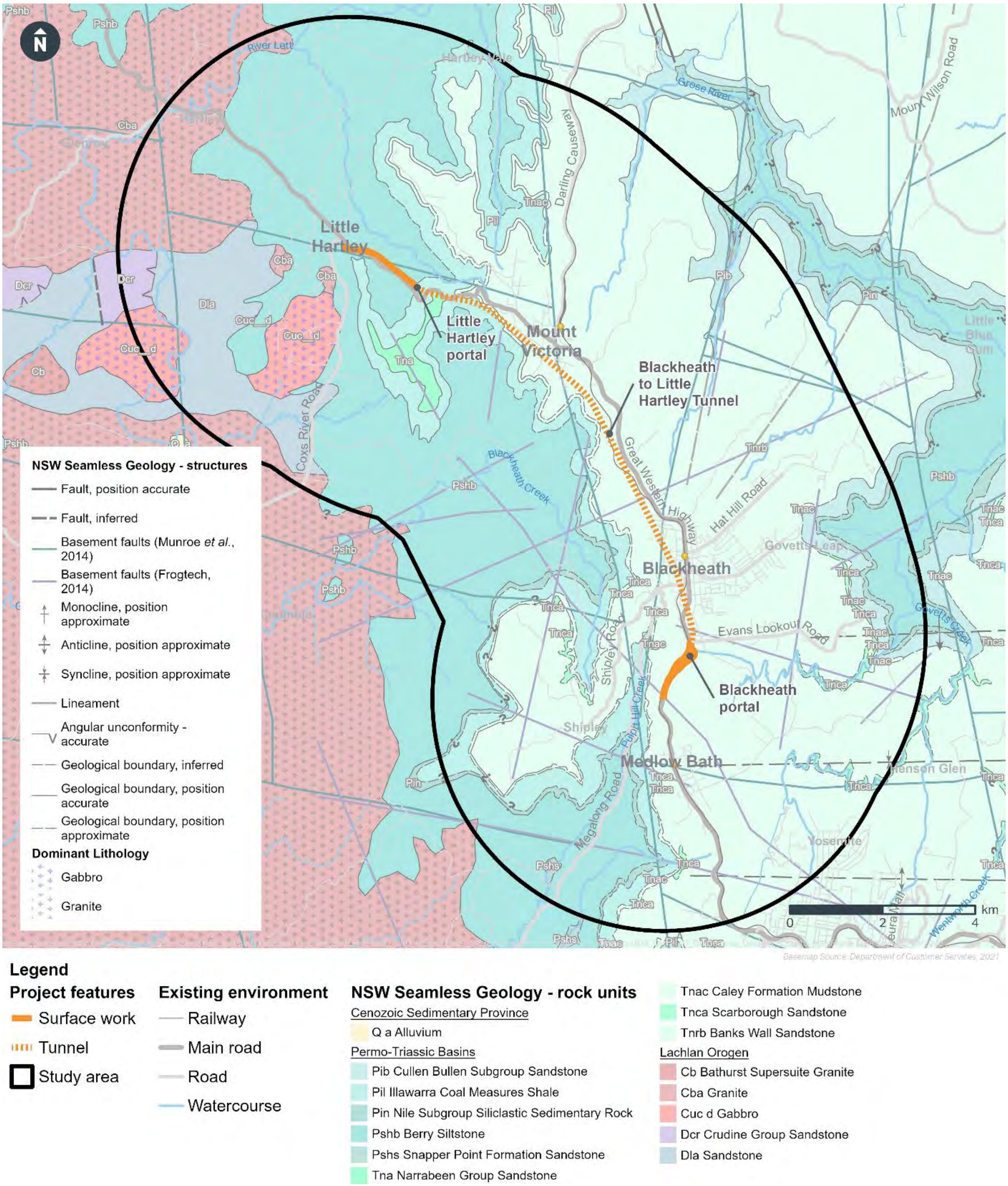

Figure 3-9 Mapped bedrock geology

3.4.2 Lithostratigraphic units

3.4.2.1 Narrabeen Group

The Narrabeen Group was deposited in the early Triassic and comprises the Grose Subgroup which is sub-divided into the Banks Wall Sandstone, Mount York Claystone, and the Burra-Moko Head Sandstone, which overlies the Caley Formation.

3.4.2.1.1 Banks Wall Sandstone

The Banks Wall Sandstone is the dominant outcropping unit within the groundwater study area, extending from Blackheath where it is thickest to Mount Victoria where it thins towards the edge of the plateau (refer to Figure 3-9). The Katoomba 1:50,000 Geological Series (Sheet 8930-I) describes the Banks Wall Sandstone as a quartz-rich sandstone, slightly lithic, with minor interbedded claystone. The unit is predominantly quartzose, but also contains abundant ironstone bands, occasional conglomerates and numerous claystone lenses several metres thick. The unit has a maximum thickness of 115 metres (Geoscience Australia (GA), 2022).

The Wentworth Falls Claystone is mapped within the eastern sections of the Banks Wall Sandstone and is described as a red brown and greenish grey claystone. The claystone is located around 90 metres above the base of the Banks Wall Sandstone and marks a change in the cross-bedding directions within the Banks Wall Sandstone.

3.4.2.1.2 Mount York Claystone

The Mount York Claystone is described as red-brown claystone (a compacted silt, clay, or sand) with relatively high quartz content and total clay content often below 50 per cent. The siltstone or claystone is usually present as two thin 1 m to 2 m thick layers separated by sandstone, however, can be separated by multiple thin layers of sandstone. This unit has a maximum thickness of 13 metres (GA, 2022).

3.4.2.1.3 Burra-Moko Head Sandstone

The Burra-Moko Head Sandstone comprises quartzose to quartz-lithic sandstone, typically cross-bedded, with thin lenticular claystone interbeds and irregular pebbly bands. This unit has a maximum thickness of 112 metres (GA, 2022). In general, the Burro-Moko Head Sandstone is distinctly more conglomeratic compared to the overlying Banks Wall Sandstone.

3.4.2.2 Caley Formation

The Caley Formation comprises claystone, shale, quartz-lithic sandstone, with a maximum thickness of 46 metres. The sandstone of the Caley Formation is fine to coarse grained, quartz-lithic, with common lithic pebbles; and the fine grained units consist of grey to grey-greenish claystone, with shale and siltstone. The formation varies in thickness from around 15 metres thick in the western margins of the Blue Mountains, and thins towards the east to over 4 metres thick in the Woodford area.

Cross-bedding is common and indicates a generally south easterly direction of transport; the palaeodrainage patterns indicate a south-easterly to easterly convergent stream pattern. It is probable that the environment of deposition of the Caley Formation changed upward from brackish or near marine at the base into fluvial, with meandering streams and overbank shale.

3.4.2.3 Illawarra Coal Measures

Widespread coal measure sedimentation commenced following the regression of the Shoalhaven ‘sea’, forming the Illawarra Coal Measures. The Illawarra Coal Measures comprise shale, quartz-lithic sandstone, conglomerate, chert, sporadically carbonaceous mudstone, coal and torbanite seams of Permian age.

This unit outcrops in in the groundwater study area almost entirely along the steep, generally forested slopes between the base of the Caley Formation and the Berry Formation (valley floor).

The Illawarra Coal Measures consist of the Wallerawang, Charbon, Cullen Bullen and Nile sub-groups. The Wallerawang Sub-group comprises of coal, claystones, sandstones, band chert, torbanite and includes the Farmers Creek Formation and Gap Sandstone. The Charbon Sub-group comprises of delta plain sediment with marine incursions of sandstone, siltstone, claystone and coal, including the State Mine Creek Formation, Watts Sandstone, Denman Formation, Glen Davis Formation, Newnes

Formation, Irondale Coal and the Long Swamp Formation. The Cullen Bullen Sub-group comprises of coarse-grained pebbly sandstone and coal and includes the Lisdale Coal seam and the Blackmans Flat and Marrangaroo Conglomerates. The Nile Sub-group comprises of lithic sandstone, siltstone, shale, coal, torbanite and includes the Coorongooba Creek Sandstone, Gundangaroo Formation and Mount Marsden Claystone.

3.4.2.4 Shoalhaven Group

The Shoalhaven Group comprises sandstone, siltstone, shale, polymictic conglomerate, claystone; rare tuff, carbonate, and evaporite. The Shoalhaven Group includes the Berry Siltstone within the groundwater study area.

The lithology of the Shoalhaven Group is like the Illawarra Coal Measures, albeit without the numerous coal seams. Outcrops of the Berry Siltstone are generally restricted to the valley floors and margins in the deeply incised Grose and Jamison Valleys. The Berry Siltstone comprises indistinct bedding to flat-bedded, mid- to dark-grey siltstone and very fine feldsphathic litharenite, interbedded with thin, fine-grained sandstone lenses. Boulder-bearing beds are common with predominantly well-rounded boulders of up to 0.6 metres in diameter of varying composition from quartzites to granites and other igneous rocks.

3.4.3 Structural geology

The Permian and Triassic age strata generally dip towards the east at about one degree and increase in thickness. The dominant geological structures in the groundwater study area include faults (shear fractures) and joints (dilating fractures).

Further east there are significant monoclinal folds that are likely a reflection of faults in the underlying Lachlan Fold Belt rocks. Similarly faults and other fracture zones in the Permian and Triassic age units within the groundwater study area are largely reflections of faulting in that basement.

Geognostics produce regional structurally enhanced depth to basement models, and outputs of these models include regional structures, and is named the Structurally Enhanced view of Economic Basement (SEEBASE^{TM}). A SEEBASE^{TM} regional study (Frogtech, 2014) identified faults that strike through the groundwater study area, as shown on Figure 3-9.

Remote sensing using available aerial photography showed numerous structural lineaments are present with a well-developed regional fracture pattern in the Banks Wall Sandstone. This fracture pattern consists of two major components:

- a regional and pervasive rectangular system of fractures that trend north-northwest and east-northeast
- a system of widely spaced long lineaments that trend north-south to north-northeast, south-southwest.

A third and minor component of the pattern consists of east-west and east-southeast, west-northwest trending fracture sets which are associated with the meridional lineaments (Shepherd *et al* 1980).

The surface water drainage pattern is strongly modified by the regional fracture patterns, where many streams follow north-northwest joints and some longer streams follow the north-north east, south-south west lineaments.

There is also a correlation between elongated hanging swamp valleys and major structural features. Thick, extensive deposits of friable sandstone occurring in the Blackheath area can be similarly correlated with the position of the Blackheath Lineament (Annexure A), where it intersects remnant plateau surfaces.

3.4.4 Acid sulfate rock

Acid sulphate rock (ASR) is unweathered rock, which contains metal sulfide minerals (commonly iron sulfide). When exposed to both oxygen and water, such as a road cutting, oxidation of the sulfide within the ASR leads to the formation of iron oxides, sulfuric acid, sulfates, and salts. Dependent on concentrations, ASR has the potential to be problematic with respect to environmental, structural and durability risks (Bridgement, N., 2017).

There is potential for ASR to be intersected within the western end of the groundwater study area within the Illawarra Coal Measures. The Berry Siltstone (Shoalhaven Group) and Marrangaroo Conglomerate (Illawarra Coal Measures) can contain sufficient disseminated pyrite to be considered ASR, which is evident in a road cutting along the Great Western Highway in Marrangaroo.

Acid sulfate rock test samples were collected from the Banks Wall Sandstone, Illawarra Coal Measures, and the underlying Berry Siltstone during project investigations. Various samples collected from the Illawarra Coal Measures and Berry Siltstone indicated a high capacity for potential ASR (PASR) and samples collected from the Banks Wall Sandstone were non-acid forming.

The probability of PASR in the Banks Wall Sandstone, Mount York Claystone and Burra-Moko Head Sandstone is considered to be low, the Caley Formation is considered to have a low to moderate probability, and the Illawarra Coal Measures and Berry Siltstone are considered to have a very high probability.

3.5 Hydrogeology

3.5.1 Groundwater occurrence

The hydrostratigraphic sequence (groundwater potential associated with the geological stratigraphy) within and around the project corridor can be broadly sub-divided into a shallow groundwater flow system located above the Mount York Claystone (a known aquitard or barrier to water flow), and an underlying deep groundwater system located below the Mount York Claystone, as summarised in Table 3-4.

Table 3-4 Hydrostratigraphic units

Geological unit	Hydrostratigraphic unit	Confined/unconfined aquifer
Banks Wall Sandstone	Shallow groundwater flow system likely comprising of multiple perched aquifers and a regional aquifer	Semi-confined and unconfined
Mount York Claystone	Discontinuous aquitard	Low permeability/aquitard
Burro-Moko Head Sandstone	Deep groundwater flow system which comprises a multi-storey aquifer system. The coal seams are the higher permeability zones in the Illawarra Coal Measures.	Semi-confined
Caley Formation		
Illawarra Coal Measures		
Berry Siltstone	Aquitard	Low permeability/aquitard

3.5.2 Groundwater levels and flow

3.5.2.1 Standing water levels

Standing water levels for groundwater monitoring standpipes within the groundwater study area were manually gauged for the Little Hartley to Lithgow Upgrade in 2011 and 2012, and the initial geotechnical investigation for the project in 2021. The gauging results are summarised in Table 3-5 and standpipe locations are shown on Figure 3-10.

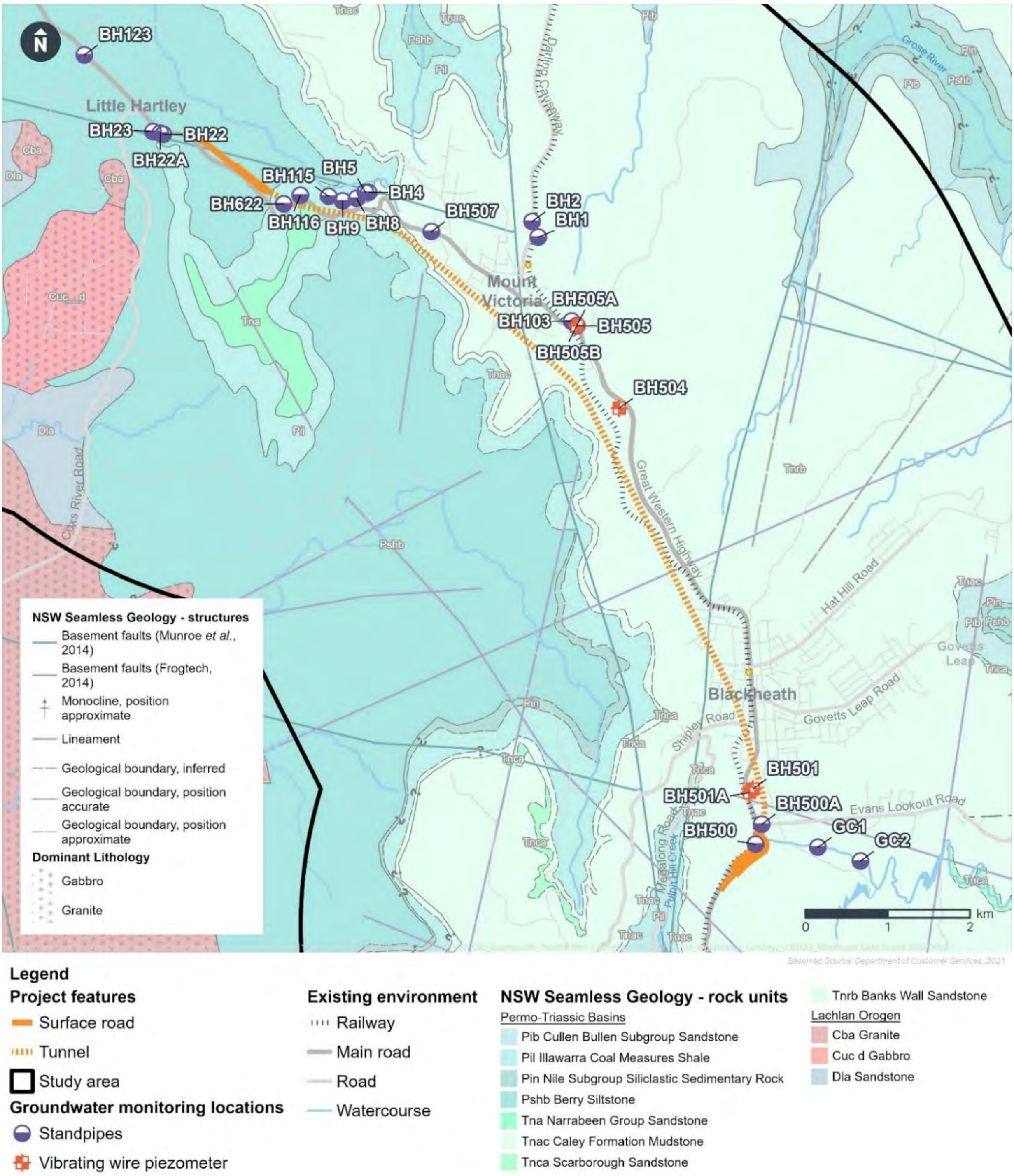

Figure 3-10 Project-specific groundwater monitoring bore locations

Table 3-5 Standing water level data for bores within the groundwater study area

Bore ID	Screened interval (mbgl)[8]	Screened formation	Location	Date gauged	Standing water level (mbgl)[7]	Groundwater elevation (mAHD)[9]
BH1	23.70-29.70	Mount York Claystone	Mount Victoria	17/05/2011	14.25	1032.35
BH2	8.48-14.48	Banks Wall Sandstone	Mount Victoria	04/05/2011	6.06	1032.04
BH4	13.95-19.95	Illawarra Coal Measures	Berghofers Pass – Mount Victoria	10/05/2011	20.2	888.73
BH5	18.85-24.85	Illawarra Coal Measures	Berghofers Pass - Mount Victoria	10/05/2011	17.59	873.87
BH8	19.55-25.55	Illawarra Coal Measures	Berghofers Pass - Mount Victoria	10/05/2011	23.07	871.27
BH9	9.00-12.00	Illawarra Coal Measures	Berghofers Pass - Mount Victoria	10/05/2011	Dry	Dry
BH22	8.90-14.90	Berry Siltstone	Little Hartley	04/05/2011	Dry	Dry
BH22A	15.00-21.00	Berry Siltstone	Little Hartley	04/05/2011	16.27	815.99
BH23	12.00-18.00	Berry Siltstone	Little Hartley	04/05/2011	14.2	817.01
BH103	14.30-17.30	Banks Wall Sandstone	Mount Victoria	01/09/2011	9.97	1020.03
BH115	11.50-17.50	Illawarra Coal Measures	Victoria Pass	01/09/2011	8.41	854.09
BH116	17.70-23.70	Illawarra Coal Measures	Victoria Pass	01/09/2011	21.55	869.45
BH123	9.40-12.40	Berry Siltstone	Little Hartley	29/08/2011	2.625	822.58
BH500	22.00-25.00	Banks Wall Sandstone	Blackheath portal	01/09/2011	Dry	Dry

[8] metres below ground level
[9] metres above Australia Height Datum

Bore ID	Screened interval (mbgl)[8]	Screened formation	Location	Date gauged	Standing water level (mbgl)[7]	Groundwater elevation (mAHD)[9]
BH500A	24.00-30.00	Banks Wall Sandstone	Blackheath portal	15/12/2021	13.93	1038.31
BH505A	21.00-24.00	Banks Wall Sandstone	Mount Victoria	15/12/2021	16.27	1055.73
BH505B	40.00-46.00	Burra-Moko Head Sandstone	Mount Victoria	15/12/2021	Dry	Dry
BH507	49.00-55.00	Burra-Moko Head Sandstone	Mount Victoria	15/12/2021	50.44	1021.56
BH622	24.00-27.00	Illawarra Coal Measures	Little Hartley portal	15/12/2021	23.15	852.41
GC1	0.25-0.75	Greaves Creek Swamp	Blackheath	No data	1.05	1008.95
GC2	0.30-0.80	Greaves Creek Swamp	Blackheath	No data	1.27	974.73

3.5.2.1.1 Previous investigation

Groundwater levels were measured at six standpipe monitoring bores installed within the Mount Victoria region during a hydrogeological investigation for the Little Hartley to Lithgow Upgrade, as shown on Figure 3-10.

A summary of the groundwater level data collected between December 2009 and October 2015 in these bores is summarised in Table 3-6. Monitoring bore hydrographs showing piezometric levels and daily or monthly rainfall long-term trends are presented in Annexure D.

Table 3-6 Summary of groundwater levels at Mount Victoria

Bore ID	Ground elevation (mAHD[10])	Geo-morphic location	Screened geology	Minimum groundwater level (mAHD)	Maximum groundwater level (mAHD)	Average groundwater level (mAHD)	Maximum change in groundwater level during monitoring period (metres)
BH1	1046.60	Mount Victoria plateau	Narrabeen Group	1028.85	1034.57	1030.60	5.72
BH2	1038.10			1028.99	1034.33	1031.51	5.34
BH4	908.93	Lower slopes of Mount Victoria western escarp-ment	Illawarra Coal Measures	888.87	890.99	889.44	2.12
BH5	891.46			872.67	877.72	874.06	5.00
BH8	894.34			871.14	872.02	871.49	0.88
BH9	896.80			884.96	886.87	885.07	1.90

The water level time series hydrographs indicate the following:

- there is a rainfall recharge relationship between rainfall and piezometric levels within the Banks Wall Sandstone, as shown at BH1 and BH2, indicating that hydrostratigraphic unit is largely influenced by rainfall recharge and effective storage (i.e., water levels decline after the wet periods as groundwater readily drains from the unit)
- there is a relationship between rainfall and piezometric levels within the Illawarra Coal Measures, which is mostly evident at BH4, BH5, and BH9, indicating the hydrostratigraphic unit in the area of the bores is largely influenced by rainfall recharge. The relatively fast piezometric response to heavy rainfall suggests direct rainfall recharge to the Illawarra Coal Measures where the unit outcrops on the lower slopes of the Mount Victoria western escarpment.

3.5.2.1.2 Project data

VWPs record pore water pressures at various intervals below ground and, after pore pressure conversion to equivalent hydrostatic pressure, can provide insights into vertical hydraulic groundwater gradients and discretisation[11] within the aquifer.

A total of 12 VWPs were installed spatially within the groundwater study area and at multiple depths within the Narrabeen Group as part of initial geotechnical investigations for the project.

Bore locations within Blackheath and Mount Victoria, are shown on Figure 3-10. At the time of writing this report, one-year of transient VWP (converted) hydrostatic pressure data was available, over the period 25 May 2021 to 16 May 2022. VWP transient pore pressure data, converted to equivalent groundwater level hydrographs, are presented in Annexure D and summarised in Table 3-7.

[10] metres above Australian Height Datum
[11] Represents or approximates (a quantity or series) using a discrete quantity or quantities

Monitoring of groundwater at bores installed in the Banks Wall Sandstone, Mount York Claystone and underlying Burra-Moko Head Sandstone indicates that potentiometric level (head) reduces with depth. The hydrographs suggest the following:

- VWP01 in BH501 and standing water levels gauged at BH500A indicate perched water on the Wentworth Falls Claystone Member, however, standpipe BH500 which was installed in the Upper Banks Wall Sandstone is dry (i.e., discontinuous perched water system)
- perched groundwater occurs on the Mount York Claystone, as shown in the hydrographs by VWP02 in BH501, VWP01 and VWP02 in BH501A, VWP01 and VWP02 in BH504, and VWP01 and VWP02 in BH505
- the highest groundwater pressures have been measured in the Burra-Moko Head Sandstone 47 m head (VWP03 in BH051A) and 30 m head (VWP04 in BH505)
- VMP03 in BH501A indicates sub-artesian conditions for the Lower Burra-Moko Head Sandstone, while in other bores (VWP03 in BH504 and VWP03 and VWP04 in BH505) the Burra-Moko Head Sandstone appears to be only partially saturated.

Table 3-7 Summary of VWP groundwater levels within the groundwater study area

Bore ID	VWP ID	VWP depth (mAHD)[12]	Date range	Location	Formation VWP installed within	Minimum groundwater level (mAHD)	Maximum groundwater level (mAHD)	Average groundwater level (mAHD)	Maximum change in groundwater level during monitoring period (metres)
BH501	VWP01	1021.5	26 May 2021 to 14 December 2021 (6.5 months)	Blackheath	Upper Banks Wall Sandstone	1023.20	1023.92	1023.60	0.72
	VWP02	1006	26 May 2021 to 17 March 2022 (9.5 months)		Lower Banks Wall Sandstone	1005.51	1006.27	1005.96	0.77
BH501A	VWP01	946	25 May 2021 to 6 August 2021 (2.5 months)	Blackheath	Lower Banks Wall Sandstone	973.09	973.42	973.28	0.33
	VWP02	931	25 May 2021 to 6 August 2021 (2.5 months)		Mount York Claystone	937.94	946.41	939.07	8.47 (not stabilised)
	VWP03	885	25 May 2021 to 6 August 2021 (2.5 months)		Lower Burro-Moko Head Sandstone	932.62	932.94	932.85	0.32
BH504	VWP01	985	25 May 2021 to 9 May 2022 (11.5 months)	Between Blackheath and Mount Victoria	Lower Banks Wall Sandstone	999.80	1002.56	1001.19	2.75
	VWP02	982	25 May 2021 to 9 May 2022 (11.5 months)		Mount York Claystone	991.81	994.07	992.67	2.27

[12] metres above Australian Height Datum

Bore ID	VWP ID	VWP depth (mAHD)[12]	Date range	Location	Formation VWP installed within	Minimum groundwater level (mAHD)	Maximum groundwater level (mAHD)	Average groundwater level (mAHD)	Maximum change in groundwater level during monitoring period (metres)
	VWP03	947	25 May 2021 to 9 May 2022 (11.5 months)		Lower Burro-Moko Head Sandstone	946.50	948.85	947.22	2.36
BH505	VWP01	1008.5	25 May 2021 to 16 May 2022 (12 months)	South east of Mount Victoria	Lower Banks Wall Sandstone	1009.24	1015.19	1012.43	5.95*
	VWP02	999	25 May 2021 to 16 May 2022 (12 months)		Mount York Claystone	1008.01	1013.01	1010.80	5.00*
	VWP03	949	25 May 2021 to 16 May 2022 (12 months)		Lower Burro-Moko Head Sandstone	964.14	964.79	964.36	0.65
	VWP04	918	25 May 2021 to 16 May 2022 (12 months)		Lower Burro-Moko Head Sandstone	948.04	948.61	948.29	0.57

*A change of frequency for VWP01 and VWP02 noted at BH505 around 28 September 2021. Pore pressure change may be due to landslide occurrence that happened during this time at a bridge located around 60 metres from the bore.

3.5.2.2 Inferred regional groundwater elevation

Groundwater elevation measurements from the project and previous investigations were used to infer the pre-construction regional groundwater elevation maps for five hydrostratigraphic units:

- the upper most saturated layer (water table)
- Banks Wall Sandstone
- Mount York Claystone
- the lower Burra-Moko Head Sandstone.

Calibration of the regional groundwater elevation maps is discussed in Annexure B.

The inferred pre-construction groundwater elevation map for the water table is shown in Figure 3-11.

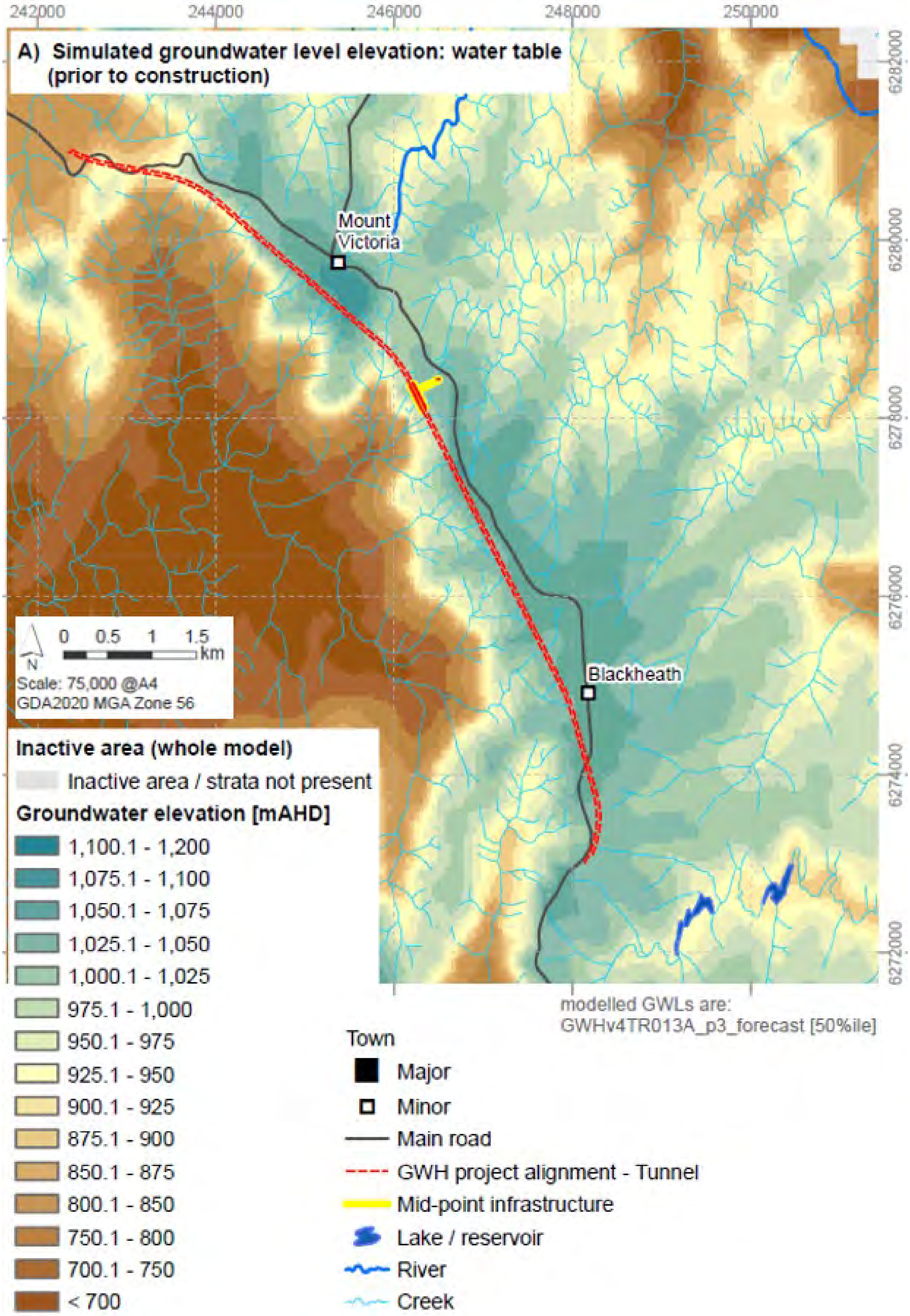

Figure 3-11 Simulated pre-construction groundwater level elevation map for the water table

3.5.2.3 Groundwater flow

Groundwater flow within deep bedrock and shallow aquifers is via secondary permeability resulting from structural features including joints, fractures, faults, shear zones, and bedding planes.

Groundwater flow through primary permeability is limited, as evident in the discharges (swamps), where groundwater flow has been described as preferentially moving through a ladder-like network of numerous semi-isolated aquifers linked by zones of higher (secondary) permeability such as joints (Reynolds, 1976).

Lateral groundwater flow direction is controlled predominantly by topography and subject to local variation due to geological structures.

Groundwater flow divides are expected to correspond reasonably closely to surface water watersheds, with some offset to the east. The expected groundwater flow direction, as developed during groundwater modelling, is summarised in Table 3-8.

Table 3-8 Groundwater flow direction

Aquifer type	Groundwater flow direction
Perched aquifers	Controlled by topography
Shallow groundwater flow system	• Controlled by topography and structure • Flows towards surface water drainage systems • Flows through interconnected mostly sub-vertical joints and sub-horizontal bedding partings, and eventually to the surface at valley sides and cliff faces • Flow in fractured rocks is ladder like, but in the overall direction of the hydraulic gradient. Locally flow may be vertical (down) or lateral in joints. However, the overall direction of flow is determined by the elevation where recharge occurs, and the elevation where discharge occurs.
Deep groundwater flow system	Flows vertically through joints and laterally through bedding partings, which connect to other vertical joints, and eventually to the surface at valley sides and cliff faces.

3.5.3 Groundwater recharge and discharge

The conceptualised recharge and discharge mechanisms for each aquifer system are summarised in Table 3-9. Information obtained from CHM completed for the Katoomba to Little Hartley Upgrade (Golder, 2021) has been refined for the project using available project-specific groundwater monitoring data.

Table 3-9 Groundwater recharge and discharge mechanisms

Groundwater system	Geological unit	Recharge mechanisms	Discharge mechanisms
Perched water in unconsolidated sediment	Unconsolidated sediments and fill material	• primarily via seasonal rainfall infiltration • irrigation of land (Little Hartley only) • seepage from surface water drainage features • leakage from stormwater, water distribution and sewerage systems	• discharge to surface water including swamps • leakage to the underlying shallow groundwater system • evapotranspiration
Shallow groundwater flow system	Banks Wall Sandstone	• infiltration of rainfall where the unit outcrops • seepage of water from overlying perched groundwater systems • seepage of water from surface water storage dams (e.g., Lake Greaves at Blackheath) • seepage from surface water drainage features (losing systems) • leakage from stormwater, water distribution and sewerage systems	• discharge to surface water flows and swamps either side of the plateau, with greater discharges expected to the swamps of the eastern escarpment (gaining systems) • leakage to or through the underlying discontinuous Mount York Claystone aquitard or where missing other aquifers within the deep aquifer system • evapotranspiration • groundwater abstraction (licenced and unlicenced bores)
Aquitard	Mount York Claystone	• infiltration of rainfall where the unit outcrops • vertical seepage of water from the overlying groundwater systems	• facilitates horizontal flow (on top of unit) resulting in discharge to surface water flows and swamps either side of the plateau, with greater discharges expected to the swamps of the eastern escarpment • evapotranspiration (hanging swamps of the escarpments) • leakage to aquifers within the deep aquifer system
Deep groundwater flow system	Burra-Moko Head Sandstone, Caley Formation, Illawarra Coal Measures	• infiltration of rainfall where these units outcrop (mostly to the north and east of the project in the upper slopes of the Grose Valley and along the upper slopes of the Megalong Valley to the west, south and north) • vertical seepage from the overlying groundwater systems • irrigation of land (Little Hartley only)	• discharge to surface water systems on either side of the plateau, with greater discharges expected to the eastern escarpment • leakage to aquifers within the deeper aquifer system • groundwater abstraction (licensed and unlicensed bores), most likely from the Burra-Moko Head Sandstone

3.5.4 Aquifer hydraulic parameters

3.5.4.1 Hydraulic conductivity

Hydraulic conductivity is the key parameter that controls drawdown in response to dewatering (tunnel inflows), it has been assessed by reviewing bore yields and aquifer hydraulic testing datasets.

3.5.4.1.1 Bore yields

Bore yield information was available on the WaterNSW Realtime Data online database for registered groundwater bores (presented in Annexure F) located within the groundwater study area. Most bores were inferred to be installed in the Banks Wall Sandstone; however, based on depth, some were inferred to target the deeper Burra-Moko Head Sandstone and Illawarra Coal Measures (noting there is a paucity of data recorded in the database).

Cumulative yields (i.e., from bores constructed ‘open hole’ hence targeting multiple hydrostratigraphic units) reported during drilling of these bores ranged between 0.01 litres per second (L/s) and 4.5 L/s, with an average yield of 0.5 L/s. This indicates the heterogeneity of the underlying sandstone units, where enhanced groundwater potential is associated with secondary permeability resulting from joints, fractures, faulting, etc.

3.5.4.1.2 Permeability testing

Packer testing was completed as part of the geotechnical investigations carried out in 2021 and 2022 for the project. Boreholes were drilled in the Narrabeen Group, Illawarra Coal Measures and Shoalhaven Group. The project-specific packer testing locations are shown on Figure 3-13.

The Houlsby Lugeon values provided from the investigations were converted to metres per day (m/day) to attain hydraulic conductivity estimates. The depth intervals of each test were assigned to the hydrostratigraphic unit within which each test was carried out. The packer testing results are provided in Annexure E and summarised below in Table 3-10.

The interpreted Lugeon values from the project-specific packer tests were plotted against the depth with rock mass discontinuity, as shown on Figure 3-12.

Table 3-10 Summary of aquifer hydraulic data

Group	Formations	Number of tests	Minimum hydraulic conductivity (m/day)[13]	Maximum hydraulic conductivity (m/day)	Geometric mean hydraulic conductivity (m/day)	Median hydraulic conductivity (m/day)
Narrabeen Group	Banks Wall Sandstone	34	2.59×10^{-5}	5.79×10^{-3}	2.19×10^{-4}	1.94×10^{-4}
	Mount York Claystone	7	8.64×10^{-7}	4.32×10^{-4}	1.16×10^{-4}	2.85×10^{-4}
	Burro Moko Head Sandstone	31	2.59×10^{-5}	8.12×10^{-2}	4.14×10^{-4}	4.32×10^{-4}
	Caley Formation	4	1.73×10^{-4}	5.01×10^{-3}	1.69×10^{-3}	3.15×10^{-3}
Illawarra Coal Measures	-	24	6.91×10^{-6}	4.92×10^{-2}	8.78×10^{-4}	2.42×10^{-3}
Shoalhaven group	Berry Siltstone	3	2.07×10^{-4}	1.04×10^{-3}	3.69×10^{-4}	2.33×10^{-4}

Notes:

Four packer test intervals did not take water and were excluded.

Packer testing data for BH602A, BH624 and BH624A was unavailable at the time of writing this report.

[13] metres per day

The rock mass discontinuity condition classification is as follows:

- <1: Very Tight
- 1 to 5: Tight
- 5 to 15: Few partly open defects
- 15 to 50: Some open defects
- 50 to 100: Many open defects.

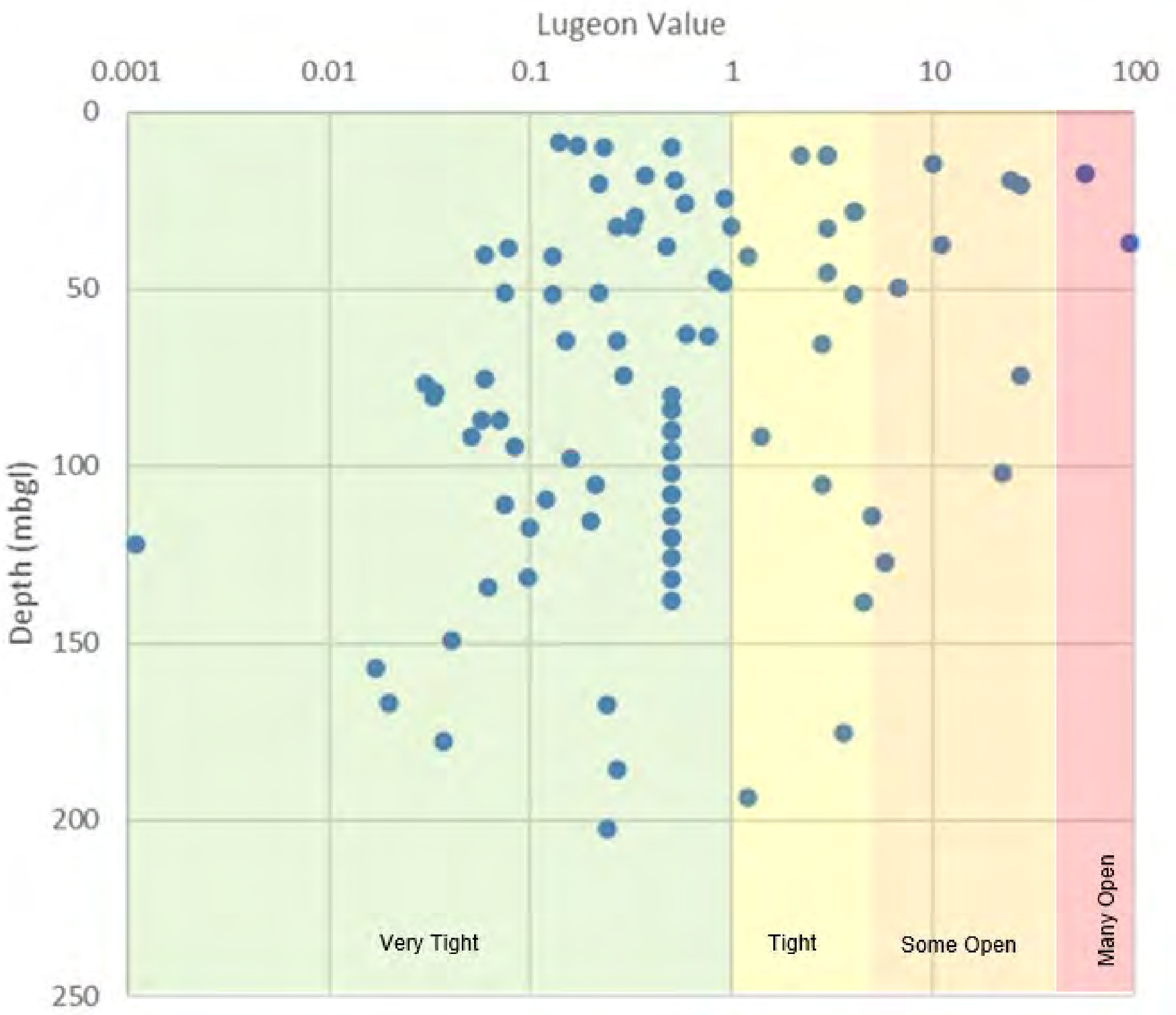

Figure 3-12 Lugeon values versus depth with rock mass discontinuity

The scatter of plotted data on Figure 3-12 indicates a high degree of heterogeneity. The plot also shows there is a rough trend of decreasing Lugeon values with depth, suggesting rock mass permeability also reduces in response to increasing overburden stress and confining pressure.

A majority of the Lugeon values fall into the “very tight” to “tight” rock mass discontinuity condition classes.

The Lugeon values classified as “few partly open defects” to “many open defects” were from tests either in fractured weathered rock within 40 metres of ground level or were associated with wash outs or void filling in the Burra-Moko Head Sandstone. A review of the behaviour of fractured Burra-Moko Head Sandstone indicated that fractured weathered sandstone is susceptible to erosion with defects suddenly washing out and test pressures unable to be maintained. This is consistent with the performance of weathered sandstone exposed at surface and the slake durability testing results obtained during the geotechnical investigations for the project.

Preliminary geotechnical investigations carried out for the Great Western Highway Upgrade Program – Katoomba to Lithgow, included four packer tests at borehole BH3, located on the Mount Victoria plateau. Additionally, packer testing and falling head tests were completed in bores at Springvale Coal Mine, located around 22.5 km from Mount Victoria. Data from these tests is presented in Table 3-11. .Findings are generally consistent with the project-specific packer test results summarised in Table 3-10 except for the maximum hydraulic conductivity for the Banks Wall Sandstone, inferred from a test conducted at the Springvale Coal Mine, which was an order of magnitude higher. This may be due to testing in a fractured zone. Details of the historical packer testing was not available and therefore could not be reviewed.

Table 3-11 Summary of packer tests completed for other investigations

Group	Formations	Number of tests	Hydraulic conductivity (m/day)	Comments
Mount Victoria – BH3				
Narrabeen Group	Burro Moko Head Sandstone	2	7×10^{-3} to 9×10^{-3}	During the third pressure stage for the second packer test, water pressure dropped from around 800 kPa to 100 kPa suggesting hydraulic fracturing may have occurred in the test zone.
	Burro Moko Head Sandstone and Caley Formation	1	1×10^{-2}	-
	Caley Formation	1	4×10^{-3}	-
Springvale Coal Mine				
Narrabeen Group	Banks Wall Sandstone	Unknown	$< 9 \times 10^{-3}$ to 0.2	-
	Mount York Claystone	Unknown	$< 9 \times 10^{-3}$	-
	Caley Formation	Unknown	$< 9 \times 10^{-3}$	-
Illawarra Coal Measures	-	Unknown	$< 9 \times 10^{-3}$ to 4×10^{-2}	-

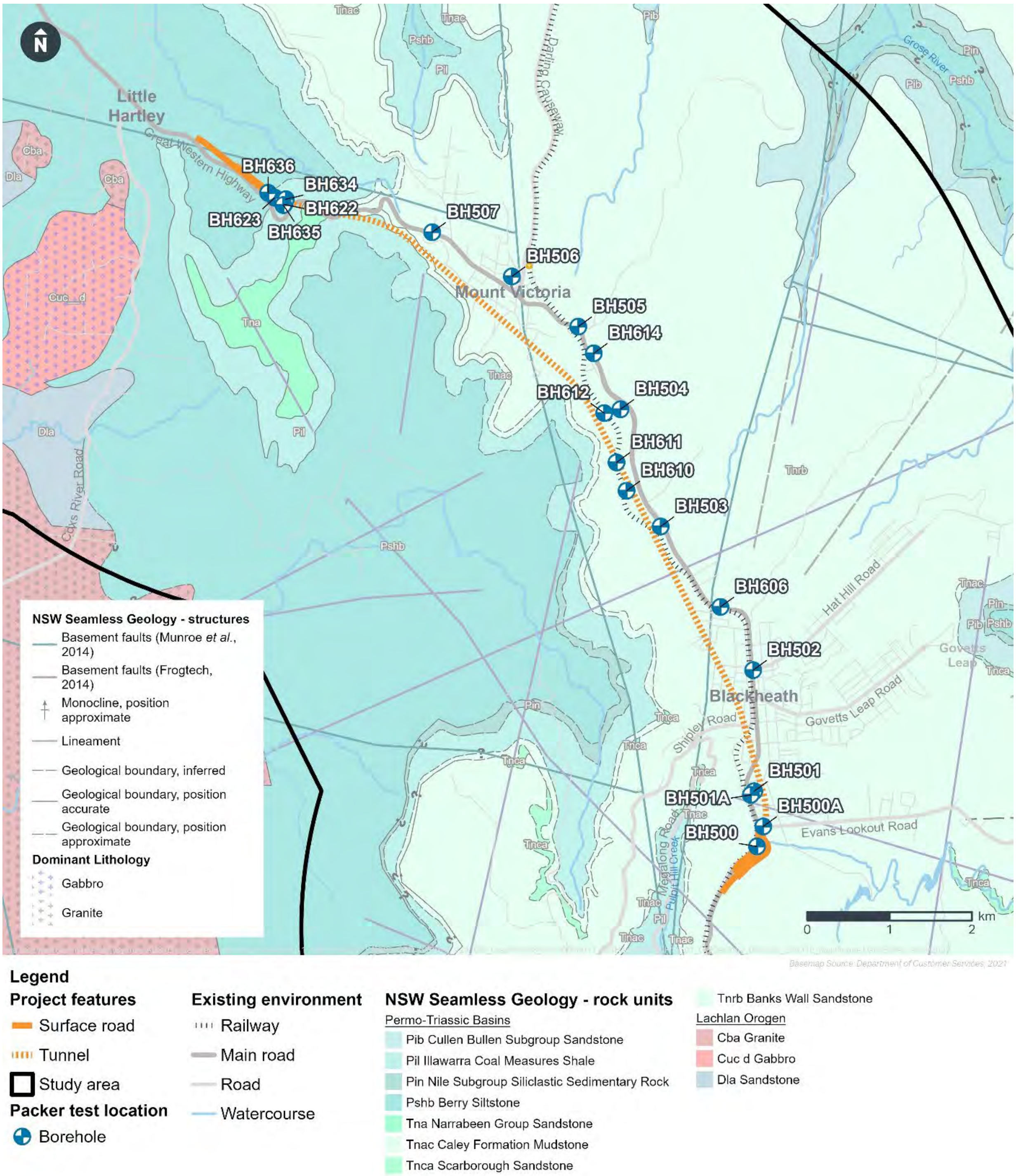

Figure 3-13 Project-specific packer test locations

3.5.5 Groundwater quality

3.5.5.1 Physico-chemical parameters

Groundwater investigations were completed in May and August 2011 for the Great Western Highway Little Hartley to Lithgow Upgrade project. Groundwater quality field parameters were collected at 11 locations within the regions of Mount Victoria and Little Hartley, summarised in Table 3-12.

Table 3-12 Groundwater field parameters for the Little Hartley to Lithgow Upgrade

Group	TDS (mg/L)[14]	EC (µS/cm)[15]	pH (pH units)	Number of samples
Narrabeen Group	46-146	69-185	4.7-5.8	3
Illawarra Coal Measures	80-711	114-1093	5.9-6.9	5
Shoalhaven Group	400-3209	644-4088	5.1-7.4	3

Notes: TDS – Total dissolved solids, EC – Electrical conductivity

Groundwater from the Narrabeen Group typically contains low salinity (hence likely recently recharged) and is slightly acidic (likely due to the inert nature of the quartz-rich sandstone). The pH values for most samples were below the ADWG (2004) aesthetic and ANZECC (2000) lower guideline value of 6.5.

Groundwater extracted from the Illawarra Coal Measures is characterised as acidic to neutral water. Three groundwater samples had pH values below the ADWG (2004) aesthetic and ANZECC (2000) lower guideline value of 6.5. Three groundwater samples exceeded the ADWG (2004) aesthetic guideline for total dissolved solids (TDS) (500 milligrams per litre (mg/L)).

Groundwater extracted from the Shoalhaven Group is characterised as acidic to neutral and fresh to brackish water. One groundwater sample had pH values below the ADWG (2004) aesthetic and ANZECC (2000) lower guideline value of 6.5. All groundwater samples exceeded the ANZECC (2000) guideline for electrical conductivity (EC) (350 microSiemens per centimetre (µS/cm) and two groundwater samples exceeded the ADWG (2004) aesthetic guideline for TDS (500 mg/L).

3.5.5.2 Major ions

The groundwater investigations carried out in May and August 2011 for the Great Western Highway Little Hartley to Lithgow Upgrade project included groundwater sampling and major ion analysis at 11 locations within the regions of Mount Victoria and Little Hartley. The groundwater samples were analysed at a laboratory for major dissolved cations (calcium, magnesium, sodium, and potassium) and anions (chloride and sulphate), and alkalinity (bicarbonate alkalinity as calcium carbonate ($CaCO_3$)), to aid in the identification of water types that may be indicative of recharge, flow and mixing processes. The analysis was plotted on a piper diagram, as shown in Figure 3-14, and the determined water types for each sample are summarised in Table 3-13.

[14] milligrams per litre
[15] microSiemens per centimetre

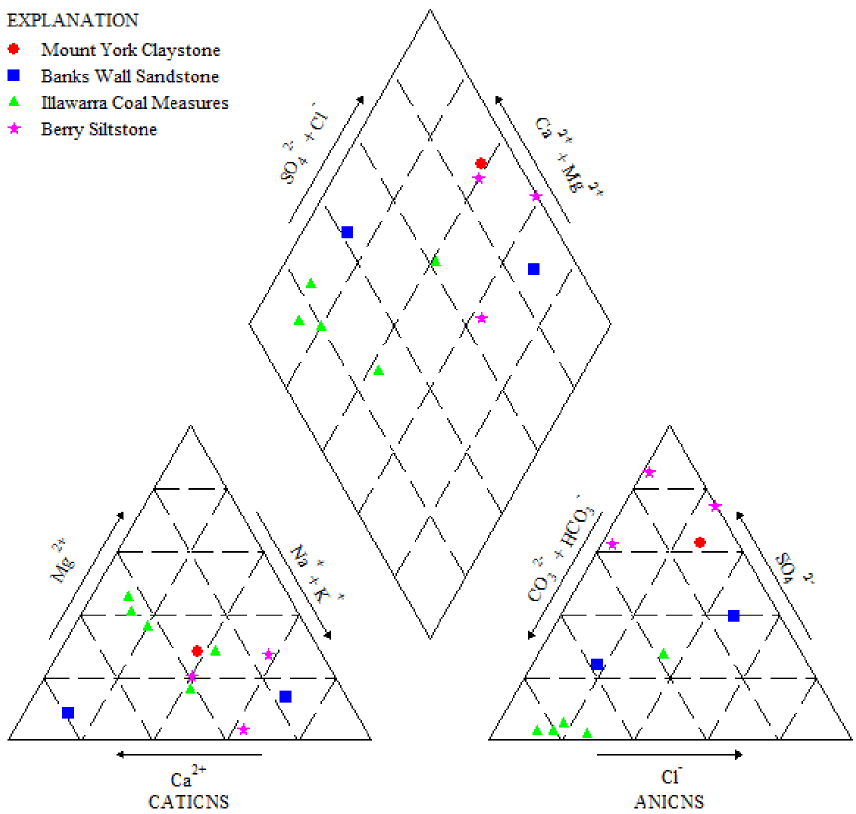

Figure 3-14 Piper diagram for sampled monitoring bores for the Little Hartley to Lithgow Upgrade

Table 3-13 Groundwater type for bores samples for the Little Hartley to Lithgow Upgrade

Group	Formation	Bore ID	Location	Water type
Narrabeen Group	Mount York Claystone	BH1	Mount Victoria	Calcium chloride
	Banks Wall Sandstone	BH2	Mount Victoria	Magnesium bicarbonate
	Banks Wall Sandstone	BH103	Mount Victoria	Sodium chloride
Illawarra Coal Measures	-	BH4	Mount Victoria	Mixed
	-	BH5	Mount Victoria	Magnesium bicarbonate
	-	BH8	Mount Victoria	Magnesium bicarbonate
	-	BH115	Mount Victoria	Magnesium bicarbonate
	-	BH116	Mount Victoria	Magnesium bicarbonate
Shoalhaven Group	Berry Siltstone	BH22A	Little Hartley	Mixed
	Berry Siltstone	BH23	Little Hartley	Sodium chloride
	Berry Siltstone	BH123	Little Hartley	Sodium chloride

A change in water type highlights either a change in the relative proportion of major ions due to water-rock interaction and hydrogeochemical reactions in an aquifer, or due to mixing of water types if the bore is damaged or screened across multiple hydrostratigraphic units or if mixing has naturally occurred in the ground. A review of the bore logs suggests that bores BH1 and BH103 are potentially screened across multiple formations within the Narrabeen Group, which may have resulted in the mixing of water types. The Illawarra Coal Measures is dominated by a magnesium bicarbonate water type and the Berry Siltstone is dominated by a sodium chloride water type.

3.5.5.3 Dissolved metals

The groundwater investigations carried out in May and August 2011 for the Great Western Highway Little Hartley to Lithgow Upgrade project included groundwater sampling and dissolved metal analysis (manganese and iron) at 11 locations within the regions of Mount Victoria and Little Hartley, as summarised in Table 3-14.

Groundwater samples collected from the Narrabeen Group had concentrations of dissolved manganese and iron below the ADWG (2004) aesthetic and human health guidelines. Samples collected from the Illawarra Coal Measures and underlying Shoalhaven Group had concentrations of manganese that exceeded both the ADWG (2004) aesthetic (0.1 mg/L) and human health guidelines (0.5 mg/L) and iron concentrations which exceeded the ADWG (2004) aesthetic guidelines (0.3 mg/L). High concentrations of iron (40.6 mg/L) were identified at BH123 located at Little Hartley around 1.2 kilometres north west of the project corridor. As part of the current field investigation for the project, possible iron precipitation issues for project construction will be investigated.

Table 3-14 Groundwater analytical results for the Little Hartley to Lithgow Upgrade – dissolved manganese and iron

Group	Manganese (mg/L)[16]	Iron (mg/L)	Total number of samples
Narrabeen Group	0.032-0.094	<0.05-0.07	3
Illawarra Coal Measures	0.078-1.52	<0.05-6.93	5
Shoalhaven Group	0.183-1.88	0.34-40.6	3

3.5.6 Potential areas of groundwater contamination

Groundwater resources in the vicinity of the project are likely to be impacted by urbanisation and commercial/industrial land use, particularly within the Blackheath and Mount Victoria townships. A search of the NSW EPA contaminated land register indicated that there were no sites currently regulated under Section 60 of the CLM Act within 500 metres of the project. Two sites within 500 metres of the project have been notified (but are not regulated), both of which are service stations located along the Great Western Highway in Mount Victoria.

Based on a desktop review and site inspection completed for the project, areas of environmental interest (AEI) for groundwater contamination were identified. For each AEI, potential sources and contaminants of potential concern (COPCs) were identified, as summarised in Table 3-15.

For more information on potential groundwater contamination, refer to Appendix K (Technical Report - Contamination) of the EIS.

[16] milligrams per litre

Table 3-15 Areas of environmental interest and contaminants of potential concern

Area of environmental interest	Source	Contaminants of potential concern
Mount Victoria rail maintenance yard	Leaks and spills from maintenance activities along rail lines, and fill materials	• Heavy metals • Polycyclic Aromatic Hydrocarbons (PAHs) • Total Recoverable Hydrocarbons (TRH) • Benzene, Toluene, Ethylbenzene, Xylenes, and Naphthalene (BTEXN)
Railway lines and rail compounds	Leaks and spills from maintenance activities along rail lines, and fill materials	• Heavy metals • PAHs • TRH • BTEXN
Current and former service stations, garages and service centres in Blackheath, Little Hartley and Mount Victoria	Leaks and spills from underground petroleum storage infrastructure/refuelling and vehicle maintenance activities	• Heavy metals • PAHs • TRH • Volatile Organic Compounds (VOCs) (including BTEXN) • Semi-volatile Organic Compounds (SVOCs) • Per- and Poly-Fluoroalkyl Substances (PFAS)
Fire stations two in Blackheath and two in Mount Victoria	Leaks and spills from underground petroleum storage infrastructure/refuelling, leaks and spills from storage of aqueous film forming foam containing PFAS and during hose clearing	• Heavy metals • PAHs • TRH • VOC (Including BTEXN) • PFAS
Electricity substations at Blackheath and Mount Victoria	Leaks and spills from maintenance activities	• Heavy metals • PAHs • TRH • VOCs (including BTEXN) • SVOCs • PFAS • Polychlorinated Biphenyls (PCBs)
Blackheath Laundrette	Leaks and spills from solvents and infrastructure	• Heavy metals • PAHs • TRH • VOCs (including BTEXN) • SVOCs
Mount Victoria Sewerage Treatment Plant and effluent outflow area	Discharge of untreated sewage and effluent	• Heavy metals • PAHs • TRH • VOCs (including BTEXN) • SVOCs (including Phenols and Organochlorine Pesticides [OCPs]) • Nutrients • PFAS

Area of environmental interest	Source	Contaminants of potential concern
Covered stockpiles adjacent to Valley View Road , Blackheath	Unknown fill	• Heavy metals • PAHs • TRH • VOCs (including BTEXN) • SVOCs (including Phenols and OCPs) • Nutrients • PCBs • PFAS
Areas of possible historical landfilling in Blackheath Tip (yet to be remediated), Blackheath Oval/Jubilee Park, Eltham Park, Mountain Christian College	Uncontrolled fill	• Heavy metals • PAHs • TRH • VOCs (including BTEXN) • SVOCs (including Phenols and OCPs) • Nutrients • PCBs • PFAS • Biological/microbiological and pathogens
Weber's Nursery and Wood You Believe Firewood	Direct application of pesticides and herbicides or storage of materials treated with termiticides	• OCPs • Organophosphorus Pesticides (OPPs) • Herbicides • Termiticides (arsenic) • Nutrients (ammonia, nitrate, nitrite, and phosphorus)
Areas of possible historical landfilling adjacent to Soldiers Pinch, Browntown Oval and Great Western Highway roadworks/cut and fill areas.	Uncontrolled fill	• Heavy metals • PAHs • TRH • VOCs (including BTEXN) • SVOCs (including Phenols and OCPs) • Nutrients • PCBs • PFAS • Biological/microbiological and pathogens
Illegal dumping	Dumping of waste and potentially contaminated materials on soils beside the road/rail corridor	• Heavy metals • PAHs • TRH • VOCs (including BTEXN) • PFAS
Lolly Bug Little Hartley former service station	Leaks and spills from underground petroleum storage infrastructure/automotive repair work	• Heavy metals • PAHs • TRH • VOCs (including BTEXN) • PFAS
Vehicle crashes and spills	Spill of fuel and potential for use of firefighting foam containing PFAS	• Heavy metals • PAHs • TRH • VOCs (including BTEXN) • PFAS

Area of environmental interest	Source	Contaminants of potential concern
Demolition of historical buildings	Demolition and potential for burial of buildings materials which contain hazardous substances	• Lead
Little Hartley airfield	Leaks and spills from underground petroleum storage infrastructure/refuelling, leaks and spills from storage of aqueous film forming foam containing PFAS and during hose clearing	• Heavy metals • PAHs • TRH • BTEXN • PFAS
Historical use of pesticides and herbicides	Direct application of pesticides and herbicides	• OCPs • OPPs • Herbicides • Termiticides (arsenic) • Nutrients (ammonia, nitrate, nitrite, and phosphorus)
Coal seam gas	Desorbed during tunnelling dewatering	• Dissolved methane and hydrogen sulfide (gas and dissolved)
Potential acid forming rock	Disturbance/oxidation during tunnelling	• Low pH
CSR Building Products Clay/Shale, Structural Clay Mine	Leaks and spills from storage of fuel, refuelling plant and machinery, maintenance activities on plant and machinery and potential import of uncontrolled fill material to fill in mined areas	• Heavy metals • PAHs • TRH • VOCs (including BTEXN) • PFAS

3.6 Registered groundwater users

A search of the WaterNSW Real Time Data online database (WaterNSW, 2022a) and the BoM Australian Groundwater Explorer (BoM, 2022d) carried out in March 2022 indicated that there are 112 registered groundwater bores located within the groundwater study area. Details of the registered groundwater bores are provided in Annexure F.

The locations of the registered groundwater bores are shown of Figure 3-15, and include:

- 85 bores used for water supply purposes (including household and livestock use)
- six bores used for irrigation purposes
- 19 bores used for monitoring purposes
- two bores used for unknown purposes.

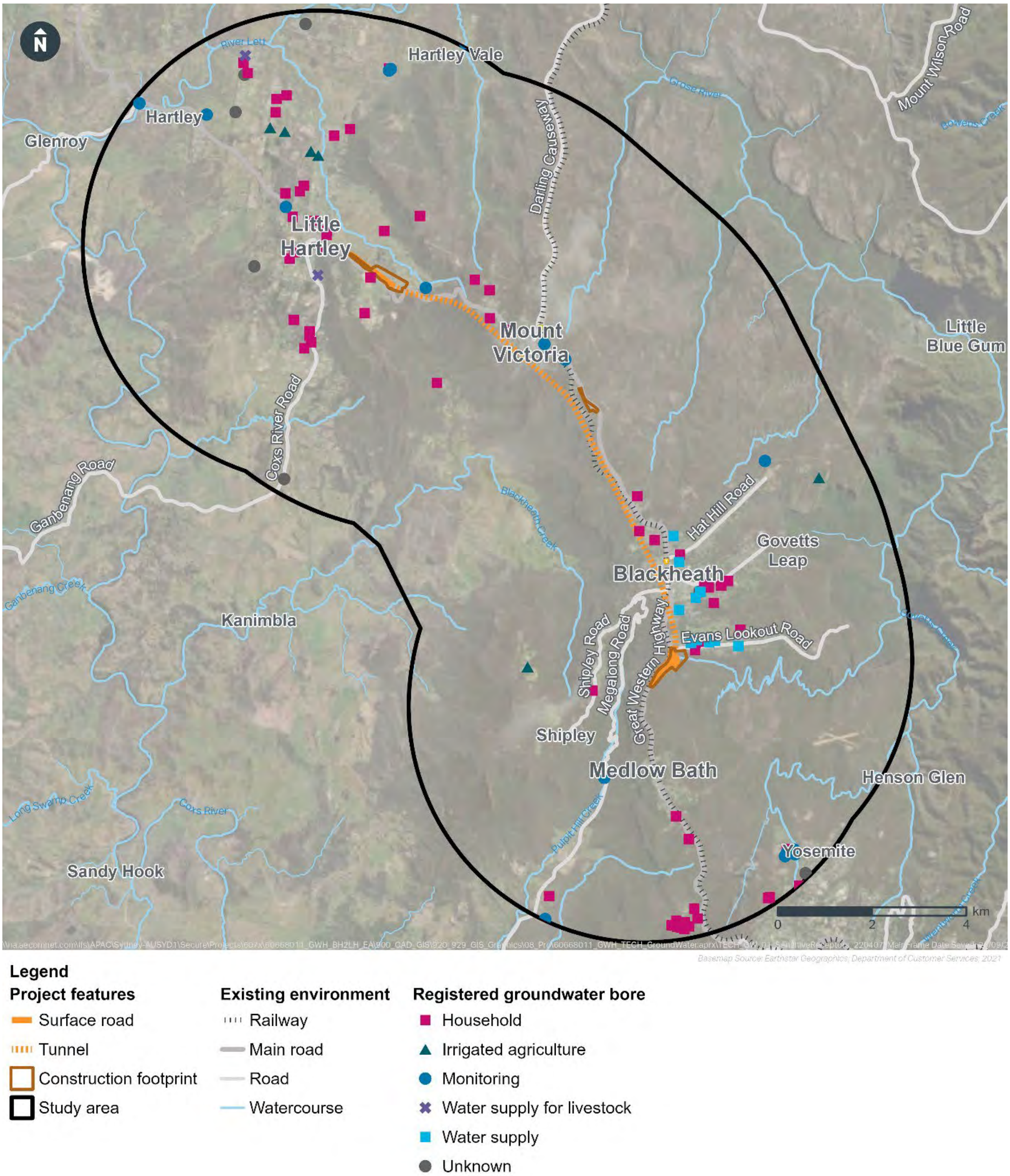

Figure 3-15 Registered groundwater bores

3.7 Groundwater dependent ecosystems

GDEs are communities of plants, animals, and other organisms whose extent and life processes are dependent on groundwater, such as wetlands or springs. The location of mapped GDEs (refer to Figure 3-16 to Figure 3-18 and Figure 3-21 to Figure 3-23) within the groundwater study area have been identified following a review of:

- the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 (the Groundwater WSP). Schedule 4 of the Groundwater WSP identifies high priority GDEs and Appendix 2 identifies GDEs
- National Atlas of Groundwater Dependent Ecosystems (BoM, 2022b).

Patches of both terrestrial and aquatic GDEs are present within the groundwater study area. Areas of aquatic GDEs correspond with mapped areas of Temperate Highland Peat Swamps on Sandstone (THPSS). THPSS are classified as GDEs and are defined as communities of plants and animals whose extent and life processes are dependent on groundwater, such as through wetlands or springs.

Terrestrial GDE’s are present within the Butlers Creek region in Little Hartley. These areas of terrestrial GDEs correspond with mapped patches of native vegetation which include Plant Community Types (PCT’s) 1248 – Sydney Peppermint – Silver Topped Ash and PCT 1256 – Tableland Swamp Meadow on Impeded Drainage. These areas are considered as THPSS, which are listed as a Threatened Ecological Community (TEC) under the EPBC Act. These areas also contain Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps Bioregions, which are also a considered a TEC under the NSW BC Act.

High Ecological Value Aquatic Ecosystems (HEVAE) were identified in isolated patches within the study area. The highest concentration of mapped HEVAE correspond to patches of native vegetation on the banks of Butlers Creek within Little Hartley. The only other areas of mapped HEVAE are located on Lake Medlow and Lake Greaves, east of the Blackheath portals.

An assessment of GDEs within the biodiversity study area, as detailed in Appendix H (Technical report – Biodiversity) of the EIS, determined that all recorded NSW Plant Community Types (PCTs) were either low probability GDEs or alternate water source non-GDEs. Separately, high probability GDEs have been mapped by DPE (2022d) to the north of Little Hartley, as shown on Figure 3-16, Figure 3-17 and Figure 3-18. Medium probability GDEs have also been mapped to the east of the Blackheath study area, associated with Adams Creek.

The project occurs adjacent to the Blue Mountains National Park, a World Heritage Listed National Park of significant ecological value within the Greater Sydney Local Land Services (LLS) region. As such, biodiversity impacts represent a key environmental issue for the project.

Further information is provided in Appendix H (Technical report - Biodiversity) and Appendix J (Technical report – Surface water and flooding) of the EIS.

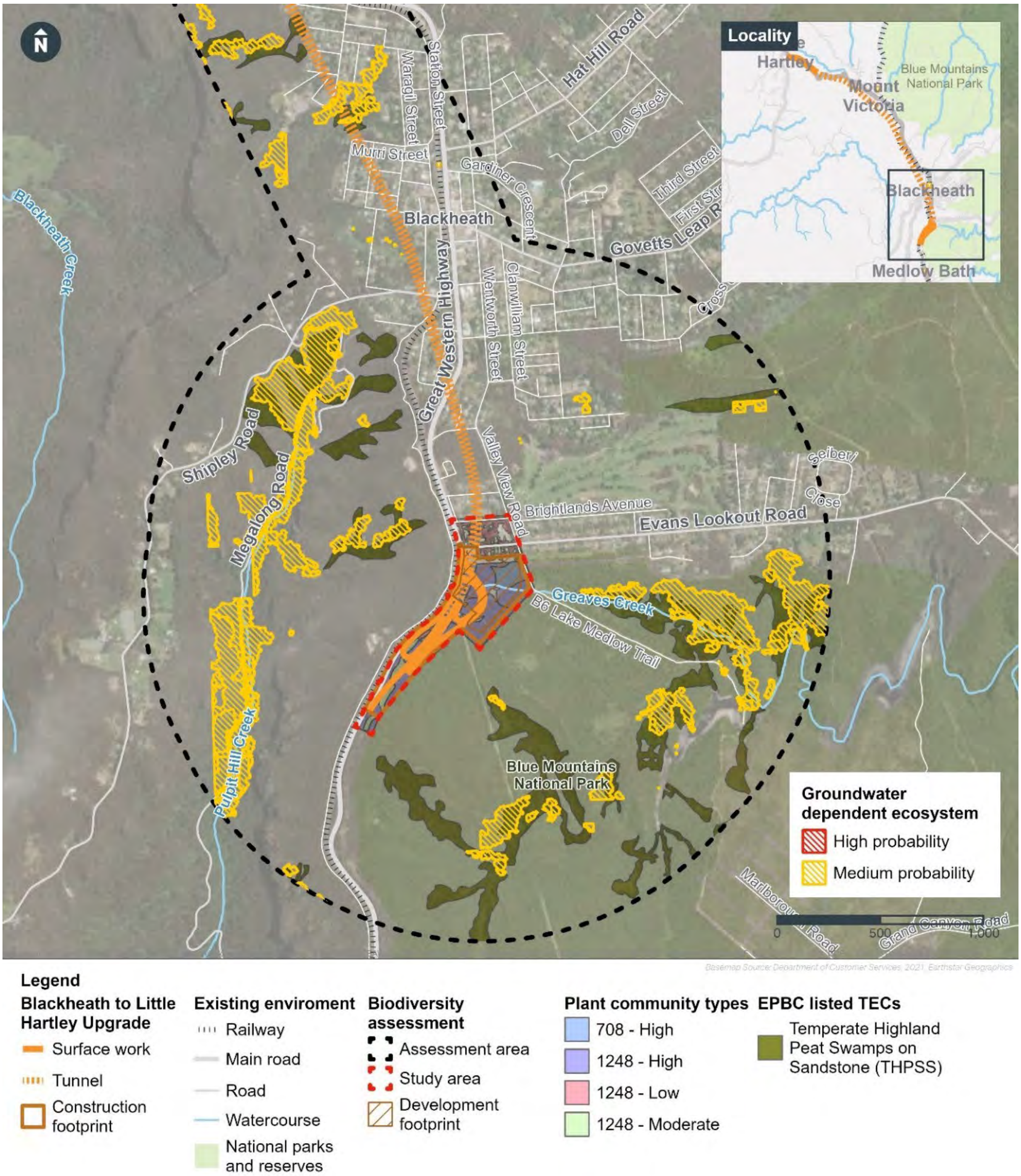

Figure 3-16 Groundwater dependent ecosystems in Blackheath

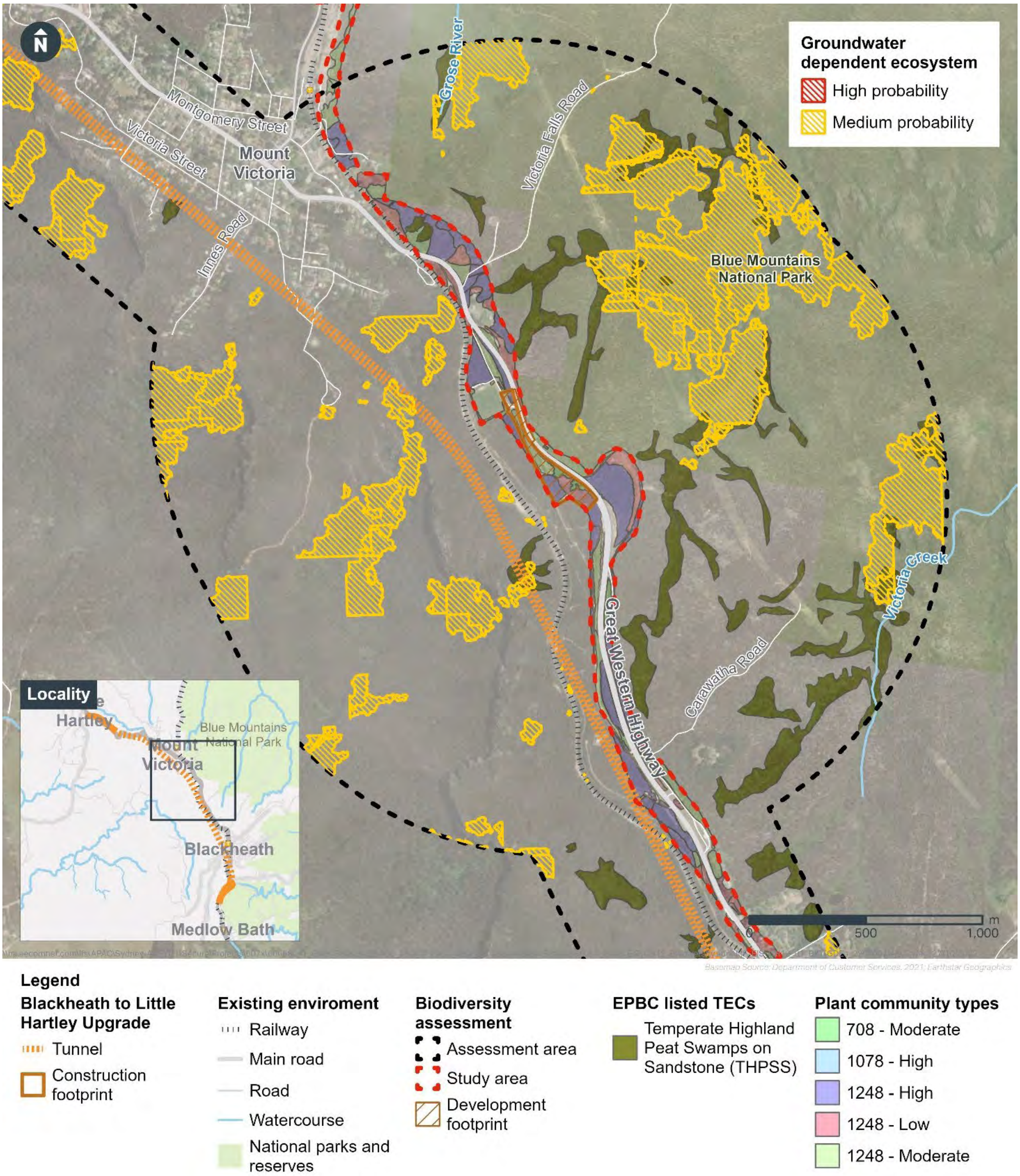

Figure 3-17 Groundwater dependent ecosystems in Soldiers Pinch

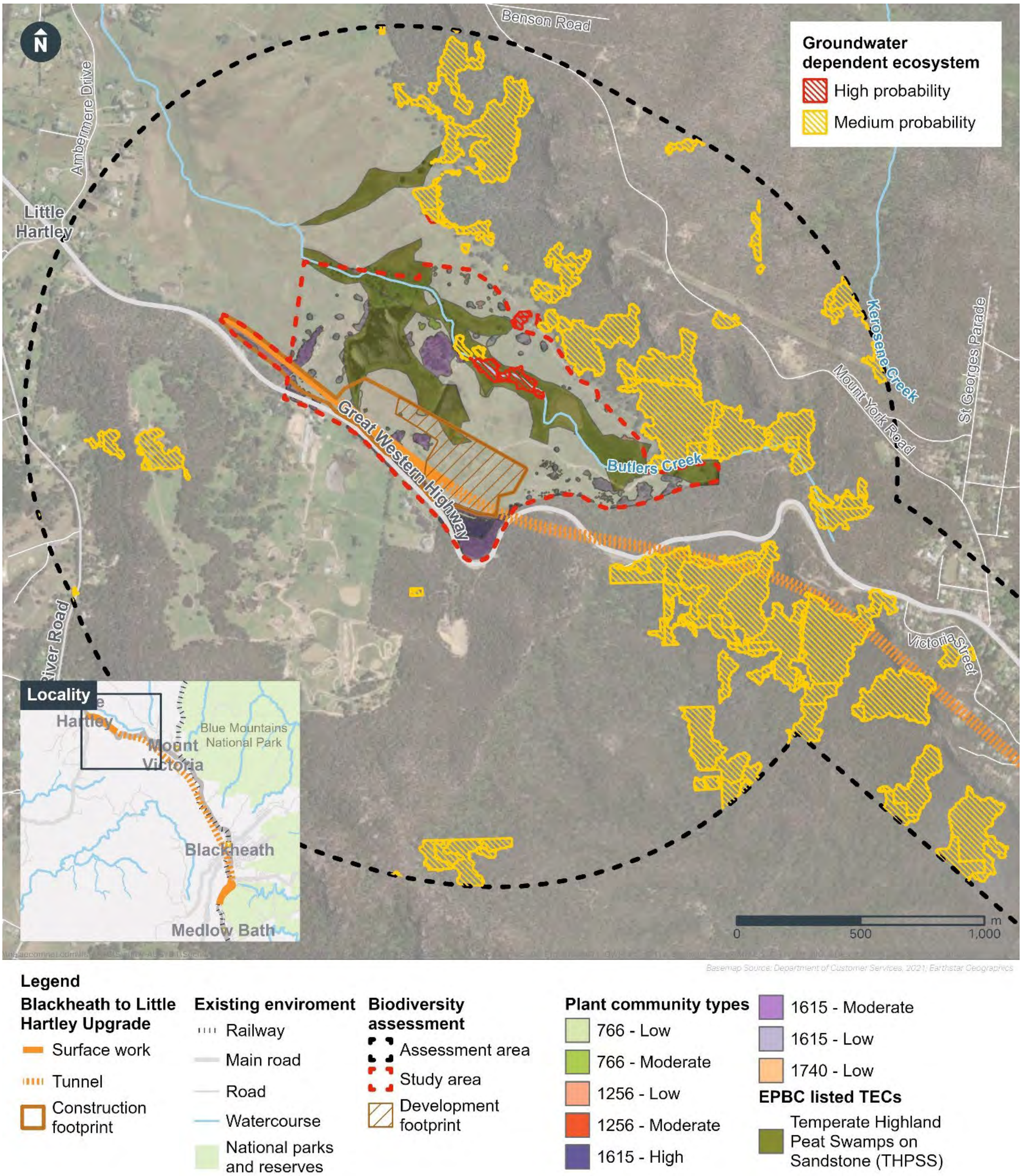

Figure 3-18 Groundwater dependent ecosystems in Little Hartley

3.7.1 Temperate Highland Peat Swamps on Sandstone

THPSS are listed as 'high priority' GDEs in the Groundwater WSP (NSW Government, 2011); as an 'endangered ecological community' under the EPBC Act; and as 'endangered' under the *Biodiversity Conservation Act 2016* (NSW). THPSS comprise of the following (Commonwealth of Australia, 2014):

- headwater swamps, which are formed near catchment divides at the headwaters of streams where topographic gradients are shallow
- valley infill swamps, which occur further down the catchment than headwater swamps, in steeper topographies filling the valley of incised second- or third-order streams
- hanging swamps, which occur on steep valley sides where there is groundwater seepage.

Conceptual model block diagrams for the three types of THPSS are shown in Figure 3-19 and Figure 3-20 (Commonwealth of Australia, 2014). A detailed summary of the three types of THPSS is provided in Table 3-16. THPSS mapped within the groundwater study area is shown on Figure 3-21 to Figure 3-23. Mapped hanging swamps were identified during a project investigation.

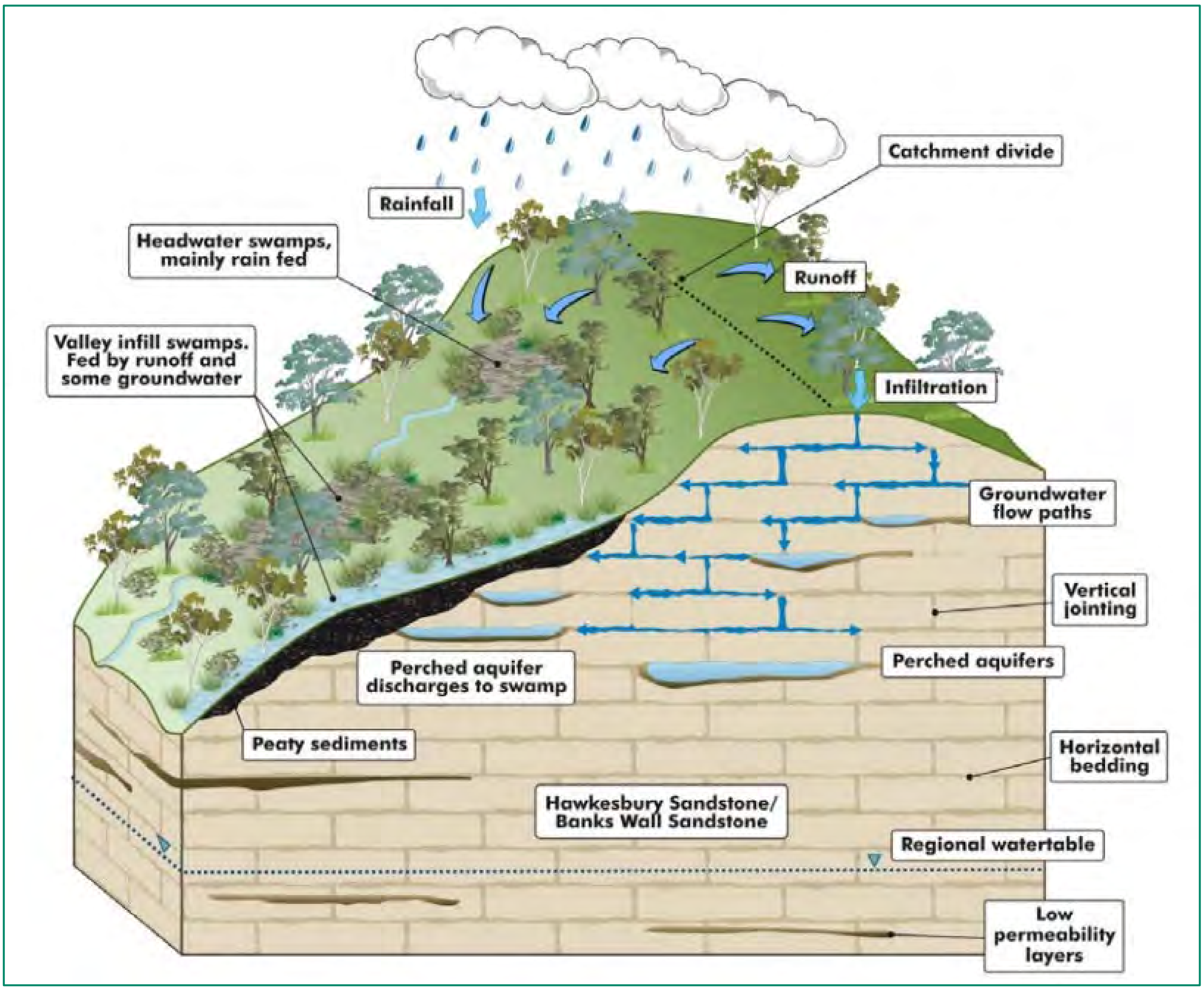

Figure 3-19 Conceptual model block diagram describing headwater and valley infill swamps (Commonwealth of Australia, 2014)

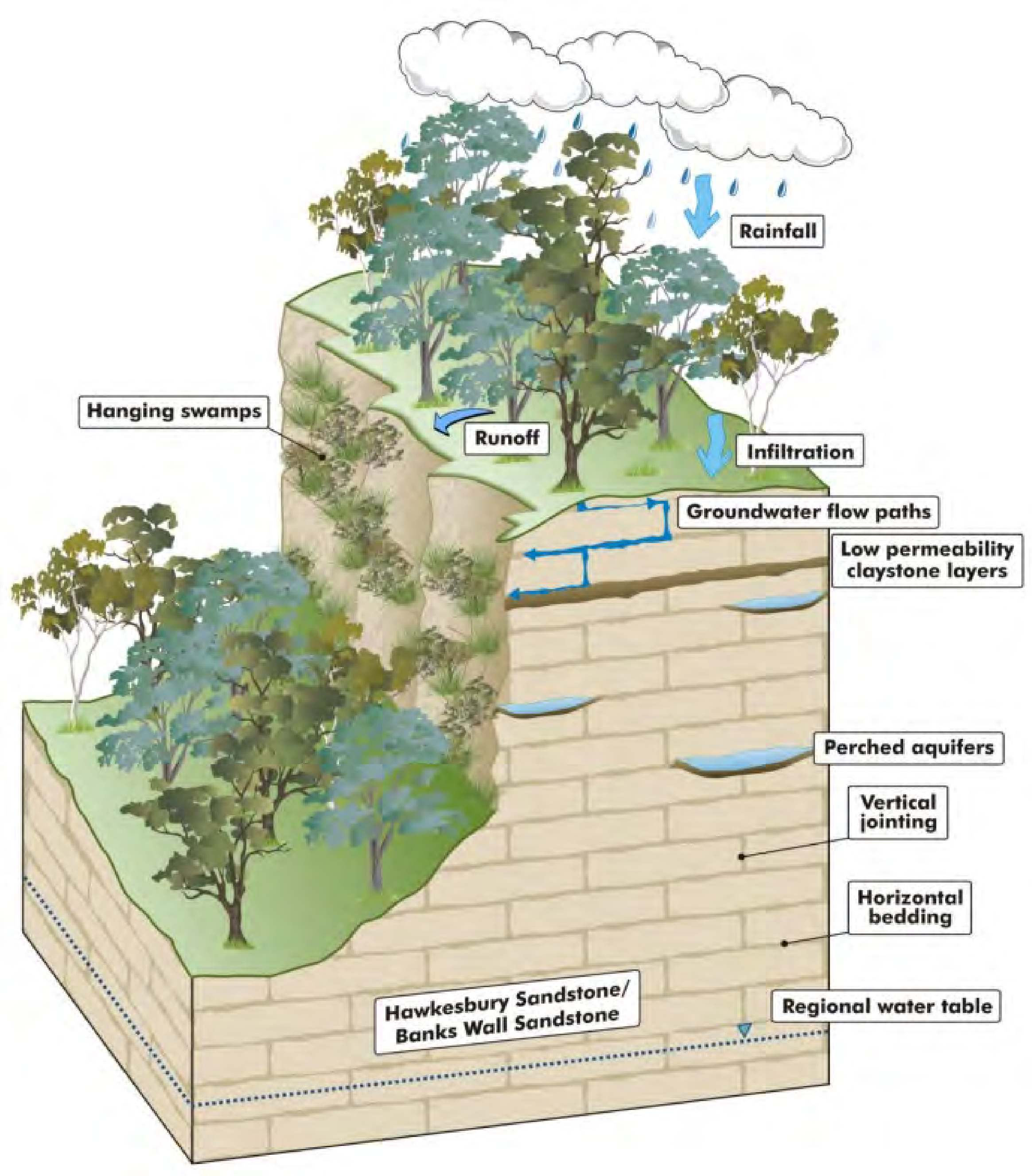

Figure 3-20 Conceptual model block diagram describing hanging swamps (Commonwealth of Australia, 2014)

Table 3-16 Detailed summary of THPSS characteristics (source Commonwealth of Australia (2014))

Characteristics	Headwater swamps	Valley infill swamps	Hanging swamps
Geology/ substrate	• Sandy/clayey peat overlying low-permeability sandstone.	• Sandy/clayey peat overlying low-permeability sandstone.	• Swamps occur at the interface between higher and lower permeability sandstone layers.
Peat thickness	• Variable, can be up to 10 metres thick.	• Variable, can be up to 10 metres thick.	• Minimal due to steep topography and is limited to sediment caught within vegetation roots.
Water source	• Swamps are recharged through direct rainfall and catchment runoff including overland flow and from headwater streams. • Groundwater can discharge to the swamps through either groundwater movement along fractures, joints or bedding planes that intersect the peat swamp or to a lesser extent, the lower permeability sandstone layers that intersect the peat swamp. • Recent recharge groundwater interacts with the swamps from a local flow system, due to short flow paths and residence times.	• Source aquifers are perched or less commonly regional sandstone aquifers of the Banks Wall Sandstone. • Recharge to the source aquifers is through infiltrated rainfall. • Recharge to the swamps is through a combination of groundwater discharge from perched or regional sandstone aquifers, rainfall and run-off. • Groundwater discharge to the swamps is through either groundwater movement along fractures, joints or bedding planes that intersect the peat swamp or to a lesser extent, the lower permeability sandstone layers that intersect the peat swamp.	• Source aquifer is the Banks Wall Sandstone. • Groundwater contributions is from perched aquifers, as direct rainfall flows along cracks and joints before discharging to the surface at steep valley sides of cliff faces above lower permeability sedimentary layers and along bedding planes. • Recharge to the source aquifers is through rainfall.

Characteristics	Headwater swamps	Valley infill swamps	Hanging swamps
Flow regimes	• Water flows through the swamps either as sheet flow along the surface of the peat, through the peat sediment, or through channels that are normally discontinuous within the peat. • The swamp surface can be either permanently or ephemerally wet. • Where a connection between groundwater and a swamp exists, the connection is most likely to be ephemeral because it relies on the presence of a perched aquifer, which is most likely to only be present after rainfall due to limited effective storage within the preferential joints and fracture flow paths.	• Water flows through the swamps either as sheet flow along the surface of the peat or through the peat or through channels within the peat. • The swamp surface can be either permanently wet, which is more likely where the regional aquifer is the source, or ephemerally wet, which is more likely where perched aquifers are the source.	• Swamps can be either permanently or ephemerally (occurring after rainfall) wet.
Water quality	• Controlled by catchment run-off. Where groundwater discharges to the swamps, water quality is expected to be fresh (similar to rain) due to short residence times within the host rock.	• Variable depending on residence time within the aquifer and is controlled by a combination of rainfall, run-off, and groundwater quality.	• Similar to local groundwater quality and expected to be fresh due to relatively short flow paths and residence times in the aquifer.

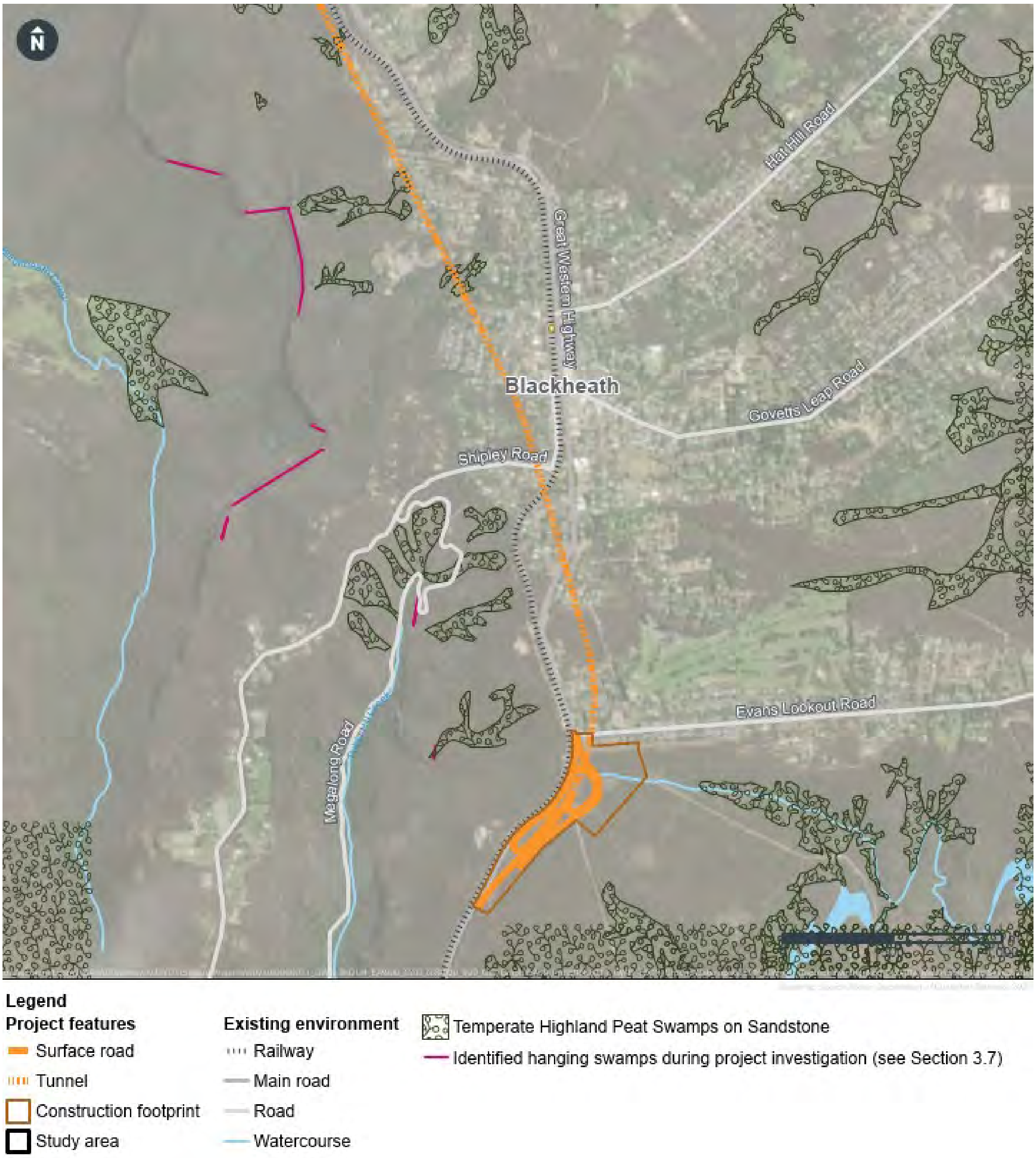

Figure 3-21 THPSS groundwater dependent ecosystems – map 1 of 3

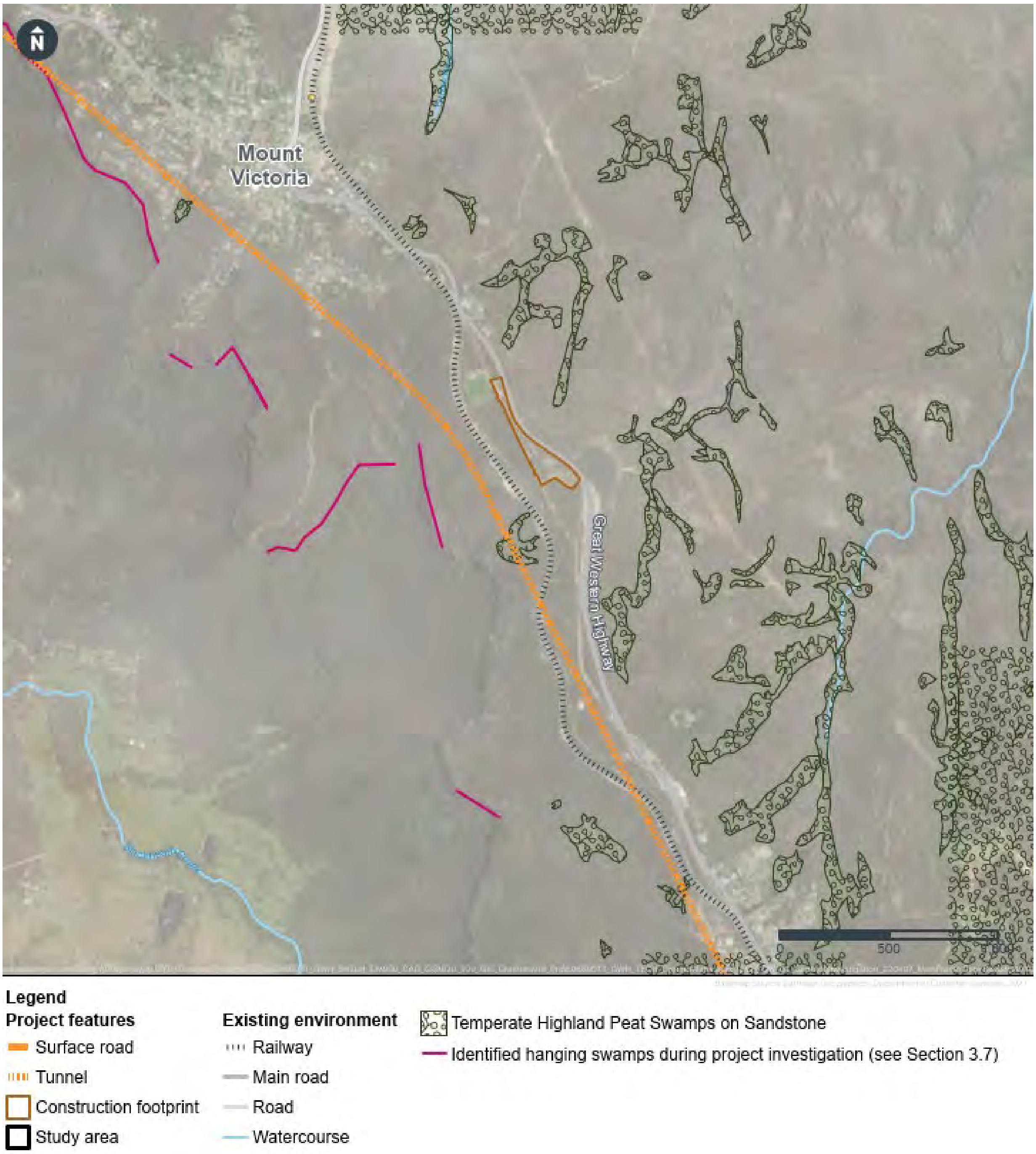

Figure 3-22 THPSS groundwater dependent ecosystems – map 2 of 3

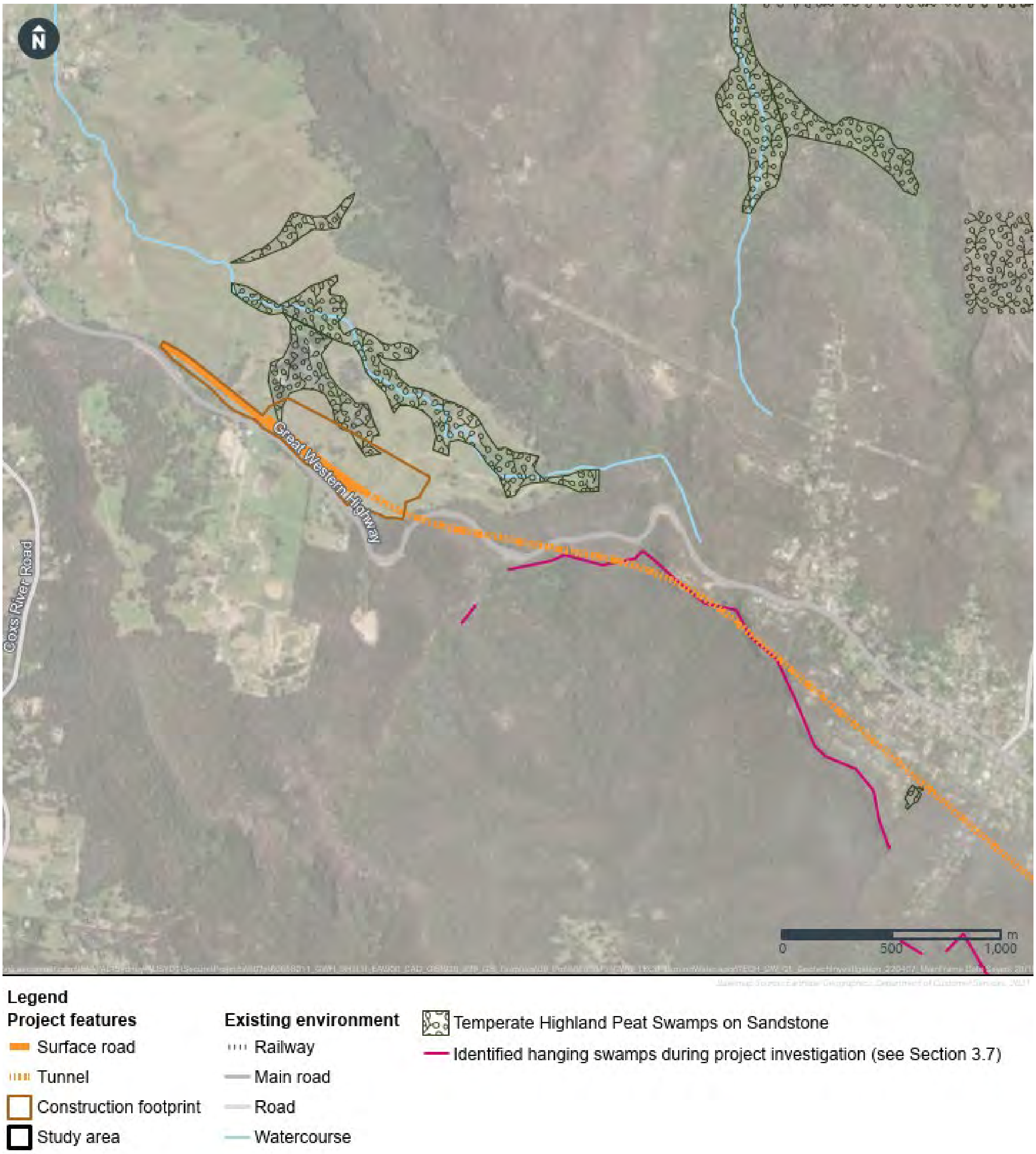

Figure 3-23 THPSS groundwater dependent ecosystems – map 3 of 3

3.8 Springs

A review of the Groundwater WSP (NSW Government, 2011) indicated that there are no ‘high priority’ springs within the groundwater study area.

3.9 Groundwater dependent culturally significant sites

A review of the Groundwater WSP (NSW Government, 2011) indicated that there are no groundwater dependent culturally significant sites listed.

3.10 Conceptual hydrogeological model

A series of CHM figures, based on the existing environment data, have been produced for the project as follows:

- Figure 3-24 - southwest to northeast cross-section through Blackheath portals, looking north.
- Figure 3-25 - southwest to northeast cross-section through southern section of twin tunnels, looking north
- Figure 3-26 - southwest to northeast cross-section through mid-tunnel infrastructure, looking north
- Figure 3-27 - southwest to northeast cross-section through northern section of twin tunnels, looking north
- Figure 3-28 - southwest to northeast cross-section through Little Hartley portals, looking north.

A 3D conceptual block model illustrating the relationship between the tunnels’ relationship with the existing landforms, groundwater levels and groundwater dependent ecosystems is provided in Figure 3-29.

For reference, Annexure A, contains a geological long-section of the whole project alignment, southeast to northwest, from Blackheath to Little Hartley.

The geological long-section and CHM cross-sections show the lithostratigraphic units that the tunnels and excavations would intersect along the project alignment, from the Triassic age upper Banks Wall Sandstone at Blackheath portal to the Permian age Nile Sub-Group at the Little Hartley portal.

The shallow groundwater system within the Banks Wall Sandstone, above the Mount York Claystone aquitard, is readily recharged by:

- rainfall infiltration where the unit outcrops
- vertical seepage from perched water within the overlying unconsolidated sediments
- leakage or seepage from surface water storage dams and drainage features
- possible artificial recharge from leakage from pipe networks such as stormwater.

The deep regional groundwater system within the hydrostratigraphic units below the Mount York Claystone aquitard are recharged by:

- rainfall infiltration where the units outcrop (mostly to the north and east of the project in the upper slopes of the Grose Valley and along the upper slopes of Megalong Valley to the west, south and north)
- vertical (downward) seepage from the overlying shallow groundwater system via joints and fractures, and discontinuous aquitards
- leakage or seepage from surface water storage dams and drainage features located directly on the older formations
- possible leakage from pipe networks such as stormwater within the northern portion of the project at Little Hartley.

Discharge from the shallow and deep groundwater systems occurs via:

- evapotranspiration losses
- baseflow discharge into surface water flows and swamps along the escarpments
- vertical leakage to underlying groundwater systems
- groundwater abstraction from licensed and unlicensed bores.

Groundwater quality is typically fresh (recent recharged) within the shallow groundwater system and slightly acidic. Groundwater quality in the deep groundwater system is fresh to brackish and slightly acidic to neutral, dependent on the residence time of the groundwater with the host rock.

Groundwater yields are generally low for both groundwater systems and higher yields are predominantly associated with secondary porosity (joints and faults).

The water quality, recharge and discharge mechanisms, plus conceptualisation of groundwater flow patterns (through secondary features) all indicate that the groundwater systems have limited effective storage, such that sustainable groundwater resources are readily influenced by rainfall rather than extraction (i.e., dewatering reduction in groundwater levels are readily recharged with good regular rainfall). The water quality, recharge and discharge mechanisms, plus conceptualisation of groundwater flow patterns (through secondary features) all indicate that the groundwater systems have limited effective storage, such that sustainable groundwater resources are readily influenced by rainfall rather than extraction (i.e., dewatering reduction in groundwater levels are readily recharged with good regular rainfall).

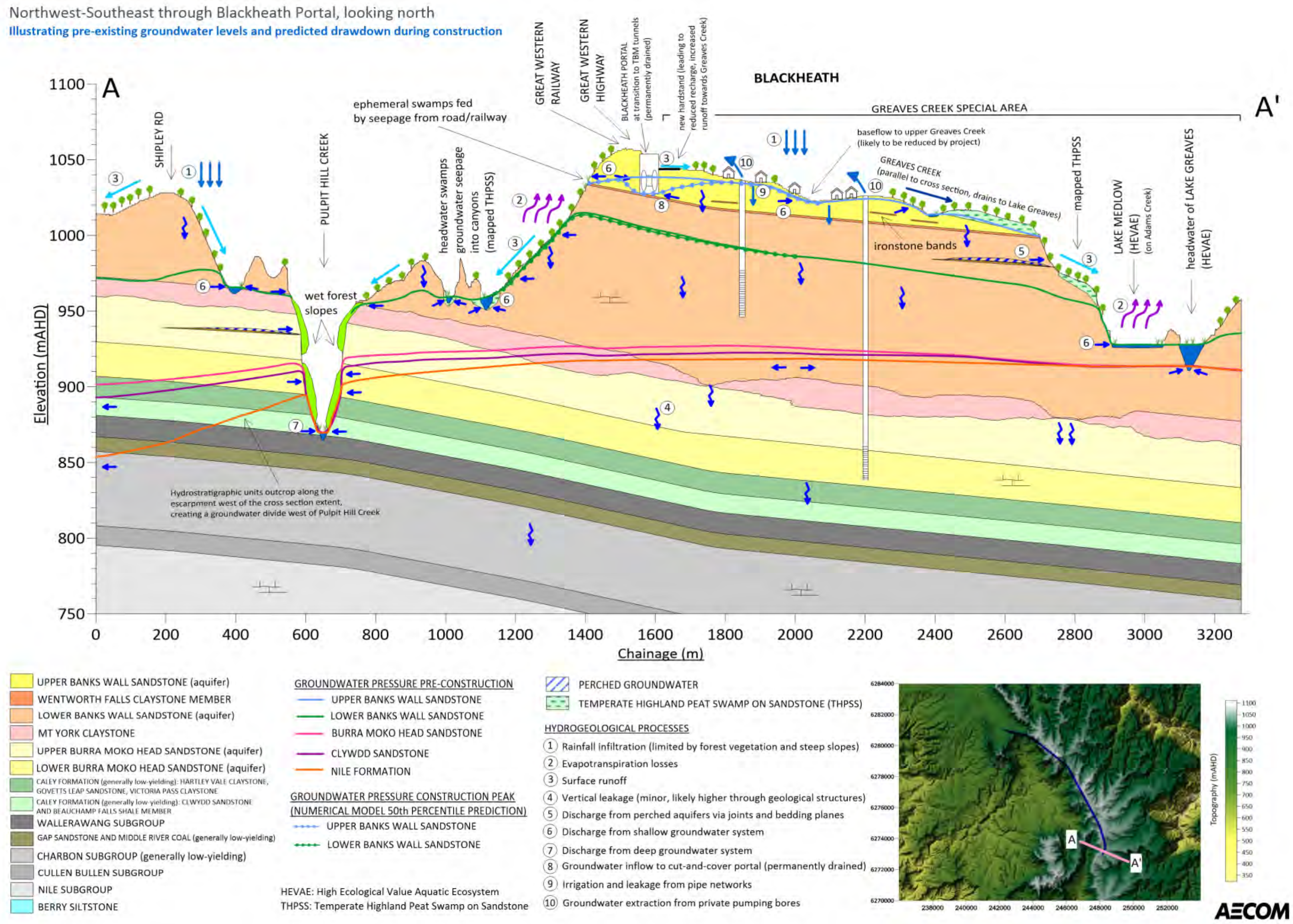

Figure 3-24 Conceptual hydrogeological model - southwest to northeast cross-section through Blackheath portals, looking north

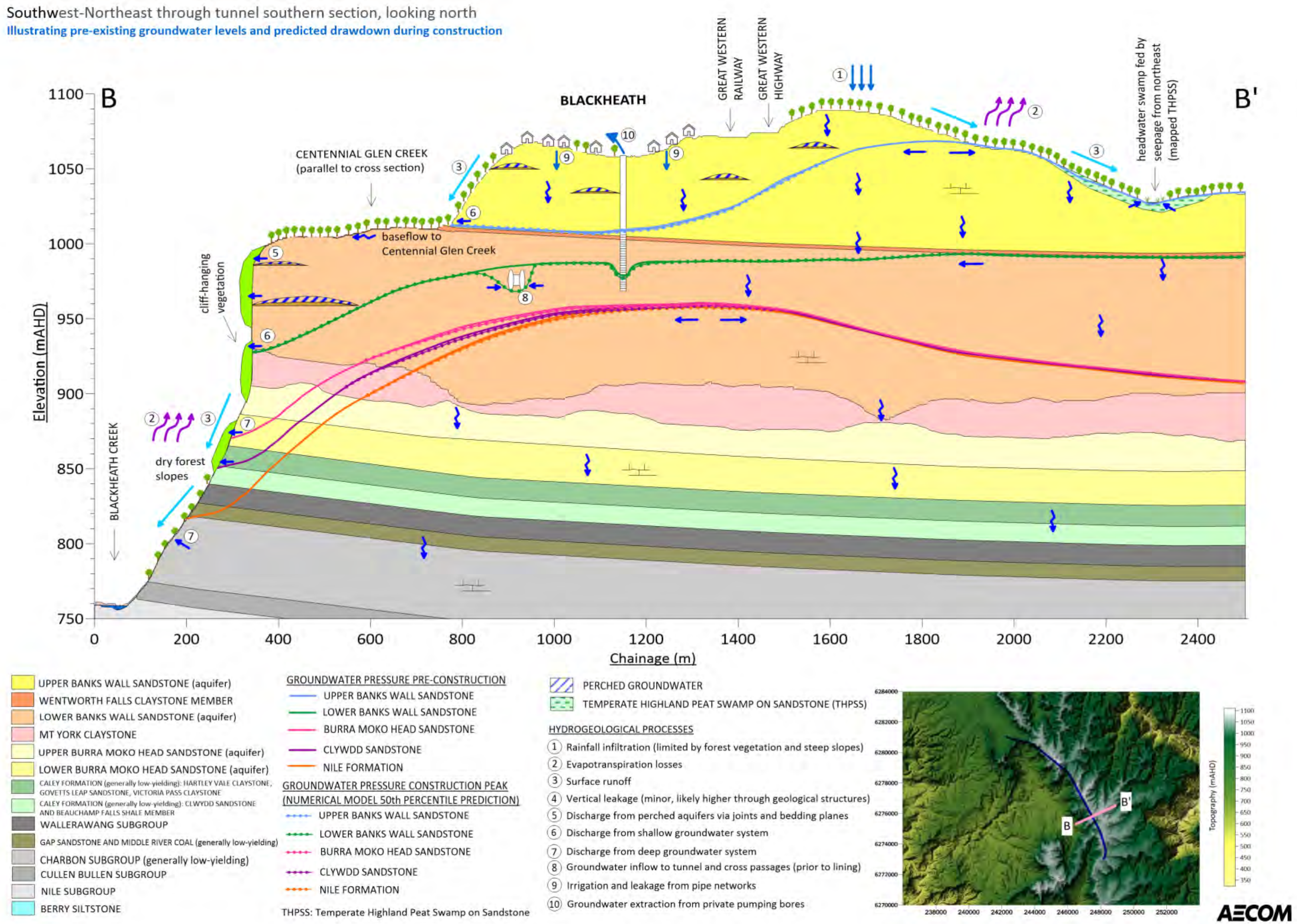

Figure 3-25 Conceptual hydrogeological model - southwest to northeast cross-section through southern section of twin tunnels, looking north

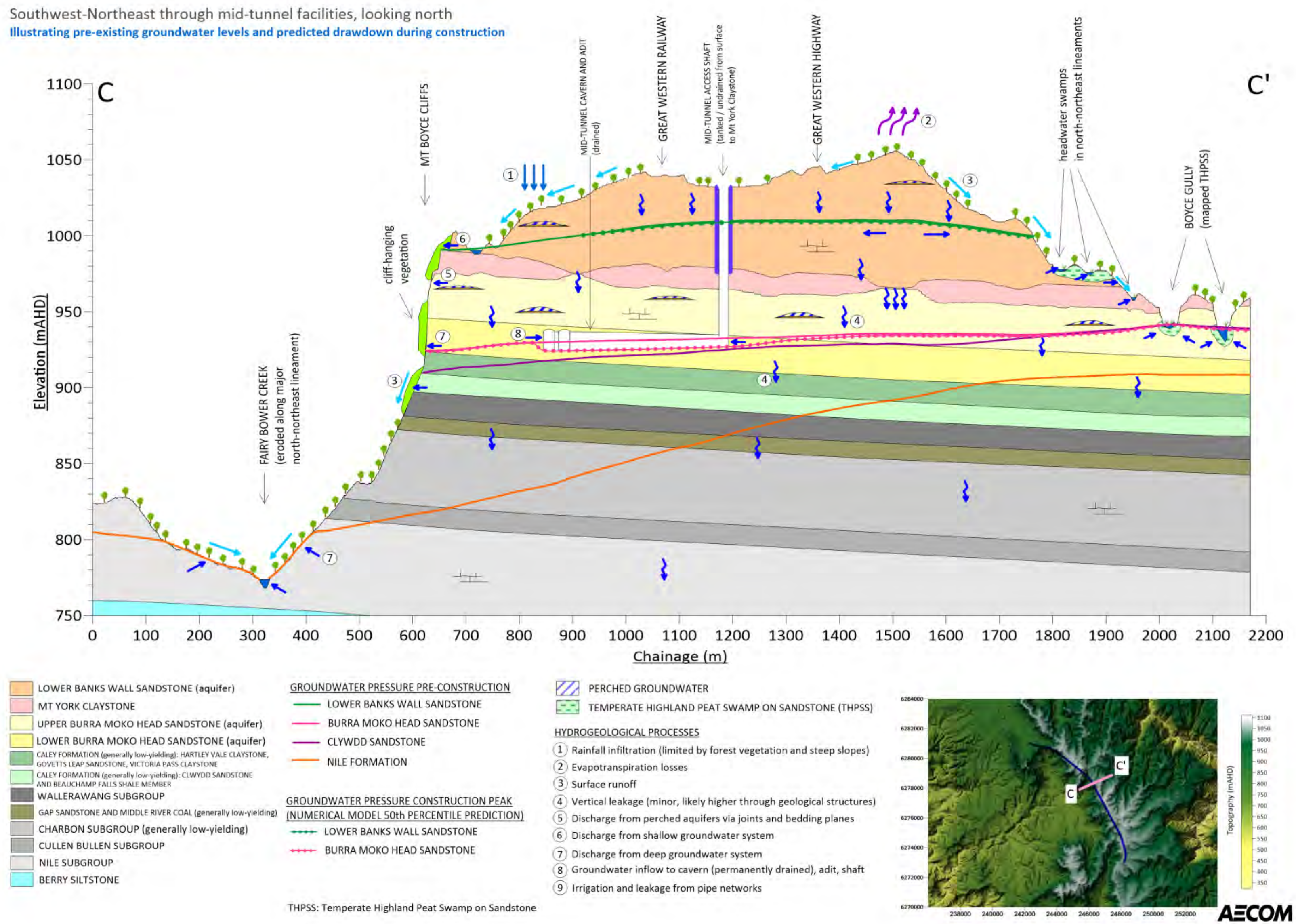

Figure 3-26 Conceptual hydrogeological model - southwest to northeast cross-section through mid-tunnel infrastructure, looking north

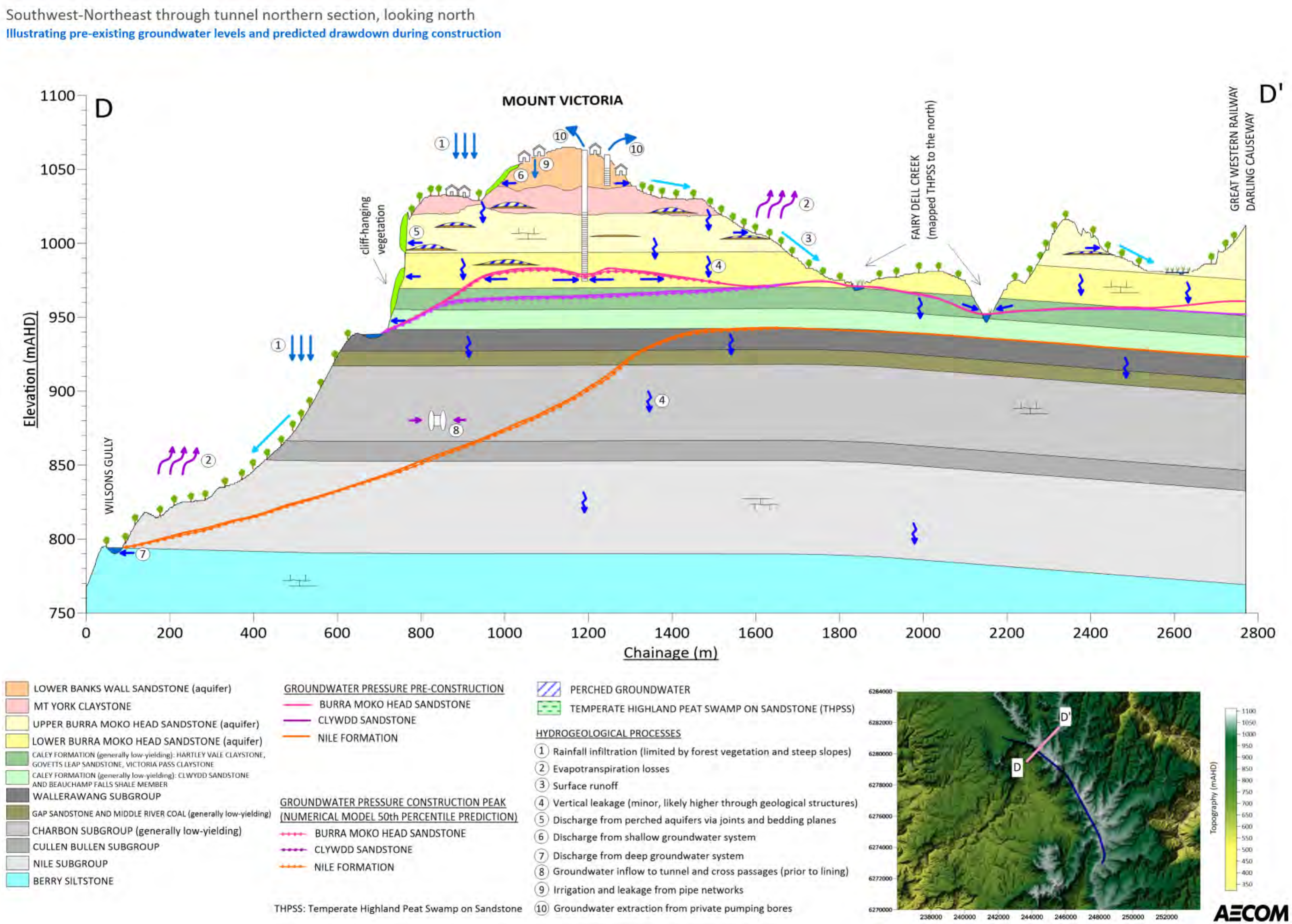

Figure 3-27 Conceptual hydrogeological model - southwest to northeast cross-section through northern section of twin tunnels, looking north

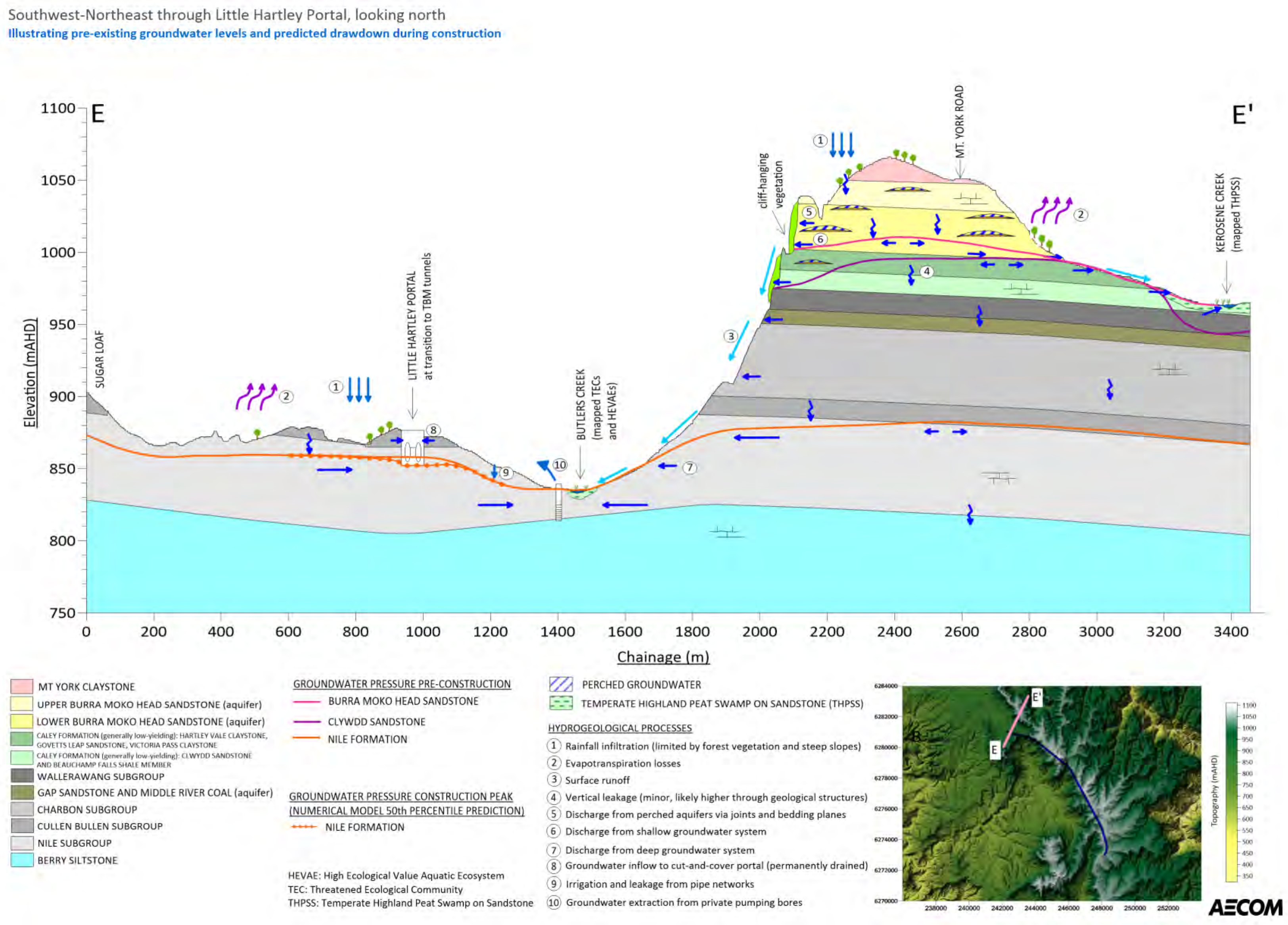

Figure 3-28 Conceptual hydrogeological model - southwest to northeast cross-section through Little Hartley portals, looking north

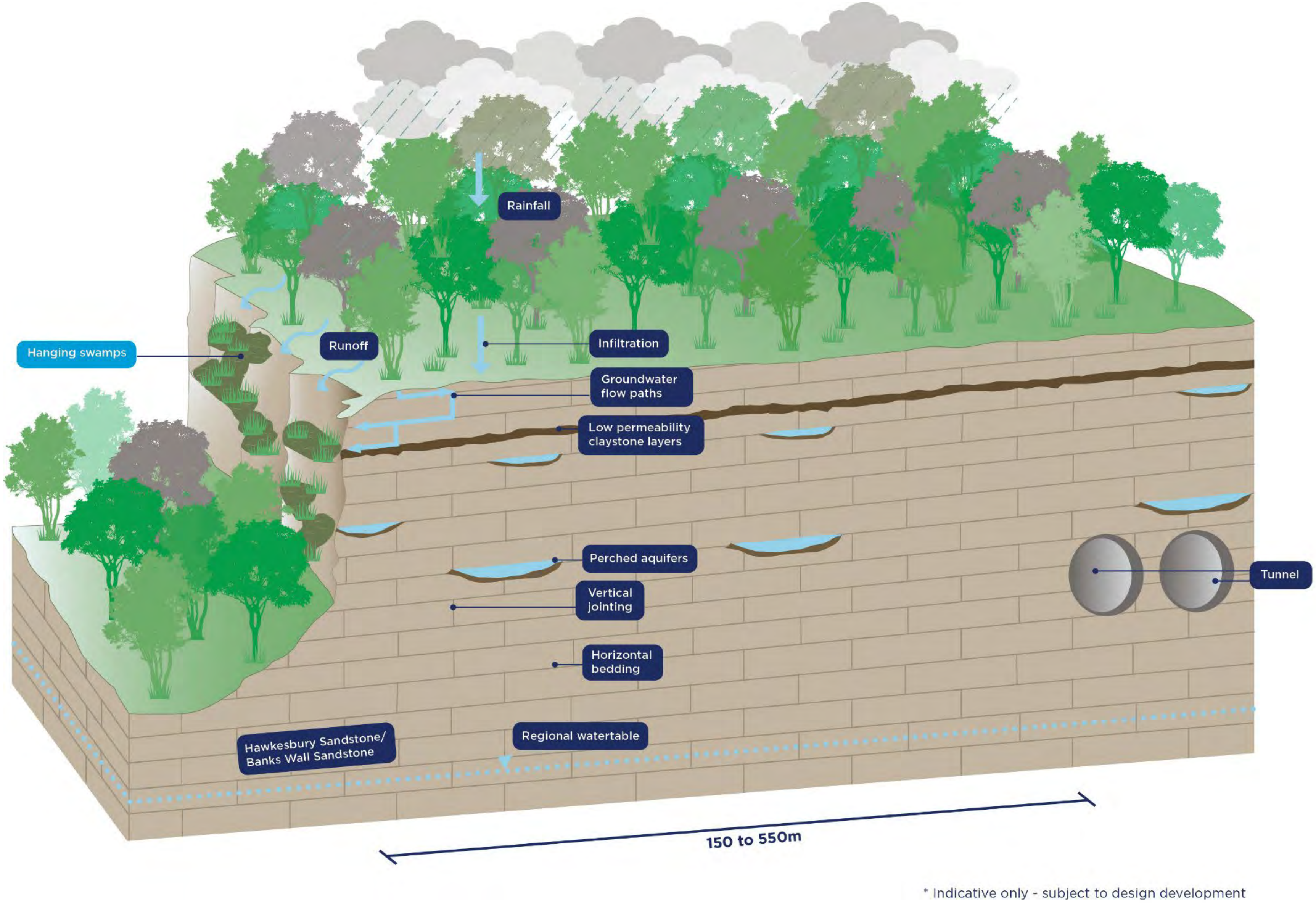

Figure 3-29 3D conceptual block model of tunnels and surrounding landform

4.0 Assessment of construction impacts

4.1 Assumed construction program

Construction of the project is expected to take around eight years. Subject to approvals, construction is proposed to commence in mid-2024 and be completed by the end of 2031, as shown on Figure 1-8 in Section 1.2.2. The project aims to be open to traffic in 2030, and as such, there will be a period where construction activities will over-lap with tunnel operations.

For numerical groundwater modelling purposes, to allow for regular model time steps, the construction phase was assumed to commence mid-2024 and conclude by the end of quarter three (Q3) of 2030 (around 6 years), as shown in Figure 1-3 of Annexure B. The construction program and construction sequencing would be subject to ongoing design development and construction planning and further detailed groundwater modelling would be carried out as part of that process.

Section 4.2 describes the project design elements that have potential to alter groundwater resources, as summarised from Chapter 5 (Construction) of the EIS, and outlines the assumptions made to allow preparation of a numerical groundwater model (Annexure B).

4.2 Project components relevant to groundwater impact assessment

The main components, with respect to effects on the groundwater system (and subsequent modelling), are described in the following subsections. The details presented are assumptions based on existing available geotechnical and groundwater information. As such, the following sections describe the currently preferred construction method that has been assumed for the purposes of this groundwater modelling and impact assessment. Additional geotechnical and groundwater data would be available in the future, which would be used to further inform design development and detailed construction planning. Timing and methods, including the TBM type(s) selected, may change as part of that process.

Tanked structures

Tanking avoids the need for ongoing draining and dewatering and therefore reduces groundwater drawdown and potential environmental impacts relative to a drained construction method

The twin tunnels would be tanked and supported by precast concrete segments installed as part of the TBM tunnelling process. Other tanked underground infrastructure would typically be supported by permanent rock bolts, fibre reinforced shotcrete and reinforced cast in-situ concrete collars. As shown in Figure 4-1, the twin tunnels, the upper-section of the mid-tunnel access shaft, and the cross-passages would be tanked.

Drained structures

Drained features allow long-term groundwater inflows. The Blackheath and Little Hartley portals, the lower-section of the mid-tunnel access shaft, the mid-tunnel caverns, and adit would be drained, as shown on Figure 4-1. Groundwater level drawdown would occur in response to groundwater inflow (dewatering) into these elements and has the potential to impact surrounding sensitive receptors. The mid-tunnel caverns and adit have been designed to be permanently drained structures on the basis the conceptual and numerical groundwater modelling predict it will result in minimal impacts to nearby environmental receptors. This is predominantly due to the depth of the caverns, and the low permeability and saturated thickness of the surrounding strata. The predicted groundwater impacts from constructing a drained mid-tunnel cavern are described in detail throughout Section 4.0 and 5.0. A drained caverns design is preferred from a design and construction perspective because the structure does not need to withstand hydrostatic pressure.

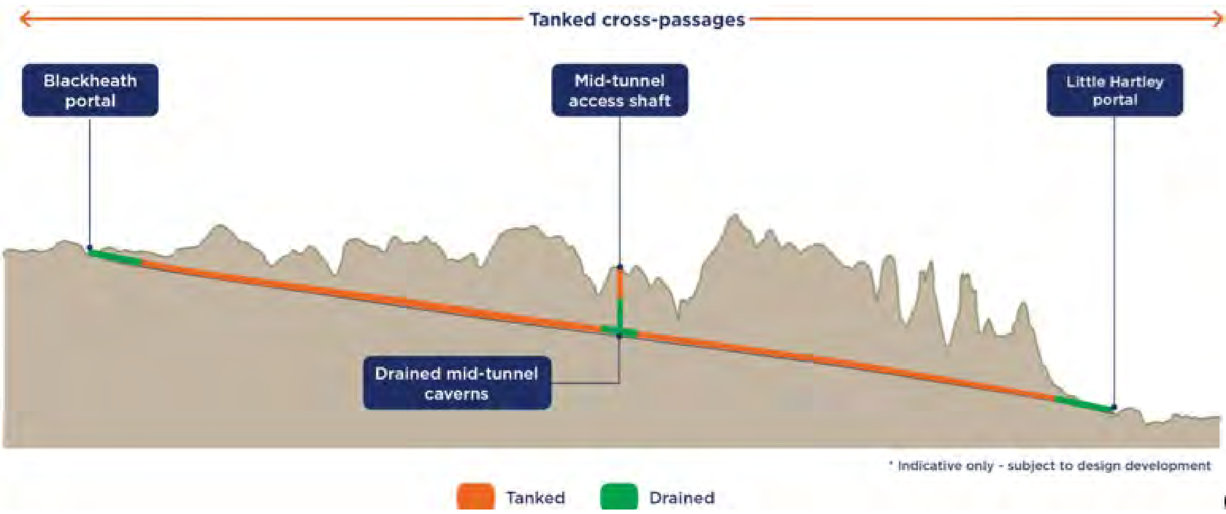

Figure 4-1 Tanked and drained features of the project

4.2.1 Tunnel portals

4.2.1.1 Blackheath

To the south of Blackheath, the westbound lanes of the Great Western Highway would enter the tunnel at one portal, which would be offset by around 50 metres from the portal for the eastbound lanes exiting the tunnel.

A cut-and-cover tunnel (portal) forms the transition zone between the TBM-constructed tunnel and ground surface. Cut-and-cover is a tunnel excavation method that generally involves excavating downwards from ground surface, then installing a base, walls, and a roof to support the surrounding soil and rock (where necessary).

The Blackheath cut-and-cover sections would be around 190 metres (westbound) and around 140 metres (eastbound) in length. For the purposes of this assessment the tunnel portals (cut and cover structures) are assumed to be permanently drained. The drained design for these cut and cover structures is a design response to manage hydrostatic pressure (under the floor of the structure) at these locations.

The cut-and-cover portals would be:

- around 50 metres west of the upper reaches of Greaves Creek, which flows to the east as one of the tributaries which discharge into Lake Greaves and is part of a declared Special Area (Blackheath portion of the Blue Mountains Special Area) and source of water supply for the Upper Blue Mountains area
- around 340 metres southeast of the nearest GDE
- around 530 metres east of the second nearest GDE (located on Greaves Creek).

Refer to Figure 3-21 for Blackheath portals location and nearby GDEs.

Immediately east of the Blackheath portals, the project would connect with the Katoomba to Blackheath GWH Upgrade.

4.2.1.2 Little Hartley

As with the Blackheath portals, a cut-and-cover construction technique would be used to transition between the TBM-constructed tunnel and ground surface at Little Hartley.

The Little Hartley cut-and-cover tunnel lengths would be around 145 metres (eastbound) and around 180 metres (westbound). The tunnel portals would be permanently drained.

The cut-and-cover portals would be around 140 metres south of the nearest valley infill swamp.

To the west of the Little Hartley portals, the project would connect with the Little Hartley to Lithgow Upgrade.

4.2.2 Twin tunnels

The project would involve construction of twin tunnels, each around 11 kilometres long. The tunnels would be constructed by two TBMs, one for each tunnel (see Figure 5-10 shown in Chapter 5 (Construction) of the EIS). The outer diameter of the tunnels is proposed to be around 14.8 metres and the width of the carriageways would be 10.5 metres.

TBMs comprise of a front shield with rotating cutterhead, which can excavate through rock and soil. As a TBM advances, precast concrete segments would be installed in the excavated tunnel. The TBM would be propelled forward by hydraulic jacks pushing off the previously installed tunnel lining segments. Gaps between the excavated tunnel wall and the tunnel lining would be filled with cement-based grout to minimise groundwater ingress in the long-term. This approach to tunnel excavation and lining results in a tanked (undrained) structure.

Construction of the tunnels between Little Hartley and the mid-tunnel caverns would proceed from Little Hartley at a consistent upward gradient through a range of geological formations in a generally south-easterly direction. The tunnels between Little Hartley and the mid-tunnel caverns have been assumed for this groundwater impact assessment to be constructed using an ‘earth pressure balance’ (EPB) TBM, in which a bentonite-based slurry is injected ahead of the TBM cutting face to stabilise the excavation and inhibit groundwater ingress. The EPB TBM method of balancing pressure ahead of the cutterhead inhibits groundwater inflow to the excavation thus minimising associated groundwater drawdown. The tunnels between the Little Hartley portals and the mid-tunnel caverns, which would be constructed using an EPB TBM, have been modelled as permanently tanked.

Once the EPB TBMs reach the mid-tunnel caverns, which would be excavated prior to the arrival of the TBMs, it has been assumed for the purposes of this groundwater impact assessment that their cutterheads would be changed to ‘single shields’, before continuing to advance the tunnels towards the Blackheath portals. The single shield TBM does not maintain a bentonite-based slurry ahead of the cutterheads, instead groundwater ingress would occur at the leading edge of the tunnel excavation for a few hours before the next segment of tunnel lining is installed. The tunnels between the mid-tunnel caverns and the Blackheath portals, which would be constructed using a single shield TBM, have been modelled as drained during construction and tanked after construction.

Selection of TBM method for this groundwater impact assessment has been made based on expected geological conditions, rather than groundwater conditions. The EPB TBM stabilises the tunnel in the less stable geology (Permian strata) identified to the west of the mid-tunnel caverns, with more stable geology (i.e., Triassic strata) expected east of the mid-tunnel caverns.

The depth of the tunnels below ground level would vary according to topography, with the deepest point of the tunnel located around 200 metres below ground level near Mount Victoria, with shallower sections near the tunnel portals at Blackheath and Little Hartley. Indicative depth of the tunnels is shown in Figure 4-5 to Figure 4-11 of Chapter 4 (Project description) of the EIS.

4.2.3 Cross-passages

Cross-passages are short tunnels that would connect the two main tunnels. Their purpose is to allow access from one tunnel to another in an emergency or for maintenance purposes.

Cross-passages linking the two mainline tunnels would be excavated using roadheaders. A drill and blast construction technique may be required for some cross-passages depending on geological conditions encountered. Cross-passages would be located at around 120 metre intervals through the tunnel and would be tanked to inhibit groundwater inflows. The length of the cross-passages would be around 11 metres between the outer edge of the of twin tunnels and would be around 5 metres wide. Due to the length of the mainline tunnels, excavation of cross-passages would occur concurrently with TBM excavation. Once the TBM has passed a cross-passage location, construction of the cross-passages would follow. The indicative construction sequence for the cross-passages would include creating an opening in the installed tunnel precast concrete segments, excavating the soil/rock material between the two tunnels. To permanently support the cross-passage opening, a reinforced cast in-situ concrete collar is proposed. Beyond the collar, a reinforced secondary concrete lining would be formed and cast against a waterproofing membrane over the full perimeter of the cross-passage.

Construction of each cross-passage is expected to take up to around three months, and multiple cross-passages would be constructed concurrently.

Prior to opening the tunnel concrete segments to excavate the cross-passage, test holes would be drilled to assess rock mass permeability, to inform plans for reducing the volume of groundwater entering the excavation. In exceptional circumstances, pre-grouting of the rock-mass would be undertaken to reduce strata permeability prior to cross-passage excavation. Cross-passages would be subject to ongoing investigations and design development in consultation with relevant stakeholders, including in relation to opportunities to reduce the number of cross-passages required for the project while meeting fire and life safety requirements. As a conservative approach (realistic worst case groundwater drawdown scenario), pre-grouting of the cross-passages has not been modelled.

4.2.4 Mid-tunnel caverns, adit and access shaft

Two caverns would be constructed at around the mid-point of the twin tunnels to support TBM refurbishment, including cutterhead maintenance and replacement, and to allow for the provision of maintenance and breakdown bays for when the tunnels are operational.

The mid-tunnel caverns would be constructed prior to the arrival of the TBMs within the Burra-Moko Head Sandstone. Roadheaders would be used to excavate the access adit from the base of the mid-tunnel access shaft to the caverns (around 260-280 metres long) and the caverns themselves.

The caverns would be around 230 metres long (along the alignment of the tunnels) and around 20 metres wide. The two caverns would be separated by a central pillar around nine metres wide, however for the purposes of the groundwater assessment the mid-tunnel caverns have been considered as a single feature.

The floor of the mid-tunnel caverns would be constructed at around 930 mAHD at the eastern end and around 926 mAHD at the western end of the caverns. The caverns would be around 16 metres high (from the invert of the TBM to the cavern roof).

The mid-tunnel access shaft, located at Soldier’s Pinch, would be bored to around 100 metres below ground level, terminating within the Burra-Moko Head Sandstone geological unit (refer to Figure 4-1). The diameter of the shaft would be around 16 metres.

The shaft would be lined (tanked) from ground level to the Mount York Claystone geological unit, located around 50 metres below ground level. The Mount York Claystone is an aquitard. The shaft below the claystone aquitard would be unlined (a drained structure) to depth within the Burra-Moko Head Sandstone. If the shaft was not lined above the aquitard, groundwater ingress would likely be markedly higher, due to the Banks Wall Sandstone permeability and recharge rate.

The mid-tunnel caverns, the base of the access shaft and the adjoining adit, would be constructed as unlined, (i.e. drained) features. The access shaft and adit would be backfilled after tunnel construction, therefore groundwater inflows and drawdown impacts related to those features would cease.

4.2.5 Other earthworks

Earthworks for surface road upgrade works would generally be completed using conventional methods of construction and areas of new cut and fill, and widening of existing cuts and embankments, including construction of retaining walls and reinforced soil walls to design levels. Groundwater impacts due to the surface road upgrade works are considered to be negligible relative to the major tunnelling and excavation works for the twin tunnels, portals and mid-tunnel infrastructure and therefore were not included in the numerical groundwater model.

Construction activities would also include a new water supply pipeline connecting the Little Hartley construction footprint with the Lithgow City Council water supply system at Lithgow. The pipeline corridor would extend around 14 kilometres in length between the project at Little Hartley and Lithgow. The water supply pipeline would be up to around 500 millimetres in diameter located within a trench up to two metres in depth, subject to localised ground conditions, topography, and geology.

Depth of groundwater between Little Hartley and Lithgow is variable and ranges between 0.5 and 18.0 metres below ground level, however, is generally greater than two metres depth (JAJV, 2021). It is likely that any potential impacts due to the construction of the new water supply pipeline intersecting groundwater would be low, as potential impacts would be localised and temporary.

The construction of a water supply pipeline between Little Hartley and Lithgow is currently the preferred water supply option. Investigations are ongoing to confirm the water supply option for the project and other options being investigated include the use of groundwater. Where key water intensive construction activities commence prior to operation of the preferred water supply option, water may need to be trucked to the Little Hartley construction site temporarily.

4.3 Predicted groundwater inflows

The flow of groundwater has been estimated using predictive groundwater modelling, as detailed in Annexure B.

The modelled total groundwater inflows (50th and 95th percentiles) to the underground structures across the project during the construction period (mid 2024 to Q3 2030) are illustrated in Figure 4-2. The 50th percentile predictions represent the likely modelled inflow forecasts and the 95th percentile predictions represent the likely worst case, as described in Section 2.3.6.

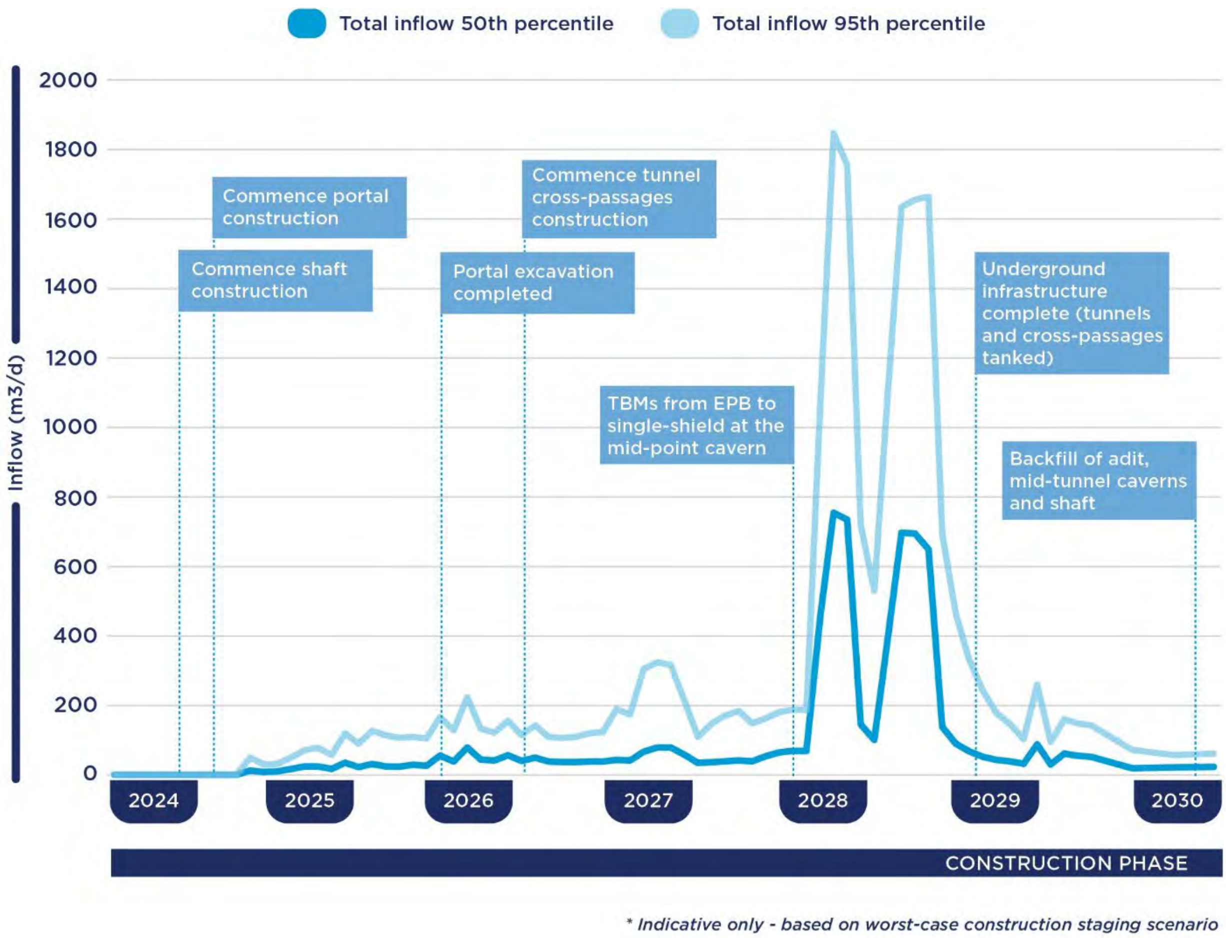

Figure 4-2 Simulated groundwater inflow volumes for underground infrastructure during the construction phase

As shown on Figure 4-2, there is an increase in groundwater inflow from the commencement of construction in mid-2024 through to 2026, then inflows remain generally steady during 2026, after the portals and mid-tunnel excavations are completed.

Groundwater inflows increase once the construction of the tunnel cross-passages commence in late 2026 and further increases in 2028 on the assumption that the TBMs change over from EPB to single-shield, once tunnelling reaches the mid-point caverns.

Groundwater inflows rapidly decrease during 2029 as construction of underground infrastructure is completed, specifically, once the cross-passages and twin tunnels are tanked.

Groundwater inflows further decrease in 2030 after the mid-tunnel access shaft and adit are backfilled (simulated as occurring in 2030).

As shown in Table 4-1, the twin tunnels between the mid-tunnel caverns and Blackheath, and the tunnel cross-passages, are predicted to contribute to the highest volumes of groundwater inflow during the construction phase. The cross-passages would be tanked upon construction completion and twin tunnels would be progressively tanked as tunnelling progresses and therefore groundwater inflows associated with these structures would be temporary and would recover after construction at these locations.

Table 4-1 Summary of modelled groundwater inflows during construction phase (mid 2024 to Q3 2030)

Feature	Final construction	Predicted construction phase groundwater inflows (m^3/day)			
		Average		Maximum	
		50th percentile	95th percentile	50th percentile	95th percentile
Tunnel – Little Hartley to mid-tunnel caverns	Tanked	0.0	0.0	0.0	0.0
Tunnel – mid-tunnel caverns to Blackheath	Tanked	26.6	82.4	704.3	1,702.3
Cross-passages	Tanked	76.5	222.1	724.6	1,756
Mid-tunnel access shaft	Tanked and drained[17] - Infilled at end of construction phase	1.2	8.9	9.9	29.6
Mid-tunnel adit	Drained - Infilled at end of construction phase	1.1	12.5	6.8	46.5
Mid-tunnel caverns	Drained	2.5	11.9	18.8	52.9
Little Hartley portals	Drained	5.6	16.2	20.6	61.8
Blackheath portals	Drained	21.0	45.4	61.4	144.4
Estimated combined inflow during construction[18]		107.8	317.2	756.2	1,847.2

The twin tunnels between Little Hartley to the mid-tunnel caverns would be constructed using a EPB TBM, in which slurry is added at the cutting face to stabilise the tunnel face to prevent groundwater inflow to the tunnels. The single-shield TBM. does not maintain pressure at the tunnel face (as is the case with the EPB machine) resulting in groundwater ingress for a period of a few hours before the tunnels are ‘tanked’ following the installation of precast concrete segments.

Each tunnel cross-passage would be constructed over a period of weeks to months prior to being tanked to reduce potential groundwater inflow. For numerical groundwater modelling purposes, the groundwater inflows presented above conservatively assume cross passages would be drained for a period of three months prior to being tanked.

The model does not simulate any pre-grouting of open joints prior to excavation of the cross-passages, which may occur if the joints are displaying high yields. Pre-grouting would reduce groundwater inflows to the excavation and therefore the modelled inflow estimates are considered conservative.

[17] The mid-tunnel access shaft will be tanked from ground surface to the Mount York Claystone and drained from the Mount York Claystone to shaft depth within the Burra-Moko Head Sandstone.
[18] The estimated combined inflow is not the sum of the inflow from each project element listed in the table above, as when these inflows occur will depend on construction staging. The estimated combined inflow is the summation of inflows based on the modelled construction staging used for the groundwater modelling (described in Annexure B).

As discussed in Annexure B, cross-passages that are located just above regional aquitards, such as the Wentworth Falls Claystone and Mount York Claystone, are predicted to have the highest (temporary) groundwater inflows.

Potential impacts to groundwater users, sensitive environmental receptors, and groundwater quality, due groundwater inflows and subsequent drawdown is further discussed in Section 4.5 below.

Collection and treatment of groundwater inflows during the modelled construction phase of the project (mid 2024 to Q3 2030) is discussed in Section 4.5.8.

4.4 Predicted drawdown

There are multiple groundwater systems located at varying depths within the hydrostratigraphic units detailed in Section 3.5.1. The main groundwater systems are associated with the Banks Wall Sandstone, Burro-Moko Head Sandstone, and the Caley Formation within the Narrabeen Group, and the Illawarra Coal Measures. During construction, groundwater level drawdown would occur within these hydrostratigraphic units in response to groundwater inflow into the project elements, as discussed in Section 4.2.

The maximum groundwater level drawdown during the construction period was predicted for the water table and groundwater systems within the lower Banks Wall Sandstone, Mount York Claystone, the lower Burra-Moko Head Sandstone, upper Caley Formation and the Marangaroo or Gundangaroo Formation hydrostratigraphic units. Figure 4-3 to Figure 4-5 show maximum groundwater drawdown predicted during the construction phase for the water table and underlying groundwater systems, regardless of when these maximum drawdowns eventuate i.e. when drawdown associated with construction of different project elements would occur will depend on construction staging. The construction program assumed for the groundwater impact assessment is described in Section 4.1

4.4.1 Water table

The water table is the uppermost saturated layer of the numerical groundwater model i.e., the uppermost saturated or partially saturated unconfined stratigraphic unit.

The median (50th percentile) model prediction for maximum drawdown, illustrated in Figure 4-3, is as follows:

- Blackheath portal: drawdown is predicted to peak at around 5.1 to 20.0 metres (at the portal). Drawdown is predicted to extend up to 800 metres around the portal, including to registered water supply bores to the east
- Little Hartley portal: drawdown is predicted to peak at around 5.1 to 20.0 metres (at the portal). Drawdown is predicted to extend up to 300 metres around the portal, including to locations of mapped GDEs to the north. Additionally, drawdown around a regional fault, located around 700 metres from the Little Hartley portals, extends north to the mapped GDEs
- cross-passages and near-surface locations along the twin tunnels between the mid-tunnel caverns and the Blackheath portals: drawdown is predicted to peak at around 5.1 to 20.0 metres and extend up to 1.75 kilometres, including to registered water supply bores and GDEs. The cross-passages and twin tunnels would be tanked upon construction completion, groundwater drawdown is predicted to cease after construction around the cross-passages.
- Regional fault located around 1.3 kilometres east of the Little Hartley portals: drawdown is predicted to peak at around 2.1 to 5.0 metres (at the portal). Drawdown is predicted to extend up to 300 metres.

The two metre drawdown contour from the more conservative 95th percentile model prediction of maximum drawdown, also illustrated (in purple) in Figure 4-3, occurs around the same features as the 50th percentile, but extends to around double the radius.

Drawdown impacts to registered groundwater users and GDEs are further discussed in Sections 4.5.3 and 4.5.4, respectively.

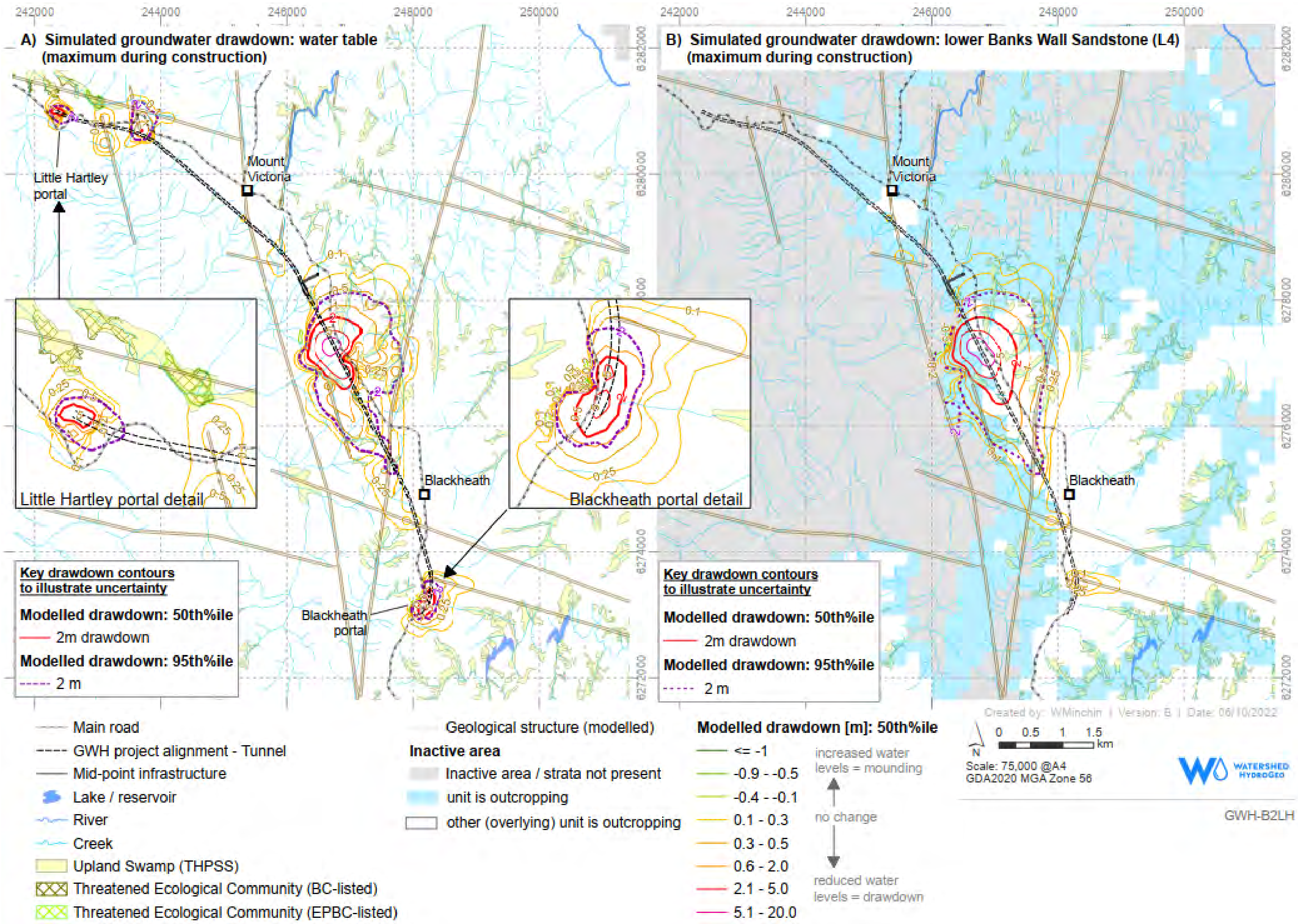

Figure 4-3 Simulated maximum drawdown of the water table and groundwater drawdown within the lower Banks Wall Sandstone during the construction phase

4.4.2 Lower Banks Wall Sandstone

The Banks Wall Sandstone is the uppermost member of the Narrabeen Group and lies above the Mount York Claystone aquitard. Drawdown within the lower Banks Wall Sandstone is predicted to occur at the cross-passages, near-surface twin tunnel locations, and geological structures between the mid-tunnel caverns and the Blackheath portals which intersect this unit, as shown in Figure 4-3.

The median (50th percentile) model prediction of the maximum drawdown is around 5.1 to 20.0 metres at the tunnel cross-passages and near-surface twin tunnels south (towards Blackheath) of the mid-tunnel caverns. The spatial extent of drawdown west of the project footprint is limited by the western escarpment of the Blue Mountains plateau, where hanging swamps are located. The extent of drawdown to the east (around 0.1 to 0.3 metres) is some 1.5 kilometres from the project footprint and extends to locations of registered water supply bores and GDEs.

The cross-passages would be tanked upon construction completion and twin tunnels would be progressively tanked as tunnelling progresses and therefore groundwater drawdown associated with these structures would be temporary and would recover after construction at these locations.

The median (50th percentile) model prediction of the maximum drawdown at a regional fault located around 300 metres from the Blackheath portals is around 0.1 to 0.3 metres, with the spatial extent of drawdown extending around 700 metres from the fault, which extends to registered water supply bores east of the tunnel.

The two metre drawdown contour from the more conservative 95th percentile model prediction of maximum drawdown, also illustrated (in purple) in Figure 4-3, occurs around the same features as the 50th percentile, but extends to around double the radius.

Drawdown impacts to registered water supply users and GDEs are further discussed in Sections 4.5.3 and 4.5.4, respectively.

4.4.3 Mount York Claystone

The Mount York Claystone aquitard underlies the Banks Wall Sandstone and overlies the Burra-Moko Head Sandstone.

Drawdown within the Mount York Claystone is predicted to occur at the cross-passages and twin tunnels south (towards Blackheath) of the mid-tunnel caverns, and geological structures that intersect the construction footprint, as shown in Figure 4-4.

The median (50th percentile) model prediction of the maximum drawdown is around 0.3 to 0.5 metres at the tunnel cross-passages and the near-surface twin tunnels south (towards Blackheath) of the mid-tunnel caverns. The spatial extent of drawdown west of the project footprint is limited by the western escarpment of the Blue Mountains plateau, where hanging swamps are located. The extent of drawdown to the east (around 0.1 to 0.3 metres) is some 1.5 kilometres from the project footprint. The cross-passages would be tanked upon construction completion and twin tunnels would be progressively tanked as tunnelling progresses and therefore groundwater drawdown associated with these structures would be temporary and would recover after construction at these locations.

The two metre drawdown contour from the more conservative 95th percentile model prediction of maximum drawdown, also illustrated (in purple) in Figure 4-3, occurs around the same features as the 50th percentile, but extends to around four times the radius.

The extent of drawdown within the Mount York Claystone does not extend to where the unit outcrops and therefore is not anticipated to impact GDEs. No registered water supply bores are known to be screened within the Mount York Claystone.

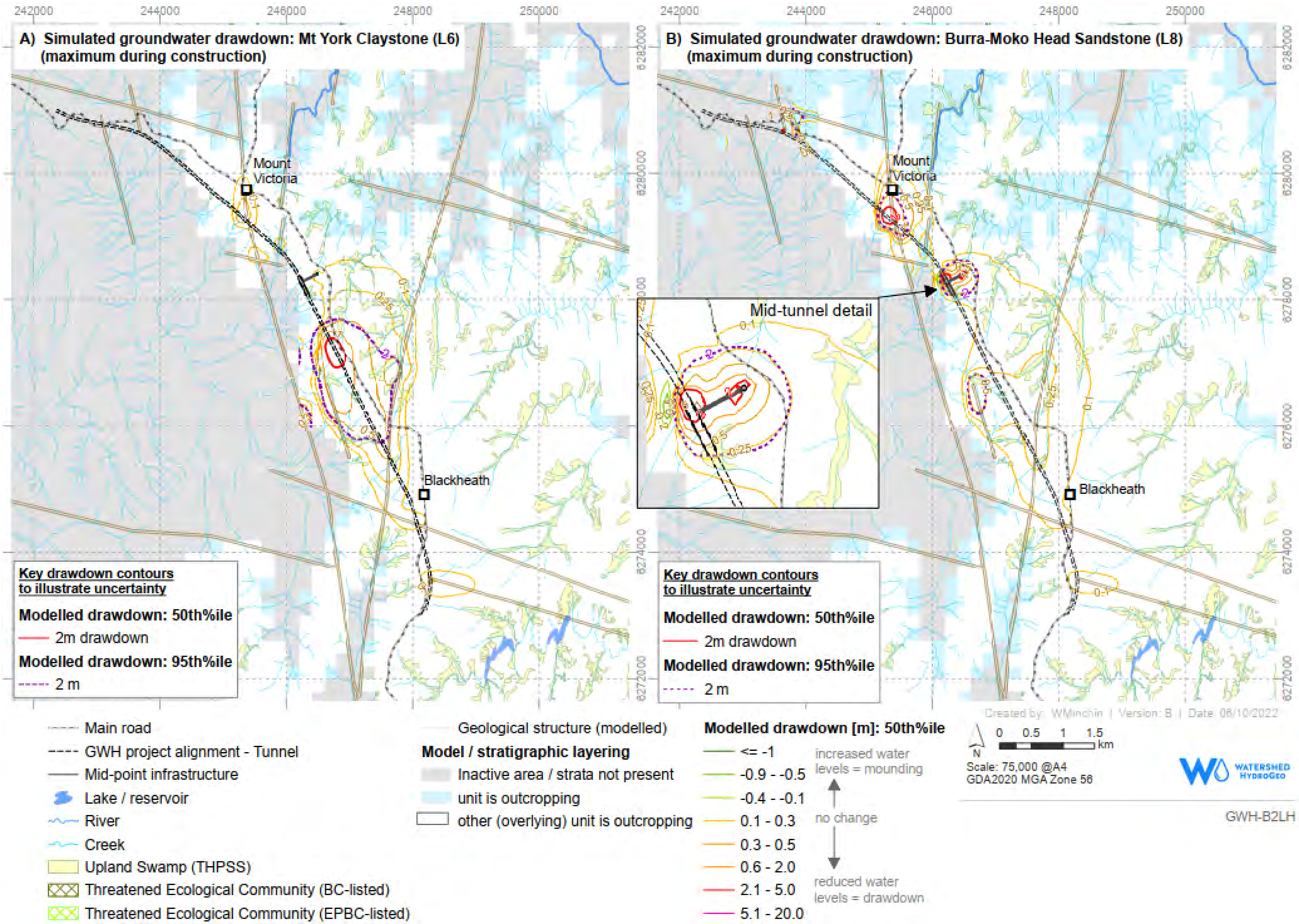

Figure 4-4 Simulated maximum groundwater drawdown within the lower Banks Wall Sandstone and the Mount York Claystone during the construction phase

4.4.4 Lower Burra-Moko Head Sandstone

The Burra-Moko Head Sandstone underlies the Mount York Claystone. Drawdown within the Burra-Moko Head Sandstone is predicted to occur where the tunnel intersects this unit at the Blackheath portals, the mid-tunnel caverns, adit and access shaft and at geological structures that intersect the construction footprint, as shown in Figure 4-4.

The median (50th percentile) model prediction of maximum drawdown is as follows: at the tunnel caverns, around 2.1 to 5.0 metres; at the access shaft, around 5.1 to 20.0 metres; and at geological structures located north of the mid-tunnel cavern, around 2.1 to 5.0 metres.

The spatial extent of drawdown west of the project footprint is limited by the western escarpment of the Blue Mountains plateau and the largest drawdown extent to the east is around 1.4 kilometres (0.1-0.3 metre drawdown) from the construction footprint, due to geological structures south of the mid-tunnel cavern. The cross-passages would be tanked upon construction completion and twin tunnels would be progressively tanked as tunnelling progresses and therefore groundwater drawdown associated with these structures would be temporary and would recover after construction at these locations.

The two metre drawdown contour from the more conservative 95th percentile model prediction of maximum drawdown, also illustrated (in purple) in Figure 4-4, occurs around the same features as the 50th percentile, but extends to around four times the radius. In addition, the two metre contour for the 95th percentile prediction, also presents at a northwest-southeast trending geological structure located south of the mid tunnel caverns.

Predicted drawdown within the lower Burro-Moko Head Sandstone does not extend to where the unit outcrops where GDEs are present. No registered water supply bores are known to be screened within the Burro-Moko Head Sandstone within the extent of drawdown.

4.4.5 Caley Formation

The Caley Formation is located between the Burra-Moko Head Sandstone and the Illawarra Coal Measures. Drawdown within this unit is largely due to the project intercepting geological structures, as shown in Figure 4-5.

The median (50th percentile) model prediction of maximum drawdown is as follows: at geological structures north of the mid-tunnel caverns, around 5.1 to 20.0 metres; east of the Little Hartley portals, around 0.6 to 2.0 metres; and south of the mid-tunnel caverns, around 0.3 to 0.5 metres. Drawdown at these geological features is the result of groundwater inflows to project components in the overlying units reducing recharge to the underlying Caley Formation.

The two metre drawdown contour from the more conservative 95th percentile model prediction of maximum drawdown, also illustrated (in purple) in Figure 4-5, occurs around the same features as the 50th percentile, but extends to around double the radius. In addition, the two metre contour for the 95th percentile prediction, also presents at a northwest-southeast trending geological structure located south of the mid tunnel caverns.

Predicted drawdown within the upper Caley Formation does not extend to where the unit outcrops (where GDEs are present) and no registered water supply bores are known to be screened within this unit within the extent of drawdown.

4.4.6 Marangaroo or Gundangaroo Formation

The Marangaroo and Gundangaroo Formations are within the lower portion of the Illawarra Coal Measures. Drawdown within this unit is largely due to geological structures intercepting the construction footprint and the Little Hartley portals, as shown in Figure 4-5.

The median (50th percentile) model prediction of maximum drawdown is 5.1 to 20.0 metres at the Little Hartley portals. Drawdown within the area of geological structures, to the east of Little Hartley portals, extends north to GDEs where the unit outcrops, as further discussed in Section 4.5.4. No registered water supply bores are known to be screened within this unit within the extent of drawdown.

The median (50th percentile) model prediction for maximum drawdown is as follows: at geological structures north of the mid-tunnel caverns, around 5.1 to 20.0 metres and south of the mid-tunnel caverns, around 0.1 to 0.3 metres. Drawdown at these geological features is the result of groundwater inflows to project components in the overlying units reducing recharge to the underlying Marangaroo or Gundangaroo Formations.

The two metre drawdown contour from the more conservative 95th percentile model prediction of maximum drawdown, also illustrated (in purple) in Figure 4-5, occurs around the same features as the 50th percentile, but extends to around four times the radius. In addition, the two metre contour for the 95th percentile prediction, also presents at a northwest-southeast trending geological structure located south of the mid tunnel caverns.

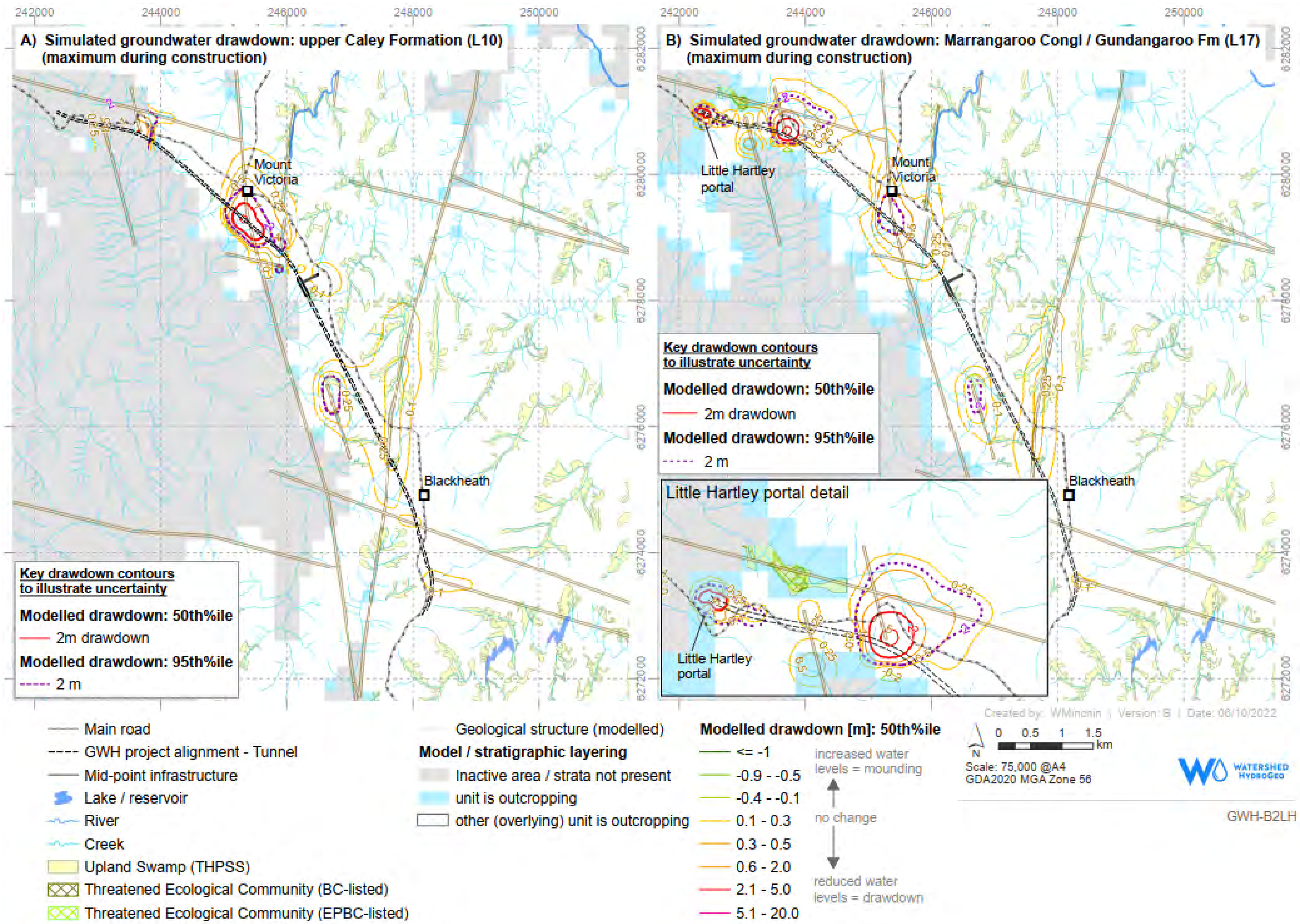

Figure 4-5 Simulated maximum groundwater drawdown within the Caley Formation and the Marrangaroo or Gundangaroo Formation during the construction phase

4.5 Potential construction phase groundwater impacts

4.5.1 Groundwater recharge

Groundwater within the project area is predominantly recharged by direct rainfall which infiltrates through the soil and rock profile. The impervious sealed surface area within the construction footprint would increase marginally during construction due to the surface road upgrade works, construction ancillary facilities (laydown areas), and vehicle access roads, as shown on Figure 1-5, Figure 1-6 and Figure 1-7. The impervious surface areas are small relative to the overall extent of the recharge area to the underlying aquifers such that the net impact on regional recharge due to the increased sealed surface within the construction footprint area is considered negligible.

4.5.2 Groundwater flow

Groundwater flow direction is inferred from east to west, towards the western escarpment.

The introduction of the tanked tunnels and other tanked infrastructure within the saturated hydrostratigraphic units has the potential to alter groundwater (through) flow, where mounding may occur on the up-gradient side of the tanked twin tunnels and drawdown on the down-gradient side of the tunnels.

Potential impacts to groundwater users, sensitive environmental receptors, and groundwater quality, due to groundwater throughflow interruption and drawdown towards drained features is further discussed in the sub-sections below.

4.5.3 Groundwater users

The numerical groundwater modelling (Annexure B) has predicted that construction of the project has the potential to impact on groundwater levels at 31 registered bores screened within the Banks Wall Sandstone.

These potentially impacted (at-risk) bores comprise six monitoring bores, 21 bores used for water supply, two bores used for unknown purposes (assumed to be used for water supply purposes), and two abandoned water supply bores.

The maximum predicted groundwater level drawdown during the construction phase at each of 23 water supply bores is summarised in Table 4-2. Registered water supply bore locations and the frequency that drawdown would be greater than or equal to two metres, is shown on Figure 4-6.

Table 4-2 Maximum predicted drawdown at existing registered water supply bores during the construction phase

Bore ID	Approximate distance from project (metres)	50th percentile of maximum predicted drawdown during construction (metres)	95th percentile of maximum predicted drawdown during construction (metres)	Frequency of model realisations with greater than or equal to two metres predicted drawdown (%)
GW055396	520	0.00	0.02	0.0%
GW056581	700	0.08	0.30	0.0%
GW057611	440	0.19	0.64	0.0%
GW057614	200	0.01	0.06	0.0%
GW058022	660	0.00	0.05	0.0%
GW058193	420	0.24	0.79	0.3%
GW058197	960	0.00	0.15	0.0%
GW058199	620	0.00	0.02	0.0%
GW058236	320	0.49	1.92	3.7%
GW059727	650	0.10	0.41	0.0%
GW059737	390	0.26	0.82	0.3%
GW061195	1,380	0.00	0.01	0.0%
GW063579	950	0.00	0.02	0.0%
GW072282	1,210	0.00	0.01	0.0%
GW072891	590	0.14	0.59	0.0%
GW100157	60	0.68	**3.14**	12.1%
GW101569	1,380	0.00	0.03	0.0%
GW102030	270	0.17	1.01	1.0%
GW102214	350	0.84	**4.76**	22.5%
GW105896	730	0.00	0.02	0.0%
GW107197	830	0.02	0.02	0.0%
GW108316	420	0.07	0.27	0.0%
GW111780	870	0.00	0.02	0.0%

Note: Bold values indicate maximum predicted drawdown greater than or equal to two metres

Figure 4-6 Frequency of model realisations in which drawdown greater than two metres was predicted at registered water supply bores during the construction phase

No registered water supply bores had a median (50th percentile) maximum predicted drawdown greater than two metres. Two registered water supply bores within Blackheath had a 95th percentile maximum predicted drawdown greater than two metres, including GW100157 (3.14 metres) and GW102214 (4.76 metres). The frequency that these bores would drawdown greater than or equal to two metres is relatively low (predicted at around 12.1% at GW100157 and around 22.5% at GW102214).

There is a low frequency (less than 4% of model realisations) that drawdown would be greater than or equal to two metres at four registered water supply bores (GW058193, GW058236, GW059737, and GW102030). In all other bores, predicted drawdown was less than two metres in all model realisations.

Although there are registered groundwater bores within Mount Victoria and Little Hartley, predicted groundwater drawdown within these areas do not impact these groundwater users as drawdown is minimal and limited in lateral extent.

In accordance with the NSW AIP (DEC, 2012), if drawdown at registered bores is predicted to exceed (or does exceed) two metres, measures are to be taken to ‘make good’ the impact. Measures taken would be dependent upon the location of the impacted bores and can be determined in consultation with the affected licence holder but could include, deepening the bore, providing a new bore (outside of drawdown), or providing an alternative water supply, as discussed in Section 7.2.

Further detailed groundwater modelling would be carried out as part of further design development and construction planning that would incorporate additional baseline groundwater data. Where this further modelling identifies potential for drawdown at registered bores of greater than two metres then a baseline assessment of each of the at-risk registered bores (GW100157 and GW102214) would be carried out prior to commencing construction activities. This would include (if access can be gained) confirmation of current bore construction, groundwater level, current yield and water quality. If a bore is found to be viable, the bores would then be monitored pre-construction and during construction, as discussed further in Section 7.2.1 and Section 7.2.2. Monitoring during construction would also help to validate model predictions.

Additionally, regular groundwater level monitoring, across the project monitoring bore network, will allow for the identification of water level drawdown trends and validation of drawdown predictions, including predicted drawdown at the registered bores. Noting that no registered water supply bores had a median predicted drawdown greater than two metres.

4.5.4 Groundwater dependent ecosystems

4.5.4.1 Groundwater drawdown at GDEs

High probability GDEs mapped by DPE (2022d) within Little Hartley, as shown on Figure 3-16, are located outside of the construction footprint and would not be directly impacted by construction activities. There is potential for indirect impacts to occur as a result of changes to groundwater levels. GDEs can be negatively impacted if the groundwater table decreases such that they can no longer access groundwater or have depleted access to groundwater.

The maximum predicted groundwater level drawdowns during the construction phase were modelled at the following GDEs within the project area (refer to Figure 4-7 and Figure 4-8):

- THPSS (EPBC Act listed TEC), located across the project area
- other types of GDEs including EPBC Act and BC Act listed TECs, all of which are located near the Little Hartley portals.

Table 4-3 includes a summary of GDEs where maximum groundwater level drawdowns were predicted. For a full set of data, refer to Table 4-7 in Annexure B.

Table 4-3 Summary of predicted groundwater drawdown at GDEs

Feature ID	GDE listed status	Maximum predicted drawdown during construction (metres)	
		50th percentile	95th percentile
Swamp_268	EPBC Act TEC (THPSS)	0.00	0.02
Swamp_317	EPBC Act TEC (THPSS)	0.00	0.02
Swamp_318	EPBC Act TEC (THPSS)	0.00	0.01
Swamp_429	EPBC Act TEC (THPSS)	0.41	1.81
Swamp_437	EPBC Act TEC (THPSS)	0.00	0.03
Swamp_448	EPBC Act TEC (THPSS)	0.00	0.09
Swamp_452	EPBC Act TEC (THPSS)	1.27	5.33
Swamp_454	EPBC Act TEC (THPSS)	0.01	0.32

Feature ID	GDE listed status	Maximum predicted drawdown during construction (metres)	
		50th percentile	95th percentile
Swamp_464	EPBC Act TEC (THPSS)	0.11	4.44
Swamp_479	EPBC Act TEC (THPSS)	0.40	5.38
Swamp_484	EPBC Act TEC (THPSS)	0.00	0.03
Swamp_1501	EPBC Act TEC (THPSS)	0.00	0.06
Swamp_1509	EPBC Act TEC (THPSS)	0.00	0.01
EPBC_2	EPBC Act TEC	0.01	0.06
EPBC_3	EPBC Act TEC	0.00	0.01
EPBC_4	EPBC Act TEC	0.05	0.70
BC_6b	BC Act TEC	0.00	0.01
BC_18	BC Act TEC	0.03	0.31

From these modelled GDE locations, simulated groundwater levels ('with' and 'without' project scenarios) have been extracted from the model and presented on hydrographs (Figure 4-9 to Figure 4-13). For additional hydrographs, refer to Section 4.6.5 in Annexure B

For THPSS locations, only five locations are projected to experience potentially impactful drawdown (refer to Figure 4-7), including locations Swamp_429 (Figure 4-9), Swamp_452 (Figure 4-10), Swamp_454, Swamp_464, and Swamp_479 (Figure 4-11).

These GDEs are located between the Blackheath portals and the mid-tunnel facility, where it was not expected to see simulated drawdown of this magnitude. The predicted drawdown may be a function of poorly constrained model history-matching and parameter set development, and the magnitude suggested by the 50th and 95th percentile estimates would not likely occur in reality. Additional detailed groundwater modelling would be carried out as part of further design development and detailed construction planning that would incorporate additional baseline groundwater data. The updated modelling would provide further information around the likelihood of impactful drawdown at these THPSS locations.

Modelled EPBC Act TEC locations (excluding THPSS) are at a low risk of drawdown from the project. Location EPBC_4 has the greatest predicted drawdown of around 0.05 metres (50th percentile) and around 0.7 metres (95th percentile), refer to Figure 4-12. Empirically, EPBC_4 is located at a similar elevation, even slightly lower, than the nearby Little Hartley portals and nearby cross-passages (Figure 4-8), and therefore drawdown effects are conceptualised to have a minimal effect at this location, which is supported by the modelling. Drawdown would be minimised after the relevant cross-passages have been tanked.

Modelled BC Act TEC locations are at a low risk of drawdown from the project. Location BC_18 has the greatest predicted drawdown of less than around 0.05 metres (50th percentile) and around 0.31 metres (95th percentile) (Figure 4-13) and is located north of the Little Hartley portals (Figure 4-8). Predicted impacts are temporary as drawdown would be minimised after the relevant cross-passages have been tanked.

For further information and assessment of potential impacts to GDEs due to groundwater drawdown, see Appendix H (Technical report – Biodiversity) of the EIS.

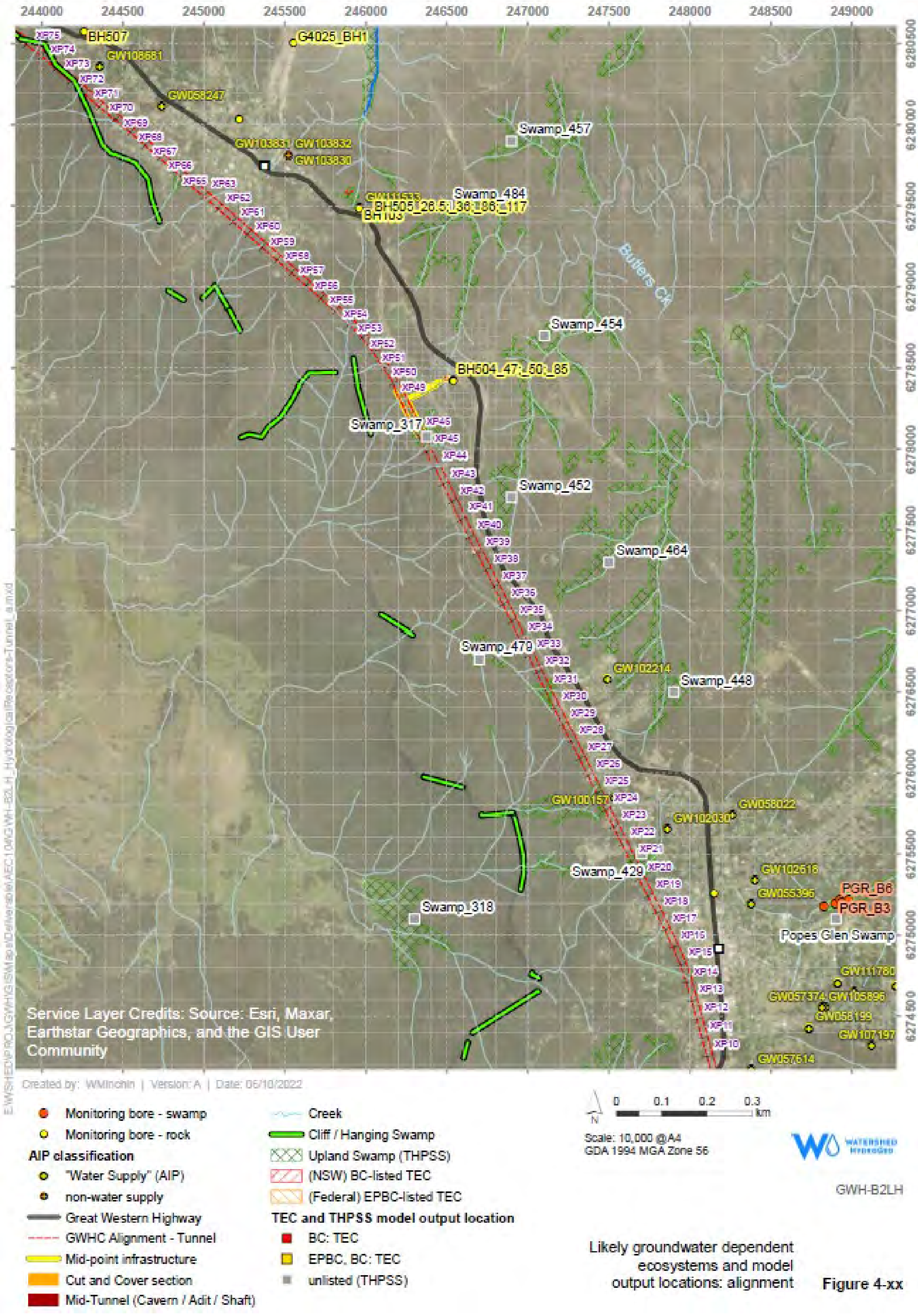

Figure 4-7 Groundwater dependent ecosystems modelled along the project alignment

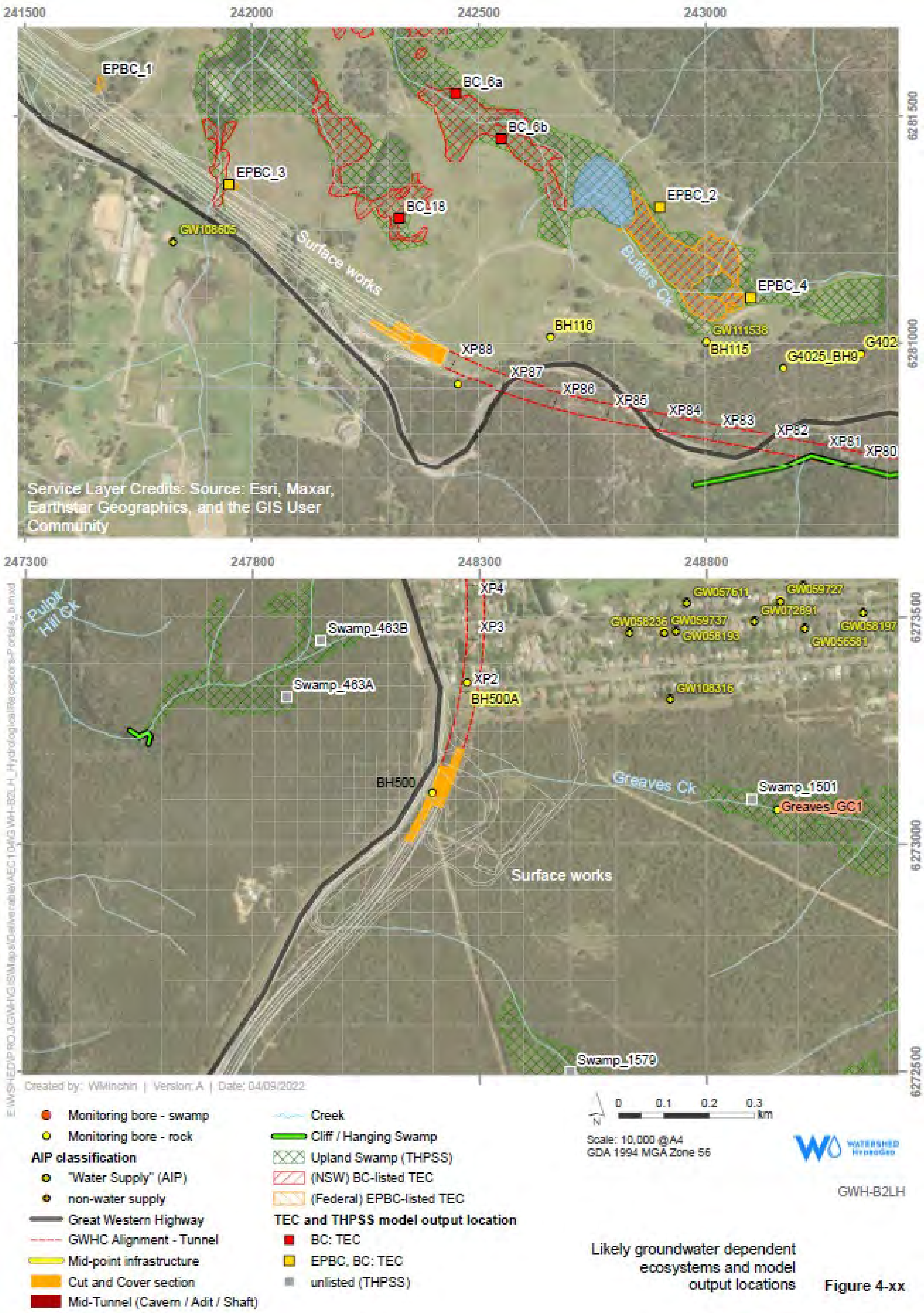

Figure 4-8 Groundwater dependent ecosystems modelled at Little Hartley and Blackheath portals

Figure 4-9 Modelled groundwater levels and drawdown at THPSS location 'Swamp_429'

Figure 4-10 Modelled groundwater levels and drawdown at THPSS location 'Swamp_452'

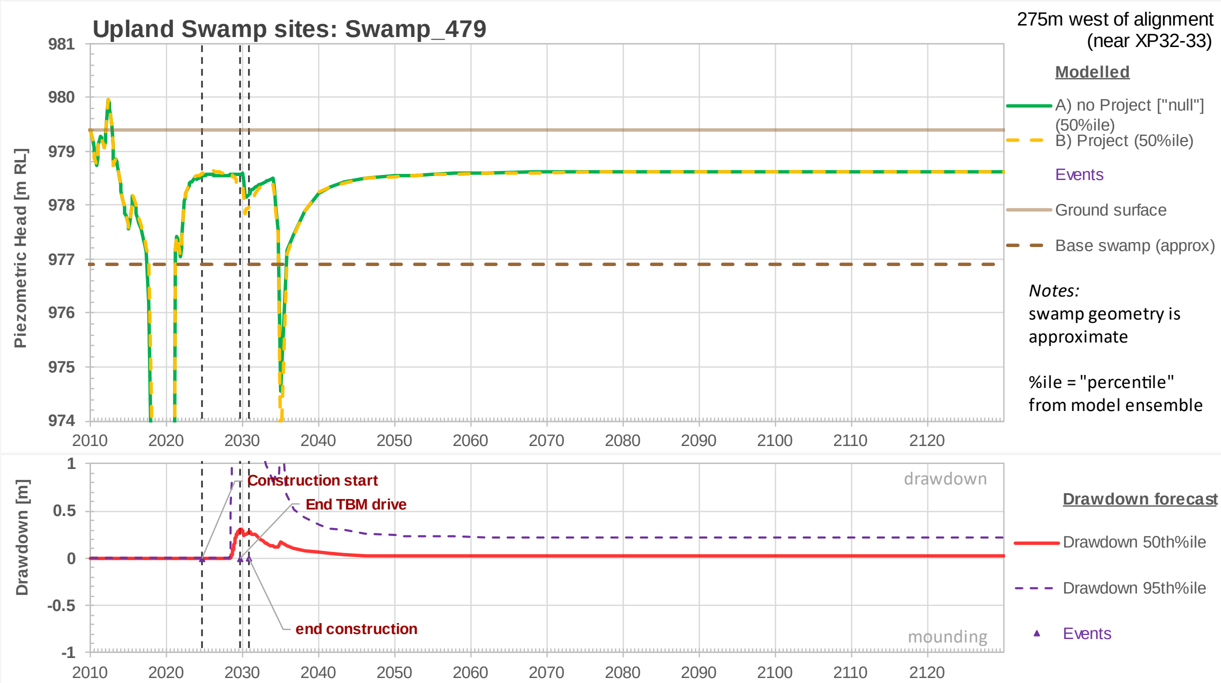

Figure 4-11 Modelled groundwater levels and drawdown at THPSS location 'Swamp_479'

Figure 4-12 Modelled groundwater levels and drawdown at EPBC Act TEC location 'EPBC_4'

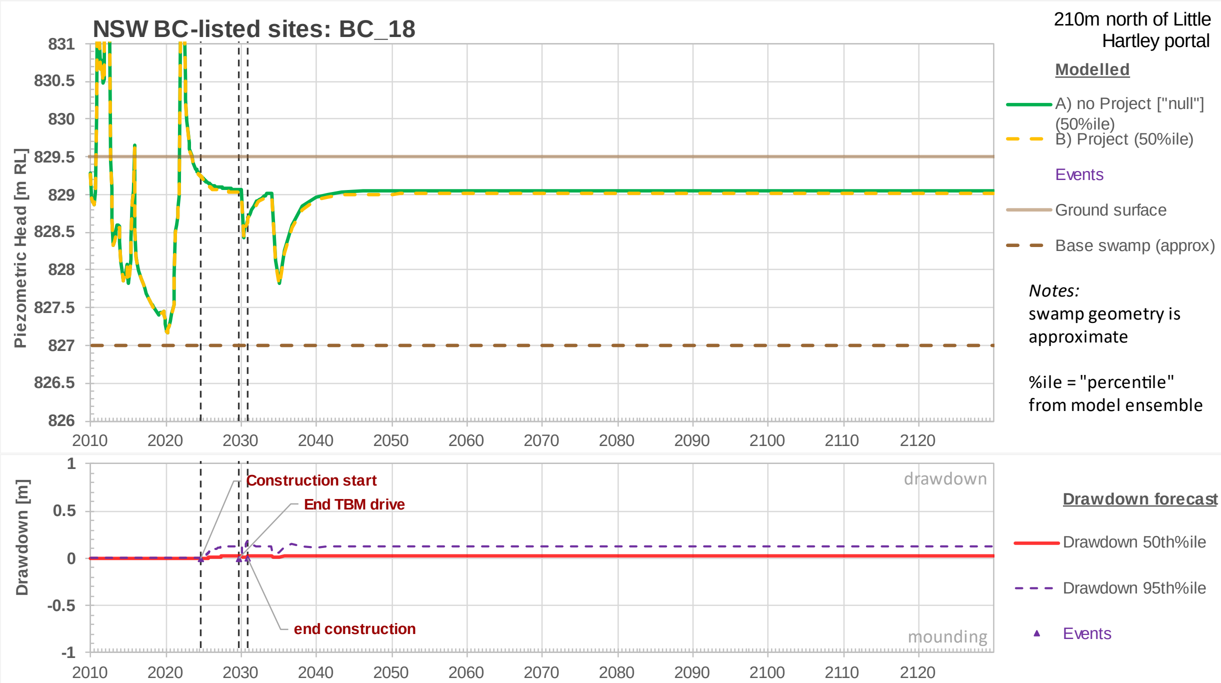

Figure 4-13 Modelled groundwater levels and drawdown at BC Act TEC location 'BC_18'

4.5.4.2 Reduction of baseflow at hanging swamps

Hanging swamps occur on steep valley sides where there is groundwater seepage. The hanging swamps that have been modelled were identified during project investigations along the western escarpment of the Blue Mountains plateau where the Banks Wall Sandstone and Burro-Moko Head Sandstone outcrop. Groundwater drawdown due to project construction has the potential to reduce the volume of groundwater discharge to the hanging swamps.

Numerical groundwater modelling was used to predict reduction of baseflow for hanging swamp zones within the project area during the construction phase (refer to Section 4.7 of Annexure B). The modelled hanging swamp zones are shown on Figure 4-14. Zones that were modelled to have a reduction in baseflow versus the low, average, or high historical modelled baseflow are provided in Table 4-4.

Predicted baseflow to the hanging swamps identified has been modelled for the following units where hanging swamps are known to be present:

- Banks Wall Sandstone
- shear zone at the base of the Banks Wall Sandstone, immediately above the Mount York Claystone aquitard
- Lower Burra-Moko Head Sandstone
- shear zone at the base of the Burra-Moko Head Sandstone, immediately above the Caley Formation (a less permeable unit).

The greatest reduction of baseflow is predicted at Porters Pass (Zone 3), Mt Boyce (Zone 4) and Fairy Bower (Zone 5). Impacts to Porters Pass (Zone 3) and Mt Boyce (Zone 4) is due to inflows at cross-passages within the Banks Wall Sandstone. Impacts would be temporary at these locations during construction of the cross-passages prior to them being tanked.

Potential pre-grouting of relevant cross-passages may also occur during construction to prevent excessive inflows which would mitigate the reduction in baseflow at the impacted hanging swamp zones.

Impacts to Fairy Bower (Zone 5) is largely due to inflows to the mid-tunnel infrastructure and impacts would reduce after the adit and shaft are infilled at the end of construction.

No baseflow was simulated to Zone 9 due to a limitation of the current model (the dimensions of the model cells along the narrow ridgeline at Victoria Pass (west of Mount Victoria)). Although this is a limitation of the model, the results for Zone 8 and the fact that the tunnel alignment would pass through strata approximately 100 metres below the ridgeline suggest that there would be minimal impact to Zone 9.

For further information and assessment of potential impacts to hanging swamps due to reduction of baseflows, see Appendix H (Technical report – Biodiversity) of the EIS.

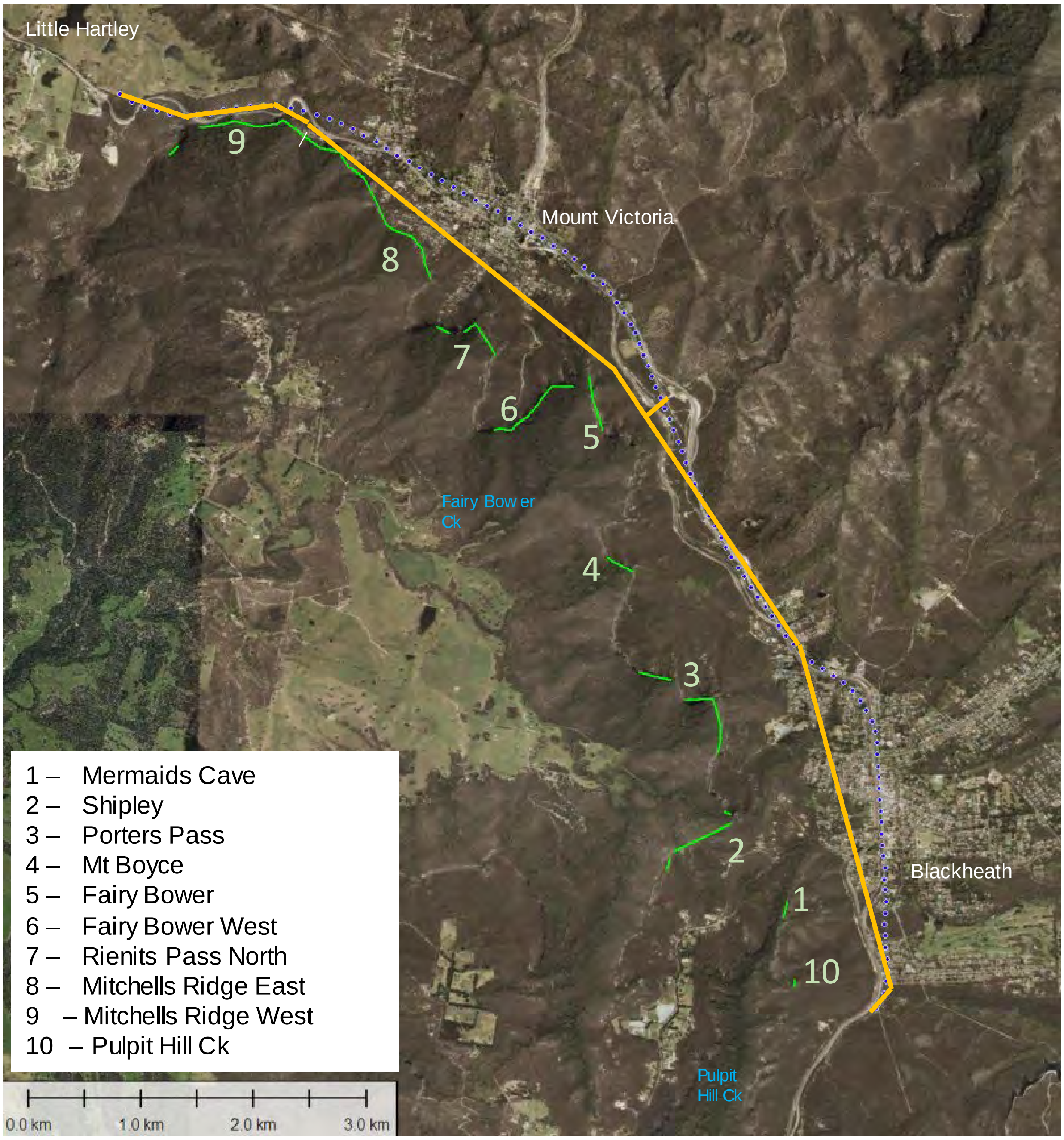

Figure 4-14 Location of observed Hanging Swamps during project investigations, modelled along the western escarpment of the Blue Mountains plateau

Table 4-4 Predicted reduction in baseflow to hanging swamps during construction phase

Zone	Change in baseflow (m^3/day)				Change in baseflow (%)					
	Average		Maximum		Minimum impact versus historical baseflow low		Average impact versus the historical baseflow average		Maximum impact versus historical baseflow high	
	50th per-centile	95th per-centile	50th per-centile	95th per-centile	50th per-centile	95th per-centile	50th per-centile	95th per-centile	50th per-centile	95th per-centile
1 – Mermaids Cave	0.00	-0.04	-0.05	-0.35	0.0	0.0	0.0	0.0	-0.1	-0.2
2 - Shipley	-0.01	-0.06	-0.10	-0.39	0.0	0.0	0.0	0.0	0.0	-0.1
3 – Porters Pass	-0.76	-6.46	-3.23	-26.82	0.0	0.0	-0.2	-1.0	-0.7	-3.3
4 – Mt Boyce	-3.64	-13.57	-17.47	-65.89	0.0	0.0	-2.2	-4.3	-7.3	-14.8
5 – Fairy Bower	-1.00	-11.90	-2.40	-16.30	0.0	0.0	-0.7	-5.1	-1.3	-4.7
6 – Fairy Bower West	-0.20	-0.60	-1.20	-4.20	0.0	0.0	-0.4	-0.5	-1.2	-1.9
7 – Rienits Pass North	-0.18	-0.59	-1.19	-4.16	0.0	0.0	-0.2	-0.3	-1.0	-1.6
8 – Mitchells Ridge East	-0.01	-0.05	-0.02	-0.18	0.0	0.0	0.0	0.0	0.0	-0.1
9 – Mitchells Ridge West	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
10 – Pulpit Hill Creek	-0.03	-0.25	-0.18	-0.91	0.0	0.0	0.0	-0.1	-0.1	-0.2

4.5.5 Surface water – groundwater interaction

Water that flows within surface water drainage systems is known as streamflow, which is a combination of water from various sources including rainfall run-off, direct rainfall into a surface water feature, (possible) discharge from stormwater pipes, and contribution from groundwater (where groundwater levels are higher than the surface water elevation). The component of groundwater contribution to streamflow is known as baseflow.

Surface water systems can be ‘gaining’ or ‘losing’ streams. In a gaining stream, groundwater seeps out into the stream as baseflow, and in a losing stream, the stream water moves into a groundwater system. If baseflow is reduced or removed from a gaining stream, the surface water system can become a losing stream. As discussed in Section 3.10 above, surface water systems within the groundwater study area are mainly gaining streams, with a small component of surface water recharging to a groundwater system.

Reduction in baseflow contribution to streamflow could have potential impacts to aquatic ecology, GDEs, and surface water quality as a result of potential changes to a waterway. It is likely that the contribution of baseflow to streamflow varies considerably along the lengths of the creeks.

Surface water – groundwater interactions may be impacted during construction activities due to groundwater inflow to the tunnels/excavations, which has the potential to cause a reduction in baseflow contribution at surface water features, via the following types of mechanisms:

- groundwater drawdown in the groundwater system that is connected to the watercourse causing a reduction in groundwater vertical gradient into the creek, such that the discharge rate (and associated volume) of baseflow is reduced
- installation of tanked infrastructure (including the tunnels) that consequently modify the path of groundwater between recharge and discharge areas. It is also possible that changes to hydraulic properties associated with the introduction of tanked tunnel infrastructure could cause very small increases to flow to some springs or watercourses, though this is considered unlikely and would likely be negligible.

Numerical groundwater modelling was used to predict reduction of baseflow for surface water sub-catchments within the project area during the construction phase (refer to Section 4.8 of Annexure B). The modelled surface water sub-catchment zones are shown on Figure 4-15. Sub-catchments that were modelled to have a reduction in baseflow versus the historical modelled low, average, or high baseflow are provided in Table 4-5. For a full set of data, refer to Section 4.8 in Annexure B.

It should be noted that the impact of a reduction in baseflow would be proportionate to its contribution to streamflow, as it is only one component of streamflow. Sub-catchments would also rely on other various sources, as mentioned above.

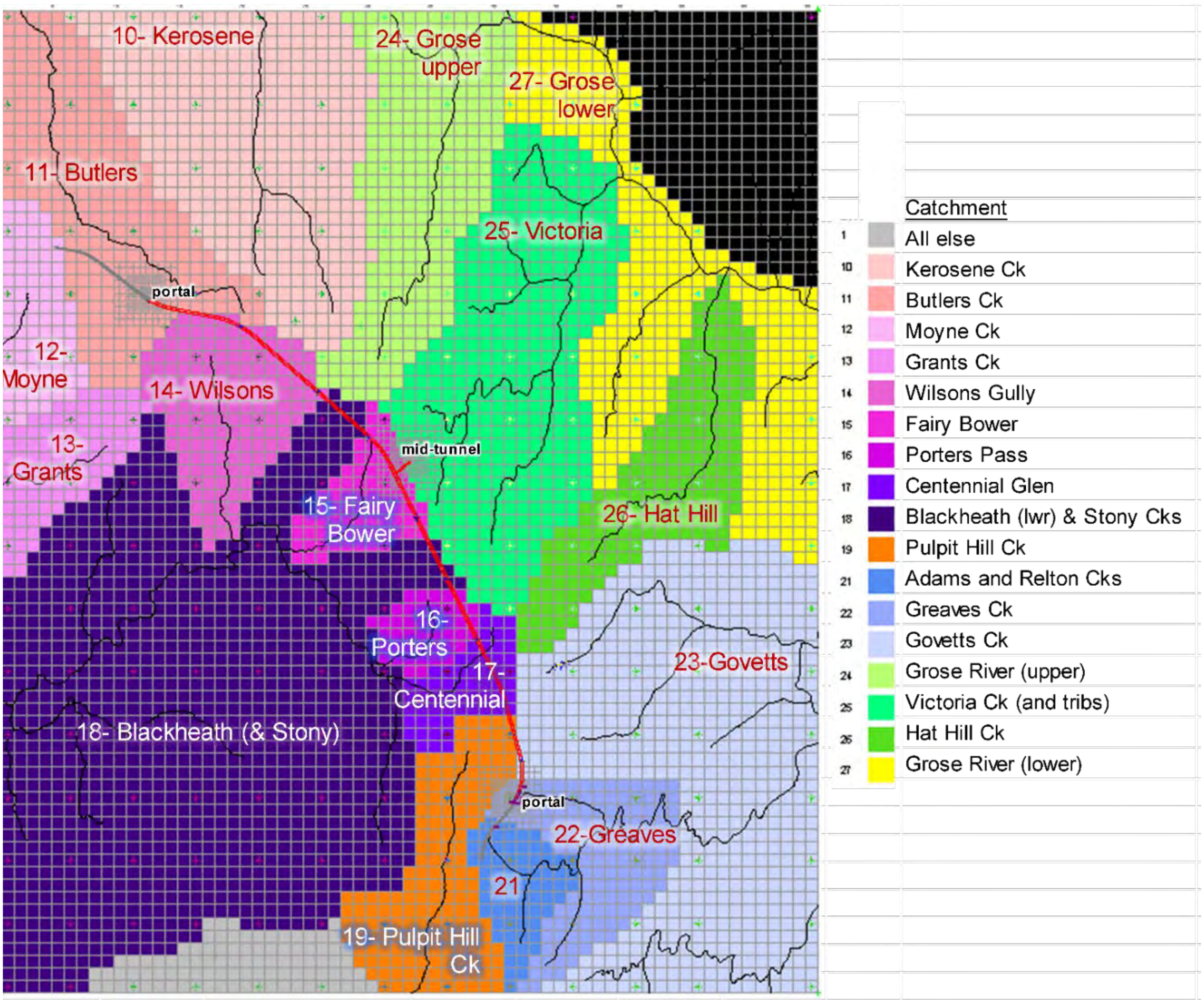

Figure 4-15 Surface water sub-catchment zones modelled for baseflow reduction

Dewatering due to construction activities is predicted to have the largest potential impact on baseflow reduction within the Fairy Bower sub-catchment, which is located immediately west of the mid-tunnel caverns, adit and access shaft, as shown on Figure 4-15.

Baseflow to the Fairy Bower sub-catchment is highest during periods of higher rainfall, when groundwater levels are elevated. The proportion of baseflow reduction resulting from tunnel construction would be highest during these wetter periods (the 50th percentile model prediction is a 2.7% reduction), as the increased aquifer saturated thickness would require more dewatering to facilitate construction. During these periods of higher rainfall, the sub-catchment would also have higher streamflow contributions from rainfall runoff, which would likely dampen the effects of the baseflow reduction. During periods of average rainfall, the proportion of baseflow reduction would be lower (the 50th percentile model prediction is a 1.1% reduction). During dry periods the baseflow to the sub-catchment is likely negligible, hence the would be no reduction from construction.

Reduction in baseflow compared with historical baseflow volumes within other sub-catchments is predicted to be negligible. Further, any sub-catchments that may be impacted due to construction of the tunnel cross-passages and/or the twin tunnels would be impacted temporary (less than six months), which would be within vegetation tolerance limits for seasonal variability.

For further information and assessment of potential impacts to surface water bodies, see Appendix J (Technical report – Surface water and flooding) of the EIS.

Table 4-5 Predicted reduction in baseflow to surface water catchments during construction phase

Sub-catchment	Change in baseflow (m^3/day)				Change in baseflow (%)					
	Average		Maximum		Minimum impact versus historical baseflow low		Average impact versus the historical baseflow average		Maximum impact versus historical baseflow high	
	50th per-centile	95th per-centile	50th per-centile	95th per-centile	50th per-centile	95th per-centile	50th per-centile	95th per-centile	50th per-centile	95th per-centile
Butlers Creek (11)	-1.32	-6.38	-4.3	-16.93	0.0	0.0	-0.1	-0.3	-0.1	-0.2
Wilsons Gully (14)	-3.2	-8.4	-7.7	-27.2	0.0	0.0	-0.2	-0.4	-0.2	-0.5
Fairy Bower (15)	-16.0	-50.8	-68.3	-208.0	0.0	0.0	-1.1	-2.4	-2.7	-5.6
Porters Pass (16)	-1.71	-10.89	-7.72	-49.32	0.0	0.0	-0.2	-0.7	-0.5	-2.0
Centennial Glen (17)	-0.153	-0.922	-0.99	-3.94	0.0	0.0	0.0	-0.1	-0.1	-0.3
Blackheath (lower) and Stony Creeks (18)	-5.50	-17.26	-23.49	-75.00	0.0	0.0	-0.1	-0.2	-0.2	-0.3
Greaves Creek (22)	-3.17	-12.36	-5.92	-18.45	0.0	-0.2	-0.3	-0.8	-0.2	-0.4
Victoria Creek (including tributaries (25)	-2.78	-14.54	-11.58	-56.56	0.0	0.0	0.0	-0.2	-0.1	-0.3

4.5.6 Groundwater quality

There is a risk that groundwater quality could be affected during construction from activities including:

- leaks or spills of fuels, oils and lubricating fluids used by construction machinery (workshops, fuel and waste storages and during fuelling operations)
- potential acid sulfate rock (PASR) seepage from stockpiles
- construction materials, such as grout and cement, used for underground structures.

These potential impacts are discussed further in the sections below. See Appendix K (Technical report: Contamination) of the EIS for further information regarding potential contamination sources.

4.5.6.1 Leaks and spills

Leaks and spills from construction machinery are possible following a malfunction of the equipment and during refuelling and in-field maintenance. Within the surface construction footprint, small-scaled leaks and spills in the order of a few litres would likely remain in the topsoil/rock surface until the affected soil/rock is managed and removed.

Larger-scale leaks, especially those that are not immediately observed and contained, may penetrate the ground further. Regular inspections and maintenance of equipment and spill-control structures such as hardstand areas and containment would further reduce the risk to groundwater. Chemicals, oils and fuels would be handled and stored in appropriately bunded areas equipped with adequate spill response kits.

Leaks and spills from construction machinery within the tunnels would not intercept groundwater due to the precast concrete segments lining the tunnels. Contaminated run-off would be captured within tunnel drainage infrastructure and treated.

4.5.6.2 Acid sulfate soil and rock

Groundwater level drawdown has the potential to desaturate areas below ground, which has the potential to result in oxidation of the acid sulfate soil and rock if present. This has the potential to lead to acidification of groundwater and mobilisation of heavy metals previously bound in the formation.

Based on the literature review (see Section 3.4.2), there is a low probability of acid sulfate soil occurrence within the construction footprint and therefore there is a low risk of encountering acid sulfate soil during construction of the proposed works. An Acid Sulfate Soil Management Plan (ASSMP) is not recommended for the project. It is, however, recommended that management of acid sulfate soils should be considered in the unexpected finds section of a Construction Environmental Management Plan (CEMP) for the project.

As described in Section 3.4.4, there is a high risk of encountering ASR/PASR conditions during tunnelling and excavation activities at the western end of the tunnel, with the spoil produced containing sulfidic materials. High risk areas for encountering ASR/PASR include Illawarra Coal Measures that may be intersected along the proposed tunnel alignment, and the area of the alignment that extends west of the foot of Victoria Pass where fresh Berry Siltstone may be encountered.

Drainage from spoil stockpiles can carry the oxidation by-products (unstable sulphide minerals if present in spoil) into the ground to the water table if not adequately covered or drained.

As such, an Acid Sulfate Rock Management Plan (ASRMP) is required for the project to manage ASR risk.

4.5.6.3 Construction materials

Construction components of the tunnel and other underground structures have the potential to impact surrounding groundwater quality. Potential sources of contamination include:

- drilling/cutting fluids at the roadheader/TBM
- particulate matter from tunnelling activities leading to an increase in suspended solids
- cement pollution arising from shotcrete application, grouting or in-situ casting of concrete
- accidental runoff of concrete washout water and spills of excess or waste concrete.

These potential contaminant sources are considered to be low risk to groundwater resources. It is expected that this risk would be mitigated through the implementation of pollution control strategies as part of the CEMP. In addition, groundwater flow during these construction activities would be towards the construction, such that migration within groundwater to areas outside the construction activities is limited.

Further information regarding potential impacts dur to surface water runoff is provided in Appendix J (Technical report: Surface water and flooding) of the EIS.

4.5.7 Areas of environmental interest for contamination

In areas of environmental interest for contamination, groundwater drawdown has the potential to impact the speed and direction of movement of possible contaminant plumes in groundwater due to the altered hydraulic gradient. Additionally, where soil contamination is present but has not migrated to groundwater, drawdown may assist in mitigating or delaying the potential for contamination to migrate to groundwater (i.e., deeper unsaturated zone which increases residence time and facilitates attenuation).

Potential sources of pre-mitigation 'medium' risk groundwater contamination along the tunnel alignment are listed in Table 4-6. The medium risk ranking is based on available data. This ranking will be refined based on the Stage 2 Detailed Site Investigation (DSI), as further discussed in Appendix K (Technical report: Contamination) of the EIS.

The medium risk ranking suggests a complete pollutant linkage may be present, however, the likelihood and consequence is considered to be medium. All other areas along the tunnel alignment are considered to be a low risk for groundwater quality alteration including the cross-passages, the mid-tunnels caverns and adit.

No areas of environmental interest were considered to be 'high' risk, as further discussed in Appendix K (Technical report: Contamination) of the EIS.

Table 4-6 Summary of potential groundwater contamination sources relevant to proposed tunnelling

Construction feature	Identified potential source sites/areas
Mid-point access shaft	Areas of possible historical landfilling adjacent to Soldiers Pinch and Great Western Highway roadworks/cut and fill areas.
Blackheath portal	Areas of possible historical landfilling adjacent to Great Western Highway roadworks/cut and fill areas.
	Illegal dumping on publicly accessible properties and adjacent Great Western Highway or rail corridor.
	Vehicle crashes and spills along the Great Western Highway.
	Demolition of historical buildings (observed at Blackheath in historical aerial photographs).
	Historical use of pesticides and herbicides on agricultural land and waterways in the vicinity of the tunnel alignment and proposed construction footprint.
Little Hartley portal	Former Little Hartley airfield, located around 1.25 kilometres northwest of the Little Hartley construction footprint.
	Historical use of pesticides and herbicides on agricultural land and waterways in the vicinity of the tunnel alignment and proposed construction footprint.
	CSR Building Products Clay/Shale, Structural Clay Mine located 450 metres south of the Little Hartley construction footprint.
	Demolition of historical buildings if required at Little Hartley construction footprint.
	Vehicle crashes and spills along the Great Western Highway.
	Lolly Bug Little Hartley former service station, located around 730 metres northwest of the Little Hartley construction footprint.
	Areas of possible historical landfilling adjacent to Great Western Highway roadworks/cut and fill areas.
	Potential acid sulfate rock may be encountered during tunnelling.
Coal seam gas drainage	Coal seams of varying thicknesses may be directly encountered during tunnel construction between Mount Victoria and Little Hartley. Therefore, coal seam gas (mostly methane with potentially small amounts of carbon monoxide, carbon dioxide and hydrogen sulfide) may also be present. The risks to safety from this would be mitigated via advance investigation and monitoring, and possibly gas drainage. Gas drainage would involve depressurising the coal seams (i.e., the reduction of the hydrostatic pressure (water level) to facilitate the desorption of gas from the coal seams). Groundwater extracted from coal seams is likely to be too saline (Section 3.5.5) and therefore unable to be directly discharged to surface water. Groundwater may also contain concentrations of dissolved methane and hydrogen sulfide, as well as some heavy metals that would require treatment prior to discharge. Further design development and construction planning would consider the need for advance grouting, and management of associated impacts is required.

There is a medium risk that the identified potential source areas listed in Table 4-6 may migrate towards the drained infrastructure due to the altered hydraulic gradient where drawdown of the water table is predicted (Section 4.4.1).

Contaminant migration would be towards the project and any contaminated inflows to the tunnels/excavations would be captured and treated prior to disposal. Contaminant migration towards the twin tunnels and cross-passages would be temporary during the construction phase and potential migration would cease once the infrastructure has been tanked and the groundwater levels (and flow patterns) recover.

The Little Hartley airfield and the Lolly Bug Little Hartley former service station are located beyond the extent of predicted water table drawdown from the Little Hartley portals (around 300 metres) and therefore the project is not predicted to facilitate any possible contaminant plume migration from these locations.

If contaminated groundwater is identified to intersect with the construction ingress, it may require treatment to meet water quality requirements prior to discharge to the receiving environment and/or depending on the conditions of the Environment Protection Licence (EPL) and/or requirements of the licensed facility accepting the wastewater. For further information, see Chapter 21 (Resource use and waste management) of the EIS.

Following adoption of mitigation and management measures during the construction phase of the project, risks arising from potential contamination migration would be minimised. Further information regarding potential contamination sources, impacts and monitoring is discussed in Appendix K (Technical report – Contamination) of the EIS.

4.5.8 Water management and disposal

For the construction of the project, water supply would be required during construction activities including:

- tunnelling activities
    - cooling of TBMs
    - dust suppression
    - spoil conditioning
    - wash-down
    - firefighting
    - mixing of cement grout
    - drilling
- surface works such as during compaction of pavement materials and for dust suppression
- concrete batching
- site offices, facilities and worker amenities.

Groundwater would be encountered during tunnelling and excavations of underground infrastructure and this, in addition to construction wastewater from the above activities would result in the need to capture, treat and reuse, or discharge water. Captured water would be treated at the construction WTPs at Blackheath, Soldiers Pinch and Little Hartley construction compounds, prior to reuse or discharge to surface waters.

The reuse of treated water would be maximised during construction works including recirculation of treated water to the TBM cutting face and for surface dust suppression. Other reuse options (include provision of treated water to nearby construction projects), would be investigated as part of ongoing design development.

Where surplus treated water needs to be discharged from the construction compounds it may be discharged to the local stormwater system or to a surrounding local watercourse via the construction WTPs, as shown in Chapter 5 (Construction) of the EIS on Figure 5-5 to Figure 5-7.

Treatment and discharge of wastewater would be addressed in the Environmental Protection Licence for the project. Stormwater treatment devices have been integrated into the design to meet the requirement for Neutral or Beneficial Effect (NorBE) on runoff water quality, thus meeting the requirements of Section 8.8 of the Biodiversity and Conservation State Environmental Planning Policy (SEPP) 2021 and the NSW Water Quality Objectives.

Water treatment, discharge requirements, and an assessment of potential impacts of treated wastewater discharges to the environment is discussed in Appendix J (Technical report – Surface water and flooding) of the EIS.

4.5.9 Settlement (ground movement)

Ground settlement during construction of the project may arise due to:

- tunnel excavation, and associated tunnel convergencies and slumping of the overlying geology
- groundwater drawdown.

The main settlement mechanism relevant to the project would be tunnel excavation. Initial modelling has predicted that groundwater settlement would be low to negligible across the project with the maximum settlement predicted to be around 1.8 millimetres. Given the perched groundwater tables are mainly confined to the rock mass and that overlying fills and clays are typically shallow in depths, long term settlement due to groundwater drawdown would not be a key concern for the project.

Settlement due to tunnel excavation has been evaluated as part of the development of the project design. Settlement calculations indicate that:

- the maximum settlement due to the project is anticipated to be up to 30.1 millimetres, and would occur in undeveloped areas
- a total of 34 buildings and structures would experience settlement greater than five millimetres, including:
  - all residential and commercial buildings would experience settlement less than the 30 millimetre criterion for buildings. The most affected building would experience settlement of 17.8 millimetres
  - all heritage items would experience settlement less than the 20 millimetre criterion for sensitive buildings, with the most affected heritage item (Tree Tops and garden (Blue Mountains LEP BH065)) affected up to 16.8 millimetres. Further discussion of settlement impacts on heritage items is provided in Chapter 17 (Non-Aboriginal heritage)
  - the Megalong Reservoir and water booster pump would experience settlement up to 6.0 millimetres, which is less than the 20 millimetre criterion
- maximum slope and tensile strain criteria would not be exceeded at any building, structure or infrastructure.

This analysis indicates that the predicted settlement values are within the acceptable criteria and therefore potential settlement impacts would be negligible. Mitigation measures to monitor potential settlement and minimise potential settlement impacts are provided in Section 13.5. Further discussion of potential settlement impacts to properties is provided in Chapter 20 (Business, land use and property).

5.0 Assessment of operational impacts

5.1 Project components relevant for groundwater impact assessment

Prediction of the project's operational impacts to groundwater has been made on the basis that the tunnels would commence operation at the beginning quarter four (Q4) 2030. The project has a 100-year design life and long-term modelling predictions (i.e., post-operation near steady-state conditions) were projected until the year 2130.

As discussed in Section 4.1, the twin tunnels and the cross-passages would be tanked by the end of the construction phase. Hence, groundwater inflows to these features would effectively cease (apart from minor leaks) at the end of construction and not continue to impact on the groundwater system. The mid-tunnel access shaft and the adit would be infilled at the end of construction, therefore during the project's operational phase, groundwater inflows and drawdown impacts related to those features would cease.

During the operational phase, the following unlined (permanently drained) features would have an ongoing influence on the groundwater environment:

- the Little Hartley and Blackheath portals
- the mid-tunnel caverns.

5.2 Predicted groundwater inflows

The flow of groundwater into project structures during operation phase was modelled, as detailed in Annexure B.

Predicted average and maximum groundwater inflows to the features that would be drained during operation phase (mid-tunnel caverns, and Little Hartley and Blackheath tunnel portals) are illustrated in Figure 5-1 and summarised in Table 5-1.

Figure 5-1 provides groundwater inflow estimates between 2030 and 2100. The inflow rates are predicted to reach a steady-state within this time period (around 2050), with some slight variation due to potential weather conditions.

Minor leakage of groundwater through seals may occur in localised areas in the tanked tunnels and cross-passages. However, leaks are expected to be relatively small and not anticipated to result in a measurable impact to groundwater, and therefore, are not presented in the impact assessment.

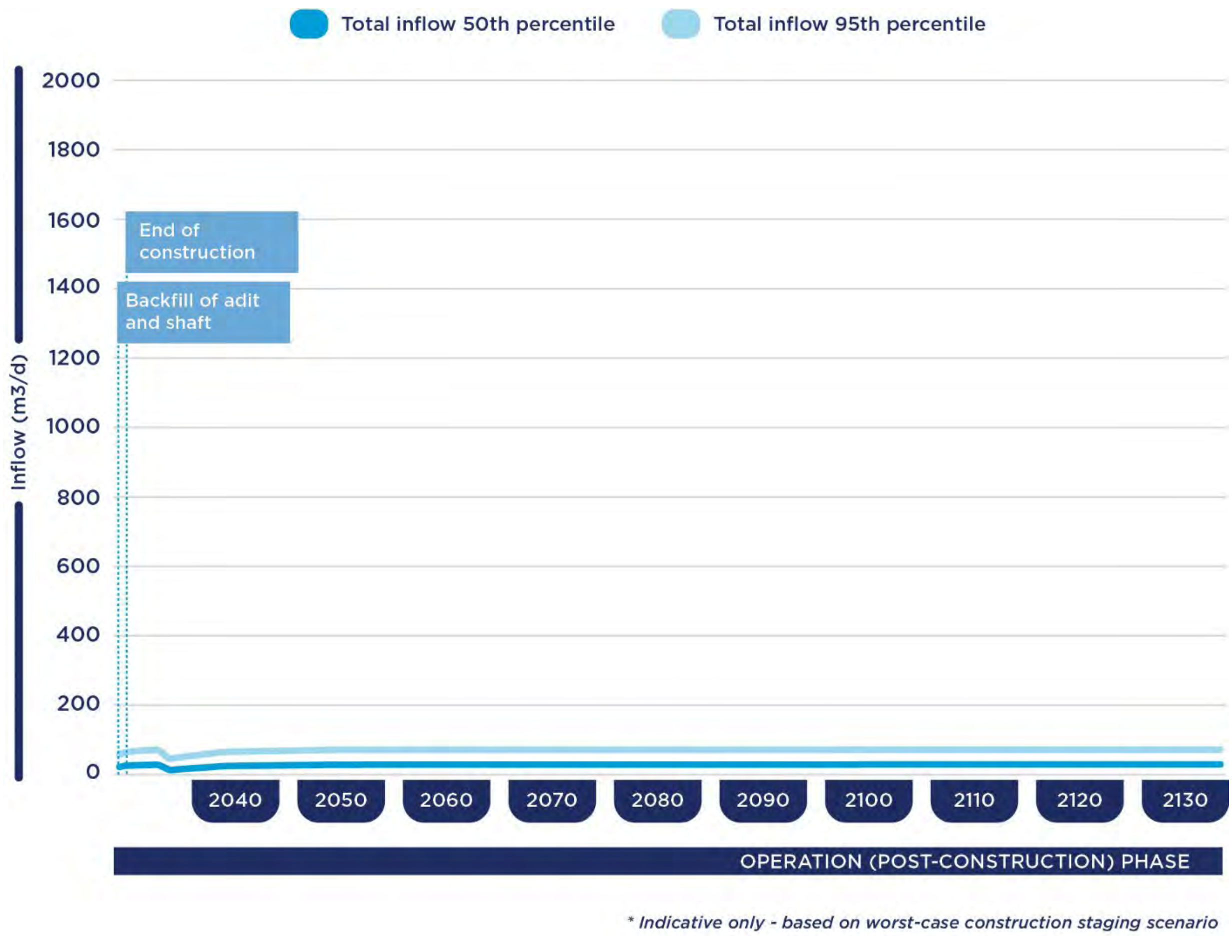

Figure 5-1 Simulated groundwater inflow volumes for underground infrastructure during the operation phase

Following construction phase, groundwater inflows decrease, stabilising by 2050. This is due to groundwater rebound reducing the hydraulic gradient over time as the system approaches a post-construction steady state.

Collection and treatment of groundwater inflows during the operation phase of the project is discussed in Section 5.4.8.

Table 5-1 Summary of modelled groundwater inflows during operation phase (Q4 2030 to 2130)

Feature	Operation phase groundwater inflows (m^3/day)			
	Average		Maximum	
	50th percentile	95th percentile	50th percentile	95th percentile
Mid-tunnel caverns	2.0	14.0	2.0	14.9
Little Hartley portal	4.2	12.8	4.6	13.6
Blackheath portal	18.2	37.7	21.2	42.1
Estimated peak inflow during operation	24.4	64.5	27.7	70.4

The average daily ingress during tunnel operation, some 24 m^3/day, is markedly lower than the average inflow estimate during construction of 108 m^3/day (Table 4-1).

5.3 Predicted drawdown

During the project operational period groundwater drawdown would occur due to inflows to the permanently drained construction elements discussed in Section 5.1.

Maximum groundwater level drawdown for long-term operation (2130) has been predicted for the water table and groundwater systems within the lower Banks Wall Sandstone, Mount York Claystone, the lower Burra-Moko Head Sandstone, upper Caley Formation, and the Marangaroo or Gundangaroo Formation hydrostratigraphic units.

5.3.1 Water table

The median (50^{th} percentile) model prediction for maximum drawdown, illustrated in Figure 5-2, is as follows:

- Blackheath portal: drawdown is predicted to peak at around 5.1 to 20.0 metres (at the portal). Drawdown is predicted to extend up to 800 metres around the portal, including to registered water supply bores to the east. Drawdown is predicted to be marginally greater than during the construction phase at this location, as the groundwater affected by the permanently drained portals would not have reached near steady state until post-construction. The spatial extent is generally consistent with that modelled for the construction phase.
- Little Hartley portal: drawdown is predicted to be around 2.1 to 5.0 metres (at the portal). Drawdown is predicted to extend up to 300 metres around the portal, including to locations of mapped GDEs to the north. Drawdown at this location is generally consistent with that predicted during the construction phase.

Minor drawdown is also predicted at geological structures that intersect the operational footprint (0.3 to 0.5 metres). Drawdown at these geological structures is due to reduced recharge to the relevant units.

The two metre drawdown contour from the more conservative 95^{th} percentile model prediction of maximum drawdown, also illustrated (in purple) in Figure 5-2, occurs around the same features as the 50^{th} percentile, but extends to around double the radius.

Drawdown impacts to registered water supply users and GDEs are further discussed in Sections 5.4.4 and 5.4.5, respectively.

5.3.2 Lower Banks Wall Sandstone

The median (50^{th} percentile) model prediction is a maximum drawdown is around 0.1 to 0.3 metres, near geological structures north of the Blackheath portals and at the Blackheath portals themselves, as shown on Figure 5-2. The spatial extent of drawdown is predicted to be around 800 metres from the project footprint. Drawdown is predicted to be less than during the construction phase as the cross-passages and twin tunnels would have been tanked prior to operation.

The spatial extent of predicted drawdown around the Blackheath portals is marginally greater than during construction, as the groundwater affected by the permanently drained portals would not have reached near steady state conditions until post-construction. The spatial extent is predicted to slightly increase post-construction to the east (including to locations of registered water supply bores), and further to the south. Drawdown impacts to registered water supply users is further discussed in Section 5.4.4

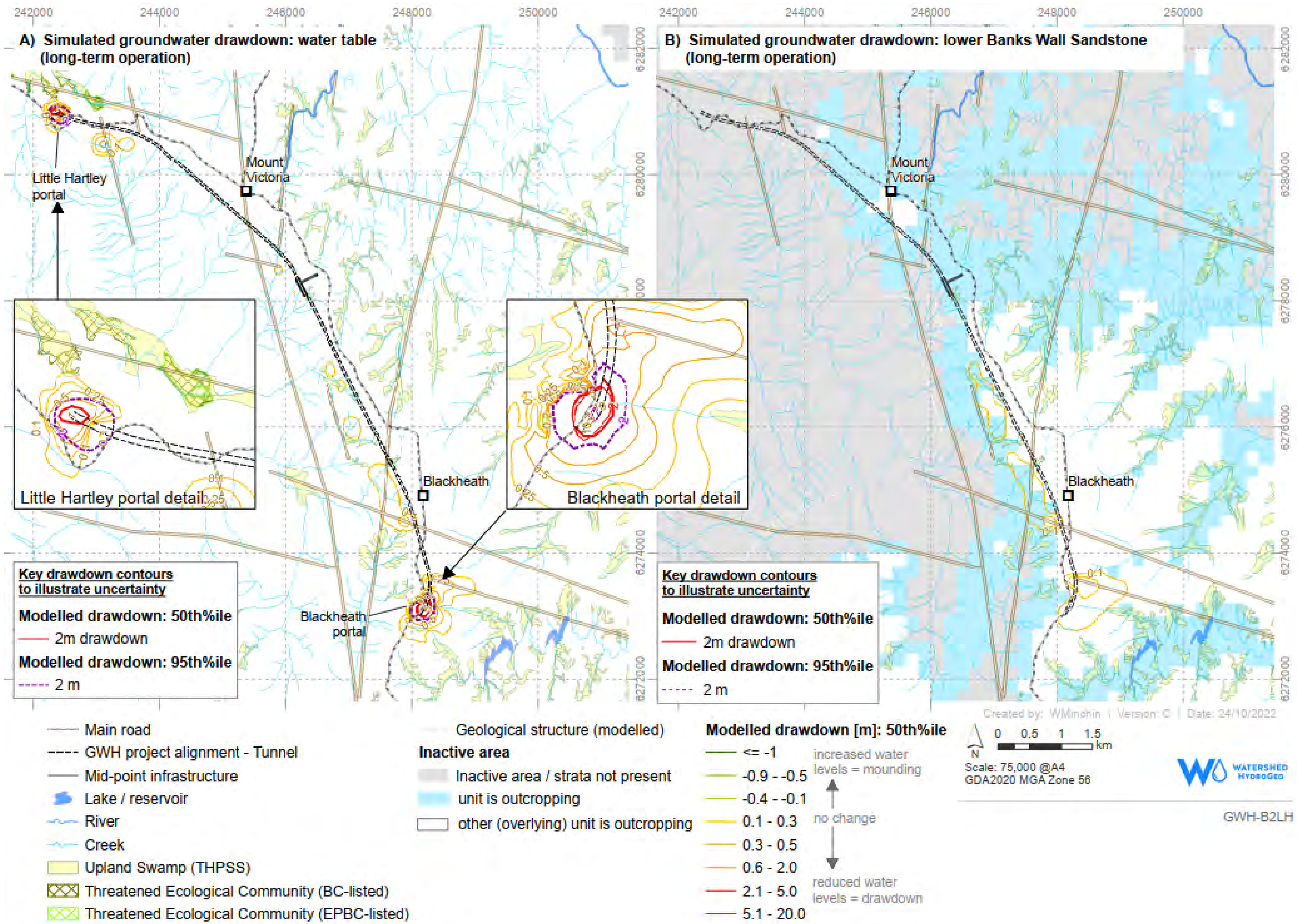

Figure 5-2 Simulated maximum drawdown of the water table during long-term operation phase

5.3.3 Mount York Claystone

The median (50th percentile) model prediction of maximum drawdown in the Mount York Claystone is around 0.3 to 0.5 metres, due to the drained mid-tunnel caverns, as shown on Figure 5-3. Minor drawdown is also predicted around regional faults located to the north of the Blackheath portals (around 0.1 to 0.3 metres). This is predicted to be associated with reduced recharge to this unit from vertical seepage from the overlying Banks Wall Sandstone, as a result of groundwater inflows to the Blackheath portals.

The two metre drawdown contour from the more conservative 95th percentile model prediction of maximum drawdown, also illustrated (in purple) in Figure 5-3 occurs around the same features as the 50th percentile but extends to around double the radius.

The extent of drawdown within the Mount York Claystone does not extend to where the unit outcrops and therefore is not predicted to impact GDEs. No registered water supply bores are known to be screened within the Mount York Claystone.

5.3.4 Lower Burra-Moko Head Sandstone

The median (50th percentile) model prediction of maximum drawdown in the Burra-Moko Head Sandstone is around 5.1 to 20.0 metres, at the mid-tunnel caverns, as shown on Figure 5-3. The drawdown would be localised around the caverns with a spatial extent of around 500 metres. The extent of drawdown would be less than the construction phase as the mid-tunnel access shaft and adit would be infilled at the end of the construction phase, hence will no longer be drained. The modelling assumed that the infilled mid-tunnel access shaft and adit would have hydraulic properties not distinctly different to the host rock and therefore groundwater flow would generally return to pre-construction conditions during the operational phase

Minor drawdown is also predicted around regional faults located north of the mid-tunnel caverns and Blackheath portals (around 0.1 to 0.3 metres). This is due to reduced recharge to this unit from vertical seepage from the overlying units, as a result of groundwater inflows to the drained mid-tunnels caverns and Blackheath portals.

The two metre drawdown contour from the more conservative 95th percentile model prediction of maximum drawdown, also illustrated (in purple) in Figure 5-3 occurs around the same features as the 50th percentile but extends to around double the radius.

The extent of drawdown within the Burro-Moko Head Sandstone does not extend to where the unit outcrops and therefore would not impact GDEs. No registered water supply bores are known to be screened within the Burro-Moko Head Sandstone.

5.3.5 Caley Formation

Drawdown within this unit is largely associated with the mid-tunnel caverns and geological structures intercepting the project footprint, as shown in Figure 5-4.

The median (50th percentile) model prediction of maximum drawdown in the Caley Formation is around 0.1 to 0.3 metres, at the mid-tunnel caverns. The spatial extent of the drawdown is predicted to be around 200 metres from the project footprint. Minor drawdown is also predicted around geological structures located north of the Blackheath portals and north of the mid-tunnel caverns (around 0.1 to 0.3 metres). This is likely due to reduced recharge to this unit from vertical seepage from the overlying units, as a result of groundwater inflows to the Blackheath portals and the mid-tunnel caverns.

The two metre drawdown contour from the more conservative 95th percentile model prediction of maximum drawdown, also illustrated (in purple) in Figure 5-4 occurs around the same features as the 50th percentile but extends to around double the radius.

Predicted drawdown within the upper Caley Formation does not extend to where the unit outcrops where GDEs are also located (and therefore no impacts to GDEs are anticipated). One registered water supply bore located near Mount Victoria Pass is potentially impacted by groundwater drawdown within this unit, as further discussed in Section 5.4.4.

5.3.6 Marangaroo or Gundangaroo Formations

The median (50th percentile) model prediction of maximum drawdown groundwater at the Little Hartley portals is around 5.1 to 20.0 metres, as shown in Figure 5-4. The spatial extent of drawdown is predicted to be localised around the portals to around 300 metres. Minor drawdown is also predicted around geological structures located north of the Blackheath portals and east of the Little Hartley portals (around 0.1 to 0.5 metres). This is due to reduced recharge to this unit from vertical seepage from the overlying units, as a result of groundwater inflows to the Blackheath and Little Hartley portals.

The two metre drawdown contour from the more conservative 95th percentile model prediction of maximum drawdown, also illustrated (in purple) in Figure 5-4 occurs around the same features as the 50th percentile but extends to around double the radius.

Predicted drawdown within the Marangaroo or Gundangaroo Formations does not extend to where the unit outcrops where GDEs are present (and therefore no impacts to GDEs are anticipated), and no registered water supply bores are known to be screened within this unit within the extent of drawdown.

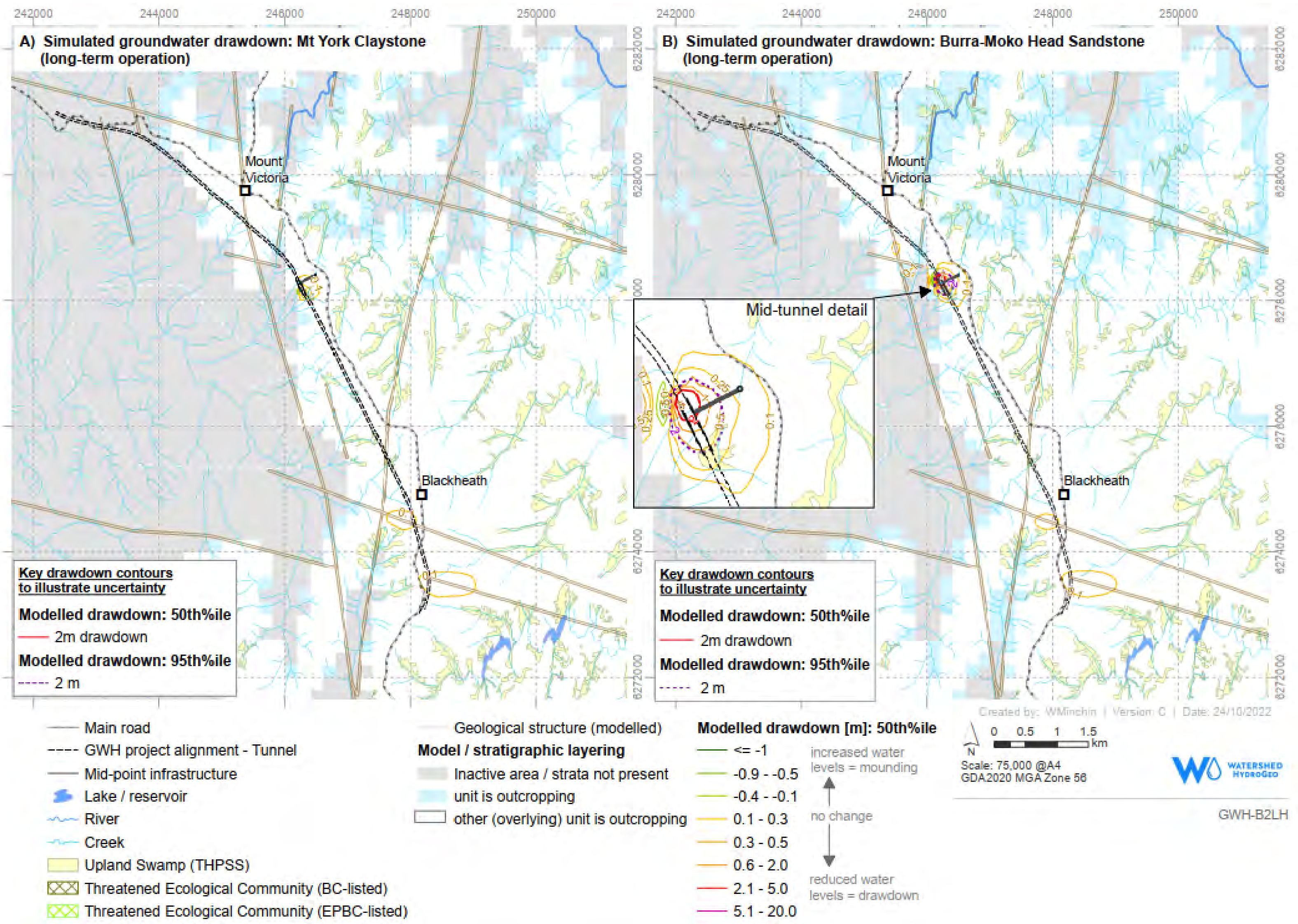

Figure 5-3 Simulated maximum drawdown of the Mount York Claystone and the Burra-Moko Head Sandstone during long-term operation phase

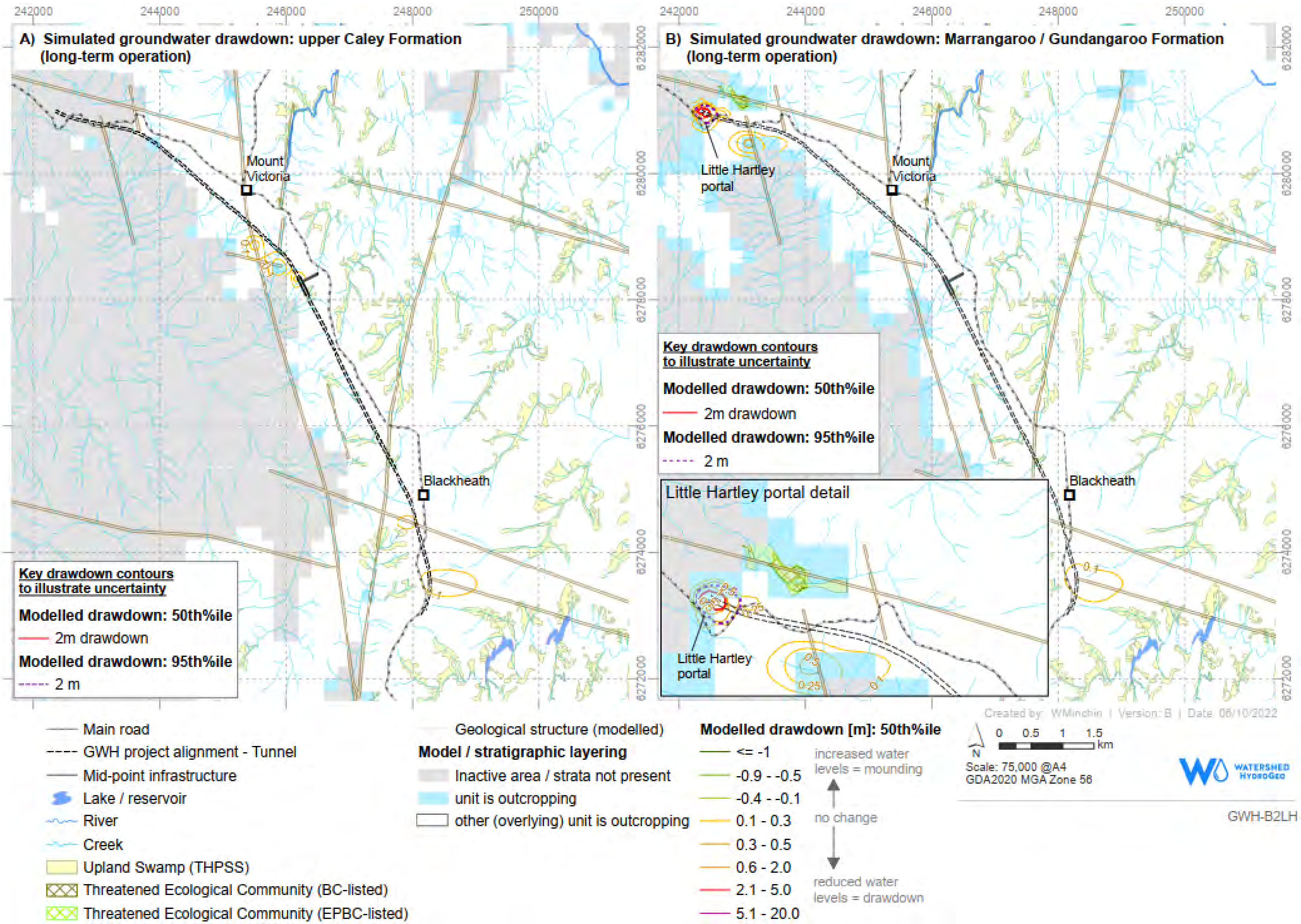

Figure 5-4 Simulated maximum drawdown of the Caley Formation and the Marangaroo or Gundangaroo Formations during long-term operation phase

5.4 Potential operational impacts

5.4.1 Potential groundwater recharge reduction

The impervious surface areas within the operation footprint, as shown on Figure 1-3 and Figure 1-4, are small relative to the overall extent of the underlying aquifers such that the net impact on regional recharge due to the increased sealed surface within the operational footprint areas is considered negligible.

5.4.2 Groundwater flow

Groundwater throughflow within the hydrostratigraphic units near the tunnel footprint, post construction, is anticipated to revert back to flow from east to west, towards the western escarpment. Impermeable underground infrastructure within the saturated hydrostratigraphic units, such as the tanked twin tunnels, have the potential to cause a localised alteration to groundwater throughflow, where mounding may occur on the up-gradient side of the tanked twin tunnels and drawdown on the down-gradient side of the tunnels. Given the magnitude and spatial extent of mounding and / or drawdown are likely to be localised to the vicinity of the project area, the project's impact on regional groundwater flow patterns is considered to be low.

Potential impacts to groundwater users and sensitive environmental receptors, due to groundwater drawdown from inflows to drained features, is further discussed in the sub-sections below.

5.4.3 Groundwater users

The numerical groundwater modelling has predicted that drawdown associated with operation of the project has the potential to impact groundwater levels at 34 registered bores screened within the Banks Wall Sandstone, Caley Formation or the Shoalhaven Group.

These at-risk bores comprise four monitoring bores, 26 bores used for water supply, two bores used for unknown purposes (assumed to be used for water supply purposes), and two abandoned water supply bores.

Long-term (year 2130) impacts are predicted at 23 of these bores, including 20 bores used for water supply, two bores used for unknown purposes (assumed to be used for water supply purposes), and one abandoned water supply bore.

The maximum predicted groundwater level drawdowns during the operation phase and the long-term predicted impact for bores used for water supply or unknown purposes, is summarised in Table 5-2. Registered water supply bore locations and the frequency that drawdown would be greater than or equal to two metres, is shown on Figure 5-5.

Table 5-2 Maximum predicted drawdown at existing registered water supply bores during the operation phase

Bore ID	Approximate distance from project (metres)	Maximum predicted drawdown during operation (metres)			Maximum long-term predicted drawdown (metres)		
		50th per-centile	95th per-centile	Frequency of model realisations with greater than or equal to two metres predicted drawdown (%)	50th per-centile	95th per-centile	Frequency of model realisations with greater than or equal to two metres predicted drawdown (%)
GW058892	620	0.00	0.01	0.0%	-0.01	0.00	0.0%
GW108604	800	0.00	0.01	0.0%	0.00	0.01	0.0%
GW055396	520	0.00	0.03	0.0%	0.00	0.00	0.0%
GW056581	700	0.12	0.37	0.0%	0.09	0.29	0.0%
GW057374	750	0.00	0.01	0.0%	0.00	0.01	0.0%

Bore ID	Approximate distance from project (metres)	Maximum predicted drawdown during operation (metres)			Maximum long-term predicted drawdown (metres)		
		50th per-centile	95th per-centile	Frequency of model realisations with greater than or equal to two metres predicted drawdown (%)	50th per-centile	95th per-centile	Frequency of model realisations with greater than or equal to two metres predicted drawdown (%)
GW057390	700	0.01	0.02	0.0%	0.00	0.02	0.0%
GW057611	440	0.26	0.71	0.0%	0.20	0.60	0.0%
GW057614	200	0.02	0.10	0.0%	-0.02	0.08	0.0%
GW058022	660	0.01	0.06	0.0%	0.00	0.00	0.0%
GW058193	420	0.30	0.95	0.3%	0.22	0.64	0.0%
GW058197	960	0.09	0.30	0.0%	0.09	0.30	0.0%
GW058199	620	0.01	0.04	0.0%	0.00	0.03	0.0%
GW058236	320	0.52	1.66	4.7%	0.38	1.21	0.3%
GW059727	650	0.17	0.51	0.0%	0.13	0.45	0.0%
GW059737	390	0.31	0.96	0.7%	0.23	0.65	0.0%
GW061195	1,380	0.01	0.02	0.0%	0.00	0.01	0.0%
GW063579	950	0.01	0.03	0.0%	0.00	0.02	0.0%
GW072282	1,210	0.01	0.03	0.0%	0.00	0.02	0.0%
GW072891	590	0.22	0.67	0.0%	0.17	0.62	0.0%
GW100157	60	0.21	0.81	0.0%	-0.23	-0.05	0.0%
GW101569	1,380	0.02	0.08	0.0%	0.02	0.08	0.0%
GW102030	270	0.10	0.48	0.0%	-0.10	0.05	0.0%
GW102214	350	0.52	1.46	1.7%	-0.12	0.00	0.0%
GW105896	730	0.01	0.04	0.0%	0.00	0.04	0.0%
GW107197	830	0.02	0.05	0.0%	0.01	0.05	0.0%
GW108316	420	0.18	0.49	0.0%	0.17	0.49	0.0%
GW111780	870	0.01	0.03	0.0%	0.00	0.02	0.0%

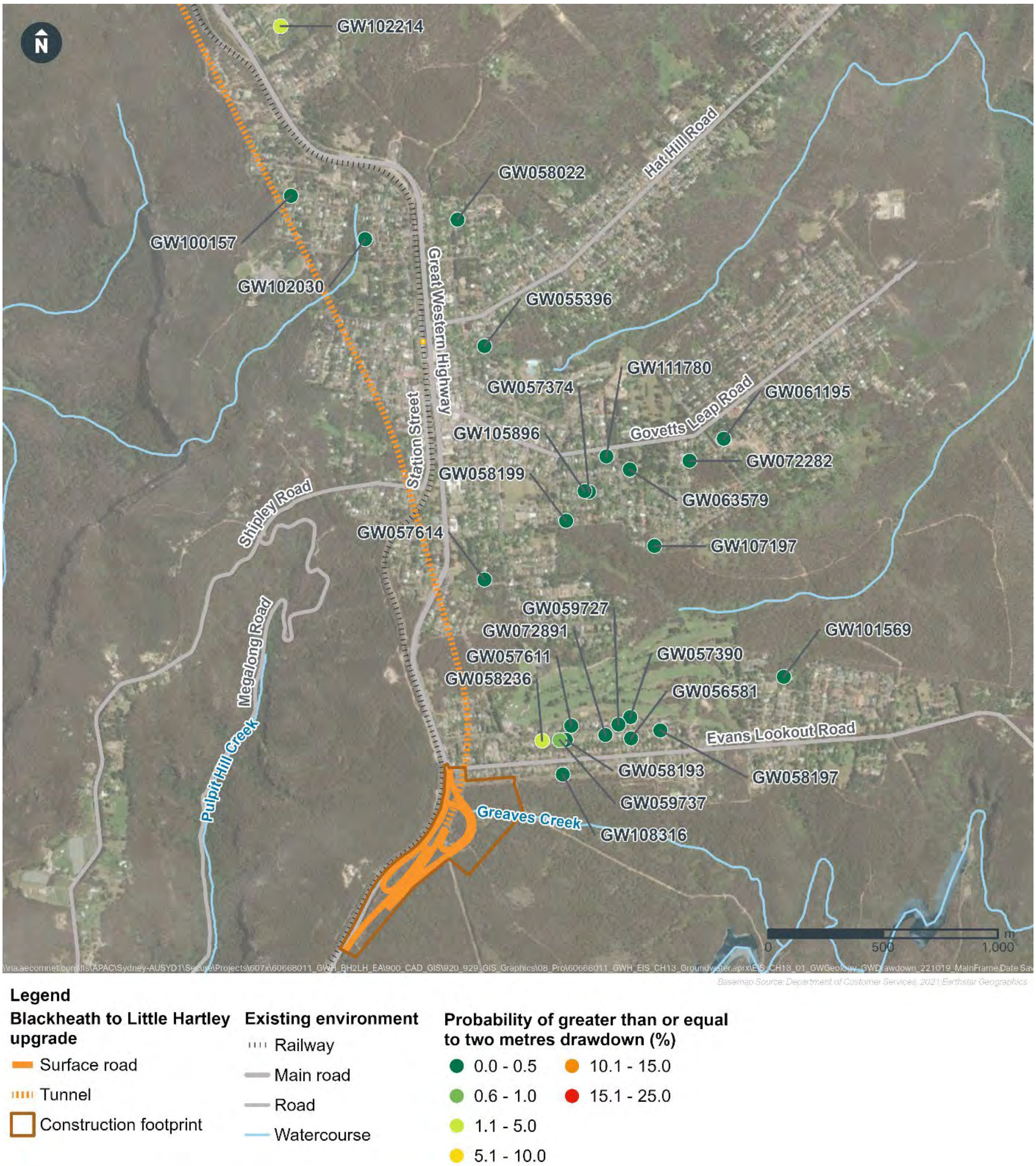

Figure 5-5 Frequency of model prediction with drawdown greater than two metres at registered water supply bores during the operational phase

No registered water supply bores had a median (50th percentile) or 95th percentile model prediction of maximum drawdown greater than two metres during the operational phase or long-term.

The 95th percentile maximum predicted groundwater drawdown during the operational phase is around 1.66 metres and is not projected to increase (the long-term maximum predicted groundwater drawdown is around 1.21 metres). The maximum predicted drawdown is minimal and not expected to impact markedly on bore yields and production.

During the operational phase, in fewer than 5% of model realisations, greater than or equal to two metres drawdown was predicted would occur at registered water supply bores, and only at four registered water supply bores (GW058193, GW058236, GW059737, and GW102214). In the long term, in fewer than 1% of model realisations, greater than or equal to two metres drawdown was predicted would occur, and only at one registered water supply bore (GW058236).

As discussed in Section 4.5.2, where at risk water supply bores have been identified via modelling predictions, monitoring during the initial operational phase would be conducted, as discussed further in Section 7.2.3. In accordance with the NSW AIP (DEC, 2012), if drawdown at registered bores is found to exceed two metres, measures are to be taken to 'make good' the impact. Monitoring during operation will also help to validate model predictions.

5.4.4 Groundwater dependent ecosystems

The maximum predicted groundwater level drawdowns during operation and long-term were modelled at the EPBC Act (including THPSS) and BC Act TECs within the project area (refer to Figure 4-7 and Figure 4-8).

Table 5-3 includes a summary of GDEs where maximum groundwater level drawdowns were predicted. For a full set of data, refer to Table 4-7 in Annexure B.

Table 5-3 Summary of predicted groundwater drawdown at GDEs

Feature ID	GDE listed status	Maximum predicted drawdown during operation (metres)		Maximum long-term predicted drawdown (metres)	
		50th per-centile	95th per-centile	50th per-centile	95th per-centile
Swamp_317	EPBC Act TEC (THPSS)	0.00	0.02	0.00	0.00
Swamp_318	EPBC Act TEC (THPSS)	0.00	0.01	0.00	0.00
Swamp_429	EPBC Act TEC (THPSS)	0.15	0.56	-0.10	0.06
Swamp_437	EPBC Act TEC (THPSS)	0.01	0.04	0.00	0.02
Swamp_448	EPBC Act TEC (THPSS)	0.00	0.10	0.00	0.00
Swamp_452	EPBC Act TEC (THPSS)	0.50	1.71	-0.01	0.00
Swamp_454	EPBC Act TEC (THPSS)	0.01	0.41	0.00	0.00
Swamp_464	EPBC Act TEC (THPSS)	0.09	1.99	0.00	0.00
Swamp_479	EPBC Act TEC (THPSS)	0.51	2.28	0.02	0.22
Swamp_484	EPBC Act TEC (THPSS)	0.00	0.04	0.00	0.00
Swamp_1480	EPBC Act TEC (THPSS)	0.00	0.03	0.00	0.02
Swamp_1501	EPBC Act TEC (THPSS)	0.00	0.05	0.00	0.02
Swamp_1509	EPBC Act TEC (THPSS)	0.01	0.04	0.01	0.03
EPBC_2	EPBC Act TEC	0.00	0.03	0.00	0.01
EPBC_3	EPBC Act TEC	0.00	0.01	0.00	0.00

Feature ID	GDE listed status	Maximum predicted drawdown during operation (metres)		Maximum long-term predicted drawdown (metres)	
		50th per-centile	95th per-centile	50th per-centile	95th per-centile
EPBC_4	EPBC Act TEC	-0.04	0.01	-0.08	0.00
BC_6b	BC Act TEC	0.00	0.01	0.00	0
BC_18	BC Act TEC	0.04	0.27	0.12	0

From these modelled GDE locations, simulated groundwater levels (‘with’ and ‘without’ project scenarios) have been extracted from the model and presented on hydrographs (Figure 4-9 to Figure 4-13). For additional hydrographs, refer to Section 4.6.5 in Annexure B.

For THPSS locations, the majority of locations are not predicted to be affected by substantial or discernible drawdown during the operation phase. There are three locations that are projected to experience discernible drawdown (refer to Figure 4-7), including locations, Swamp_452 (0.5 to 1.72 metres), Swamp_464 (0.09 to 1.99 metres), and Swamp_479 (0.51 to 2.28 metres) (refer to Figure 4-11). As discussed in Section 4.5.4, the predicted drawdown may be a function of poorly constrained model history-matching and parameter set development, and the magnitude suggested by the 50th and 95th percentile estimates would probably not occur in reality. Long-term, these locations are not predicted to be affected by substantial or discernible drawdown. Monitoring during the initial operational phase would be conducted to further investigate potential impacts, as discussed further in Section 7.2.3. Monitoring during operation will also help to validate model predictions.

Modelled EPBC Act TEC locations are at a low risk of drawdown from the project. Location EPBC_2 has the greatest predicted drawdown of around 0.03 metres (95th percentile) due to its locality north of the permanently drained Little Hartley portals, refer to Figure 4-12. The drawdown at this location is predicted to decline during the operation phase to around 0.01 metres (95th percentile) in the long-term.

Modelled BC Act TEC locations are at a low risk of experiencing impacts associated with drawdown from the project. Location BC_18 has the greatest predicted drawdown of around 0.04 metres (50th percentile) to around 0.27 metres (95th percentile) (Figure 4-13) and is located north of the Little Hartley portals (Figure 4-8), drawdown at this location is predicted to decline after construction due to the tanking of cross-passages, and is predicted to continue to decline to around 0.12 metres (95th percentile) in the long-term.

For further information and assessment of potential impacts to GDEs due to groundwater drawdown, see Appendix H (Technical report – Biodiversity) of the EIS.

5.4.4.1 Reduction of baseflow at hanging swamps

Numerical groundwater modelling was used to predict reduction of baseflow for hanging swamp zones within the project area during the operational phase (refer to Section 4.7 of Annexure B). The modelled hanging swamp zones are shown on Figure 4-14. Zones that were modelled to have a reduction in baseflow versus the historical modelled low, average, or high baseflows are provided in Table 5-4. For a full set of data, refer to Section 4.7 in Annexure B.

The greatest reductions in baseflow is predicted at Porters Pass (Zone 3), Mt Boyce (zone 4) and Fairy Bower (Zone 5) due to inflows to the mid-tunnel caverns.

Positive values in Table 5-4 indicate a modelled increase in baseflow. This could eventuate by the presence of the tanked twin tunnels, which could act as a barrier to groundwater flow. This effect could cause diversion of groundwater flow, with the potential to increase, decrease or not effect net groundwater flux to certain hanging swamps or other features. The ability of the model to simulate this effect is limited and the simulated positive changes in baseflow are all relatively small in magnitude.

For further information and assessment of potential impacts to hanging swamps due to reduction of baseflows, see Appendix H (Technical report – Biodiversity) of the EIS.

Table 5-4 Predicted reduction in baseflow to hanging swamps during operational phase

Zone	Change in baseflow (m^3/day)				Change in baseflow (%)					
	Average		Maximum		Minimum impact versus historical baseflow low		Average impact versus the historical baseflow average		Maximum impact versus historical baseflow high	
	50th per-centile	95th per-centile	50th per-centile	95th per-centile	50th per-centile	95th per-centile	50th per-centile	95th per-centile	50th per-centile	95th per-centile
1 – Mermaids Cave	-0.07	-0.41	-0.09	-0.47	-0.3	-0.7	-0.2	-0.5	-0.2	-0.3
2 - Shipley	-0.11	-0.47	-0.14	-0.53	-0.2	-0.3	-0.1	-0.3	-0.1	-0.2
3 – Porters Pass	-1.59	-8.58	-2.97	-15.90	-0.2	-0.7	-0.5	-1.3	-0.7	-2.0
4 – Mt Boyce	-1.47	-5.03	-3.98	-13.26	-0.1	-0.2	-0.9	-1.6	-1.7	-3.0
5 – Fairy Bower	-1.04	-10.64	-1.69	-13.39	-0.6	-5.4	-0.8	-4.6	-0.9	-3.9
6 – Fairy Bower West	-0.01	-0.27	-0.11	-0.44	0.5	-0.2	0.0	-0.2	-0.1	-0.2
7 – Rienits Pass North	-0.01	-0.27	-0.11	-0.44	0.1	-0.1	0.0	-0.1	-0.1	-0.2
8 – Mitchells Ridge East	0.02	0.00	0.00	-0.03	0.2	0.0	0.0	0.0	0.0	0.0
9 – Mitchells Ridge West	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
10 – Pulpit Hill Creek	-0.21	-0.87	-0.22	-0.93	-0.1	-0.3	-0.1	-0.3	-0.1	-0.2

5.4.5 Surface water – groundwater interaction

Surface water – groundwater interactions may be impacted during the project operational phase due to continued groundwater inflow to the drained features (portals and mid-tunnel caverns), potentially causing some long-term reduction in stream baseflow at surface water features.

Groundwater modelling was used to predict any reduction of baseflow for surface water sub-catchments within the project area during the operation phase (refer to Section 4.8 of Annexure B). The modelled surface water sub-catchment zones are shown on Figure 4-6. Sub-catchments that were modelled to have a reduction in baseflow versus the historical modelled low, average or high baseflow are provided in Table 5-5.

Table 5-5 Predicted reduction in baseflow to surface water catchments during the operational phase

Sub-catchment	Change in baseflow (m^3/day)				Change in baseflow (%)					
	Average		Maximum		Minimum impact versus historical baseflow low		Average impact versus the historical baseflow average		Maximum impact versus historical baseflow high	
	50th percentile	95th percentile	50th percentile	95th percentile	50th percentile	95th percentile	50th percentile	95th percentile	50th percentile	95th percentile
Butlers Creek	0.06	-3.88	-0.32	-4.53	0.1	-0.8	0.0	-0.2	0.0	0.0
Wilsons Gully	-4.76	-10.03	-5.36	-10.99	-0.6	-0.9	-0.3	-0.5	-0.1	-0.2
Fairy Bower	-9.45	-27.52	-19.84	-54.22	-0.3	-0.9	-0.6	-1.3	-0.8	-1.5
Porters Pass	-3.49	-13.02	-6.49	-23.47	-0.1	-0.5	-0.3	-0.8	-0.4	-0.9
Centennial Glen	-0.91	-2.24	-1.13	-3.41	-0.1	-0.2	-0.1	-0.2	-0.1	-0.2
Blackheath (lower) and Stony Creeks	-3.05	-8.49	-7.34	-20.91	0.0	-0.1	-0.1	-0.1	0.0	-0.1
Pulpit Hill Creek	-1.21	-3.09	-1.31	-3.20	0.0	-0.1	0.0	-0.1	0.0	0.0
Adams and Relton Creeks	-0.14	-0.56	-0.22	-0.65	-0.6	-2.5	0.0	-0.1	0.0	0.0
Greaves Creek	-5.14	-15.93	-6.07	-17.93	-15.5	-17.0	-0.5	-1.0	-0.2	-0.4
Victoria Creek (including tributaries)	-3.23	-10.22	-8.57	-21.51	0.0	0.0	-0.1	-0.1	-0.1	-0.1

The highest projected reduction in baseflow due to the operation of the project was within the Greaves Creek sub-catchment, which is located immediately east of the drained Blackheath portals, as shown on Figure 4-6.

Baseflow reduction within this sub-catchment is due to the permanently drained Blackheath portals, which are predicted to cause a persistent reduction in baseflows in areas of GDEs (valley infill swamps) associated with Greaves Creek. The greatest change in baseflow versus historical baseflow volumes is during dry periods (low rainfall), when the system is under the greatest amount of stress due to reduction in overall streamflow contribution and increased dependence on baseflow.

During periods of average rainfall, the loss of baseflow would be offset by the increased contribution of other streamflow sources such as rainfall runoff (due to the increased in impervious pavement introduced by the project), and therefore sufficient moisture is likely to be available to the valley infill swamps during average rainfall periods. A CHM for the Greaves Creek sub-catchment in shown in Figure 5-6.

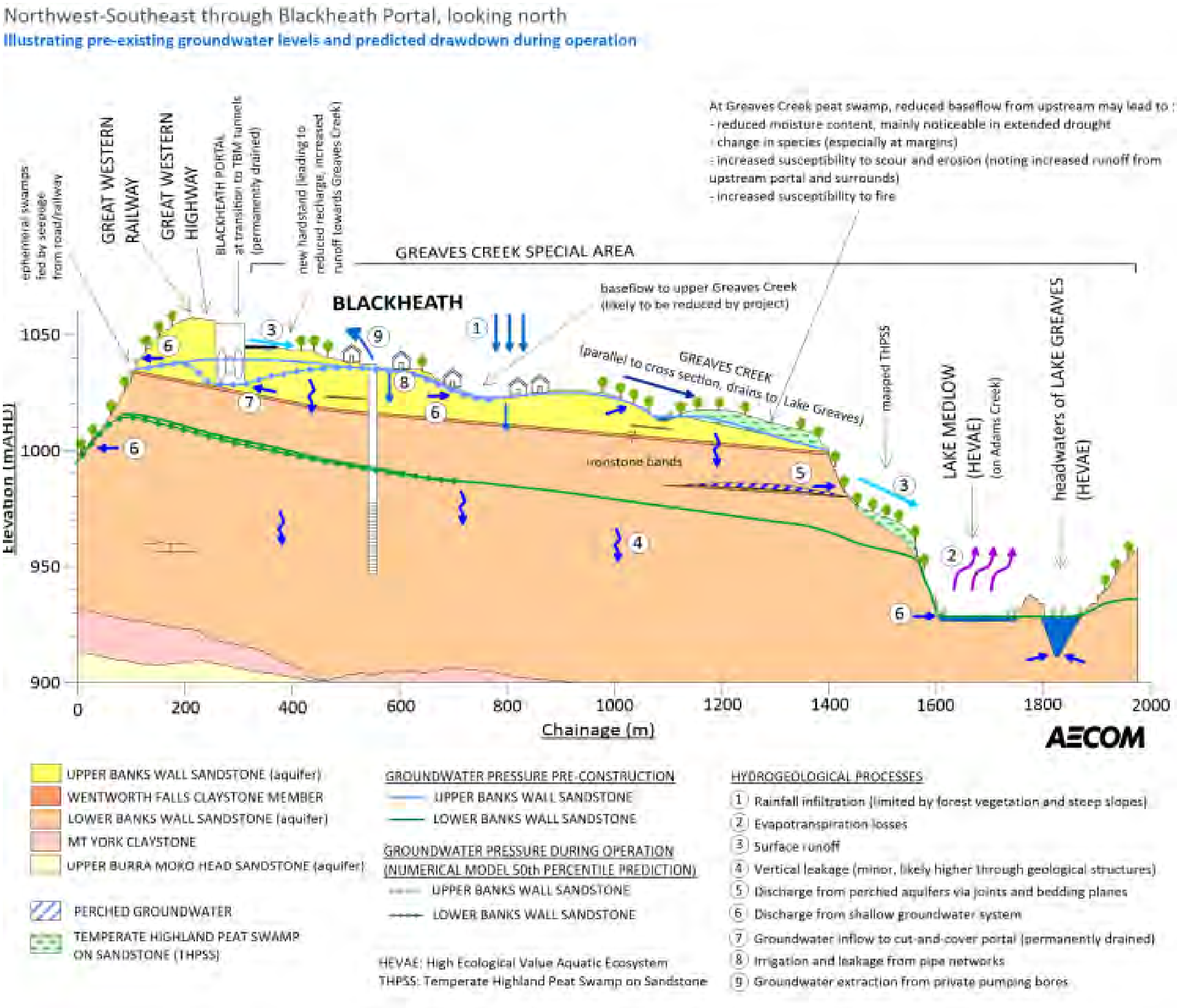

Figure 5-6 Conceptual hydrogeological model of Greaves Creek sub-catchment

Lake Medlow and Lake Greaves are located around 1.3 kilometres and 1.9 kilometres, respectively, from the Blackheath portals within the modelled Adams and Relton Creeks sub-catchment (Lake Medlow) and Greaves Creek sub-catchment (Lake Greaves). These lakes are located within the Blackheath portion of the Blue Mountains Special Area, listed under Schedule 1 of the WaterNSW Regulation. This area forms part of the water supply network for populations of Medlow Bath, Blackheath and Mount Victoria.

The change in groundwater-surface water flow were modelled for these two lakes, which indicated that a loss (95th percentile model prediction) from the lakes would be around 0.06 m^3/day (60 L per day) for Lake Medlow and around 0.07 m^3/day (70 litres per day) for Lake Greaves, as a result of the drained Blackheath portals. When combined with the reduction of baseflow for Adams and Relton Creeks sub-catchment and Greaves Creek sub-catchments, the impact to these lakes during dry periods could reduce the amount of water available to be used for water supply purposes, however the loss is considered to be minimal.

For further information and assessment of potential impacts to surface water bodies and GDEs, see Appendix J (Technical report – Surface water and flooding) and Appendix H (Technical report – Biodiversity) of the EIS.

Further investigation into the impacts of baseflow reductions on watercourses and swamps will be undertaken during design development. Future investigations would include field hydrogeological investigations to provide more accurate, site-specific parameters that can be used in predictive groundwater modelling. Modelling would then be revised for this catchment to enable more accurate predictions of the likely impact of the Blackheath portal on baseflow reductions.

If revised modelling determines that a reduction in baseflow to the valley floor infill swamps of Greaves Creek is likely and that there is a risk of detrimental impacts to these ecosystems as a result, then further mitigation measures would be investigated. Performance outcomes for the mitigation measures would be developed and agreed upon by subject matter experts, and mitigation actions including design responses such as lining the Blackheath tunnel portal would be assessed for their effectiveness in addressing the risk.

In the instance that residual risk is predicted monitoring would continue during construction for the hydrogeology, geomorphology and vegetation community likely to be impacted. Observations would be assessed against set triggers, trigger thresholds, and responses for observed impacts. Monitoring methods would be developed with reference to supporting justification including the recommendations of Commonwealth of Australia (2014) where appropriate.

5.4.6 Groundwater quality

There is a risk that groundwater could be altered (mixing or blending) during the operational phase from activities including:

- leaks or spills of fuels, oils and lubricating fluids used by vehicles using the tunnels.
- seepage from rock containing PASR (Little Hartley portals)
- firefighting system deluge and testing (including vehicle fires if accidents occur within the tunnels) and unintended discharge from the storage areas.

The following sections discuss these aspects in further detail.

5.4.6.1 Leaks and spills

Groundwater quality has potential to be impacted from accidental spills and leaks of substances as a part of normal operation and maintenance activities.

To manage spills and leaks associated with vehicle accidents during the operation of the project, spill containment facilities would be located in tunnels and in other locations where the risk of impact from spills is high. A risk assessment would be carried out during further design development to determine the final locations of these facilities. Typically, they would be located on highway sections where the chance of vehicle accidents is higher. This risk assessment would also take into account proximity to waterways, where the risk of harm to aquatic environments is assessed to be greater.

Any spills that occur within the tunnel would be collected within the tunnel drainage system and treated at the WTP at Little Hartley prior to discharge.

Further information regarding proposed stormwater treatment devices and procedures for spills management is discussed in Appendix J (Technical report – Surface water and flooding) of the EIS.

5.4.6.2 Acid sulfate soil and rock

There is an extremely low to low probability of acid sulfate soil occurrence within the operation footprint of the project, as discussed in Section 3.4.1, and any impacts to water quality due to long-term drawdowns would be negligible.

As discussed in Section 3.4.4, there is a risk that the western end of the tunnel and Little Hartley portal may be constructed within ASR/PASR conditions. The tunnels would be tanked at completion of the construction phase and therefore minimal seepage is expected at the tunnels. Groundwater drawdown is expected around the Little Hartley portals as they would be permanently drained during operation of the project. The high acidity and associated heavy metal content would affect the groundwater quality of inflows to the portals. Inflows would be managed through the WTP in Little Hartley and re-used or discharged appropriately.

5.4.6.3 Firefighting system

Water from the deluge firefighting system during emergency events or system testing has the potential to mobilise contamination. These potential contaminant sources are considered to be low risk to groundwater resources, as firefighting water and foams would be collected within the tunnel drainage system and treated at the wastewater treatment facility at Little Hartley prior to reuse or discharge.

5.4.7 Area of environmental interest for contamination

There is a medium risk that the potential contamination source areas around the Blackheath and Little Hartley portals, listed in Table 4-6, may migrate towards the drained infrastructure due to drawdown predicted during the operation phase (Section 5.3.1).

As discussed in Section 4.5.7, any contaminant migration would be towards the portals and any contaminated inflows to the portals would be captured and treated prior to disposal. A risk assessment will be carried out during further project design development to evaluate the likelihood of vehicle accidents during the operation of the project. Spill containment facilities would be located where high-risk spill/contamination risk areas are identified.

Tunnel groundwater inflows during operation of the project would be pumped to the Little Hartley WTP for treatment and disposal. The groundwater treatment facilities at the WTP would be designed such that treated effluent would be of suitable quality for discharge to the receiving environment, in accordance with the approval conditions and agreed discharge criteria. Trigger levels for discharge are provided in Appendix J (Technical report – Surface water and flooding) of the EIS.

Following adoption of mitigation and management measures during the operational phase of the project, risks arising from the disturbance of potential contamination and the disposal of potentially contaminated materials are minimised. Further information regarding potential contamination sources, impacts and monitoring is discussed in Appendix K (Technical report – Contamination) of the EIS.

5.4.8 Water management and disposal

During operation of the project, water would be required for:

- testing and operation of the tunnel deluge system, which forms part of the fire and life safety system
- tunnel cleaning systems
- tunnel operations facility amenities
- landscape irrigation.

Measures to avoid and minimise water use, particularly potable water, have been included in the project design. An example of these measures includes the reuse of groundwater entering the tunnels where possible to reduce the demand for potable water.

Water for operation of the project would be sourced according to the following hierarchy, where feasible and reasonable and where water quality and volume requirements are met:

- treated groundwater (non-potable water)
- rainwater harvesting (non-potable water)
- raw water and potable water.

Indicative water demand for each operational activity is provided in Table 5-6. Connection to and supply of mains water would be confirmed during further design development, in consultation with relevant stakeholders. A new pipeline connecting the project with the Lithgow town water supply would provide operational water supply for the project at Little Hartley (noting that use of recycled water sourced from the project would be prioritised). The new pipeline is the preferred water supply option. Investigations are ongoing to confirm the water supply option for the project and other options being investigated include the use of groundwater.

Table 5-6 Indicative operational water requirements

Operational activity	Total water demand (kilolitres/year)
Deluge testing	7,300
Washdown and cleaning	530
Amenities	5,110
Landscaping	8,980[19]

The tunnels would include drainage infrastructure to capture groundwater and stormwater, spills, maintenance water, fire deluge and other potential water sources. The tunnel drainage streams would receive water that may contain a variety of pollutants (such as fuel, oil grease, and fire suppressants) requiring different treatment before discharge. Due to the potentially saline nature of the groundwater that may be encountered within the project locality (particularly coal seams), groundwater would need to be treated prior to discharge/re-use to ensure there are no negative impacts to receiving environments. Treatment of contaminated groundwater is a scheduled activity under Schedule 1 of the NSW Protection of the Environment Operations Act 1997.

The project therefore includes construction and operation of a WTP which would treat groundwater and wastewater to ensure water is of adequate quality prior to discharge or re-use. Captured water would be treated so it meets the requirements for discharge to the Sydney drinking water catchment in accordance with Section 8.2.2 of the SEPP (Biodiversity and Conservation) 2021 which requires that developments have a neutral or beneficial effect (NorBE) on water quality.

Treatment of contaminated water, discharge requirements, and an assessment of potential impacts of treated wastewater discharges to the environment is discussed in Appendix J (Technical report – Surface water and flooding) of the EIS.

5.4.9 Settlement (ground movement)

As discussed in Section 4.5.9, the preliminary assessment of ground surface settlement showed that the predicted effects on all identified critical infrastructure were less than the acceptance criteria, including the sensitivity analyses undertaken.

The predicted groundwater drawdown induced from the tunnelling is expected to be limited as the tunnel would be tanked upon construction. Additional ground surface settlement during the operational phase (beyond that experienced in the construction phase) is not expected.

The predicted settlement impacts to properties are discussed in Chapter 20 (Business, land use and property).

[19] For planting/establishment in the first year only

6.0 Assessment of cumulative impacts

Cumulative impacts have the potential to occur when impacts (beneficial or determinantal) from a project overlap or interact with those of other projects, potentially resulting in a larger overall effect (beneficial or adverse) on the environment or local communities. Cumulative impacts may occur when projects are constructed or operated concurrently or consecutively. Once the project is operational, other projects which interrelate may enhance or diminish the project impacts and create positive or negative cumulative benefits.

Four other projects were reviewed against the following screening criteria for this cumulative impact assessment:

- spatially relevant (i.e., the development or activity overlaps with, is adjacent to or within two kilometres of project)
- timing (i.e., the expected timing of its construction and/or operation overlaps or occurs consecutively with the project construction and/or operation)
- scale (i.e., large-scale major development or infrastructure projects that have the potential to result in cumulative impacts with the project, as listed on the NSW Government Major Project website and on relevant council websites)
- status (i.e., projects in development with sufficient publicly available information to inform this environmental impact statement and with an adequate level of detail to assess the potential cumulative impacts).

Projects identified as contributing to potential cumulative impacts, which met these criteria, included:

- Katoomba to Blackheath Upgrade (including Medlow Bath Upgrade)
- Little Hartley to Lithgow Upgrade.

Given the regional setting of the project primarily within the Blue Mountains Local Government Area (LGA) and within the Lithgow LGA, there are fewer major projects within the locality.

Figure 1-8 shows the interface of the Katoomba to Blackheath Upgrade (including Medlow Bath) and the Little Hartley to Lithgow Upgrade with the project. Chapter 24 (Cumulative impacts) details the full cumulative impact assessment methodology adopted for the project.

6.1 Construction

6.1.1 Katoomba to Blackheath Upgrade (including Medlow Bath Upgrade)

The Katoomba to Blackheath Upgrade involves widening of around 5.3 kilometres of the existing Great Western Highway between Rowan Lane, Katoomba and Tennyson Road, Blackheath from one to two lanes in each direction. The Medlow Bath Upgrade involves upgrade of a 1.2 kilometre section of the existing Great Western Highway at Medlow Bath to a four-lane divided carriageway as part of the Great Western Highway Upgrade Program – Katoomba to Lithgow (the Upgrade Program).

Proposed excavations (cuts) for Katoomba to Blackheath Upgrade are less than five metres depth in the vicinity of the Great Western Highway Blackheath to Little Hartley project (the project), and are not anticipated to intercept groundwater (Golder, 2020).

6.1.2 Little Hartley to Lithgow Upgrade

The project includes upgrade of around 14 kilometres of highway to a four lane divided highway. Changes in groundwater levels and flow due to the Little Hartley to Lithgow Upgrade are predicted to be due to localised excavations (cuts). There are two cuts (L2R-1 and L2R-2) near the western end of the project, as shown on Figure 6-1. Cut L2R-1 is located around 0.4 kilometres from the Little Hartley portals. The maximum depth of the cut is about 5.5 metres, above the water table depth of 6.0 metres below ground level and therefore is unlikely to impact groundwater levels at this location (JAJV, 2021).

The maximum depth of cut L2R-2 is about 14 metres below ground level, and is anticipated to intercept the water table. The lateral extent of the estimated maximum groundwater drawdown at L2R-2 is around 80 metres (JAJV, 2021). As discussed in Section 4.4.1, the maximum simulated drawdown of the water table during the construction phase of the project at the Little Hartley portals is around 2.1 to 5.0 metres, and the spatial extent of drawdown is around 300 metres from the portals. Given that cut L2R-2 is around 1.2 kilometres west from the Little Hartley portals, the estimated groundwater drawdown contours are not anticipated to overlap (no risk of superposition of groundwater level drawdown cones) and therefore no cumulative impact to groundwater level or flow is expected.

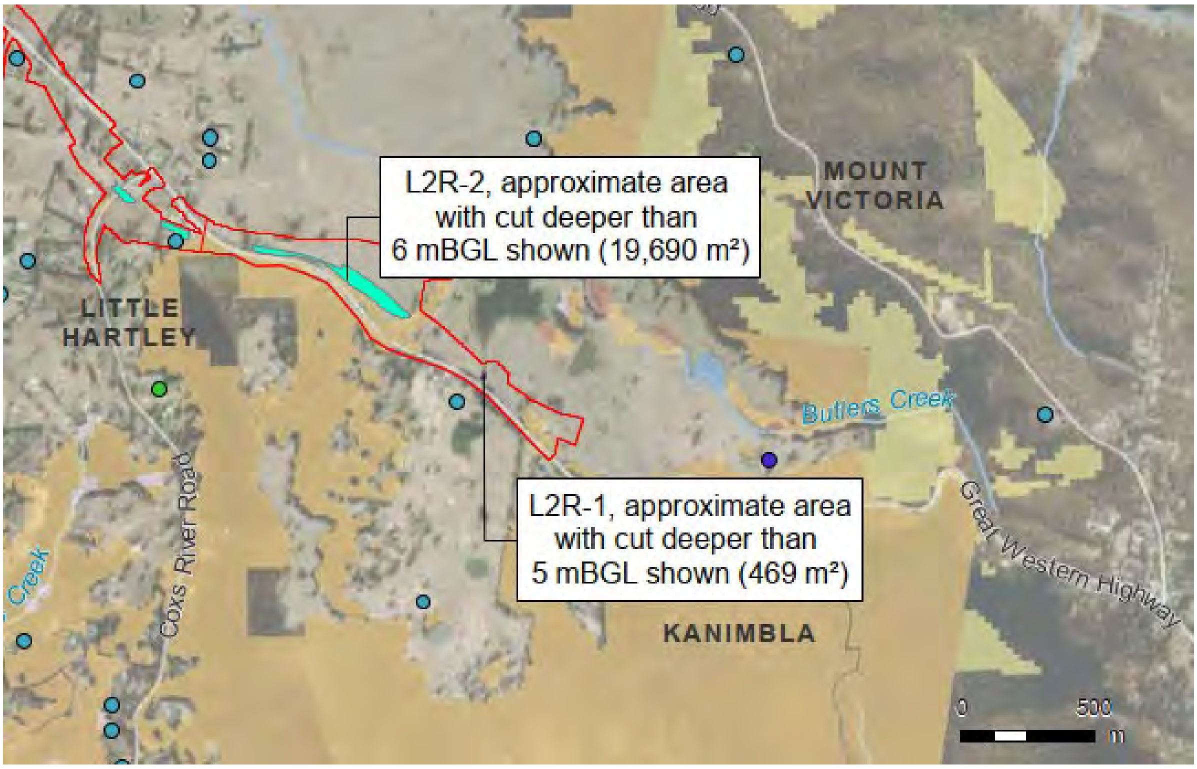

Figure 6-1 Road cuts associated with the Little Hartley to Lithgow Upgrade (JAJV, 2021)

Based on the above assessment, potential impacts to sensitive receptors and groundwater users due to the long-term cumulative groundwater drawdown associated with the construction phase of this project is considered to be low.

6.2 Operation

As discussed in Section 6.1.2, proposed cuts for the Katoomba to Blackheath Upgrade are less than five metres depth within the vicinity of the project, and are not anticipated to intercept groundwater (Golder, 2020).

The maximum simulated spatial extent of water table drawdown, during the operation phase (long-term) of the project at the Little Hartley portals, is expected to be less than 0.5 kilometres from the portals. Given that closest cut that intercepts groundwater (L2R-2) for the Great Western Highway between Little Hartley and Lithgow is around 1.2 kilometres west from the Little Hartley portals, the estimated groundwater drawdown contours are not anticipated to overlap and therefore no cumulative impact to groundwater level or flow is expected.

Based on the above assessment, potential impacts to sensitive receptors and groundwater users due to the long-term cumulative groundwater drawdown associated with the operational phase of this project is considered to be negligible to low.

7.0 Management of impacts

7.1 Performance outcomes

Performance outcomes have been developed that are consistent with the SEARs for the project. The performance outcomes for the project are summarised below in Table 7-1 and identify measurable, performance-based standards for environmental management.

Table 7-1 Performance outcomes for the project - groundwater

<table>
<tr><th>SEARs desired performance outcome</th><th>Project performance outcome</th><th>Timing</th></tr>
<tr><td>Long term impacts on surface water and groundwater hydrology (including drawdown, flow rates and volumes) are minimised.</td><td rowspan="2">Design and operate the project to minimise adverse long term impacts on surface water and groundwater, and related environmental values, including:
• minimising the volume and rate of groundwater inflow to the project during operation
• minimising the magnitude and extent of groundwater drawdown around the project during operation
• minimising the reduction in baseflow volumes in watercourses affected by groundwater drawdown around the project during operation
• surface water discharge from the project, including site runoff and water treatment plant discharges, achieves a neutral or beneficial effect on the receiving watercourse and catchment, taking into account relevant Water Quality Objectives.</td><td rowspan="2">Design, construction and operation</td></tr>
<tr><td>The environmental values of nearby, connected and affected water sources, groundwater and dependent ecological systems are maintained (where values are achieved) or improved and maintained (where values are not achieved).</td></tr>
<tr><td>Sustainable use of water resources.</td><td>Design, construct and operate the project to minimise the volume of water and rate of water consumption required during construction and operation. Subject to quality and volume requirements, maximise the reuse and recycling of water within the project.</td><td>Design, construction and operation</td></tr>
<tr><td>Consideration of tunnel boring methods to minimise groundwater drawdown impacts and dewatering.</td><td>Design and construct the project to minimise groundwater inflow and groundwater drawdown around the project during construction and operation.</td><td>Design, construction and operation</td></tr>
<tr><td>The project is designed, constructed, and operated to protect the NSW Water Quality Objectives where they are currently being achieved, and contribute towards achievement of the Water Quality Objectives over time where they are currently not being achieved, including downstream of the project to the extent of the project impact including estuarine and marine waters (if applicable).</td><td>Manage surface water discharges from the project during construction and operation, including collection and treatment where necessary, to achieve a neutral or beneficial effect on the receiving watercourse and catchment, taking into account relevant Water Quality Objectives.</td><td>Design, construction and operation</td></tr>
</table>

7.2 Groundwater monitoring program

Groundwater monitoring (water level and quality) will be conducted pre-construction, during construction, and during the initial operation of the project, as detailed in the following subsections.

In addition, monitoring of surface water is outlined in Appendix J (Technical report: Surface water and flooding) of the EIS. Monitoring of potential contamination is outlined in Appendix K (Technical report: Contamination) of the EIS.

7.2.1 Pre-construction

Baseline data will continue to be collected to refine the understanding of the groundwater environment, and enhance the current assessment of potential impacts to groundwater (identifying natural fluctuation of water levels, baseflow contributions, and natural seasonal variation of water quality), and to provide information to further refine the CHM and numerical groundwater model.

The existing pre-construction groundwater monitoring programme would be augmented to include:

- further drilling investigations, to facilitate measurement of groundwater levels and groundwater quality within the proposed project monitoring bore network, as shown on Figure 2-2, in addition to the ongoing monitoring of existing project monitoring bores. These data will provide additional site-specific baseline data prior to the construction of the project.

  Further investigations could include the installation of additional monitoring bores or conducting further hydrogeological testing in areas where impacts to sensitive receptors are predicted and could be used to refine the numerical groundwater model.

- bore census of registered bores including groundwater levels and quality, if they are found to be viable (suitable for monitoring), baseline data could include:
  - transient water level data, which could consist of installation of water level loggers, collection of manual measurements, and temporary installation of flow meters at the bores to obtain natural fluctuation data, influence of groundwater extraction, and long-term trends (pre-construction)
  - collection of additional groundwater quality samples to develop water quality trigger levels to instigate water quality impact assessment studies during construction. and operation.

7.2.2 Construction

Groundwater monitoring will continue through construction of the project (refer GW3 in Table 7-2), which may include:

- continuation of groundwater level and quality monitoring within the currently installed and proposed project monitoring bore network, as shown on Figure 2-2, to validate and inform the update and refinement of the groundwater model and to act as early warning bores between project activities and the registered bores, GDEs, and surface water resources
- continuation of groundwater level and quality monitoring within viable registered groundwater bores to assess groundwater level changes, and possible alteration of water quality
- monitoring the quality and quantity of groundwater inflows into the tunnels and drained infrastructure during construction
- monitoring the quantity and quality of the treated wastewater discharges from the WTPs proposed within the Blackheath, Soldiers Pinch, and Little Hartley construction footprints
- monitoring of groundwater levels and quality beneath identified medium risk sites for contamination prior to and during construction
- elevation surveys in possible areas of ground settlement.

Monitoring will occur monthly throughout the duration of construction and reported quarterly by a suitable qualified person.

7.2.3 Operation

Groundwater monitoring will continue through operation of the project (refer GW3 in Table 7-2), which may include:

- continuation of groundwater level and quality monitoring within the operational monitoring bore network to validate predicted groundwater rebound
- monitoring the quality and quantity of groundwater inflows into the drained tunnel features beneath identified medium risk sites for contamination
- monitoring quantity and quality of the treated wastewater discharges from the WTP located at Little Hartley.

Monitoring will occur quarterly for up to two years, dependent on the stabilisation of groundwater conditions (as predicted post-construction). After two years of data collection, the data will be used to re-run the numerical groundwater model (if considered to be required). After review of the data and model outcomes, requirements for further monitoring will be developed in consultation with the EPA and DPE Water.

7.3 Management of construction and operation impacts

A CEMP will be prepared for the project. The CEMP will detail the proposed approach to environmental management, monitoring, and reporting during construction. A number of sub-plans (and other supporting documentation, as required) would also be prepared as part of the CEMP.

A community and stakeholder engagement plan (Engagement Plan) has been prepared for the Upgrade Program and would be used to guide community and stakeholder engagement activities during construction of the project. Engagement during construction would include updates on planned construction activities and would respond to concerns and enquiries in a timely manner, seeking to minimise potential impacts, including groundwater, where possible.

Construction and operational mitigation measures to manage acid sulfate soil, acid sulfate rock, and contamination due to accidental leakage or spills are outlined in Appendix K (Technical Report – Contamination) of the EIS.

Construction and operational mitigation for water management and disposal is outlined in Appendix J (Technical Report – Surface water and flooding) of the EIS.

Construction and operational mitigation measures to manage potential impacts to GDEs are outlined in Appendix H (Technical report – Biodiversity) of the EIS.

Construction and operational mitigation measures to manage potential groundwater impacts of the project are outlined in Table 7-2.

Table 7-2 Construction and operational management and mitigation measures – groundwater

ID	Mitigation measure	Timing
GW1	The numerical groundwater model for the project will be updated as part of ongoing design development, will consider the construction schedule and methodology, and will take into account relevant additional geotechnical and groundwater monitoring data. Anticipated groundwater impacts will be confirmed and if required inform the development of detailed groundwater mitigation and management measures. The updated numerical groundwater numerical model will be calibrated against groundwater monitoring data collected during the construction phase. If observed groundwater level responses identified through monitoring markedly differ from predictions made by the updated numerical groundwater model, including extent of drawdown and timing, the model will be further refined and calibrated against the observed groundwater conditions.	Design

ID	Mitigation measure	Timing
GW2	Where the updated groundwater model predicts groundwater impacts or related baseflow reductions in surface water resources that markedly differ from predictions presented in the EIS, further environmental mitigation measures and/or design responses will be identified and applied where feasible and reasonable. Design responses could include the review of tanked or drained infrastructure elements, pre-grouting of cross-passages and/or the treatment and discharge of treated groundwater into the affected creeks to address baseflow reductions.	Design
GW3	As part of detailed design, the existing groundwater monitoring network will be reviewed and maintained in consultation with relevant government agencies, and monitoring data will be made available to those agencies upon request, to: • continue to gather representative groundwater monitoring data to inform ongoing project design development, and the updated numerical groundwater model for the project • characterise the hydrogeological environment along and around Greaves Creek and associated groundwater dependent ecosystems in more detail • monitor groundwater prior to, during, and after construction of the project • complement the surface water monitoring network for the project (refer to environmental mitigation measure SW2). A suitably qualified person, such as a hydrogeologist and/or an environmental scientist will undertake periodic reviews of the groundwater monitoring data, and advise on potential groundwater impacts and appropriate mitigation and management measures prior to, during and after construction of the project for up to two years.	Design
GW4	Registered groundwater bores identified as being potentially impacted by two or more metres of drawdown in the updated numerical groundwater model, will be inspected in consultation with the relevant groundwater licence holders. The inspection will aim to confirm the current viability of the bores. If the bores are identified to be viable, they will be monitored and if a material loss of yield occurs as a consequence of the project, make good provisions will be offered to the relevant groundwater licence holders.	Design
GW5	An updated assessment of potential ground settlement as a consequence of tunnel construction activities will be carried out as part of further design development at appropriate locations above the tunnel alignment. Where the assessment or monitoring data identifies an exceedance, or potential for an exceedance, of the acceptance criteria for settlement for buildings/ structures, heritage items and other sensitive buildings, or critical infrastructure, additional mitigation measures will be identified, which may include design and construction measures, and/ or reparatory works to affected buildings, structures or infrastructure.	Construction

7.4 Management of cumulative impacts

As discussed in Section 6.0, the groundwater impact to sensitive receptors and groundwater users from the construction and operation of the project is not expected to be greater as a result of the cumulative effects of other project impacts.

8.0 Compliance

8.1 Licencing

The AIP clarifies the licensing requirements for any aquifer interference activities that interfere with, or take water from, an aquifer. The tunnelling and excavation components of the project constitute aquifer interference activities, as these components would allow groundwater ingress that would require collection and disposal. The removal of water from the aquifer(s) due to groundwater inflows must be accounted for within the extraction limits of the Groundwater WSP. Further, Transport must satisfy the requirements of licensing set out in the Greater Metropolitan Region WSP and satisfy the approval requirements of the AIP.

The AIP specifies that the application for the take of water must be supported by robust predictions of the volumetric take from the aquifer(s) to ensure compliance with licensed volumes, and with the established limits for the aquifer as stated in the WSP. The estimated groundwater take for the construction and operation phases of the project is summarised in Table 8-1. Inflow volumes and the methods used to predict them have been outlined in Annexure B.

Table 8-1 Estimated groundwater 'take' for the project

Groundwater source	Estimated groundwater take (ML/year)[20]	
	Construction phase (mid 2024 to Q3 2030)	Operation phase (Q4 2030 to 2130)
Sydney Basin Blue Mountains	35 to 90	5 to 11
Sydney Basin Coxs River	119 to 271	6 to 15

The ranges of estimated groundwater take, as shown in Table 8-1, should be considered in the context of the potential for mitigation of some of the construction inflows by treatment of strata (pre-grouting) prior to the construction of the tunnel cross-passages, which could reduce groundwater take. Estimated groundwater take could be refined in future following further field investigations.

The inflows generated by the project would need to be assigned to the project through an annual allocation of unassigned water under the Groundwater WSP, or by purchasing an existing entitlement if there is insufficient unassigned water. There is currently about 6,901 ML/year unassigned under the long-term average annual extraction limit (LTAAEL) for the Sydney Basin Blue Mountains Groundwater Source and about 10,182 ML/year unassigned under the LTAAEL for the Sydney Basin Coxs River Groundwater Source.

During the construction phase, annual inflows for the project would equate to up to around 1.3% of the unassigned water for the Sydney Basin Blue Mountains Groundwater Source and up to around 2.7% of the unassigned water for the Sydney Basin Coxs River Groundwater Source. During the operation phase, annual inflows for the project would equate to up to around 0.2% of the unassigned water for the Sydney Basin Blue Mountains Groundwater Source and up to around 0.2% of the unassigned water for the Sydney Basin Coxs River Groundwater Source. This project is therefore not likely to substantially impact the unassigned water available under the WSP.

Section 5.23 of the EP&A Act, states that a water use approval under section 89, a water management work approval under section 90 or an activity approval under section 91 of the *Water Management Act 2000*, is not required for approved State Significant Infrastructure. As such, water supply works approvals and water use approvals would not be required for this project. An aquifer interference approval under Section 91(3) of the WM Act is not required for the project as a proclamation has not been made under section 88A of the WM Act.

[20] Ranges are the annualised 50th and 95th percentile maximum groundwater 'take'

8.2 NSW Aquifer Interference Policy - minimal impact considerations

The AIP clarifies the licensing and assessment requirements for aquifer interference activities under the WM Act and will form the basis of the assessment and subsequent advice provided by the Minister for the project under the EP&A Act.

The WM Act includes the concept of ensuring “no more than minimal harm” to any water source, or its dependent ecosystems due to aquifer interference activities, for both the granting of WALs and approvals. The minimal impact considerations have been developed for impacts on groundwater sources, connected water sources, and their dependent ecosystems, culturally significant sites and water users, by aiming to maintain water levels, water pressure and water quality in aquifers.

Tunnels and excavations for the project would intercept the Narrabeen Group, Illawarra Coal Measures, and the Shoalhaven Group. Aquifers within these hydrostratigraphic units are classified as:

- a ‘less productive aquifer’ because recorded yields for water supply works are generally less than five L/s and the Shoalhaven Group has total dissolved solid (TDS) values recorded above 1,500 mg/L, and porous or fractured rock aquifer(s).
- a porous or fractured rock aquifer(s).

The minimal impact considerations for this aquifer type are summarised in Table 8-2, together with the response developed in this assessment.

Table 8-2 Minimal impact consideration for a ‘less productive porous or fractured rock aquifer’

<table>
<tr><th colspan="2">Minimal impact considerations</th><th>Response</th></tr>
<tr><td colspan="3">Water Table</td></tr>
<tr><td>Level 1</td><td>Less than or equal to 10 per cent cumulative variation in the water table, allowing for typical climatic “post-water sharing plan” variations, 40 metres from any:
a. high priority groundwater dependent ecosystem; or
b. high priority culturally significant site;
listed in the schedule of the relevant water sharing plan.

A maximum of a two metres decline cumulatively at any water supply work.</td><td rowspan="2">THPSS are listed as ‘high priority’ GDEs in Schedule 4 of the Groundwater WSP (refer to Section 3.7). THPSS north of the Little Hartley portals are likely within the zone of predicted groundwater change (Sections 4.5.4 and 5.4.4). Reduction of baseflows have also been predicted at the hanging swamps along the western escarpment (Sections 4.5.4.2 and 5.4.4.1), and surrounding surface water features, particularly Greaves Creek, which supplies water to downgradient valley infill swamps (Sections 4.5.5 and 5.4.5). Further monitoring will be undertaken to validate the numerical groundwater model. Mitigation measures should be implemented to further reduce predicted impacts on groundwater levels and nearby GDEs. Mitigation measures could include design responses as outlined in Section 7.3.

As outlined in Section 3.9, there are no high priority culturally significant sites within the groundwater study area.

As discussed in Section 4.5.3, numerical groundwater modelling has predicted groundwater drawdown of greater than two metres at registered water supply bores GW100157 and GW102214, during the construction phase. Prior to commencing construction activities, a baseline assessment at these bores would be performed, including (if access can be gained), visiting the bore to</td></tr>
<tr><td>Level 2</td><td>If more than 10 per cent cumulative variation in the water table, allowing for typical climatic “post- water sharing plan” variations, 40 metres from any:
a. high priority groundwater dependent ecosystem; or
b. high priority culturally significant site;
listed in the schedule of the relevant water sharing plan if appropriate studies demonstrate to the Minister’s satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site.

If more than a two metre decline cumulatively at any water supply work</td></tr>
</table>

Minimal impact considerations		Response
	then make good provisions should apply.	confirm current bore construction, groundwater level, current yield and extraction, and water quality. If a bore is found to be viable, it would then be monitored pre-construction and during construction. In accordance with the NSW AIP, if drawdown at registered bores is found to exceed two metres, measures are to be taken to 'make good' the impact, as described in Section 7.3. Additionally, to manage any uncertainties within the numerical groundwater model, monitoring would be carried out pre-construction, during construction and post-construction at viable registered bores that have been identified as being potentially impacted by groundwater drawdown, as outlined in Section 7.2.
Water pressure		
Level 1	A cumulative pressure head decline of not more than a two metre decline, at any water supply work.	As discussed in Section 4.5.3, numerical groundwater modelling has predicted groundwater drawdown of greater than two metres at registered water supply bores GW100157 and GW102214, during the construction phase. These bores are assumed to be installed in the Banks Wall Sandstone which is considered to be a semi-confined to unconfined aquifer, as outlined in Section 3.5.1., and therefore there is a potential that bores may be under pressure. Prior to commencing construction activities, a baseline assessment at these bores would be performed, including (if access can be gained), visiting the bore to confirm current bore construction, groundwater level, current yield and extraction, and water quality. If a bore is found to be viable, it would then be monitored pre-construction and during construction. In accordance with the NSW AIP, if drawdown at registered bores is found to exceed two metres, measures are to be taken to 'make good' the impact, as described in Section 7.3. Additionally, to manage any uncertainties within the numerical groundwater model, monitoring would be carried out pre-construction, during construction and post-construction at viable registered bores that have been identified as being potentially impacted by groundwater drawdown, as outlined in Section 7.2.
Level 2	If the predicted pressure head decline is greater than requirement 1. above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long-term viability of the affected water supply works unless make good provisions apply.	

Minimal impact considerations		Response
Water quality		
Level 1	Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.	With the implementation of mitigation measures outlined in Section 7.3, Appendix K (Technical Report – Contamination) and Appendix J (Technical Report – Surface water and flooding) of the EIS, impacts to groundwater quality associated with the project are considered to be minor. Additionally, any groundwater contamination caused by construction activities would likely flow towards the project rather than away from it, due to groundwater drawdown. As discussed in Sections 4.5.8 and 5.4.8, the tunnels would include drainage infrastructure to capture groundwater, stormwater, spills, maintenance water, fire deluge and other potentially contaminated water sources. Captured surface water would be treated so it meets the requirements for discharge to the Sydney drinking water catchment in accordance with Section 8.2.2 of State Environmental Planning Policy (Biodiversity and Conservation) 2021 which requires that developments have a neutral or beneficial effect (NorBE) on water quality.
Level 2	If condition 1 is not met, then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.	
Additional considerations		
Potential for: • acidity issues to arise, for example exposure of acid sulphate soils; • waterlogging or water table rise to occur, which could potentially affect land use, groundwater dependent ecosystems and other aquifer interference activities. Specific limits will be determined on a case-by-case basis, depending on the sensitivity of the surrounding land and groundwater dependent ecosystems to waterlogging and other aquifer interference activities to water intrusion.		As discussed in Section 3.4.1.1, there is a low and extremely low probability of encountering potential acid sulfate soils within the project. Therefore, it is expected that acid sulfate soils would be managed via an unexpected finds procedure. Where potential acid sulfate soils are encountered during construction, an ASSMP would be developed. Acid sulfate rock (ASR) around Little Hartley may lead to acidification of runoff during tunnel construction excavation and earthworks. A ASRMP will be prepared and implemented during the construction phase of the project, detailing measures to address any ASR found during tunnel construction, and to provide an overall monitoring program to identify ASR, and contingency measures that may be implemented if ASR is found.

8.3 Water Sharing Plan

The Groundwater WSP provides rules to manage and allocate the groundwater resource, including specific rules on taking groundwater near high priority GDEs, groundwater dependent culturally significant sites, sensitive environmental areas, and near licensed bores.

Relevant rules from the Groundwater WSP are summarised in Table 8-3, with the response developed through this EIS.

Table 8-3 Relevant rules from the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011

WSP rule	Comment
Part 7 – Rules for granting access licences Part 8 – Rules for managing access licences	Transport is exempt from the requirement to hold a licence for the take of water during construction and operation for the project, under Schedule 4, Part 1, clause 2 of the WM Regulation. Transport is not required to obtain an aquifer interference approval under Section 91(3) of the WM Act for groundwater ingress to tunnels and inflow volumes need to be assigned under the LTAAEL, as further discussed in Section 8.1.
Part 9 – Rules for water supply work approvals	The approval process would determine distance restrictions to minimise interference between water supply works. The water supply works for this project would include temporarily drained twin tunnels, cross-passages, the mid-tunnel access shaft and adit during construction (tanked or infilled upon completion), and the permanently drained portals and the mid-tunnel caverns.
Part 9-39 Distance restrictions to minimise interference between water supply works	
• Distance restriction from an approved water supply work nominated by another access licence is 400 metres	The water supply works for the project are within 400 metres of approved supply work nominated by another access licence, as discussed in Table 8-2.
• Distance restriction from an approved water supply work for basic landholder rights only is 100 metres	The water supply works for the project are within 100 metres of approved water supply work for basic landholder rights, as discussed in Table 8-2.
• Distance restriction from the property boundary is 50 metres	The project is within 50 metres of property boundaries and would result in groundwater drawdown at nearby properties. The tunnels are predominantly at depth and there is a reticulated water supply to those properties. Ground settlement may occur at these properties, however, as discussed in Sections 4.5.9 and 5.4.9, the settlement component potentially caused by groundwater drawdown is expected to be negligible to slight.
• Distance restriction from an approved water supply work nominated by a local water utility or major utility access licence is 1,000 metres	There are no approved water supply works nominated by a local water utility or major utility access licence within 1,000 metres of the project, however, the following is noted: • The majority of the project would be located within or beneath the Coxs River catchment, which forms part of the Sydney drinking water catchment eventually draining to Warragamba Dam. • Lake Medlow and Lake Greaves are located around 1.3 kilometres and 1.9 kilometres, respectively, from the Blackheath portals and are within the Blackheath portion of the Blue Mountains Special Area, listed under Schedule 1 of the WaterNSW Regulation. The area forms part of the water supply

WSP rule	Comment
	network for populations of Medlow Bath, Blackheath and Mount Victoria. Refer to Section 5.4.5 for discussion of potential impacts to the Sydney drinking water catchment and Blackheath portion of the Blue Mountains Special Area.
• Distance restriction from a Department observation bore is 200 metres	DPE do not have any observation bores within 200 metres of the project or within the extent of groundwater drawdown.
Part 9-40 – Rules for water supply works located near contamination sources	There are medium risk AEIs for contamination within the project area and within the extent of predicted drawdown. Approval can be granted for water supply works within the specified distance of contaminated sites as long as the water source, GDEs, and public health and safety are not threatened. No EPA notified contaminated sites have been identified near the project or within the extent of predicted drawdown and any contamination identified is expected to migrate towards the tunnels, away from sensitive receptors, where contaminated groundwater can be collected and treated prior to disposal.
Part 9-41 – Rules for water supply works located near sensitive environmental areas	Required distances from sensitive environmental areas include: • 200 metres of a high priority GDE • 500 metres of a karst GDE • 40 metres from a lagoon or escarpment Groundwater drawdown is within 200 metres of high priority GDEs, as discussed in Table 8-2. Karst GDEs are greater than 500 metres from the project. Lagoons and escarpments are greater than 40 metres from the project, however reduction of baseflow to hanging swamps on the western escarpment is predicted, as discussed in Table 8-2.
Part 9-42 – Rules for water supply works located near groundwater dependent culturally significant sites	There are no groundwater dependent culturally significant sites in the area of drawdown surrounding the project
Part 9-44 – Rules for water supply works located within distance restrictions	If water supply works are located within restricted distances, proponents must not take more water than specified in the WAL. There is potential for water supply works to be within restricted distances from registered water supply bores and GDEs. Although Transport is exempt from having to hold a WAL, project approval may still specify an allowable extraction volume (or inflow rates) for the project to protect the groundwater users and GDEs.
Part 10 – Access licence dealing rules	Refer to Part 7 comments

9.0 Conclusion

This Groundwater Technical Report has been prepared as part of the EIS for this project. This report has assessed the potential impacts of the construction and operational phases of the project on groundwater. The project's SEARs have been considered to ensure that all potential impacts have been adequately assessed.

Construction of the project is expected to take around eight years. Subject to planning approval, construction is planned to commence in 2024 and be completed by late 2031; however, the project would be open to traffic by 2030.

9.1 Construction impacts

The proposed construction methodology and project design has sought to minimise groundwater impacts, including:

- the use of TBMs to excavate the twin tunnels, a construction method that lines the tunnels with precast concrete segments, a very low permeability casing/membrane that minimises groundwater inflows to negligible rates as the TBMs progresses
- tanking of the tunnel cross-passages and upper-section of the mid-tunnel access shaft upon construction completion.

The key potential construction phase groundwater impacts identified in this assessment include:

- groundwater users may be impacted. Bore water levels may decrease at up to around 23 registered water supply bores within the extent of groundwater drawdown due to dewatering associated with tunnel construction. The maximum predicted drawdown would exceed two metres at two registered water supply bores.
- groundwater drawdown (up to around 5.4 metres) resulting in potential baseflow impacts to hanging swamps (classified as a THPSS GDE) located west of the project footprint, due to the construction of the tunnel and cross-passages (prior to being tanked) and the mid-tunnel caverns, adit and access shaft
- groundwater drawdown resulting in potential for increased risk of contaminated groundwater migration, where areas of environmental interest (AEI) for contamination has been identified
- ground settlement impacts to buildings and structures due to tunnelling activities.

9.2 Operational impacts

The twin tunnels and the cross-passages would be tanked by the end of the construction phase and the mid-tunnel access shaft and the adit would be infilled at the end of construction. Therefore, during the project's operational phase, groundwater inflows and drawdown impacts related to those features would cease (apart from minor leaks within the tunnels and cross-passages).

Groundwater flows and drawdown impacts during operation would be associated with the permanently drained features of the project, allowing long-term groundwater inflows to these features. Drained features include the portals at Blackheath and Little Hartley, and the mid-tunnel caverns.

The key potential operational phase groundwater impacts identified in this assessment include:

- groundwater drawdown resulting in potential baseflow reductions at creeks, including Greaves Creek at Blackheath (predicted to be up to around 18%), and potential for impacts on THPSS GDEs
- groundwater drawdown (up to around 2.3 metres) resulting in potential baseflow impacts to hanging swamps (classified as a THPSS GDE) west of the project footprint, between the mid-tunnel caverns and Blackheath portals, due to the permanently drained mid-tunnel caverns
- groundwater drawdown resulting in potential for increased risk of contaminated groundwater migration, where areas of environmental interest (AEI) for contamination has been identified

9.3 Management of impacts

Groundwater monitoring would continue during construction to manage potential impacts on groundwater during the construction and operational phases of the project.

The numerical groundwater model would be updated and refined as additional information from geotechnical and hydrogeological investigations, groundwater monitoring programs and further design development becomes available. Where a marked reduction in baseflow (groundwater contribution to surface water) is predicted due to construction of the project, design responses and/or other mitigation would be implemented, particularly for potential baseflow loss to surface water resources around the Blackheath portal. Design responses could include the review of tanked or drained infrastructure elements, pre-grouting of cross-passages and/or the treatment and discharge of water into the affected creeks to maintain pre-construction baseflows.

Potential loss of groundwater available to existing groundwater users due to the project would be monitored. This would include a baseline assessment of each of the registered groundwater bores predicted to have drawdown impacts greater than two metres. In accordance with the NSW AIP, if drawdown at registered bores is found to exceed two metres during construction and the initial stage of operation of the project, then measures would be taken to ‘make good’ the impact.

Additionally, the CEMP would be implemented to manage potential impacts to groundwater due to contaminant migration from AEIs.

Groundwater inflows collected from the drained underground infrastructure would be treated at three water treatment plants during construction (Blackheath, Soldiers Pinch and Little Hartley) and one during operation of the project at Little Hartley, prior to discharge. All surface water leaving the site would be treated and managed in accordance with Managing urban stormwater: soils and construction (the Blue Book) to ensure no dirty water would be released into drainage lines and/or waterways.

An updated assessment of potential ground settlement as a consequence of tunnel construction activities would be carried out based on further design development for the project, to confirm that acceptance criteria for settlement will not be exceeded for buildings/ structures, heritage items and other sensitive buildings, or critical infrastructure.

Ground settlement monitoring would be carried out during tunnel construction activities to confirm that settlement predictions are not exceeded. Where monitoring data identifies an exceedance, or potential for an exceedance, of the acceptance criteria for settlement, additional mitigation measures would be identified, which may include design and construction measures, monitoring and/ or reparatory works to affected buildings, structures or infrastructure.

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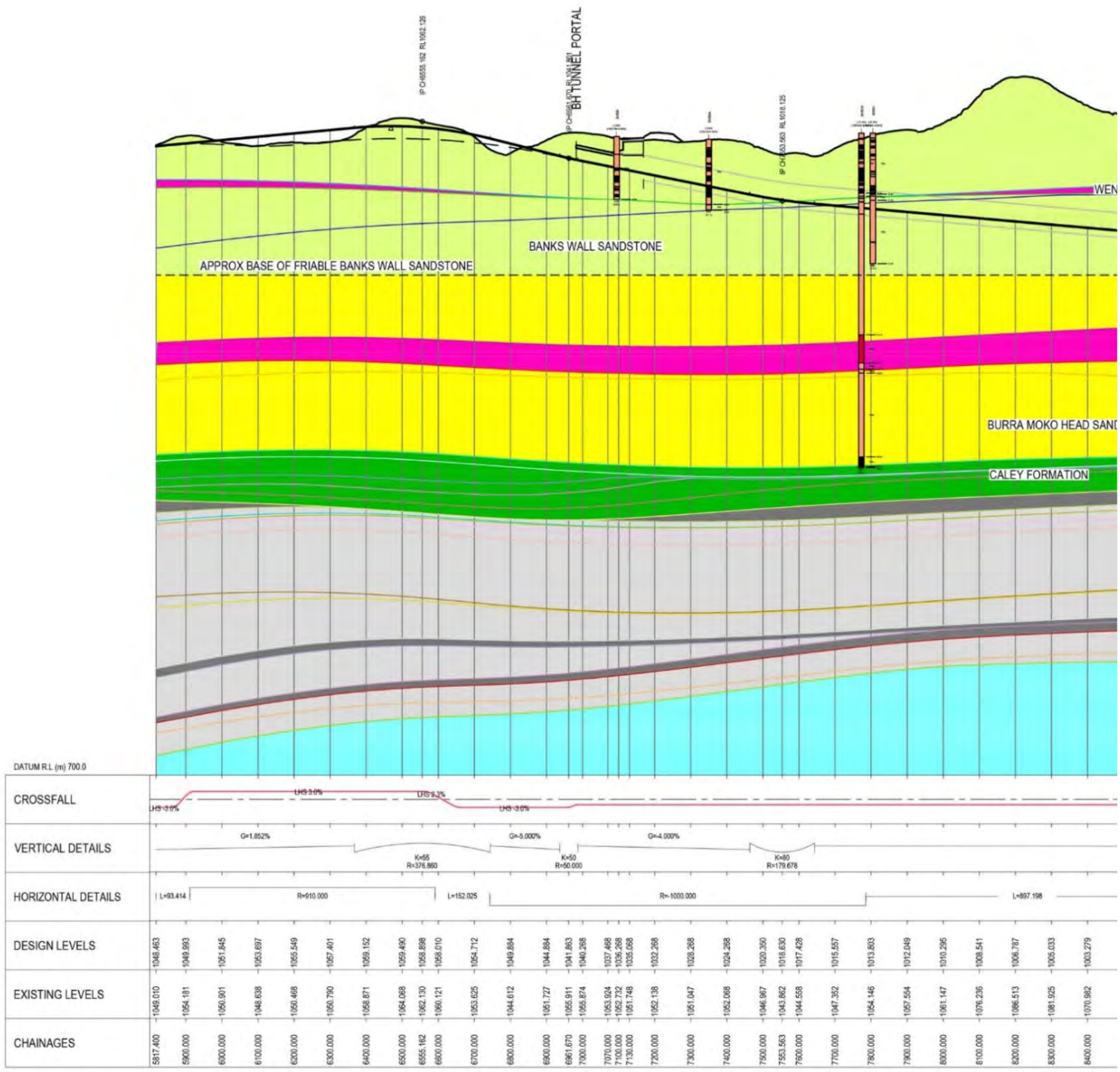
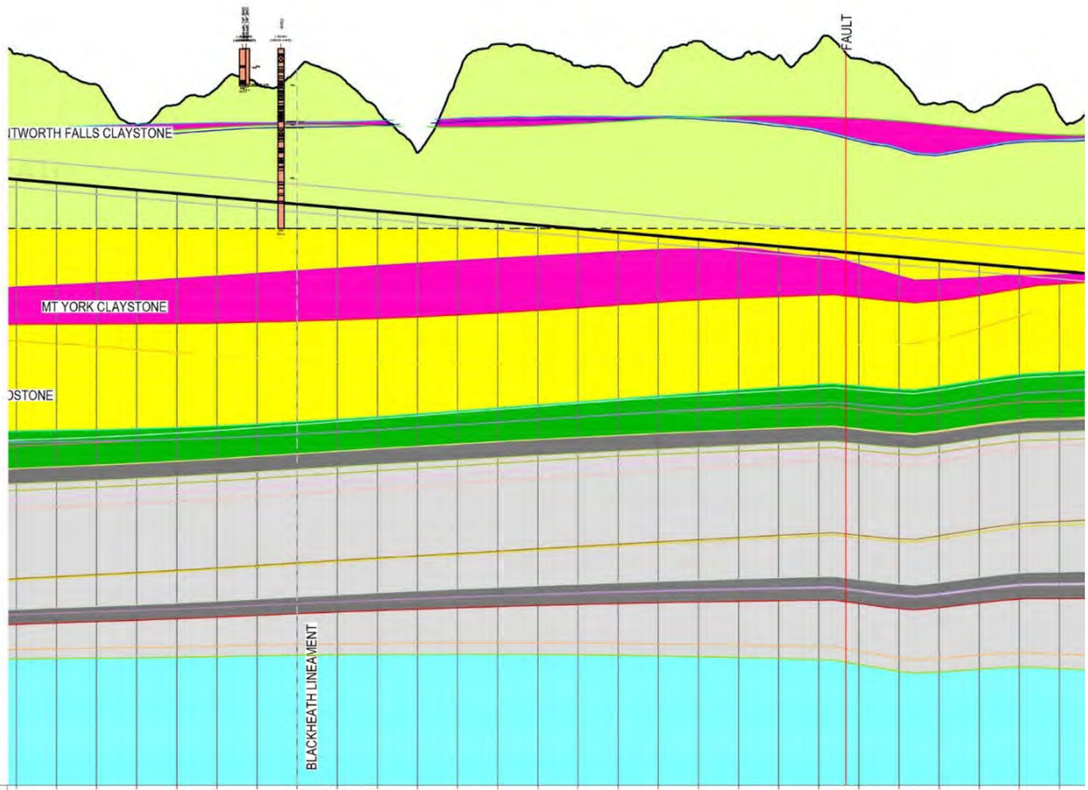
Annexure A

Long section

Annexure A Long section





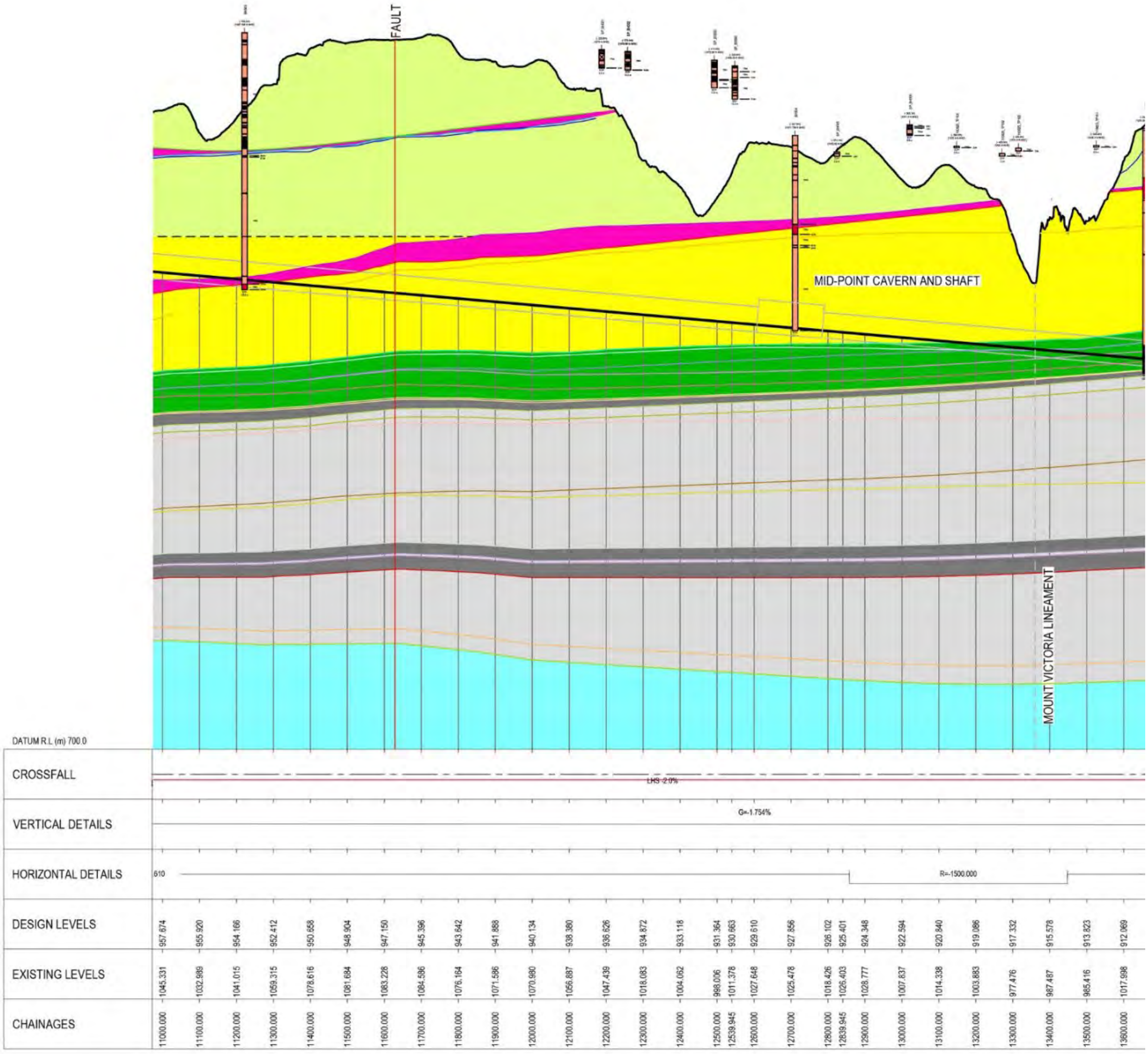
CROSSFALL

VERTICAL DETAILS

HORIZONTAL DETAILS R=-2000.000 L=3795.610

CHAINAGES	8500.000	8600.000	8700.000	8800.000	8900.000	9000.000	9100.000	9200.000	9300.000	9400.000	9500.000	9600.000	9700.000
DESIGN LEVELS	1001.524	999.770	998.016	996.262	994.508	992.754	991.000	989.246	987.492	985.738	983.984	982.230	980.476
EXISTING LEVELS	1064.099	1056.904	1048.672	1028.666	1038.655	1046.818	1048.895	1055.969	1053.662	1036.161	1014.676	1053.280	1068.851

CHAINAGES	9800.000	9900.000	10000.000	10100.000	10200.000	10300.000	10400.000	10500.000	10600.000	10700.000	10800.000	10900.000	11000.000	11100.000
DESIGN LEVELS	978.722	976.968	975.214	973.460	971.706	969.952	968.198	966.444	964.690	962.936	961.182	959.428	957.674	955.920
EXISTING LEVELS	1065.485	1057.967	1054.310	1061.189	1070.214	1061.757	1063.185	1069.561	1061.450	1052.145	1038.883	1035.918	1045.331	1032.989


FAULT
MID-POINT CAVERN AND SHAFT
MOUNT VICTORIA LINEAMENT
DATUM R.L (m) 700.0
CROSSFALL
LHS -2.0%
VERTICAL DETAILS
G=-1.754%
HORIZONTAL DETAILS
610
R=-1500.000
DESIGN LEVELS
957.674 955.920 954.166 952.412 950.658 948.904 947.150 945.396 943.642 941.888 940.134 938.380 936.626 934.872 933.118 931.364 930.663 929.610 927.856 926.102 925.401 924.348 922.594 920.840 919.086 917.332 915.578 913.823 912.069
EXISTING LEVELS
1045.331 1032.989 1041.015 1059.315 1078.616 1081.684 1083.228 1084.586 1076.164 1071.586 1070.980 1056.887 1047.439 1018.083 1004.062 998.006 1011.378 1027.648 1025.478 1018.426 1026.403 1028.777 1007.837 1014.338 1003.883 977.476 987.487 985.416 1017.998
CHAINAGES
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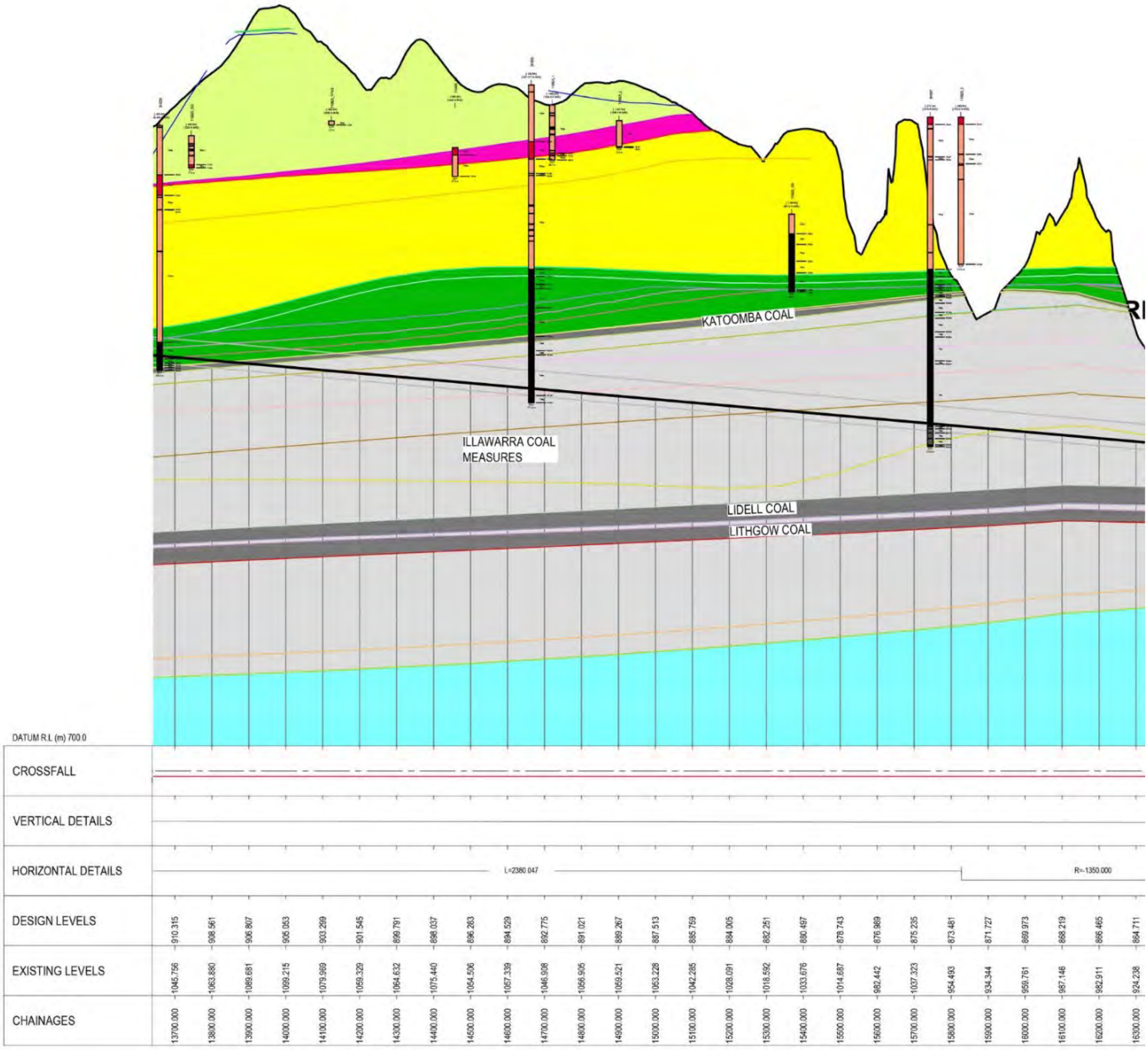
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ILLAWARRA COAL MEASURES
LIDELL COAL
LITHGOW COAL
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CROSSFALL
VERTICAL DETAILS
HORIZONTAL DETAILS
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R=-1350.000
DESIGN LEVELS
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EXISTING LEVELS
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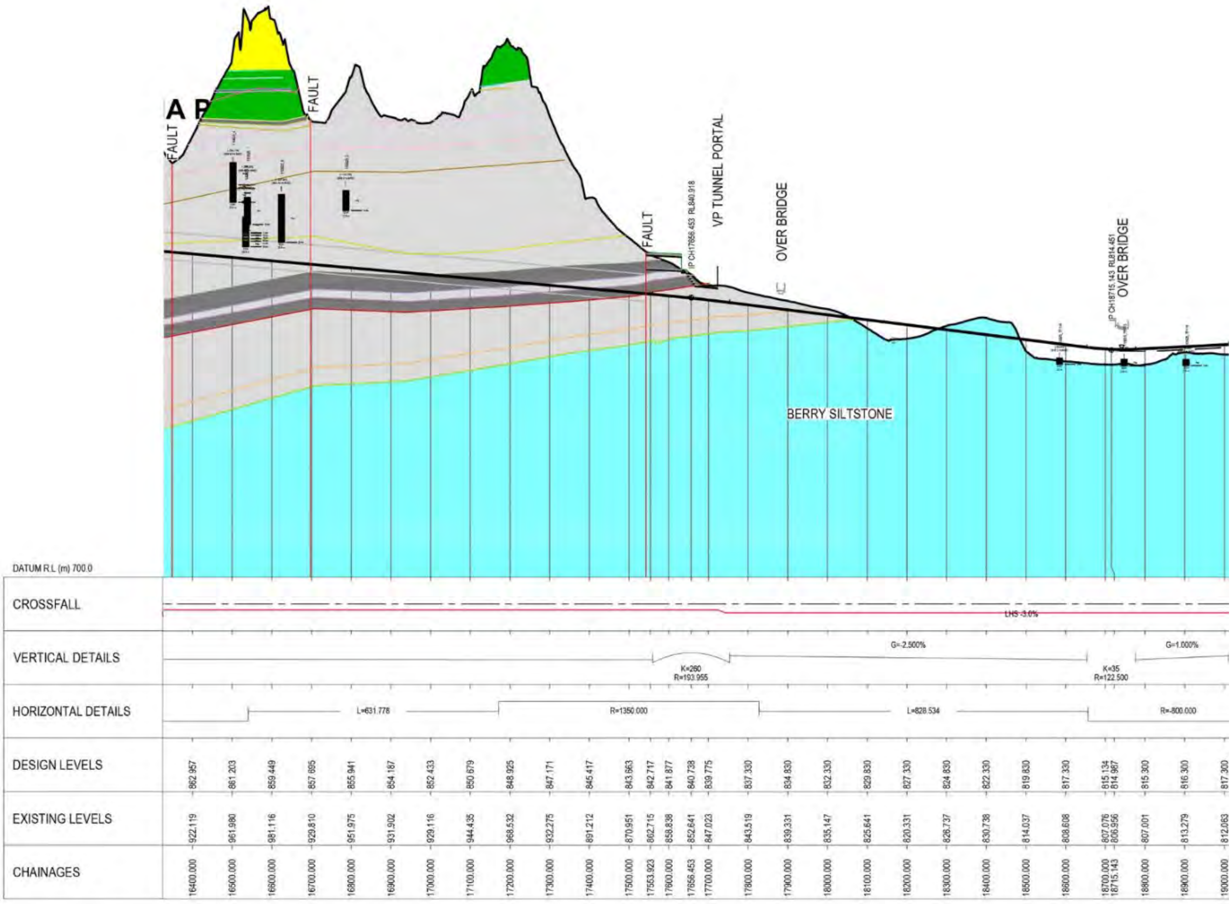
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OVER BRIDGE
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G=-2.500%
K=35
R=122.500
G=1.000%
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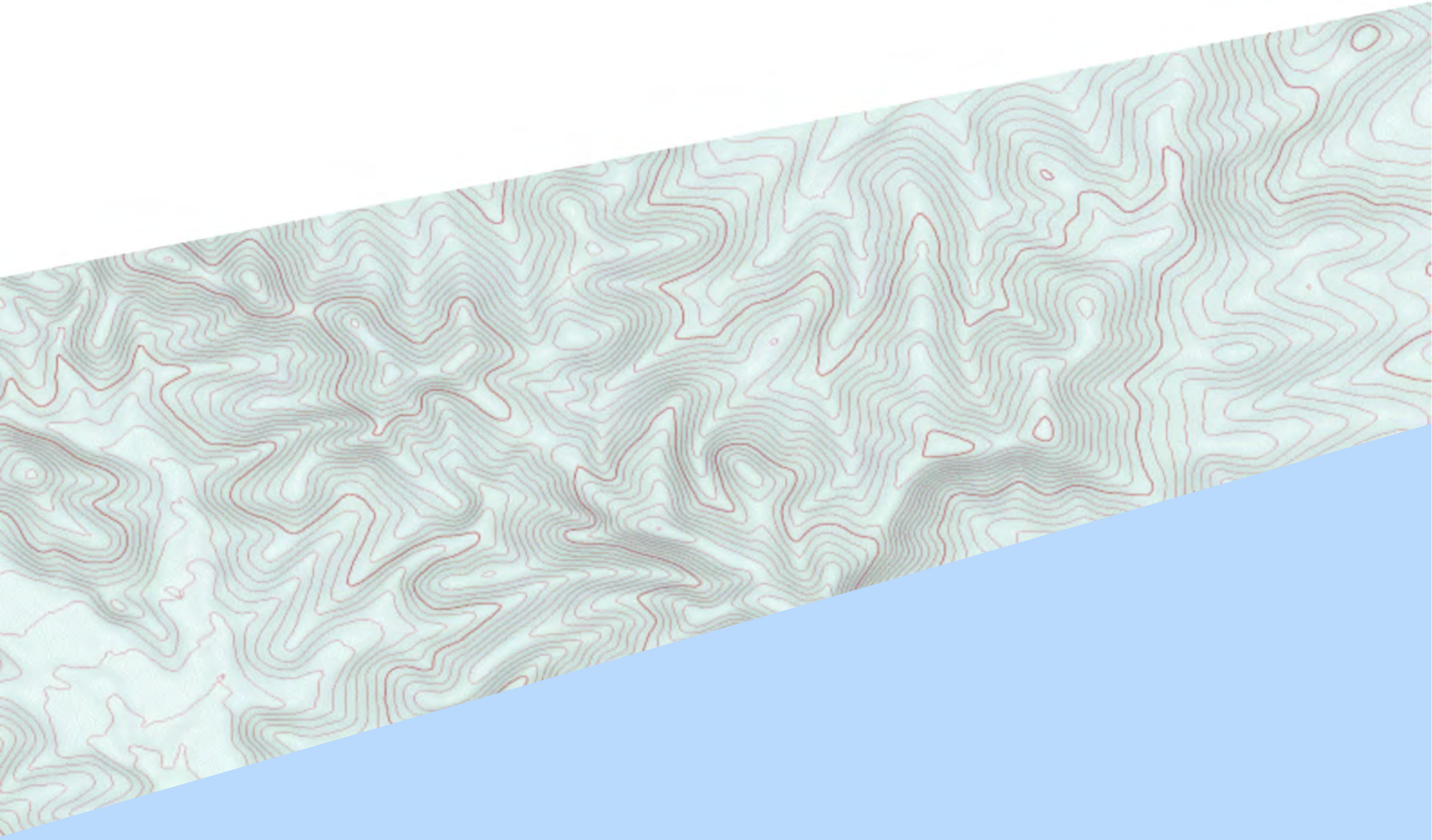
Annexure B

Numerical Groundwater Modelling Report

WATERSHED HYDROGEO



Great Western Highway – Blackheath to Little Hartley

Groundwater Modelling Report

for the Environmental Impact Statement

January 2023

Document ID
GWHC-AEAU-GWH-GE-RPT-000016

Document Register

Revision	Date	Comments
A	02/09/2022	Draft for comment
B	13/09/2022	Revised draft for AECOM review
C	16/09/2022	Revised addressing AECOM and early Transport comments
D	07/10/2022	Revised following reviewer comments, all sections populated
E	26/10/2022	Revised following comments from Peer Reviewer, Transport, AAJV hydrogeology/geotechnical/tunnelling/EA teams. Document prepared for the EIS/EA - Draft for DPE Consistency Review.
F	01/01/2023	Minor revision following DPE Consistency Review

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Quality Control

Process	Staff	Signature	Date
Authors	Will Minchin	WMinchin	01/01/2023
Approved	Hayden Seear (AECOM)		01/01/2023

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Abbreviations

Abbreviation	Meaning
AGMG	Australian Groundwater Modelling Guidelines
AIP	Aquifer Interference Policy (NSW government)
BoM	Bureau of Meteorology
DPE	NSW Department of Planning and Environment
EPA	NSW Environment Protection Authority
IESC	Independent Expert Scientific Committee (advising Federal and state governments)
L/s	Litres per second
mAHD	Metres above Australian Height Datum (effectively elevation as metres above sea level)
mBG	Metres below ground
ML/d	Megalitres per day
QOI	Quantity of Interest (i.e. primary or key predictions required from the numerical model)
TEC	Threatened Ecological Community (either Federally or State-listed)
THPSS	Temperate Highland Peat Swamps on Sandstone

Glossary of key construction and modelling terminology

Word	Meaning
Drained	A subsurface feature at which groundwater ingress or inflow can occur (depending on groundwater pressures and excavation geometry), and at which that water needs to be continually or regularly managed ('drained') to allow safe access.
Tanked	A subsurface feature that is constructed to effectively prevent groundwater ingress.
Model realisation	Given uncertainty in a hydrogeological system, which is the inability to know the exact value of hydraulic properties (e.g. permeability, porosity), a set of many plausible sets of parameters are modelled. Each of these is a realisation.
Model ensemble	This is the set of realisations used stochastically to simulate the project area and the project. Each realisation within the ensemble is plausible, and so the ensemble is used to estimate the approximate probability of some quantum of inflow or drawdown.
"modelled", "model representation"	How a feature/process is represented in a numerical model (i.e. model package, inputs, parameters)
"simulated" or "modelled"	Model outputs (e.g. groundwater levels, drawdown, inflow) when comparing to observations (in a historical / calibration period)
"model-predicted" or "projected"	Model outputs (e.g. groundwater levels, drawdown, inflow) in a future period or scenario
"projection"	Use of a numerical model in a subjective sense to make an estimate of future behaviour (e.g. the results of a single model realisation/scenario)
"forecast"	Use of a numerical model in a systematic sense to make an estimate of future behaviour to inform decision-making/impact assessment (i.e. the summary statistics from an ensemble) [although there is subjectivity in all modelling]

1 Introduction

The Great Western Highway is the key east-west road freight and transport route between Sydney and Central West New South Wales (NSW) (**Figure 1-1**). Together, the Australian Government and the NSW Government are investing more than $4.5 billion towards upgrading the Great Western Highway between Katoomba and Lithgow (the Upgrade Program). Once upgraded, over 95 kilometres of the Great Western Highway will be two lanes in each direction between Emu Plains and Wallerawang.

The Upgrade Program comprises the following components:

- Great Western Highway Upgrade – Medlow Bath (Medlow Bath Upgrade): upgrade and duplication of the existing surface road corridor with intersection improvements and a new pedestrian bridge (approved)
- Great Western Highway East – Katoomba to Blackheath (Katoomba to Blackheath Upgrade): upgrade, duplication and widening of the existing surface road corridor, with connections to the existing Great Western Highway east of Blackheath (approved)
- Great Western Highway Upgrade Program – Little Hartley to Lithgow (West Section) (Little Hartley to Lithgow Upgrade): upgrade, duplication and widening of the existing surface road corridor, with connections to the existing Great Western Highway at Little Hartley (approved)
- Great Western Highway Blackheath to Little Hartley: construction and operation of a twin tunnel bypass of Blackheath and Mount Victoria and surface road works for tie-ins to the east and west of the tunnel (the project).

The components of the Upgrade Program are shown in **Figure 1-2**.

Transport for NSW (Transport) is seeking approval under Division 5.2, Part 5 of the Environmental Planning and Assessment Act 1979 (NSW) (EP&A Act) to upgrade the Great Western Highway between Blackheath and Little Hartley (the project).

The project would comprise the construction and operation of new twin tunnels around 11 kilometres in length between Blackheath and Little Hartley, and associated surface road upgrade work for tie-ins to the east and west of the proposed tunnel portals.

The project would be located around 90 kilometres west of the Sydney CBD (**Figure 1-1**) and located within the Blue Mountains and Lithgow Local Government Areas (LGA).

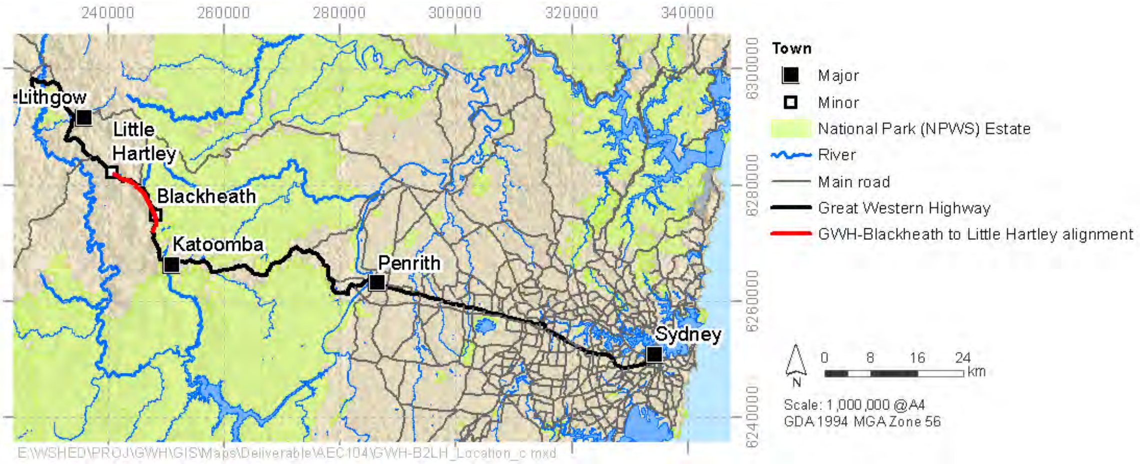


Figure 1-1 Great Western Highway location plan

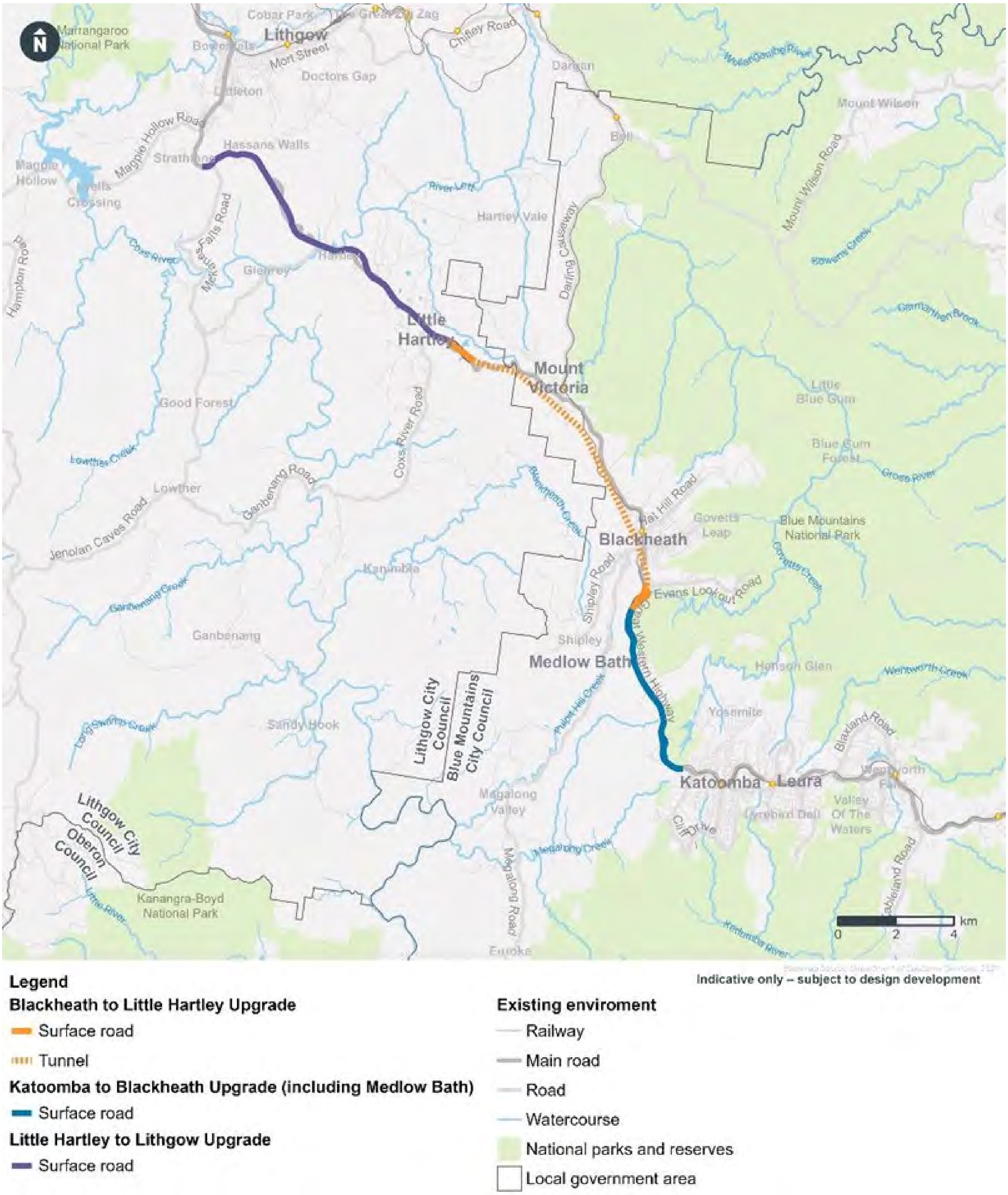


Figure 1-2 Great Western Highway Blackheath to Little Hartley Upgrade and broader Program

The majority of the project would be located below ground generally along or adjacent to the west of the existing Great Western Highway between around Blackheath and Little Hartley. An Environmental Impact Statement (EIS) is being prepared to meet the Department of Planning (DPE) Secretary's Environmental Assessment Requirements (SEARs) for the project as part of planning approval process. This report describes the groundwater modelling component of the Groundwater Assessment (AECOM, 2022) that informs the EIS for the project as well as informing design considerations.

1.1 Project context

1.1.1 Topographic context

The Great Western Highway forms a key link between Sydney and inland NSW through the Blue Mountains where transport routes are constrained by the rugged topography. The existing Great Western Highway between Blackheath and Mt Victoria (shown in **Figure 1-2**) generally follows the alignment of Coxs Road, the original road constructed across the mountains in 1815. The route follows a ridgeline between the Grose Valley (to the east) and the Kanimbla Valley (to the west). The road then descends through an escarpment to the floor of the Hartley Valley via Victoria Pass.

The towns of Blackheath and Mt Victoria are located around railway stations where there are areas of flat to moderately sloping land suitable for development. Between these towns the ridgeline is narrow and bounded on both sides by steeply sided valleys, often containing hanging swamps, that drain to the World Heritage-listed Blue Mountains National Park (to the east) and crown reserves (to the west).

The southern end of the project, south of Blackheath, is located between the rail corridor and the Blackheath Special Area (Drinking Water Catchment) (**Figure 1-4**) that protects the catchment of Lake Greaves and Lake Medlow that provide potable water supply to the upper Mountains.

Victoria Pass descends through the escarpment by contouring down a spur running east-west off the main ridgeline. This alignment is steep (up to 1 in 8) and contains heritage constraints, including buttressed sandstone walls that bridge a gap between sandstone cliff lines. From the foot of Victoria Pass the alignment crosses the undulating valley floor to the junction of the Great Western Highway and Ambermere Drive.

1.1.2 Great Western Highway – Blackheath to Little Hartley Upgrade

Transport intends to construct a tunnel (of approximately 11 km) between the village of Little Hartley, in the northwest, to Blackheath, in the southeast of the project area (**Figure 1-2** and **Figure 1-4**). The tunnel would be constructed between two portals, the Western (or Little Hartley) Portal and the Eastern (or Blackheath) Portal and includes associated mid-tunnel access point and enlargements.

The key features of the project tunnel design and construction methods, with respect to groundwater effects and simulation in the groundwater model, are described in Section 1.2 and sub-sections

1.2 The project

The project layout is shown on **Figure 1-4**. The main components, with respect to effects on the groundwater system (and subsequent modelling), are described in the following sections. The details presented are assumptions based on existing available geotechnical and groundwater information. As such, the following sections describe the currently preferred construction method that has been assumed for the purposes of this groundwater modelling and impact assessment. Additional geotechnical and groundwater data would be available in the future, and which would be used to further inform further design development and detailed construction planning. Timing and methods, including the TBM type(s) selected, may change as part of that process.

For context, although the tunnel alignment within the project area is primarily north-south oriented, the general direction of the Great Western Highway is east-west, i.e. travelling north means travelling on the westbound lanes, while travelling south means travelling on the eastbound lanes. The “eastbound”/”westbound” or “eastern”/”western” descriptors are adopted here for consistency with other project documentation.

1.2.1 Construction program and timing

The following is a summary of the construction schedule assumed for the numerical simulation of the project activities. The construction schedule is summarised in **Figure 1-3**. Preliminary construction works are planned to commence in mid-2024, subject to planning approval. The portal and shaft excavations are planned to commence later in 2024. Twin tunnelling activities are planned to begin in late-2025 and are estimated to be complete by mid-2029.

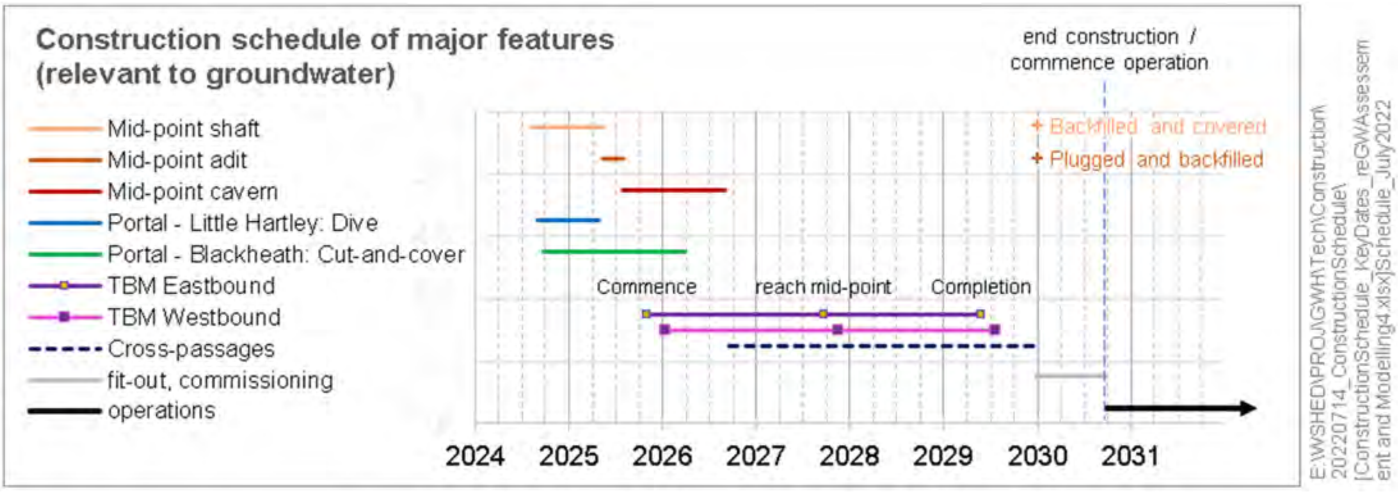


Figure 1-3 Construction schedule of major features related to groundwater assessment

Operation of the tunnel is planned for late 2030. For simplicity, the later modelling assumes the operational period commences in Q4 2030.

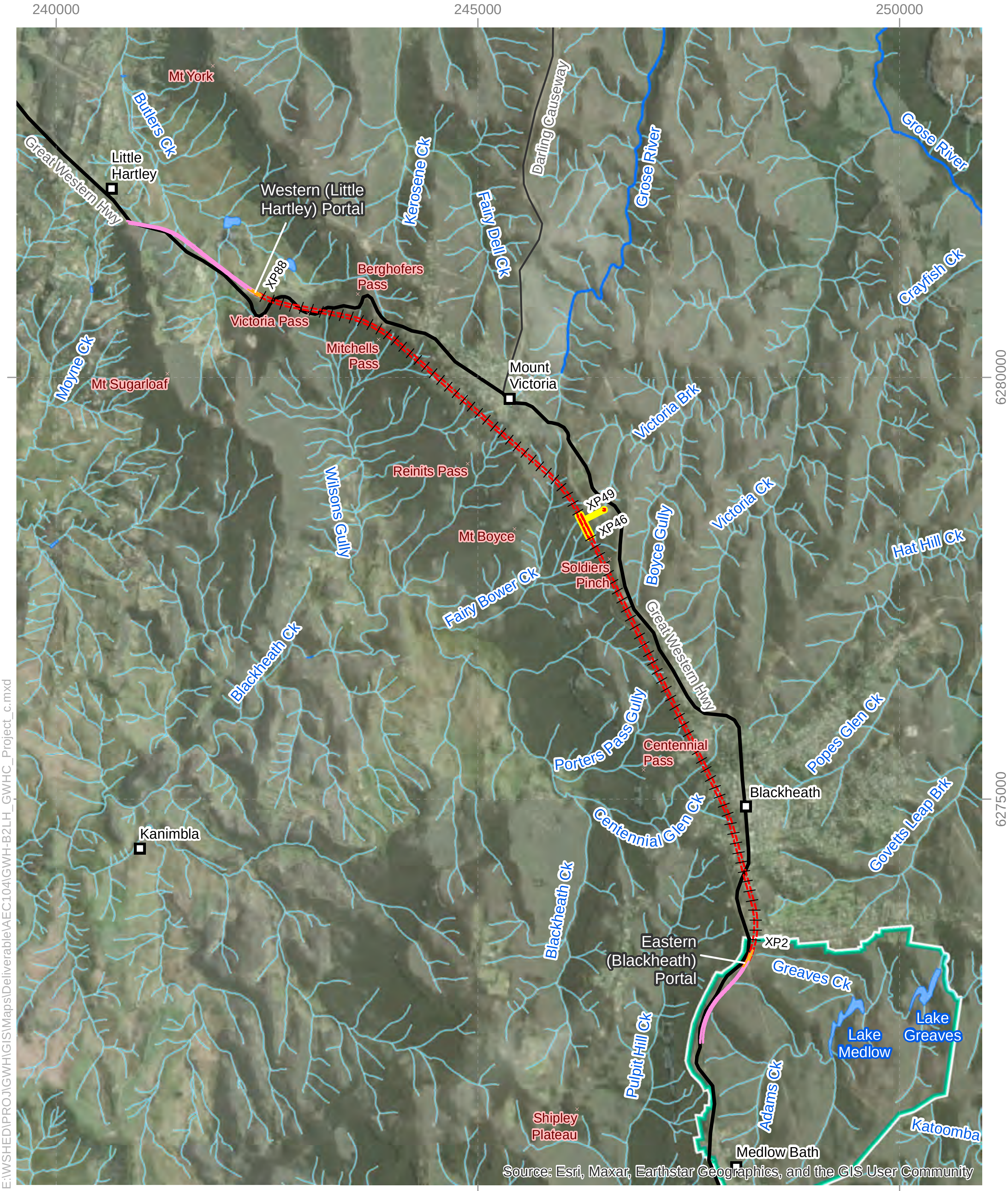
Transport’s nominated Design Life of the tunnel is 100 years.

1.2.2 Tunnel design

Refer to EIS Section 4 (Project Description) and 5 (Construction). This section also relies on advice provided by project designers and geotechnical engineers throughout model development.

The project comprises twin tunnels approximately 11 kilometres in length that between Blackheath and Little Hartley. Each tunnel is planned to have a carriageway approximately 10.5 metres (m) wide, including two lanes plus shoulders. The diameter of each tunnel is planned to be approximately 15 m. The twin tunnels would be constructed with an approximate 17 m separation between their centrelines, meaning the tunnels are approximately 11 m apart. The total width of highway (the two tunnels and separation) would be approximately 40 m (see **Figure 1-5**, **Figure 1-9** and **Figure 1-11**). Tunnelling would be performed using two tunnel boring machines (TBMs), one for each tunnel.

At the western end of the project, the Great Western Highway would join the tunnels’ western (Little Hartley) portal at an elevation of approximately 838 mAHD, proceeding through a cut-and-cover section (Section 1.2.8).



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Town
- Major
- Minor
- Landscape feature
- Main road
- Great Western Highway
- River
- Creek
- WaterNSW Special Area
- GWH project alignment - Surface
- GWH project alignment - Tunnel
- Cross-passage location (feature not to scale)
- Cut and Cover section
- Mid-point infrastructure

N
0 0.5 1 1.5 km
Scale: 60,000 @A4
GDA 1994 MGA Zone 56

GWH-B2LH

GWH Blackheath to Little Hartley project layout

Figure 1-4

From the western portal, the tunnels would progress in a generally south-easterly direction at an upward gradient, intersecting or passing through a range of geological formations (the stratigraphic sequence, including a long-section, is described in Section 2.4.3).

As the tunnel progress in a generally south-easterly direction the thickness of overburden material increases, from nil at the Little Hartley portal to approximately 180 m near Mount Victoria.

Continuing in a generally south-southeasterly direction from Mount Victoria the overburden thins as the tunnel continues to rise at a consistent gradient, until it reaches ground surface at the eastern (Blackheath) portal at an elevation of approximately 1035 mAHD, again passing through a cut-and-cover section (Section 1.2.7).

The design and construction approach, with respect to potential groundwater effects, is described in the following sub-sections.

1.2.3 TBM tunnels

The assumption is that from the Little Hartley portal to the mid-tunnel cavern (Section 1.2.6) the tunnels would be constructed using a ‘earth pressure balance’ (EPB) TBM for which slurry is added at the cutting face to stabilise the tunnel face. This means there is no period for which the tunnel is open between initial excavation and installation of the tunnel lining, i.e. this method of balancing pressure prevents groundwater inflow to the tunnel and prevents associated groundwater drawdown.

The assumption is that tunnels from the mid-tunnel cavern to Blackheath portal would be constructed using a ‘single-shield’ TBM method. This means that the pressure at the face is not maintained, and groundwater ingress to each section of the tunnel could occur, but only for a period of a few hours before the precast concrete segmental lining is installed. As such, there is the potential for negligible to minor groundwater ingress into the un-lined sections before these tunnels are fully ‘tanked’ (i.e. constructed to essentially prevent groundwater ingress).

As a TBM moves forward, precast concrete segmental lining rings are installed in the excavated tunnel behind the cutting head and this low permeability material effectively prevents groundwater ingress. Gaps in the tunnel lining would be filled with cement-based grout (typically with a hydraulic conductivity of approximately 1E-3 m/d). It is acknowledged that a very minor or negligible residual rate of seepage is likely in localised areas, however the completed lining is considered ‘tanked’ and is designed to withstand up to 50 m of groundwater head to minimise groundwater ingress in the long-term. We note that existing or in situ groundwater pressures monitored at the project site are significantly lower than this, except in the lower Burra-Moko Head Sandstone where pressures of 30-48 m have been observed (AECOM, 2022).

It is expected that the TBMs would progress eastbound on an uphill slope at an average rate of between around 70 to 90 m per week.

Once the TBMs reach the mid-tunnel caverns the excavation approach would change from an EPB to a single shield TBM (as described above). The selection of TBM method has been made due to expected geological conditions, rather than groundwater conditions, based on knowledge to this point. The actual TBM method adopted may be further subject to review as additional information becomes available. The EPB TBM stabilises the tunnel in the less stable geology (Permian-age strata) identified to the west of the mid-tunnel cavern, whereas the geology east of mid-tunnel cavern (i.e. Triassic-age and sandstone-rich strata) is anticipated to be more stable, as indicated by project geotechnical engineers.

The total tunnelling time for the TBMs is anticipated to be around 3.5 years. For the purpose of modelling, TBM launch is assumed in November 2025 (and January 2026. The two TBMs are assumed to arrive at the mid-tunnel cavern in approximately September 2027 and November 2027, respectively. TBM retrieval at the Blackheath portals is assumed to occur in mid-2029.

1.2.4 Cross-passages

Refer to EIS Section 4 (Project Description) and Section 5 (Construction).

Cross-passages would connect the two tunnels at regular intervals along their length. A total of 85 cross-passages are currently assumed, spaced at approximately 120 m for plant items such as substations and to allow emergency pedestrian egress between tunnels when an incident occurs in one tunnel.

Figure 1-4 shows the indicative locations of the proposed cross-passages. Those at the ends of the two main sections of the TBM tunnels are labelled, i.e. XP2 near the Blackheath portal, XP46 and X49 on either side of the mid-tunnel caverns, and XP88 at the Little Hartley portal.

The indicative easting/northing and floor elevation of the cross-passages has been provided for input to the groundwater model. The cross-passages are approximately 11 m long between the outer edge of the mainline tunnels and would be approximately 6 m wide and high (**Figure 1-5**).

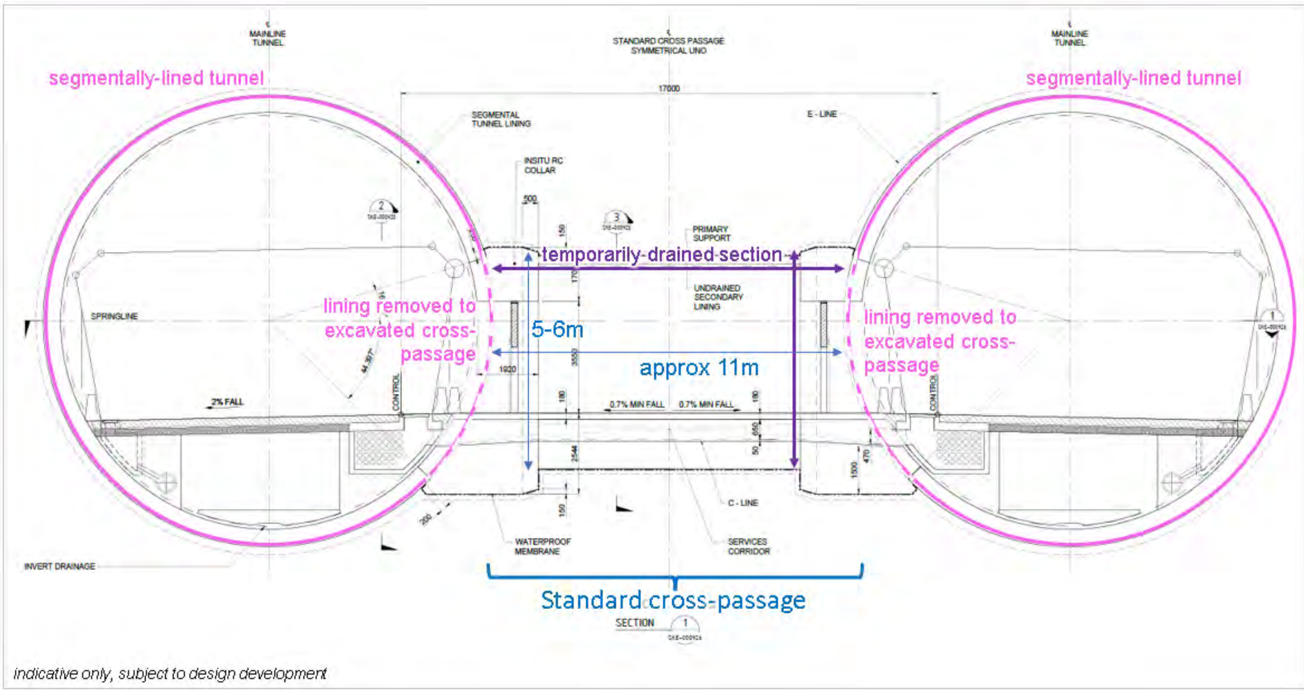

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Figure 1-5 Indicative cross-passage design

Opening of the tunnel linings to allow excavation and construction of the cross-passages would occur some months behind TBM excavation and lining. Based on the construction schedule, the assumption is that this would occur approximately six (6) months after the TBMs have passed a cross-passage location.

Construction of these cross-passages would follow a sequence of opening the installed pre-cast tunnel lining, then constructing the passage by sequentially excavating with a roadheader and supporting the excavation with shotcrete and rockbolts. During this time, the passage would be open to groundwater ingress (i.e. 'drained'). For the purposes of assessment it has been assumed that each cross-passage would be 'drained' for around three (3) months, after which time waterproofing and concrete lining would be completed.

Prior to breaking through the tunnel liner, test holes would be drilled through the segmental lining to assess rock mass permeability. If groundwater flow into the test holes was identified as high enough to suggest it may impede construction of the cross-passage, pre-grouting would be undertaken prior to cross-passage excavation to reduce rock mass permeability.

1.2.5 Mid-tunnel access shaft and adit

Refer to EIS Section 4 (Project Description) and 5 (Construction).

At the mid-point of the tunnel alignment (near Soldier's Pinch - **Figure 1-4**), an access shaft would be constructed to allow subsequent development of the mid-tunnel cavern or enlargements (discussed below). The assumed design of this shaft is presented on **Figure 1-6**.

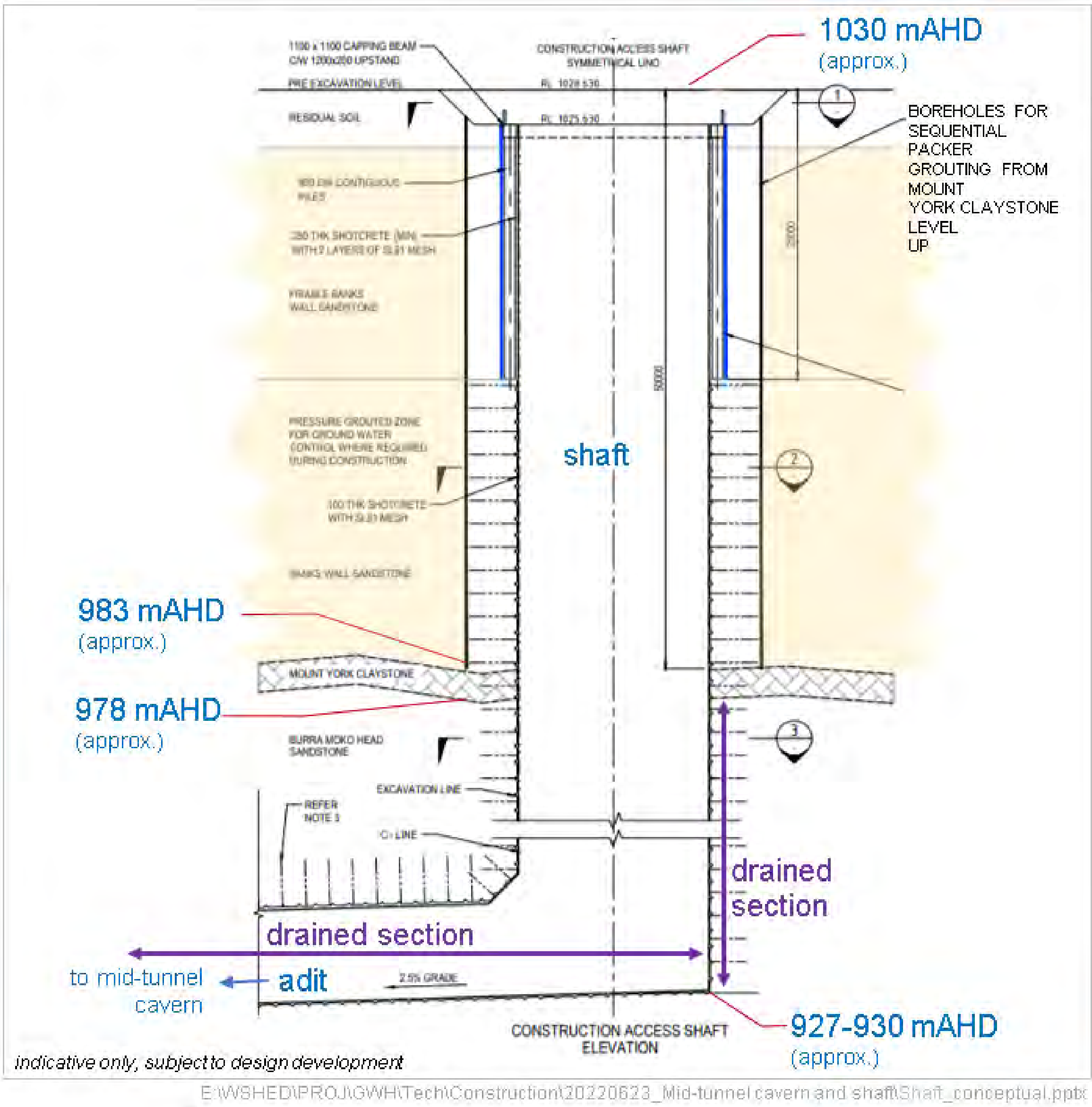

Figure 1-6 Assumed construction method for mid-tunnel access shaft

As shown on **Figure 1-6,** the access shaft would be sunk to approximately 100 mBG so that it terminates within the Burra-Moko Head Sandstone at a floor elevation of approximately 927 mAHD.

The upper section of this shaft (through the Banks Wall Sandstone down to the Mount York Claystone) would be lined to minimise groundwater ingress (i.e. "tanked"). In the Burra-Moko Head Sandstone (below the Mount York Claystone) this feature will be drained during construction.

The diameter of the shaft would be approximately 16 m, although effectively slightly wider in the upper section of the shaft to accommodate secondary lining and piles.

An adit would be constructed to link the shaft to the caverns (Section 1.2.6) located approximately 280 m to the west. This adit would be 'drained' during the construction period.

At the end of the construction phase, the adit would be plugged and the shaft would be backfilled with alternating layers of flowable fill (a self-levelling mortar applied as a fluid to fill spaces with restricted access) and compacted backfill (**Figure 1-7**). A cover structure would also be installed at the top of the shaft to prevent infiltration of surface water and rainfall.

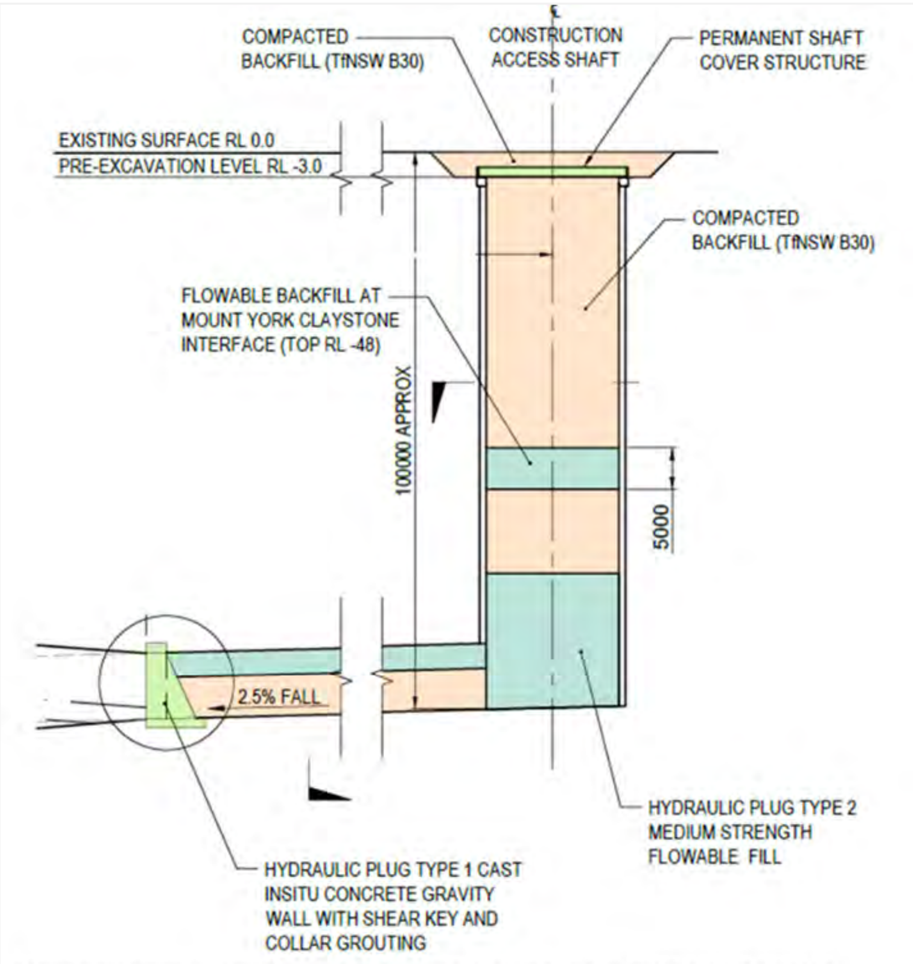

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Figure 1-7 **Indicative method to backfill of mid-tunnel shaft and adit**

For simulation it has been assumed that after backfilling, the hydraulic conductivity and storage of the interior of the shaft and adit would return to pre-excavation properties. Given the location of the hydraulic plug in the adit (**Figure 1-7** and Section 1.2.6), this simplification is reasonable.

1.2.6 Mid-tunnel caverns

The mid-tunnel caverns (also referred to as the Midpoint Enlargement) would be constructed at the mid-point of the tunnels to support TBM refurbishment and other construction activities including tunnel fit out. Roadheaders would be used to excavate caverns.

The caverns would be approximately 230 m long (along the tunnel alignment) and approximately 21 m wide. The two caverns would be separated by a central pillar (approximately 9 m wide), however from a regional groundwater impact perspective can be considered to be a single feature.

For simulation, the floor of the mid-tunnel cavern has been assumed as having the following:

Location	Chainage	TBM invert elevation	Constructed floor elevation
Eastern end	12570	925.3 mAHD	930.3 mAHD
Western end	12800	921.6 mAHD	926.3 mAHD

Figure **1-8** presents a cross-section showing these features in relation to stratigraphy and receptors, duplicated from the Groundwater Technical Report (AECOM, 2022).

The caverns would typically be approximately 11-12 m high from the road surface to the roof, except for the section where the TBM would traverse the cavern (the invert of the TBM would be approximately 5 m lower, making the height of the roof approximately 15 m along the path of the TBM). The mid-tunnel caverns would be constructed within the Burra-Moko Head Sandstone.

The mid-tunnel caverns are proposed to be un-lined and therefore considered a permanently 'drained' feature (simulated of this described in Section 2.5.7).

Southwest-Northeast through mid-tunnel facilities, looking north

Illustrating pre-existing groundwater levels and predicted drawdown during construction

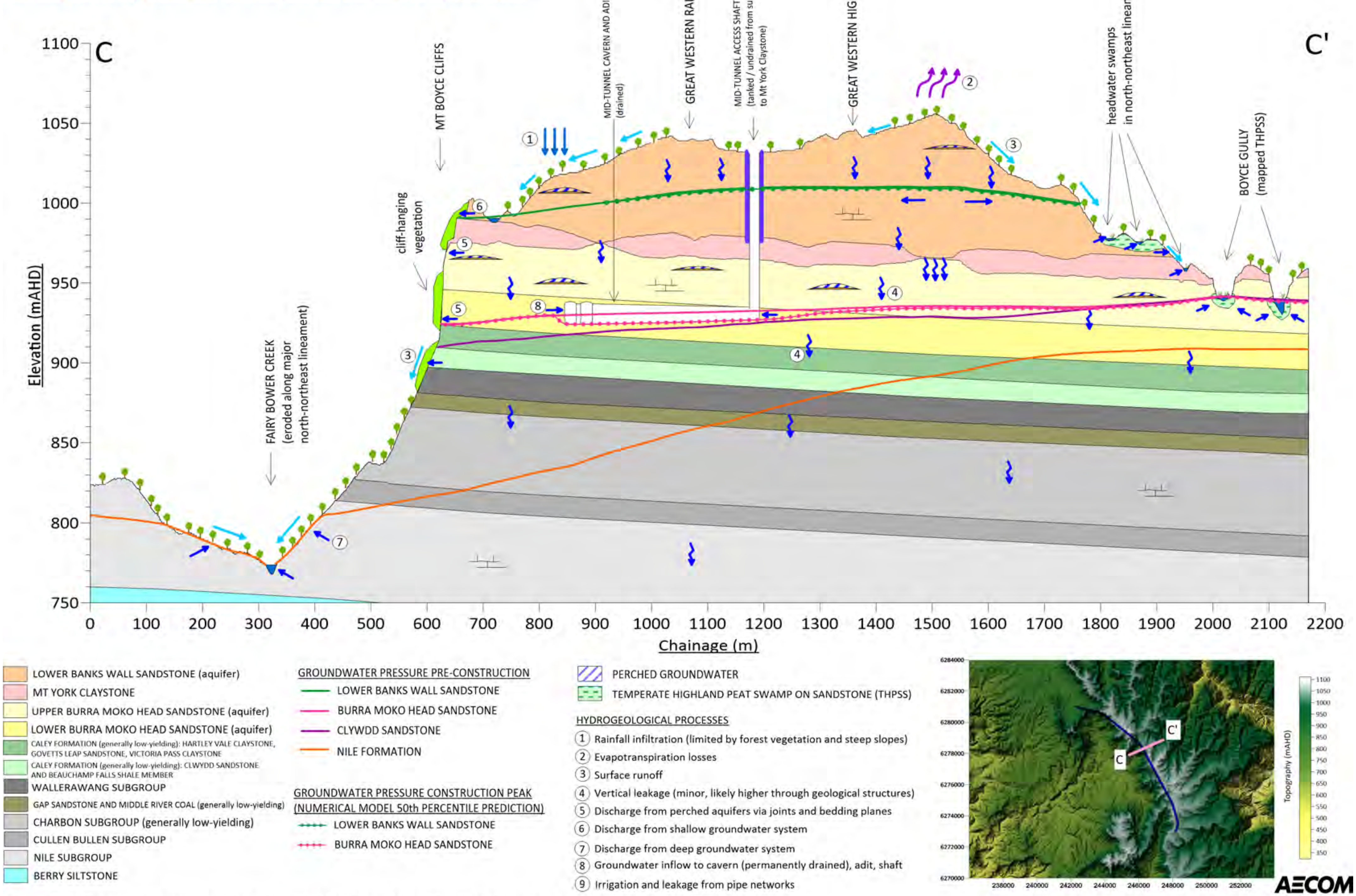


Figure 1-8 Conceptual cross-section through Mid-Tunnel facilities (looking north)

1.2.7 Portal – Blackheath

Just south of Blackheath, the westbound lanes of the Great Western Highway enter the tunnel at one portal, which is offset by 50 m from the portal for the eastbound lanes. The section between the portal(s) and the end of the TBM-constructed or driven tunnel is to be constructed as a cut-and-cover structure. The cut-and-cover sections would be approximately 190 m (westbound) and approximately 140 m (eastbound). **Figure 1-9** shows the arrangement.

Figure 1-9 Blackheath Portal – general arrangement and construction methods

For the cut and cover sections, excavation (cut) would be followed by construction of walls prior to covering to form the tunnel entrance. These sections are proposed to be ‘drained’ permanently. The cut-and-cover sections are proposed to be:

- approximately 50 m west of the mapped top of Greaves Creek (which flows to the east), and is part of a declared Special Area and source of water supply for the Upper Blue Mountains area (**Figure 1-4**);
- approximately 340 m southeast of the nearest Upland Swamp;
- approximately 530 m east of the second nearest Upland Swamp (located on Greaves Creek).

An assumed elevation profile was provided by designers and was used for setting up model boundary conditions (Section 2.5.7).

To the immediate south of this, the project would connect with the Katoomba to Blackheath Upgrade (Great Western Highway Upgrade East project - **Figure 1-2**).

The Groundwater Technical Report (AECOM, 2022) presents a number of cross-sections showing the project features in relation to stratigraphy and natural features. **Figure 1-10** presents the conceptual cross-section for the Blackheath portal, showing its location on the ridgeline between the Pulpit Hill Creek/Coxs River catchment (west) and near the headwaters of the Greaves Creek catchment (east).

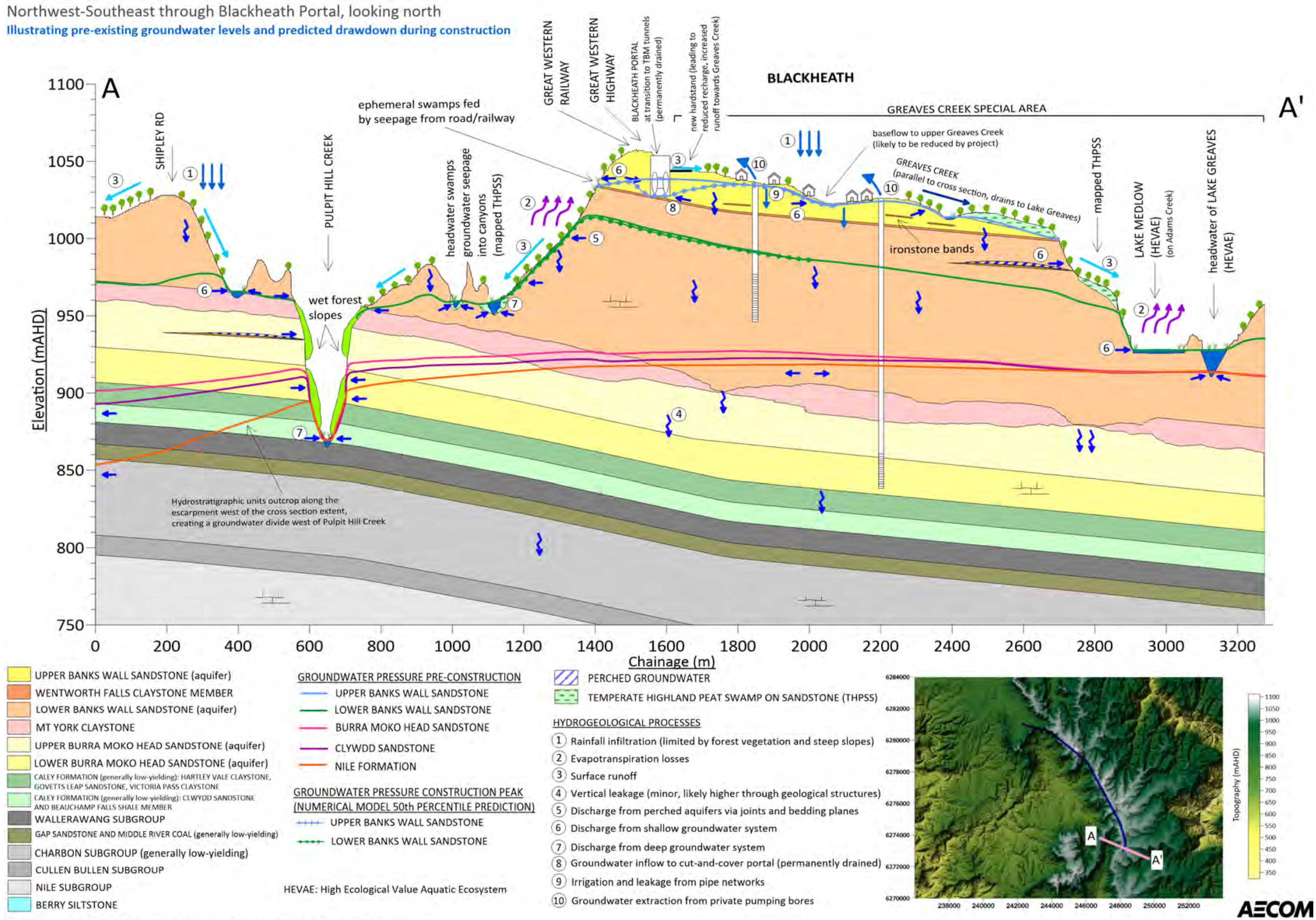


Figure 1-10 Conceptual cross-section through Blackheath portal

1.2.8 Portal – Little Hartley

Approximately 145-180 m of the tunnel at the Little Hartley portal would be cut-and-cover, with the longer cut-and-cover section for the westbound lanes. The arrangement is shown on **Figure 1-11**. Excavation (cut) would be followed by construction of walls prior to covering to form the tunnel. These sections would be 'drained' permanently.

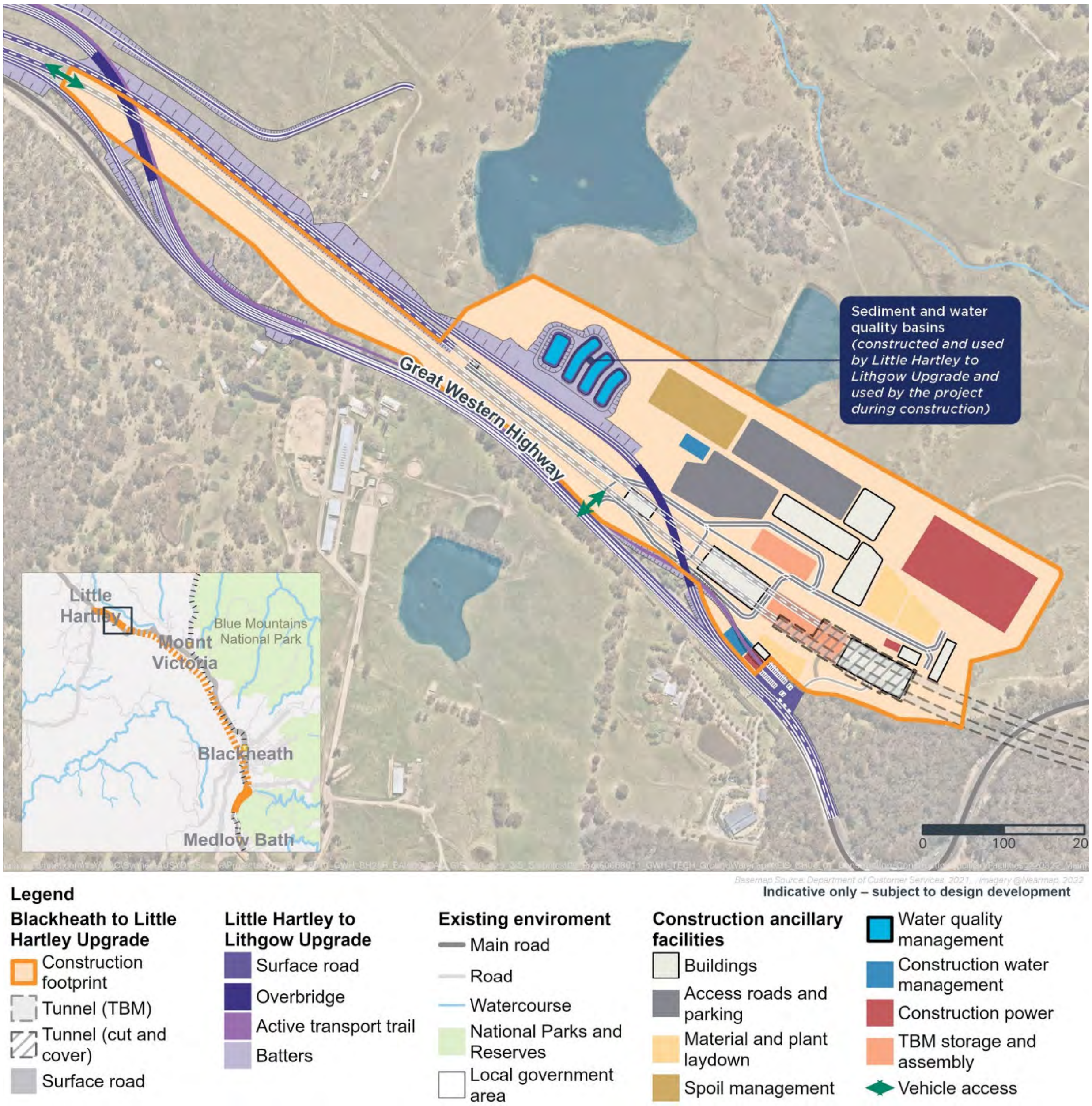


Figure 1-11 Little Hartley Portal – general arrangement and construction methods

An assumed elevation profile provided by designers was used for setting up model boundary conditions (Section 2.5.7).

A conceptual cross-section from the Groundwater Technical Report is presented in **Figure 1-12**. This shows the drained portal in the context of stratigraphy and nearby environmental features, including Threatened Ecological Communities (TECs) around Butlers Creek to the north of the alignment. Northwest of the portal, the project would connect with the Little Hartley to Lithgow Upgrade (**Figure 1-2**).

Southwest-Northeast through Little Hartley Portal, looking north

Illustrating pre-existing groundwater levels and predicted drawdown during construction

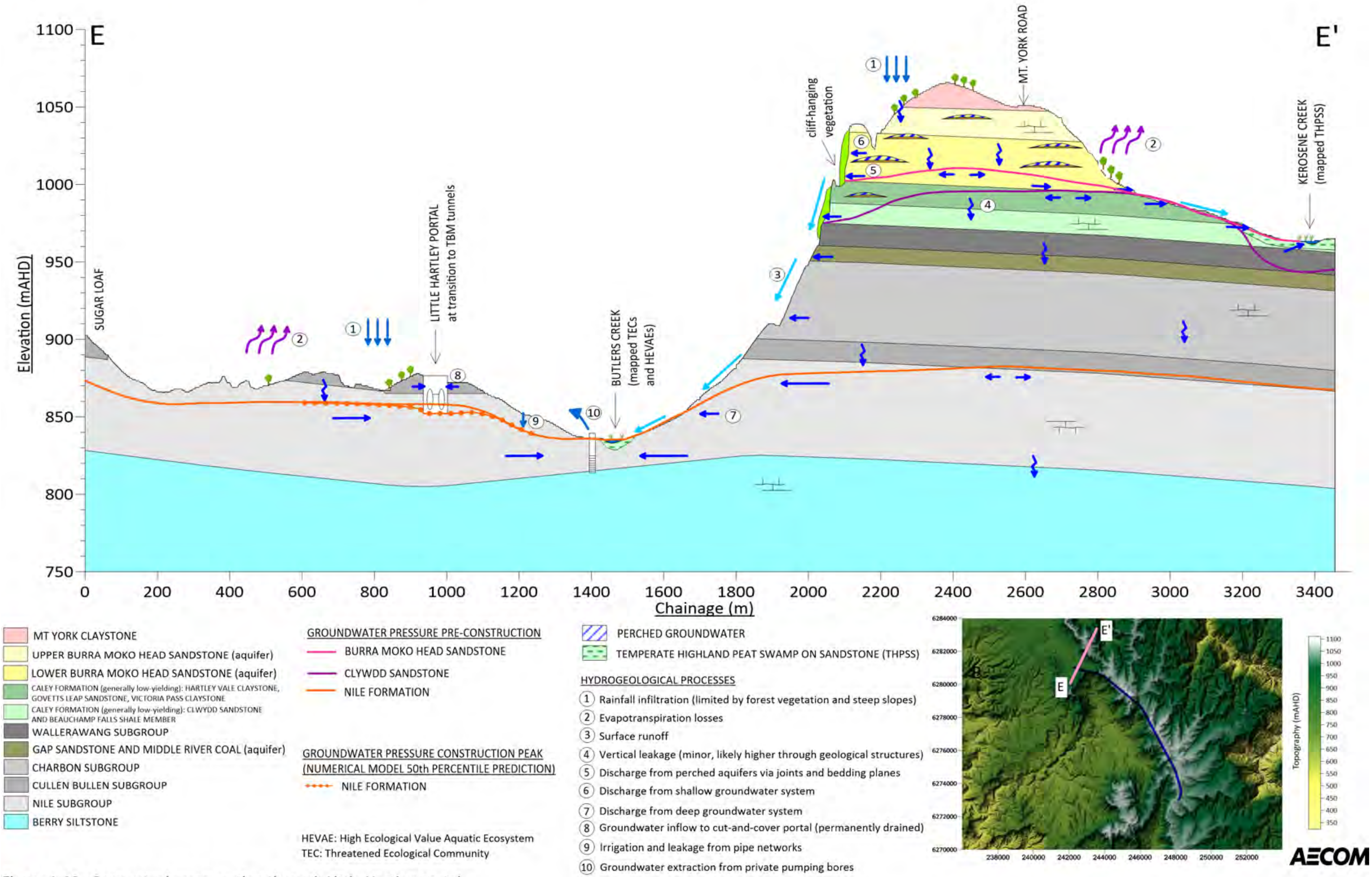


Figure 1-12 Conceptual cross-section through Little Hartley portal

1.2.9 Coal seam gas drainage

(refer to Chapter 22 of the EIS)

Coal seams of varying thicknesses will be directly intersected during tunnel construction between Mount Victoria and Little Hartley. Therefore, coal seam gas may be sorbed to the coal seams. Risks of coal seam gas desorption, and resultant risks to safety, can occur when dewatering reduces hydrostatic pressure. This would be mitigated via advance investigation and possibly gas drainage.

Gas drainage would involve depressurising the coal seams (of gas and water). However the quantities involved and short period for which this would be required mean that this is not assessed in the numerical modelling.

1.3 Purpose and scope of this report

This groundwater modelling assessment provides information to Transport and regulators about potential groundwater behaviour in response to tunnel and infrastructure construction and operation. This assessment estimates the inflow of groundwater to the tunnel, and the resultant impacts of the project on groundwater, watercourses and other water features. The potential for cumulative effects related to other relevant projects was considered.

The assessment must meet requirements from a number of sources:

- NSW Aquifer Interference Policy 2012 ('AIP').
- Recommendations for licensing under the Water Management Act 2000.
- DPE SSD Guidelines (released by DPE during this study).
- Project SEARS set by DPE; and
- Recommendations made by other agencies.

1.3.1 Secretary's Environmental Assessment Requirements (SEARs)

SEARs for application SSI-22004371 were issued by DPE on 27/08/2021. Items from the SEARs relevant to this Groundwater Modelling assessment are listed in **Table 1-1**.

Table 1-1 Summary of DPE SEARs (27/08/2021) – groundwater-related issues

Ref. in SEARs	Issue	Reference in this document (or EIS)
General requirements		
2	For each key issue, the EIS must include a summary of the results of the assessment of the potential impacts of the project undertaken in detailed studies, including:	
	(a) a summary of the condition of the existing environment;	Groundwater hydrology described in the Groundwater Technical Report (EIS Appendix I) and EIS Chapter 13.

Ref. in SEARs	Issue	Reference in this document (or EIS)
17) Water - hydrology		
1	Describe (and map) the existing hydrological regime for any surface and groundwater resources (including reliance by users and for ecological purposes or by groundwater dependent ecosystems) likely to be impacted by the project, including stream orders, as well as the location of all proposed intake and discharge locations	Groundwater hydrology described in Groundwater Technical Report (EIS Appendix I)
2.	Provide a detailed construction and operational water balance for ground and surface water including the volume, frequency and quality of discharges at proposed intake and discharge locations, and confirmation that any water supply needs can be sourced from an appropriately authorised and reliable supply, including the source of the supply.	Groundwater ingress presented in Section 4.5. (see EIS Chapter 5 – Construction and Chapter 14 – Water Balance).
3.	Surface and groundwater hydrological impacts of the construction and operation of the project and any ancillary facilities (both built elements and discharges) in accordance with the current guidelines, including:	Model predictions of groundwater effects and impacts in Sections 4.5 to 4.10, as well as the Groundwater Technical Report (EIS Appendix I).
	(a) natural processes within rivers and wetlands that affect the health of fluvial and riparian systems;	Not relevant to this report. Addressed in BDAR (EIS Appendix H) and Surface Water Assessment (EIS Appendix J).
	(b) impacts to downstream water-dependent fauna and flora;	Not relevant to this report. Addressed in the BDAR (EIS Appendix H). However changes to spring and stream flows are described in Section 4.7 and 4.8.
	(c) impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, barriers to flows, implications for groundwater dependent surface flows, waterfalls, hanging swamps, other ecosystems and species, groundwater users, and the potential for settlement;	Effects on groundwater hydrology described in Groundwater Technical Report. Potential for settlement is also addressed in those reports (EIS Chapter 13). Potential interruption to flow modelled as described in Section 2.6.5. Simulated drawdown effects described in Sections 4.6.2, 4.6.3, 4.6.4 and 4.6.5. Simulated changes in flux described in the following item.
	(d) changes to environmental water availability and flows, both regulated/licensed and unregulated/rules-based sources;	Simulated changes in flux to natural features are in Sections 4.7 and 4.8, potential losses from reservoirs in Section 4.9, and overall water takes in Section 4.10.

Ref. in SEARs	Issue	Reference in this document (or EIS)
	(g) water take (direct or passive) from all surface and groundwater sources with estimates of annual volumes during construction and operation.	Simulated changes in flux (water takes) described in Section 4.10. Temporal detail of groundwater take presented in Section 4.5.
4	Identify any requirements for baseline monitoring of hydrological attributes through the use of groundwater pump testing and other hydrogeological testing to assess regional impacts on aquifers, including open hole monitoring bores along and perpendicular to the tunnel alignment, to assess the existing regional hydrogeology, potential groundwater extraction impact area. The results of the baseline monitoring must be included in the EIS.	Existing monitoring and investigations described in Groundwater Technical Report. Groundwater level monitoring summarised in Section 2.7.1 of this report with respect to use as model targets. Recommendations for monitoring are presented in Section 5.1.1.
5	Identify design approaches to minimise or prevent drainage of groundwater through the use of tunnel excavation/boring methods.	Groundwater Technical Report (EIS Appendix I).
6	A series of detailed geological cross-sections and long-sections of the underground tunnel, these include:	Groundwater Technical Report (EIS Appendix I) presents cross-sections, some of which are duplicated in this report (Figure **1-8**, **Figure 1-10**, **Figure 1-12**, as well as **Figure 2-3**, **Figure 2-4**).
7	A schematic of the hydrogeological conceptual model must include geology units, known geological structures, proposed tunnel alignment, relevant monitoring bores and their relative depths, with groundwater levels and groundwater dependent ecosystems. The model must be developed in consultation with DPIE Water.	Groundwater Technical Report. Briefings with DPE Water regarding conceptualisation and model planning and updates summarised in Section 1.3.3.
8.	Assessment of groundwater impacts must be undertaken using a numerical model (steady state/transient). The model should be in a form that can be made available to DPIE Water to access along with the data used for model construction and predictions.	This report describes the groundwater modelling. Modelling conducted in MODFLOW-USG-T software, and available in Groundwater Vistas v.8 (GWV) format (discussed with DPE staff, as per Section 1.3.3).
9.	Details of the proposed groundwater monitoring to identify construction and operational impacts including changes to groundwater levels, impacts on groundwater dependent ecosystems and volume of groundwater discharges.	Recommendations for monitoring (and possible further modelling) are in Section 5.1 of this report, and in the Groundwater Technical Report (EIS Appendix I).
18) Water - quality		
1	Water quality impacts, including:	Refer to the Surface Water Assessment (EIS Appendix J).
	(i) identifying proposed monitoring locations, monitoring frequency and indicators of surface and groundwater quality. The results of the baseline monitoring must be included in the EIS	Groundwater Technical Report (EIS Appendix I).

1.3.2 NSW DPE Water Groundwater Guidelines for SSI / SSD projects

NSW DPE released the *Guidelines for Groundwater Documentation for SSD/SSI Projects* in early 2022, after the commencement of this assessment. These new guidelines related to modelling (DPE, 2022) were reviewed to confirm that the modelling approach adopted for this assessment is consistent with those guidelines. Some requirements of these new guidelines have not been met, including submission of a formal Groundwater Modelling Plan to DPE Water. However, DPE Water has been briefed periodically during the development of the groundwater numerical model for the project, including with regards to the available data, model conceptualisation and numerical modelling approach (Section 1.3.3).

1.3.3 Agency engagement

During this modelling study, AECOM and Watershed HydroGeo have engaged with DPE and DPE Water specialists on a number of occasions (**Table 1-2**) to present the project and related Groundwater Technical Report, including the modelling presented here.

Table 1-2 Briefings to DPE Water

#	Date	Reason for meeting / key agenda items
1	07/04/2022	Summary of project, present existing conditions
2	22/04/2022	Discuss proposed modelling method
3	20/07/2022	Present model build and calibration via PESTPP-IES

The main comments raised by DPE Water in those meetings are summarised below (**Table 1-3**), with a description regarding how or where that comment is addressed in this report or the over-arching Groundwater Technical Report (EIS Appendix I).

Table 1-3 Items raised by DPE Water

Meeting	DPE Comment	Response / where addressed
1	Provide examples of projects where similar segmentally lined tunnels have been used.	Provided a list in the Groundwater Technical Report (EIS Appendix I).
	Provide geological cross-section(s) to describe the project	Provided a number of sections in the Groundwater Technical Report (EIS Appendix I), with a subset duplicated in this report (Figure 1-8, Figure 1-10, Figure 1-12, as well as Figure 2-3, Figure 2-4).
	Queried whether pressure-relief was required for the tunnel?	Confined conditions not expected or spatially restricted, given lateral drainage along escarpment. Monitored pressure head briefly discussed in Section 1.2.3.
	Have existing private bores been identified, noting multiple such bores around Blackheath? Need to understand impacts/drawdowns at those users.	Registered bores have been identified. Modelled drawdowns at these are presented in Section 4.6.4.
2	Are these indications of artesian pressures?	No data gathered indicates artesian conditions. See Groundwater Technical Report (EIS Appendix I).
	Are hydrogeological parameter changes expected due to engineering activity and/or depressurisation?	None from depressurisation. In a change to what was discussed at that meeting, minor changes due to the presence of effective impermeable tunnel linings are simulated via the TVM package, as per Section 2.6.5.
	Indicated that the use of quadtree mesh, rather than more detailed unstructured mesh, was a practical approach to model construction given the potential for design changes.	Model mesh described in Section 2.4.1.
	What is the anisotropy of the various geological units?	The available dataset is used to provide estimates of horizontal and vertical hydraulic conductivity, augmented with data from other sites in the Sydney Basin (Section 2.6). Anisotropy is an adjustable parameter for PEST, vertical head separation targets are employed (Section 2.7.2) and so the sensitivity of vertical anisotropy is embedded in predictions.
	Would there be enough model layers to represent vertical gradients?	Groundwater model uses 20 layers (Section 2.4.3) to achieve vertical head separation. Vertical head separation targets are employed (Section 2.7.2).
	Is there a third-party reviewer for the modelling, as per the AGMG?	Peter Dundon of Dundon Consulting has carried out the peer-review.
	Request to check on the possibility of updating the model with hydraulic property and GW data collected during the tunnel construction	Yes, further data is being obtained now, and recommendations for further data are made in the Groundwater Technical Report. Given the duration of the project, it is likely that modelling would be updated/revised with new data.
	Will it be possible to understand GW takes from separate water sources (Sydney Basin Blue Mountains vs Sydney Basin Cox's River)?	Groundwater inflow is modelled in Section 4.5. The groundwater take is then partitioned between Groundwater Sources (Section 4.10).
3	Queried how 'shear zones' are represented.	Horizontal bedding shear zones existing on major claystone layers (3 of them = layers 3, 5 and 9), as in Sections 2.4.3 and 2.6. These are different from vertical features, like faults, that are represented via pilot points/PLPROC, also in Section 2.6.

1.3.4 Report structure

The structure of this report is outlined in **Table 1-4**. This report has been written to be relatively stand-alone, i.e. there is enough description of the project to allow the reader to understand the project and the modelling. More detail on the project, especially details that are not considered relevant to the groundwater modelling, is available elsewhere in the EIS.

Table 1-4 Outline of report structure

Section		Contents
1	Introduction	Description of study requirements and objective (scope of work). Description of construction of the GWH Blackheath to Little Hartley project (with respect to potential effects on groundwater).
2	Numerical model development	Describes the approach to numerical modelling and the inputs to that process, as well as describing the 3D groundwater model and linkages to other tools.
3	Model performance and history-matching	Outlines the procedure and the results of model history-matching phase of work, focussing on observations and data that are most relevant to the predictions required.
4	Forecasting of effects	Presents output from the model, including predicted groundwater inflow, groundwater level and pressure hydrographs/maps/profiles, and take from surface water features and GDEs.
5	Conclusions	Summarises the modelling assessment of the Project against relevant requirements. Recommendations regarding monitoring.
6	References	List of documents referred to in this report

Requests for data presented in this report will be considered.

1.4 Objectives of this assessment

The objectives of this report are to present an assessment of groundwater ingress to the tunnel and associated infrastructure, and the resultant effects of the project on the surrounding hydrogeological system and relevant environmental features. The modelling and reporting here aim to inform both the Environmental Impact Statement (EIS) via the Groundwater Technical Report [Appendix I of the EIS] (AECOM, 2022) and the technical advisor role.

Dewatering or drainage associated with the project would cause perturbations to groundwater pressures and levels and to fluxes, as described in the hydrogeological conceptual model presented in the Groundwater Technical Report. Numerical groundwater modelling will be used to quantify potential impacts that may be caused by construction activities below groundwater level and longer-term operation of the project, as well as considering cumulative impacts.

The modelling to quantify the potential effects is consistent with the conceptual model and observational data to enable forecasting of effects from the project on groundwater and connected surface water systems.

Specifically, the forecasts of groundwater and surface water effects from the project, including estimates of uncertainty; would include:

- Estimated groundwater inflow to infrastructure (e.g. tunnels, caverns).
- Estimates of the extent and rate of drawdown at specific locations including at private bores in the area.
- Estimates of the magnitude and timing of changes to baseflow (groundwater discharge) to watercourses.

- Estimates of the magnitude and timing of changes to leakage from reservoirs as a result of drawdown effects.
- Estimates of the timing and magnitude of effects on Groundwater Dependent Ecosystems (GDEs) (primarily hanging swamps and upland swamps).

Following that, recommendations were provided related to:

- Areas of potential risk where groundwater impact mitigation/monitoring measures may be necessary.
- Water supply or assets that may be affected by groundwater drawdown.
- Potential losses from designated Groundwater and Surface Water Sources and Management Zones, and the implications for groundwater and surface water licence allocations.

Model development addressed the following items:

i. Provision of a model projection of the time to reach steady state conditions and the predicted effects of steady state conditions.
ii. Use of the existing piezometric time series data to perform a transient calibration run.
iii. The predictive model provides sufficient detail to model geological structures with high inflow potential.
iv. Sensitivity analysis with a realistic range of parameters.
v. Uncertainty analysis results and interpretation presented with the model results (as per IESC, 2018).
vi. Model predictions identifies zones that are likely to exceed nominated inflow criteria, with recommendations on potential actions to mitigate this.
vii. Predictive model scenarios to evaluate potential impact(s) in relation to the creeks, baseflow, waterfalls, swamps, and/or public water supply reservoirs, and provision of recommendations to avoid these impacts.
viii. Provision and justification of all design hydrogeological parameters and assumptions used in the numerical modelling.
ix. Identification of any credible hydrogeological or groundwater related hazards, including contamination and saltwater intrusion or salinity that could affect the environmental receptors and project over the Design Life (see Section 1.2.1) and identify management or mitigation methods for the hazards. Hazards and their management or mitigation measures must be collated into a register or table in the report.

1.5 Numerical modelling approach

The approach to groundwater modelling in this project is based on principles outlined in the Australian Groundwater Modelling Guidelines ['AGMG'] (Barnett et al., 2012a) and the IESC guidelines for uncertainty analysis (Middlemis and Peeters, 2018). The overall scope of the model and the choice of uncertainty analysis method was appropriate to the environmental risks and project scope.

Groundwater modelling is typically carried out to support or inform management decisions. Models provide better support for environmental decisions if they are developed with the aim of assessing a specific question or testing a hypothesis, rather than with the aim of replicating all (or many) elements of the hydrogeological system (Doherty and Moore, 2019). Based on this view, Doherty and Moore (2019) recommend that modelling is carried out using the following approach (which is similar to the uncertainty-driven workflow of Middlemis and Peeters (2018) and the draft update of the uncertainty guidelines (Peeters and Middlemis, 2022), and implicit in the Planning phase of modelling as described in the AGMG):

- Identify the decision-critical prediction(s) or Quantities of Interest (QOI) required of the numerical model.
- Conceptualise the systems and identify or include properties that contribute most to uncertainty of that prediction.
- Identify existing data (and/or collect new data) that can inform relevant parameters and reduce uncertainty through an appropriate data assimilation process (i.e. history matching).
- Use the model to calculate forecast values and uncertainty.

The above approach has implications for the design of the numerical model. In particular, the adoption of automated methods for parameter estimation and uncertainty analyses such as those in PEST/PESTPP (Watermark Numerical Computing, 2018; White et al., 2020) require that the model is numerically stable and has a relatively short runtime. The details of the modelling carried out for this study are presented in Sections 2 to 4.

PESTPP-IES (White et al., 2020) ['IES' stands for Iterative Ensemble Smoother] is used here to carry out history-matching while generating an ensemble of alternative model realisations, not just a single "calibrated" or minimum error variance model, that embed parameter sensitivity in predictions.

1.6 Potential for cumulative impacts

The GWH Upgrade Program involves sections other than the Blackheath to Little Hartley (this project).

As noted in Section 1.2.7, to the south of the Blackheath portal the project would interface with the East Section of this upgrade program, specifically the "Katoomba to Blackheath Upgrade". The Review of Environmental Factors ('REF') for the Katoomba to Blackheath Upgrade (Aurecon, 2022) indicates that, because the works are focussed on upgrading surface roads with no significant excavations and intersection of water tables, there would be no significant effects on groundwater due to the Katoomba to Blackheath Upgrade in this area. Hence this means that there are no cumulative effects on groundwater that require consideration in the numerical modelling presented here.

As noted in Section 1.2.8, to the northwest of the Little Hartley portal the project would interface with the West Section of this upgrade program, namely the "Little Hartley to Lithgow Upgrade". The works in that upgrade involve widening and upgrading the existing surface road corridor. As such, there is no 'aquifer interference' expected, and therefore no cumulative effects on groundwater that require consideration in the numerical modelling presented here.

No other excavations or operations have been identified in this area that require cumulative impact assessment alongside the project.

1.7 Water management

NSW DPE Water and WaterNSW manage water resources, including groundwater, via Water Sharing Plans (WSP). The area around the Project is managed via the *Greater Metropolitan Region Groundwater Sources WSP (2011)*, which is divided into separate Groundwater Sources (**Figure 1-13**). The Project lies primarily within the:

- Sydney Basin Cox's River Groundwater Source; and
- Sydney Basin Blue Mountains Groundwater Source (within the margin of this source, especially in the southern (or eastern) half of the proposed alignment.

These are classified by DPE Water as 'Less Productive' Porous Rock Groundwater Sources under the AIP.

It is understood that the Sydney Basin Cox's River Groundwater Source and the Sydney Basin Blue Mountains Groundwater Source are likely to be merged in 2023 to form the "Sydney Basin West Groundwater Source". This would be undertaken as part of DPE's "*Draft replacement of the Water Sharing Plan for the Greater Metropolitan Groundwater Sources (2023)*"[1]. The current Blue Mountains Groundwater Source is embargoed, preventing further groundwater entitlement to be granted, while the status of that embargo once the WSP is revised is unclear. We note that this assessment addresses the current situation, i.e. two separate groundwater source areas, rather than the draft WSP, as discussed with DPE Water in July-2022.

Surface water sources and management zones are presented on **Figure 1-14**. This shows that the project is generally within the:

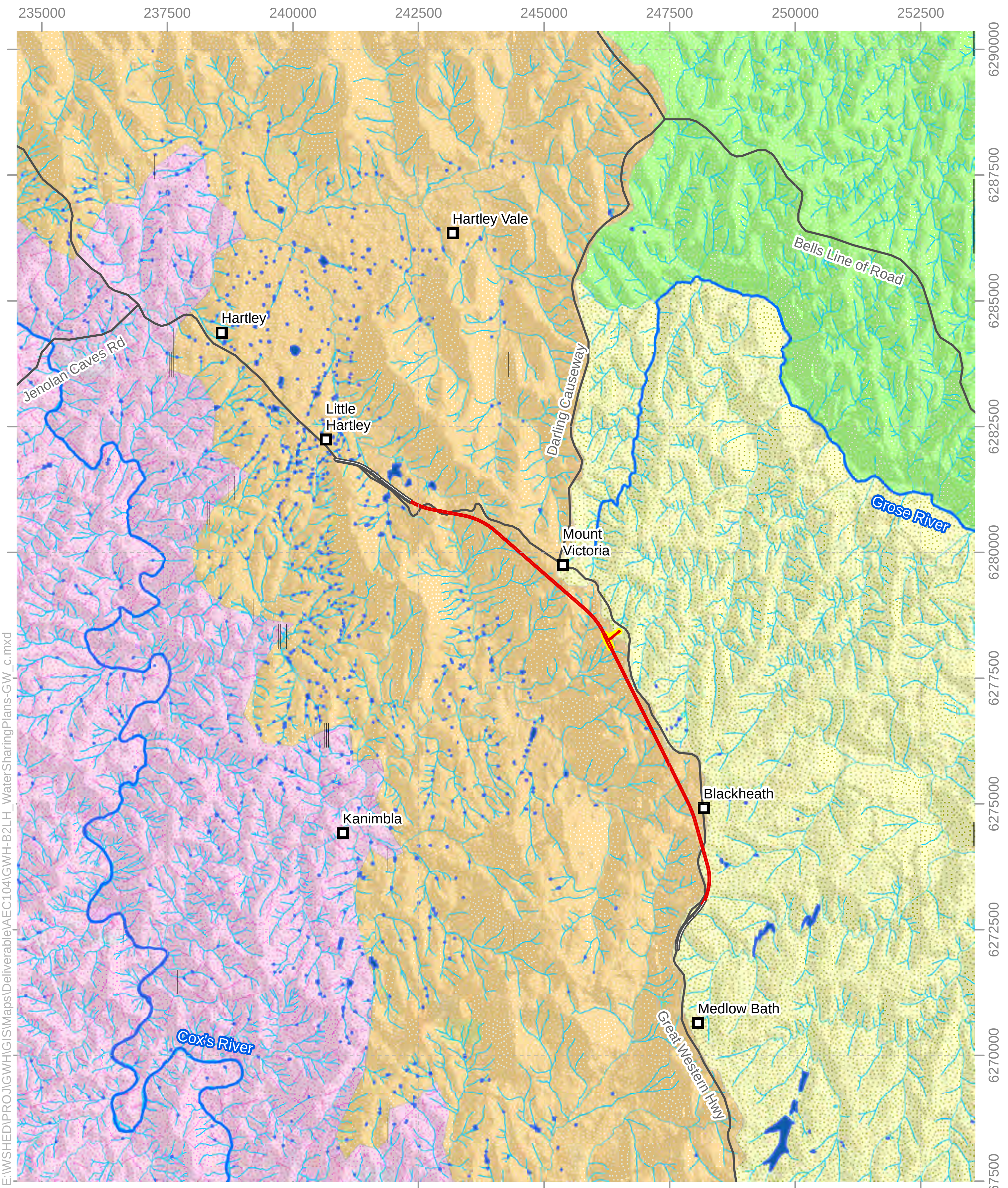
- Upper Nepean and Upstream Warragamba Water Source, and specifically the Dharabuladh Management Zone within that Water Source.

and sometimes within, especially in the southern half of the proposed alignment, the

- Hawkesbury and Lower Nepean Rivers Water Source, and specifically the Grose River Management Zone within that Water Source.

Effects on water resources in these zones are presented in Sections 4.8 and 4.10.

[1] https://www.industry.nsw.gov.au/water/plans-programs/water-sharing-plans/recently-on-public-exhibition/greater-metropolitan-region-groundwater/components-for-consultation



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N 0 0.5 1 1.5 2 km

Scale: 100,000 @A4
GDA 1994 MGA Zone 56

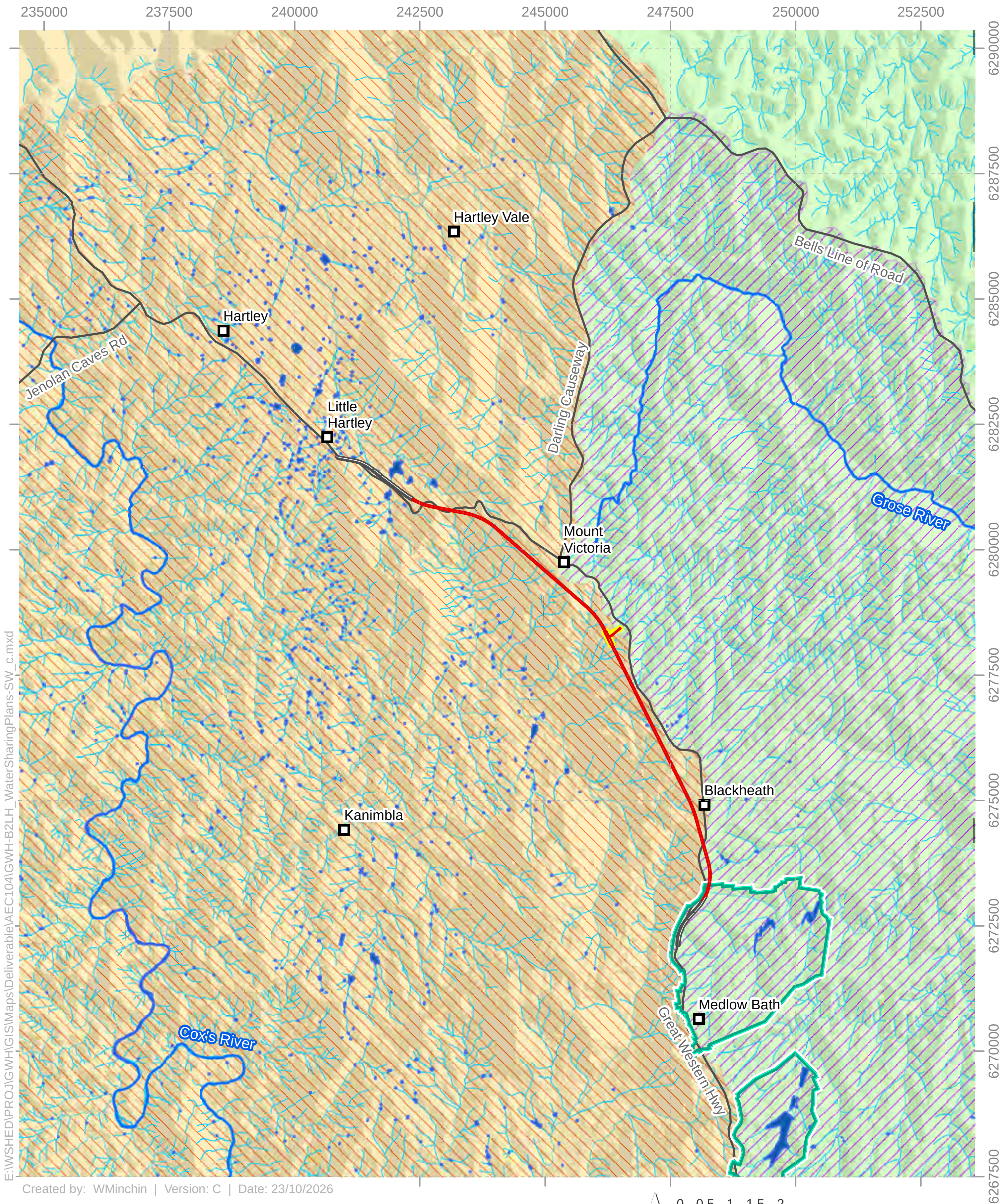
Town
- Major
- Minor
- Main road
- River
- Creek
- Lake / reservoir

- GWH project alignment - Tunnel
- Mid-point infrastructure
- GWH project alignment - Surface

GW Source (WSP, 2011)
- Coxs River Fractured Rock Groundwater Source
- Sydney Basin Richmond Groundwater Source
- Sydney Basin Coxs River Groundwater Source
- Sydney Basin Blue Mountains Groundwater Source

GWH-B2LH

Relevant Management Zones - *WSP for Greater Metroplitan Region Groundwater Sources 2011* **Figure 1-13**



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Town

- Major
- Minor
- Main road
- River
- Creek
- Lake / reservoir
- WaterNSW Special Area
- GWH project alignment - Tunnel
- Mid-point infrastructure
- GWH project alignment - Surface

Unregulated Water Source (WSP, 2011)

- Upper Nepean & Upstream Warragamba Water Source
- Hawkesbury and Lower Nepean Rivers Water Source

Management Zone

- Dharabuladh Management Zone
- Grose River Management Zone

N

0 0.5 1 1.5 2 km

Scale: 100,000 @A4

GDA 1994 MGA Zone 56

WATERSHED HYDROGEO

GWH-B2LH

Relevant Management Zones - *Greater Metropolitan Region Unregulated River Water Sources 2011*

Figure 1-14

2 Numerical groundwater model design

The conceptualisation of the groundwater regime is the foundation of the modelling and impact assessment, and to the development and calibration of the numerical model. The conceptual hydrogeological model is an idealised and simplified representation of the natural system, and is a description of how the groundwater system operates given the available data and analysis carried out to date. The conceptual groundwater model of the Project and surrounding area is described in the Groundwater Technical Report (AECOM, 2022).

The purpose of this numerical modelling report (Sections 2 to 4) is to describe the numerical model setup, calibration or history-matching, and predictive scenarios undertaken considering uncertainty.

2.1 Modelling objectives

The numerical model must quantify the likely inflow to the tunnel and associated subsurface features (e.g. cavern, cross-passages) during construction and in the post-construction (i.e. operational) phase, as well as assess the resultant drawdown and associated change in groundwater discharge fluxes (baseflow to springs and watercourses and swamps), including the temporal nature of these potential effects.

The SEARs state that "*Assessment of groundwater impacts must be undertaken using a numerical model…*" that allows quantification of "*Surface and groundwater hydrological impacts of the construction and operation of the project and any ancillary facilities (both built elements and discharges) in accordance with the current guidelines*" (SEARS 17.8 and 17.3 - **Table 1-1**).

Further review of the SEARs, and our own appreciation of the problem following conceptualisation, leads to the following specific objectives.

Item	Reference in requirements	Reference in this report
Quantify effects on *(a) natural processes within rivers and wetlands that affect the health of fluvial and riparian systems;*	17.3a	Modelled changes in water availability are presented in Sections 4.6.5, 4.7 and 4.8. The significance of these are addressed in the BDAR (EIS Appendix H) and Surface Water Assessment (EIS Appendix J).
Quantify *(b) impacts to downstream water-dependent fauna and flora;*	17.3b	Ecological effects address in the BDAR, but changes to availability of water are estimated in Sections 4.6.5, 4.7 and 4.8
Quantify *(c) impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, barriers to flows, implications for groundwater dependent surface flows, waterfalls, hanging swamps, other ecosystems and species, groundwater users, and the potential for settlement;*	17.3c	Modelled barriers to groundwater flow in Section 2.6.5. Otherwise, dewatered/drained features modelled as per Section 2.5.7. Resultant effects in Sections 4.4 to 4.10, simulated via comparing differences between model scenarios with and without the project.
(d) changes to environmental water availability and flows, both regulated/licensed and unregulated/rules-based sources;	17.3d	Changes presented in Sections 4.4 to 4.10, simulated via comparing differences between model scenarios with and without the project.

Item	Reference in requirements	Reference in this report
(g) water take (direct or passive) from all surface and groundwater sources with estimates of annual volumes during construction and operation.	17.3g	Groundwater take described in Sections 4.5 (inflow) and 4.10 (take from Groundwater Sources). Take from surface water described in Sections 4.8 (baseflow reduction), 4.9 (reservoirs) and 4.10 (overall take from Water Sources) .
Account for and "*Provide detail to model geological structures with high potential inflows.*"		Construction methods to minimise inflow will be employed (e.g. advance drilling and grouting). Conceptualisation (AECOM, 2022) identified potentially significant structures (C Jewell, pers.comm) and numerical modelling considers such mapped features (Sections 2.6.1, 2.6.2 and 2.6.3). Further geotechnical investigations are underway to further characterise the project area.
Details of the proposed groundwater monitoring to identify construction and operational impacts including changes to groundwater levels, impacts on groundwater dependent ecosystems and volume of groundwater discharges.	17.9	A summary of the recommendations made on the basis of the conceptualisation and numerical modelling is provided in Section 5.1. A more complete description of monitoring recommendations, including those from this report, is provided in the EIS Groundwater Assessment (AECOM, 2022).

The outputs above have been produced for a specific (assumed) construction schedule (Sections 1.2.1 and 4.1.1).

To provide more confidence in the model's ability to inform the impact assessment and decision-making process, 'calibration' to field measurements of groundwater levels and vertical head gradients is carried out via history-matching. Model development and history matching are described in Section 2.3 to 2.8 and Section 3. The subsequent application of the model to make forecasts of behaviour and effects associated with the project is described in Section4.

2.2 Modelling approach

Experience with previous tunnel projects is that developing a detailed unstructured mesh, such as via AlgoMesh (HydroAlgorithmics, 2020), and which has benefits of representing tunnel geometry more closely, can be easily made obsolete or inappropriate in places by even relatively minor changes to tunnel alignment. Re-meshing the grid and modifying inputs/outputs is not a trivial task.

The design of the model is described in Section 2 and model calibration or history-matching is the focus of Section 3. The use of the model for predictive modelling under uncertainty is described in Section 4. **Figure 2-1** summarises the modelling workflow.

The workflow adopts the industry-standard parameter estimation and uncertainty analysis software, PEST (Watermark Numerical Computing, 2018; White et al., 2020) as a central element, coupled with a MODFLOW groundwater model (Section 2.3).

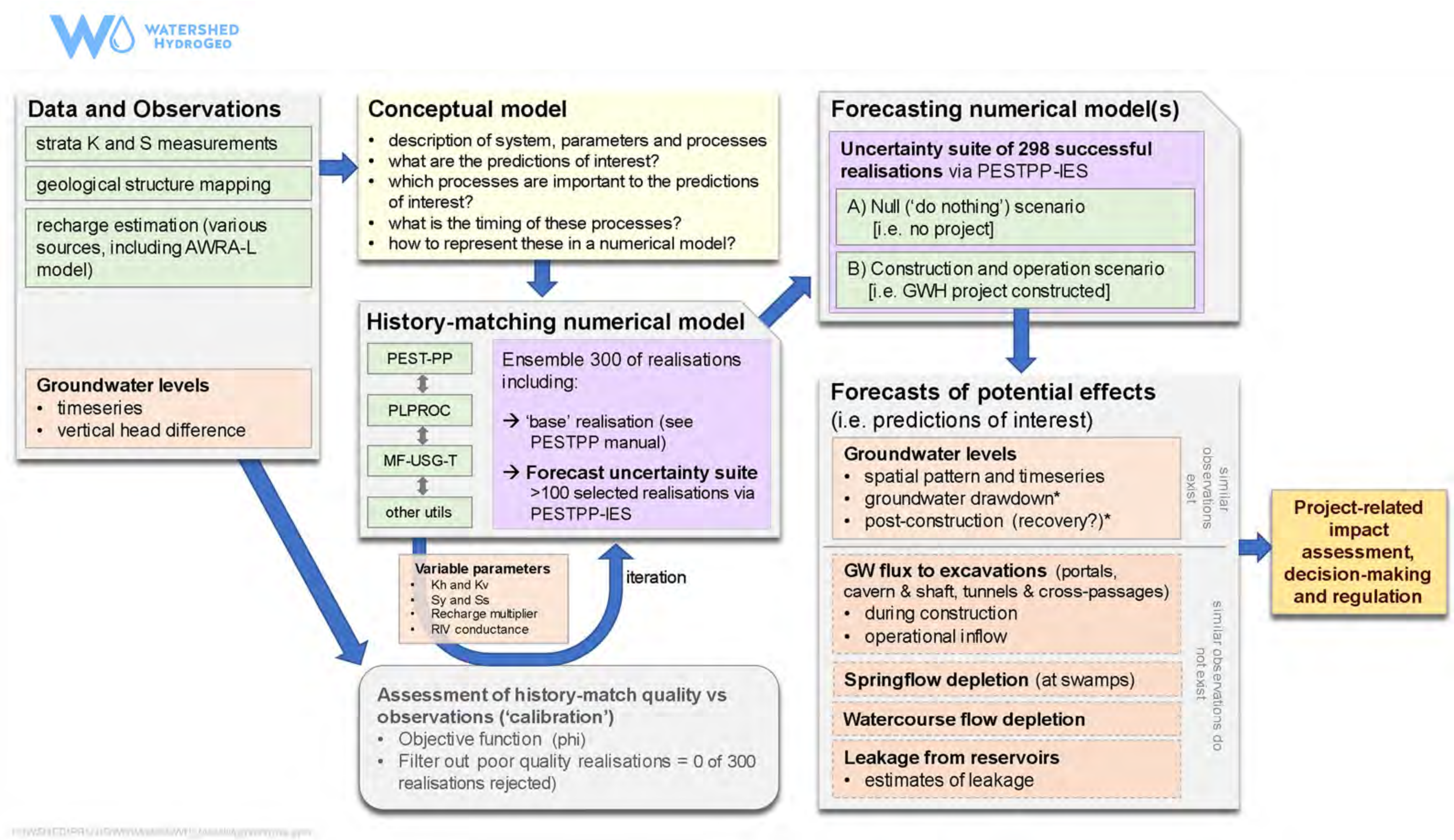


Figure 2-1 Workflow to integrate data and to achieve modelling objectives

2.2.1 Sensitivity analysis

As noted in Section 1.3 and Figure 2-1, PESTPP-IES is to be used, and done so in combination with pilot points for hydraulic conductivity and storage parameters to develop a large number of alternative model realisations. This highly parameterised method is focussed on simulating the key predictions or "Quantities of Interest" multiple times with a range of parameter values, and therefore precludes the need for a formal sensitivity analysis which is typically done to assess the scale of changes to model outputs as a result of changing input parameters, Doherty (2022) states: With the availability of regularised, highly parameterised inversion, sensitivity analysis, undertaken for this reason, is no longer required".

More importantly, the parameter sensitivities developed in Section 3 are embedded in the quantification of uncertainty presented for the various predictions in Section 4.

2.3 Model code and design

The conceptualisation of the Project site, and the requirements of some agencies, means that a 3-dimensional (3D) numerical groundwater model is required to address the objectives in Section 1.4.

The GWH-C groundwater model reported here utilised the industry-standard MODFLOW-USG-Transport v1.9.0 software package (Panday, 2022; Panday et al., 2013), referred to as "MODFLOW-USG" herein. This is a MODFLOW variant that uses the Control Volume Finite Difference method, which allows for an unstructured model grid (as opposed to structured grids). MODFLOW-USG is considered industry-standard software, having been used for many impact assessment models and for a variety of applications (mining, civil and construction, contaminant transport) in NSW.

Other than the incorporation of unstructured grids, MODFLOW-USG has another feature that is important to this project. The 'upstream-weighting' capability allows for simulation of unsaturated flow, which is important in this sedimentary sequence and for the simulation of tunnel features within that.

The modelling uses Groundwater Vistas (v8) (Environmental Simulations, 2020) as a pre-processor and as a repository for data, in order to be able to transfer the model to agencies (e.g. DPE Water), as required by the SEARs (Section 1.3.1).

2.3.1 Model confidence classification

The Australian Groundwater Modelling Guidelines [AGMG] (Barnett et al., 2012a) recommend adoption of "confidence level" classification terminology with further guidance on the application of the classification provided by Middlemis and Peeters (2018). The confidence level classification comprises Class 1, Class 2 and Class 3, in order of increasing confidence level. The level of confidence typically depends on the available knowledge and data, consistency between the calibration conditions and predictive analysis scenario, and the level or severity of stresses being simulated (relative to baseline conditions). The AGMG includes a table of quantifiable indicators with which to assess a models confidence level based on those attributes. Middlemis and Peeters(2018) recommends that the confidence level should be determined by indicating which attributes in the table are satisfied for a given model and considering the score counts in each class.

Using this approach, the current project groundwater model is considered to satisfy some attributes of the different confidence classes. Overall, it is considered to be a 'Class 2' (medium confidence) model but is currently limited by temporally and spatially sparse datasets (e.g., groundwater levels, permeability testing, geological characterisation), and especially so by a lack of flux data or targets (e.g., baseflow) and tunnel inflow (because it is a 'greenfield' site with respect to tunnels). The annotated classification table, updated after model development, is included in **Appendix G**.

The availability, or not, of types of data has led to the adoption of the ensemble approach to model predictions. It is considered that this approach is most suitable for the current level of knowledge. As further data is gathered (and there is an ongoing investigation program), other approaches may become more appropriate once that data, such as revised model layering or new head/drawdown/flux targets, is incorporated.

2.3.2 Qualitative uncertainty analysis

It is good practice that a qualitative analysis of uncertainty should be carried out at an early stage of the Groundwater Technical Report workflow. The qualitative assessment provides an overview of sources of uncertainty within a risk management framework and provides guidance in relation to further quantitative uncertainty analysis, if required. A qualitative assessment:

- Identifies key decisions and specific forecasts.
- Identifies assumptions and parameters important to each forecast.
- Identifies uncertainty or gaps in knowledge, data and assumptions.
- Assesses the degree to which existing and new data may reduce uncertainty.

In respect of the current assessment the key model forecasts or ‘Quantities of Interest’ are as follows:

- Groundwater inflow to unlined (“drained”) subsurface features.
- Groundwater depressurisation / drawdown at key receptors:
  - Groundwater user bores.
  - Groundwater dependent ecosystems, i.e. upland swamps and hanging swamps.
- Changes in baseflow to watercourses flow due to depressurisation and drawdown.
- Seepage losses from water storage reservoirs.
- Direct and indirect groundwater and surface water take for the purpose of water licensing.

A qualitative uncertainty analysis relating the forecasts of interest to this assessment is presented in **Table 2-1**. The table also includes reference to data used to constrain the relevant model parameters, as well as whether a factor or parameter is to be tested or varied in subsequent modelling.

Table 2-1 Qualitative assessment of model forecast uncertainty

Key knowledge / assumptions	Knowledge and uncertainty	Uncertainty in key forecasts	Scope for uncertainty reduction	How dealt with
Horizontal hydraulic conductivity (Kh or Kx)	Hydraulic conductivity of strata is moderately well understood from packer testing.	**Moderate**. Affects estimated rate of inflow, drawdown and recovery.	**Yes**. Scope for further uncertainty reduction through history matching of vertical gradients, and use of pilot points to quantify possible variability and heterogeneity.	Model calibration to groundwater levels, but no flux targets available.
	Structural zones: Hydraulic conductivity of structural zones is poorly understood. Regional mapping is available and used here, but local-scale features may not be detected.	**Moderate**. Affects estimated rate of inflow, drawdown and recovery. These can reduce or enhance impacts through compartmentalisation or preferential flow paths.		Regional structural features incorporated as possible high Kh/Kv zones, and these parameters are adjustable by modelling software.
Vertical hydraulic conductivity (Kv or Kz)	Not well-constrained known; order of magnitude estimates, and assumptions regarding vertical anisotropy.	**Low**. Negligible influence on inflow to Blackheath portal, and also relatively low at Little Hartley portal. Low groundwater pressures at Mid-Tunnel also suggest it is not a strong influence.		Model calibration to groundwater levels and gradients. Scenarios considering alternative Kh and Kv.
Specific yield (Sy)	Limited data from literature.	**Low**. Affects estimates of drawdown and recovery, as well as initial dewatering rates.	**Yes**. Scope for further uncertainty reduction through history matching	Model calibration to groundwater levels and inflow.
Specific Storage (Ss)	Most relevant strata are not confined. Ss not constrained by direct measurement. Estimates from rock properties used to estimate an appropriate range (Section 2.6.4).	**Low**. Might affect estimates of drawdown and recovery, but most strata adjacent to the escarpment are unconfined.		Model calibration to groundwater levels.
Recharge	Moderately well-constrained by published regional water balance studies and models.	**Low**. forecasts of inflow to mid-tunnel infrastructure should not be sensitive to this. **Moderate**: Inflow to portals will be sensitive to this parameter.	**Limited**. Scope for further uncertainty reduction; high correlation with Kh and Kv.	Model uses of independent estimates of recharge, plus calibration to groundwater levels.

2.4 Model structure

2.4.1 Spatial discretisation: model mesh

The model extent is shown on **Figure 2-2**, with the town of Blackheath inside the southern boundary and Little Hartley in the north-western corner. The model is a rectangle, with a portion of the model domain inactivated (assigned as "no-flow"). This area in the north-eastern corner of the model, on the other side of the Grose River valley, which is a significant hydraulic and hydrogeological feature, typically eroded through 13 to 18 layers of the modelled sequence of 20 layers, and hence is a convenient and appropriate boundary for the model domain.

The calibration model mesh only utilises some of the 'unstructured' capability of MODFLOW-USG. It primarily uses a regular or rectilinear model mesh, with cells of uniform dimensions (200 m x 200 m). The main feature of unstructured grids that is employed here is that model layers do not have to be fully extensive across the model domain, which is important given the significant topographic relief and absence (through erosion) of layers in some areas.

Each layer has a maximum possible 5,784 cells, with a possible total of 115,680 across all model layers. The 'pinch-out' functionality was used for this model and removed 49,365 cells where the thickness was calculated as less than 0.1 m (i.e. where geological units are eroded away/absent). A later figure shows the number of active layers in each vertical column of model cells (**Figure 2-7**).

The inactive part of the domain (north-eastern corner, **Figure 2-2**) is not written to the MODFLOW input files, removing a further 5,673 cells (total across 20 layers), leaving a total of 60,639 active cells across all model layers (Section 2.4.3).

2.4.2 Temporal discretisation: model stress periods

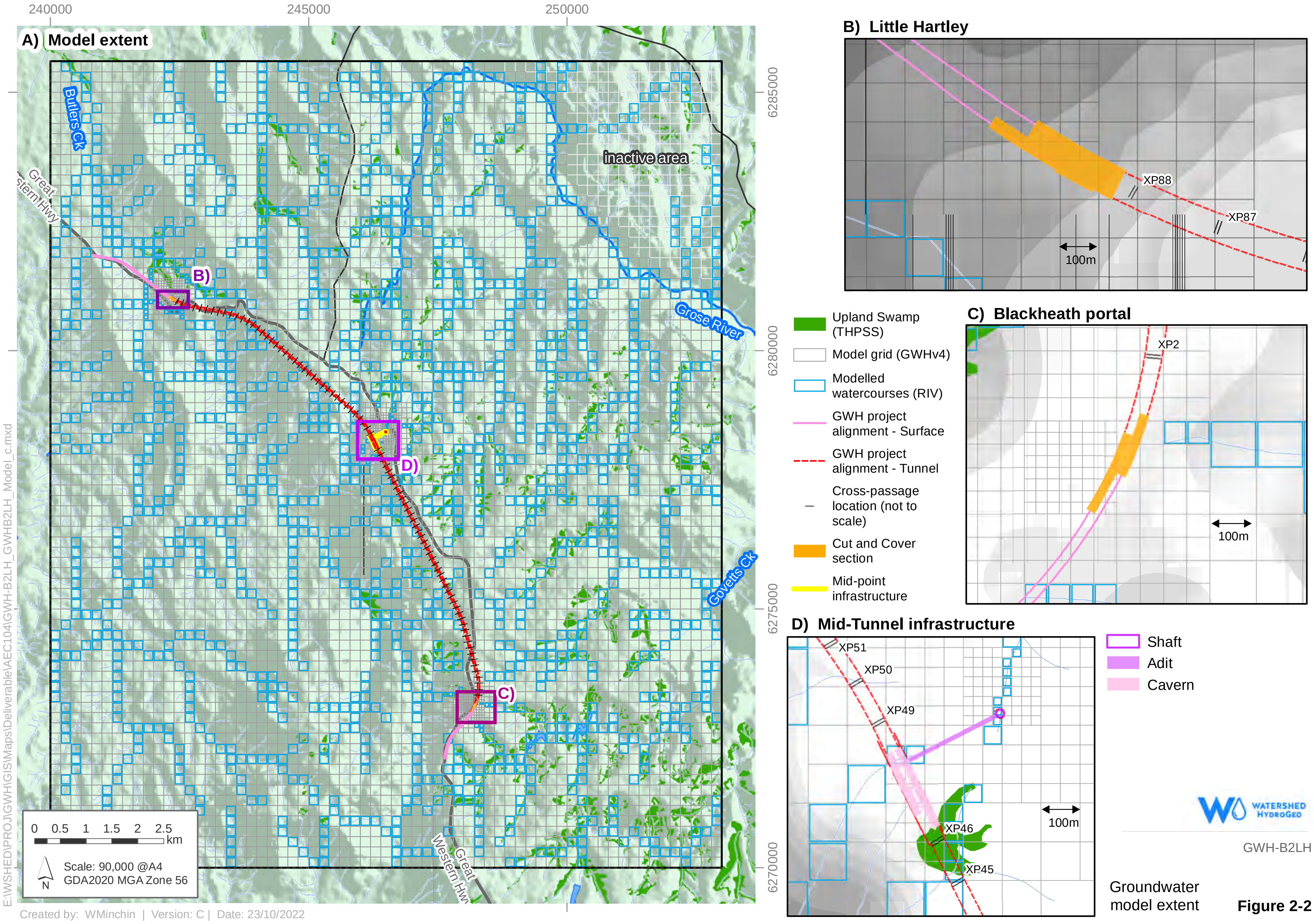
The model stress period schedule is included as **Appendix C** to this report, along with annotations of construction schedule (for predictive simulations).

The modelled time period, covering 2008 to 2130 for history-matching and forecasting, is discretised into a total 121 stress periods:

- Historical period: 38 stress periods covering the period 2008 to the end of June 2022, of which the first stress period is a steady state period used to initialise groundwater levels in response to simulated hydraulic conductivities, recharge and other boundary conditions.
- Predictive period: 83 stress periods covering the period July 2022 to 2130. The proposed start of construction is mid-2024 and completion in 2030. The end of the modelling period (2130) has been chosen to simulate the post-construction operational period extending into the future to Transport's 100-year design-life of the tunnel/project (see Section 1.2.1).

Prior to running the transient historical model (stress periods 2-38), the results of the initial steady state stress period (i.e. stress period 1) were examined to ensure that the groundwater levels were sensible (i.e. not resulting in flooding and were representative of the observed groundwater level data).

Stress periods are set at a fine resolution for the duration of construction, including excavation and construction of the cut-and-cover portal structures, TBM development of the main tunnels, the construction of the mid-tunnel facility and the construction of cross-passages. This allows simulation of the progressive changes to the groundwater system in response to construction.



Groundwater model extent

Figure 2-2

2.4.3 Hydrostratigraphy and model layering

A 3-dimensional (3D) geological model of the GWH study area was developed by the project's geotechnical engineers. The geological model includes surfaces for 30 geological contacts. This was developed from borelogs from Transport's investigative boreholes near the alignment, as well as published data and literature (e.g. NSW government Seamless Geology; Goldbery, 1969; Bembrick and Holmes, 1972; Bembrick, 1980; Yoo et al, 2001). We note the geological model will be refined as further site-specific data is obtained and analysed. Section 3.6 describes how future changes to the geological model (among other factors that affect the groundwater modelling) might influence the model simulation and predictions made here.

From the geological model and based on the hydrogeological conceptualisation, a subset of layers (**Table 2-2**) was developed for the groundwater model.

This 20-layer framework is based on the geological model, but with the following additional considerations:

- considering broad concepts of 'aquifer' vs 'aquitard', but noting that primary porosity typically does not dictate permeability in this environment (i.e. secondary features facilitate groundwater flow within the project);
- groundwater model layers of generally similar thickness where appropriate, so as not to bias the simulation of inflow to excavations/tunnels and resultant drawdown; and
- a need, as identified in the hydrogeological conceptual model, to simulate some lateral (horizontal) features more explicitly, namely bedding plane/shear plane fracturing above the major claystone units.

With the exception of the preferential flow horizon layers (layers X, Y, Z), the layers are based on the geological model provided by the project geotechnical engineers. The lateral extent and top elevation of each model layer is shown in **Figures D1-D5** (**Appendix D**).

The layer thicknesses at two representative locations along the main ridgeline (Mount Victoria and Blackheath - where most units are present and close to their full thickness) are described in **Table 2-2**.

The 'dominant lithology' classification is used for each model layer for the assignment of model hydraulic properties (Section 2.6). It is a simplification of the actual stratigraphic units assigned to each model layer.

Figure 2-3 and **Figure 2-4** show a long-section of the tunnel alignment as it passes through the stratigraphic sequence from south to north. Note that the geometry shown here is the same as used in the groundwater model. As noted above, the groundwater modelling had to proceed with a geological model at a point in time, and updates could be incorporated in the groundwater modelling in future.

Table 2-2 Stratigraphy and model layer assignment

	Layer	Stratigraphy		Comment	Thickness [m]		Model dominant lithology
					Mount Victoria	Blackheath	
	1	Swamps	THPSS	THPSS or upland swamps (for Hanging Swamps, see Section 2.5.6)	2-3 m	2-3	Swamp
Narrabeen Group	2	Banks Wall Sandstone (upper) / Burralow Formation	BWSS_u		18	16	Sandstone
Narrabeen Group	3	Bedding plane shear zone #1	BPSZ1	lower 1m of upper Banks Wall Sst/ Burralow Formation	1	1	shear
Narrabeen Group	4	Wentworth Falls Claystone	WFCS	primarily the Banks Wall Sandstone (lower), but the overlying Wentworth Falls Claystone would influence vertical K (Kv).	67	105	Claystone
Narrabeen Group		Banks Wall Sandstone (lower)	BWSS_l				Sandstone
Narrabeen Group	5	Bedding plane shear zone #2	BPSZ2	lower 1m of lower Banks Wall Sst	1	1	shear
Narrabeen Group	6	Mt York Claystone	MYCS		22	21	Claystone
Narrabeen Group	7	Burra-Moko Head Sandstone (upper)	BMHS_u	includes unnamed claystone	23	22	Sandstone
Narrabeen Group	8	Burra-Moko Head Sandstone (lower)	BMHS_l	informal division - estimated at 50% of total Burra-Moko Head Sst thickness	23	22	Sandstone
Narrabeen Group	9	Bedding plane shear zone #3	BPSZ3	lower 1m of Burra-Moko Head Sst	1	1	shear
Narrabeen Group	10	Caley Formation (upper units)		includes Hartley Vale Clst, Govetts Leap Sst,	15	14	Sandstone
Narrabeen Group	11	Caley Formation (lower units)		includes Victoria Pass Clst, Clwydd Sst, Beauchamp Falls Shale	14	13	Claystone
Illawarra Coal Measures	12	Wallerawang Subgroup (upper)		includes Katoomba Coal, Farmers Creek Fm, Burragorang Claystone	11	10	Claystone
Illawarra Coal Measures	13	Wallerawang Subgroup (lower)		includes Gap Sandstone, Middle River Fm	10	14	Sandstone
Illawarra Coal Measures	14	Charbon Group (upper)		includes State Mine Creek Fm, Irondale Coal	29	24	Sandstone
Illawarra Coal Measures	15	Long Swamp Formation		part of Charbon Subgroup	25	25	Claystone
Illawarra Coal Measures	16	Cullen Bullen Subgroup		includes Lidsdale Coal, Blackmans Flat Conglomerate and Lithgow Coal	6	6	Sandstone
Illawarra Coal Measures	17	Marrangaroo Congl. / Gundangaroo Fm		Marrangaroo Conglomerate (Cullen Bullen Sg) and Gundangaroo Fm (Nile Sg)	44	42	Sandstone
Illawarra Coal Measures	18	Coorongooba Creek Sandstone		part of Nile Subgroup	25	25	Sandstone
	19	Shoalhaven Group		Berry Siltstone and Snapper Point Fm	201	195	Sandstone
	20	Basement			50	50	Sandstone

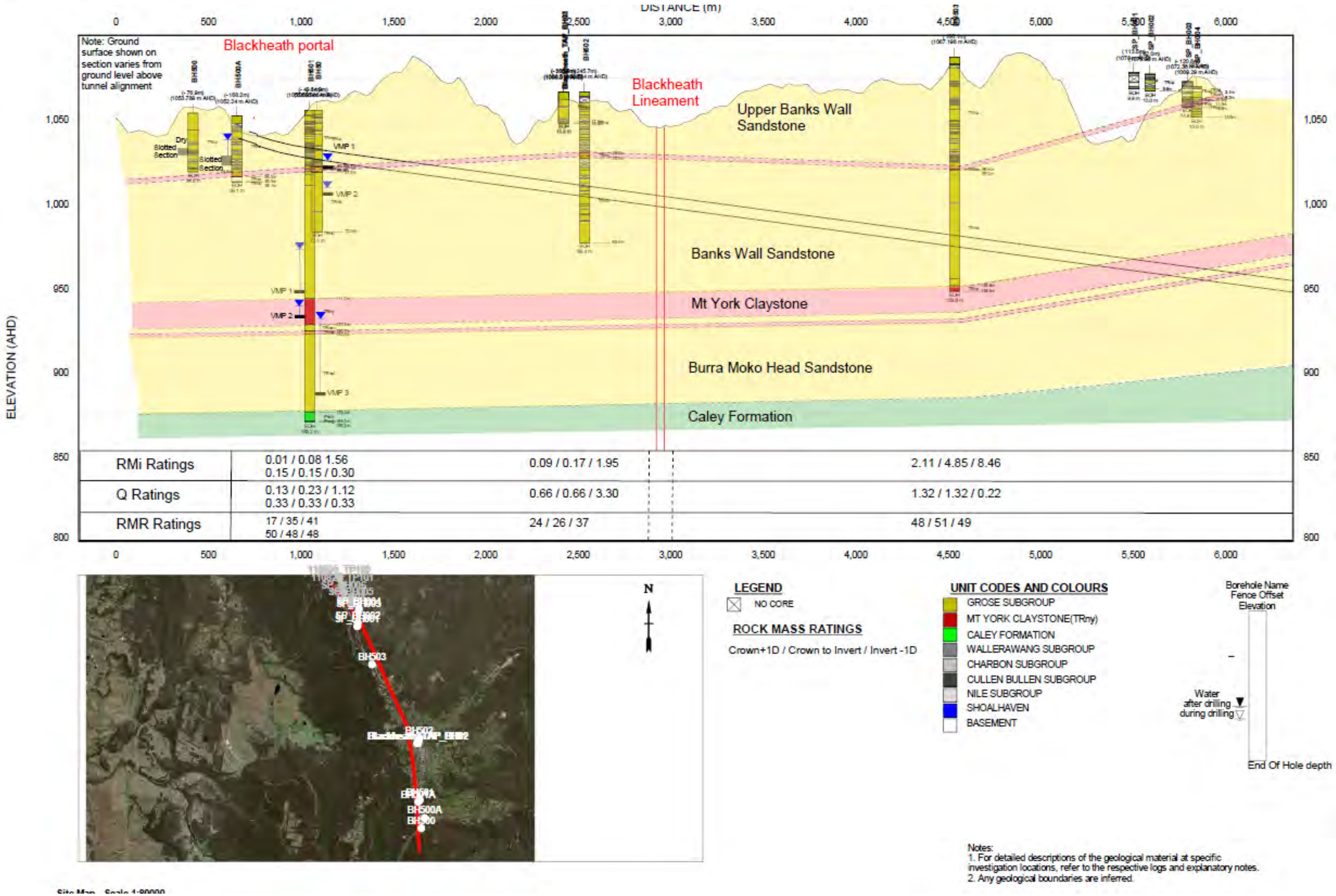


Figure 2-3 Long-section of tunnel alignment – showing modelled geology in southern part of project

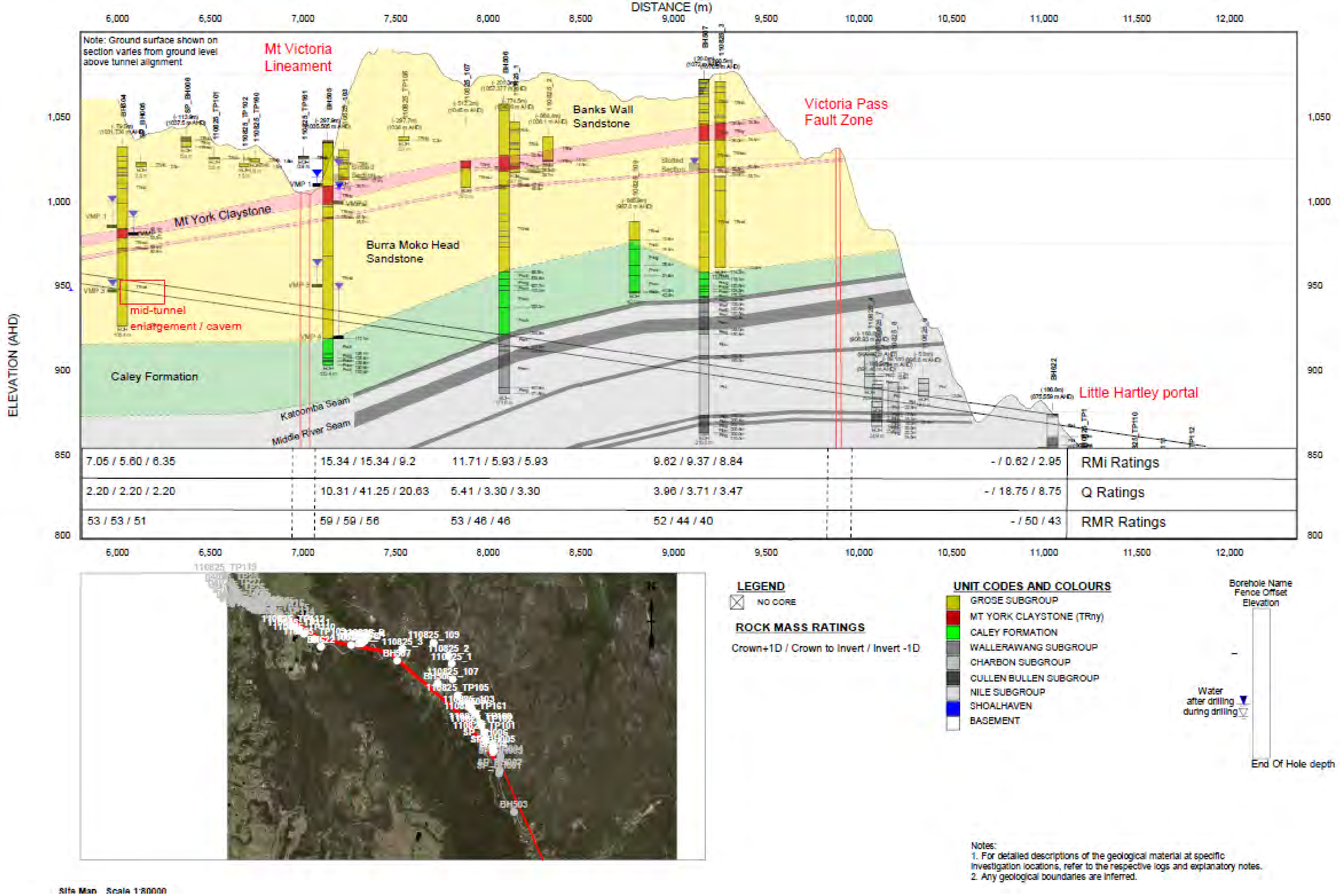


Figure 2-4 Long-section of tunnel alignment – showing modelled geology in northern part of project

2.5 Boundary conditions

A summary of the boundary conditions is presented in the following sub-sections. **Figures D6-D10** (**Appendix D**) present a summary of boundary condition locations (watercourses/springs, general head boundaries and inactive areas) for each layer.

2.5.1 Rainfall recharge

Rainfall recharge is simulated using the MODFLOW Recharge (RCH) package.

The model domain is divided into zones that account for variability in 'average rainfall' between Blackheath and Little Hartley (declining to the northwest), aligned with BoM long-term average rainfall contours, with higher rainfall and recharge at the top of the escarpment and lower rainfall on the plain to the north and west.

Zones applied to the modelling are (**Figure 2-5**) (note: zone 2 is deliberately missing from this list; earlier versions of the zonation included zone 2, but this was simplified out):

- 1 - Triassic-age rock outcrop around Blackheath;
- 3 – Permian-age rock outcrop near to Little Hartley;
- 4 – Basement outcrop (western portion of model domain); and
- 5 – Upland Swamps, primarily around Blackheath and Mount Victoria.

This study and the Groundwater Technical Report included a review of recharge estimates from AWRA (BoM, 2018) and other literature (Crosbie, 2015; EMM, 2015). Secondary data sources, including Springvale and Angus Place groundwater assessments (Adhikary and Wilkins, 2013), which adopted estimates of recharge as being 5% of long-term average rainfall, i.e. approximately 55 mm/yr) were also considered. Based on comparison of these data sources, the AWRA estimate has been used as the basis for (historical) variability in time (**Figure 2-6**).

The initial recharge estimate applied to the model (which was then adjusted by the parameter estimation and uncertainty analysis software, PEST) is essentially the AWRA-L rate for the Blackheath and Little Hartley zones (1 and 3, above), but modified slightly, as per **Table 2-3**, based on the review of groundwater level hydrographs, and based on our experience that the AWRA-L estimates tend not to be variable enough through wet and dry periods.

Table 2-3 Recharge estimates

Zone		AWRA-L annual average recharge	Initial estimate (mm/yr)	Comment	Range in multiplier given to PEST
1	Triassic outcrop	130 mm/yr	125	Reduced by 1/3 during dry periods, increased by 2 during wet periods. Based on experience, the AWRA estimates tend to be too constant through time.	0.3 to 3 (x initial estimate)
3	Permian outcrop	76 mm/yr	50		
4	Basement outcrop		25		
5	Upland Swamps	n/a	252	Based on Zone 1, doubled due to permeable nature of sediments	

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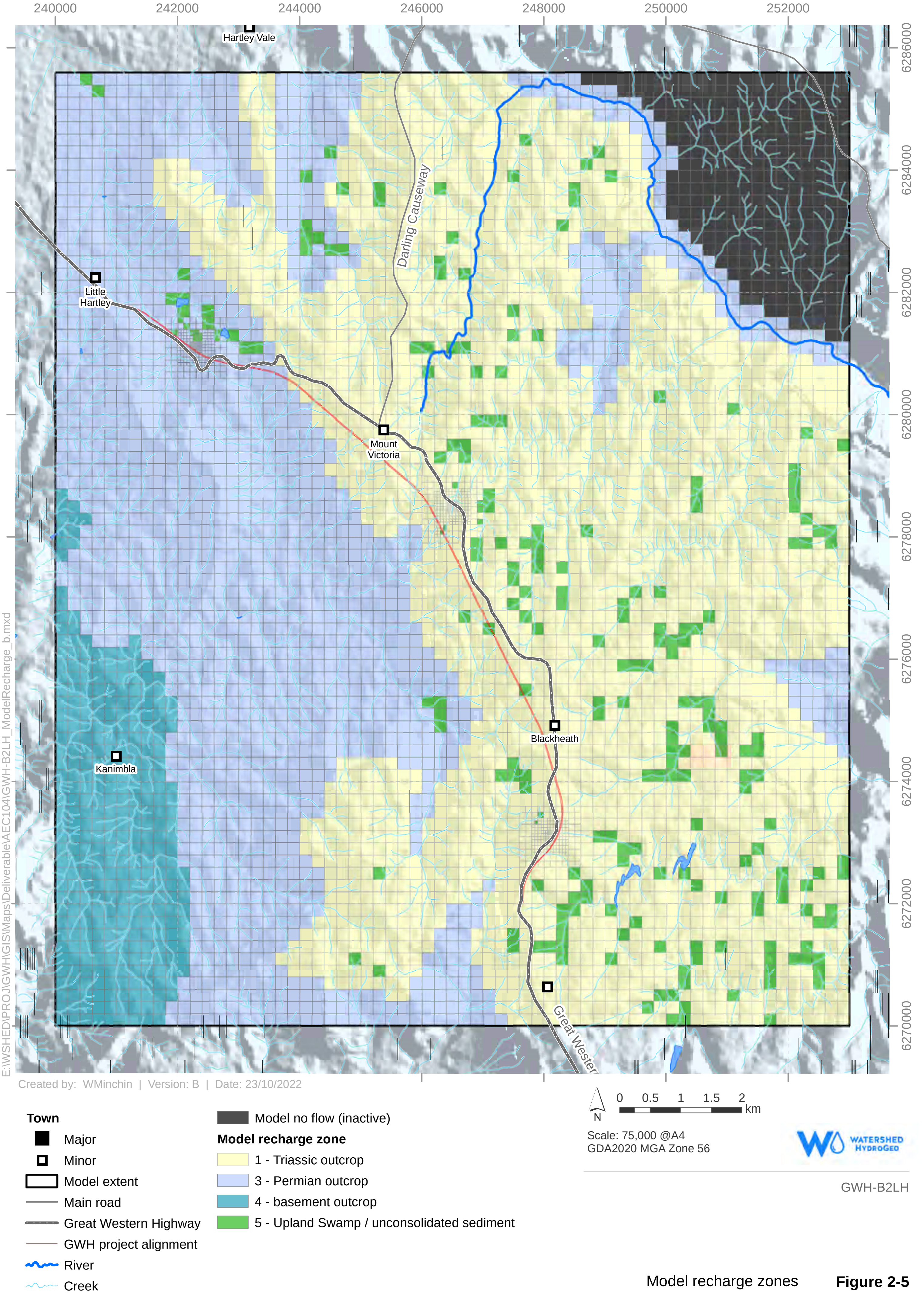
The initial estimate of average recharge is therefore equivalent to approximately 9.8% (Blackheath / Triassic outcrop) and 4% (Little Hartley / Permian outcrop) of long-term average annual rainfall.



Model recharge zones **Figure 2-5**

PEST was supplied with a range of 0.3 to 3 for a global multiplier to constrain recharge (**Table 2-3**), which means that there was a significant amount of freedom to move those recharge estimates up and down within the PESTPP-IES realisations.

Estimates of rainfall recharge to unconsolidated deposits within swamp areas were not available but were conceptualised as being more than that of the rock outcrop. As a result, average modelled recharge of about 250 mm/year is assumed, equivalent to 20% of long-term average (LTA) rainfall (at Blackheath).

The groundwater model simulates variable recharge rates until model stress period 38 (equivalent of Apr-June 2022), and then a repeated average value was utilised to simulate recharge for stress periods 39-121 (to the end of the simulation period) with two exceptions. As shown on **Figure 2-6**, two periods of low rainfall (low recharge) was simulated, one toward the end of the construction period and one in 2034 in order to investigate the change in groundwater level and flux in dry periods at ecological receptors.

Figure 2-6 **Model recharge and evapotranspiration sequences**

Of note in **Figure 2-6** is the extended period of low recharge from mid-2017 through 2019, followed by higher recharge in response to wet conditions through much of 2020 and into 2022.

Future gathering of high frequency (daily/weekly) water table data from swamps could allow for improved estimation of recharge estimates and revision of this parameter in the model.

2.5.2 Evapotranspiration

The AWRA-L model does not provide estimates of the excess potential evapotranspiration (PE) demand remaining after recharge and runoff are incorporated. A separate water balance model was developed to estimate this, using inputs of rainfall and PE from SILO[2] , and training it to the infiltration

[2] https://www.longpaddock.qld.gov.au/silo/

recharge estimated by AWRA. The excess PE on any day during the sequence is then averaged across model stress periods (**Figure 2-6**) and applied to the MODFLOW model via the Evapotranspiration (EVT) package. The potential rate of evapotranspiration from groundwater was modelled at approximately 300 mm/yr for the outcropping rock in the model area, and higher at swamps (750 mm/yr), but in both cases applied transiently through the model period in accordance with rainfall and PE.

Rooting depths (‘extinction depths’) were set at 2 m for areas on outcropping rock, some of which is urban and some is sclerophyll forest. This is a simplification of reality, but not considered to be significant with respect to the forecasts of interest. The vertical extent of roots within swamp deposits is likely to be 0.4-0.8 m, based on information in Shaygan *et al* (2022) and Shaygan (pers. comm), and 0.8 m has been adopted in the model.

Potential evapotranspiration rate and rooting depth were not set as adjustable parameters in the PEST simulations because they are not considered significant to quantifying potential inflow or drawdown around tunnel features.

2.5.3 Regional groundwater flow

General Head Boundaries (GHB) were set around parts of the model domain where regional groundwater flow is conceptualised as being into or out of the model (rather than predominantly parallel to the edge of the model).

Inflow was conceptualised as occurring along the ridgeline to the south of Blackheath. GHBs are set under the ridgeline, as shown on **Figure D6** (**Appendix D**). These GHBs are set in layers 3 and 4. It is plausible that there is some inflow/outflow in deeper layers, however this is not considered critical to simulating the effects of the project. The elevation or stage of these is based on or extrapolated from nearby groundwater levels (bore G4898_KB2) from observation bores for the different strata (where available). The distance from these GHBs to the Blackheath portal) is 3 km, so their influence on the tunnel (and the uncertainty associated with their parameterisation) is minimal.

A set of GHBs are applied in the south-eastern corner in the basement (layer 20) with a stage of 1050 mAHD (**Figure D10**).

To the east, the topography means that watercourses control groundwater discharge in most layers. However, in the some of the deeper layers there is limited opportunity for discharge to watercourses. As such, a set of GHBs has been set in Layer 18 (**Figure D10**, **Appendix D**) along part of the eastern boundary to allow groundwater flux in or out (primarily out) of the model domain. The stage of these varies linearly between 604 mAHD (near the Grose River) to 730 mAHD. A similar set of GHBs are applied to the basement [model layer 20] along the eastern boundary (**Figure D10**).

No GHBs are set along the northern boundary. The topography means that groundwater inflow/outflow is not likely to be significant (other boundary conditions would be more important). In this area, other than where River boundary conditions are present (described below), no flow conditions are assumed.

To the west of the model domain, on the plain to the west of the escarpment, some groundwater flow might occur in/out of the model domain, however again it is not considered significant nor important for the purpose of the model. No GHBs are set along this boundary. In this area, other than where River boundary conditions are present (described below), no flow conditions are assumed.

2.5.4 Watercourses (creeks and rivers)

Watercourses are also represented using the MODFLOW River (RIV) package (**Figures D6-D10**, **Appendix D**). The River boundary conditions within a selection of sub-catchments have been identified and assigned a common 'reach' identifier (**Table 2-4**).

These reach identifiers are used set parameters for the River boundary conditions, where some of these (related to conductance) have been set as being adjustable or varied by PEST, except for Reach 0 which includes small catchments away from the project alignment and which are not considered significant to the calibration or forecasting.

Table 2-4 River reaches used for PEST/MODFLOW

Reach	Catchment	Location related to Project
1	Butlers Creek	flowing northwest
2	Coxs River	flowing west
3	Govetts Creek	flowing east
4	Greaves Creek	eastward, to reservoirs
5	Pulpit Hill Creek	flowing south
6	Grose River (upper)	flowing north
7	Grose River (lower)	flowing north and east
0	others	

The parameters for the watercourse River boundary conditions are described in **Table 2-5**.

Table 2-5 Modelled parameters for Rivers along watercourses

Parameter	Value	Comment
Riverbed elevation (mAHD)	Variable	Based on local topography (DEM)
Stage depth (m)	0	Tributary (unnamed)
	0.5	Named watercourses
	1	Lakes Medlow and Greaves
River (channel) width (m)	1	Tributary (unnamed)
	3	Named watercourses
	5	Lakes Medlow and Greaves
Hydraulic conductivity (m/d)	0.1	initial estimate from permeability dataset
Conductance (m^2/d) dependent on model cell size, initial hydraulic conductivity and channel width	1 or 2 to 200 (initially)	PEST then adjusts conductance: 2 to 200 (reaches 1-7)

2.5.5 Reservoirs

MODFLOW 'River' (RIV) boundary conditions have been employed to represent the small water supply reservoirs to the east of Blackheath.

These boundary conditions are set in the uppermost active model layer (predominantly Layer 4 in this area), with bed conductance estimated based a hydraulic conductivity of 1E-1 m/d and on model cell area (as per **Table 2-5**, above. The locations of the River cells are shown in **Appendix D**.

2.5.6 Springs and seeps

Groundwater discharge is via the vertical or nearly vertical escarpment and cliff faces that are common in the project area. In many instances, groundwater discharge from these faces is sufficient to support vegetation, including 'Hanging Swamps', as described in the Groundwater Technical Report (AECOM, 2022). River boundary conditions were used to represent this, and were applied across the escarpments and cliffs, as shown in **Figures D6-D10** (**Appendix D**). There are 4249 such River boundaries, each with its own unique "reach" number (10 to 4534).

These River boundaries have been parameterised as shown in **Table 2-6**.

Table 2-6 Model parameters for springs (modelled using Rivers)

Parameter	Value	Comment
Stage (mAHD)	Different for all these boundaries	Typically assigned as 1/3 height of the cell above the layer bottom
Riverbed elevation (mAHD)	Equal to stage	Allow baseflow discharge only
Conductance (m^2/d)	20 (initial)	Adjustable range: 2 to 200

2.5.7 Dewatering and drainage

During construction and operational phases, groundwater could enter excavated features (tunnels, excavations, shafts, cross-passages), depending on depth and the method of construction. The construction method can also influence the timing over which groundwater ingress can occur. More detail on construction methods and the conceptual model of their influence on groundwater flow is presented in Sections 1.2.2 to 1.2.8 and the EIS Groundwater Assessment (AECOM, 2022)

MODFLOW 'Drain' boundary conditions are used to represent or simulate dewatering of the excavations/infrastructure that allow some groundwater ingress to occur (i.e. features that are not immediately 'tanked'). The key features are shown on **Figure 2-2**. The timing of the various features of the project that are represented by Drains are described in Section 4.1.1.

Cross-passages: These features are constructed using road-headers, and after a period of weeks to months are then lined to reduce the potential for groundwater inflow. These are assumed conservatively to be "drained' for 3 months for this assessment. The typical spacing of 120 m means that some model cells (200 m x 200 m) have two cross-passages within them, and one model cell has three cross-passages (XPs 61-63).

Drains to represent each cross-passages are only active for three model stress periods and then inactivated. The modelled elevation or stage of the Drain is the lowest invert (floor) elevation of any currently unlined cross-passage within the relevant model cell.

TBM: Based on the discussion in Section 1.2.3, the EPB TBM driving from the Little Hartley portal to the mid-tunnel cavern is designed to mitigate groundwater ingress. As such, it is not represented by Drains in the model.

The single shield TBM will allow groundwater ingress behind the cutting face for a short period of time (hours) and over a short section of tunnel, as described in Section 1.2.3. Drains are therefore used to represent the advance of the TBM. Within a single monthly stress period the TBM would progress through multiple model cells, even though the opening would only be located within one model cell (and a fraction of that) at a time. As noted below, a correction to the conductance term has been assumed to approximate this effect. The stage of these Drains is set at the approximate invert elevation of the TBM as it progresses.

Portals and mid-tunnel features: The cut-and-cover excavations at the portals, the shaft, adit and the mid-tunnel cavern are all of similar size to the model cells, and are also proposed to be drained' features, i.e. their construction approach will allow groundwater ingress in perpetuity.

For these features, drains are set at 0.1 m above the base of the relevant model cell if that cell is fully penetrated by the features (mainly this applies to the part of the mid-tunnel access shaft) or are set at an elevation corresponding to the inverts in the proposed design.

Drain conductances were based on the discussion in Zaidel *et al* (2010) which indicates that conductances can be set to high values when the model cell size that the Drain is set in is up to approximately 3 x the size of the opening that it is being used to represent. This applies to the portal and mid-tunnel features.

For smaller features, the conductance should be calculated to correct for the difference between the opening size and the model cell size. This is relevant to the cross-passages. As a result, cross-passage conductance is calculated based on the methods outlined by Zaidel *et al*. Conductances are therefore based on the orientation of the opening (e.g. vertical shaft or horizontal tunnel or cavern), opening dimensions, hydraulic conductivity related to the opening orientation (i.e. Kx and/or Kz), and the size of the model cell.

A further correction has been applied to the Drains representing the single-shield TBM. This is because the opening behind the cutting face is small and only open for a short period of time while the model stress periods are monthly during the construction phase.

Initial estimates of drain conductance are shown in **Table 2-7**.

Table 2-7 Model Drain boundary conditions (initial conductance)

Feature	Model Layer(s)	Cell geometry [m]	Conductance (m^2/day)
Little Hartley portal	18	25x25 or 50x50	76 to 126
Blackheath portal	2	25x25 or 50x50	76 to 126
Mid-tunnel - shaft	7 and 8	25x25	33 to 66
Mid-tunnel - adit	8	25x25 or 50x50	21 to 91
Mid-tunnel – cavern	8	25x25 or 50x50	8 to 68
TBM – EPB	18 to 7	50x50, 100x100, 200x200	0
TBM – Single-shield	7 to 2	50x50, 100x100, 200x200	0.027 to 0.25
Cross-passages	17 to 2	50x50, 100x100, 200x200	0.03 to 0.09

E:\WSHED\PROJ\GWH\Model\Construction\Boundaries\Drains\DRN_CrossPassages_&_MidTunnel&Portals_V3.xlsx

For each Drain boundary condition, the conductance is re-calculated following the interpolation of input Kx and Kz (Sections 2.6.1 to 2.6.3). This means that for the forecasting realisations (Section 4), higher K in a cell with a Drain boundary condition will result in a higher conductance, which minimise the potential for the Drain conductance to artificially limit inflow and drawdown at the excavation feature.

2.6 Parameterisation – hydraulic properties

This section outlines the modelled hydraulic properties based on the compilation of data and review of literature presented in the Groundwater Technical Report.

Aquifer hydraulic properties, hydraulic conductivity (Kh and Kv), specific yield (Sy) and specific storage (Ss), were assigned to the groundwater model using a combination of pilot points and parameter zones. Note that in this report, Kx is used interchangeably with Kh, as is Kz with Kv, as in **Table 2-1**.

2.6.1 Pilot point distribution

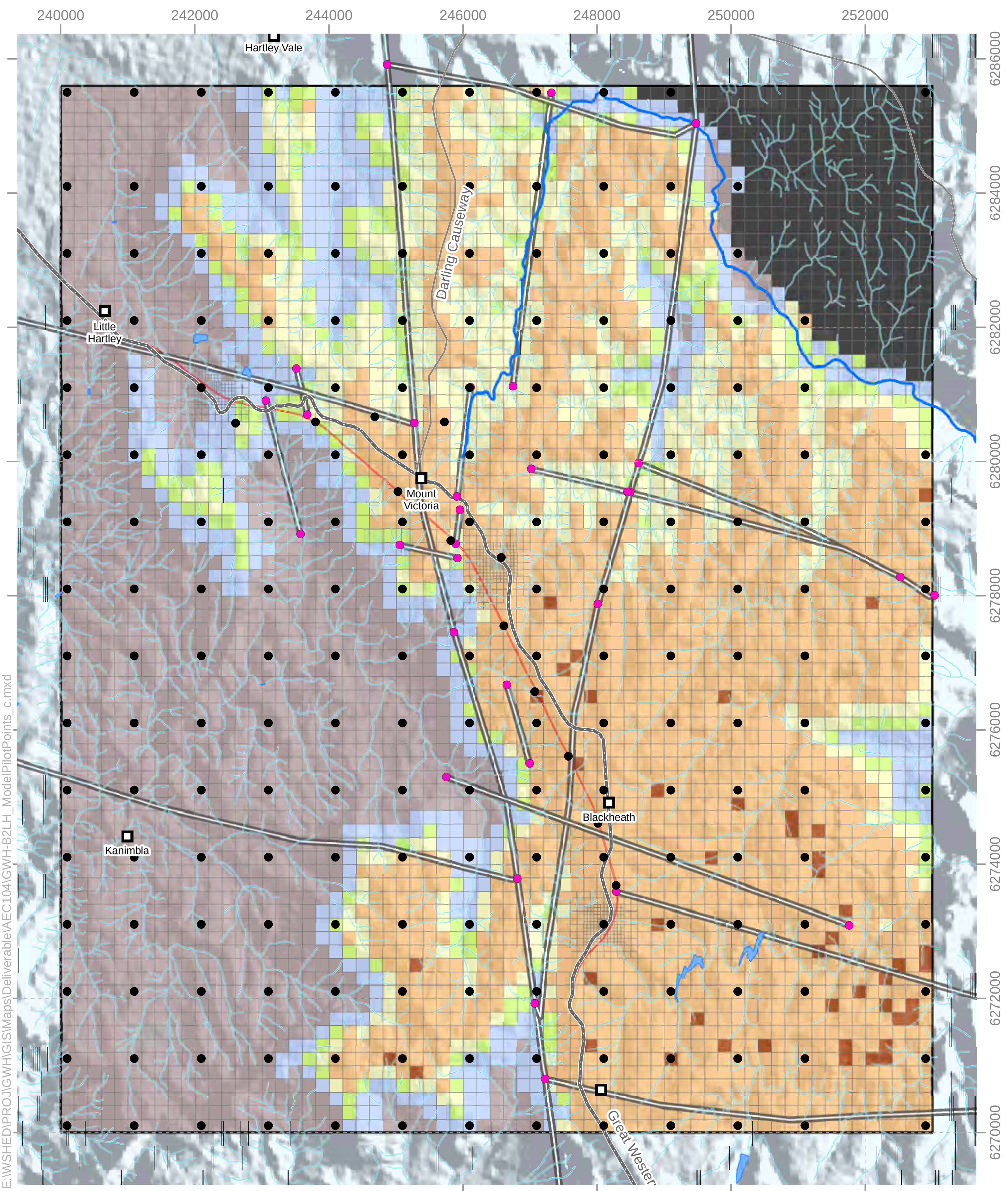
To allow PEST to adjust hydraulic conductivity and storage parameters in the groundwater model, the pre-processing software PLPROC (v3.11; Watermark Numerical Computing) is used with pilot points. The pilot point distribution is shown on **Figure 2-7**, and is based on:

- Regularly spaced points on a 1x1 km grid pattern (with the exception of the most northerly and most easterly lines of points, which have been shifted to align with the last row or column of the model extent respectively); and
- Additional points placed at selected points near the tunnel alignment between the regularly spaced points.

This has resulted in a maximum possible 212 points per model layer, but noting that pilot points are not active in pinched out or no flow areas, with the exception of the most north-easterly corner. **Figure 2-7** indicates where layers are absent (eroded). The number of pilot points to parameterise each stratigraphic unit (zone), where the zones correspond to model layers except for regolith and geological structures, are summarised in Table E1 (**Appendix E**).

The conceptual model identified that geological structures could potentially control groundwater flow. In the lateral (XY) plane, layers 3, 5 and 9 are included to represent shear horizons (Section 2.4.3). In the vertical plane (XZ or YZ or some component of those) significant structures were identified during this project (C Jewell, pers.comm.), and these are mapped on **Figure 2-7**. Figure E6 in **Appendix E** also shows these features and how some of them extend beyond the model boundary.

These structures were included in the PLPROC scripting that assigned hydraulic conductivity (Kx and Kz) to the groundwater model.



Created by: WMinchin | Version: C | Date: 01/12/2022

E:\WSHED\PROJ\GWH\GIS\Maps\Deliverable\AEC104\GWH-B2LH_ModelPilotPoints_c.mxd

Model extent
Main road
Great Western Highway
GWH project alignment
River
Creek
Pilot point --> model Kx,Kz,Sy,Ss
Geological structure (significant)
Structural pilot points

Model no flow (inactive)

Model grid

No. of active model layers

1 - 3
4 - 7
8 - 11
12 - 15
16 - 19
20

N 0 0.5 1 1.5 2 km

Scale: 75,000 @A4
GDA2020 MGA Zone 56

WATERSHED HYDROGEO

GWH-B2LH

Model pilot point distribution
and geological structures
used in model parameterisation

Figure 2-7

The PLPROC "*calc_linear_gauss_interp_factors*" function is used for this purpose. This function is supplied with the geometry (XY coordinates) of each structure line, and a pilot point (purple circle) is assigned to each end of the geological structure lines on **Figure 2-7**, and for the two longest features (two north-south trending thrust faults – coloured yellow and orange on Figure E6 in **Appendix E**), also at the mid-tunnel of that line. Note that some of these structural pilot points are located outside the extent of the groundwater model domain.

The Kx (or Kz) field is then interpolated by PLPROC along each structural feature using the relevant Kx (or Kz) structure pilot points. The K of a model cell is then estimated by using a distance-weighted interpolation of the structural Kx (or Kz) and the general layer-wide Kx (or Kz) determined from the pilot points shown on **Figure 2-7**, and as described by **Figure 2-8**.

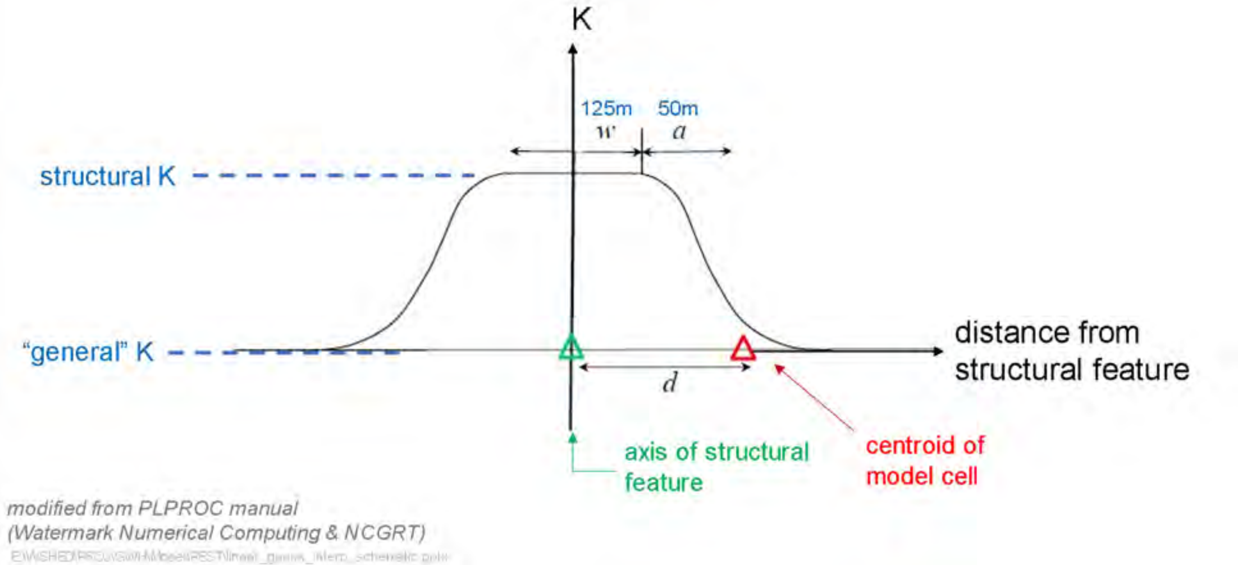


Figure 2-8 Interpolation between structural features and background K

For model cells whose centroid is:

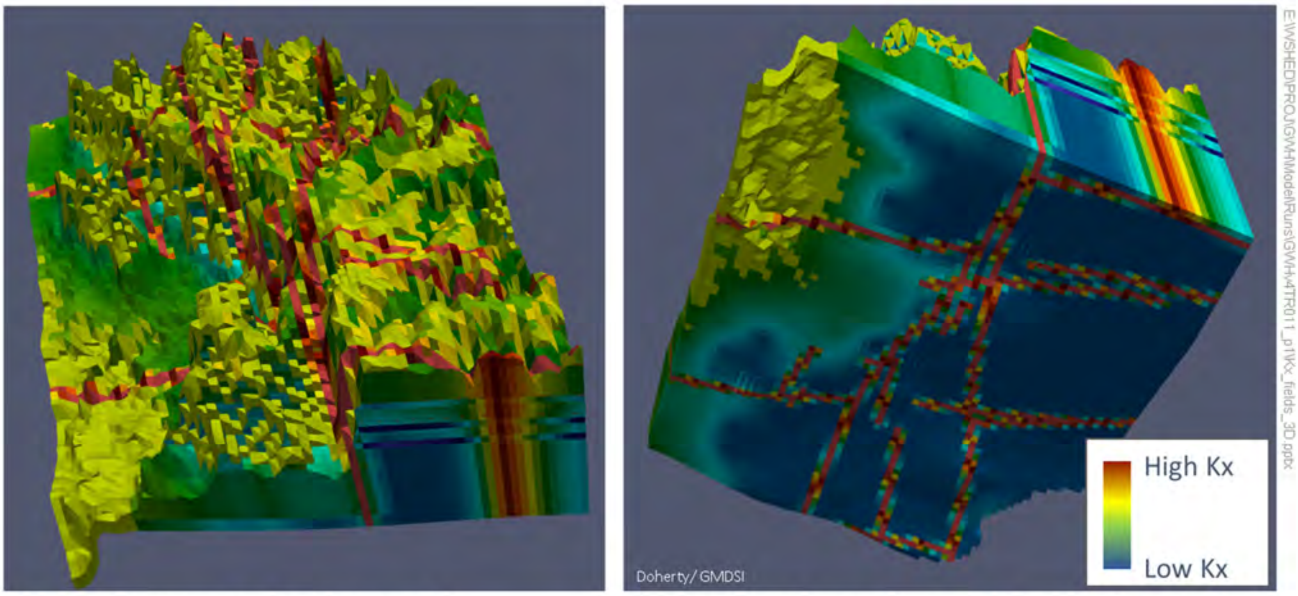
- within 125 m (this is user-specified) from the structural feature line, the structural Kx (or Kz) is used [125 m is selected as it is larger than half the largest model cell];
- beyond 175 m (user specified = 125 + 50) the general Kx (or Kz) values are used; and
- between those two, a distance-weighted average of the structural K and general K is used.

There is uncertainty about the vertical extent or persistence and the nature (i.e. open / closed, or permeable / impermeable) of these structures through the stratigraphic sequence. The modelling assumes that the structural Kx and Kz fields penetrate layers 2-20 (i.e. not upland swamp deposits, layer 1), and that there is no depth-dependence for the Kx or Kz applied along the structures.

The parameter values and ranges applied to the general and structural pilot points are described in the following sub-sections.

Figure 2-9 presents a 3D representation of a hydraulic conductivity (K) field that results from the combination of the structural features and the general or background K distribution.

We note that many fault structures could act as a barrier to lateral flow (across the fault) and as a conduit to vertical flow. To represent this explicitly would require finer model cells to simulate the impermeable fault core (gouge) and permeable damage zone on either size. If this conceptualisation is evident from field investigation at a structure located near a key feature of the project, it could be represented in a future revision of the model.



A) View from south (looking north) B) View from beneath model (looking NNE)

Figure 2-9 3D representation of hydraulic conductivity distribution supplied to PEST

This clearly shows the influence of the nominated structural features and the potential for them to influence (modelled) groundwater flow and head distribution.

2.6.2 Hydraulic conductivity - horizontal (Kh or Kx)

The available dataset of site-specific hydraulic conductivity data was, at the time of model calibration, relatively limited but provides a suitable basis for characterisation. Further data is currently being acquired in a field investigation program. The primary source of data are packer (lugeon) tests carried out at sites along or near the alignment. Secondary data was available from a review of literature. More data is being obtained by Transport, and could be included in the future revisions of the model (or could be used to confirm current assumptions, noting that the ensemble model approach is designed to cover a broad range of plausible parameters and embed that range in the predictions).

For the swamp deposits, useful data from elsewhere in the Sydney Basin was obtained from information compiled in Shaygan *et al* (2022).

For the hard rock units, experience in similar environments suggests that Kh will be reliant on the stratigraphic unit (essentially the lithology of that unit), degree of weathering, fracturing and presence of geological structure, as well as the depth of the strata. On this last point, trends in Kh with depth have been identified for Narrabeen Group and Permian (Illawarra Coal Measures strata) at sites elsewhere in the Sydney Basin, and so are assumed for this site.

The data available for this site at the time of model set-up was not sufficient to quantify those trends. As a result, trends from coal mines in the Southern Coalfield (Watershed HydroGeo, 2022) are adopted here (**Figure 2-10**).

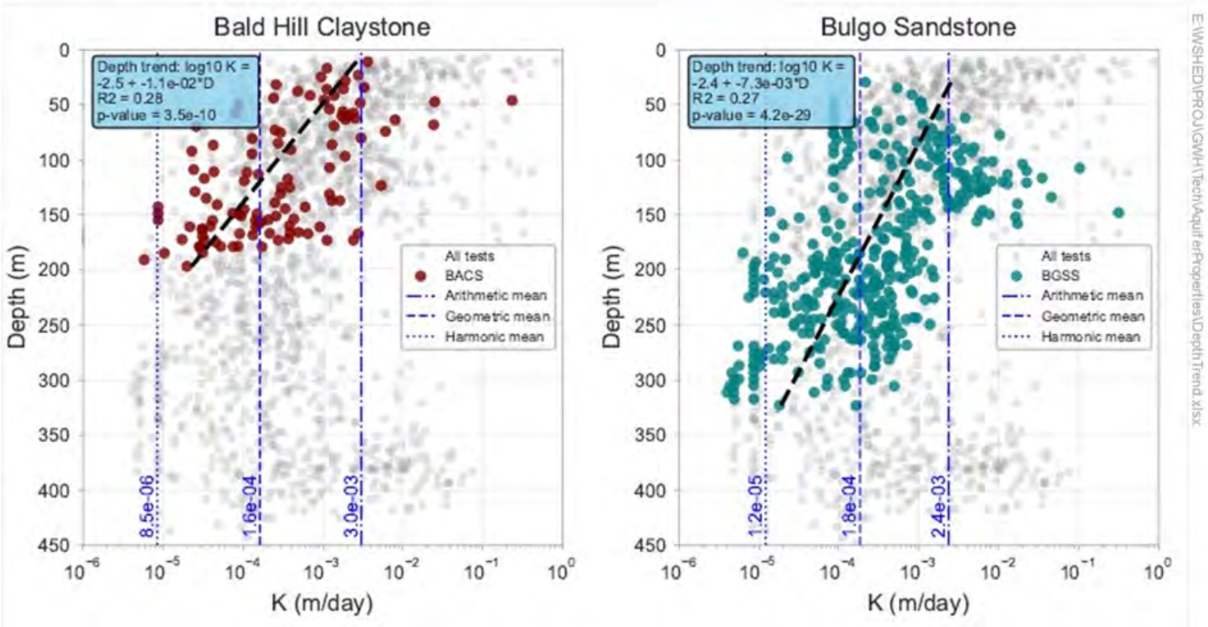


Figure 2-10 Example of K variation and depth trends in Triassic Sydney Basin strata (Southern Coalfield)

The trends illustrated on **Figure 2-10** can be summarised as:

- 0.8 log cycle decrease in Kh for every 100 m additional depth for units that are predominantly sandstones.
- 1.1 log cycle decrease in Kh for every 100 m additional depth for units that are predominantly claystones.
- The relationship is likely to be asymptotic at some depth, however the data above shows a trend to 200 m and 300 m respectively. As a result, we will assume that Kh does not systematically decrease with depth beyond 300 m.
- Coal seam permeability (not shown) is not considered to be depth-dependent, based on the significant dataset obtained in Southern Coalfield coal mines. Furthermore, the groundwater model does not explicitly represent coal seams in the layer framework (**Table 2-2**).

The modelling adopts the generalised depth trends for each sandstone and claystone unit, with PEST then allowing perturbation from that generalised depth trend. A summary of the range in modelled values (min-max and arithmetic mean) by broad lithology is shown **Figure 2-11**, along with packer testing data.

Each pilot point for Kh in the numerical model was assigned to a layer and attributed with the broad lithology of the layer or stratigraphic unit (**Table 2-2**). Then the depth of the pilot point was estimated using the mid-depth of the model cell at the pilot point location. These lithology and depth attributes were then used to define the initial Kh value (the mean value – heavy dark orange line on **Figure 2-11**) and the allowable range in Kh for that pilot point described by the lighter orange lines on **Figure 2-11**.

Figure 2-11 indicates that there is no depth-dependent K below 300 m depth, which is deeper than the proposed tunnel. For all pilot points shallow than this, then a depth-dependent Kh was applied.

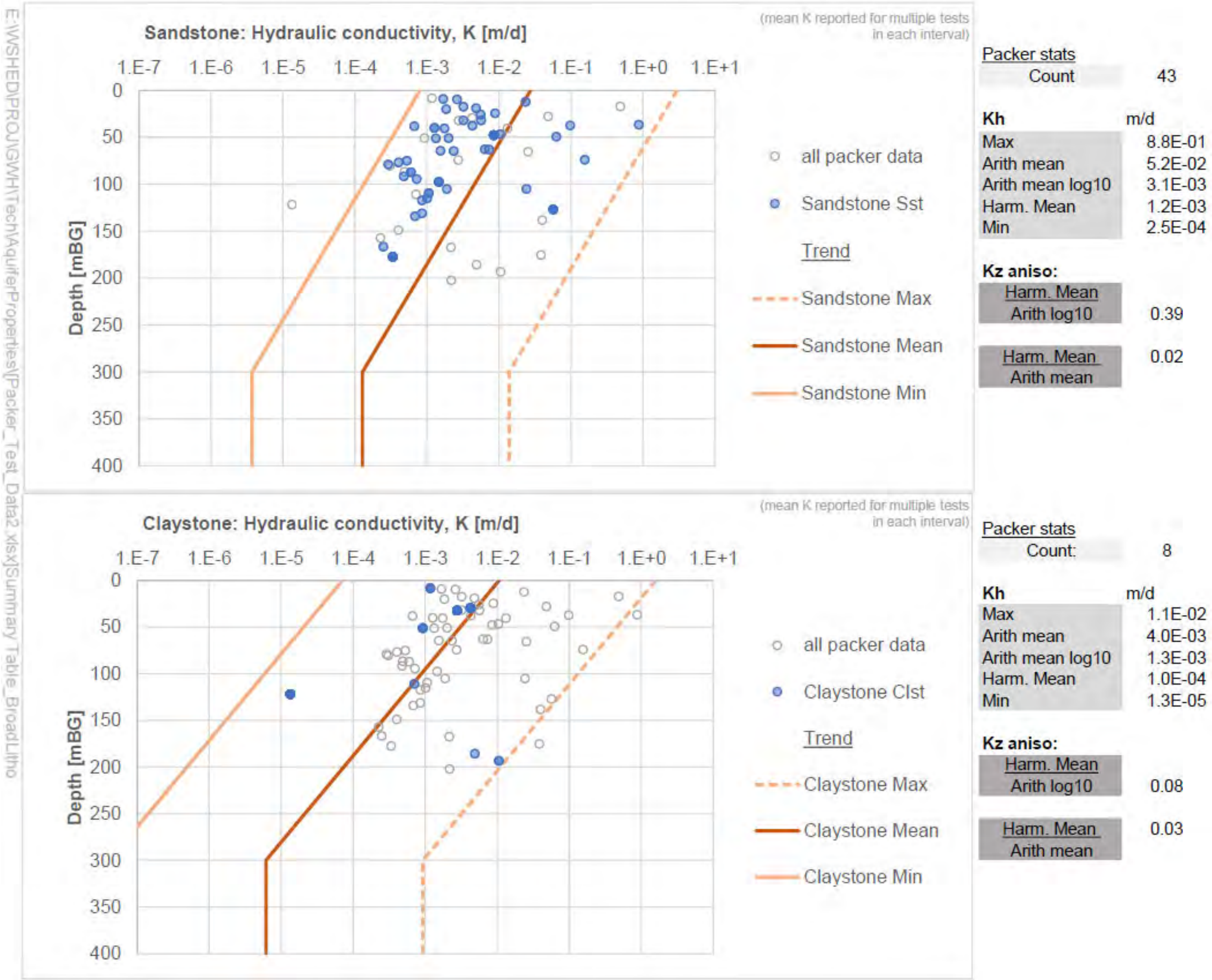


Figure 2-11 Summary of Kh data and depth trend

<u>Structural K</u>: for the geological structures identified on **Figure 2-7**, the range of Kx supplied to PEST was different to that of the general Kx pilot points described above. The K-range for these extends up to 2 m/d. Values up to 100 m/d (i.e. for open fractures) were initially used to define the range in the modelling, but this led to excessive desaturation ('dry' model cells) along the ridgeline due to the resultant high transmissiveness along these features given that model cells are generally 200 m wide.

As noted above, there is no depth-dependent K applied to the structural features.

Figure 2-12 summarises the initial values of Kx (and Kz) and the allowable range for pilot points in each model layer/zone. Note that for the initial values, the average of the initial values in each zone is displayed, noting that the Kx is depth-dependent, as per the discussion above.

A summary of posterior values, i.e. those developed as a result of the PESTPP-IES history-matching process, are described in Section 3.5.

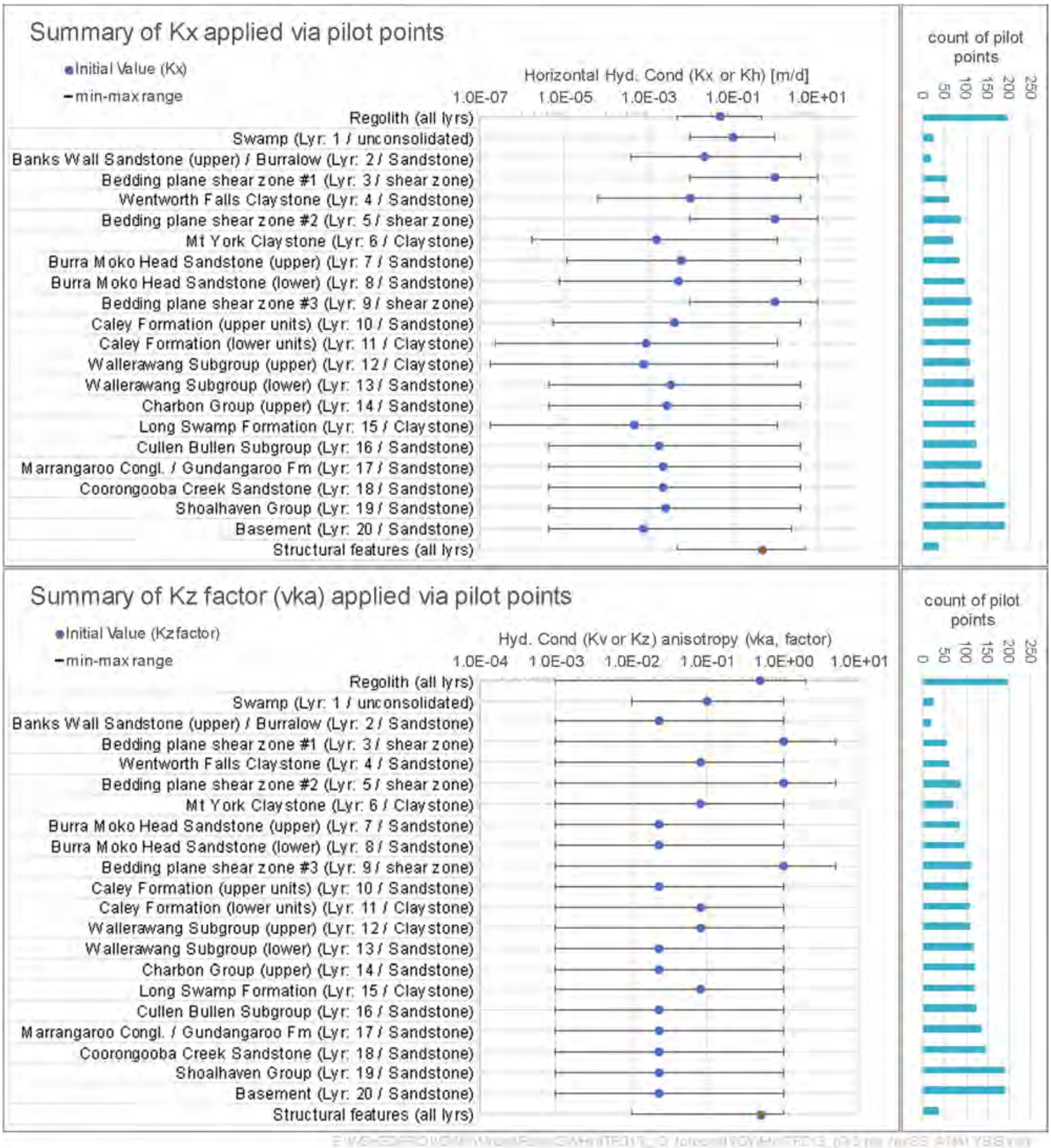


Figure 2-12 **Summary of modelled Kx and vertical anisotropy by unit/layer (initial values)**

2.6.3 Hydraulic conductivity - vertical (Kv or Kz)

The available dataset of site-specific hydraulic conductivity data provides a useful basis for characterisation, using a statistical analysis of harmonic mean and its relationship to arithmetic averages (see **Figure 2-11**).

Pilot points are used to assign a value of vertical anisotropy (vka) for interpolation across each layer, which is subsequently converted to Kv or Kz = vka x Kx.

As with the Kx (Kh) parameters, structural features are incorporated within the model via PLPROC's *calc_linear_gauss_interp_factors* function (Section 2.6.1).

Figure 2-12 provides a summary of the vertical anisotropy range and initial values used by PEST, prior to them being transposed to Kz for input to the groundwater model.

2.6.4 Aquifer storage

Model parameters of confined and unconfined storage (Ss and Sy, respectively) are not well-constrained by local data. The general conceptual model is that there would be higher Sy and Ss in units that are dominantly sandstones and the coal seams compared to units that are dominantly claystone/mudstone.

Sy values are based on review of literature, discussion with project staff, and experience of modelling projects elsewhere in the Sydney Basin. Adhikary and Wilkins (2013) and JBS&G (2019) include modelled "porosity". The CSIRO values, equate to drainable porosity (Sy) range from 0.15 (regolith), 0.5-0.2 for sandstones, and 0.05-0.1 or 0.15 for claystones and coals, while the JBS&G parameters are significantly higher, and are not relied on here. For the swamps, good data is available in in Shaygan *et al* (2022).

Reasonable estimates of Ss can be made from engineering geology parameters for the relevant rock types (Mackie, 2009; David et al., 2017). Using data obtained by the project's geotechnical engineers, estimates of Ss have been made for claystones and sandstones, and then estimates for shear zones and regolith have been estimated from those. These were compared to the estimates of Rau *et al.* (2018) and Chowdhury *et al*. (2022) and model estimates from JBS&G (2019). These estimates were then applied as the initial value used by PEST. PEST's allowable range in Ss was set as an order of magnitude above and below this initial value, albeit further constrained, where necessary, by the limits recommended by Rau *et al* (2018), 2E-7 to 1.3E-5 m^{-1}, especially the stated upper limit.

Figure 2-13 summarises the initial values and ranges for the storage parameters supplied to PEST.

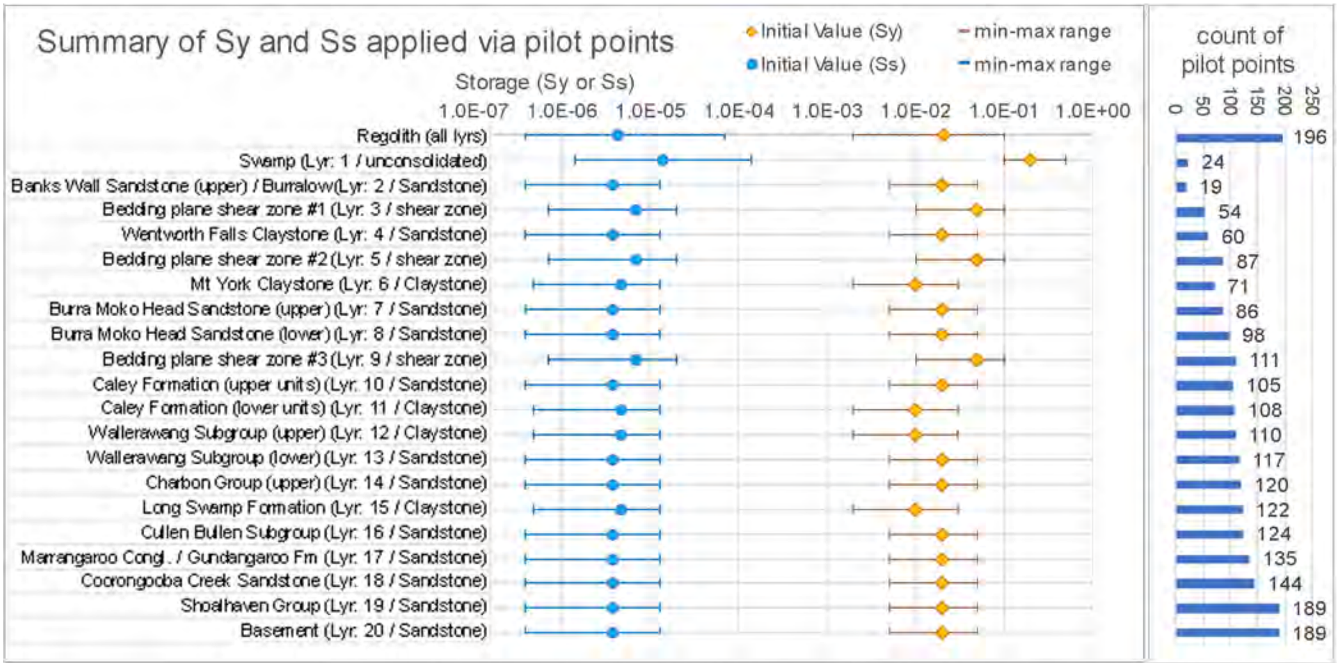


Figure 2-13 Summary of Storage properties (Sy and Ss) applied via pilot points (initial values)

Sy and Ss parameters are supplied to PLPROC and PEST using the general set of pilot points shown on **Figure 2-7**. This means that although a general conceptual trend of decreasing Ss with depth is likely, the adjustment by PEST at each pilot point means that this may not eventuate. The structural features are not used for application of Sy and Ss parameters. A summary of posterior values after PESTPP-IES history-matching are described in Section 3.5.

2.6.5 Representation of segmentally lined tunnels as a barrier to throughflow

The installation of twin segmentally lined tunnels, which are effectively impermeable linear features, could form a barrier to groundwater throughflow and potentially result in localised mounding of (downgradient side) groundwater or drawdown (downgradient) and possible re-direction of flow.

The scale of the tunnel features means that representing the lined tunnels explicitly as low permeability features in the numerical model is not practical. Therefore, the time-varying material properties (.TVM) approach of MODFLOW-USG (Merrick, 2016) was adopted.

The TVM method achieves the change in transmissivity caused by the insertion of the low permeability feature (i.e. the tunnels) within a hydrostratigraphic unit not by modifying the effective cross-sectional area through which groundwater can flow, but by changing the hydraulic conductivity of the model cells to have an equivalent or proportional effect. This is illustrated in **Figure 2-14**. This only applies to the TBM-driven tunnels, not to the portals (cut-and-cover) or mid-tunnel infrastructure.

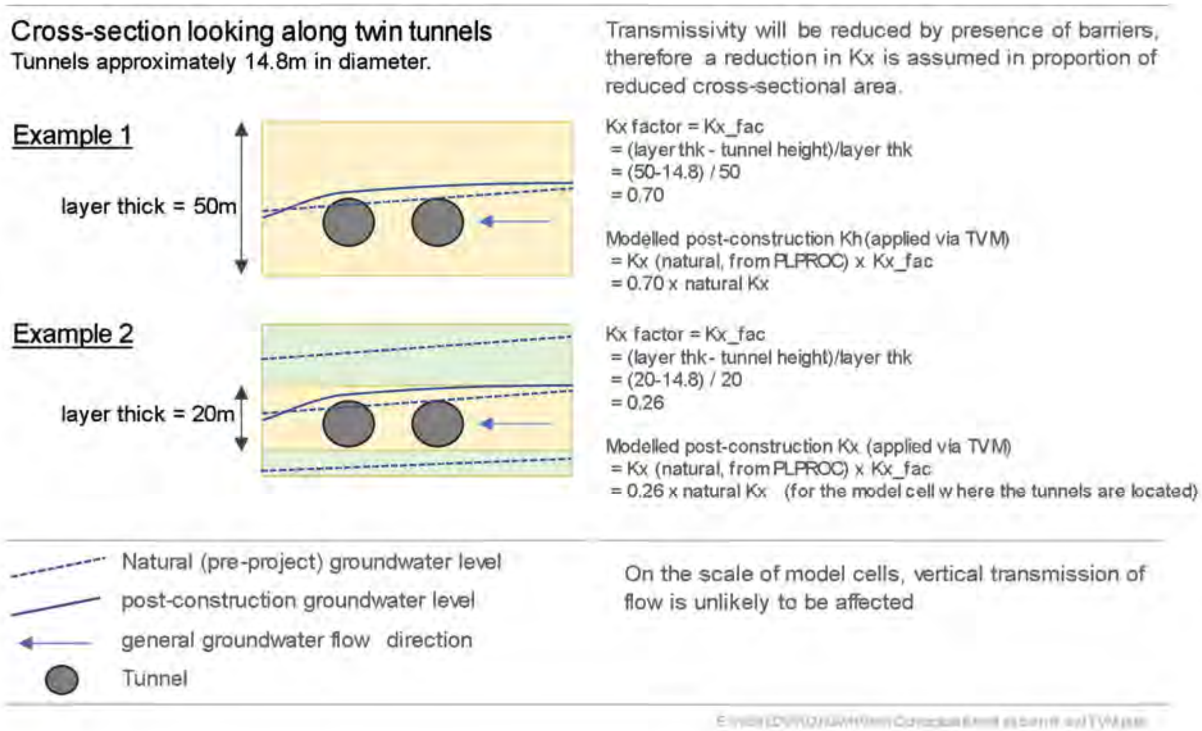


Figure 2-14 Schematic showing potential effect of lined tunnels on lateral groundwater flow and representation via TVM

Although these changes to hydraulic conductivity would, in reality, occur as the segmentally-lined tunnel is installed, the subsequent opening of the linings and construction of the cross-passages means that it is more practical to imposed these changes in the model after the relevant cross-passages are fully constructed and ‘tanked’. Therefore, the change to hydraulic conductivity is activated via the TVM package in the stress period after any local cross-passages are scheduled to be completed. The change to horizontal hydraulic conductivity remains until the end of the model period (i.e. in perpetuity).

A script that reads the modelled natural Kx and writes the post-construction Kx to the TVM is used to account for the variable or adjusted Kx (calculated via PLPROC, Sections 2.6.1-2.6.3) for each model realisation.

As noted on **Figure 2-14**, changes to vertical hydraulic conductivity are considered to be insignificant given the scale of model cells compared to the size of the tunnels, and the generally low vertical hydraulic conductivity in this sequence. Likewise, changes to storage properties due to the installation of the twin tunnels are also considered insignificant.

2.7 Observation data

History-matching or calibration has considered two types of observation:

- Groundwater levels or heads.
- Head differences (from the groundwater levels).

There are currently no flux targets available for use in the modelling, which affects the confidence classification regarding the objectives and forecasts (**Appendix G**).

Additionally, further qualitative constraints have been added to improve model utility in the forecasting sense and constrain the simulation. That is, early attempts at history-matching and generation of multiple realisations via PESTPP-IES resulted in many realisations having desaturation conditions along many parts of the escarpment, including areas where hanging swamps are known to occur.

In the absence of quantitative monitoring data in many relevant locations across the model domain and in the relevant stratigraphic horizons, a number of constraints were added by the modeller – in essence these are calibration targets, but reliant on an estimated (not monitored) groundwater level in a number of locations adjacent to observed swamps and hanging vegetation features. It is reasonable to use this “soft data” in the absence of hard or quantitative data, because we know there must be groundwater present at these locations due to the presence of relevant environmental features, and therefore there should be an attempt to constrain model simulation to reproduce that behaviour.

The total number of observations (224) are summarised by observation type in **Table 2-8**.

Table 2-8 Observations used in model history-matching (calibration)

Observation type (group)	Count	Comment / source
Groundwater levels	203	Groundwater levels from monitoring bores, including transient records at some bores where the dataset is available
Groundwater level differences	14	Groundwater level differences calculated from nested sites
Constraints	7	Estimated groundwater levels at known seepage locations

Each of these are described further in the following sub-sections.

2.7.1 Groundwater levels

A dataset of groundwater level measurements has been collated across a total of 36 target instruments (bores, vibrating wire piezometers [VWP]) from which groundwater level observations have been used to derive transient “calibration targets”. The locations of monitoring points used for groundwater level calibration are mapped on **Figure 2-15**. Additional sites are being installed or planned at the time of writing. Further recommendations for data gathering are made in Section 5.1.1.

The groupings of monitoring sites used to provide targets are summarised in **Table 2-9**.

Table 2-9 Groundwater level observation sites

Location/ area	Site IDs	Monitoring present	Formation(s)	Model layer	Data availability	Comment
Victoria Pass	G4025_BH1	Standpipe	Mt York	6	5 years	
	G4025_BH2	Standpipe	Banks Wall Sst	4	<3 years	
	G4025_BH4	not stated (assume standpipe)	Long Swamp Fm	15	5 years	
	G4025_BH5	Standpipe piezo, 50mm	Marrangaroo/ Gundangaroo	17	5 years	
	G4025_BH8	Standpipe piezo, 50mm	Gundangaroo / Coorongooba	17 (18?)	5 years	
	G4025_BH9	Standpipe piezo, 50mm	Long Swamp Fm	15	5 years	
	G4898_KB2	not stated (assume standpipe)	Burralow Facies / Upr Banks Wall Sst	2	None	
Mount Victoria	BH504_47	VWP	Banks Wall Sst	4	1 year*	
	BH504_50	VWP	Mt York	6	1 year*	
	BH504_85	VWP	Burra-Moko Head Sst	7	1 year	~adjacent to Mid-Tunnel cavern
Mount Victoria	BH505_26.5	VWP	Banks Wall Sst	4	2 months*	
	BH505_36	VWP	Mt York	6	2 months*	
	BH505_86	VWP	Burra-Moko Head Sandstone (lwr)	8	2 months*	
	BH505_117	VWP	Caley Fm	10	2 months*	
	BH505A	Standpipe	Banks Wall Sst	2 -4	1 reading	
	BH505B	Standpipe	Burra-Moko Head	7-8	Single dip -	
	BH507	Standpipe piezo	Burra-Moko Head Sandstone (upr)	7	1 reading	
Blackheath	BH500	Standpipe	Banks Wall Sst	4	Single dip -	
	BH500A	Standpipe piezo	Burralow Facies / Upr Banks Wall Sst	2	1 reading*	
	BH501_33	VWP	Banks Wall Sst	4	7 months*	These three all in same layer in similar/same XY location, but with different GWLs
	BH501_49	VWP	Banks Wall Sst	4	8 months*	
	BH501A_10	VWP	Banks Wall Sst	4	2 months*	
	BH501A_12	VWP	Mt York	6	2 months*	
	BH501A_ 170	VWP	Burra-Moko Head Sandstone (lwr)	8	2 months*	
	BH622	n/a	n/a	n/a	1 reading	
	BH103	n/a	Banks Wall Sst	4	1 reading	

Location/ area	Site IDs	Monitoring present	Formation(s)	Model layer	Data availability	Comment
	BH115	n/a	Marrangaroo	17	1 reading	
	BH116	n/a	Blackmans Congl.	16	1 reading	
Popes Glen Swamp	PGR_B1	Swamp	Swamp	1	3 manual	
	PGR_B3	Swamp	Swamp	1	3 manual	
	PGR_B4	Swamp	Swamp	1	3 manual	
	PGR_B5	Swamp	Swamp	1	1 manual dip	
	PGR_B6	Swamp	Swamp	1	3 manual	
Greaves Ck / Grand Canyon	Greaves_GC1	Swamp	Swamp	1	1 manual dip	
	Greaves_GC2	Swamp	Swamp	1	1 manual dip	
	GCP2	Swamp	Swamp	1	all GWL data	All false zeroes?
	GCP1	Swamp	Swamp	1	1 manual dip	
Wentworth Falls	GW75005	VWP-equipped bore			Long record	10 km SE of Blackheath --> outside the model domain
	GW75006	VWP-equipped bore			Long record	
	GW75007	VWP-equipped bore			Long record	
Various	Registered bores				single SWL at some sites	Low confidence
* more data is available than stated here. This table indicates that data available at the time of model calibration.						

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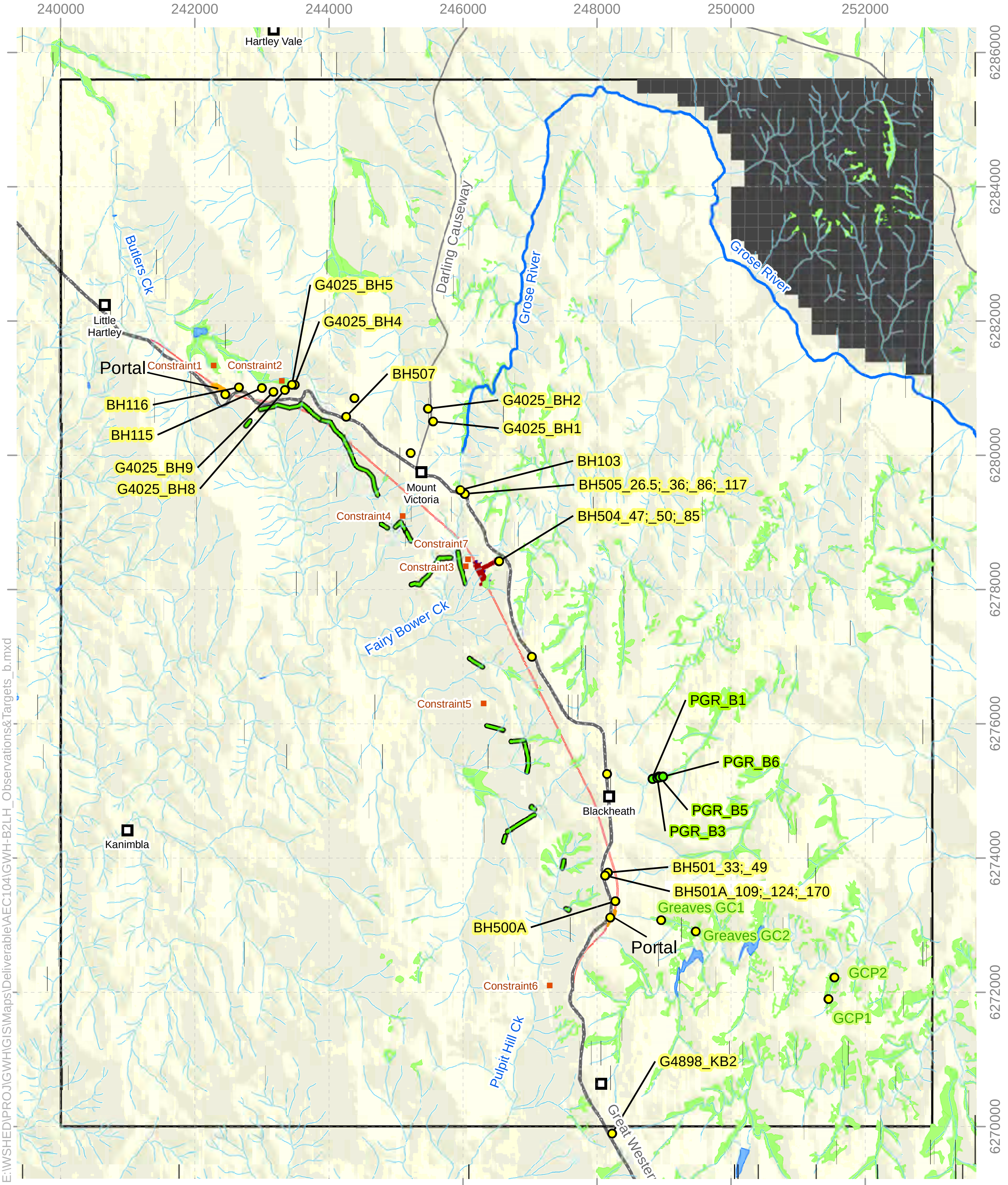


Created by: WMinchin | Version:B | Date: 10/10/2021

Major town
Minor town
Model extent
Model no flow (inactive)
Main road
Great Western Highway
GWH project alignment - Tunnel
Cut and Cover section
Mid-Tunnel (Cavern / Adit / Shaft)
River
Creek
Temperate Highland Swamps (THPSS)
Cliff (Hanging) Swamps
Monitoring bore - swamp
Monitoring bore - rock
Constraints
(labelled where GWL data is available)

N
0 0.5 1 1.5 2 km

Scale: 75,000 @A4
GDA 1994 MGA Zone 56

WATERSHED HYDROGEO

GWH-B2LH

Groundwater monitoring and observations

Figure 2-15

Groundwater levels from the 4025-series bores were assigned to observation group 1. Groundwater levels from the 500-series bores were assigned to observation group 2, with some infrequent data readings from the 500-series or other similar project-related bores assigned to group 3. Popes Glen Swamp data was assigned to group 4.

From the sub-daily or daily data recorded at those sites, the data have been converted into 205 targets using, where possible, the groundwater level on the last day of a model stress period. Of these, 175 are “good” quality (weighting >0).

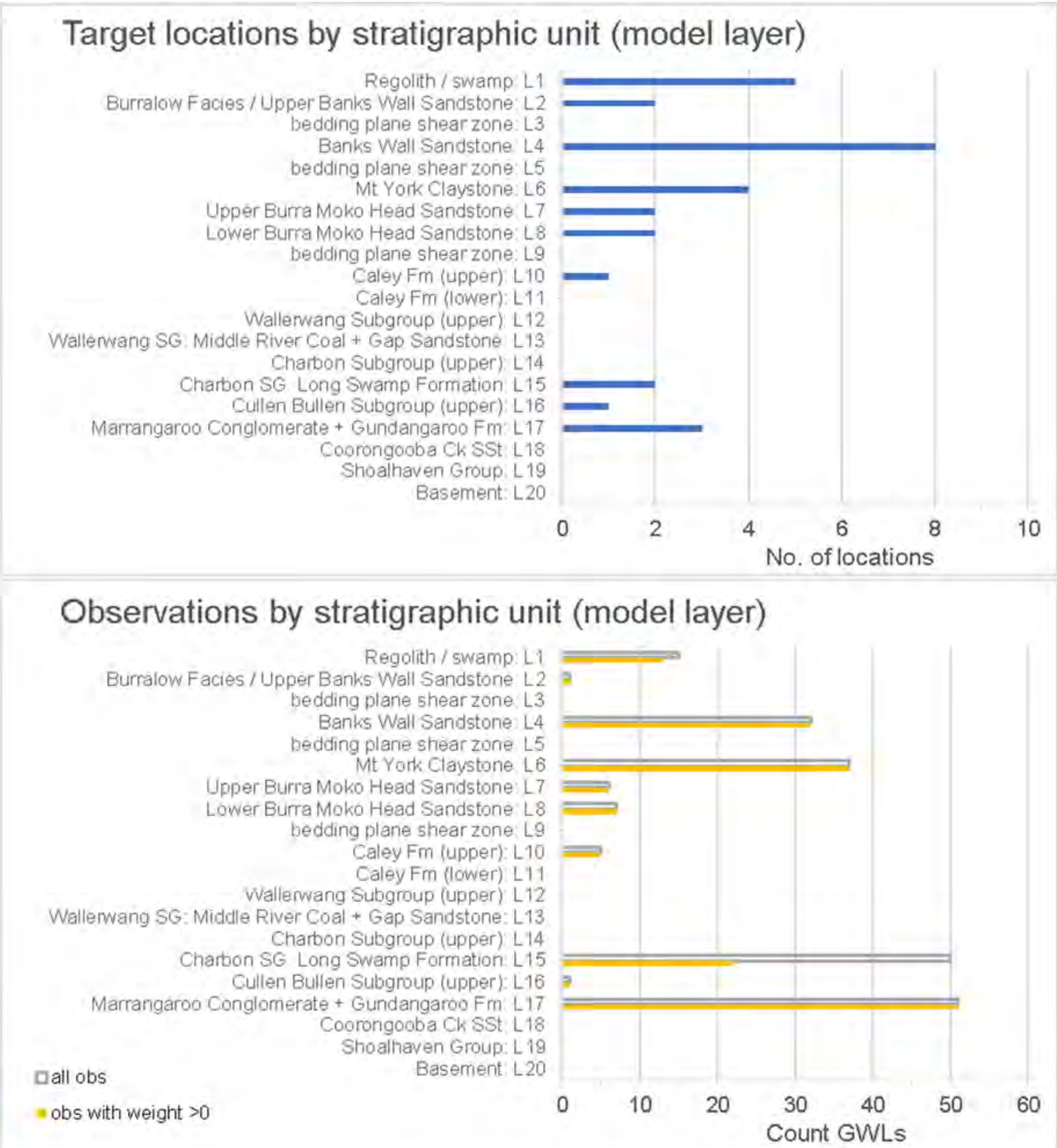


Figure 2-16 Summary of data availability by model layer / stratigraphic unit

The data is summarised on **Figure 2-16**. Data quality assessment of the targets is as follows:

- Clearly erroneous data has been removed (weighted as 0).
- Readings where the groundwater pressure recorded is below the VWP sensor elevation, but clearly not zero, have been weighted as 0.8. In future, this assumed weighting could be

modified (possibly to remove the observation), especially if more data is available at other nearby sites.

- Saturated groundwater level readings (positive pressures) at BH504_85, which is located adjacent to but just above the mid-tunnel cavern have been assigned a weighting of 10 in the PEST calibration, due to their perceived importance.
- Other readings are assigned a weighting of 1.

Comparison of modelled groundwater levels and the targets is presented in Section 3.3.

Later in this study, a number of additional 'constraints' were added to the PEST history-matching process. These are estimates of groundwater levels at or adjacent to environmental features. These have been added to reduce the potential or occurrence of desaturated model cells in the PESTPP-IES realisations, which was a common feature of earlier PEST runs during the history-matching process (too high a transmissivity in cells initially).

The locations of these are plotted on **Figure 2-15**, and these are summarised in **Table 2-10**. The groundwater level elevations are estimated, based on inspection of locations of important swamp features and model layer elevations (i.e. with the concept that the model layer must be saturated or partially saturated at or adjacent to the identified groundwater-dependent feature).

Table 2-10 Groundwater level constraints

Target Name	Easting	Northing	Date	GWL target (mAHD)	Layer	Weighting	Group
Constraint1	242283	6281340	1/03/2020	828.5	1	1	6
Constraint2	243300	6281110	1/03/2020	875	1	1	6
Constraint3	246040	6278345	1/03/2020	930	8	1	6
Constraint4	245100	6279100	1/03/2020	935	8	1	6
Constraint6	247295	6272100	1/03/2020	872	8	1	6
Constraint5	246305	6276305	1/03/2020	882	8	1	6
Constraint7	246075	6278450	1/03/2020	1000	4	1	6

E:\WSHED\PROJ\GWH\Model\Construction\Targets\Constraintsv1.csv

2.7.2 Groundwater gradients (differences)

Vertical head gradients (expressed as head differences) have been calculated between co-located monitoring sites (e.g. two piezometers installed in one borehole) and used in the history-matching process. The aim of this was to constrain the modelled Kz more so than by using groundwater level observations alone. These are summarised in **Table 2-11**.

We note that the observed head differences are significant (and downward) suggesting perched conditions are common in upper layers. The aquitards, if not the regional claystone units (e.g. Mount York Claystone) may be very thin, possibly too thin to include in model layering, and as such the model/PEST may need to adopt very low Kz (or high vertical anisotropy) in order to match the observed head separation. That said, the posterior parameters (those from the PESTPP-IES history matching process) in Section 3.5.1and **Figure 3-13** seem reasonable.

Table 2-11 Vertical head difference targets

Target Name	Easting	Northing	Date	GWL_Diff (m)	Layer_1	Layer_2	Weighting	Group
BH501A_0406	248121	6273740	1/07/2021	35.1	4	6	1	5
BH501A_0406	248121	6273740	7/08/2021	35.2	4	6	1	5
BH501A_0608	248121	6273740	1/07/2021	5.4	6	8	1	5
BH501A_0608	248121	6273740	7/08/2021	5.2	6	8	1	5
BH504_0406	246538	6278422	2/07/2021	8.1	4	6	1	5
BH504_0406	246538	6278422	2/10/2021	8.6	4	6	1	5
BH504_0607	246538	6278422	2/07/2021	43.3	6	7	1	5
BH504_0607	246538	6278422	2/10/2021	45	6	7	1	5
BH505_0406	246026	6279426	2/07/2021	1.1	4	6	1	5
BH505_0406	246026	6279426	2/10/2021	1.7	4	6	1	5
BH505_0608	246026	6279426	2/07/2021	44.2	6	8	1	5
BH505_0608	246026	6279426	2/10/2021	47.3	6	8	1	5
BH505_0810	246026	6279426	2/07/2021	16	8	10	1	5
BH505_0810	246026	6279426	2/10/2021	16.1	8	10	1	5

E:\WSHED\PROJ\GWH\Model\Construction\Targets\MonitoringBoreDetails.xls

The target names in **Table 2-11** have the following format “XXXX_YYZZ”, where XXXX is the bore name at which the vertical head separation was calculated (i.e. from two piezometers in that bore), while YY indicates the upper stratigraphic or model layer and ZZ indicates the lower layer between which the head separation was calculated.

2.7.3 Flux targets

At this time, there are no flux targets available to constrain the modelling. In future, it is possible that baseflow or spring flow estimates might be available to add to the target dataset.

2.8 Model execution

Despite the model having 20 layers, the relatively simple approach to the mesh, and the lack of subsurface stresses (i.e. no tunnel yet, nor any groundwater bore pumping) resulted in a relatively short model run time:

- The historical model of 38 stress periods runs in 3-5 minutes (slower when including pre- and post-processing and runs in parallel).
- The ‘Full Development’ predictive model (91 stress periods, including the historical period again) takes approximately 4-6 minutes to run (slower when including pre- and post-processing and runs in parallel).
- Most of the model runs have been carried out on an i9-9900, 3.1 Ghz CPU with 64 GB of RAM, but for PESTPP-IES these have been parallelised on this machine or to other local machines.

Heads and budget outputs are saved on multiple timesteps (usually 2 – see **Appendix C**) during each stress period, producing approximately 350 megabytes (Mb) of output for each historical model run, and 650 Mb when including both historical and predictive periods. The run-time and disk space requirements are amenable to automated calibration and forecasting under uncertainty via many realisations.

The numerical solver used is the MODFLOW-USG 'SMS' solver (Panday et al., 2013; Panday, 2021) with a head close criterion of 0.001 m (outer iterations) and 0.0001 m (inner iterations). Other solver settings are available on request. Adaptive time-stepping is not used. The resultant model mass balance error is reported in Section 3.4.

3 Model performance and history matching

This section presents model results for the historical calibration period (Section 2.4.2) compared to observed data or targets (Section 2.7). Subsections describe the general approach for model calibration (Section 3.1), and broad review of the simulated regional water balance (Section 3.4). The capability of the model in replicating observed data is presented for the different types of observations (Section 2.7).

Model history-matching is considered in the Model Confidence Classification (Section 2.3.1 and **Appendix G**). Model history-matching is also commonly referred to as model "calibration" and the terms may be used interchangeably.

3.1 Approach

Model history-matching is the process of replicating hydrogeological targets (Section 2.7) by varying key model parameters such as hydraulic conductivity and storage within the range of reasonable values described in Section 2.6 and some of the boundary condition parameters in Section 2.5.

The modelling relies on many available values of hydraulic conductivities and storage parameters Some trial-and-error calibration and testing of the model was carried out to adjust boundary conditions and hydraulic conductivity (horizontal and vertical), and storage parameters of model layers or zones to test model stability and plausible representation to groundwater levels.

Along with trial and error methods, PESTPP-IES (White et al., 2020) has been used to carry out automated calibration. PESTPP-IES does not focus solely on 'calibration' per se. White *et al* (2020) state: that the exploration and regularisation or parameters "implemented by PESTPP-IES thus attempts to ensure that parameters comprising each realisation are changed from their initial values by the smallest amount required for model outputs to reproduce field observations "acceptably" well". So while performing 'calibration', PESTPP-IES also generates a set of plausible alternative model realisations that fit the observations or targets to this "acceptable" degree.

The following documents provide a full description of the methods applied to the modelling in this report:

- The PESTPP-IES manual (White et al., 2020) and associated literature for detailed information on practical application of the PEST and PESTPP-IES software, in addition to description of concepts and processes.
- PEST – The Book (Doherty, 2015) for the theory behind the approach to inversion and uncertainty analysis and application to environmental modelling.

In addition, the methods applied here were decided upon in discussion of the specific project with John Doherty via the Groundwater Modelling Decision Support Initiative (GMDSI)[3], with some assistance also provided in executing some of the methods.

3.2 History-matching (calibration) and ensemble development

At the end of the PESTPP-IES history-matching process presented in the following sections, PESTPP-IES had run the model 2,200 times to the end of the fifth PEST iteration. From that 5th iteration, an ensemble of 300 alternative realisations was developed (**Figure 3-1A**). This includes the 'Base'

[3] https://gmdsi.org/about/

realisation which represents the optimised version of the initial (prior) base parameter realisation provided to PESTPP-IES.

To achieve an acceptable calibration or fit to the targets, PESTPP-IES adjusts the specified parameters, of which there were 13,393 in total (Table E1, **Appendix E**), within their user-specified allowable ranges (based on site-specific and literature data and "expert knowledge"), and compares the modelled results against the targets. The overall measure of 'fit' to the targets (or overall model error) is the objective function ("phi"). During the iterations (of which 5 has been specified as the maximum (NOPTMAX) PESTPP-IES reduces phi as shown in the **Figure 3-1B**.

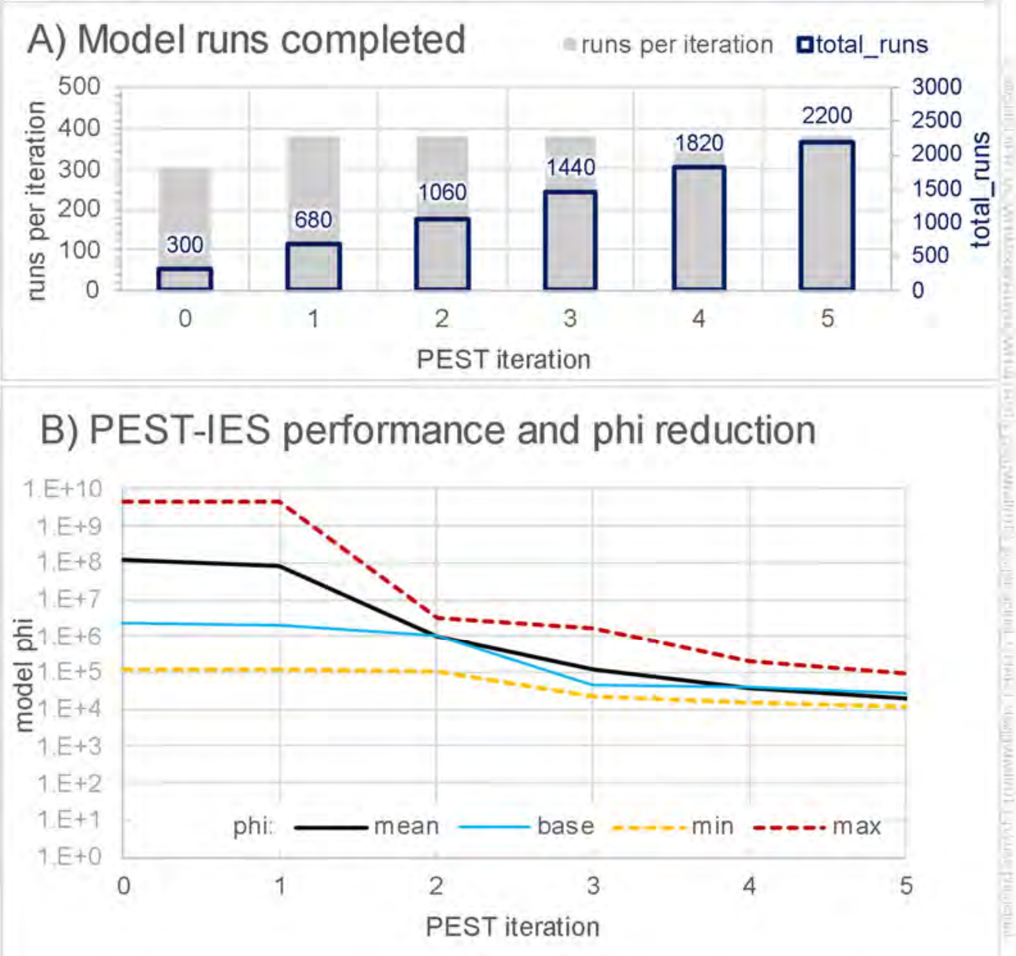


Figure 3-1 Summary of PESTPP-IES reduction in objective function (phi)

The "min" and "max" and "mean" phi series on the upper chart represent the range across all model runs in each iteration, while the Base phi illustrates the change in phi for the Base realisation. The chart shows fairly consistent improvement in phi, especially between iterations 1 and 4. From iteration 4 to 5, the reduction in phi is smaller.

A phenomenon that sometimes occurs using an ensemble smoother like PESTPP_IES (and was encountered in earlier PEST runs for this project) "is a collapse in diversity of parameter realizations as the iterative adjustment process progresses. Sometimes this collapse can invalidate the integrity of posterior parameter and predictive probability distributions that the ensemble attempts to characterize" (White et al., 2020). To minimise the potential for this ensemble collapse to occur, the PEST iteration process was ceased at the end of the fifth iteration, while other settings such as automatic adaptive localization functionality were enabled to assist with this. This has also meant that the overall phi and sRMS in the reported modelling have been deliberately relaxed compared to was reported in progress meetings with DPE Water.

The results and outputs presented in the following sub-sections (Sections 3.3 and 3.4) to illustrate the capability of the model to replicate observations and conform to expected behaviours are primarily for PESTPP-IES "Base" realisation, and some show the range across all 300 realisations.

3.3 Groundwater levels

This section describes the calibration process that referenced groundwater level measurements from the project's monitoring network, followed by comparison with vertical groundwater level differences. Contour maps of simulated (pre-construction) groundwater levels are then presented at the end of this section.

3.3.1 Project monitoring sites

A summary of model performance with respect to the overall simulation of groundwater levels is provided below, with simulated heads plotted against the observed head targets (described in Section 2.7.1) on **Figure 3-2**. This presents the base realisation, as well as showing the range in simulated groundwater levels across the ensemble.

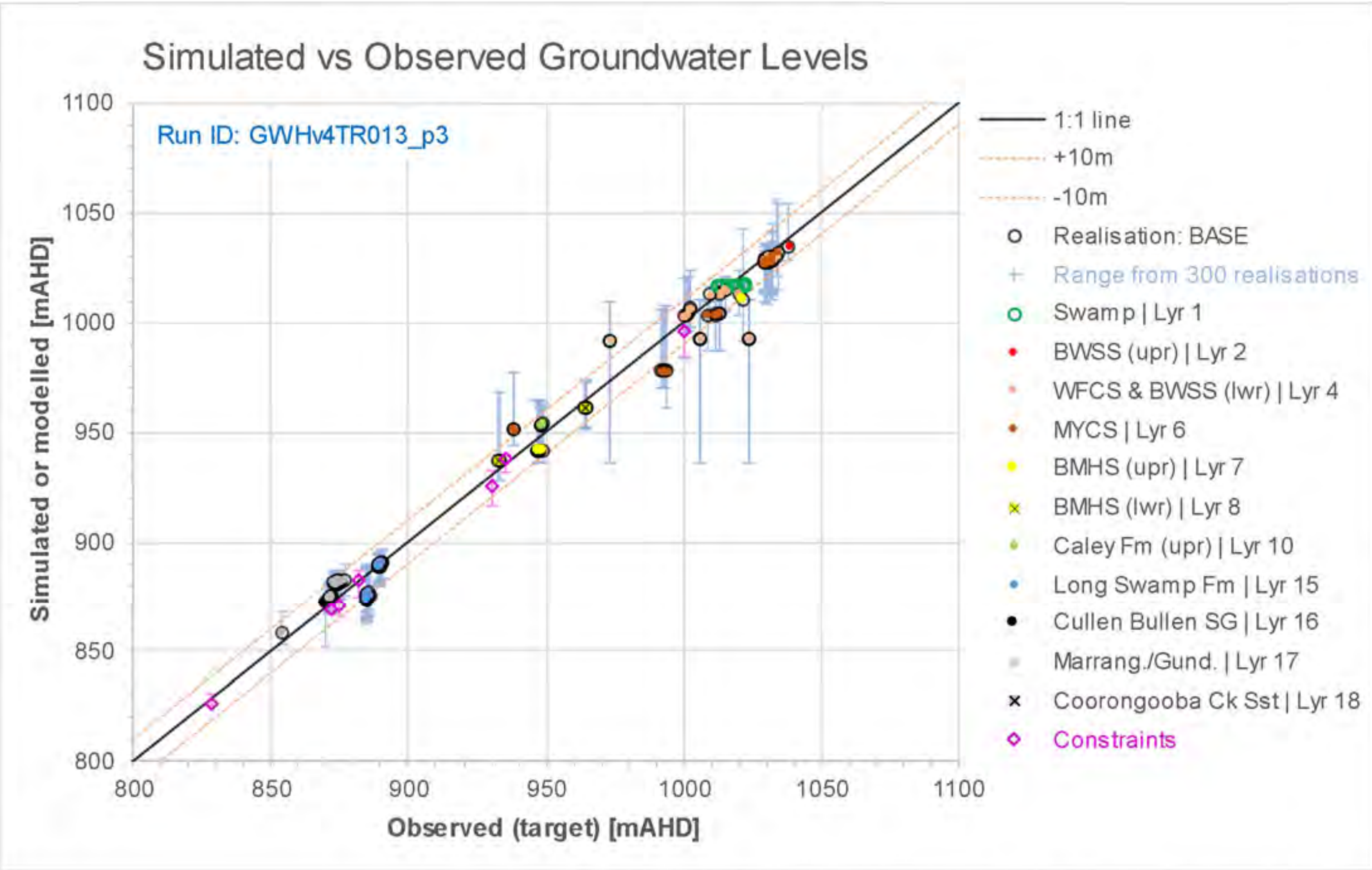


Figure 3-2 Summary of groundwater level calibration

This shows results that tend to cluster around the 1:1 line across the range of stratigraphic units (at least those for which targets or observations are available). While there is some spread (variance) from that line, generally the simulated groundwater levels lie within +/- 10 m, and without apparent bias to over- or under-estimation.

The key possible reasons for the variation between observed and simulated heads, other than the model trying to simulate a complex heterogeneous and anisotropic groundwater system, on the X:Y plot are:

- potentially incorrect layer assignment. For example, a VWP sensor located within the mid-Burra-Moko Head Sandstone may be assigned to the lower- Burra-Moko Head Sandstone but could be validly assigned to the upper Burra-Moko Head Sandstone. Such piezometers have been weighted down in the calculation of statistics (Section 2.7.1), but that does not affect the display;
- incorrect or uncertain data which has not been identified or cannot be confirmed as incorrect, and so is used 'as-is';
- model layers may be markedly thicker than the strata that is actually monitored by a piezometer (especially a VWP or standpipes with short screens); and
- incorrect or imperfect boundary condition elevations and parameterisation of the model re: K, S, recharge parameters, either on a local or larger-scale.

A number of statistical measures of calibration quality are suggested in the AGMG (Barnett et al., 2012a). A few of these are reported for the base realisation as follows:

- Mean residual ('error'): 1.8 m
- Mean absolute residual ('error') : 6.1 m
- SRMS 5.3%.

The scaled Root-Mean-Square (SRMS) error for the correlation between observed data and the transient model groundwater levels is within the often-quoted example of 10 % (MDBC (Murray Darling Basin Commission), 2000; (Barnett et al., 2012a), while the residuals quoted are acceptable for a model of this scale and complexity, and in a fractured rock environment.

Groundwater level hydrographs are presented in the following pages. These sites represent most of the sites with a relatively long record for which a water level time series hydrograph can be produced (as noted previously, more data is being gathered, so in future longer hydrographs, and potentially more sites, can be simulated and presented).

The full set of monitoring sites for which a useful hydrograph can be produced is presented in **Appendix F**. These hydrographs show the model representation of groundwater processes in response to historical variation in recharge and in locations that are in proximity to the features of the project (locations shown on **Figure 2-15**):

- Bore BH501, approximately 650 m north of the Blackheath Portal (**Figure 3-3**);
- Bore BH501A, approximately 600 m north of the Blackheath Portal (**Figure 3-4**);
- Bore BH504, near the mid-tunnel access shaft (**Figure 3-5**);
- Bore G4025_BH1, 1000 m north of the alignment near to Mount Victoria (**Figure 3-6**);
- Bore G4025_BH8, 950 m east of the Little Hartley Portal (**Figure 3-7**); and
- Bore G4025_BH9, 750 m east of the Little near to Little Hartley Portal (**Figure 3-8**) (although this bore is typically dry).

The format of these hydrographs is as follows:

- The key has been oriented to emphasise that the model layers and piezometers are set out in order of depth.
- The observed data (piezometers) are aligned to their corresponding model layer, noting that multiple piezometers might be present within a single model layer (e.g. in bore BH501, and that model layers are thicker than the strata thickness monitored by the most piezometers.
- The error bars are related to the modelled series, but are shown only for times when there is an available observation. The error bars show the range in modelled groundwater levels from all 300 realisations from PESTPP-IES (Section 3.2).

Key points to note from the hydrographs shown below are:

- In some instances the base model replicates groundwater levels reasonably well (BH501A, BH504, G4025_BH1 and G4025_BH8). In others, the base realisation does not, but the observations or targets are within the range simulated by all 300 model realisations.
- The timing of historical recharge is reasonably well represented, as shown for G4025_BH1 and G4025_BH19.

Figure 3-3 Modelled vs observed groundwater level hydrograph – bore BH501

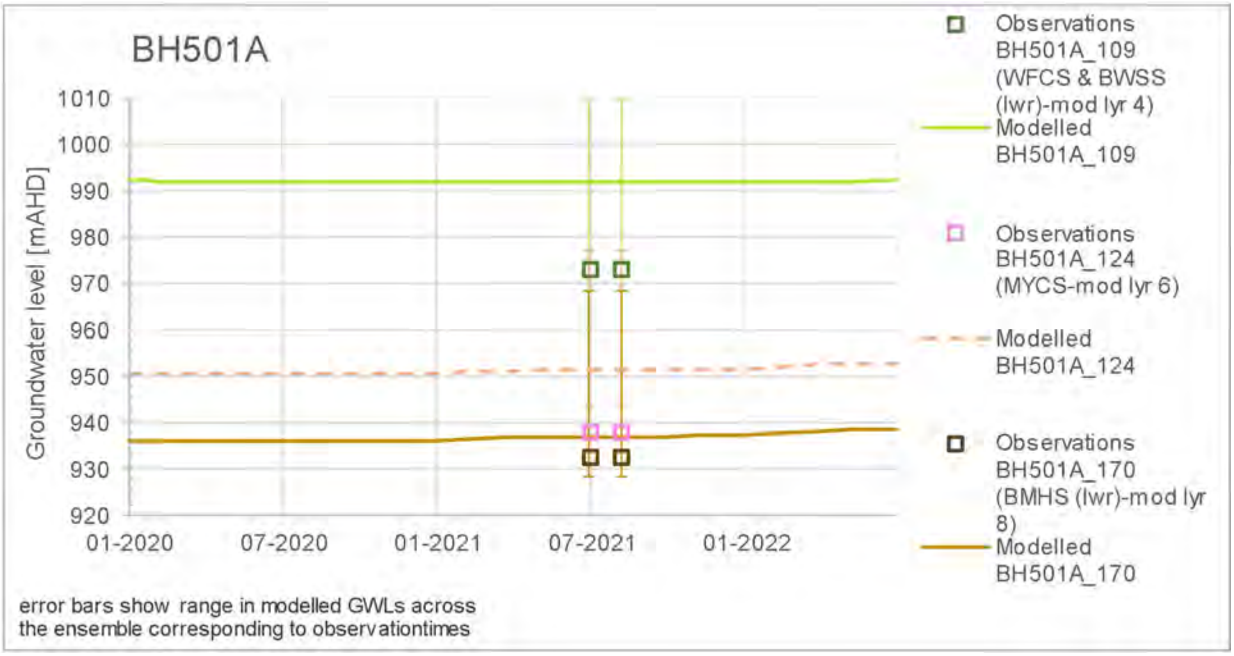


Figure 3-4 Modelled vs observed groundwater level hydrograph – bore BH501

Figure 3-5 Modelled vs observed groundwater level hydrograph – bore BH504

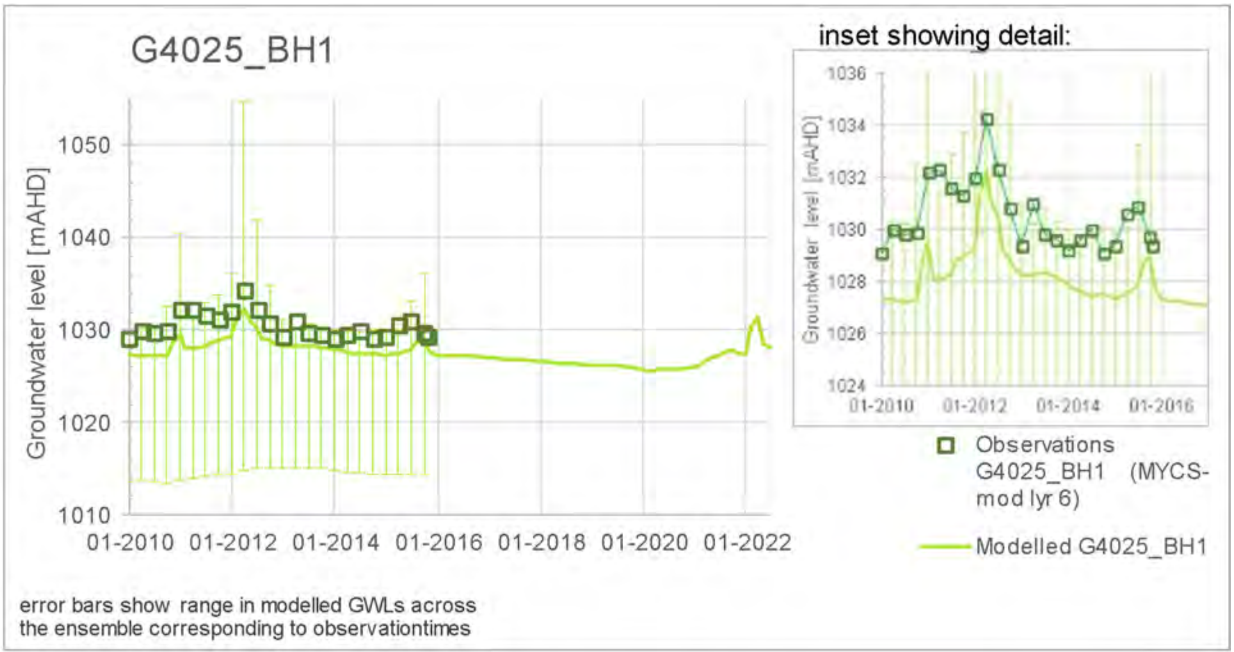


Figure 3-6 Modelled vs observed groundwater level hydrograph – bore G4025_BH1

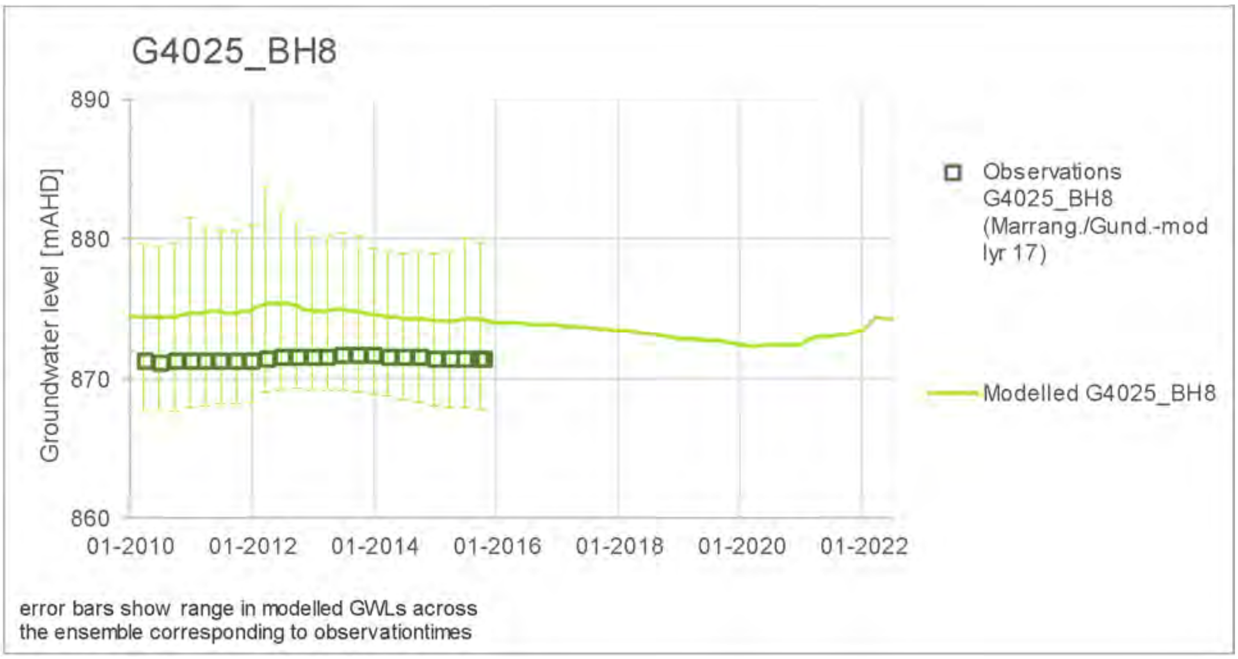


Figure 3-7 Modelled vs observed groundwater level hydrograph – bore G4025_BH8

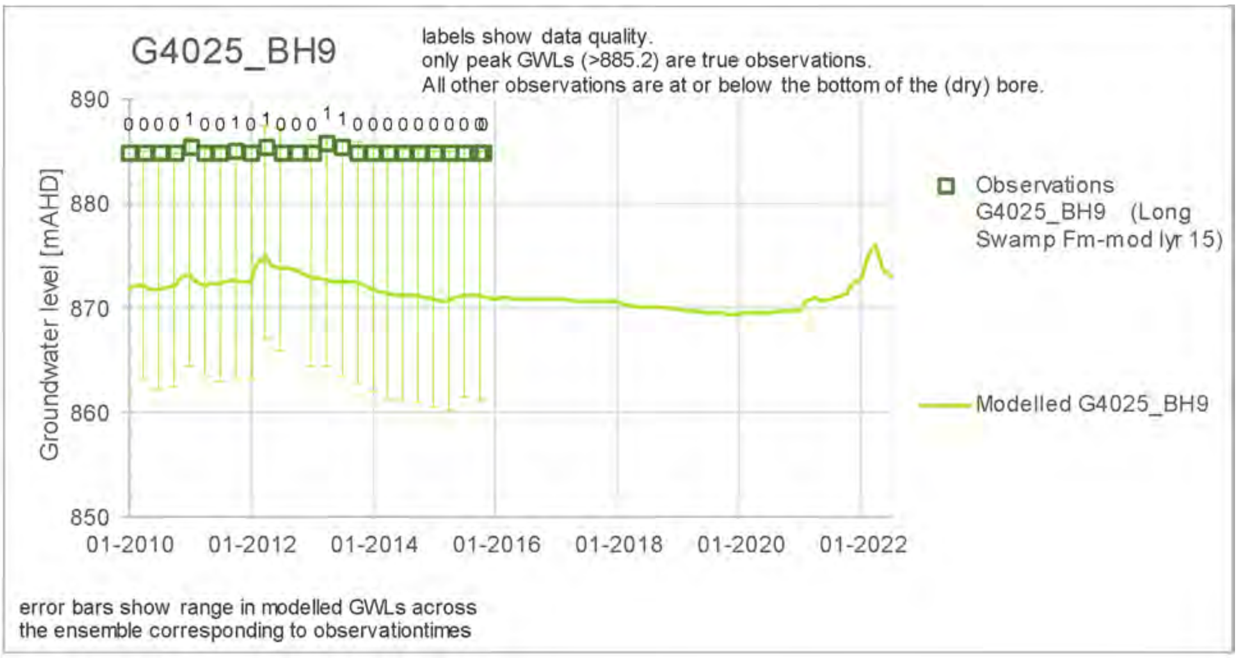


Figure 3-8 Modelled vs observed groundwater level hydrograph – bore G4025_BH9

3.3.2 Groundwater level separation or difference

Head gradients, or more specifically, vertical head separation has been provided to PESTPP-IES as a 'target' (Section 2.7.2). **Figure 3-9** below presents a summary of the modelled head separations at each of the relevant locations and times.

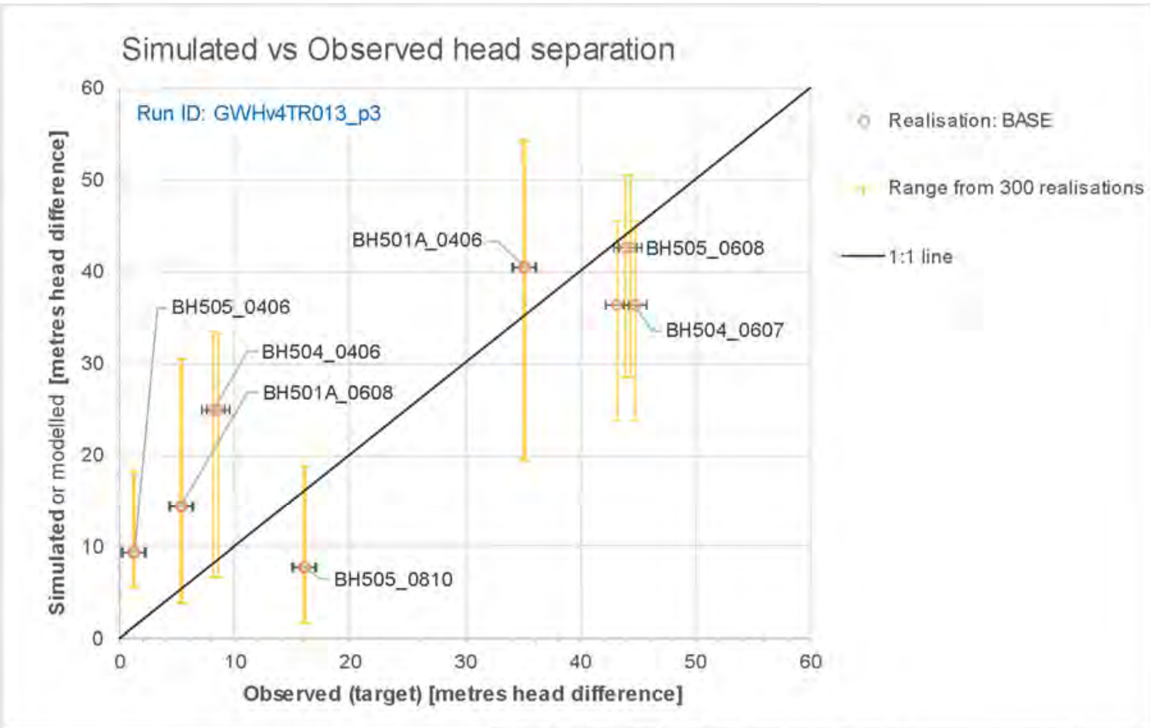


Figure 3-9 Summary of groundwater level difference calibration

The locations are labelled on the chart with the following format "XXXX_YYZZ" where XXXX is the bore name at which the vertical head separation was calculated (i.e. from two piezometers in that bore), while YY indicates the upper model layer and ZZ indicates the lower model layer between which the head separation was calculated (as per Section 2.7.2).

Figure 3-9 shows that the Base realisation generally overestimates vertical gradients, especially the lower head difference targets. However, the chart illustrates that the ensemble as a whole is capable of simulating the head difference at all the target sites, except at BH505 between model layers 4 and 6. Across the ensemble there is significant variability (illustrated by the error bars) covering the target value.

The head difference at BH504 between layers 6 and 7 (between the Mount York Claystone and Burra-Moko Head Sandstone) near the mid-tunnel facility is represented moderately well by the Base realisation.

That the model overestimates head separation at the three observations where Layer 4 is the upper layer (i.e. those with the _0406 suffix) might indicate that splitting this layer into two in future could improve this behaviour.

3.3.3 Groundwater level contour maps

Two figures are provided here to summarise the modelled regional behaviour of the groundwater system. These contours are produced from the 50th percentile (median) groundwater level from the model ensemble.

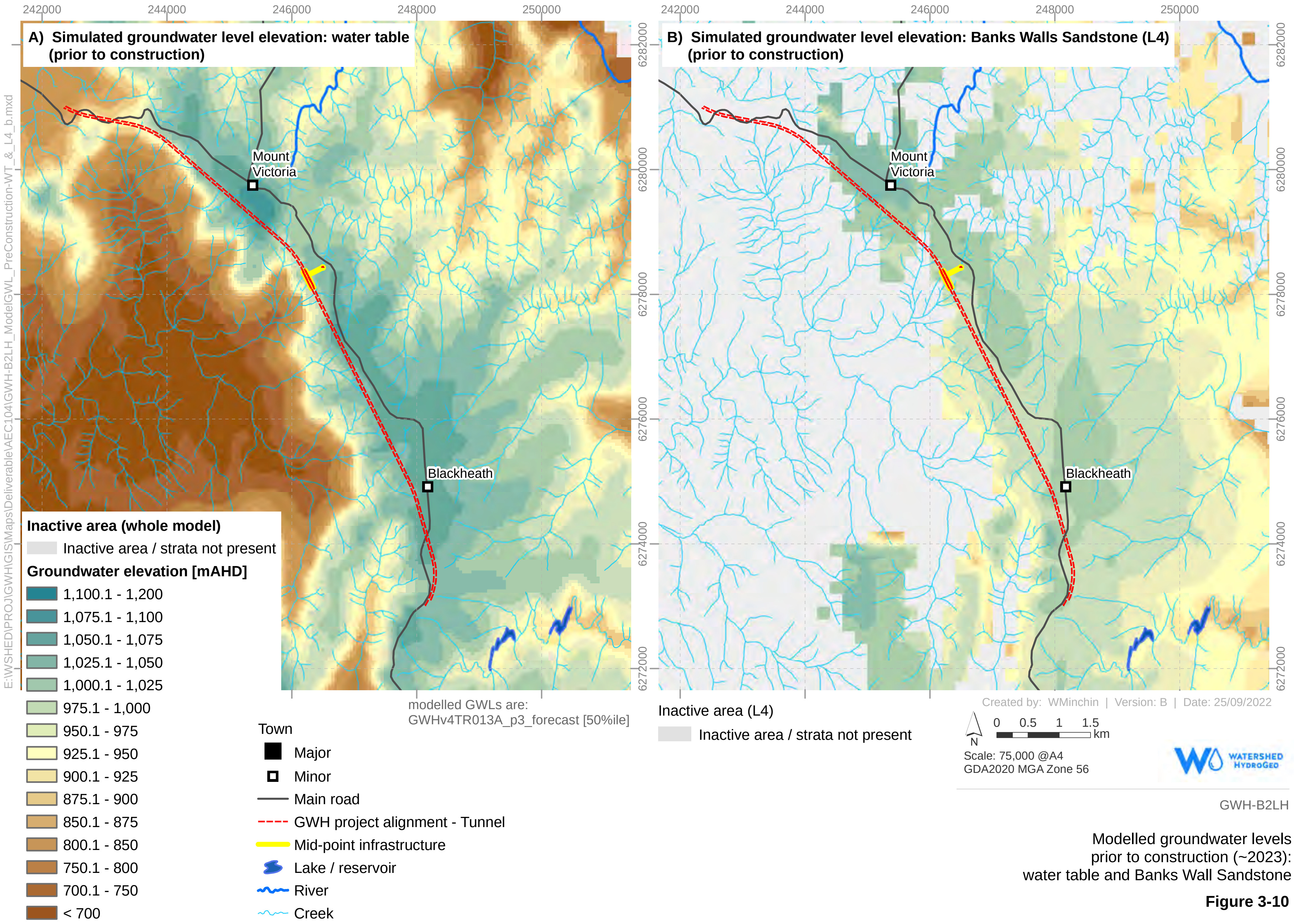
Figure 3-10 shows the modelled water table and groundwater levels in the lower Banks Wall Sandstone (layer 4). This shows the highest groundwater levels present along the ridgeline between Blackheath and Mount Victoria (and also to the south of Blackheath toward Medlow Bath), essentially along the current alignment of the highway.

The water table mapping shows that groundwater levels decline rapidly to the west of this ridgeline due to the presence of the escarpment, where groundwater can discharge via springs. The decline in groundwater levels is more gentle to the east of the ridgeline, following the generally shallower topographic gradient toward the east and toward Govetts Creek.

The groundwater levels for the lower Banks Wall Sandstone (layer 4) are highest along the ridgeline, especially near Mount Victoria. The groundwater levels are generally lower than the modelled water table, suggestive of potential for a downward hydraulic gradient (provided that vertical hydraulic conductivity permits). This stratigraphic unit (and model layer) is eroded and absent in many areas.

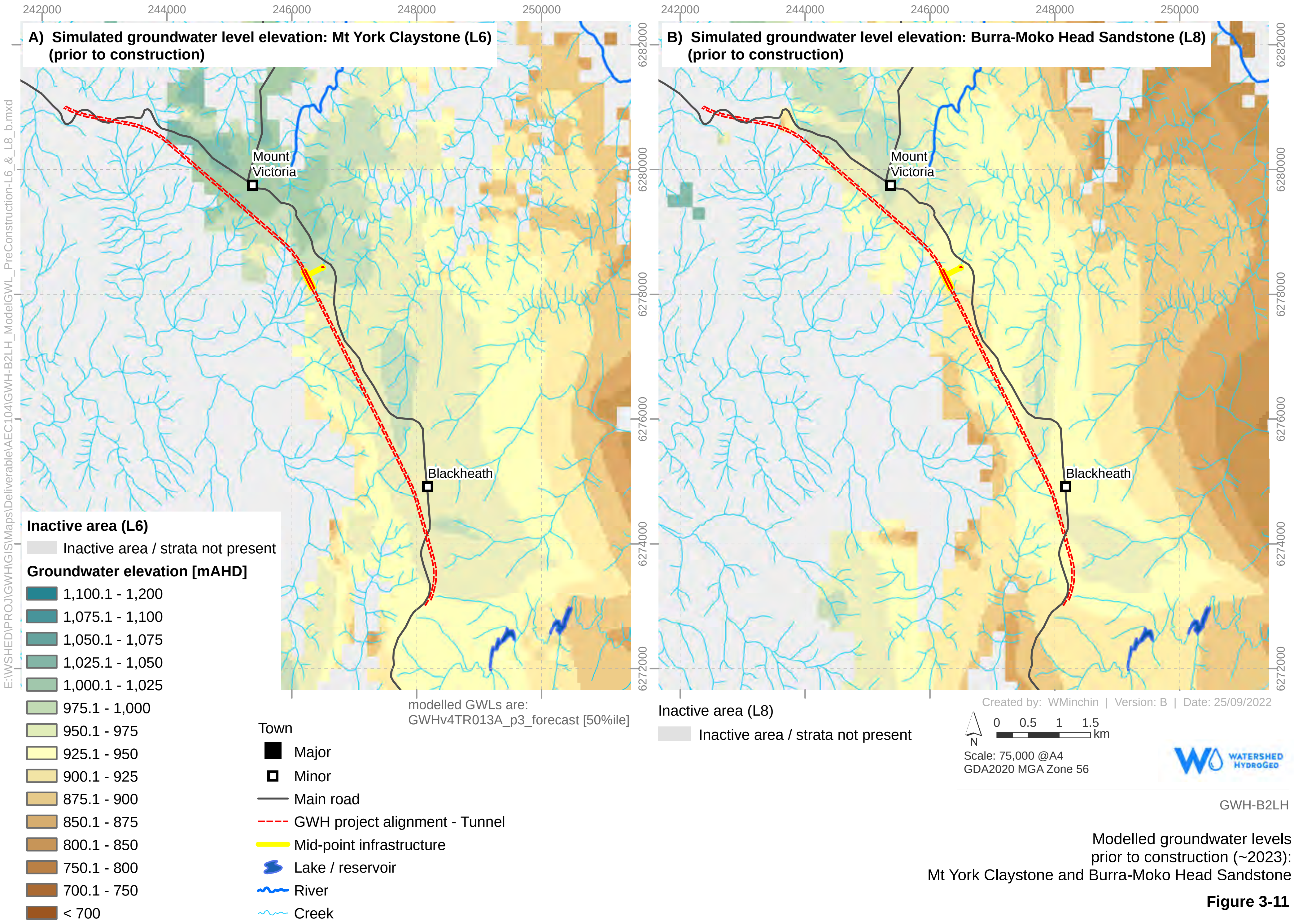
Figure 3-11 presents groundwater levels in the Mount York Claystone (layer 6) and lower Burra-Moko Head Sandstone (layer 8). As with layer 4, the highest groundwater levels are generally present along the highway/ridgeline, and relatively high at Mount Victoria. The high modelled groundwater levels along the ridgeline, and just east of the project alignment, suggests that the project alignment is located just west of a groundwater divide (although this may differ in alternative model realisations).

The groundwater levels are clearly declining down through the sequence, which is expected based on the monitoring data, and consistent with the conceptual model where the escarpment and associated springs (including hanging swamps) act to drain the stacked sequence of Triassic and Permian hydrostratigraphic units) (AECOM, 2022).



Modelled groundwater levels prior to construction (~2023): water table and Banks Wall Sandstone

Figure 3-10



Modelled groundwater levels prior to construction (~2023): Mt York Claystone and Burra-Moko Head Sandstone

Figure 3-11

3.4 Model water balance

A tabulated water balance for the whole model domain is summarised in **Table 3-1**. This presents the average water balance for the historical period, 2008-2022.

In general, the largest simulated influx and outflux components being recharge (62 ML/d) is expected, as well as this being balanced by watercourse baseflow (43 ML/d) and evapotranspiration from the water table (21 ML/d). Net groundwater storage change is relatively small for this period, representing a slight increase in modelled groundwater levels across the model for the selected period.

Table 3-1 Simulated water balance: model-wide water balance – average 2008-2022

Modelled component	Catchment process	Simulated flux [ML/d]	
		In	Out
Storage	Groundwater storage	8.86	9.75
Recharge	Infiltration recharge	62.47	0.00
River Leakage	Groundwater interaction w/ watercourses and springs (leakage/baseflow)	3.47	43.34
Evapotranspiration	Evapo-transpiration from water table	0.00	21.53
Head Dep Bounds	Regional groundwater flow	0.23	0.40
Drains	Inflow to tunnels / dewatering	0.00	0.00
Total (ML/d)		75.022	75.022
E:\WSHED\PROJ\GWH\Model\Runs\GWHv4TR013_p3\[GWHv4TR013_MassBalance_SP38ts2.xlsx]SUMMARY_SP38			Realisation:Base

At the end of the calibration period (mid-2022, stress period 38), the modelled mass balance error was less than 0.01%, which is within the 1-2% error recommended by the AGMG (Barnett et al., 2012a).

3.4.1 Transient mass balance error

As noted above, at the end of the calibration period (stress period 38), the modelled cumulative mass balance error was less than 0.01%, which is well within the thresholds recommended by the AGMG. **Figure 3-12** presents a timeseries of the mass balance error for each timestep in the model simulation.

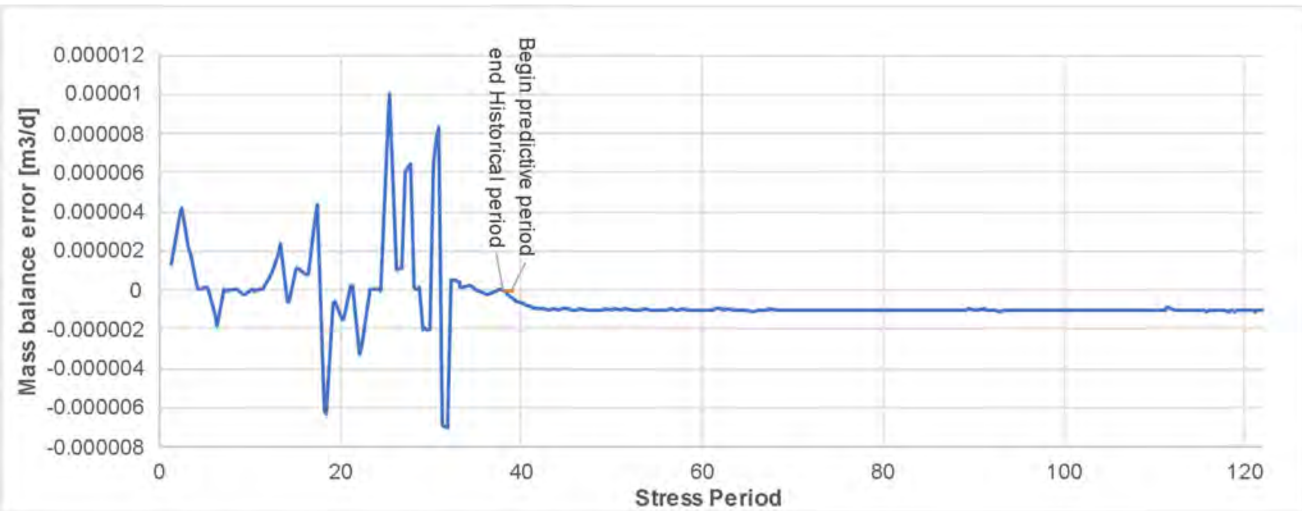


Figure 3-12 Time series of model mass balance (closure) error

Figure 3-12 presents the mass balance error for both the historical and predictive periods. In the historical period, there are frequent spikes in error, usually associated with wet periods in the historical simulation, but as can be seen the error is low and acceptable. For the forecast period, errors are also low and acceptable, with a persistent but small mass balance error. Some model realisations are likely to have higher mass balance errors, however the mass balance above gives confidence that the numerical model is not artificially introducing error and provides a sound basis for using the model for forecasting.

3.5 Simulated (posterior) parameters

The method of adjusting and applying hydraulic properties (K and S) to the groundwater model is described in Section 2.6. This section presents the result modelled parameters at the end of the PESTPP-IES history matching process, i.e. the 'posterior' parameters.

Maps of the modelled hydraulic parameters (K and S) are provided in **Appendix E**. Due to the number of layers in the groundwater model (20), only selected layers are provided (those most relevant to the key features of the project or resultant effects) and only for the base realisation.

3.5.1 Hydraulic conductivity

Hydraulic conductivity (Kx) and the vertical anisotropy (vka) applied to the 300 realisations following the history-matching process is charted on **Figure 3-13**, compared to the initial estimate and the range.

The charts in **Figure 3-13** show that the median for all 300 realisations is generally slightly lower than the initial Kx estimate, while the average Kx for the base realisation is slightly higher. The posterior min-max range is essentially the same as the initial or allowable range, but the 10^{th}-90^{th} percentile range indicates that the Kx typically inhabits a narrower band, especially in the range above the median Kx (with the exception of the three shear zone layers, where parameters more often lie at the top of the allowable range).

Figure 3-13 shows very wide ranges (typically at least 3 orders of magnitude or more for Kx and 2-3 orders of magnitude for Kz) across the 300 model realisations. This indicates that the hydraulic conductivity parameters are relatively unconstrained through history matching (calibration). This suggests that the hydraulic conductivity parameters are insensitive to the history-matching process, or at least non-unique, across the model domain as a whole.

This means that the forecasting (Section 4) explores the sensitivity of the predictions of interest to a large range of Kx and vka/Kz parameters.

This observation, and the conceptual model of effects and impacts (and subsequent model predictions of impacts that consider and account for parameter sensitivities), guides recommendations for data-gathering near Blackheath portal and the mid-tunnel area (Section 5.1.1), which might lead to further analysis and modelling (Section 5.1.2).

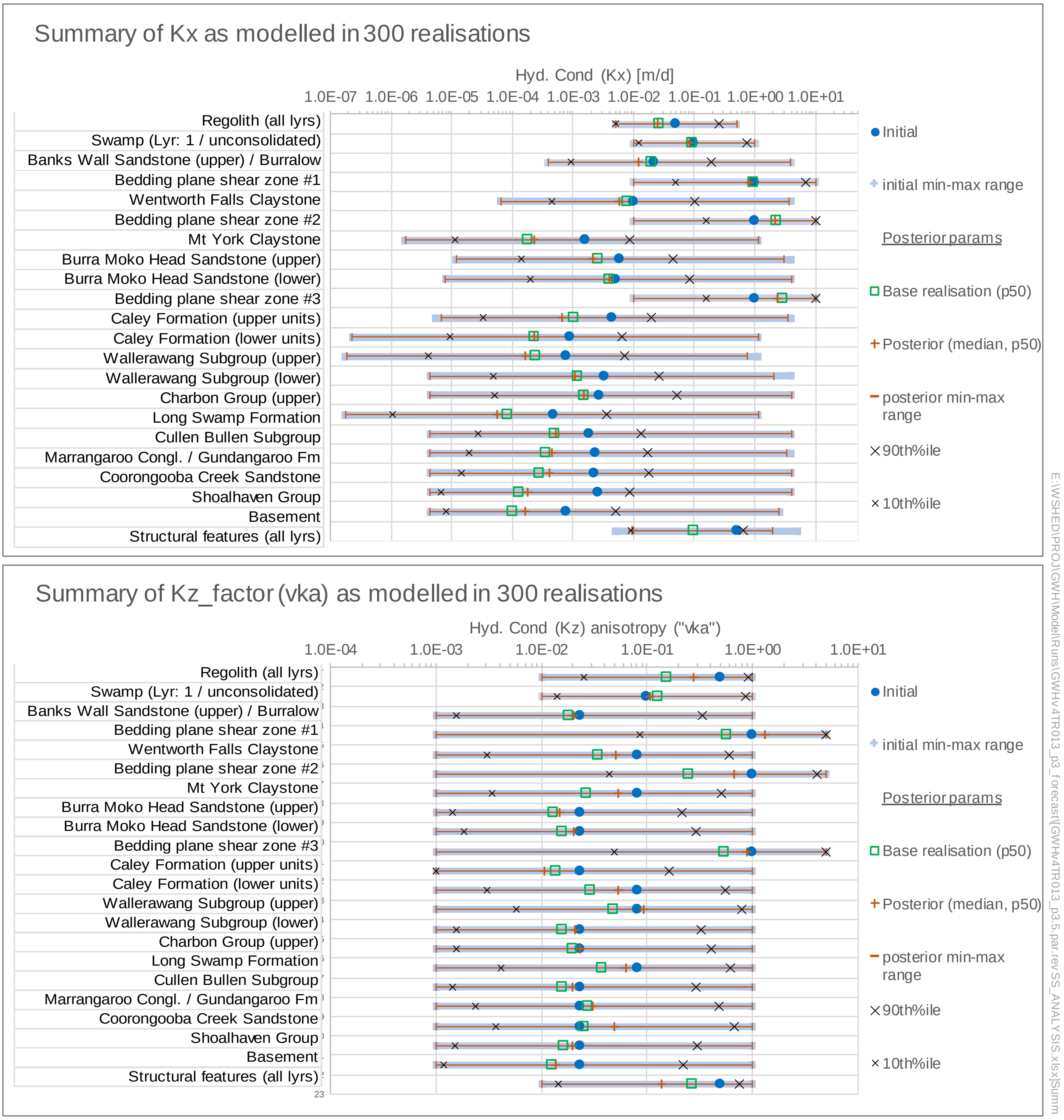


Figure 3-13 Modelled (posterior) hydraulic conductivity parameters

3.5.2 Storage properties

The storage parameter ranges shown on **Figure 3-14** indicate the ensemble is using almost the full range of parameters initially specified.

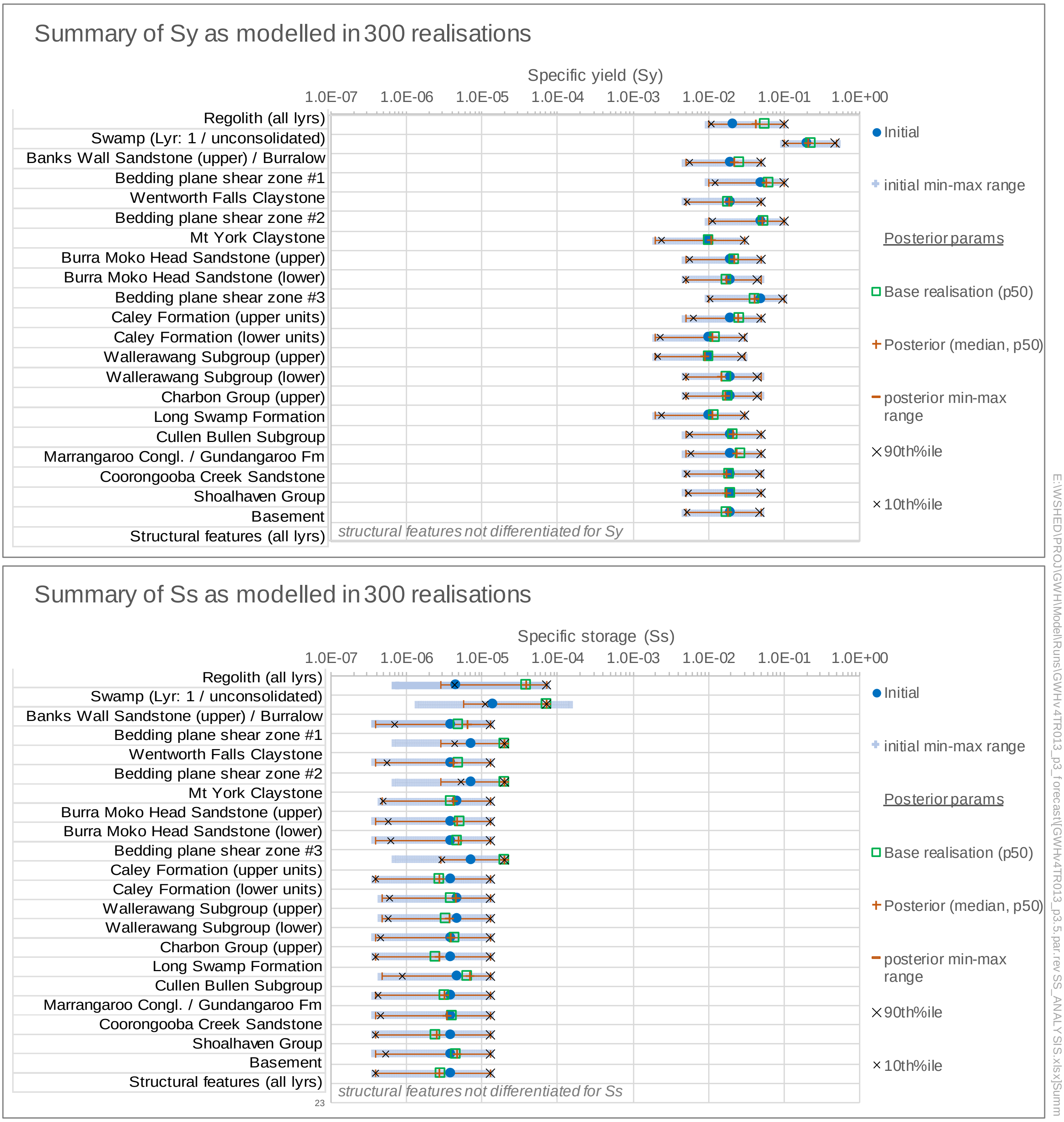


Figure 3-14 Modelled (posterior) storage parameters

As with hydraulic conductivity, this means that on the scale of the model domain, the history-matching process is not able to constrain these parameters to a significant extent. As a result, forecasts presented in Section 4 are made for the predictions of interest that account for the sensitivity to a large range in storage properties.

3.5.3 Recharge and riverbed conductance

The posterior range in the recharge multiplier is 0.91 to 2.51, with a median of 1.38. The base realisation value was 1.21. This compares to the initial value of 1.0 (Section 2.5.1). It is likely that the ratio of recharge to hydraulic conductivity cannot be constrained without the availability of flux measurements (e.g. baseflow), as noted in Sections 2.7.3 and 5.1.1. This means that forecasting in Section 4 embeds the sensitivity to this uncertain recharge parameter in the prediction error bands.

The posterior range in River conductance for all reaches (Sections 2.5.4 and 2.5.6) is 1 to 83, with a median of 20.05. This compares to the initial value of 20.

3.6 Summary of model performance and suitability

The comparison of model results with the observations (groundwater levels and gradients and the constraints) in the preceding section provides some confidence that the model is suitable for use in predictive analysis for estimating project-related effects.

The use of multiple realisations in the predictive modelling phase (Section 4) then addresses the issue of parameter variability, limited constraint by observations and uncertainty.

As noted in **Appendix K**, while the model is capable of simulating groundwater levels at the currently available monitoring sites, groundwater levels in some 3D locations and key fluxes (baseflow, spring flow to hanging swamps and, with respect to the future project, tunnel inflow) that are required to assess the impacts of the project are 'uncalibrated'.

Recommendations have been made regarding data gathering and further modelling (Section 5.1).

As noted elsewhere in this document, data-gathering and monitoring is ongoing. This will lead to improved geological models and layer elevation mapping (Section 2.4.3) and structure mapping (incorporated as parameter "zones" in Section 2.6.1), improved characterisation of aquifer properties, and expanded groundwater level datasets for conceptualisation and model calibration (Section 2.7). This should not be treated as a negative, but is part of the modelling process, as acknowledged by DPE Water in the SSD modelling guidelines (DPE, 2022).

This new data, once analysed, would likely require the groundwater model to be refined with updated layer geometry (stratigraphic unit top/bottom elevations), updated mapping of geological structures. The predictions presented in Section 4 of this report would remain relevant, however impacts at some specific features (e.g. drawdown at a specific registered bore, inflows to specific cross-passages) might change due to a possible change to the stratigraphic unit they are assumed to be located in.

However, we re-iterate that we consider the modelling approach and the numerical groundwater model developed this point to be fit-for-purpose considering the requirements of the model for impact assessment and the data/knowledge obtained to this time. In some instances, following review of results in Section 4, it seems that in some areas the model-predicted drawdown over-estimated (i.e. conservative).

As per the AGMG, this modelling assessment has been peer-reviewed. This independent review is by Peter Dundon (Dundon Consulting Pty Ltd).

4 Predictive modelling of project effects

This section presents results from the model ensemble which is described in Section 4.2. The objectives of the predictive or forecast modelling are to provide estimates of the following:

- Groundwater inflow to the tunnel and associated features during and following construction;
- Groundwater drawdown adjacent to the alignment, including specific consideration of:
  - water table drawdown at upland swamps;
  - drawdown at registered bores;
- Change in groundwater flux (baseflow or spring flow) to hanging swamps;
- Change in baseflow to watercourses/catchments.
- Change in baseflow to water supply reservoirs.

4.1 Forecasting scenarios

To assess the effects of the project, predictive scenarios are used to represent the development, and these are summarised in **Figure 4-1**. Comparison of the outputs of these runs allows quantification of the effect or impact of the development(s), and assessment of project-specific effects.

Figure 4-1 Summary of development scenarios for forecasting

Scenario	Run	Name	Comment
A	GWHv4TR013A	Null (as existing conditions)	'Null run' as per Barnett et al, 2012.
B	GWHv4TR013B	Project – proposed development schedule	"Likely" effects. Comparison against A gives effects of the project

Each predictive run simulates the period to the year 2130 (**Appendix C**), with a sequence of climatic inputs (recharge, evapotranspiration) based on historical average conditions (Sections 2.5.1 and 2.5.2). A more detailed representation of these scenarios is presented in the following sub-section.

The focus of the development scenarios is on simulating the features that are proposed to be drained indefinitely (portal and associated cut-and-cover sections, and the mid-tunnel infrastructure). These features have the greatest potential for groundwater ingress, with associated water management requirements and environmental effects.

4.1.1 Construction and operation schedule

An indicative construction schedule is presented in Section 1.2.1 (**Figure 1-3**). A more detailed plan related to the scheduling and methods assumed for model scenarios is presented in **Figure 4-2**. For the forecasting and impact assessment, three periods of interest are considered: 'construction phase' (mid-2024 to Sept-2030, based on the assumptions used for this assessment), post-construction (Oct-2030-onward) and long-term or end of design life (2130).

The potential for cumulative impacts on groundwater with the adjacent sections of the GWH upgrade has been considered (Section 1.6). Our review of the documentation for the adjacent upgrade projects to the east and west indicates that there is no need to simulate those sections of the highway upgrade to assess cumulative effects due to them being upgrades to surface roads with minimal excavation.

Figure 4-2 Detail of model development scenarios

Scenario A **Null (No Development / Base case)**

Period start date:	Jan-24		Jul-24		Jan-25		Jul-25		Jan-26		Jul-26		Jan-27		Jul-27		Jan-28		Jul-28		Jan-29		Jul-29		Jan-30		Jul-30		2031	…-->	2130
Model stress period:	42	44	45	48	51	54	57	60	63	66	69	72	75	78	81	84	87	90	93	96	99	102	105	108	111	112	113	114	115	#N/A	#N/A
No GWH project																															

Scenario B **Realistic construction schedule, based on currently proposed construction program**

Period start date:	Jan-24		Jul-24		Jan-25		Jul-25		Jan-26		Jul-26		Jan-27		Jul-27		Jan-28		Jul-28		Jan-29		Jul-29		Jan-30		Jul-30	Oct-30	2031	…-->	2130
Model stress period:	42	44	45	48	51	54	57	60	63	66	69	72	75	78	81	84	87	90	93	96	99	102	105	108	111	112	113	114	115	#N/A	#N/A
Little Hartley Portal - cut-and-cover				Construction -------> end			drained --►																					tunnel operational --►			
Blackheath Portal - cut-and-cover				Construction commences							end construction		drained --►															(possibly earlier)			
Mid-tunnel shaft and adit				Construction -->		end construction		drained --►																--► |	backfilled - return to ~natural K						
Mid-tunnel cavern constructed							Construction commences					end construction		drained --►																	
Tunnel constructed: ch17560 to ch15400								EPB TBM (from Little Hartley portal)																							
Tunnel constructed: ch15400 to ch12800														arrive mid-point																	
Tunnel constructed: ch12570 to ch9940																switch to single-shield															
Tunnel constructed: ch9940 to ch7200																					TBM arrive Blackheath										
Cross-passages drained: ch17560-15400	(Cross-passages XP88 to XP68)											excavated / drained				tanked - low K applied along alignment following cross-passage completion															
Cross-passages drained: ch17560-15400	(Cross-passages XP67 to XP49)														excavated / drained				tanked - low K, as above												
Cross-passages drained: ch17560-15400	(Cross-passages XP46 to XP24)																	excavated / drained				tanked - low K, as above									
Cross-passages drained: ch17560-15400	(Cross-passages XP23 to XP2)																				excavated / drained				tanked - low K, as above						

The schedule above is summarised on 3-monthly intervals unless noted otherwise, although monthly-stress periods are used to simulate the construction phase.
The schedule and methods are assumptions for modelling (based on preferred options)

Legend:
- construction of drained feature
- post-construction, drained feature
- construction of driven tunnel using Earth Pressure Balance (EPB) TBM
- construction of driven tunnel using Single-Shield TBM
- following cross-passage construction, the segmentally-lined tunnels are represented as a low permeability feature.

Assumptions: EPB TBM uses slurry or paste that might reduce permeability of strata.
For conservatism this has not been simulated when estimating inflow to cross-passages or drawdown around these features.

Single-shield TBM will have short sections (~10m) un-lined and drained for a period of hours. Groundwater ingress is expected to be minimal. For conservatism and practicality this has been simulated as longer sections being sequentially drained over month-long periods then tanked, and the two tunnels driven simultaneously.

Tunnel features are smaller than model cells, so reduced permeability following tunnel construction (due to segmental linings) will be approximate only.

Each cross-passage assumed un-lined (drained) for up to 3-months.
Modelling simulates progressive and sequential drainage of cross-passages, i.e. typically 5-6 are being drained during any month-long model stress period.

E:\WSHED\PROJ\GWH\Tech\Construction\20220714_ConstructionSchedule\[ConstructionSchedule_KeyDates_reGWAssessement and Modelling4.xlsx]Scenario_TABLE

4.2 Uncertainty analysis

Given the available dataset of hydraulic properties, and the currently 'unstressed' or green-field nature of this area with respect to tunnels or similar sub-surface excavations, there is uncertainty about the behaviour of the groundwater system (e.g. magnitude of drawdown) in response to a feature such as the project. While the construction methods are generally favourable for minimising the effects on the groundwater system, there remains a need to explore the model and system uncertainty related to the potential effects and impacts of the project.

PESTPP-IES has been selected for this purpose. As described in Section 3.1, as a result of the iterative history-matching process, PESTPP-IES generates a set of plausible alternative model realisations that fit the observations or targets to an "acceptable" degree. This ensemble of posterior realisations is used in combination with the development scenarios (Section 4.1) to quantify the potential effects of the project and the uncertainty in these effects.

The mechanics of this are:

- 300 realisations (the 'ensemble') were run by PESTPP-IES for forecasting, The assumption here is that this number of realisations represents the full range parameter uncertainty (at the scale of the model cells) in this groundwater system. The ensemble size is larger than the 100 recommended in literature as the minimum size (Peeters and Middlemis, 2022).
- 298 of these 300 realisations were completed successfully by PESTPP-IES. The two unsuccessful realisations likely failed due to non-convergence of one of the development scenarios. This small number of failures has no effect on the ensemble's use in characterising uncertainty associated with the various predictions (Sections 4.4 to 4.10).
- For the inflow forecasts, the results of the 'B' development scenario (**Figure 4-1**) were analysed for each of the 298 successful realisations, and for various zones and features (e.g. mid-tunnel facility and portals).
- For head (groundwater level) forecasts, such as those presenting contours of heads, the results of the 'A' and 'B' development scenarios are analysed independently for each of the 298 successful realisations. A particular statistic, such as the median groundwater level for any model cell across all realisations, is used for mapping (Section 4.6.2).
- For the drawdown forecasts (e.g. Section 4.6.3, 4.6.4 and 4.6.5) the difference between the groundwater level results of the 'A' (Null) and 'B' (project) development scenarios were analysed for each of the 298 successful realisations, yielding 298 estimates of drawdown for every model cell and model timestep. For each realisation, the maximum drawdown during each period of interest (i.e. 'construction phase', post-construction and long-term) was assessed for each model cell. The maximum drawdown is then summarised as 5th, 50th and 95th percentile, where the 50th percentile (median) estimate is the central (or "likely") value from the ensemble, while the 5th percentile represents a "likely best case" and the 95th percentile represents a "likely worst case". The impact assessment is focussed on the 50th and 95th percentile forecasts ("likely" and "likely worst case").
- For the registered bores, we have also calculated the number of model realisations for which there is more than 2 m drawdown (as per the AIP minimal harm criteria) predicted during each of the periods of interest. This number of realisations is then divided by 298 to give an approximate probability of there being more than the specified drawdown criteria.

This approach is consistent with the recommendations in the AGMG (Barnett et al., 2012a), IESC uncertainty guidelines (Middlemis and Peeters, 2018; Peeters and Middlemis, 2022), and the broad methods described in Section 7.3 of the NSW SSI modelling guidelines (DPE, 2022).

4.3 Climate change

Climate change is predicted to affect rainfall and other climatic variables, of which rainfall has the most significant effect on recharge to groundwater. One source of projected changes in rainfall has been reviewed:

- NARCliM (NSW / ACT Regional Climate Modelling) for the area around Blackheath and Little Hartley.

Table 4-1 presents the projection for change in rainfall from this source for the 'near future' (2020-2039) and longer-term projections for (2060-79) – at this stage, this latter projection is the best available for the end of tunnel Design Life (2130).

Rainfall projections show little change from recent history, at least on an annual basis, for 2020-2039, but more variable for the 2060-2079 forecast (**Table 4-1**). These projections generally suggest a wetter climate for 2060-2079.

Table 4-1 Climate Change Projections – Percentage Change in Rainfall

Period	2020-39		2060-79	
	Little Hartley	Blackheath	Little Hartley	Blackheath
Summer	-0.2	-0.4	+12.2	+10.5
Autumn	+10.0	+10.0	+12.8	+11.7
Winter	+1.8	+0.4	-4.8	-5.9
Spring	-0.4	+0.8	+4.6	+4.2
Annual	**+2.7**	**+2.6**	**+7.4**	**+8.5**

https://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/Interactive-map

Based on experience in rainfall-runoff-recharge modelling (including for consideration of climate change projections for water resource assessments in other settings) and literature, a general rule is that broad changes in rainfall (e.g. rainfall increased by 3%) are typically magnified 2-4 times when converted to rainfall recharge (e.g. recharge then increased by 6-12%) ('rainfall elasticity in recharge'), as has been described as occurring for historical climate variability (Barron et al., 2012). Using this concept, the tabulated changes in rainfall are predicted to result in changes in rainfall recharge in the order of +7-8% in the near future, increasing to +21-25% in the longer term. However, some rainfall projections indicate that higher rainfall would be derived from larger, more frequent high rainfall events, which could lead to more runoff and lower recharge.

The effect of the predicted climate change has not been specifically assessed for the project groundwater inflow as the average change in recharge during the construction phase would be in the order of 7% and the effect on inflow is likely to be minor. In the short-term, climate variability, rather than climate change, will govern whether rainfall is similar to the long-term average or not. The variability between 2019 and 2022 rainfall is an example of this.

In the post-construction or operational period the 2060-2079 predictions from NARCliM suggest that average rainfall is likely to increase. This would result in greater inflow, mainly at the portals (which are at the surface), and a lower degree of change in inflow to the mid-tunnel facilities (which are typically 100 m deep).

4.4 Simulated regional water balance

Simulated water balances are useful for understanding how a change in one or more water balance components (a stress or stresses) can affect others.

The model water balance for development scenarios A and B, along with the calculated difference in the model water balance to show the incremental change due to the project, is summarised in **Table 4-2** (construction phase) and **Table 4-3** (post-construction). This is reported for the 'base' realisation, which is representative of the median or 50^{th}%ile inflow projection (Section 4.5).

The project-related effects occur primarily due to the construction dewatering along the alignment and continued dewatering at the portals and mid-tunnel facilities. On a regional scale (i.e. the scale of the model domain), the project's dewatering flux is minor during construction and very minor in the post-construction period. That aside, it results in changes to all parts of the model water balance, causing changes to groundwater storage (i.e. a reduction in groundwater levels, especially during construction), reduced baseflow to watercourses and springs, and reduced evapotranspiration from groundwater.

Table 4-2 Model-predicted water balance: whole model domain during construction phase – 2024-2030

Modelled component	Catchment process	Null/Natural		With GWH project		Change in water balance: Project effect		
		Scenario A		Scenario B		=Scenario A - Scenario B		
		In	Out	In	Out	delta IN	delta OUT	Net
Storage	Groundwater storage	2.82 (GWL decline)	0.73 (GWL rise)	2.90	0.76	-0.08	-0.03	-0.12
Drains	Groundwater inflow / dewatering	0.0	0.0	0.0	0.09	0.00	-0.09	-0.09
River leakage	GW-SW interaction w/ watercourses, springs	3.46	40.92	3.46	40.89	0.00	0.03	0.03
ET	Evapo-transpiration from water table	0.0	23.62	0.0	23.61	0.00	0.01	0.01
Head Dep Bounds	Regional groundwater flow	0.23	0.41	0.23	0.41	0.00	0.00	0.00
Recharge	Infiltration recharge	59.16	0.0	59.16	0.0	0.00	0.00	0.00
	Total	65.68	65.68	65.77	65.77	-0.08	-0.08	-0.17

Units are ML/d.

Results for Base realisation (#299): E:\WSHED\PROJ\GWH\Model\Runs\GWHv4TR013_p3_forecast\Proc\WaterBalance_TR013A-B_Real299(Base).xlsx

Table 4-3 Model-predicted water balance: whole model domain post-construction – 2030-2130

Modelled component	Catchment process	Null/Natural Scenario A			With GWH project Scenario B			Change in water balance: Project effect =Scenario A - Scenario B		
		In	Out		In	Out		delta IN	delta OUT	Net
Storage	Groundwater storage	0.33 (GWL decline)	0.38 (GWL rise)		0.33	0.38		0.00	0.00	0.00
Drains	Groundwater inflow / dewatering	0.00	0.00		0.00	0.03		0.00	-0.03	-0.03
River leakage	GW-SW interaction w/ watercourses, springs	3.45	40.83		3.45	40.81		0.00	0.02	0.01
ET	Evapo-transpiration from water table	0.00	23.41		0.00	23.41		0.00	0.01	0.01
Head Dep Bounds	Regional groundwater flow	0.23	0.41		0.23	0.41		0.00	0.00	0.00
Recharge	Infiltration recharge	61.02	0.00		61.02	0.00		0.00	0.00	0.00
	Total	65.03	65.03		65.04	65.04		0.00	0.00	0.00

Units are ML/d. Results for Base realisation (#299): E:\WSHED\PROJ\GWH\Model\Runs\GWHv4TR013_p3_forecast\Proc\WaterBalance_TR013A-B_Real299(Base).xlsx

4.5 Inflow forecasting for the project

This section describes the forecasting of inflow to the various elements of the project, and the total. Two items to note are:

1) The model does not simulate any possible treatment (pre-grouting) of cross-passages that might occur (after investigation) prior to opening the tunnel lining and excavating these features (Section 1.2.4). Therefore, the inflow estimates, and the resultant drawdowns and changes to other fluxes (e.g. baseflow, spring flow, groundwater take) are conservative.
2) It is likely that the model overestimates the groundwater ingress around the single-shield TBM south of the mid-tunnel facility. Simulation of this small opening that is effectively drained for a period of hours as the TBM progresses via 'Drain' conductance (Sections 1.2.3 and 2.5.7) is approximate.

Total inflow estimates: **Figure 4-3** presents the model-predicted total inflow of groundwater entering the tunnel and associated features during construction (2024-2030) and post-construction into the long-term. After construction, model-predicted average inflow reaches a pseudo-steady state, although would vary slightly with weather conditions (dry conditions are illustrated by the slight decline in mid-2030s – see Section 2.5.1).

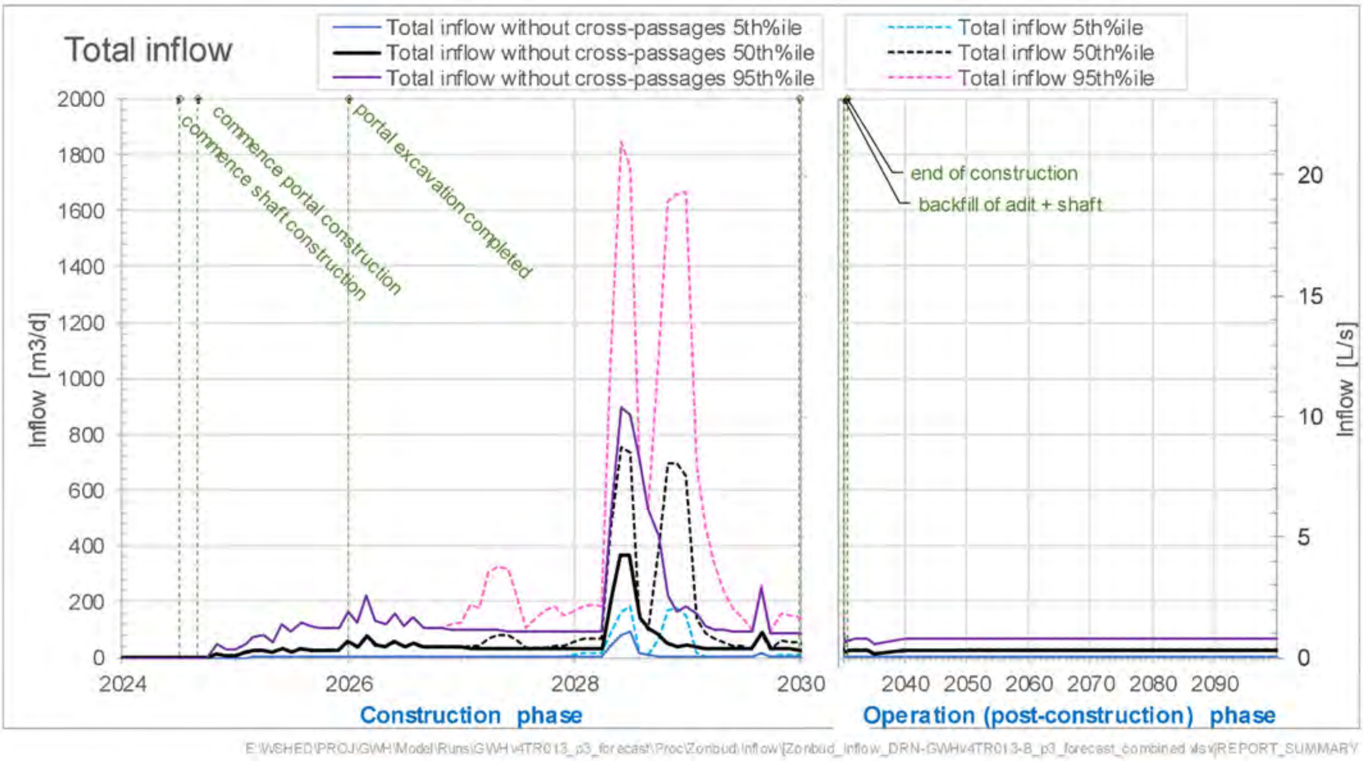


Figure 4-3 **Estimated total groundwater inflow to the project**

The total inflow is presented with and without the inclusion of the inflow at cross passages, and is summarised as the 5th, 50th and 95th percentile estimates from the model ensemble. The "realistic" case is that some cross-passages are pre-grouted, and therefore the resultant total inflow would be between the with and without cases.

All of the estimates show a general increase in inflow from the commencement of construction through to 2026, then a general plateauing from 2026 (after the portals and mid-tunnel excavations are completed), and then short-lived increase during the remaining construction period as different parts of the strata are drained by the TBM and cross-passages.

The period 2028-29 is when the model predicts the greatest inflow. This is when the TBM is passing through the Burra-Moko Head Sandstone just south of the mid-tunnel facility, and again when it passes through the lower Banks Wall Sandstone, and when the cross-passages in those some areas are constructed and drained (see **Table 4-5**, below). After 2030, the inflow is forecast to remain relatively steady as no further excavation occurs and the drawdown stabilises.

Table 4-4 summarises the key statistics for inflow to the various features. **Figure 4-4** shows the timeseries for the two portals and mid-tunnel infrastructure. The total inflow estimates are considered further in discussion on water 'take' in Section 4.10. Note that the different timing of each of the features means that addition of the tabulated maxima (**Table 4-4**) does not equal the maxima shown on **Figure 4-3**.

Table 4-4 Summary of projected groundwater inflow

Zone / Feature (as per assumed construction method)		Inflow during construction [m3/d]						Inflow post-construction [m3/d]					
		Average			Maximum			Average			Maximum		
		5th%ile	50th%	95th%	5th%ile	50th%	95th%	5th%ile	50th%	95th%	5th%ile	50th%	95th%
1	Cross-passages (total)	17.7	76.5	222.1	182.6	724.6	1756.0	0.0	0.0	0.0	0.0	0.0	0.0
90	TBM drive - northern/ EPB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
91	TBM drive -southern/ Single-Shield	5.2	26.6	82.4	160.0	704.3	1702.3	0.0	0.0	0.0	0.0	0.0	0.0
100	Mid-tunnel - Shaft	0.1	1.2	8.9	1.7	9.9	29.6	0.0	0.0	0.0	0.0	0.0	0.0
101	Mid-tunnel - Adit	0.0	1.1	12.5	0.0	6.8	46.5	0.0	0.0	0.0	0.0	0.0	0.0
102	Mid-tunnel - Cavern	0.2	2.5	11.9	5.2	18.8	52.9	0.2	2.0	14.0	0.2	2.0	14.9
200	Portal – Little Hartley	0.3	5.6	16.2	2.6	20.6	61.8	0.2	4.2	12.8	0.2	4.6	13.6
300	Portal - Blackheath	0.1	21.0	45.4	0.7	61.4	144.4	0.0	18.2	37.7	0.0	21.2	42.1
Total without cross-passages		4.6	49.5	155.1	91.6	367.9	896.7	0.3	24.4	64.5	0.4	27.7	70.4
Total including cross-passages		18.3	107.8	317.2	183.2	756.2	1847.2	0.3	24.4	64.5	0.4	27.7	70.4

The "realistic" estimate of total inflow likely between the estimate with and without cross-passages due to possibility that some cross-passages will be pre-grouted.

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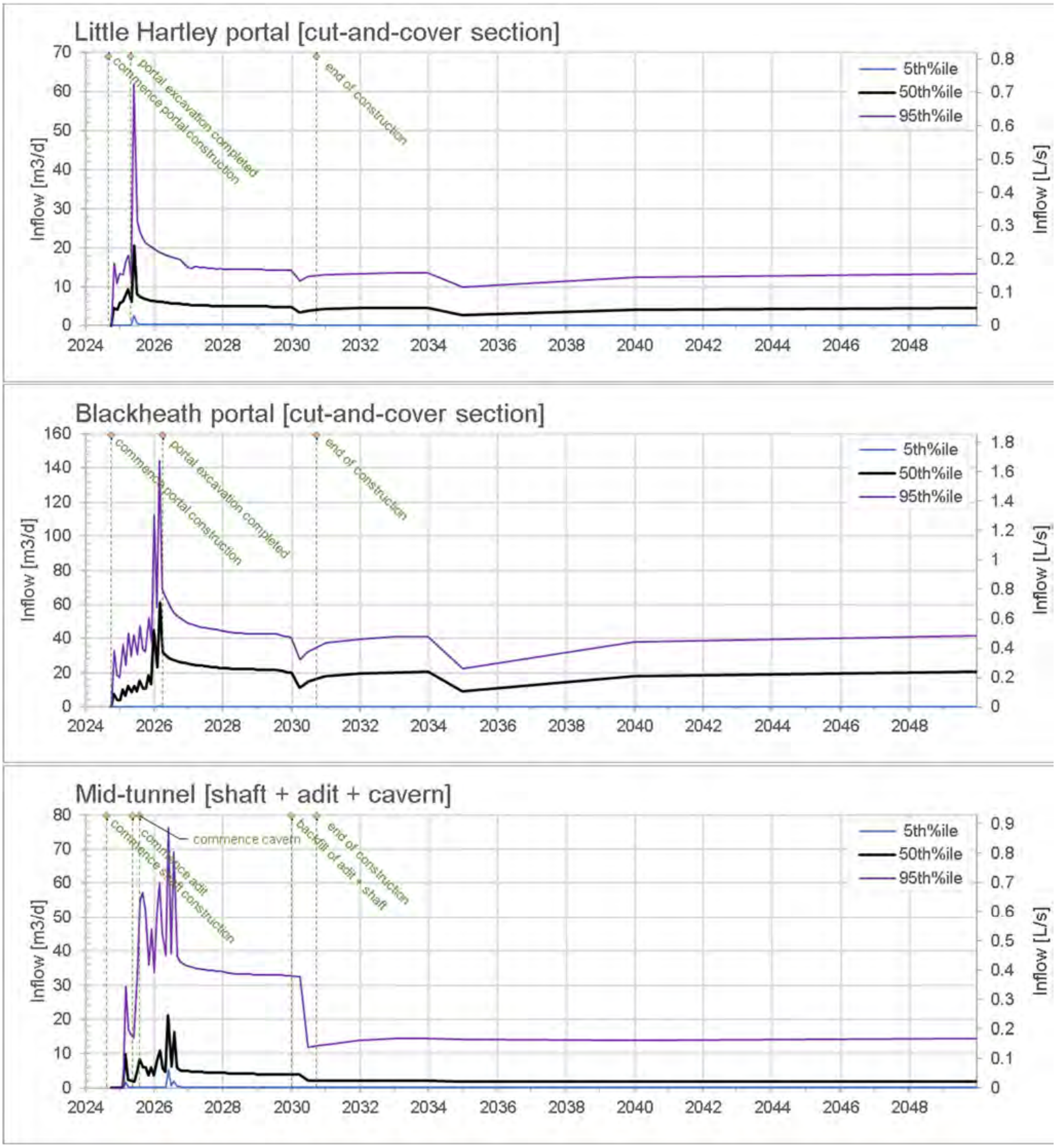

Figure 4-4 Summary of predicted groundwater inflow to the portals and mid-tunnel

__Major features__: For the three major features of the project, **Figure 4-4** illustrates that the inflow increases from the commencement of construction until the relevant excavations are completed, and then plateaus to a steady state. The inflow to the mid-tunnel facility is predicted to decline once the adit and shaft are backfilled (simulated as occurring in 2030).

The variability in the first quarter of 2030 and during 2034 at the portals is related to the simulated low-rainfall (Section 2.5.1). In contrast to the portals which are at surface, this effect is not noticeable in relation to predicted inflows to the mid-tunnel facilities due to the depth of those features.

Cross-passages: A summary of the predicted inflow at cross-passages is presented on **Table 4-5**.

Table 4-5 Summary of model-predicted groundwater inflow to cross-passages

			Peak Inflow [m3/d]			Peak Inflow [L/s]		
Zone	Cross passages	Indicative. timing	5th%ile	50th%ile	95th%ile	5th%ile	50th%ile	95th%ile
2	XP2	Nov-29	11.13	31.42	70.27	0.13	0.36	0.81
3	XP3	Nov-29	0.00	0.00	0.00	0.00	0.00	0.00
4	XP4	Nov-29	0.00	0.00	0.00	0.00	0.00	0.00
5	XP5	Oct-29	0.00	0.00	0.00	0.00	0.00	0.00
6	XP6-7	Oct-29	0.00	0.00	0.00	0.00	0.00	0.00
8	XP8-9	Sep-29	0.00	0.00	0.27	0.00	0.00	0.003
10	XP10-11	Sep-29	0.00	0.00	1.55	0.00	0.00	0.02
12	XP12-13	Aug-29	0.00	0.00	4.86	0.00	0.00	0.06
14	XP14	Jul-29	0.00	0.23	0.95	0.00	0.003	0.01
15	XP15-16	Jul-29	0.00	0.16	2.14	0.00	0.002	0.02
17	XP17-18	Jun-29	0.00	0.24	3.81	0.00	0.003	0.04
19	XP19-20	May-29	0.00	2.21	23.28	0.00	0.03	0.27
21	XP21	May-29	0.00	5.38	26.35	0.00	0.06	0.31
22	XP22	Apr-29	0.00	1.05	8.15	0.00	0.01	0.09
23	XP23-24	Apr-29	0.00	3.19	24.80	0.00	0.04	0.29
25	XP25	Mar-29	0.00	2.37	16.13	0.00	0.03	0.19
26	XP26	Mar-29	0.00	1.99	16.25	0.00	0.02	0.19
27	XP27-28	Mar-29	0.74	9.31	62.16	0.01	0.11	0.72
29	XP29	Feb-29	0.78	8.07	41.79	0.01	0.09	0.48
30	XP30-31	Mar-29	2.36	22.31	140.26	0.03	0.26	1.62
32	XP32-33	Jan-29	3.68	29.84	165.72	0.04	0.35	1.92
34	XP34-35	Dec-28	6.59	34.27	175.23	0.08	0.40	2.03
36	XP36-37	Nov-28	80.75	313.32	739.12	0.93	3.63	8.55
38	XP38-39	Nov-28	88.77	336.68	676.72	1.03	3.90	7.83
40	XP40	Oct-28	0.00	0.01	0.10	0.00	0.0001	0.001
41	XP41	Oct-28	0.00	0.01	0.13	0.00	0.0001	0.002
42	XP42-43	Sep-28	0.00	0.02	0.31	0.00	0.0002	0.004
44	XP44	Sep-28	0.00	0.00	0.16	0.00	0.000	0.002
45	XP45	Aug-28	0.01	0.07	0.66	0.00	0.001	0.01
46	XP46	Aug-28	0.00	0.10	0.78	0.00	0.001	0.01
49	XP49	Jul-28	0.00	0.00	0.61	0.00	0.00	0.01
50	XP50	Jun-28	0.00	0.09	1.78	0.00	0.001	0.02
51	XP51	Jun-28	0.00	0.00	0.17	0.00	0.00	0.00
52	XP52-53	May-28	0.00	4.35	16.23	0.00	0.05	0.19
54	XP54	Apr-28	4.69	16.45	37.04	0.05	0.19	0.43
55	XP55	Apr-28	0.01	0.06	0.75	0.00	0.00	0.01
56	XP56	Mar-28	0.02	0.11	1.25	0.00	0.001	0.01
57	XP57-58	Mar-28	5.64	11.96	33.06	0.07	0.14	0.38
59	XP59-60	Feb-28	10.63	23.76	54.82	0.12	0.27	0.63
61	XP61-62-63	Jan-28	0.15	1.87	12.17	0.00	0.02	0.14
64	XP64-65	Nov-27	0.32	3.01	18.93	0.00	0.03	0.22
66	XP66-67	Oct-27	0.15	2.16	28.22	0.00	0.02	0.33
68	XP68	Sep-27	0.07	1.26	19.29	0.00	0.01	0.22
69	XP69	Sep-27	0.22	2.08	27.79	0.00	0.02	0.32
70	XP70	Aug-27	0.00	0.00	0.39	0.00	0.00	0.00
71	XP71	Oct-27	0.01	0.14	2.61	0.00	0.002	0.03
72	XP72-73	Jul-27	0.00	0.07	2.42	0.00	0.001	0.03
74	XP74	Jun-27	0.04	0.66	7.23	0.00	0.01	0.08
75	XP75-76	Jul-27	0.00	0.07	2.65	0.00	0.00	0.03
77	XP77-78	May-27	4.79	44.16	219.50	0.06	0.51	2.54
79	XP79	Apr-27	0.03	0.42	4.59	0.00	0.00	0.05
80	XP80-81	Mar-27	0.00	0.00	1.87	0.00	0.00	0.02
82	XP82	Feb-27	0.00	0.00	21.71	0.00	0.00	0.25
83	XP83	Feb-27	0.69	5.41	50.52	0.01	0.06	0.58
84	XP84	Jan-27	0.02	0.34	3.10	0.00	0.004	0.04
85	XP85	Jan-27	0.02	0.41	4.26	0.00	0.005	0.05
86	XP86	Dec-26	0.03	0.49	5.62	0.00	0.006	0.07
87	XP87	Dec-26	0.05	0.84	7.49	0.00	0.01	0.09
88	XP88	Nov-26	0.03	0.58	5.31	0.00	0.007	0.06

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As noted earlier, the model-predicted inflow to the cross-passages is for the 'untreated' case, the assumption that each cross-passage being drained for 3 months during their respective construction, and reliant on the geological model and assumptions related to permeability. Cross-passages are proposed to be spaced at 120 m intervals. Given the model cell sizes, this typically means that one or two cross-passages can lie within a single model cell, or in one case, three cross-passages (61-63) in one model cell.

Cross-passages (XPs) or groups of cross-passages that are modelled as high inflow, as identified on **Table 4-5**, are (highest predicted inflow first):

- XP36, 37, 38 and 39 – these are modelled as being located at or near the base of the lower Banks Wall Sandstone. Higher permeability is assumed for the basal 1 m (model layer 5), and the presence of the Mount York Claystone below means that saturation and driving head are relatively high.
- XP30, 31, 32, 33, 34 and 35 – these are located slightly higher in the lower Banks Wall Sandstone than XPs36-39, so saturated thickness above the invert of the excavation is smaller, hence the modelled inflow is lower.
- XP77 and 78 – these are modelled as being in model layer 17 (Marrangaroo Conglomerate/Coorongooba Creek Sandstone) as are most of the surrounding cross-passages. The difference is that these are located at a regional lineament that trends NNW-SSE at Berghofers Pass (**Figure 1-4**). This highlights the potential role for geological structures.
- XP2 and 3 – these are modelled as being located above the Wentworth Falls Claystone, and in or near the conceptualised shear zone at the base of the upper Banks Wall (Burralow) Sandstone (model layer 3).

The actual cross-passages that are at risk of greatest inflow could well change as the geological model and characterisation improves, however the concepts derived from the modelling should still hold) i.e. where cross-passages are located just above regional aquitards it is expected that inflow would be higher).

4.6 Groundwater level forecasts

A variety of methods of presenting modelled groundwater levels are provided in the following sections, including groundwater level hydrographs, contour maps of groundwater levels at particular time intervals, as well as contours of the model-predicted maximum drawdown (at various times) in a selection of model layers.

4.6.1 Groundwater level hydrographs

Hydrographs of model-predicted groundwater levels at increasing distances from the alignment for three representative transects. The hydrographs show groundwater level fluctuations over time in the same geological unit that the nearest major project feature is located in at the following locations:

- Blackheath portal: at distances of 100 m, 250 m and 500 m from the portal (**Figure 4-5**).
- Mid-tunnel facility: at distances of 100 m, 250 m and 500 m from the cavern (**Figure 4-6**).
- Little Hartley portal: at distances of 100 m, 250 m and 500 m from the portal (**Figure 4-7**).

These figures indicate that the degree of drawdown generally decreases with distance from the major features. In all cases, the drawdown increases from the commencement of construction and then declines over time after construction has ceased.

Exceptions to this are the locations nearest each of these major features, where the drawdown does decline slightly after construction, but the persistent drainage of the nearby features means that groundwater levels reach a new post-construction equilibrium at a lower level (e.g. approximately 1 m below natural 100 m east of the Blackheath portal - **Figure 4-5**).

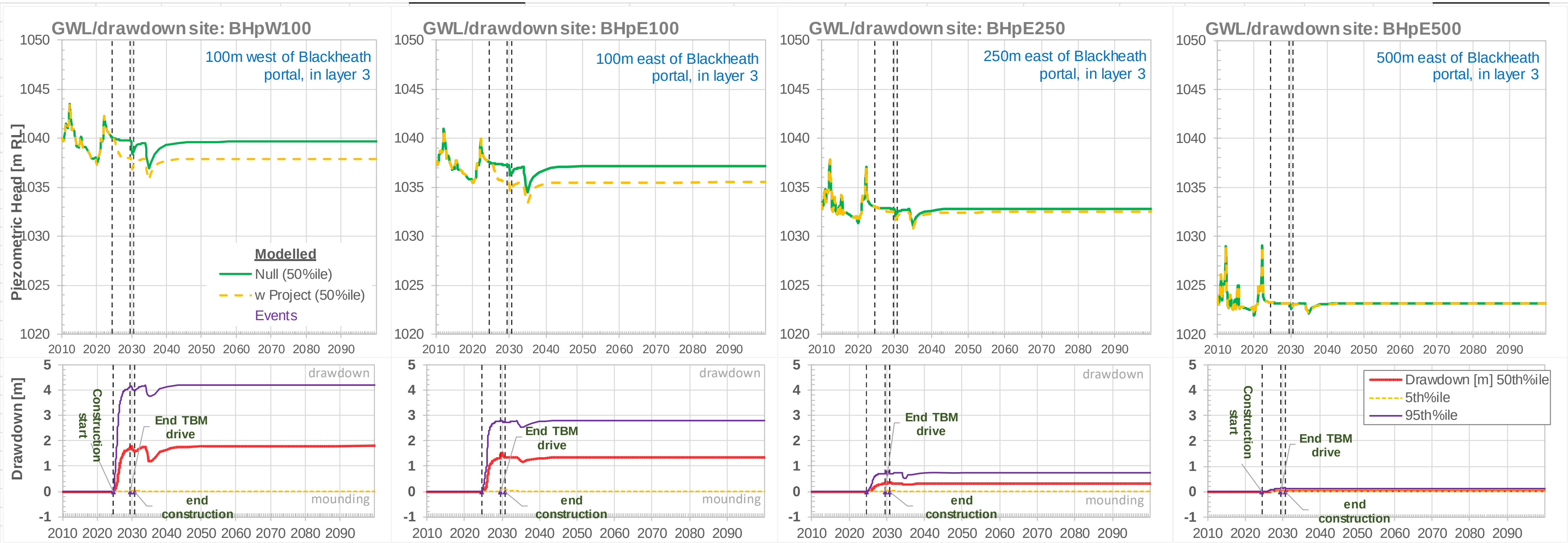

Figure 4-5 **Predicted groundwater levels and drawdown through time – hydrograph for sites east of Blackheath Portal**

These charts show that variation in model-predicted drawdown, i.e. 50th percentile drawdown (1.2-1.9 m at 100 m from Blackheath portal – considering site both west and east) is approximately half the 95th percentile estimates of 2.9-4.1 m, with the 5th percentile estimate is essentially zero. In all three cases the drawdown declines with distance, and at 500 m the 5th, 50th and 95th percentile estimates of drawdown are all very similar, and very small.

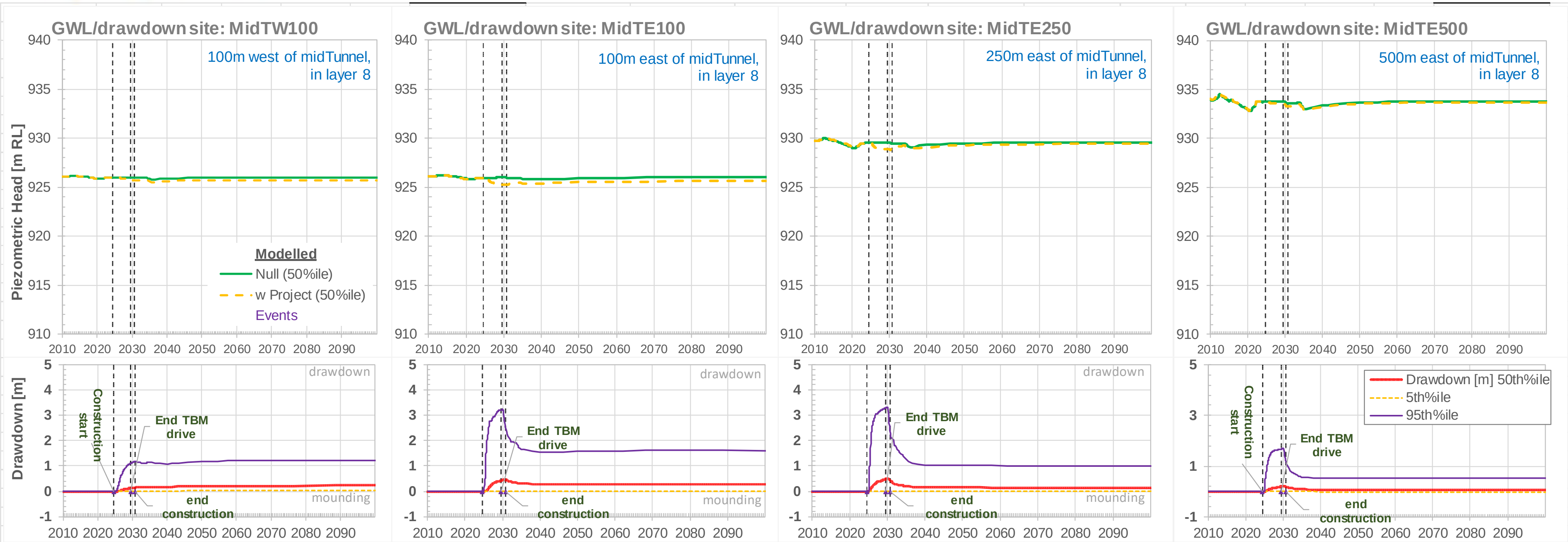

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Figure 4-6 Predicted groundwater levels and drawdown through time – hydrograph for sites east of the mid-tunnel facility

These charts show that drawdown during construction is about double (or more) the drawdown in the long-term after construction. The backfill and sealing of the adit and shaft clearly has an effect on groundwater levels, causing a partial recovery after construction.

The two left-hand charts show locations on either side of the alignment. The model-predicted drawdown at the site to the west does not peak to the same magnitude as at the site to the east, even though the post-construction / long-term drawdown at the two sites is similar. This is likely due to the proximity of the eastern sites to the shaft and adit (which are proposed to be backfilled) while the western site is closer to the persistently drained cavern/enlargement.

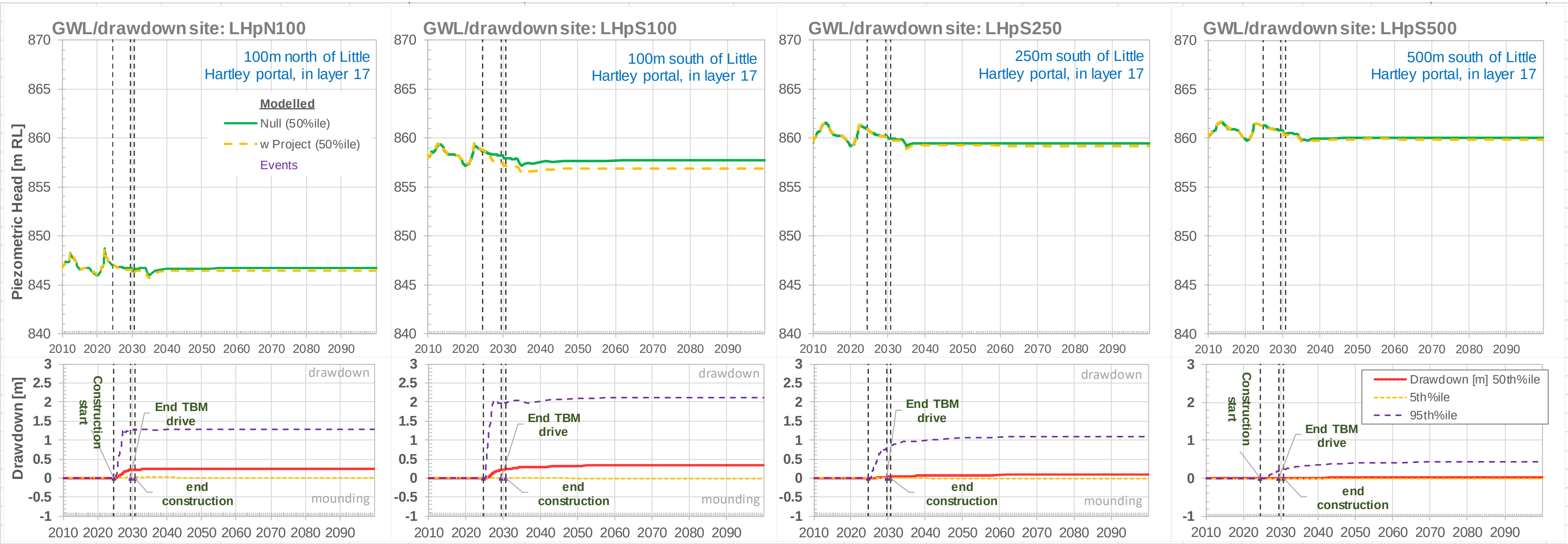


Figure 4-7 Predicted groundwater levels and drawdown through time – hydrograph for sites south of Little Hartley Portal

As with the sites near Blackheath portal, the persistent drainage of the portal means that drawdown in this area remains high, even after construction. There is a significant difference between the 50th and 95th percentile estimates at this location, potentially due to nearby geological structure included in the model. However the drawdown at 500 m caused by the drainage of the portal is relatively low (0.5 m) even for the 95th percentile estimate.

At the site 100 m north of the Little Hartley portal (left-hand chart above), the model-predicted drawdown is slightly lower than that predicted 100 m south (2nd chart from left). This is related, at least in part, to the change in topography to the north, with the topography declining down to the Butlers Creek floodplain.

4.6.2 Groundwater level contour maps

Groundwater level contour maps for the predictive period have not been produced (as they were for the historical period – Section 3.3.3). The large range in groundwater levels across the study area, and the relatively small drawdown predicted as a result of the project (see following section) means that the differences are too subtle, and such maps would not add value. Contour maps can be produced on request (e.g. for the layers listed in Section 4.6.3).

4.6.3 Maximum groundwater drawdown contour maps

Groundwater level contour maps are useful for illustrating the simulated pattern of groundwater levels, and the inferred direction of flow, as a result of the excavations that form the project and other processes. For environmental impact assessment, the simulated location, extent and magnitude of drawdown is more important than actual groundwater level. The maximum drawdown predicted in every model cell in a number of selected 'stratigraphic' layers, as well as the drawdown in the simulated water table has been calculated during construction (2024-2030), and in the long-term for the following stratigraphic units or layers:

- Water table (calculated here as the modelled water level in the uppermost saturated model layer, i.e. uppermost saturated or partially saturated stratigraphic unit);
- Banks Wall Sandstone [BWSS] (model layer 4);
- Mt York Claystone [MYCS] (model layer 6);
- lower Burra-Moko Head Sandstone [BMHS] (model layer 8);
- Caley Formation (model layer 10); and
- Marrangaroo Conglomerate / Gundangaroo Formation (model layer 17).

These maps are presented on the following pages, with **Figure 4-8** to **Figure 4-10** showing the maximum modelled drawdown during construction, and **Figure 4-11** to **Figure 4-13** showing the maximum modelled drawdown in the long-term.

The median or 50th percentile estimate of the maximum drawdown from the ensemble is the main focus on these maps, but the key drawdown contours from the 5th and 95th percentile are also shown to illustrate uncertainty in the predictions. The 2 m drawdown contour for the 95th percentile is shown to show the conservative estimate of the extent of this contour (re: the AIP). The 5th percentile estimates of drawdown are deliberately not shown for simplicity. The following discussion and observations are made from inspection of these drawdown maps.

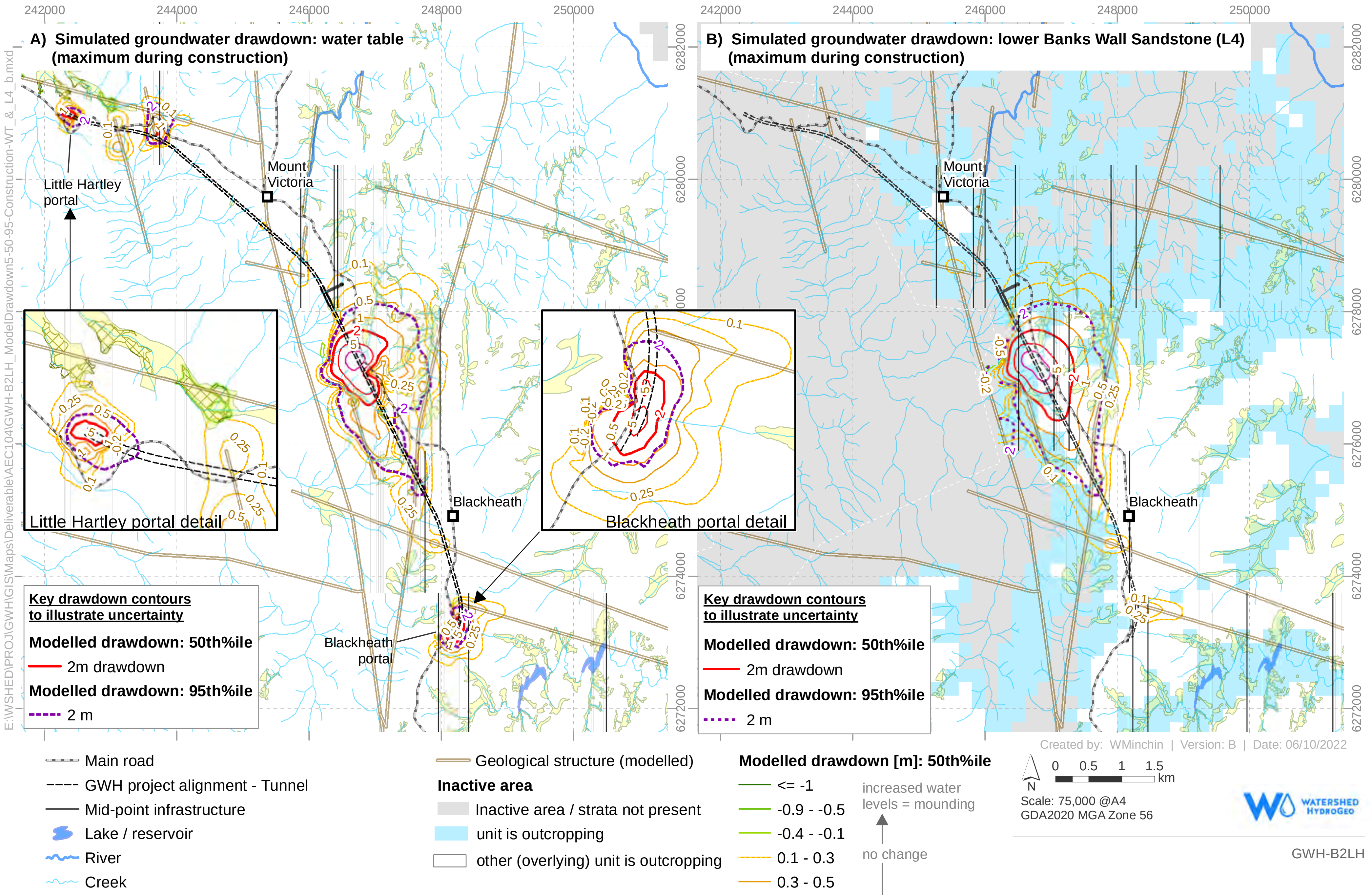
In general, groundwater drawdown is predicted to be greatest during the construction phase, due to the construction of cross-passages along the tunnel alignment (each drained for 2-3 months – Section 1.2.4) and the draining of the mid-tunnel shaft and adit prior to those being backfilled (Sections 1.2.5 and 1.2.6). After construction, groundwater levels recover across most of the project area, with the exception of around the mid-tunnel cavern (Section 1.2.6) and the two portals and their drained cut-and-cover sections – Sections 1.2.7 and 1.2.8).

The water table drawdown during construction (**Figure 4-8A**) is focussed on portals and near-surface parts of the tunnel, as well as a significant area of drawdown around cross-passages just south of the mid-tunnel facility (XPs 38 and 39). The water table drawdown around the Little Hartley portal does extend north to the ecological receptors north of the portal, but the contour suggests the drawdown is minimal (0.1 m). More detail is provided in Section 4.6.5. Significant drawdown in the water table is also simulated around XPs 77and 78 to the east of the portal. This is simulated here because of regional geological structure identified in the conceptual model - **Figure 2-7**, and also shown on these maps).

In the same manner as the water table drawdown around XPs 38-39, the area around these cross-passages also shows up as an area of higher drawdown during the construction phase in the Banks Wall Sandstone (**Figure 4-8B**), shifting further north in deeper layers such as the Mount York Claystone (**Figure 4-9A**). In the lower Burra-Moko Head Sandstone, the main area of drawdown is focussed on the mid-tunnel facilities, with some isolated drawdown at Mount Victoria and to the south of the mid-tunnel area (again related to the regional geological structures included in the modelling).

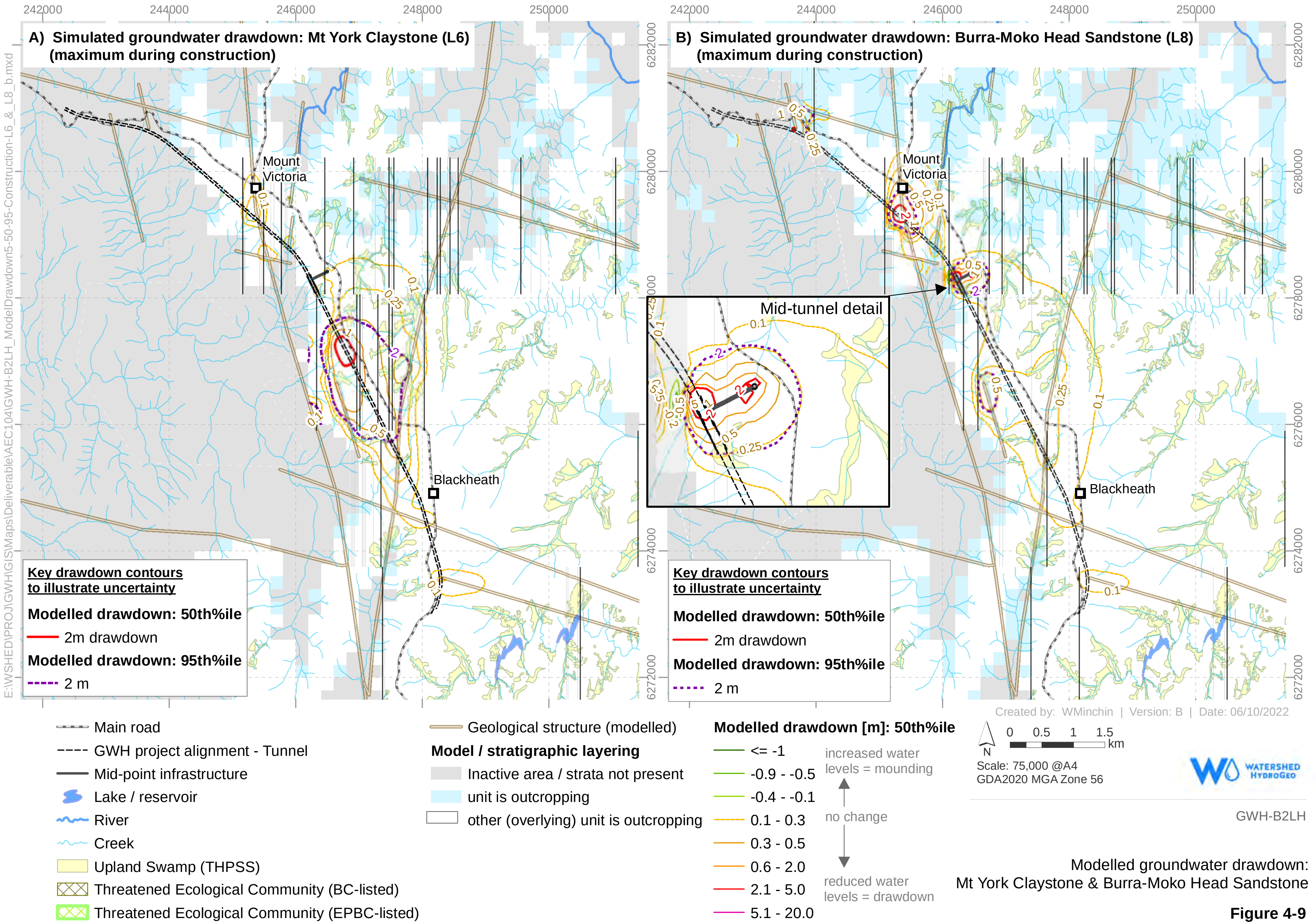
In the long-term, water table drawdown is predicted to be focussed on the portals, with some areas of very mild drawdown around other parts of the alignment (**Figure 4-11A**). A similar pattern is observed in the Banks Wall Sandstone (**Figure 4-11B**) and Mount York Claystone (**Figure 4-12A**) and deeper units (**Figure 4-13**). Significant but localised drawdown is predicted to persist in the lower Burra-Moko Head Sandstone because of the mid-tunnel cavern (**Figure 4-12B**).

In layer 17, the drawdown around the Little Hartley portal and nearby cross-passages is of most interest. The extent of drawdown declines from construction phase (**Figure 4-10B**) to post-construction (**Figure 4-13B**), however there is a persistent cone of depression prediction around the portal/cut-and-cover section. Isolated areas of drawdown along the alignment in the construction phase (**Figure 4-10B**), mainly from the 95th percentile estimate, are generally related to the regional geological structures identified in the conceptual model and included in the numerical modelling.



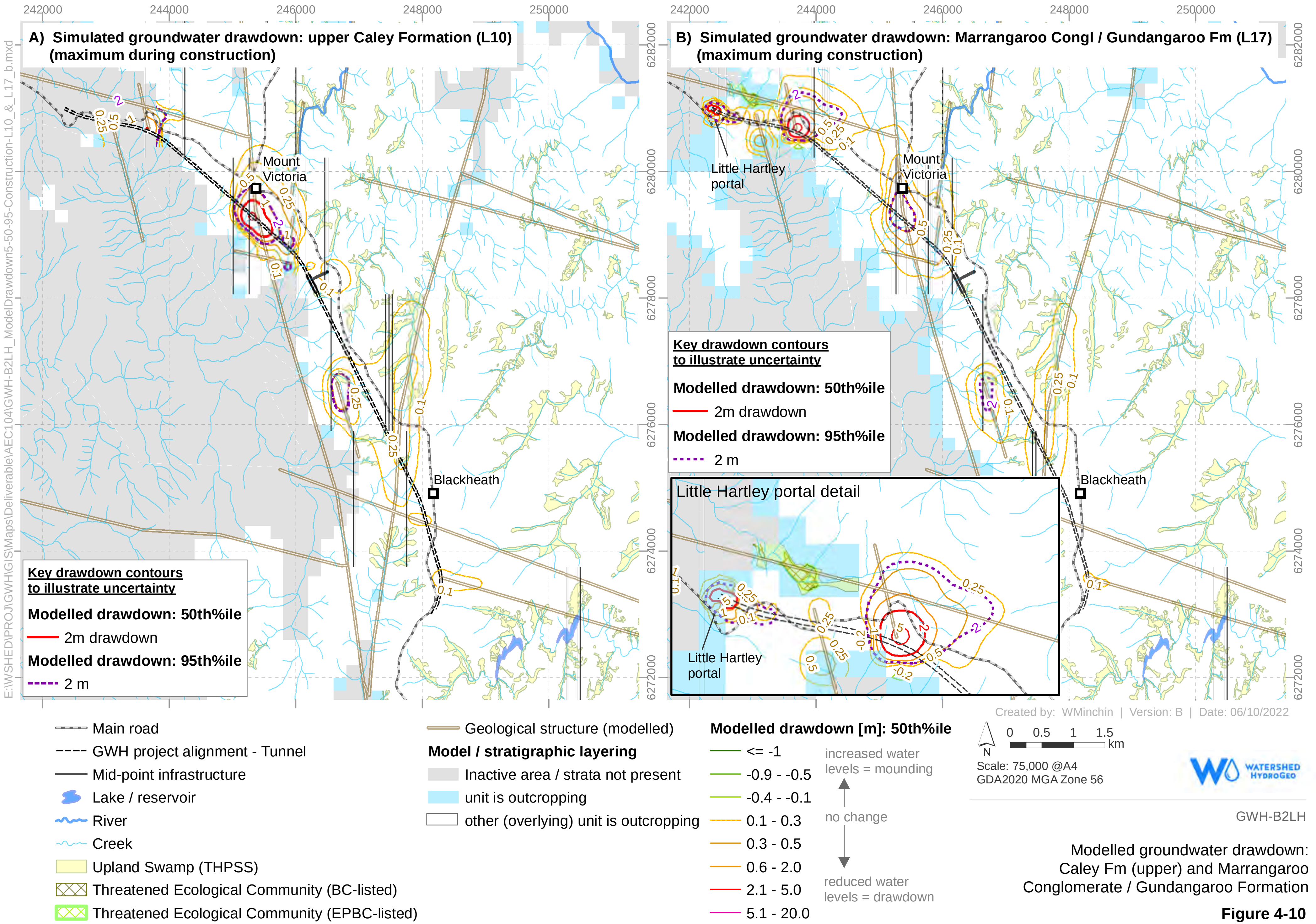
Modelled groundwater drawdown: water table & Banks Wall Sandstone

Figure 4-8



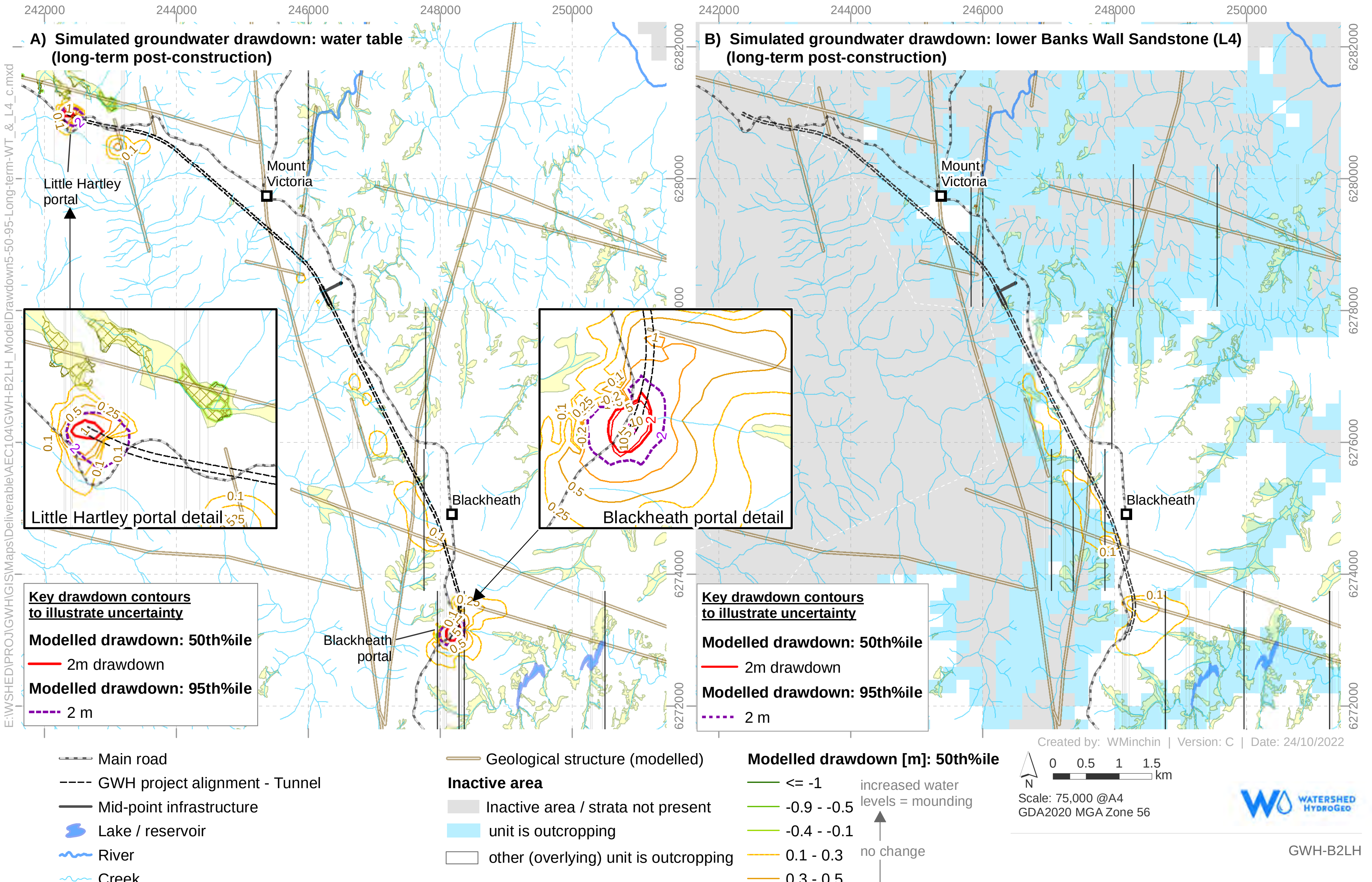
Modelled groundwater drawdown:
Mt York Claystone & Burra-Moko Head Sandstone

Figure 4-9



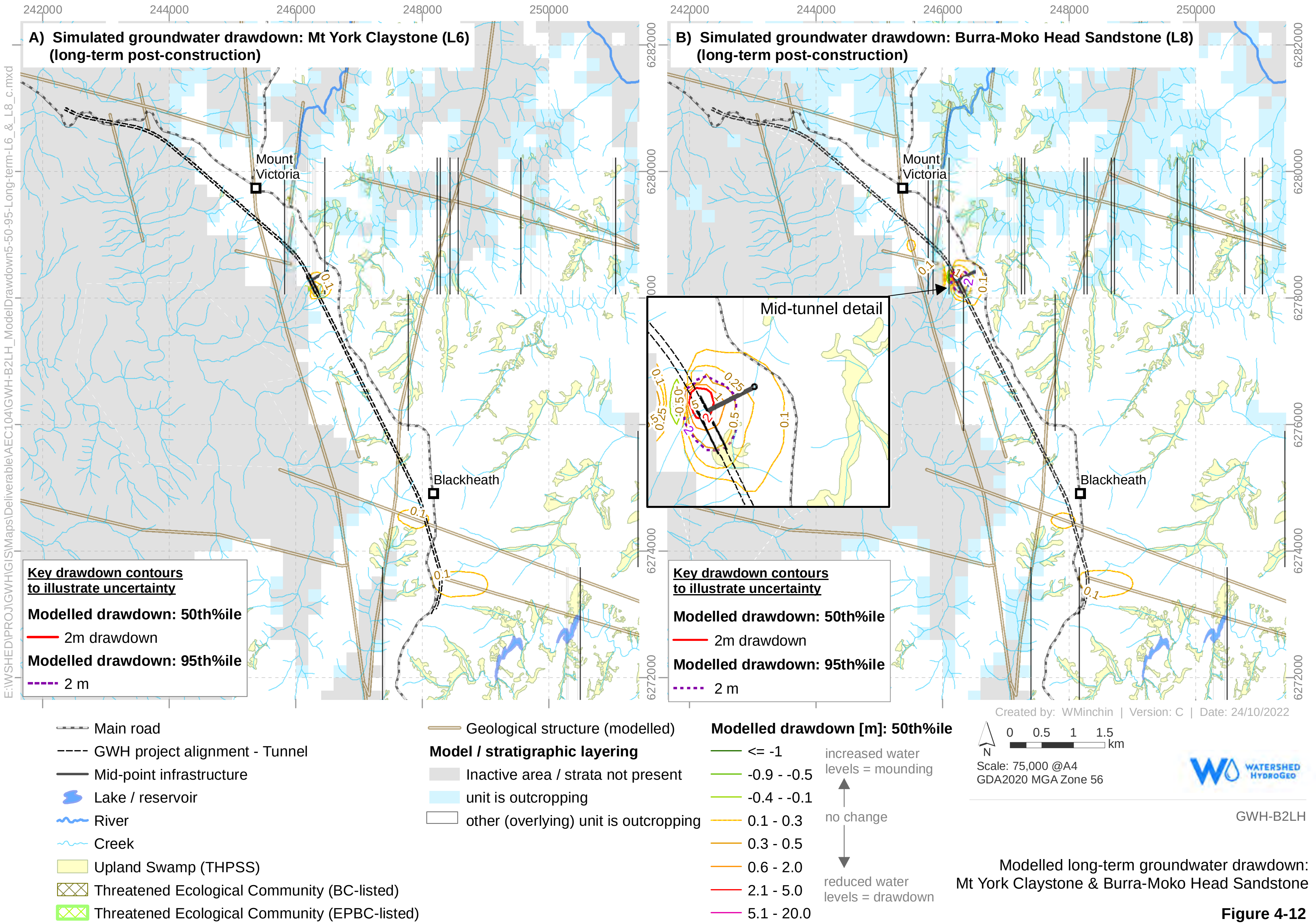
Modelled groundwater drawdown: Caley Fm (upper) and Marrangaroo Conglomerate / Gundangaroo Formation

Figure 4-10



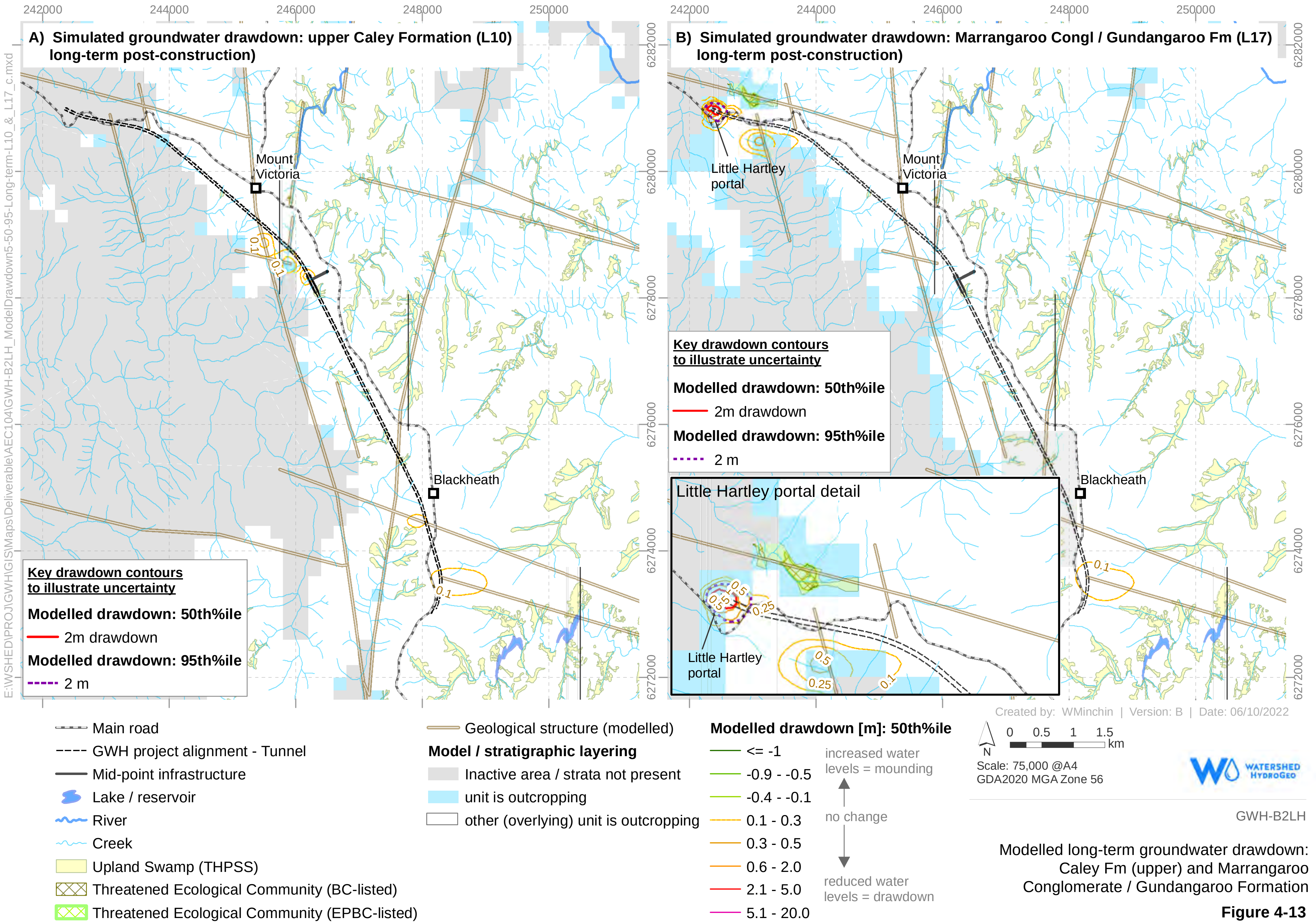
Modelled long-term groundwater drawdown: water table & Banks Wall Sandstone

Figure 4-11



Modelled long-term groundwater drawdown:
Mt York Claystone & Burra-Moko Head Sandstone

Figure 4-12



Modelled long-term groundwater drawdown: Caley Fm (upper) and Marrangaroo Conglomerate / Gundangaroo Formation

Figure 4-13

4.6.4 Drawdown at registered groundwater bores

NSW Government maintains a database of registered 'Groundwater Works' that have been registered with them over time. The 'works' can generally be assumed to be bores, but also includes wells and excavations (AECOM, 2022).

73 registered groundwater works are located within the bounds of the groundwater model. The database includes an attribute for the purpose of the groundwater works, and of these, we consider that the following are 'water supply' works as per the AIP:

- 'Commercial and industrial';
- 'Irrigation';
- 'Stock and Domestic';
- 'Water Supply';
- 'Other'; and for conservatism,
- 'Unknown'.

Those classed as 'Dewatering', 'Monitoring' and 'Exploration' are not considered 'water supply' works.

This classification means that 65 have been classed as 'water supply', and these are the features requiring assessment under the AIP. Locations are shown on **Figure 4-14**. Each of these has been assigned a model layer, water-bearing zones, bore construction details or bore depth – whichever are recorded in the bore database. The assignment of bores to layers is uncertain.

The AIP deems the threshold for 'minimal harm' at a water supply work to be 2 m drawdown due to the proposed activity or activities.

The forecasting ensemble results suggest that, of the 65 water supply works in the project area, none (0) for the median or "likely" estimate and 2 bores for the 95th percentile ("likely worst case") could be affected by more than the 2 m drawdown threshold by the project (**Table 4-6**). This indicates that the excavations and drainage of the relevant project features are not likely to cause >2 m drawdown at registered bores. This is not surprising, given the method of tunnelling, and the few features that would cause long-term drainage and drawdown, and the relative distance of those from registered bores.

Table 4-6 >2 m Drawdown at 'water supply' works

Case	No. of GW works affected > 2 m		
	During construction	Post-construction	Long-term (2130)
50th percentile from ensemble ("likely")	0	0	0
95th percentile from ensemble ("likely worst case")	2	0	0

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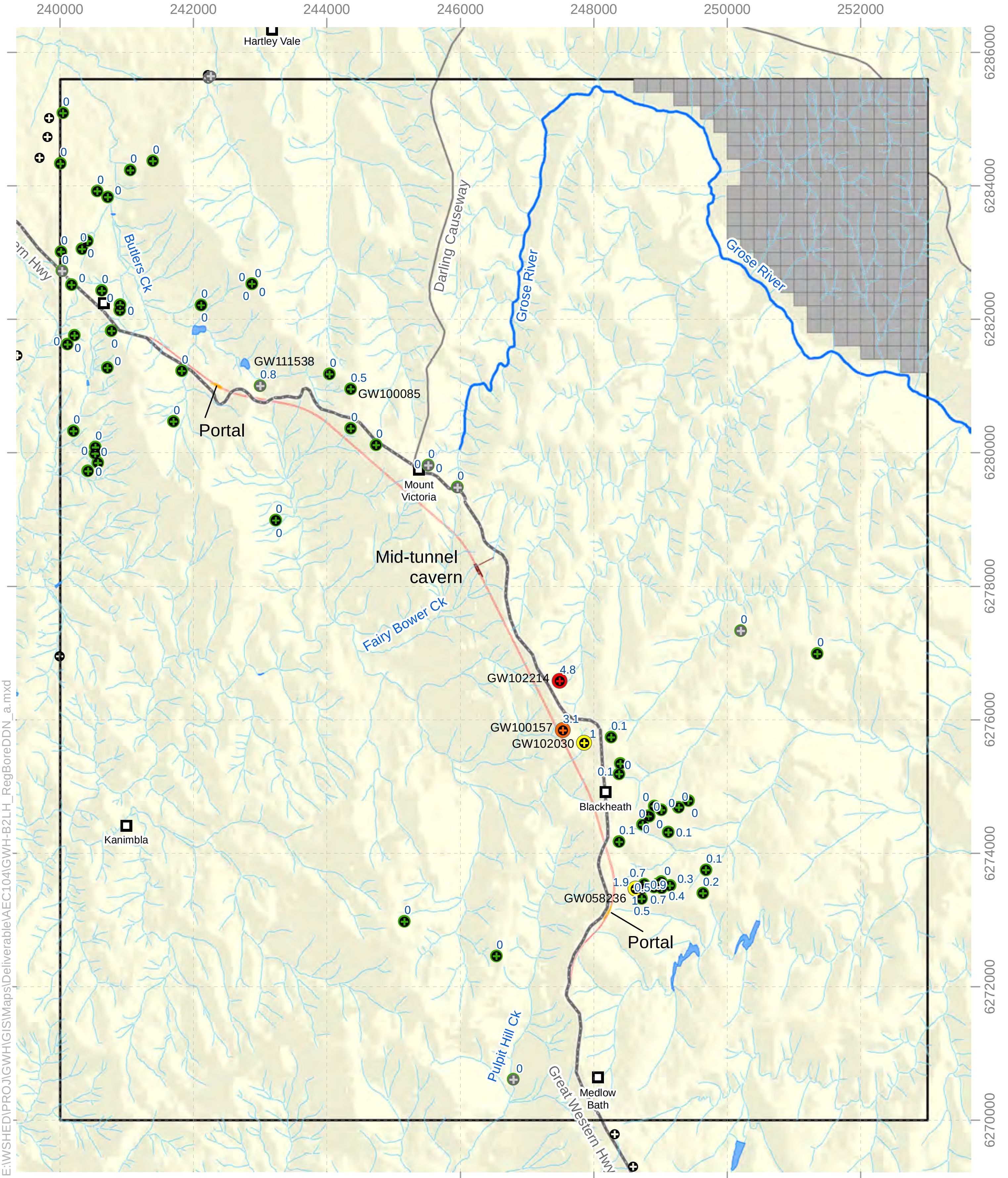
Appendix H summarises the model results for all 'water supply' works and registered monitoring bores in the model domain for the development scenarios. This includes an estimate of the probability of exceeding 2 m drawdown at each bore, calculated from the number of realisations with >2 m drawdown out of the 298 successful realisations.

Figure 4-14 summarises the maximum drawdown estimated ensemble of realisations, and highlights the estimated probability of >2 m drawdown during construction phase, which is when most drawdown would occur, which is supported by the hydrographs for the most-affected bores presented below.



Created by: WMinchin | Version:A | Date: 29/09/2021

- Model extent
- Model no flow (inactive)
- Main road
- Great Western Highway
- GWH project alignment
- Cut and Cover section
- Mid-Tunnel Facilities
- River
- Creek

Registered bore

- Water Supply (AIP)
- non-water supply

(labelled with max modelled DDN [m] during entire simulation period for all realisations)

Model Probability of >2m DDN

- 0% - 0.5%
- 0.5% - 1%
- 1% - 5%
- 5% - 10%
- 10% - 15%
- 15% - 25%

N

0 0.5 1 1.5 2 km

Scale: 75,000 @A4
GDA 1994 MGA Zone 56

GWH-B2LH

Estimated probability of >2m drawdown at registered bores (during construction)

Figure 4-14

The hydrograph for GW102214 (**Figure 4-15**) shows peak drawdown (0.76-4.7 m for 50th and 95th percentiles) toward the end of the construction period. The drawdown is predicted to decline within a few years once construction is completed.

Figure 4-15 Modelled groundwater levels and drawdown at bore GW102214

The hydrograph for GW100157 (**Figure 4-16**) shows peak drawdown (0.66-3.1 m for 50th and 95th percentiles) toward the end of the construction, and the drawdown declining following construction, similar to GW102214.

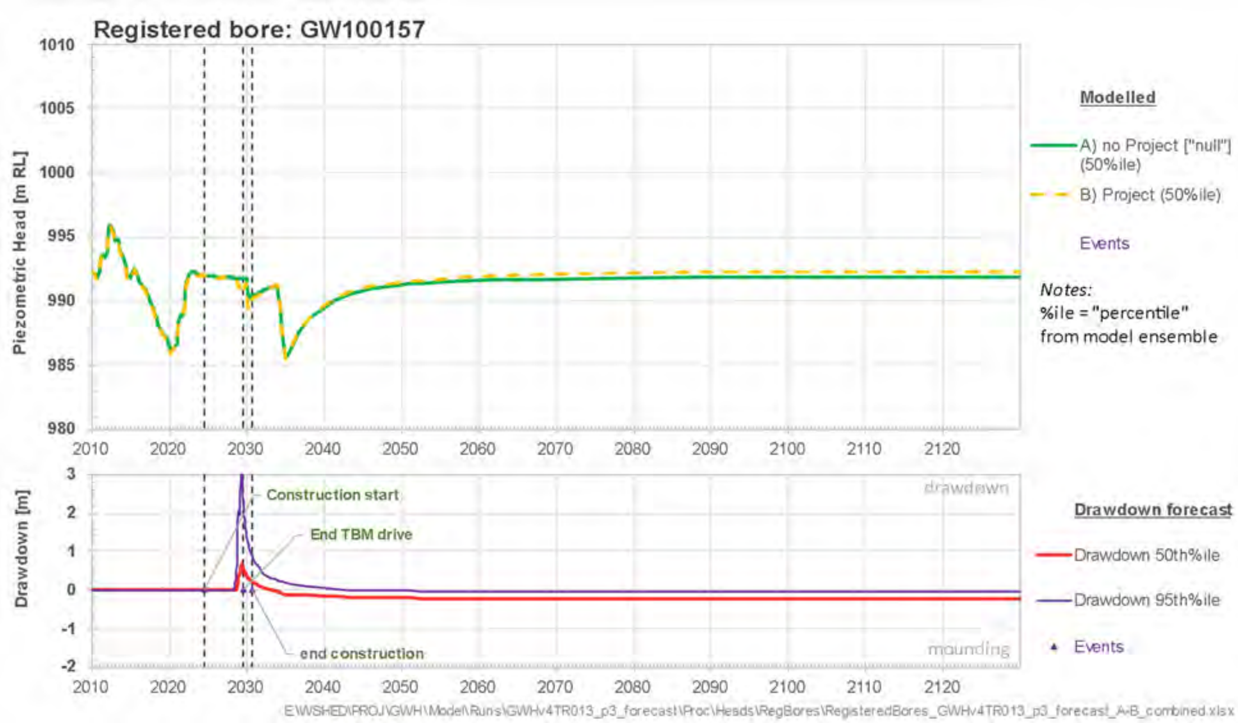


Figure 4-16 Modelled groundwater levels and drawdown at bore GW100157

4.6.5 Drawdown at ecological receptor sites

Ecological receptors and possible groundwater dependent ecosystems (GDEs) are located across the project area. These receptors include:

- Temperate Highland Peat Swamps on Sandstone – referred to in this report as 'upland swamps'. These are located across the project area (**Figure 2-15** and **Figure 4-17**).
- Other areas of ecological significance, including EPBC[4] and BC[5]-listed Threatened Ecological Communities ("TECs"), as identified by project ecologists, all of which are located near the Little Hartley Portal.

The above sites, especially those near the portals, have been compared against NSW government mapping developed using the HEVAE methodology (Dabovic et al., 2019). These sites have been "named" arbitrarily by the groundwater modeller, and the names are not linked to real world identifiers. The key locations are shown on **Figure 4-17** (for most of the alignment) and **Figure 4-18** (around the two portals), with the model output locations marked and labelled. These output locations are at the centre of model cells, hence may not correspond exactly to the extent of the real-world feature.

For these locations, simulated groundwater levels have been extracted from the model ensemble for the A (null) and B ('with project') development scenarios (**Figure 4-1**). A selection of hydrographs is presented below, and a summary of any predicted drawdown at all such sites is shown in **Table 4-7**.

For the period 2010-2022, historical rainfall was used, hence why simulated groundwater levels are variable in the historical period on the hydrographs below. From 2022-onward, average rainfall and potential evaporation conditions were adopted, other than for two periods of low rainfall (Section 2.5.1), hence the simulated groundwater levels are relatively constant in the future period. The only difference between the A ("Null") and B ("w/ Project") scenarios is the presence of the project.

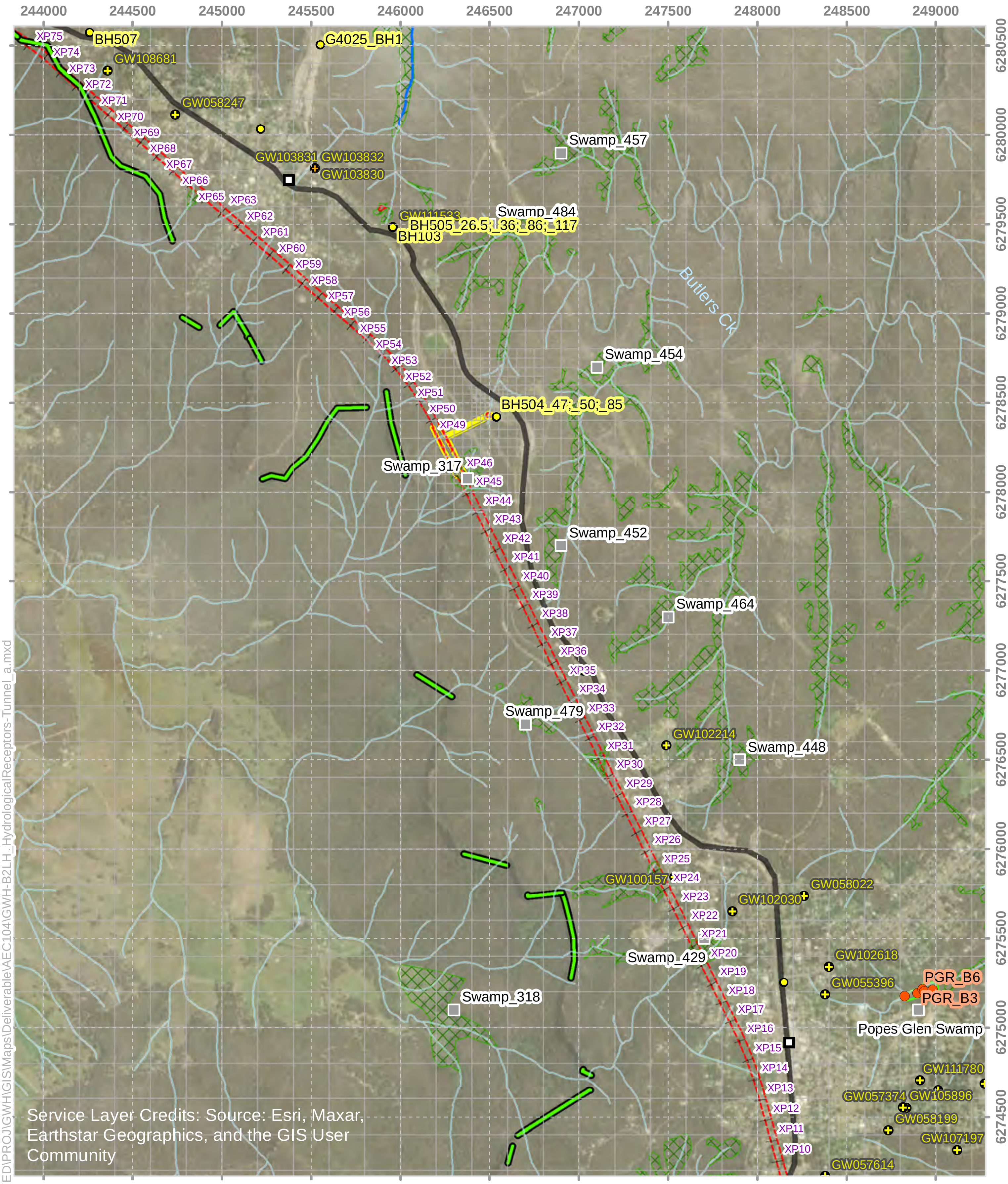
The following observations are made from the hydrographs and summary table (**Table 4-7**).

The EPBC-listed TEC sites are located in areas with a low risk of drawdown due to the project. Site EPBC_4 has the largest predicted drawdown (0.7 m during construction – 95th percentile and then recovering to natural or near natural conditions), while the 50th percentile estimate is for 0.05 m drawdown. As these sites are located at a similar elevation, even slightly lower, than the nearby Little Hartley Portal and associated cross-passages (**Figure 4-18A**), the drawdown effects are conceptualised to be minimal effect at these sites, and the modelling supports this.

Like the EPBC-listed sites, the BC-listed sites are located in similar positions relative to the portal and alignment, and as such are generally considered to be at negligible risk of measurable drawdown from the project. The forecast is that BC_18 could potentially experience 0.31 m drawdown during construction and declining over time to 0.12 m (95th percentile estimates). 50th percentile estimates of drawdown at this site are less than 0.05 m.

Of the Upland Swamp sites assessed, most are not predicted to be affected by measurable drawdown. Locations are shown on **Figure 4-17**. However, of the set presented in **Table 4-7**, five are located in areas where drawdown is forecast to occur: sites 454, 452 (**Figure 4-26**), 464, 479 (**Figure 4-27**) and 429 (**Figure 4-28**). Locations are shown on **Figure 4-18**. These sites are located between the Blackheath Portal and the mid-tunnel facility, where it was not expected to see simulated drawdown of this magnitude. This may be a function of poorly constrained model parameters (i.e. insufficient data to calibrate to or insensitive parameters), or structural errors in the model.

[4] *Environment Protection and Biodiversity Conservation Act 1999* ["EPBC"] – Federal legislation
[5] *Biodiversity Conservation Act 2016 No 63* ["BC"]- NSW Legislation



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- Monitoring bore - swamp
- Monitoring bore - rock

AIP classification

- "Water Supply" (AIP)
- non-water supply
- Great Western Highway
- GWH project alignment - Tunnel
- Mid-point infrastructure
- Cut and Cover section
- Mid-Tunnel (Cavern / Adit / Shaft)
- Creek
- Cliff / Hanging Swamp
- Upland Swamp (THPSS)
- (NSW) BC-listed TEC
- (Federal) EPBC-listed TEC

TEC and THPSS model output location

- BC: TEC
- EPBC, BC: TEC
- unlisted (THPSS)

N

0 0.1 0.2 0.3 km

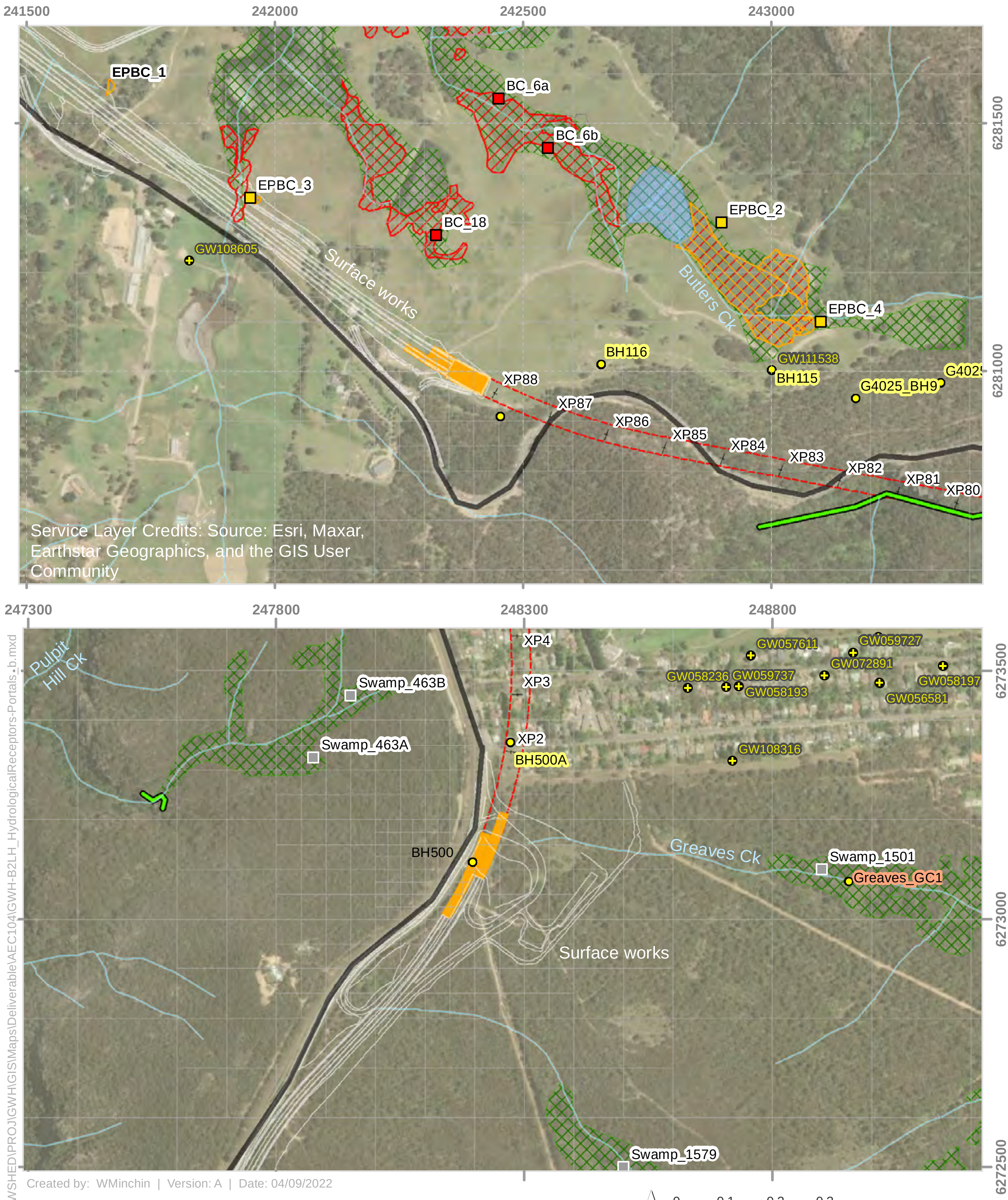
Scale: 10,000 @A4
GDA 1994 MGA Zone 56

WATERSHED HYDROGEO

GWH-B2LH

Likely groundwater dependent ecosystems and model output locations: alignment

Figure 4-17



Created by: WMinchin | Version: A | Date: 04/09/2022

Monitoring bore - swamp
Monitoring bore - rock

AIP classification

"Water Supply" (AIP)
non-water supply
Great Western Highway
GWH project alignment - Tunnel
Mid-point infrastructure
Cut and Cover section
Mid-Tunnel (Cavern / Adit / Shaft)
Creek
Cliff / Hanging Swamp
Upland Swamp (THPSS)
(NSW) BC-listed TEC
(Federal) EPBC-listed TEC

TEC and THPSS model output location

BC: TEC
EPBC, BC: TEC
unlisted (THPSS)

N 0 0.1 0.2 0.3 km

Scale: 10,000 @A4
GDA 1994 MGA Zone 56

GWH-B2LH

Likely groundwater dependent ecosystems and model output locations

Figure 4-18

In most instances, the model-predicted drawdown is less than the simulated historical variability in groundwater levels. However, while it is considered unlikely drawdown of the magnitude suggested by the 50th and 95th percentile estimates would occur in reality, recommendations for data gathering and monitoring , and modelling, this area are made in Sections 5.1.1 and 5.1.2.

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Figure 4-19 Modelled groundwater levels and drawdown at site EPBC_2

Site EPBC_3 (**Figure 4-20**) is more likely to be affected by physical or construction disturbance (see Figure 4-17**Figure 4-18**), which is not simulated by the groundwater model.

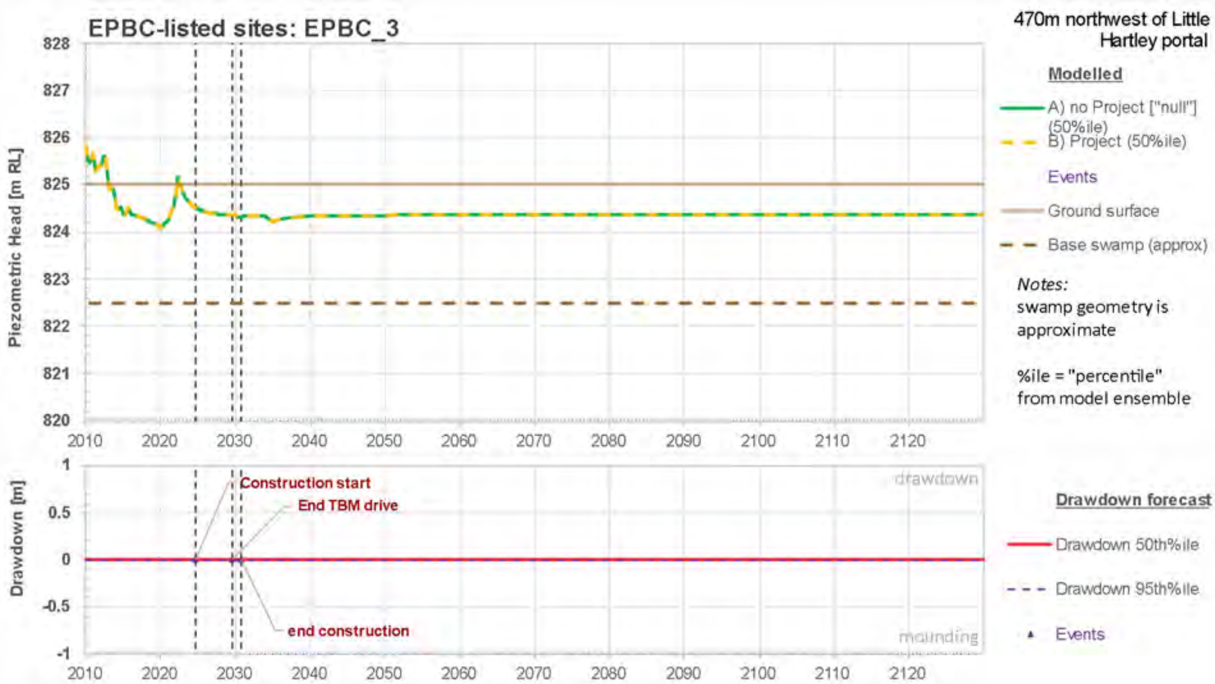

Figure 4-20 Modelled groundwater levels and drawdown at site EPBC_3

Figure 4-21 Modelled groundwater levels and drawdown at site EPBC_4

In the figure above, the model suggests a mild increase in groundwater level (i.e. groundwater mounding). This very minor effect is likely a result of the simulated low permeability barrier that results from the installation of the segmentally-lined tunnel (Section 2.6.5).

Figure 4-22 Modelled groundwater levels and drawdown at site BC_4

Figure 4-23 Modelled groundwater levels and drawdown at site BC_6a

Figure 4-24 Modelled groundwater levels and drawdown at site BC_6b

Figure 4-25 Modelled groundwater levels and drawdown at site BC18

Figure 4-26 Modelled groundwater levels and drawdown at site Upland Swamp 452

Figure 4-27 Modelled groundwater levels and drawdown at site Upland Swamp 479

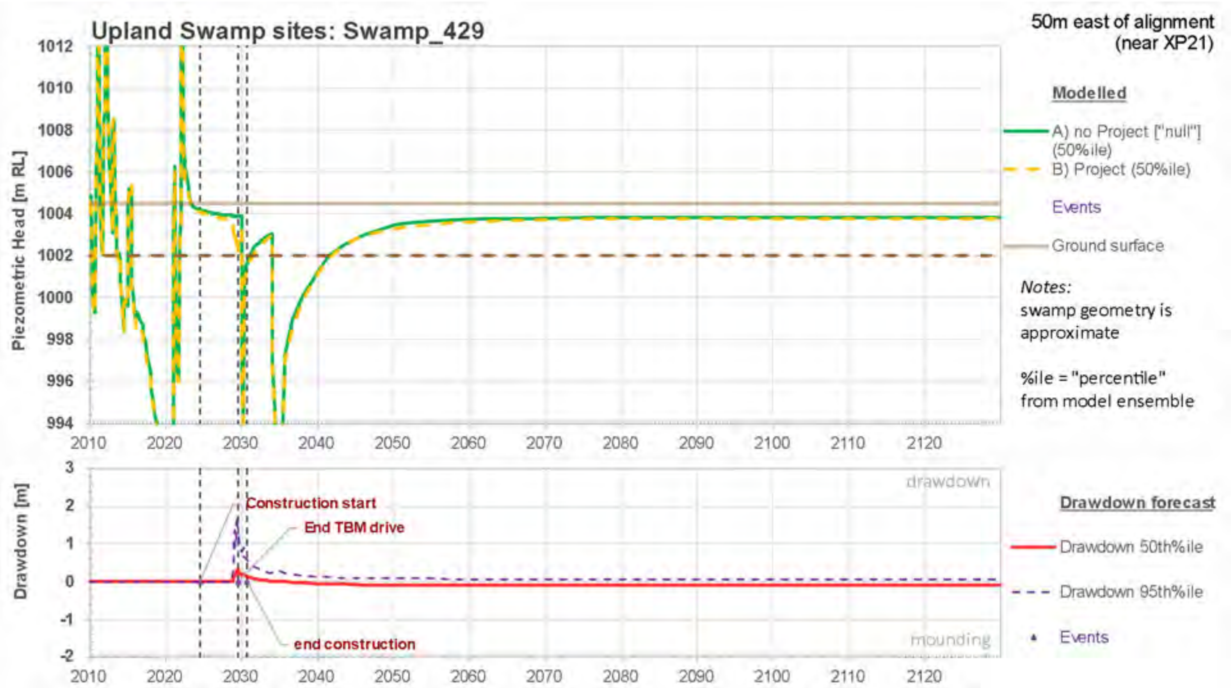

Figure 4-28 Modelled groundwater levels and drawdown at site Upland Swamp 429

Table 4-7 Summary of predicted drawdown at ecological sites

Feature	Listing	Easting	Northing	Comment	Max drawdown [m] during construction				Max drawdown [m] post-construction				Max long-term (~2130) drawdown [m]			
					(%iles from model ensemble)				(%iles from model ensemble)				(%iles from model ensemble)			
					5th%ile [m]	Median [m]	95th%ile [m]	% probability of >=2m	5th%ile [m]	Median [m]	95th%ile [m]	% probability of >=2m	5th%ile [m]	Median [m]	95th%ile [m]	% probability of >=2m
EPBC_1	EPBC, BC	241667	6281570	840m from Little Hartley portal - too small & not model	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
EPBC_2	EPBC, BC	242900	6281300	near Little Hartley portal, 350m N of XP85 (on Butlers (	0.00	0.01	0.06	0%	-0.01	0.00	0.03	0%	-0.03	0.00	0.01	0%
EPBC_3	EPBC, BC	241950	6281350	470m NW of Little Hartley portal	0.00	0.00	0.01	0%	0.00	0.00	0.01	0%	0.00	0.00	0.00	0%
EPBC_4	EPBC, BC	243100	6281100	near Little Hartley portal, 280m N of XP83 (on Butlers (	0.00	0.05	0.70	0%	-0.21	-0.04	0.01	0%	-0.28	-0.08	0.00	0%
BC_4	BC	241900	6281900	820m N of Little Hartley portal, (on Butlers Ck)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
BC_6a	BC	242450	6281550	500m N of Little Hartley portal (on Butlers Ck)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
BC_6b	BC	242550	6281450	460m N of Little Hartley portal (on Butlers Ck)	0.00	0.00	0.01	0%	0.00	0.00	0.01	0%	0.00	0.00	0.00	0%
BC_18	BC	242325	6281275	210m N of Little Hartley portal	0.00	0.03	0.31	0%	0.00	0.04	0.27	0%	0.00	0.03	0.12	0%
Swamp_268	TPHSS	246100	6280700	1.4 km NE of XPs 60-64 (on Grose River)	0.00	0.00	0.02	0%	-0.01	0.00	0.00	0%	-0.02	-0.01	0.00	0%
Swamp_457	TPHSS	246900	6279900	1.4 km NE of XPs 52-55	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
Swamp_484	TPHSS	246500	6279500	900m NE of XPs 52-55	0.00	0.00	0.03	0%	0.00	0.00	0.04	0%	0.00	0.00	0.00	0%
Swamp_454	TPHSS	247100	6278700	640m NE of mid-tunnel shaft (on Boyce Gully)	0.00	0.01	0.32	0%	0.00	0.01	0.41	0%	0.00	0.00	0.00	0%
Swamp_317	TPHSS	246375	6278075	130m SE of mid-tunnel shaft (near XP46)	0.00	0.00	0.02	0%	0.00	0.00	0.02	0%	0.00	0.00	0.00	0%
Swamp_452	TPHSS	246900	6277700	750m SE of mid-tunnel shaft (near XP42)	0.00	1.27	5.33	37%	0.00	0.50	1.71	1%	-0.05	-0.01	0.00	0%
Swamp_464	TPHSS	247500	6277300	640m east of alignment (near XP36-38)	0.00	0.11	4.44	17%	0.00	0.09	1.99	5%	-0.11	0.00	0.00	0%
Swamp_479	TPHSS	246700	6276700	275m west of alignment (near XP32-33)	0.02	0.40	5.38	22%	0.02	0.51	2.28	9%	0.00	0.02	0.22	0%
Swamp_448	TPHSS	247900	6276500	610m east of XP30	0.00	0.00	0.09	0%	0.00	0.00	0.10	0%	-0.02	0.00	0.00	0%
Swamp_429	TPHSS	247700	6275500	50m east of alignment (near XP21)	0.02	0.41	1.81	4%	-0.07	0.15	0.56	0%	-0.42	-0.10	0.06	0%
Swamp_318	TPHSS	246300	6275100	1.3 km W of XPs 18-22 (on Blackheath Ck)	0.00	0.00	0.01	0%	0.00	0.00	0.01	0%	0.00	0.00	0.00	0%
PopesGlen		248900	6275100	960m east of XP16	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
Swamp_1532	TPHSS	250100	6274900	2 km east of XP14	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
Swamp_1476	TPHSS	250700	6274900	2.6 km east of XP14	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
Swamp_437	TPHSS	247700	6274100	350m west of XP9	0.00	0.00	0.03	<0.3%	0.00	0.01	0.04	0%	-0.01	0.00	0.02	0%
Swamp_1547	TPHSS	249700	6274100	1.5 km east of XP8	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
Swamp_463B	TPHSS	247950	6273450	300m west of XP2 | 350m NW of Blackheath portal	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
Swamp_463A	TPHSS	247875	6273325	420m west of XP2 | 360m WNW of Blackheath portal	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
Swamp_1509	TPHSS	250500	6273300	2.2 km E of Blackheath portal (on Greaves Ck)	0.00	0.00	0.01	0%	0.00	0.01	0.04	0%	0.00	0.01	0.03	0%
Swamp_1501	TPHSS	248900	6273100	650m east of Blackheath portal (Greaves Ck)	0.00	0.00	0.06	0%	0.00	0.00	0.05	0%	0.00	0.00	0.02	0%
Swamp_1480	TPHSS	249300	6272700	1.1 km SE of Blackheath portal	0.00	0.00	0.00	0%	0.00	0.00	0.03	0%	0.00	0.00	0.02	0%
Swamp_1579	TPHSS	248500	6272500	650m SE of Blackheath portal	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%

Notes:

+ve values represent modelled drawdown; -ve values represent groundwater mounding.

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4.7 Effects on groundwater discharge at hanging swamps

Zones are set up to extract model results and carry out flow accounting for the springs/hanging swamps at the locations shown on **Figure 4-29**, and in the following model layers as per the conceptual groundwater model for the area:

- Layers 4 and 5: Banks Wall Sandstone and the shear zone at base of (immediately above Mt York Claystone).
- Layers 8 and 9: lower Burra-Moko Head Sandstone (BMHS) and the shear zone at base of BHMS (immediately above Caley Fm).

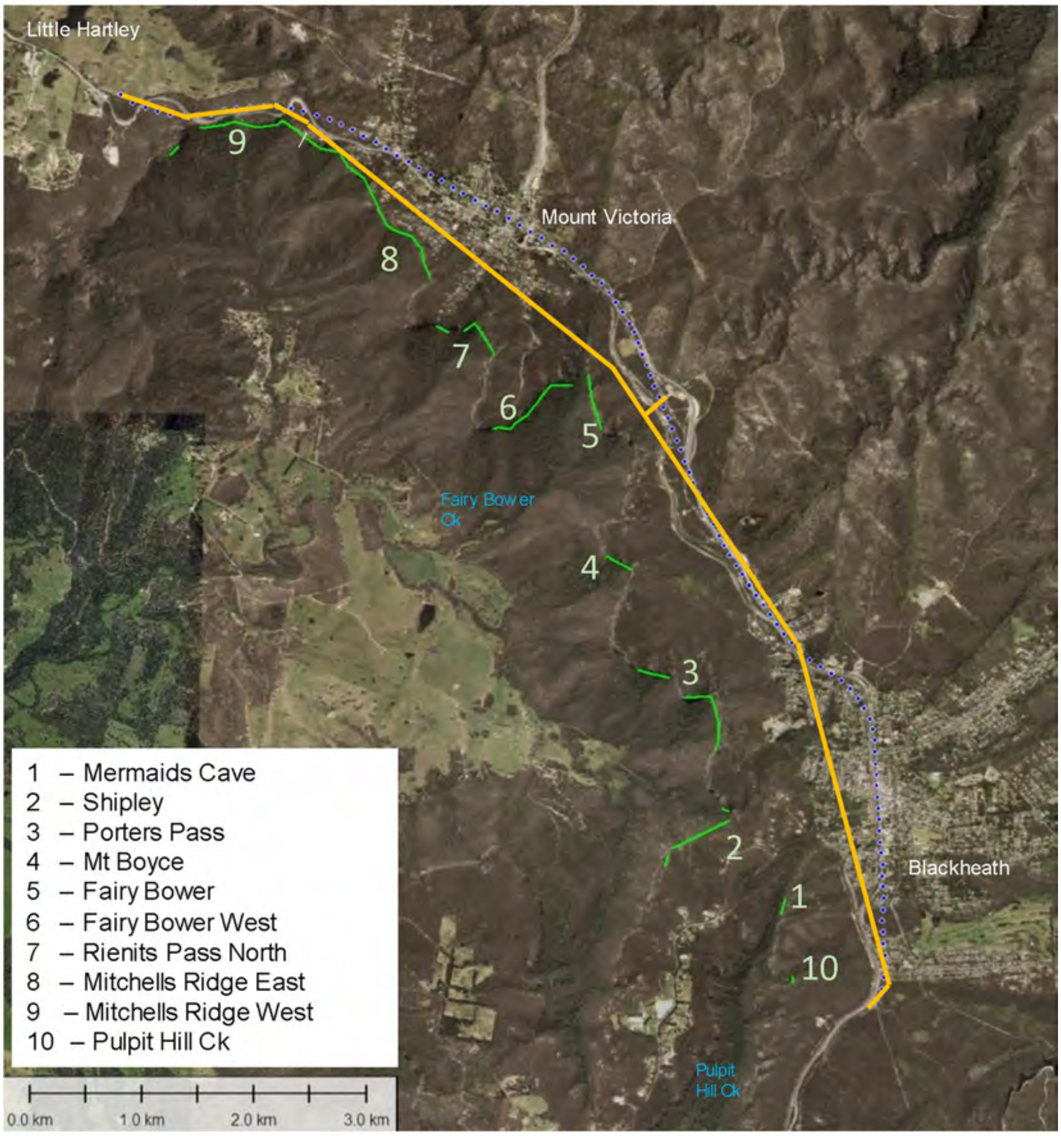

Figure 4-29 Location of hanging swamp receptors

Actual flows to these hanging swamp features has not been quantified in the field or by some other method, so there is uncertainty in these. Simulated baseflow to the Hanging Swamps for the historical period is quantified in **Table 4-8** from the ensemble of models (blue columns). In the following columns (dark grey shading in middle **Table 4-8**), the model-predicted change in baseflow is presented for the construction and post-construction periods. This change is then expressed as a % of the simulated historical baseflow (right-hand columns with light grey shading).

Table 4-8 Summary of change in groundwater discharge to Hanging Swamps

		Historical baseflow (simulated) [m^3/d]			Change in baseflow [m3/d] during construction			Change in baseflow [m3/d] post-construction			Change in baseflow [%] during construction			Change in baseflow [%] post-construction		
Hanging swamp zone	Fore-cast	Dry/low	Average	Wet/high	Min	Average	Peak	Min	Average	Peak	Min impact vs dry	Av. impact vs av. baseflow	Max impact vs wet	Min impact vs dry	Av. impact vs av. baseflow	Max impact vs wet
1 Mermaids Cave	5th%ile	8	12	21	0.000	0.00	0.00	0.09	0.04	0.00	0.0%	0.0%	0.0%	1.2%	0.3%	0.0%
	50th%ile	20	30	50	0.000	0.00	-0.05	-0.05	-0.07	-0.09	0.0%	0.0%	-0.1%	-0.3%	-0.2%	-0.2%
	95th%ile	52	91	151	0.000	-0.04	-0.35	-0.38	-0.41	-0.47	0.0%	0.0%	-0.2%	-0.7%	-0.5%	-0.3%
10 Pulpit Hill Ck	5th%ile	54	68	90	0.000	0.00	-0.02	-0.01	-0.02	-0.03	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	50th%ile	142	166	211	0.000	-0.03	-0.18	-0.19	-0.21	-0.22	0.0%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%
	95th%ile	256	297	373	0.000	-0.25	-0.91	-0.82	-0.87	-0.93	0.0%	-0.1%	-0.2%	-0.3%	-0.3%	-0.2%
2 Shipley	5th%ile	15	28	50	0.00	0.00	0.0	0.00	-0.01	-0.01	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	50th%ile	51	81	137	0.000	-0.01	-0.1	-0.08	-0.11	-0.14	0.0%	0.0%	0.0%	-0.2%	-0.1%	-0.1%
	95th%ile	119	176	274	0.000	-0.06	-0.39	-0.37	-0.47	-0.53	0.0%	0.0%	-0.1%	-0.3%	-0.3%	-0.2%
3 Porters Pass	5th%ile	105.6	147	226	0.000	-0.052	-0.386	0.098	-0.192	-0.391	0.0%	0.0%	-0.2%	0.1%	-0.1%	-0.2%
	50th%ile	271.2	341	451	0.000	-0.756	-3.232	-0.490	-1.591	-2.972	0.0%	-0.2%	-0.7%	-0.2%	-0.5%	-0.7%
	95th%ile	519.6	644	809	0.000	-6.458	-26.817	-3.741	-8.580	-15.903	0.0%	-1.0%	-3.3%	-0.7%	-1.3%	-2.0%
4 Mt Boyce	5th%ile	41.6	58	88	0.000	-0.371	-1.633	0.047	-0.277	-0.850	0.0%	-0.6%	-1.9%	0.1%	-0.5%	-1.0%
	50th%ile	123.8	163	238	0.000	-3.637	-17.471	-0.136	-1.466	-3.983	0.0%	-2.2%	-7.3%	-0.1%	-0.9%	-1.7%
	95th%ile	240	314	446	0.000	-13.568	-65.886	-0.525	-5.031	-13.257	0.0%	-4.3%	-14.8%	-0.2%	-1.6%	-3.0%
5 Fairy Bower	5th%ile	46	65	99	0.000	-0.1	-0.2	0.14	-0.06	-0.23	0.0%	-0.1%	-0.2%	0.3%	-0.1%	-0.2%
	50th%ile	96	130	193	0.000	-1.0	-2.4	-0.57	-1.04	-1.69	0.0%	-0.7%	-1.3%	-0.6%	-0.8%	-0.9%
	95th%ile	173	232	347	0.000	-11.9	-16.3	-9.41	-10.64	-13.39	0.0%	-5.1%	-4.7%	-5.4%	-4.6%	-3.9%
6 Fairy Bower West	5th%ile	6	15	34	0.000	0.0	-0.1	0.46	0.19	0.01	0.0%	-0.1%	-0.2%	7.1%	1.3%	0.0%
	50th%ile	21	46	102	0.000	-0.2	-1.2	0.10	-0.01	-0.11	0.0%	-0.4%	-1.2%	0.5%	0.0%	-0.1%
	95th%ile	71	112	222	0.000	-0.6	-4.2	-0.12	-0.27	-0.44	0.0%	-0.5%	-1.9%	-0.2%	-0.2%	-0.2%
7 Rienits Pass North	5th%ile	18	26	37	0.000	-0.01	-0.06	0.459	0.19	0.01	0.0%	-0.1%	-0.2%	2.5%	0.7%	0.0%
	50th%ile	80	94	115	0.000	-0.18	-1.19	0.10	-0.01	-0.11	0.0%	-0.2%	-1.0%	0.1%	0.0%	-0.1%
	95th%ile	178	207	261	0.000	-0.59	-4.16	-0.12	-0.27	-0.44	0.0%	-0.3%	-1.6%	-0.1%	-0.1%	-0.2%
8 Mitchells Ridge East	5th%ile	15	26	44	0.018	0.001	0.00	0.23	0.10	0.02	0.1%	0.0%	0.0%	1.6%	0.4%	0.0%
	50th%ile	44	65	105	0.000	-0.005	-0.02	0.07	0.02	0.00	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
	95th%ile	110	152	255	0.000	-0.048	-0.18	0.02	0.00	-0.03	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%
9 Mitchells Ridge West	5th%ile	0	0	0	0.000	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	50th%ile	0	0	0	0.000	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	95th%ile	0	0	0	0.000	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Notes: Negative values indicate a model-predicted reduction in baseflow. Positive values indicate a modelled increase in baseflow. “Dry/low” = lowest modelled net baseflow during historical period. “Wet/high” = highest modelled net baseflow during historical period. “Min”/ “Average”/ “Peak” change = smallest/mean/largest **reduction in baseflow** during respective period

For context, zones are listed south to north. Zones 1 and 10 are nearest the Blackheath Portal, and Zone 5 is nearest the mid-tunnel infrastructure.

No baseflow is simulated to Zone 9. This is a limitation of the current model, and relates to the dimensions of the model cells along the narrow ridgeline at the Pass of Victoria (west of Mount Victoria), meaning that some geological units, which might be present at the top of the narrow ridgeline, are not represented across a 200 m wide model cell. Although this is a limitation of the model, the results for Zone 8 and the fact that the tunnel alignment would pass through strata approximately 100 m below the ridgeline suggest that there would be minimal induced reduction in the flux to the swamp. Recommendations regarding this limitation are presented in Section 5.1.2

Table 4-8 shows that the most significant reduction in spring flow or baseflow is to zones 3, 4 and 5. Regarding Zone 5, this finding was expected, noting that the predicted losses are fairly consistent in both the construction period and the post-construction period. This zone is nearest to the mid-tunnel facilities (**Figure 4-29**), which includes the permanently drained caverns.

For Hanging Swamp zones 3 and 4, the reduction in baseflow is higher in the construction phase and declines significantly (i.e. long-term baseflow is closer to pre-construction baseline) after construction is completed (**Table 4-8**). These two zones are closest to cross-passages within the Banks Wall Sandstone, especially those modelled with higher short-term inflow in Section 4.5 and **Table 4-5**. Once those cross-passages are lined, inflow and drawdown would decline significantly. This explains why the modelled baseflow returns to near-baseline conditions in the post-construction phase.

Positive values in **Table 4-8** indicate a modelled increase in baseflow. This could eventuate by the presence of the segmental tunnel linings acting as a barrier to groundwater throughflow (Section 2.6.5). This effect could cause local diversion of groundwater flow, with the potential to increase, decrease or not effect net groundwater flux to certain hanging swamps or other features. The ability of the model to simulate this effect is relatively low, given the geometry of TBM linings compared to the 3D dimensions of model cells. The simulated positive changes in **Table 4-8** are all relatively small in magnitude.

4.8 Effects on stream baseflow

Dewatering of tunnel features could cause a reduction in stream baseflow via two mechanisms:

- groundwater depressurisation or drawdown in the groundwater system that is connected to the watercourse (i.e. outcropping beneath the watercourse); and
- installation of segmental linings along the TBM tunnels can result in a local barrier to groundwater flow, modifying the path of groundwater between recharge and discharge areas (Section 2.6.5). It is also possible that changes to hydraulic properties associated with the segmental lining could cause very small increases to flow to some springs or watercourses, though this is considered to be unlikely and would likely be imperceptible.

The numerical model has been used to estimate loss from watercourses on sub-catchment or catchment scale. With respect to this forecast, the model is not calibrated to baseflow fluxes nor to measured changes in baseflow flux (**Appendix G**).

Noting the recharge sequence used for predictive modelling (Section 2.5.1), changes to baseflow to surface water catchments are calculated for selected time periods:

- During construction 2024-2030.
- Post-construction 2031-2130.
- Long-term (2130).

These are the catchments defined for model output and estimation of reduction in baseflow are presented in **Figure 4-30**.

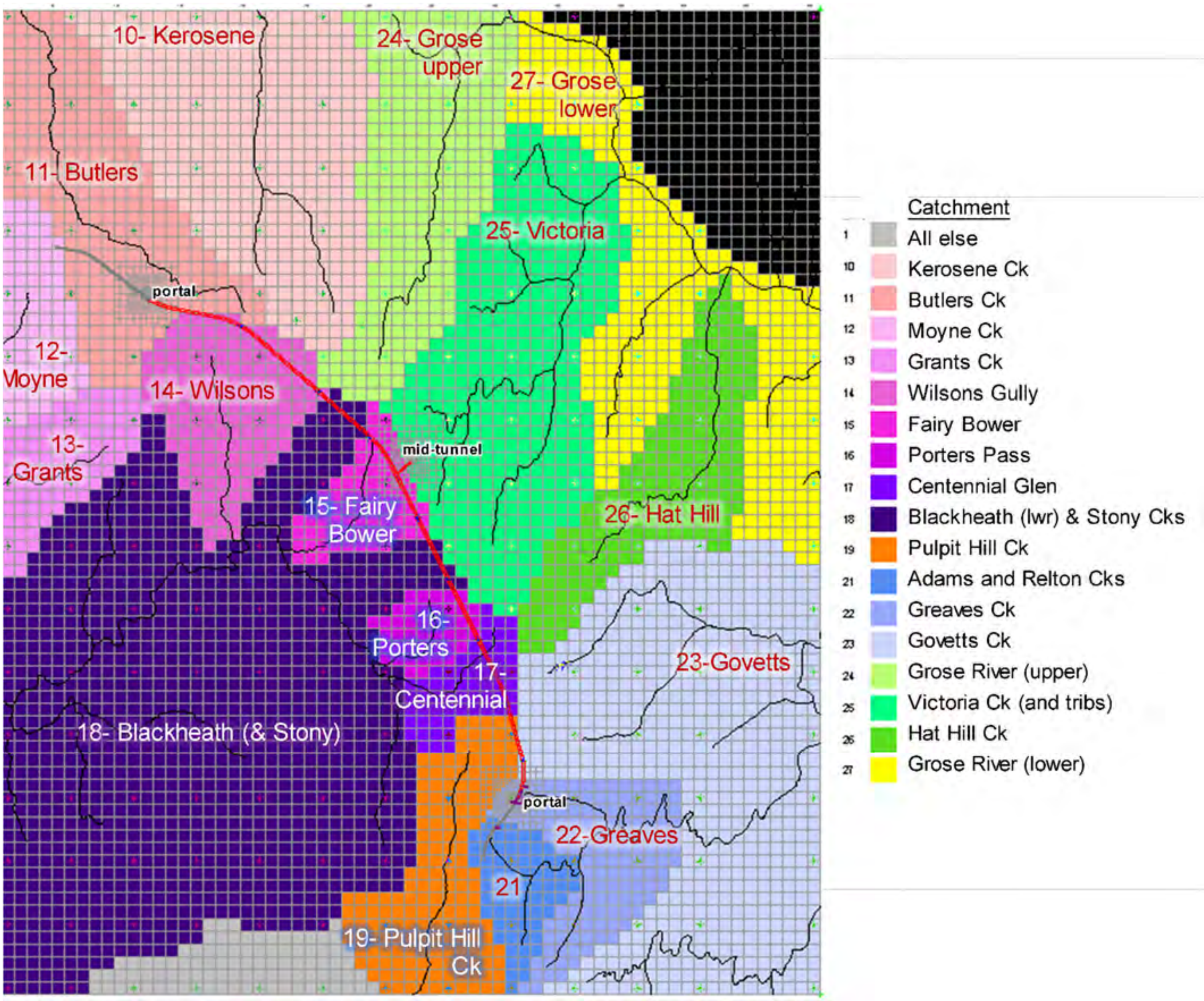

Figure 4-30 Modelled surface water sub-catchment zones

Of these sub-catchments, those numbered 10-19 flow to Coxs River, and are within the *Upper Nepean and Upstream Warragamba Water Source,* specifically the Dharabuladh Management Zone (MZ).

Sub-catchments 21-27 flow to Grose River, and are within the *Hawkesbury and Lower Nepean Rivers Water Source*, specifically the Grose River MZ.

Changes to baseflow in these sub-catchments are summarised in **Table 4-9**. The results indicate that during construction, Fairy Bower Creek and other tributaries of Blackheath Creek (flowing west from the escarpment/alignment), and Victoria Creek and Greaves Creek (flowing east) are likely to experience some reduction in baseflow as a result of the project. For most of these catchments, most of the reduction would be limited to the construction phase (associated with temporary drainage of cross-passages) and baseflow reduction impacts diminish significantly after construction has been completed.

Table 4-9 Predicted reduction in baseflow to surface water catchments in the study area

PEST: p3_forecast

Zone	Subcatch	Catchment	Area [m^2]*	%ile from ensemble	HIstorical baseflow (simulated) [m^3/d]			Change in baseflow [m3/d] during construction			Change in baseflow [m3/d] post-construction			Change in baseflow [%] during construction			Change in baseflow [%] post-construction		
					Dry/low	Average	Wet/high	Min	Average	Peak	Min	Average	Peak	Min impact vs dry	Av. impact vs av. baseflow	Max impact vs wet	Min impact vs dry	Av. impact vs av. baseflow	Max impact vs wet
1	All else	Coxs River	3,864,591	5th%ile	200	390	862	0.000	0.000	0.000	0.000	0.000	0.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1		Coxs River	3,864,591	50th%ile	302	575	1399	0.000	0.000	0.000	0.000	0.000	0.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1		Coxs River	3,864,591	95th%ile	427	862	2178	0.000	0.000	0.000	0.000	0.000	-0.001	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10	Kerosene Ck	Coxs River	16,218,165	5th%ile	2028	3370	6533	0.380	0.04	-0.01	1.67	0.96	0.44	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
10		Coxs River	16,218,165	50th%ile	2736	4727	9951	0.050	-0.05	-0.18	0.67	0.31	0.07	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10		Coxs River	16,218,165	95th%ile	3621	6680	14225	0.000	-0.33	-0.87	0.28	0.01	-0.24	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
11	Butlers Ck	Coxs River	12,058,230	5th%ile	356	951	3812	1.70	0.25	-0.7	3.45	2.71	1.79	0.5%	0.0%	0.0%	1.0%	0.3%	0.0%
11		Coxs River	12,058,230	50th%ile	415	1412	6608	-0.004	-1.32	-4.3	0.38	0.06	-0.32	0.0%	-0.1%	-0.1%	0.1%	0.0%	0.0%
11		Coxs River	12,058,230	95th%ile	429	2180	10465	-0.040	-6.38	-16.93	-3.36	-3.88	-4.53	0.0%	-0.3%	-0.2%	-0.8%	-0.2%	0.0%
12	Moyne Ck	Coxs River	3,667,204	5th%ile	-7.2	107	942	0.000	0.000	0.000	0.002	0.001	0.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
12		Coxs River	3,667,204	50th%ile	-2.7	237	1741	0.000	0.000	-0.001	0.000	0.000	-0.001	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
12		Coxs River	3,667,204	95th%ile	-4.4	577	3242	0.000	-0.004	-0.009	-0.006	-0.007	-0.008	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
13	Grants Ck	Coxs River	3,907,536	5th%ile	-7.9	93	615	0.000	0.000	0.000	0.000	0.000	0.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
13		Coxs River	3,907,536	50th%ile	1.4	177	1108	0.000	0.000	0.000	0.000	0.000	-0.001	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
13		Coxs River	3,907,536	95th%ile	-17	380	2129	0.000	-0.001	-0.002	-0.002	-0.006	-0.014	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
14	Wilsons Gully	Coxs River	6,746,089	5th%ile	493	960	2533	0.000	-1.1	-2.6	-1.76	-1.98	-2.14	0.0%	-0.1%	-0.1%	-0.4%	-0.2%	-0.1%
14		Coxs River	6,746,089	50th%ile	716	1378	3818	0.000	-3.2	-7.7	-4.14	-4.76	-5.36	0.0%	-0.2%	-0.2%	-0.6%	-0.3%	-0.1%
14		Coxs River	6,746,089	95th%ile	969	1987	5843	0.000	-8.4	-27.2	-9.17	-10.03	-10.99	0.0%	-0.4%	-0.5%	-0.9%	-0.5%	-0.2%
15	Fairy Bower	Coxs River	3,037,831	5th%ile	815	1092	1674	0.000	-3.1	-11.4	-0.97	-3.06	-6.92	0.0%	-0.3%	-0.7%	-0.1%	-0.3%	-0.4%
15		Coxs River	3,037,831	50th%ile	1067	1476	2484	0.000	-16.0	-68.3	-3.31	-9.45	-19.84	0.0%	-1.1%	-2.7%	-0.3%	-0.6%	-0.8%
15		Coxs River	3,037,831	95th%ile	1450	2134	3710	0.000	-50.8	-208.0	-12.91	-27.52	-54.22	0.0%	-2.4%	-5.6%	-0.9%	-1.3%	-1.5%
16	Porters Pass	Coxs River	1,637,700	5th%ile	593	765	1156	0.000	-0.21	-1.14	0.078	-0.70	-1.18	0.0%	0.0%	-0.1%	0.0%	-0.1%	-0.1%
16		Coxs River	1,637,700	50th%ile	866	1113	1655	0.000	-1.71	-7.72	-0.93	-3.49	-6.49	0.0%	-0.2%	-0.5%	-0.1%	-0.3%	-0.4%
16		Coxs River	1,637,700	95th%ile	1218	1610	2482	0.000	-10.89	-49.32	-5.62	-13.02	-23.47	0.0%	-0.7%	-2.0%	-0.5%	-0.8%	-0.9%
17	Centennial Glen	Coxs River	2,456,741	5th%ile	344	471	699	0.000	-0.025	-0.21	-0.18	-0.30	-0.38	0.0%	0.0%	0.0%	-0.1%	-0.1%	-0.1%
17		Coxs River	2,456,741	50th%ile	470	659	986	0.000	-0.153	-0.99	-0.55	-0.91	-1.13	0.0%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%
17		Coxs River	2,456,741	95th%ile	645	989	1553	0.000	-0.922	-3.94	-1.26	-2.24	-3.41	0.0%	-0.1%	-0.3%	-0.2%	-0.2%	-0.2%
18	Blackheath (lwr) and Stony Cks	Coxs River	45,981,172	5th%ile	2011	3709	9812	0.000	-1.38	-4.72	0.16	-1.15	-2.80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
18		Coxs River	45,981,172	50th%ile	2498	5299	14988	0.000	-5.50	-23.49	-0.43	-3.05	-7.34	0.0%	-0.1%	-0.2%	0.0%	-0.1%	0.0%
18		Coxs River	45,981,172	95th%ile	3003	8027	24327	0.000	-17.26	-75.00	-1.60	-8.49	-20.91	0.0%	-0.2%	-0.3%	-0.1%	-0.1%	-0.1%
19	Pulpit Hill Ck	Coxs River	6,775,596	5th%ile	1931	2876	4368	0.000	-0.018	-0.21	-0.20	-0.35	-0.48	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
19		Coxs River	6,775,596	50th%ile	2712	3891	5991	0.000	-0.20	-1.06	-1.12	-1.21	-1.31	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
19		Coxs River	6,775,596	95th%ile	3833	5641	8951	0.000	-0.98	-3.34	-2.96	-3.09	-3.20	0.0%	0.0%	0.0%	-0.1%	-0.1%	0.0%
21	Adams and Relton Cks	Grose River	2,754,384	5th%ile	26	201	866	0.000	0.000	-0.007	-0.01	-0.01	-0.01	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
21		Grose River	2,754,384	50th%ile	18	389	1778	0.000	-0.02	-0.09	-0.10	-0.14	-0.22	0.0%	0.0%	0.0%	-0.6%	0.0%	0.0%
21		Grose River	2,754,384	95th%ile	16	652	2892	-0.001	-0.28	-0.55	-0.39	-0.56	-0.65	0.0%	0.0%	0.0%	-2.5%	-0.1%	0.0%
22	Greaves Ck	Grose River	5,471,645	5th%ile	21	533	1703	0.000	-0.02	-0.31	-0.05	-0.19	-0.36	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%
22		Grose River	5,471,645	50th%ile	21	941	2857	-0.001	-3.17	-5.92	-3.22	-5.14	-6.07	0.0%	-0.3%	-0.2%	-15.5%	-0.5%	-0.2%
22		Grose River	5,471,645	95th%ile	62	1540	4434	-0.11	-12.36	-18.45	-10.53	-15.93	-17.93	-0.2%	-0.8%	-0.4%	-17.0%	-1.0%	-0.4%
23	Govetts Ck	Grose River	25,536,319	5th%ile	2564	6749	12619	0.000	-0.01	-0.09	0.51	0.04	-0.12	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
23		Grose River	25,536,319	50th%ile	3666	9366	18211	0.000	-0.07	-0.40	-0.25	-0.43	-0.56	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
23		Grose River	25,536,319	95th%ile	5464	13426	27812	0.000	-0.41	-1.70	-1.12	-1.44	-1.86	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
24	Grose River (upper)	Grose River	1,437,393	5th%ile	1498	2505	4488	0.27	0.02	-0.04	0.89	0.54	0.28	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
24		Grose River	1,437,393	50th%ile	1943	3484	6628	0.050	-0.02	-0.15	0.38	0.19	0.07	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
24		Grose River	1,437,393	95th%ile	2521	4894	9751	0.000	-0.14	-0.58	0.14	0.03	-0.07	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
25	Victoria Ck (and tribs)	Grose River	17,839,556	5th%ile	2610	4615	7871	0.000	-0.35	-1.97	2.47	-0.01	-1.92	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
25		Grose River	17,839,556	50th%ile	3359	6261	11377	0.000	-2.78	-11.58	0.63	-3.23	-8.57	0.0%	0.0%	-0.1%	0.0%	-0.1%	-0.1%
25		Grose River	17,839,556	95th%ile	4549	8925	17266	0.000	-14.54	-56.56	-1.00	-10.22	-21.51	0.0%	-0.2%	-0.3%	0.0%	-0.1%	-0.1%
26	Hat Hill Ck	Grose River	8,393,303	5th%ile	389	1613	3429	0.000	-0.002	-0.020	0.52	0.09	-0.03	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
26		Grose River	8,393,303	50th%ile	659	2541	5210	0.000	-0.024	-0.17	0.05	-0.13	-0.22	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
26		Grose River	8,393,303	95th%ile	1109	3829	7966	0.000	-0.23	-1.40	-0.07	-0.81	-1.43	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
27	Grose River (lower)	Grose River	26,157,369	5th%ile	1908	3498	6325	0.000	0.000	0.000	0.020	0.004	0.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
27		Grose River	26,157,369	50th%ile	2428	4652	8582	0.000	-0.002	-0.010	0.000	-0.014	-0.020	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
27		Grose River	26,157,369	95th%ile	3282	6579	12898	0.000	-0.022	-0.090	-0.010	-0.064	-0.100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Notes: *area within model domain

+ve = net postive baseflow

+ve = net increase in baseflow, -ve = reduction in baseflow due to the project

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The main exception to this is Greaves Creek (zone 22), which from the confluence with Adams and Relton Creeks (zone 21) extends quite close to the Blackheath portal (**Figure 4-30**).

The presence of this drained portal feature would capture a proportion of recharge within this catchment, and is predicted to cause a reduction in dry weather flow of approximately 15-17% (based on the 50th and 95th percentile forecasts). These potential reductions in dry weather baseflow at Greaves Creek have been discussed with ecologists and hydrologists. Smaller percentage reductions are indicated for average and high baseflow conditions.

Licensing implication of the modelled reductions in baseflow are presented in Section 4.10.

4.9 Estimated leakage from storage reservoirs

WaterNSW operates two water supply reservoirs near Blackheath: Lake Medlow (Adams and Relton Creeks) and Lake Greaves (on Greaves Creek) as labelled on **Figure 1-4**. These are included in the groundwater model as River boundary conditions (Section 2.5.5) and the change in groundwater-surface water flow for these water features has been quantified from the model ensemble. Note that this is for the specific water features, not the catchments leading to them. Changes in flux within the catchments the reservoirs are in are presented in the previous section.

Modelling indicates that losses from the reservoirs themselves as a result of the project would be:

- Lake Medlow: 95th percentile peak loss of 0.02 m^3/d during construction, with losses increasing to 0.06 m^3/d after construction, as a result of proximity (1.3 km) to the Blackheath portal.
- Lake Greaves: 95th percentile peak loss of 0.04 m^3/d during construction, with losses increasing to 0.07 m^3/d after construction, as a result of the presence of the Blackheath portal 2 km to the west and in the headwaters of Greaves Creek.

These rates of loss are negligible in isolation, and only a fraction of the model-predicted loss of baseflow to the catchments to these reservoirs presented in **Table 4-9**. Note that potential total loss of water resource for these catchments is quantified in Section 4.8, which accounts for both change in groundwater discharge (baseflow) as well as estimated increased seepage.

4.10 Water ‘take’ or capture

The AIP requires estimation of ‘take’ or groundwater and surface water captured or lost from the environment or hydrological systems.

Table 4-10 presents recommended or indicative ranges for groundwater licensing, based on the estimates of ‘take’ derived from model-predicted groundwater inflow (Section 4.5) while **Table 4-11** presents the range in surface water ‘take’ based on the baseflow reduction forecasts (Section 4.8).

These tables take into account partitioning of ‘take’ from the relevant Groundwater and Surface Water Sources and Management Zones (see **Figure 1-13** and **Figure 1-14** in Section 1.7), and these ranges have been provided to the Groundwater Technical Report (AECOM, 2022) and Surface Water Assessment (EIS Appendix J).

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Table 4-10 Indicatives takes for licensing - groundwater (shares or ML/year)

Water Source / Management Zone	Estimated Take^ (ML/yr)		Comment
	Construction	Post-construction	
Groundwater: Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011			
Sydney Basin Coxs River Groundwater Source	119 to 271*	6 to 15	Maximum groundwater take via inflow to relevant tunnel sections (Section 4.5) and partitioning to account for induced flow between zones.
Sydney Basin Blue Mountains Groundwater Source	35 to 90*	5 to 11	
* This will depend on pre-treatment options at cross-passages and further data acquisition. ^ Ranges are the annualised 50th%ile and 95th%ile maximum take.			

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The model ensemble predicts zero take from the adjacent Groundwater Sources (Sydney Basin Richmond Groundwater Source and Coxs River Fractured Rock Groundwater Source - **Figure 1-13**).

Table 4-11 Indicatives takes for licensing – surface water (shares or ML/year)

Water Source / Management Zone	Estimated Take^ (ML/yr)		Comment
	Construction	Post-construction	
Surface Water: Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011			
Upper Nepean & Upstream Warragamba Water Source – Dharabuladh MZ	41 to 139*	24 to 43	Maximum surface water take calculated from sub-catchment reductions in baseflow (Section 4.8).
Hawkesbury and Lower Nepean Rivers Water Source: Grose River MZ	10 to 29*	11 to 16	
* This will depend on pre-treatment options at cross-passages and further data acquisition. ^ Ranges are the annualised 50th%ile and 95th%ile maximum take.			

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5 Conclusions

Data from Transport's field investigations at the GWH Blackheath to Little Hartley project area has been compiled and analysed in this current study and previous studies for Transport. Conceptualisation of the data is presented in associated EIS Groundwater Technical Report documentation (AECOM, 2022) (as well as some precursor studies for Transport), and in the early sections of this document. This, combined with a review of the proposed project, has led to development of a numerical groundwater model, which is the subject of this document.

The numerical groundwater model developed uses the MODFLOW-USG-Transport software code with variable cell sizes and orientation to simulate groundwater behaviour, including drawdown in more detail around selected excavation features and in less detail via more widely spaced model cells in areas away from the project alignment. The groundwater model is used in conjunction with PEST software (specifically PESTPP-IES) to carry out history-matching and generation of 300 alternative model realisations (a model 'ensemble') to explore uncertainty.

This model has been assessed for calibration using the available dataset of targets derived from observations of groundwater levels from approximately 30 bore and piezometer locations. The model is not calibrated for fluxes, which means there is uncertainty around the forecasts of inflow to the tunnel features and other forecasts of changes to groundwater fluxes.

Rainfall recharge input to the groundwater model has also been estimated based on various estimates from analysis of field data and literature, mainly BoM's AWRA-L estimates of recharge. This parameter has been adjusted by PESTPP-IES. Other adjustable parameters are:

- River bed conductance;
- Hydraulic conductivity (Kx and Kz), via pilot points, including incorporation of identified regional geological structures which have the potential to significantly influence groundwater flow.; and
- Storage properties (Ss and Sy), via pilot points.

The forecasting model (in essence, the combination of MODFLOW-USG with PESTPP-IES and associated processing tools) provides suitable capability for assessing and quantifying potential project-related groundwater behaviour under uncertainty via the use of the ensemble. An assessment of "model confidence", as per the Australian Groundwater Modelling Guidelines, is presented in **Appendix G**.

The forecasting model focuses on construction-phase and the post-construction behaviour of the groundwater system in response to the project. The following results and information were obtained from the groundwater modelling.

Inflow is predicted by the model at the various features of the project, including the two portals, the mid-tunnel facilities and cross-passages (Section 4.5). The modelling indicates peak inflow of approximately 370 to 900 m^3/d [4 to 10 L/s] (50th and 95th percentile estimates) during construction, rising to 760-1850 m^3/d [9 to 21 L/s] if considering inflow to untreated cross-passages. Average inflow during construction is likely to be between 50 and 317 m^3/d. Following construction, inflow is projected to decline to between 24 and 70 m^3/d [i.e. up to 1 L/s].

Cross-passages at greatest risk of high inflow during construction have been identified from the modelling. The current modelling indicates that these would include XP27-38, XP77-78, and XP57-60 (see **Table 4-5**). Conceptually, the cross-passages located just above aquitards are likely to have the greatest available groundwater head, and therefore the greatest risk of high inflow. Pre-grouting may be required – although would likely be confirmed by site-specific permeability testing prior to cross-passage construction. Such treatment could influence (mitigate) inflow and drawdown and associated effects on nearby environmental features (e.g. hanging swamps).

Based on the above, a range of possible groundwater 'take' is presented in Section 4.10, although the actual take will depend in part on possible pre-treatment of cross-passages.

During construction, groundwater levels would respond to inflow and dewatering of the project, resulting in drawdown around the various 'drained' features. In most areas, drawdown would peak during or at the end of construction, and then groundwater levels are likely to recover where temporarily drained features are lined/tanked or backfilled. Groundwater levels, even around the 'drained' portals and mid-tunnel cavern, would equilibrate to an approximate steady state over time after construction.

Modelling suggests that groundwater drawdown is unlikely to exceed AIP minimal impact criterion (2 m drawdown) at any of the 65 water supply works located within the bounds of the numerical model (Section 4.6.4 and **Appendix H**). Two registered bores are identified as being at risk under the 95th percentile ("likely worst case") estimates. These findings are expected given the construction methods of the project and 3D distances to registered 'water supply' bores.

A number of EPBC- and BC-listed Threatened Ecological Communities (TECs) are located near to the Little Hartley portal, often associated with Butlers Creek which flows to the northwest from near the alignment. Modelling suggests that groundwater drawdown is unlikely to be significant or discernible at EPBC- and BC-listed TECs. Despite the low level of risk identified, further groundwater level monitoring in these areas is recommended.

A substantial number of 'Upland Swamps' (peat swamps) are located in the study area, especially on the escarpment around Blackheath and Mount Victoria. Most of these are at low to negligible risk of drawdown from the project, however a small set are predicted to experience significant drawdown, even considering the 50th percentile forecasts from the model ensemble (Section 4.6.5 and **Table 4-7**). As noted above, conceptually, this was a surprising result, and is possibly a consequence of imperfectness or a structural error of the model (e.g. layering). However, however data acquisition and monitoring are recommended in this area, with the possibility of revising modelling at some point in the future with further 'soft data' constraints (as described in Section 2.7.1) or, preferably, field-measurements to improve confidence in this prediction.

The persistent drawdown around the portals and the mid-tunnel area is predicted to result in a reduction in baseflow to some nearby surface water catchments, notably the upper part of Greaves Creek (near the Blackheath portal), Fairy Bower Creek, Victoria Creek (near the mid-tunnel cavern) and Butlers Creek (near the Little Hartley portal). Estimates of the reduction in baseflow are presented in Section 4.8. These changes to surface water flow have been used to quantify likely surface water 'take' for licensing purposes (Section 4.10).

Similarly, spring flow to hanging swamps, which are located along the escarpment to the immediate west of the alignment, is likely to be reduced. Short-lived reductions would occur during construction (mainly related to cross-passage construction), however reductions would likely persist at hanging swamp sites around the mid-tunnel cavern (Section 4.7).

5.1 Recommendations

5.1.1 Monitoring and data gathering

Recommendations for further monitoring developed from the modelling have been passed to the Groundwater Technical Report (AECOM, 2022). To avoid duplication, only a brief set of recommendations are made here, mainly regarding those that could have a bearing on potential updates to modelling.

It is also noted that additional monitoring bores are currently being installed as part of an ongoing geotechnical and hydrogeological investigation program. Recommendations for new sites, beyond that current program, are:

- Some bores are required offset from or perpendicular to the alignment, especially near the major project-related stresses (as modelled in Section 4), i.e. the mid-tunnel and portals;
- Nested monitoring bores at locations simulated as being affected by drawdown of the water table just south of the mid-tunnel facility (Sections 4.6.3 and 4.6.5 and **Figure 4-8**) are recommended, especially within/adjacent to Upland Swamps. This will provide further constraints on any revised or updated modelling, as well as monitoring during construction and operations.

However the specifics of any new sites should be determined after the current investigation program is completed and initial data is analysed.

If predicted baseflow reductions in the Fairy Bower Creek and upper Greaves Creek catchments are considered significant from an ecological or hydrological perspective, further testing of permeability should be carried out adjacent to the mid-tunnel facility and to the Blackheath Portal.

Associated with this, surface water flow gauging around the project align could further inform the impact assessment, with quantification of stream flow in Greaves Creek and estimating spring flow at hanging vegetation areas near the mid-tunnel being the priorities. With regard to the latter, there may be significant practical limitations to what can be achieved. The alternative might be to consider targeted groundwater monitoring adjacent to this hanging vegetation.

Although the risk to spring flow at this zone is considered minimal or negligible, characterisation of the source aquifer for the Hanging Swamp zone 9 (**Figure 4-29**) is prudent. This information would then allow further decisions to be made regarding investigation of this feature.

5.1.2 Modelling

A Groundwater Modelling Plan should be prepared outline potential refinement of the modelling. The timing of this should be confirmed in consultation with DPE Water. Certain elements of the hydrological system may need to be focussed on, and this plan should document how the key issues should be investigated (data acquisition and conceptualisation), and then possibly simulated in numerical model(s).

The current modelling has adopted a relatively coarse model mesh for the purpose of facilitating uncertainty analysis, and also to reflect experience on projects where tunnel alignments have changed late in the project and rendered obsolete parts of a bespoke model mesh built to explicitly represent tunnel features. As part of ongoing design development, for both environmental impacts and for technical purposes (construction), the model mesh could be improved to better represent the final tunnel design, while still retaining parameterisation from this modelling study.

Additionally, the geotechnical and groundwater monitoring programs are on-going at the time of writing. Once these are more developed, information (e.g. geological mapping, groundwater levels and permeability testing) should be incorporated into an updated conceptual and numerical model. This would include an update to model layering and geometry, a more extensive database of hydraulic properties, refined mapping of geological structures, and additional targets (observations) to constrain model calibration and inverse modelling.

The above points mean that the model could be 'refined', given that layering and mesh configuration are central to a groundwater model. That this is recommended should not be taken as criticism of the current modelling– it is an expected part of the modelling process.

Modelling would benefit from additional groundwater level targets to constrain the simulated water table position and head separation from deeper aquifer units (e.g. groundwater pressures in the Banks Wall Sandstone and Mt York Claystone) and improve confidence in predictions of water table drawdown, especially in the area to the south of the mid-tunnel facility where drawdown of the water table is predicted, but is possibly over-estimated.

Modelling would benefit from having some flux targets to constrain the calibration. The highest value would be obtaining flow data for Greaves Creek and assessing the baseflow (groundwater discharge) component of that and using this as a target. Otherwise, flux targets related to Butlers Creek and/or hanging vegetation (if it is practical and achievable to measure that) would be useful.

Aligned with the flow monitoring at Greaves Creek, aquifer testing, preferably via pumping tests rather than short duration packer testing, would be beneficial to understanding the potential drawdown around the Blackheath portal and how that might (or might not) extend into the Greaves Creek catchment.

Although it is unlikely to be affected by the project, future modelling should consider the need to have refined layer geometry and model cell geometry around the ridgeline west of Mount Victoria and Berghofers Pass/Mitchell Ridge. This should improve confidence in estimates of baseflow or spring flow reduction at Hanging Swamp zone 9 (**Figure 4-29**).

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Appendix A: Groundwater level targets

Head (groundwater level) targets from monitoring data in Table A1.

Head difference estimates from monitoring data in Table A2.

Table A1 Head targets (Aug-2022)

BoreID_piezo	Easting	Northing	Owner	MonitorGrp	GroundElev_mAHD	MaxDrilledDepth_m	AquiferMonitored	GWL_Date	GWL_mAHD	Comment	SP	ElapsedTime_d	Group	Layer_upper	Weight
BH500A	248272.3	6273356.38	TfNSW	500-series_single	1052.24	39.11	Burralow Facies / Upper Banks Wall Sst	15/12/2021	1038.31		36	5098	3	2	0.8
BH507	244259.1	6280575.33	TfNSW	500-series_single	1072	210	Burra Moko Head Sandstone (upr)	15/12/2021	1021.56		36	5098	3	7	0.8
BH103	245959	6279483.9	TfNSW	500-series_single	1030	17.3	Banks Wall Sst	15/12/2021	1020.03		36	5098	3	4	0.8
BH115	243002.3	6281003.4	TfNSW	500-series_single	862.5	17.78	Illawarra Coal Measures - Marrangaroo?	15/12/2021	854.09		36	5098	3	17	0.8
BH116	242658.1	6281014.6	TfNSW	500-series_single	891	24.34	Illawarra Coal Measures - Blackmans Congl?	15/12/2021	869.45		36	5098	3	16	0.8
BH501_33	248161.6	6273784.4	TfNSW	500-series_transient	1055.68	72.25	Banks Wall Sst	30/06/2021	1023.5		34	4930	2	4	1
BH501_33	248161.6	6273784.4	TfNSW	500-series_transient	1055.68	72.25	Banks Wall Sst	30/09/2021	1023.7		35	5022	2	4	1
BH501_33	248161.6	6273784.4	TfNSW	500-series_transient	1055.68	72.25	Banks Wall Sst	14/12/2021	1023.9		36	5097	2	4	1
BH501_49	248161.6	6273784.4	TfNSW	500-series_transient	1055.68	72.25	Banks Wall Sst	30/06/2021	1006.1		34	4930	2	4	1
BH501_49	248161.6	6273784.4	TfNSW	500-series_transient	1055.68	72.25	Banks Wall Sst	30/09/2021	1005.99		35	5022	2	4	1
BH501_49	248161.6	6273784.4	TfNSW	500-series_transient	1055.68	72.25	Banks Wall Sst	30/12/2021	1005.96		36	5113	2	4	1
BH501_49	248161.6	6273784.4	TfNSW	500-series_transient	1055.68	72.25	Banks Wall Sst	24/01/2022	1005.98		37	5138	2	4	1
BH501A_109	248121	6273740	TfNSW	500-series_transient	1055	185.21	Banks Wall Sst	29/06/2021	973.4		34	4929	2	4	1
BH501A_109	248121	6273740	TfNSW	500-series_transient	1055	185.21	Banks Wall Sst	6/08/2021	973.2		35	4967	2	4	1
BH501A_124	248121	6273740	TfNSW	500-series_transient	1055	185.21	Mt York Claystone	29/06/2021	938.3		34	4929	2	6	1
BH501A_124	248121	6273740	TfNSW	500-series_transient	1055	185.21	Mt York Claystone	6/08/2021	938.0		35	4967	2	6	1
BH501A_170	248121	6273740	TfNSW	500-series_transient	1055	185.21	Burra Moko Head Sandstone (lwr)	29/06/2021	932.9		34	4929	2	8	1
BH501A_170	248121	6273740	TfNSW	500-series_transient	1055	185.21	Burra Moko Head Sandstone (lwr)	6/08/2021	932.8		35	4967	2	8	1
BH504_47	246538	6278422	TfNSW	500-series_transient	1032	105.42	Banks Wall Sst	30/06/2021	1000.1		34	4930	2	4	1
BH504_47	246538	6278422	TfNSW	500-series_transient	1032	105.42	Banks Wall Sst	30/09/2021	1000.9		35	5022	2	4	1
BH504_47	246538	6278422	TfNSW	500-series_transient	1032	105.42	Banks Wall Sst	31/12/2021	1001.6		36	5114	2	4	1
BH504_47	246538	6278422	TfNSW	500-series_transient	1032	105.42	Banks Wall Sst	31/03/2022	1002.1		37	5204	2	4	1
BH504_47	246538	6278422	TfNSW	500-series_transient	1032	105.42	Banks Wall Sst	9/05/2022	1002.6		38	5243	2	4	1
BH504_50	246538	6278422	TfNSW	500-series_transient	1032	105.42	Mt York Claystone	30/06/2021	992.00		34	4930	2	6	1
BH504_50	246538	6278422	TfNSW	500-series_transient	1032	105.42	Mt York Claystone	30/09/2021	992.30		35	5022	2	6	1
BH504_50	246538	6278422	TfNSW	500-series_transient	1032	105.42	Mt York Claystone	31/12/2021	992.90		36	5114	2	6	1
BH504_50	246538	6278422	TfNSW	500-series_transient	1032	105.42	Mt York Claystone	31/03/2022	993.30		37	5204	2	6	1
BH504_50	246538	6278422	TfNSW	500-series_transient	1032	105.42	Mt York Claystone	9/05/2022	994.10		38	5243	2	6	1
BH504_85	246538	6278422	TfNSW	500-series_transient	1032	105.42	Burra Moko Head Sst	30/06/2021	948.7	high importance	34	4930	2	7	**10**
BH504_85	246538	6278422	TfNSW	500-series_transient	1032	105.42	Burra Moko Head Sst	30/09/2021	947.3	high importance	35	5022	2	7	**10**
BH504_85	246538	6278422	TfNSW	500-series_transient	1032	105.42	Burra Moko Head Sst	31/12/2021	946.8	just below piezo	36	5114	2	7	0.8
BH504_85	246538	6278422	TfNSW	500-series_transient	1032	105.42	Burra Moko Head Sst	31/03/2022	946.8	just below piezo	37	5204	2	7	0.8
BH504_85	246538	6278422	TfNSW	500-series_transient	1032	105.42	Burra Moko Head Sst	9/05/2022	947.3	high importance	38	5243	2	7	**10**
BH505_26.5	246026	6279426	TfNSW	500-series_transient	1035	132.36	Banks Wall Sst	30/06/2021	1009.6	high importance	34	4930	2	4	**10**
BH505_26.5	246026	6279426	TfNSW	500-series_transient	1035	132.36	Banks Wall Sst	30/09/2021	1013.2		35	5022	2	4	1
BH505_26.5	246026	6279426	TfNSW	500-series_transient	1035	132.36	Banks Wall Sst	31/12/2021	1013.6		36	5114	2	4	1
BH505_26.5	246026	6279426	TfNSW	500-series_transient	1035	132.36	Banks Wall Sst	31/03/2022	1014.9		37	5204	2	4	1
BH505_26.5	246026	6279426	TfNSW	500-series_transient	1035	132.36	Banks Wall Sst	16/05/2022	1015.2		38	5250	2	4	1
BH505_36	246026	6279426	TfNSW	500-series_transient	1035	132.36	Mt York Claystone	30/06/2021	1008.5		34	4930	2	6	1
BH505_36	246026	6279426	TfNSW	500-series_transient	1035	132.36	Mt York Claystone	30/09/2021	1011.5		35	5022	2	6	1
BH505_36	246026	6279426	TfNSW	500-series_transient	1035	132.36	Mt York Claystone	31/12/2021	1011.8		36	5114	2	6	1
BH505_36	246026	6279426	TfNSW	500-series_transient	1035	132.36	Mt York Claystone	31/03/2022	1012.9		37	5204	2	6	1
BH505_36	246026	6279426	TfNSW	500-series_transient	1035	132.36	Mt York Claystone	16/05/2022	1013		38	5250	2	6	1
BH505_86	246026	6279426	TfNSW	500-series_transient	1035	132.36	Burra Moko Head Sandstone (lwr)	30/06/2021	964.3		34	4930	2	8	1
BH505_86	246026	6279426	TfNSW	500-series_transient	1035	132.36	Burra Moko Head Sandstone (lwr)	30/09/2021	964.2		35	5022	2	8	1
BH505_86	246026	6279426	TfNSW	500-series_transient	1035	132.36	Burra Moko Head Sandstone (lwr)	31/12/2021	964.3		36	5114	2	8	1
BH505_86	246026	6279426	TfNSW	500-series_transient	1035	132.36	Burra Moko Head Sandstone (lwr)	31/03/2022	964.6		37	5204	2	8	1
BH505_86	246026	6279426	TfNSW	500-series_transient	1035	132.36	Burra Moko Head Sandstone (lwr)	16/05/2022	964.8		38	5250	2	8	1
BH505_117	246026	6279426	TfNSW	500-series_transient	1035	132.36	Caley Fm	30/06/2021	948.3		34	4930	2	10	1
BH505_117	246026	6279426	TfNSW	500-series_transient	1035	132.36	Caley Fm	30/09/2021	948.1		35	5022	2	10	1
BH505_117	246026	6279426	TfNSW	500-series_transient	1035	132.36	Caley Fm	31/12/2021	948.3		36	5114	2	10	1
BH505_117	246026	6279426	TfNSW	500-series_transient	1035	132.36	Caley Fm	31/03/2022	948.5		37	5204	2	10	1
BH505_117	246026	6279426	TfNSW	500-series_transient	1035	132.36	Caley Fm	16/05/2022	948.6		38	5250	2	10	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	30/12/2009	1029.1		1	730	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	30/03/2010	1030.0		2	820	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	29/06/2010	1029.8		3	911	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	29/09/2010	1029.9		4	1003	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	30/12/2010	1032.2		5	1095	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	30/03/2011	1032.3		6	1185	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	29/06/2011	1031.6		7	1276	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	29/09/2011	1031.3		8	1368	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	30/12/2011	1032.0		9	1460	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	30/03/2012	1034.3		10	1551	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	29/06/2012	1032.3		11	1642	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	29/09/2012	1030.8		12	1734	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	30/12/2012	1029.4		13	1826	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	30/03/2013	1031.0		14	1916	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	29/06/2013	1029.8		15	2007	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	29/09/2013	1029.6		16	2099	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	30/12/2013	1029.2		17	2191	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	30/03/2014	1029.6		18	2281	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	29/06/2014	1030.0		19	2372	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	29/09/2014	1029.1		20	2464	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	30/12/2014	1029.4		21	2556	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	30/03/2015	1030.6		22	2646	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	29/06/2015	1030.9		23	2737	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	29/09/2015	1029.7		24	2829	1	6	1
G4025_BH1	245552.9	6280505.1	TfNSW	G4-series_transient	1046.6	29.74	Mt York Claystone	20/10/2015	1029.4		25	2850	1	6	1
G4025_BH2	245477.7	6280694.6	TfNSW	G4-series_transient	1038.1	14.48	Banks Wall Sst	30/12/2009	1029.1		1	730	1	4	1
G4025_BH2	245477.7	6280694.6	TfNSW	G4-series_transient	1038.1	14.48	Banks Wall Sst	30/03/2010	1031.3		2	820	1	4	1
G4025_BH2	245477.7	6280694.6	TfNSW	G4-series_transient	1038.1	14.48	Banks Wall Sst	29/06/2010	1029.9		3	911	1	4	1
G4025_BH2	245477.7	6280694.6	TfNSW	G4-series_transient	1038.1	14.48	Banks Wall Sst	29/09/2010	1030.2		4	1003	1	4	1
G4025_BH2	245477.7	6280694.6	TfNSW	G4-series_transient	1038.1	14.48	Banks Wall Sst	30/12/2010	1032.5		5	1095	1	4	1
G4025_BH2	245477.7	6280694.6	TfNSW	G4-series_transient	1038.1	14.48	Banks Wall Sst	30/03/2011	1032.2		6	1185	1	4	1
G4025_BH2	245477.7	6280694.6	TfNSW	G4-series_transient	1038.1	14.48	Banks Wall Sst	29/06/2011	1031.4		7	1276	1	4	1
G4025_BH2	245477.7	6280694.6	TfNSW	G4-series_transient	1038.1	14.48	Banks Wall Sst	29/09/2011	1032.0		8	1368	1	4	1
G4025_BH2	245477.7	6280694.6	TfNSW	G4-series_transient	1038.1	14.48	Banks Wall Sst	30/12/2011	1032.5		9	1460	1	4	1
G4025_BH2	245477.7	6280694.6	TfNSW	G4-series_transient	1038.1	14.48	Banks Wall Sst	30/03/2012	1033.8		10	1551	1	4	1
G4025_BH2	245477.7	6280694.6	TfNSW	G4-series_transient	1038.1	14.48	Banks Wall Sst	29/06/2012	1032.3		11	1642	1	4	1
G4025_BH2	245477.7	6280694.6	TfNSW	G4-series_transient	1038.1	14.48	Banks Wall Sst	27/09/2012	1030.7		12	1732	1	4	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	30/12/2009	889.3		1	730	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	30/03/2010	889.2		2	820	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	29/06/2010	889.1	suspect data	3	911	1	15	0
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	29/09/2010	889.1	suspect data	4	1003	1	15	0
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	30/12/2010	889.1	suspect data	5	1095	1	15	0
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	30/03/2011	889.3		6	1185	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	29/06/2011	889.4		7	1276	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	29/09/2011	889.5		8	1368	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	30/12/2011	889.4		9	1460	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	30/03/2012	890.5		10	1551	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	29/06/2012	890.4		11	1642	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	29/09/2012	889.9		12	1734	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	30/12/2012	889.5		13	1826	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	30/03/2013	889.9		14	1916	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	29/06/2013	889.6		15	2007	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	29/09/2013	889.6		16	2099	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	30/12/2013	889.3		17	2191	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	30/03/2014	889.1	suspect data	18	2281	1	15	0
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	29/06/2014	889.1	suspect data	19	2372	1	15	0
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	29/09/2014	889.1	suspect data	20	2464	1	15	0
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	30/12/2014	889.1	suspect data	21	2556	1	15	0
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	30/03/2015	889.1	suspect data	22	2646	1	15	0
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	29/06/2015	889.5		23	2737	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	29/09/2015	889.4		24	2829	1	15	1
G4025_BH4	243488.3	6281050.1	TfNSW	G4-series_transient	908.93	19.95	Long Swamp Fm	20/10/2015	889.3		25	2850	1	15	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	30/12/2009	872.8		1	730	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	30/03/2010	874.9		2	820	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	29/06/2010	874.5		3	911	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	29/09/2010	874.8		4	1003	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	30/12/2010	875.7		5	1095	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	30/03/2011	874.8		6	1185	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	29/06/2011	873.4		7	1276	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	29/09/2011	873.4		8	1368	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	30/12/2011	873.4		9	1460	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	30/03/2012	877.2		10	1551	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	29/06/2012	875.0		11	1642	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	29/09/2012	873.8		12	1734	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	30/12/2012	873.1		13	1826	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	30/03/2013	874.5		14	1916	1	17	1

BoreID_piezo	Easting	Northing	Owner	MonitorGrp	GroundElev_mAHD	MaxDrilledDepth_m	AquiferMonitored	GWL_Date	GWL_mAHD	Comment	SP	ElapsedTime_d	Group	Layer_upper	Weight
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	29/06/2013	874.2		15	2007	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	29/09/2013	873.6		16	2099	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	30/12/2013	873.2		17	2191	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	30/03/2014	873.2		18	2281	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	29/06/2014	873.7		19	2372	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	29/09/2014	873.6		20	2464	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	30/12/2014	873.5		21	2556	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	30/03/2015	873.8		22	2646	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	29/06/2015	873.9		23	2737	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	29/09/2015	873.6		24	2829	1	17	1
G4025_BH5	243448.9	6281052.4	TfNSW	G4-series_transient	891.46	24.85	Marrangaroo/Gundangaroo	20/10/2015	873.5		25	2850	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	30/12/2009	871.3		1	730	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	30/03/2010	871.3		2	820	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	29/06/2010	871.2		3	911	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	29/09/2010	871.3		4	1003	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	30/12/2010	871.3		5	1095	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	30/03/2011	871.3		6	1185	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	29/06/2011	871.3		7	1276	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	29/09/2011	871.3		8	1368	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	30/12/2011	871.3		9	1460	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	30/03/2012	871.5		10	1551	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	29/06/2012	871.6		11	1642	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	29/09/2012	871.6		12	1734	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	30/12/2012	871.6		13	1826	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	30/03/2013	871.6		14	1916	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	29/06/2013	871.7		15	2007	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	29/09/2013	871.7		16	2099	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	30/12/2013	871.7		17	2191	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	30/03/2014	871.6		18	2281	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	29/06/2014	871.6		19	2372	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	29/09/2014	871.6		20	2464	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	30/12/2014	871.5		21	2556	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	30/03/2015	871.5		22	2646	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	29/06/2015	871.5		23	2737	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	29/09/2015	871.5		24	2829	1	17	1
G4025_BH8	243343	6280976.9	TfNSW	G4-series_transient	894.34	25.55	Gundangaroo or Coorongooba	20/10/2015	871.5		25	2850	1	17	1
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	30/12/2009	885.0	dry	1	730	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	30/03/2010	885.0	dry	2	820	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	29/06/2010	885.0	dry	3	911	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	29/09/2010	885.0	dry	4	1003	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	30/12/2010	885.6		5	1095	1	15	1
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	30/03/2011	885.0	dry	6	1185	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	29/06/2011	885.0	dry	7	1276	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	29/09/2011	885.2		8	1368	1	15	1
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	30/12/2011	885.0	dry	9	1460	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	30/03/2012	885.5		10	1551	1	15	1
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	29/06/2012	885.0	dry	11	1642	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	27/09/2012	885.0	dry	12	1732	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	30/12/2012	885.0	dry	13	1826	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	30/03/2013	886.0		14	1916	1	15	1
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	29/06/2013	885.5		15	2007	1	15	1
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	29/09/2013	885.0	dry	16	2099	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	30/12/2013	885.0	dry	17	2191	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	30/03/2014	885.0	dry	18	2281	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	29/06/2014	885.0	dry	19	2372	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	29/09/2014	885.0	dry	20	2464	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	30/12/2014	885.0	dry	21	2556	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	30/03/2015	885.0	dry	22	2646	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	29/06/2015	885.0	dry	23	2737	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	29/09/2015	885.0	dry	24	2829	1	15	0
G4025_BH9	243171.5	6280945.9	TfNSW	G4-series_transient	896.8	12	Long Swamp Fm	20/10/2015	885.0	dry	25	2850	1	15	0
PGR_B1	248826	6275178	BMCC	Swamp	1022.9	<3	Swamp	30/09/2019	1022.6		29	4291	4	1	1
PGR_B1	248826	6275178	BMCC	Swamp	1022.9	<3	Swamp	31/12/2019	1021.9		30	4383	4	1	1
PGR_B1	248826	6275178	BMCC	Swamp	1022.9	<3	Swamp	15/03/2020	1022.6		32	4458	4	1	1
PGR_B3	248897	6275193	BMCC	Swamp	1019.5	<3	Swamp	30/09/2019	1019.4		29	4291	4	1	1
PGR_B3	248897	6275193	BMCC	Swamp	1019.5	<3	Swamp	31/12/2019	1018.3		30	4383	4	1	1
PGR_B3	248897	6275193	BMCC	Swamp	1019.5	<3	Swamp	15/03/2020	1019.4		32	4458	4	1	1
PGR_B4	248924	6275215	BMCC	Swamp	1019	<3	Swamp	30/09/2019	1018.9		29	4291	4	1	1
PGR_B4	248924	6275215	BMCC	Swamp	1019	<3	Swamp	31/12/2019	1018.0		30	4383	4	1	1
PGR_B4	248924	6275215	BMCC	Swamp	1019	<3	Swamp	15/03/2020	1018.8		32	4458	4	1	1
PGR_B5	248935	6275203	BMCC	Swamp	1016.3	<3	Swamp	30/09/2019	1016.1		29	4291	4	1	1
PGR_B5	248935	6275203	BMCC	Swamp	1016.3	<3	Swamp	31/12/2019	-	??	30	4383	4	1	0
PGR_B5	248935	6275203	BMCC	Swamp	1016.3	<3	Swamp	15/03/2020	-	??	32	4458	4	1	0
PGR_B6	248982	6275213	BMCC	Swamp	1013.7	<3	Swamp	30/09/2019	1013.6		29	4291	4	1	1
PGR_B6	248982	6275213	BMCC	Swamp	1013.7	<3	Swamp	31/12/2019	1012.5		30	4383	4	1	1
PGR_B6	248982	6275213	BMCC	Swamp	1013.7	<3	Swamp	15/03/2020	1013.6		32	4458	4	1	1
GC1	248955	6273076	TFNSW	Swamp	1010	1.5	Swamp	31/12/2021	1008.2		36	5114	4	1	1
GC2	249473	6272907	TFNSW	Swamp	976	1.5	Swamp	31/12/2021	974.01		36	5114	4	1	1
GCP2	251540	6272220	BMCC	Swamp	917	<3	Swamp	27/03/2021	917	false zeroes?	33	4835	4	1	0
GCP1	251450	6271900	BMCC	Swamp	951	<3	Swamp	27/03/2021	951.31		33	4835	4	1	1
											E:\WSHED\PROJ\GWH\Model\Construction\Targets\[MonitoringBoreDetails.xls]Targets_HDS				

Table A2 Vertical head difference targets

BoreID_piezo_1	BoreID_piezo_2	Depth_1	Depth_2	Head_1	Head_2	TargetName	Easting_1	Northing_1	Elapsed_d	vDiff_m	Layer_1	Weighting	Layer_2	Date
BH501A_109	BH501A_124	109	124	973.4	938.3	**BH501A_0406**	248121	6273740	4929	**35.1**	4	1	6	30/06/2021
BH501A_109	BH501A_124	109	124	973.2	938.0	**BH501A_0406**	248121	6273740	4967	**35.2**	4	1	6	7/08/2021
BH501A_124	BH501A_170	124	170	938.3	932.9	**BH501A_0608**	248121	6273740	4929	**5.4**	6	1	8	30/06/2021
BH501A_124	BH501A_170	124	170	938	932.8	**BH501A_0608**	248121	6273740	4967	**5.2**	6	1	8	7/08/2021
BH504_47	BH504_50	47	50	1000.1	992.0	**BH504_0406**	246538	6278422	4930	**8.1**	4	1	6	1/07/2021
BH504_47	BH504_50	47	50	1000.9	992.3	**BH504_0406**	246538	6278422	5022	**8.6**	4	1	6	1/10/2021
BH504_50	BH504_85	50	85	992.0	948.7	**BH504_0607**	246538	6278422	4930	**43.3**	6	1	7	1/07/2021
BH504_50	BH504_85	50	85	992.3	947.3	**BH504_0607**	246538	6278422	5022	**45**	6	1	7	1/10/2021
BH505_26.5	BH505_36	26.5	36	1009.6	1008.5	**BH505_0406**	246026	6279426	4930	**1.1**	4	1	6	1/07/2021
BH505_26.5	BH505_36	26.5	36	1013.2	1011.5	**BH505_0406**	246026	6279426	5022	**1.7**	4	1	6	1/10/2021
BH505_36	BH505_86	36	86	1008.5	964.3	**BH505_0608**	246026	6279426	4930	**44.2**	6	1	8	1/07/2021
BH505_36	BH505_86	36	86	1011.5	964.2	**BH505_0608**	246026	6279426	5022	**47.3**	6	1	8	1/10/2021
BH505_86	BH505_117	86	117	964.3	948.3	**BH505_0810**	246026	6279426	4930	**16**	8	1	10	1/07/2021
BH505_86	BH505_117	86	117	964.2	948.1	**BH505_0810**	246026	6279426	5022	**16.1**	8	1	10	1/10/2021

E:\WSHED\PROJ\GWH\Model\Construction\Targets\[MonitoringBoreDetails.xls]Targets_vDiff

Appendix B: Variation in packer test permeability

Packer testing data from site, prior to Aug-2022 on the following charts**.**

Summary of GWH B2LH packer testing: by depth and straigraphic unit

E:\WSHED\PROJ\GWH\Tech\AquiferProperties\[Packer_Test_Data2.xlsx]Final Summary Table

Appendix C: Model stress period schedule

Model stress period schedule

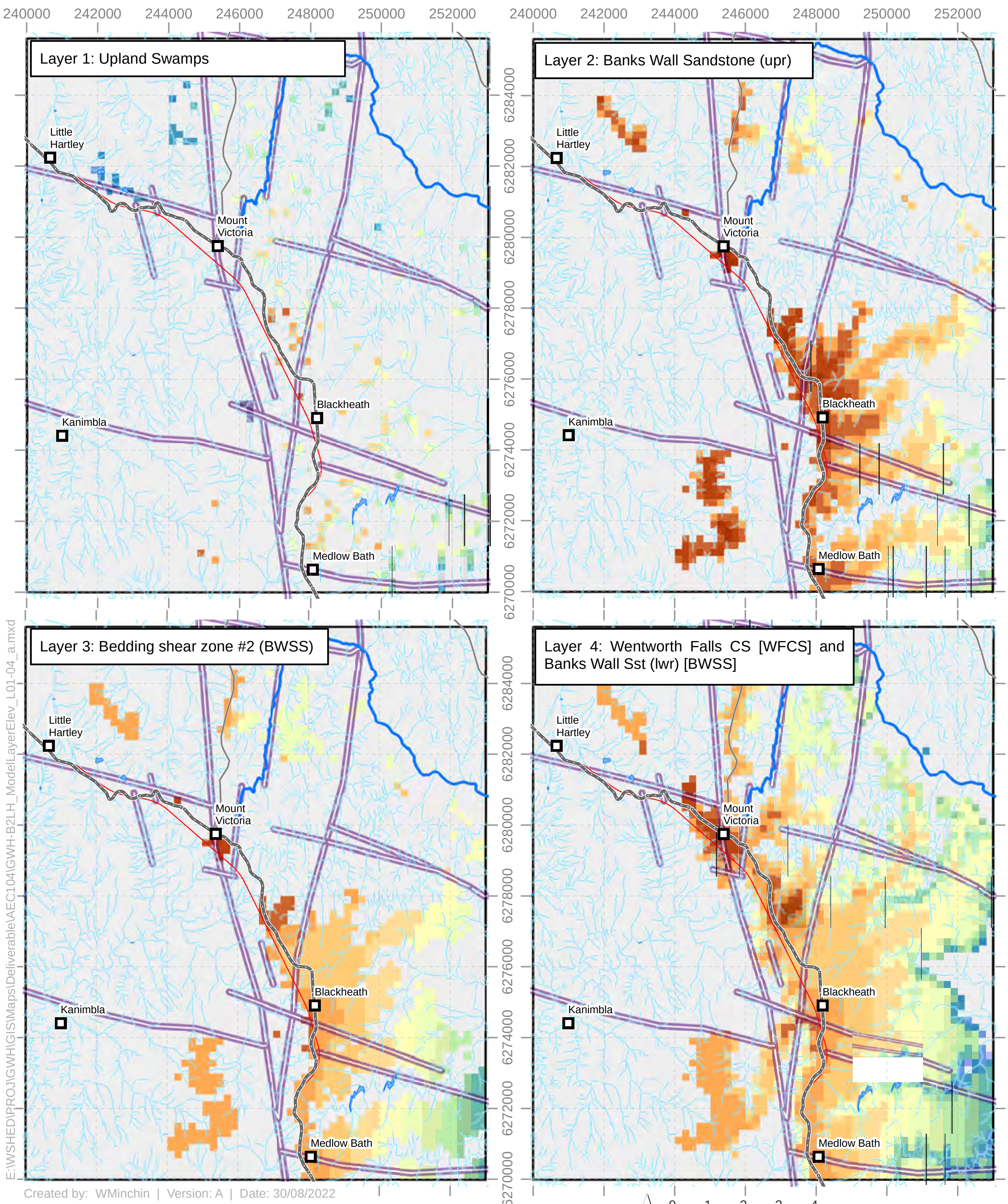
SP	DateStart	DateEnd	Length	Steady State or Transient	No. of timesteps	Elapsed time (d)	Comment
1	1/01/2008	31/12/2009	731	SS	1	731	Initialising in steady state
2	1/01/2010	31/03/2010	90	TR	2	821	Commence transient
3	1/04/2010	30/06/2010	91	TR	2	912	historical period
4	1/07/2010	30/09/2010	92	TR	2	1004	
5	1/10/2010	31/12/2010	92	TR	2	1096	
6	1/01/2011	31/03/2011	90	TR	2	1186	
7	1/04/2011	30/06/2011	91	TR	2	1277	
8	1/07/2011	30/09/2011	92	TR	2	1369	
9	1/10/2011	31/12/2011	92	TR	2	1461	
10	1/01/2012	31/03/2012	91	TR	2	1552	
11	1/04/2012	30/06/2012	91	TR	2	1643	
12	1/07/2012	30/09/2012	92	TR	2	1735	
13	1/10/2012	31/12/2012	92	TR	2	1827	
14	1/01/2013	31/03/2013	90	TR	2	1917	
15	1/04/2013	30/06/2013	91	TR	2	2008	
16	1/07/2013	30/09/2013	92	TR	2	2100	
17	1/10/2013	31/12/2013	92	TR	2	2192	
18	1/01/2014	31/03/2014	90	TR	2	2282	
19	1/04/2014	30/06/2014	91	TR	2	2373	
20	1/07/2014	30/09/2014	92	TR	2	2465	
21	1/10/2014	31/12/2014	92	TR	2	2557	
22	1/01/2015	31/03/2015	90	TR	2	2647	
23	1/04/2015	30/06/2015	91	TR	2	2738	
24	1/07/2015	30/09/2015	92	TR	2	2830	
25	1/10/2015	31/12/2015	92	TR	2	2922	
26	1/01/2016	31/12/2016	366	TR	4	3288	
27	1/01/2017	31/12/2017	365	TR	4	3653	
28	1/01/2018	31/12/2018	365	TR	4	4018	
29	1/01/2019	30/09/2019	273	TR	4	4291	
30	1/10/2019	31/12/2019	92	TR	4	4383	
31	1/01/2020	29/02/2020	60	TR	4	4443	
32	1/03/2020	31/12/2020	306	TR	6	4749	
33	1/01/2021	31/03/2021	90	TR	2	4839	
34	1/04/2021	30/06/2021	91	TR	2	4930	
35	1/07/2021	30/09/2021	92	TR	2	5022	
36	1/10/2021	31/12/2021	92	TR	2	5114	
37	1/01/2022	31/03/2022	90	TR	2	5204	
38	1/04/2022	30/06/2022	91	TR	2	5295	End historical period.
39	1/07/2022	30/09/2022	92	TR	2	5387	Commence forecast
40	1/10/2022	31/12/2022	92	TR	2	5479	period.
41	1/01/2023	31/12/2023	365	TR	4	5844	
42	1/01/2024	29/02/2024	60	TR	2	5904	
43	1/03/2024	30/04/2024	61	TR	2	5965	
44	1/05/2024	30/06/2024	61	TR	2	6026	
45	1/07/2024	31/07/2024	31	TR	2	6057	
46	1/08/2024	31/08/2024	31	TR	2	6088	
47	1/09/2024	30/09/2024	30	TR	2	6118	
48	1/10/2024	31/10/2024	31	TR	2	6149	
49	1/11/2024	30/11/2024	30	TR	2	6179	
50	1/12/2024	31/12/2024	31	TR	2	6210	
51	1/01/2025	31/01/2025	31	TR	2	6241	
52	1/02/2025	28/02/2025	28	TR	2	6269	
53	1/03/2025	31/03/2025	31	TR	2	6300	
54	1/04/2025	30/04/2025	30	TR	2	6330	
55	1/05/2025	31/05/2025	31	TR	2	6361	
56	1/06/2025	30/06/2025	30	TR	2	6391	
57	1/07/2025	31/07/2025	31	TR	2	6422	
58	1/08/2025	31/08/2025	31	TR	2	6453	
59	1/09/2025	30/09/2025	30	TR	2	6483	
60	1/10/2025	31/10/2025	31	TR	2	6514	
61	1/11/2025	30/11/2025	30	TR	2	6544	
62	1/12/2025	31/12/2025	31	TR	2	6575	
63	1/01/2026	31/01/2026	31	TR	2	6606	
64	1/02/2026	28/02/2026	28	TR	2	6634	
65	1/03/2026	31/03/2026	31	TR	2	6665	
66	1/04/2026	30/04/2026	30	TR	2	6695	
67	1/05/2026	31/05/2026	31	TR	2	6726	
68	1/06/2026	30/06/2026	30	TR	2	6756	
69	1/07/2026	31/07/2026	31	TR	2	6787	
70	1/08/2026	31/08/2026	31	TR	2	6818	

Model stress period schedule

SP	DateStart	DateEnd	Length	Steady State or Transient	No. of timesteps	Elapsed time (d)	Comment
71	1/09/2026	30/09/2026	30	TR	2	6848	
72	1/10/2026	31/10/2026	31	TR	2	6879	
73	1/11/2026	30/11/2026	30	TR	2	6909	
74	1/12/2026	31/12/2026	31	TR	2	6940	
75	1/01/2027	31/01/2027	31	TR	2	6971	
76	1/02/2027	28/02/2027	28	TR	2	6999	
77	1/03/2027	31/03/2027	31	TR	2	7030	
78	1/04/2027	30/04/2027	30	TR	2	7060	
79	1/05/2027	31/05/2027	31	TR	2	7091	
80	1/06/2027	30/06/2027	30	TR	2	7121	
81	1/07/2027	31/07/2027	31	TR	2	7152	
82	1/08/2027	31/08/2027	31	TR	2	7183	
83	1/09/2027	30/09/2027	30	TR	2	7213	
84	1/10/2027	31/10/2027	31	TR	2	7244	
85	1/11/2027	30/11/2027	30	TR	2	7274	
86	1/12/2027	31/12/2027	31	TR	2	7305	
87	1/01/2028	31/01/2028	31	TR	2	7336	
88	1/02/2028	29/02/2028	29	TR	2	7365	
89	1/03/2028	31/03/2028	31	TR	2	7396	
90	1/04/2028	30/04/2028	30	TR	2	7426	
91	1/05/2028	31/05/2028	31	TR	2	7457	
92	1/06/2028	30/06/2028	30	TR	2	7487	
93	1/07/2028	31/07/2028	31	TR	2	7518	
94	1/08/2028	31/08/2028	31	TR	2	7549	
95	1/09/2028	30/09/2028	30	TR	2	7579	
96	1/10/2028	31/10/2028	31	TR	2	7610	
97	1/11/2028	30/11/2028	30	TR	2	7640	
98	1/12/2028	31/12/2028	31	TR	2	7671	
99	1/01/2029	31/01/2029	31	TR	2	7702	
100	1/02/2029	28/02/2029	28	TR	2	7730	
101	1/03/2029	31/03/2029	31	TR	2	7761	
102	1/04/2029	30/04/2029	30	TR	2	7791	
103	1/05/2029	31/05/2029	31	TR	2	7822	
104	1/06/2029	30/06/2029	30	TR	2	7852	
105	1/07/2029	31/07/2029	31	TR	2	7883	
106	1/08/2029	31/08/2029	31	TR	2	7914	
107	1/09/2029	30/09/2029	30	TR	2	7944	
108	1/10/2029	31/10/2029	31	TR	2	7975	
109	1/11/2029	30/11/2029	30	TR	2	8005	
110	1/12/2029	31/12/2029	31	TR	2	8036	
111	1/01/2030	31/03/2030	90	TR	2	8126	"drought" for prediction (0)
112	1/04/2030	30/06/2030	91	TR	2	8217	
113	1/07/2030	30/09/2030	92	TR	2	8309	
114	1/10/2030	31/12/2030	92	TR	2	8401	
115	1/01/2031	31/12/2031	365	TR	4	8766	
116	1/01/2032	31/12/2032	366	TR	4	9132	
117	1/01/2033	31/12/2033	365	TR	4	9497	
118	1/01/2034	31/12/2034	365	TR	4	9862	"drought year" for prediction (x0.2)
119	1/01/2035	31/12/2039	1826	TR	4	11688	
120	1/01/2040	31/12/2049	3653	TR	4	15341	
121	1/01/2050	1/01/2130	29220	TR	10	44561	End forecast period [100-year design life]

E:\WSHED\PROJ\GWH\Model\Construction\Time\[StressPeriods_GWHV3.xlsx]StressPer

Appendix D: Model layer extent and boundary conditions



Created by: WMinchin | Version: A | Date: 30/08/2022

GWHC Alignment
Creek
Geological structure (significant)
Model extent
Model no flow (inactive/pinch-out)

0 1 2 3 4 km

Scale: 142,879 @A4
GDA2020 MGA Zone 56

WATERSHED HYDROGEO

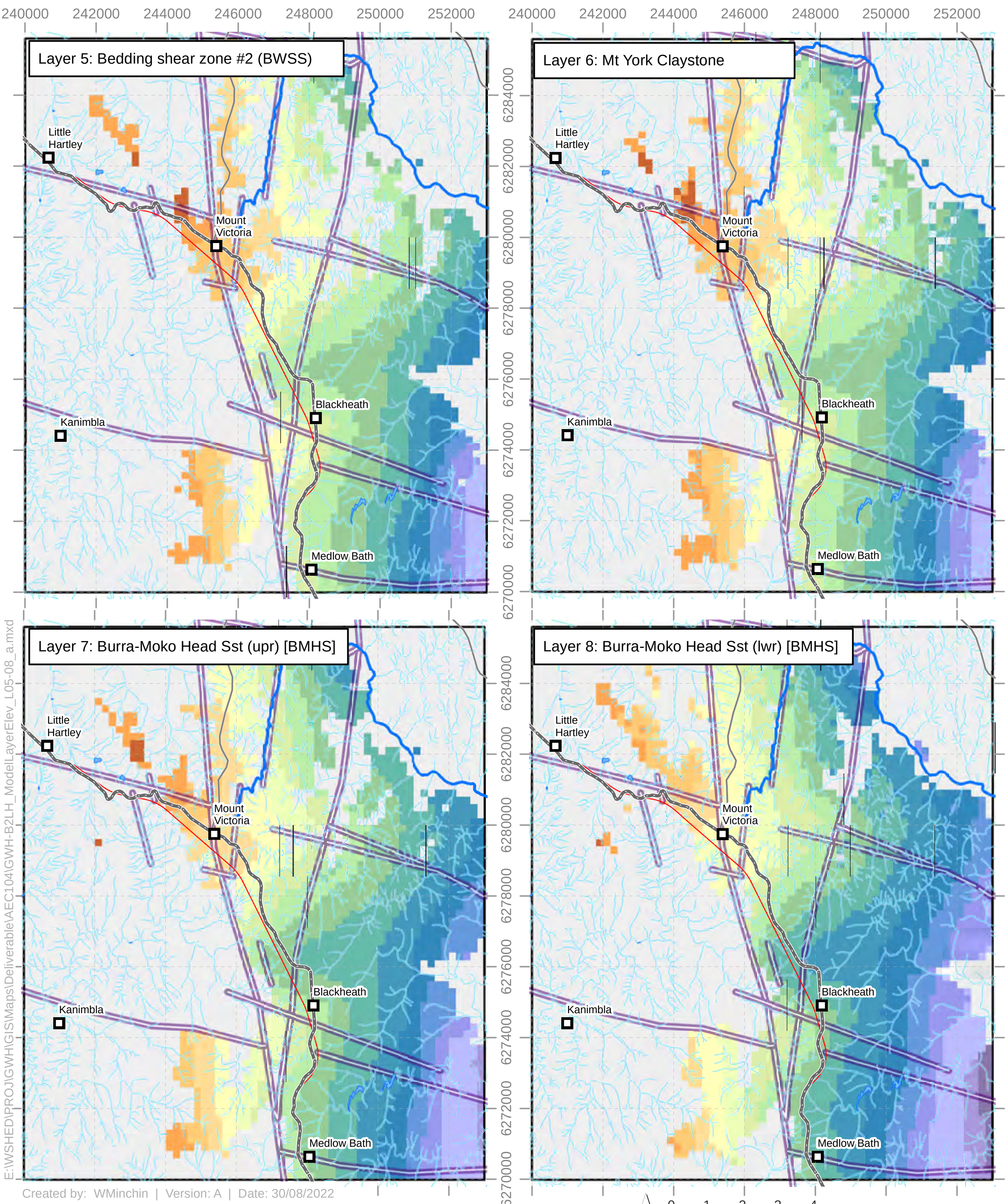
GWH-B2LH

Top elevation [mAHD]

< 700, 701 - 720, 721 - 740, 741 - 780, 781 - 800, 801 - 820, 821 - 840, 841 - 860, 861 - 880, 881 - 900, 901 - 920, 921 - 940, 941 - 960, 961 - 980, 981 - 1000, 1001 - 1020, 1021 - 1040, 1041 - 1060, 1061 - 1080, 1081 - 1100

Model geometry (top elevation):
Layers 1 to 4

Figure D1



Created by: WMinchin | Version: A | Date: 30/08/2022

GWHC Alignment
Creek
Geological structure (significant)
Model extent
Model no flow (inactive/pinch-out)

N
0 1 2 3 4 km

Scale: 142,879 @A4
GDA2020 MGA Zone 56

WATERSHED HYDROGEO

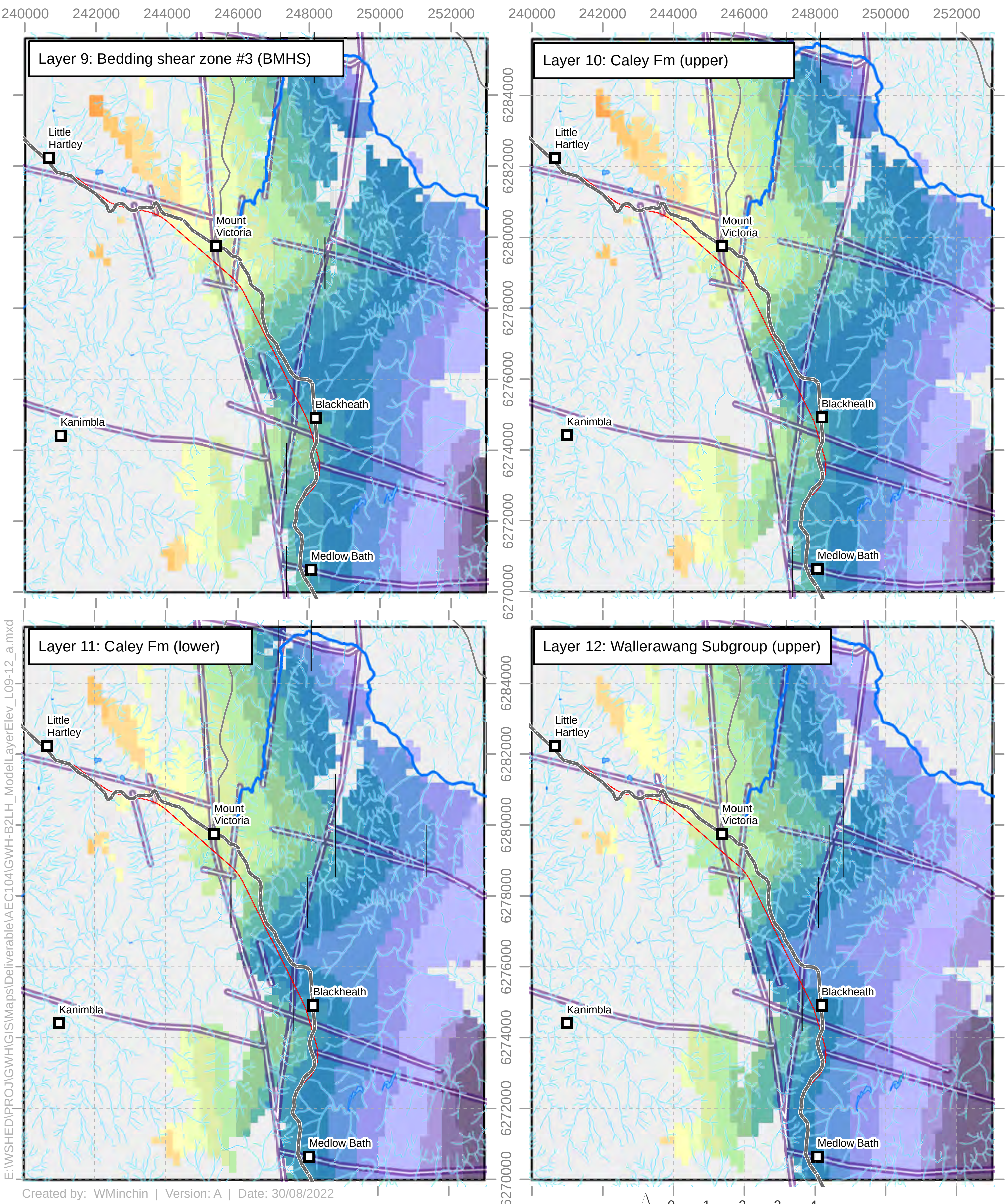
GWH-B2LH

Top elevation [mAHD]

< 700, 701 - 720, 721 - 740, 741 - 780, 781 - 800, 801 - 820, 821 - 840, 841 - 860, 861 - 880, 881 - 900, 901 - 920, 921 - 940, 941 - 960, 961 - 980, 981 - 1000, 1001 - 1020, 1021 - 1040, 1041 - 1060, 1061 - 1080, 1081 - 1100

Model geometry (top elevation):
Layers 5 to 8

Figure D2



Created by: WMinchin | Version: A | Date: 30/08/2022

GWHC Alignment

Creek

Geological structure (significant)

Model extent

Model no flow (inactive/pinch-out)

N

0 1 2 3 4 km

Scale: 142,879 @A4
GDA2020 MGA Zone 56

WATERSHED HYDROGEO

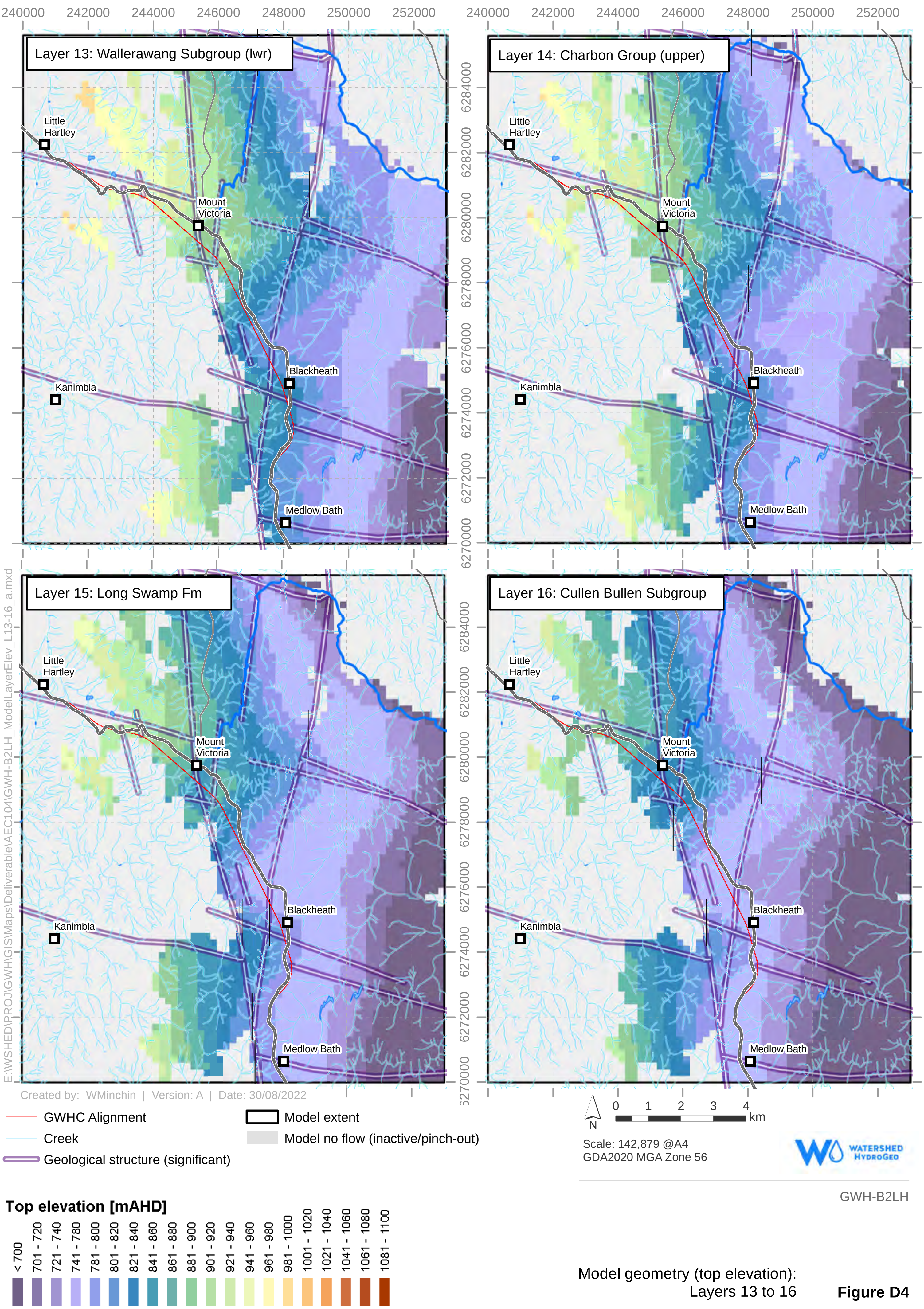
Top elevation [mAHD]

< 700, 701 - 720, 721 - 740, 741 - 780, 781 - 800, 801 - 820, 821 - 840, 841 - 860, 861 - 880, 881 - 900, 901 - 920, 921 - 940, 941 - 960, 961 - 980, 981 - 1000, 1001 - 1020, 1021 - 1040, 1041 - 1060, 1061 - 1080, 1081 - 1100

GWH-B2LH

Model geometry (top elevation):
Layers 9 to 12

Figure D3



E:\WSHED\PROJ\GWH\GIS\Maps\Deliverable\AEC104\GWH-B2LH_ModelLayerElev_L13-16_a.mxd

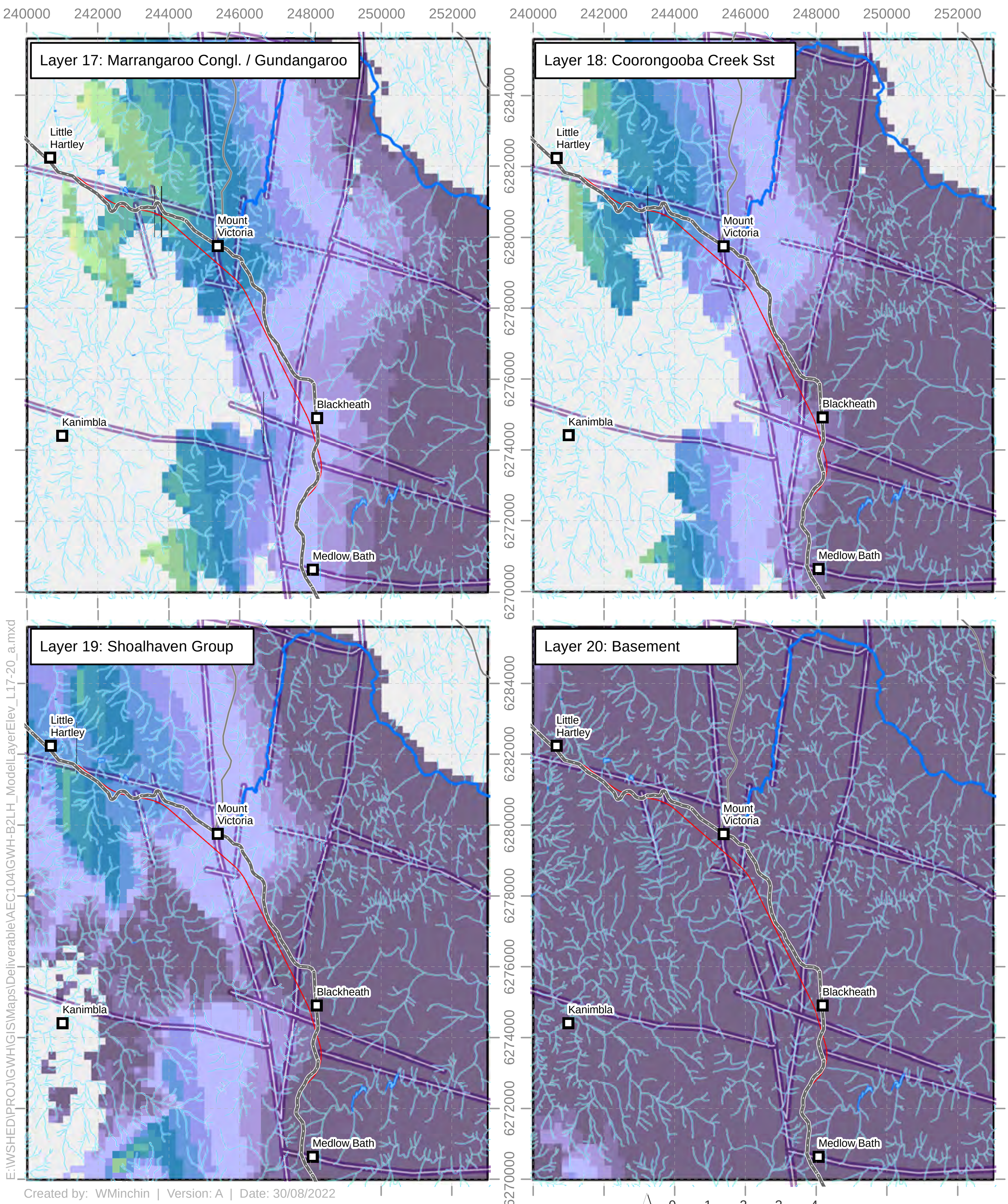
Created by: WMinchin | Version: A | Date: 30/08/2022

Scale: 142,879 @A4
GDA2020 MGA Zone 56

GWH-B2LH

Model geometry (top elevation):
Layers 13 to 16

Figure D4



Created by: WMinchin | Version: A | Date: 30/08/2022

GWHC Alignment
Creek
Geological structure (significant)
Model extent
Model no flow (inactive/pinch-out)

N
0 1 2 3 4 km

Scale: 142,879 @A4
GDA2020 MGA Zone 56

WATERSHED HYDROGEO

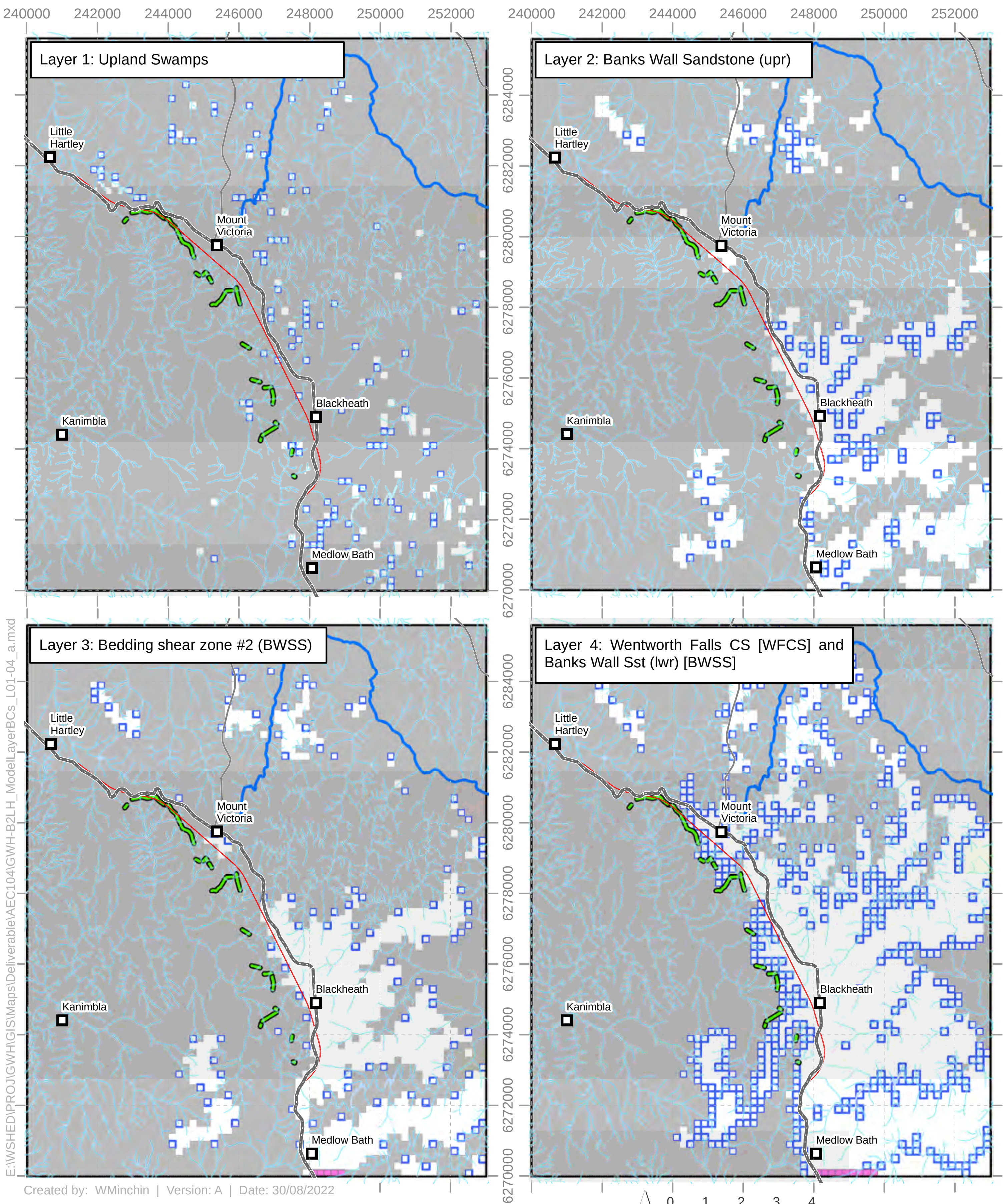
GWH-B2LH

Top elevation [mAHD]

< 700
701 - 720
721 - 740
741 - 780
781 - 800
801 - 820
821 - 840
841 - 860
861 - 880
881 - 900
901 - 920
921 - 940
941 - 960
961 - 980
981 - 1000
1001 - 1020
1021 - 1040
1041 - 1060
1061 - 1080
1081 - 1100

Model geometry (top elevation):
Layers 17 to 20

Figure D5



GWHC Alignment
Creek
Cliff (Hanging) Swamps

Boundary condition

General Head (GHB)
River (RIV)
No flow (inactive)

Model extent
Model no flow (inactive/pinch-out)

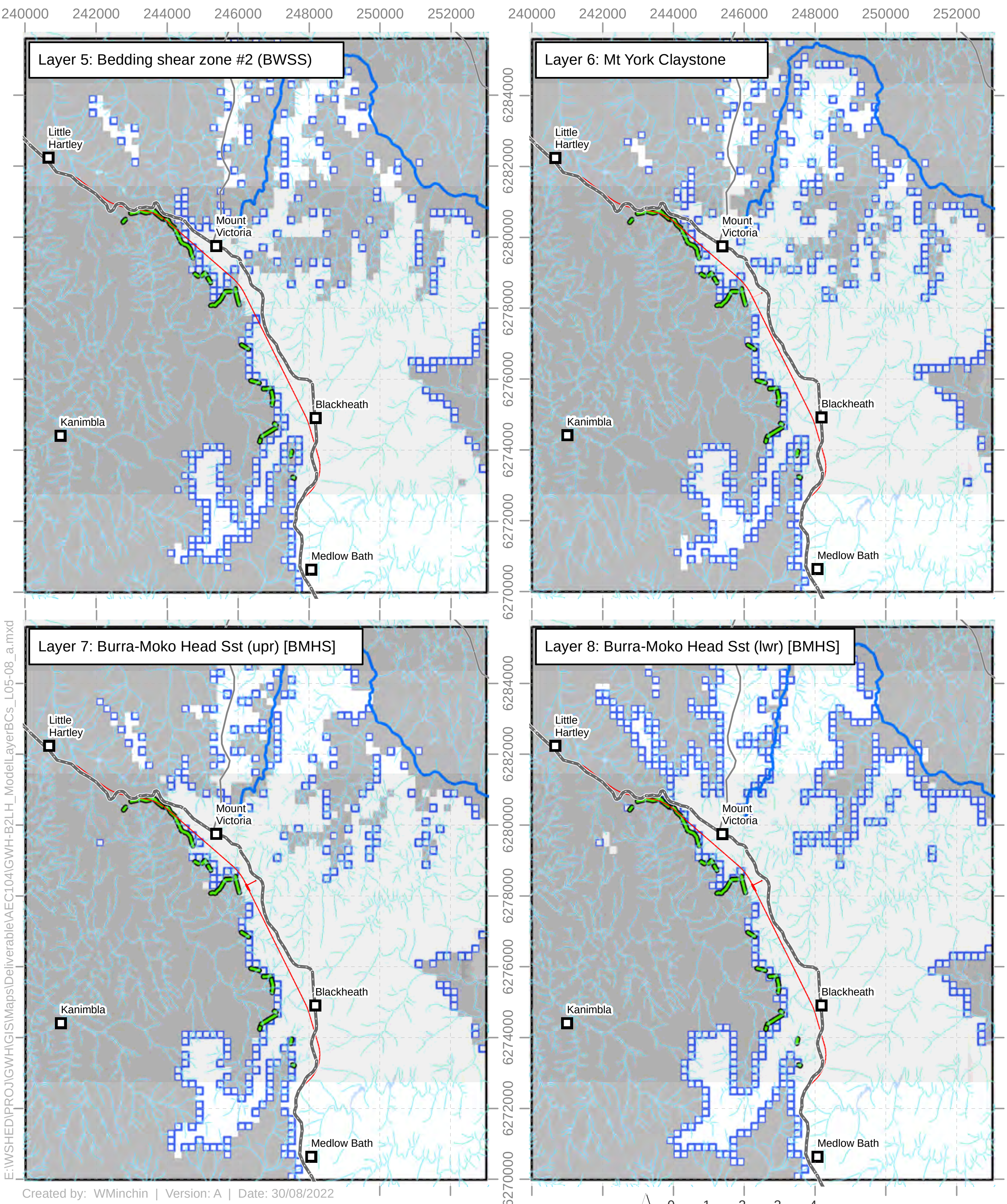
Scale: 142,879 @A4
GDA2020 MGA Zone 56

WATERSHED HYDROGEO

GWH-B2LH

Model boundary conditions:
Layers 1 to 4

Figure D6



Created by: WMinchin | Version: A | Date: 30/08/2022

GWHC Alignment
Creek
Cliff (Hanging) Swamps

Boundary condition

General Head (GHB)
River (RIV)
No flow (inactive)

Model extent
Model no flow (inactive/pinch-out)

N
0 1 2 3 4 km

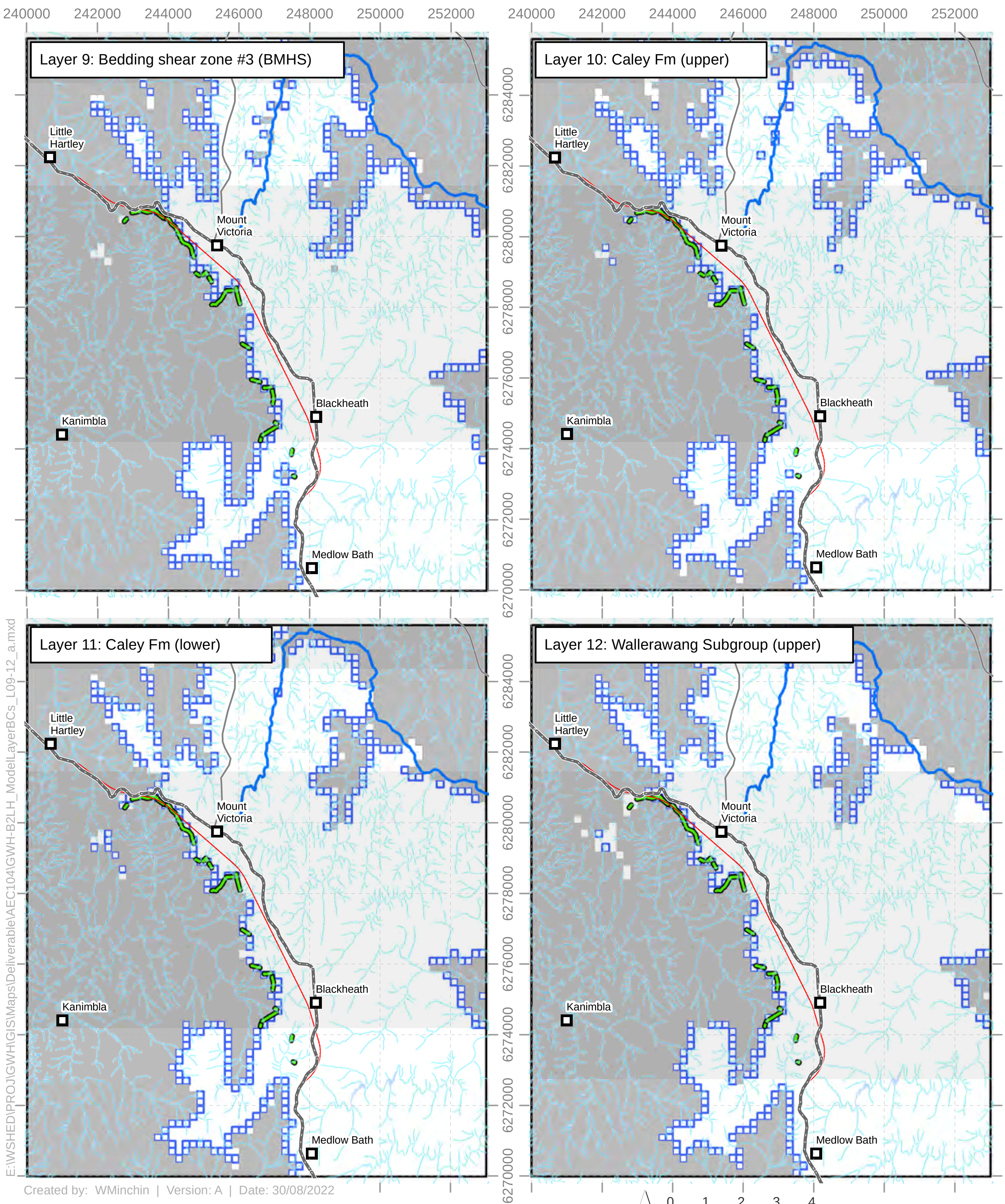
Scale: 142,500 @A4
GDA2020 MGA Zone 56

WATERSHED HYDROGEO

GWH-B2LH

Model boundary conditions:
Layers 5 to 8

Figure D7



Created by: WMinchin | Version: A | Date: 30/08/2022

GWHC Alignment
Creek
Cliff (Hanging) Swamps
Model extent
Model no flow (inactive/pinch-out)

Boundary condition

General Head (GHB)
River (RIV)
No flow (inactive)

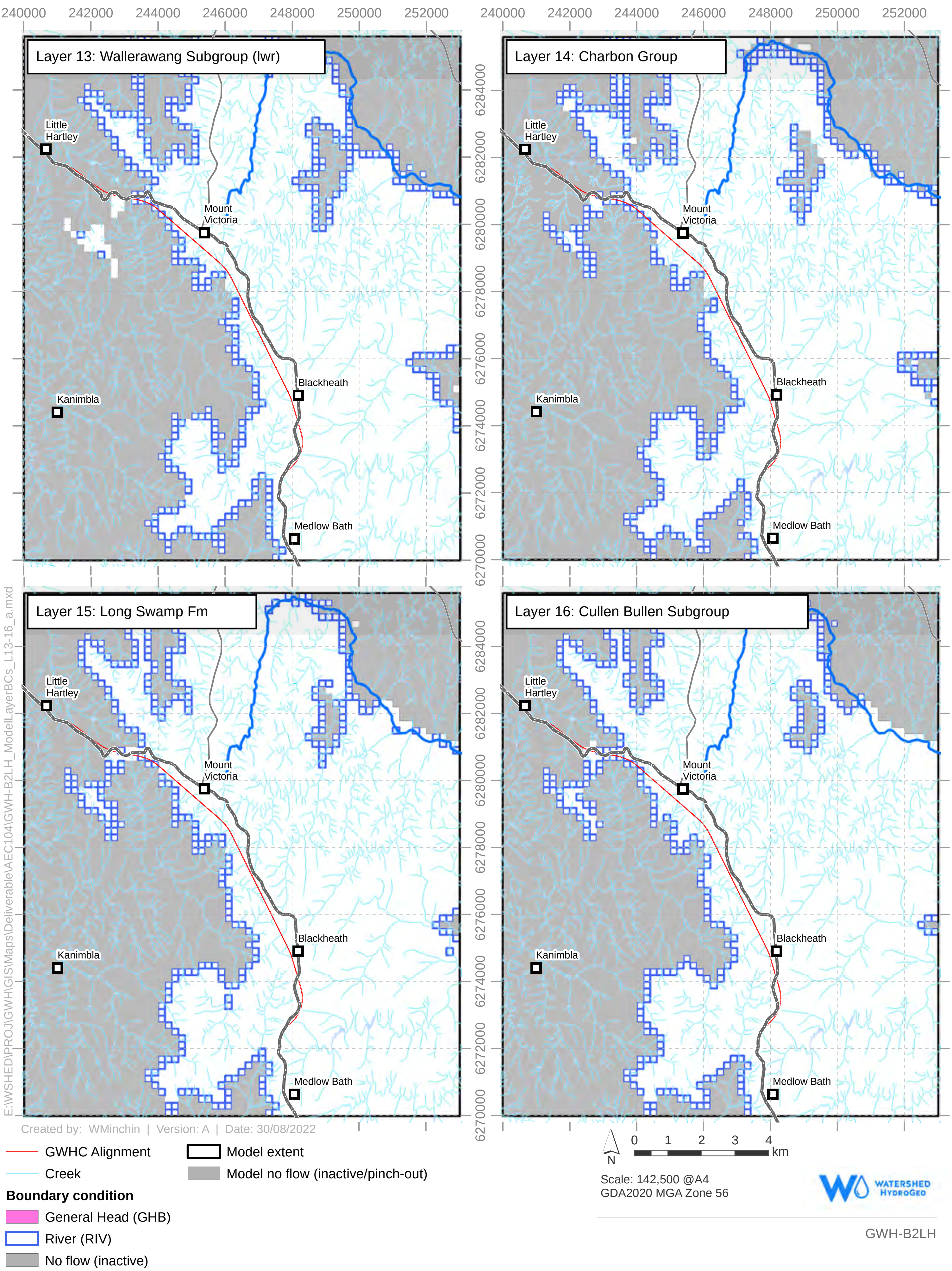
N
0 1 2 3 4 km

Scale: 142,879 @A4
GDA2020 MGA Zone 56

GWH-B2LH

Model boundary conditions:
Layers 9 to 12

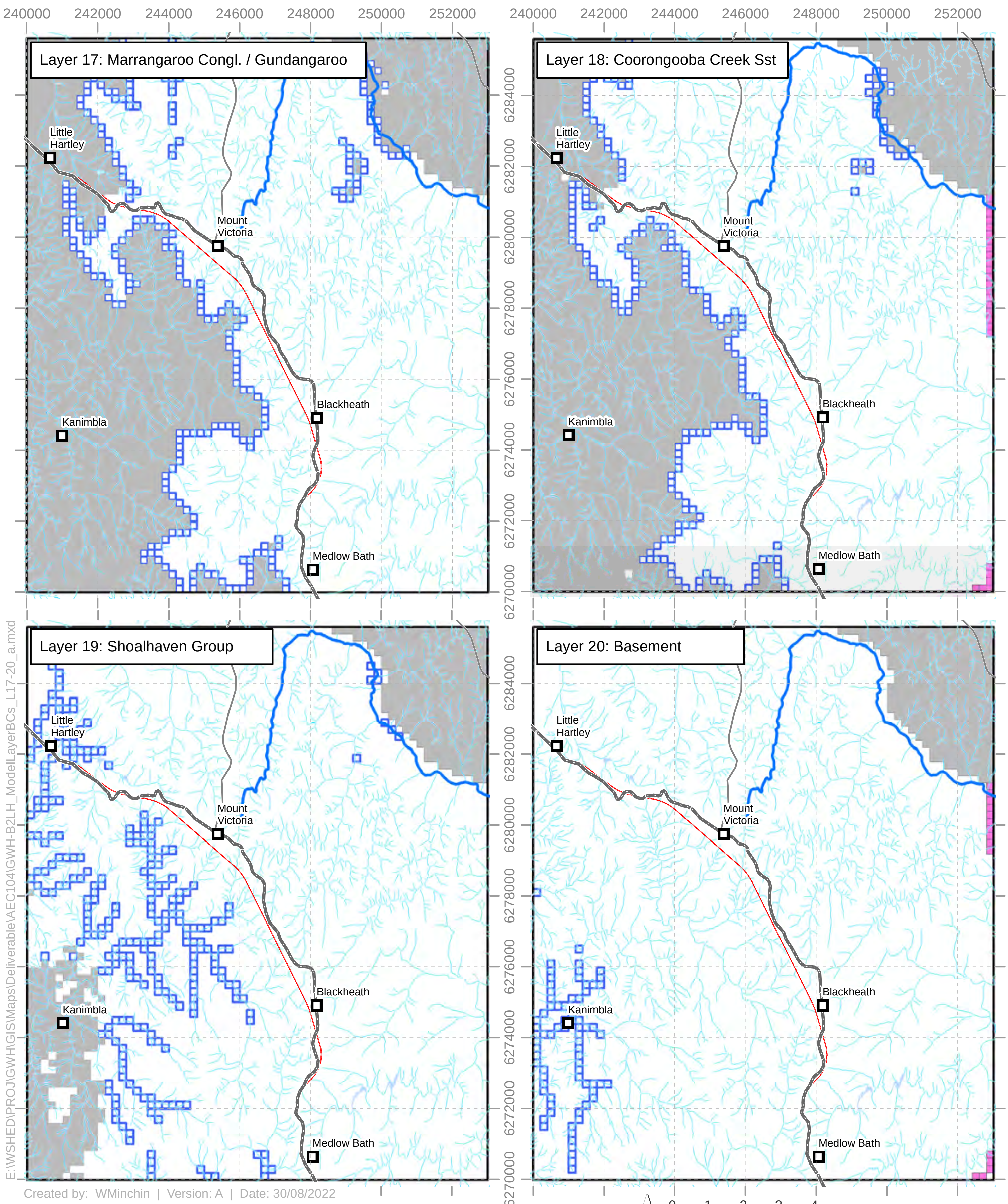
Figure D8



GWH-B2LH

Model boundary conditions:
Layers 13 to 16

Figure D9



GWHC Alignment

Creek

Model extent

Model no flow (inactive/pinch-out)

Boundary condition

General Head (GHB)

River (RIV)

No flow (inactive)

Scale: 142,500 @A4
GDA2020 MGA Zone 56

WATERSHED HYDROGEO

GWH-B2LH

Model boundary conditions:
Layers 17 to 20

Figure D10

Appendix E: Model hydraulic conductivity and storage properties

Maps on the following pages show the modelled Kx, Kz, Ss and Sy properties for the 'base' realisation and for:

Figure E1: Layer 2 – Banks Wall Sandstone (upr) / Burralow Fm

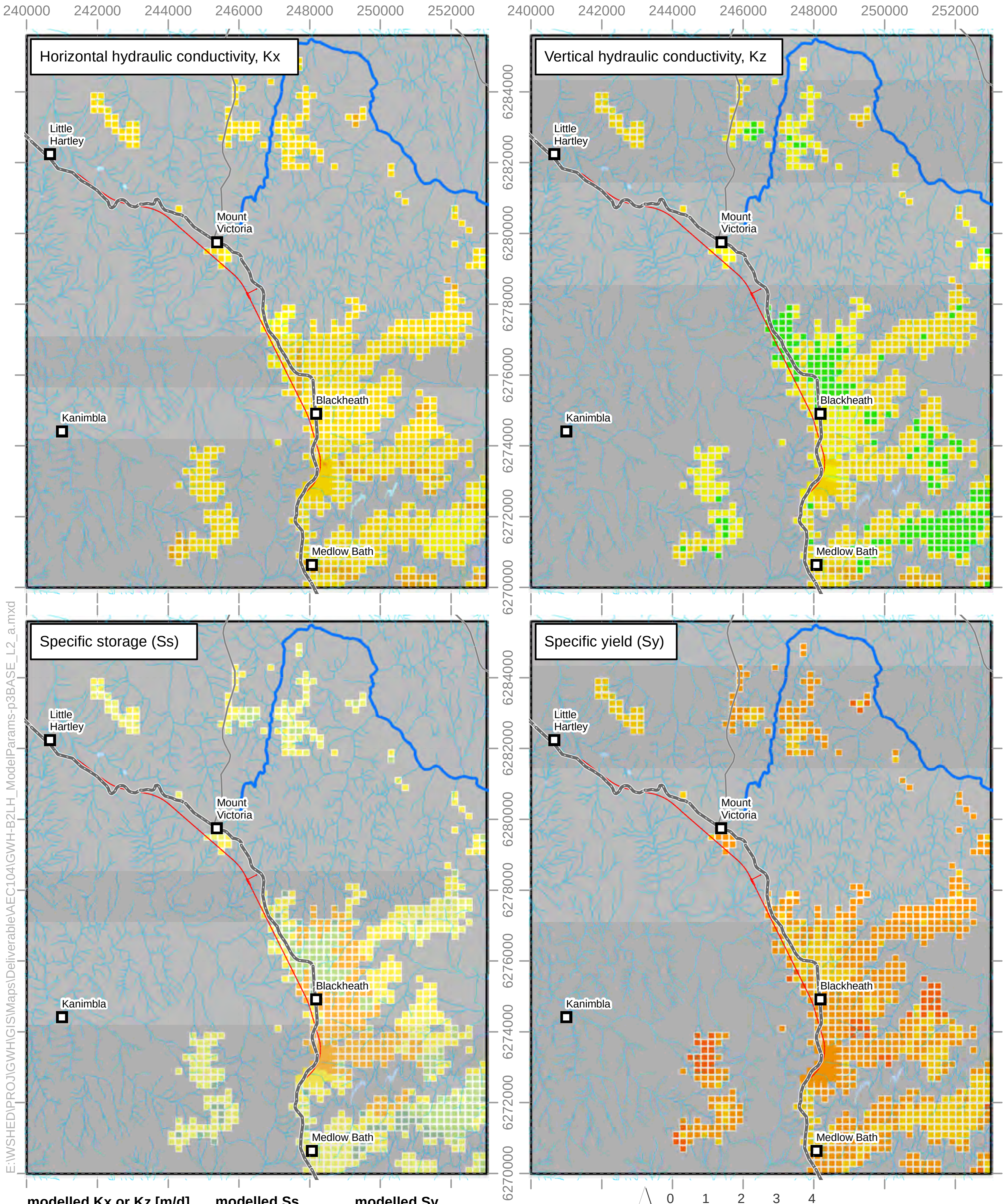
Figure E2: Layer 4 – Banks Wall Sandstone / Wentworth Falls Claystone;

Figure E3: Layer 6 – Mount York Claystone

Figure E4: Layer 8 – Burra-Moko Head Sandstone (lwr)

Figure E5: Layer 17 - Marrangaroo Congl. / Gundangaroo Fm

Figure E6: Location of geological structures and structural pilot points used to assign hydraulic conductivity



modelled Kx or Kz [m/d]	modelled Ss	modelled Sy
< 1.0e-07	<1E-6	< 0.01
1.1e-07 - 1.0e-06	1E-6 - 2E-6	0.01 - 0.04
1.1e-06 - 1.0e-05	2E-6 - 5E-6	0.04 - 0.08
1.1e-05 - 1.0e-04	6E-6 - 1E-5	0.08 - 0.12
1.1e-04 - 1.0e-03	1E-5 - 5E-5	0.12 - 0.2
1.1e-03 - 1.0e-02	5E-5 - 1E-4	> 0.2
1.1e-02 - 1.0e-01	1E-4 - 5E-4	
1.1e-01 - 1.0e+00	5E-4 - 1E-3	
1.1e+00 - 1.0e+01	1E-3 - 5E-3	
1.1e+01 - 1.0e+02	5E-3 - 1E-2	

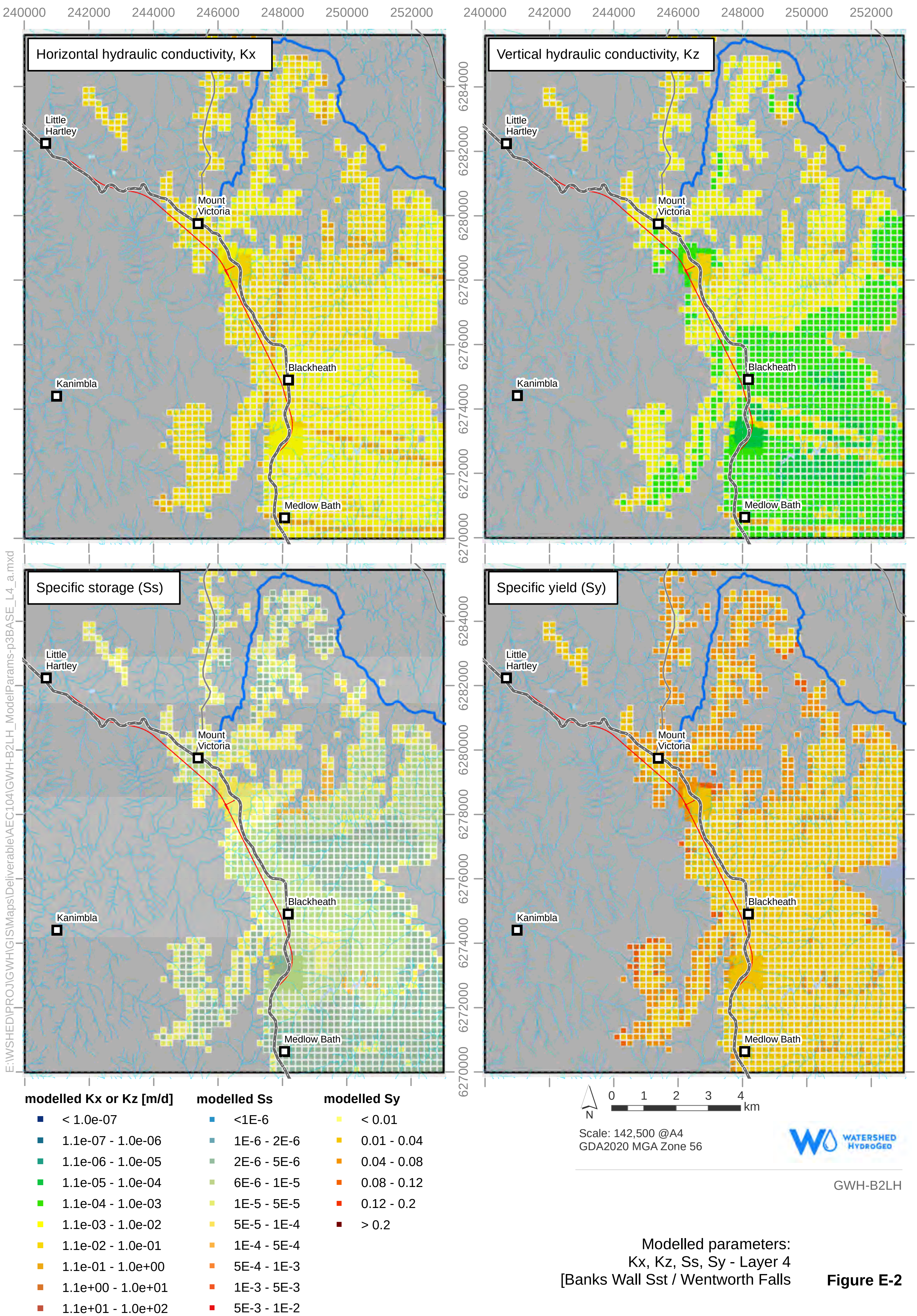
N 0 1 2 3 4 km

Scale: 142,500 @A4
GDA2020 MGA Zone 56

GWH-B2LH

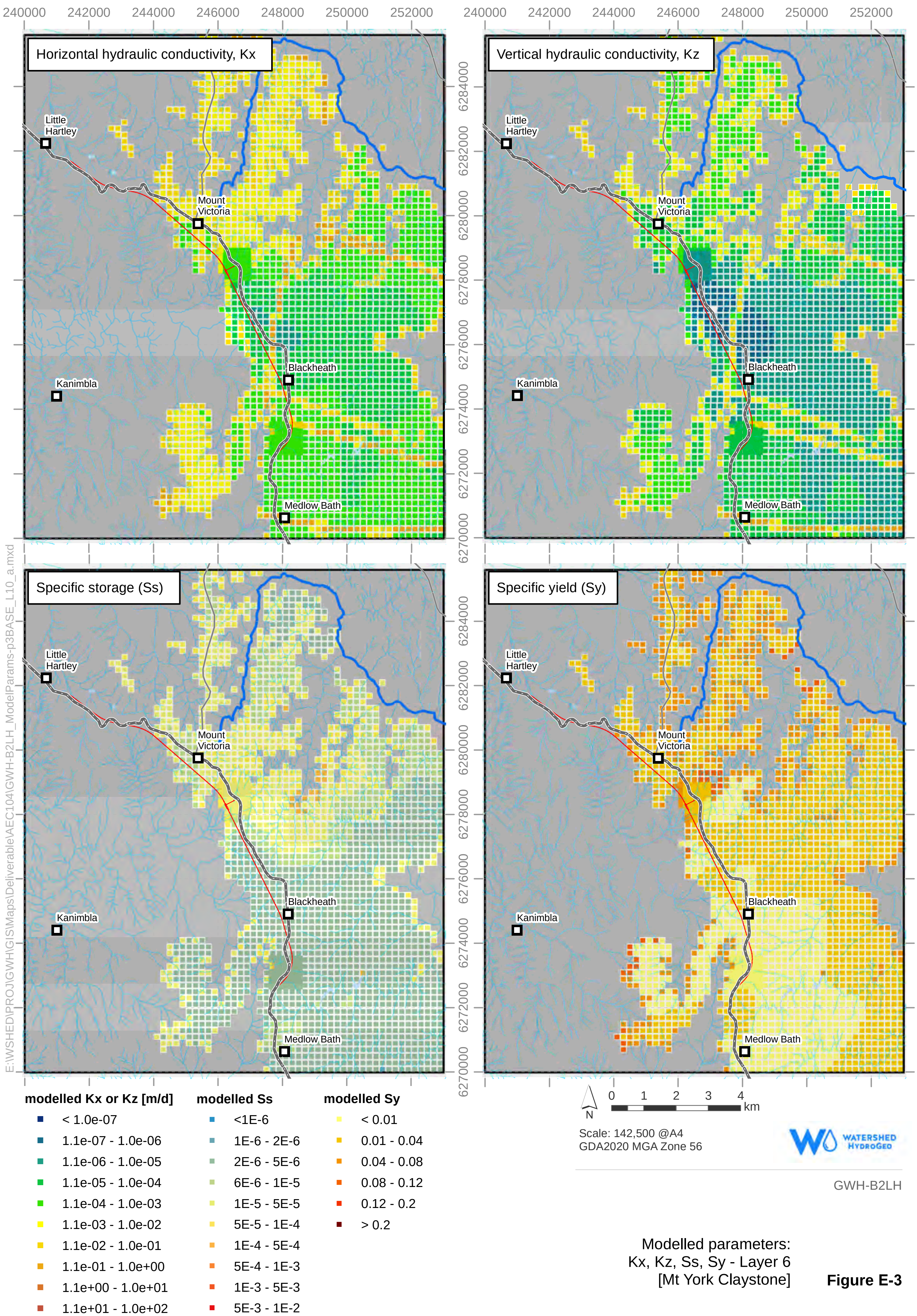
Modelled parameters:
Kx, Kz, Ss, Sy - Layer 4
Banks Wall Sst (upr) / Burralow Fm

Figure E-1



Modelled parameters:
Kx, Kz, Ss, Sy - Layer 4
[Banks Wall Sst / Wentworth Falls

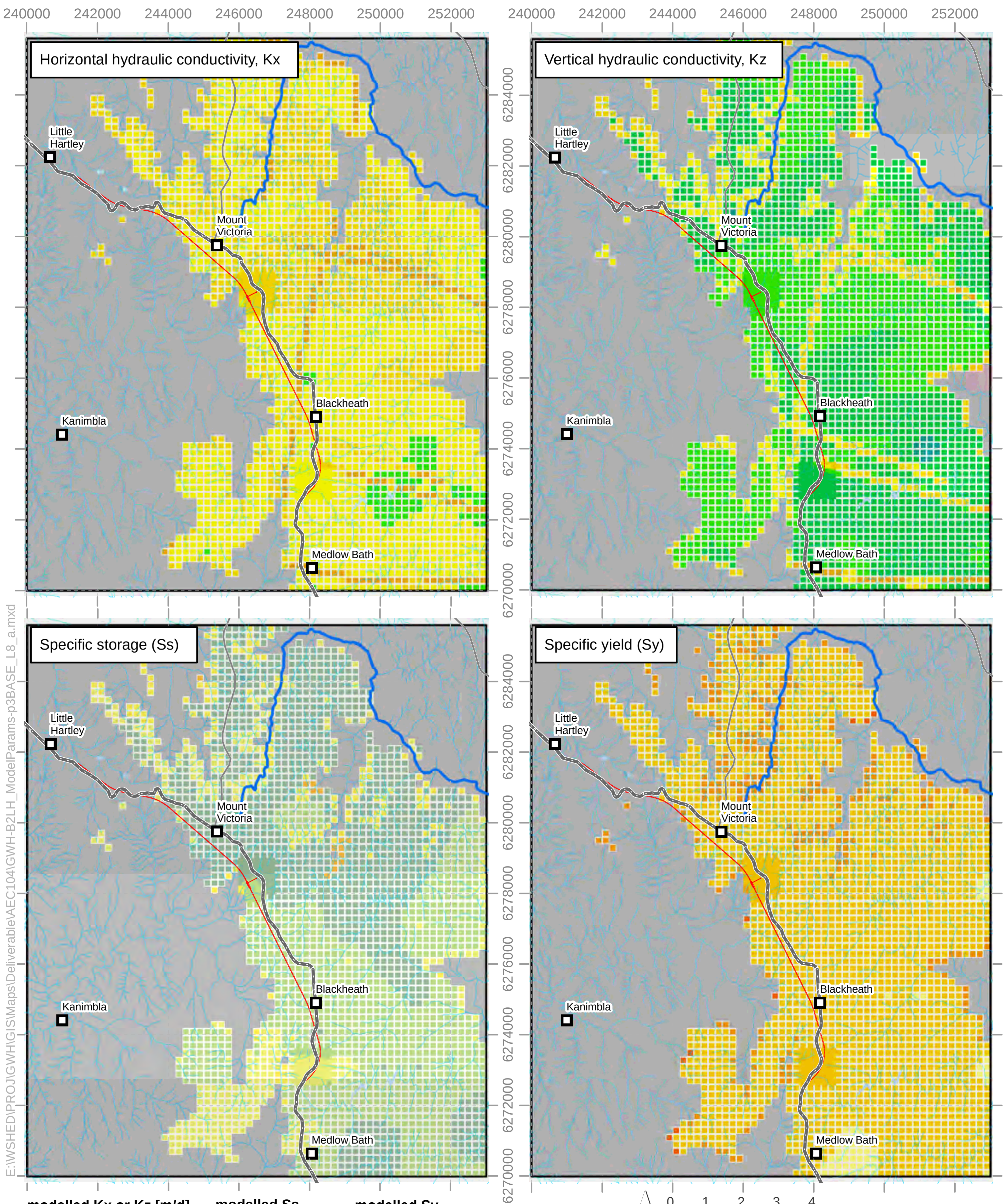
Figure E-2



GWH-B2LH

Modelled parameters:
Kx, Kz, Ss, Sy - Layer 6
[Mt York Claystone]

Figure E-3



modelled Kx or Kz [m/d]
- < 1.0e-07
- 1.1e-07 - 1.0e-06
- 1.1e-06 - 1.0e-05
- 1.1e-05 - 1.0e-04
- 1.1e-04 - 1.0e-03
- 1.1e-03 - 1.0e-02
- 1.1e-02 - 1.0e-01
- 1.1e-01 - 1.0e+00
- 1.1e+00 - 1.0e+01
- 1.1e+01 - 1.0e+02

modelled Ss
- <1E-6
- 1E-6 - 2E-6
- 2E-6 - 5E-6
- 6E-6 - 1E-5
- 1E-5 - 5E-5
- 5E-5 - 1E-4
- 1E-4 - 5E-4
- 5E-4 - 1E-3
- 1E-3 - 5E-3
- 5E-3 - 1E-2

modelled Sy
- < 0.01
- 0.01 - 0.04
- 0.04 - 0.08
- 0.08 - 0.12
- 0.12 - 0.2
- > 0.2

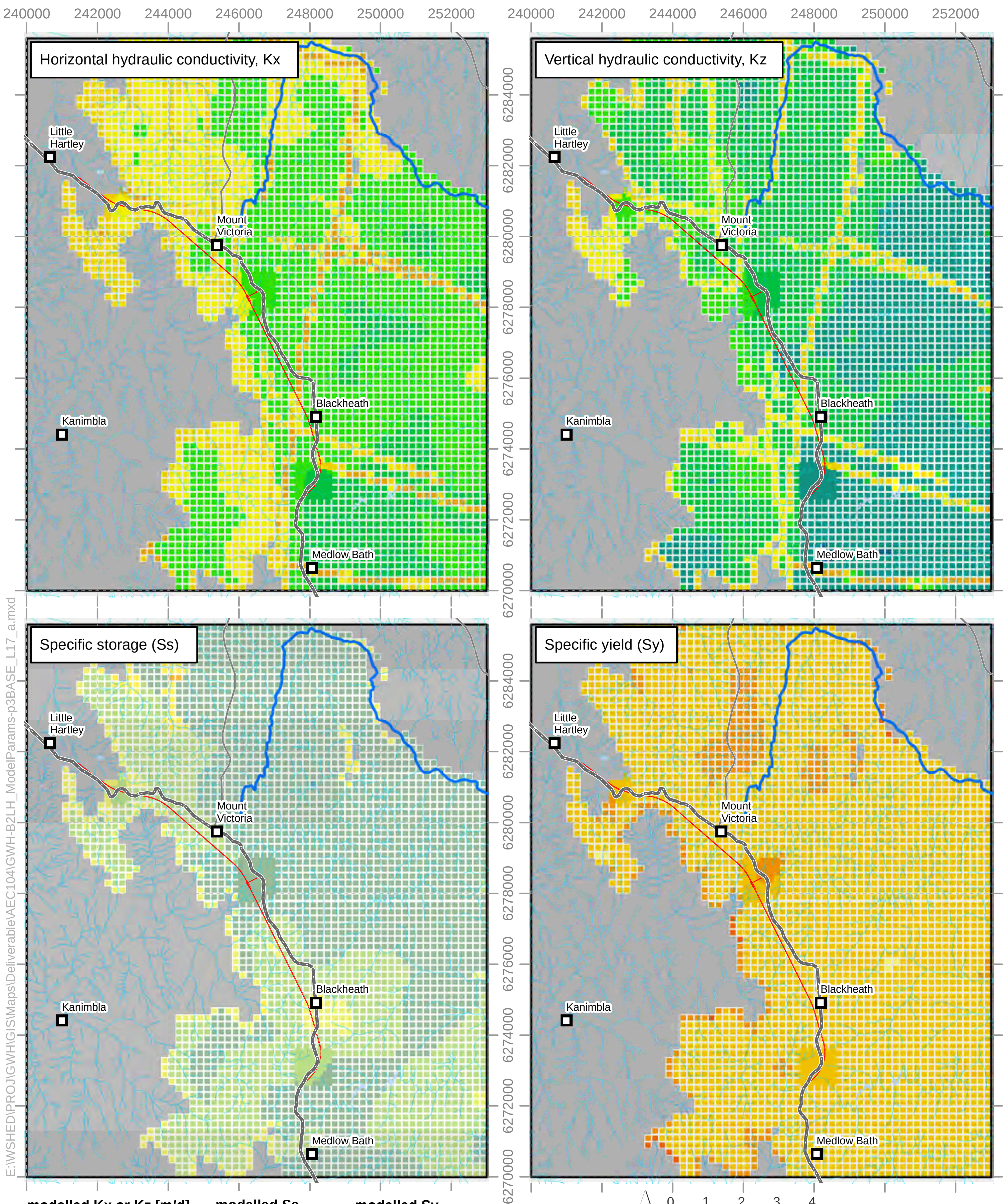
Scale: 142,500 @A4
GDA2020 MGA Zone 56

WATERSHED HYDROGEO

GWH-B2LH

Modelled parameters:
Kx, Kz, Sy, Ss - Layer 8
[Lower Burra-Moko Head Sst]

Figure E-4



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modelled Kx or Kz [m/d]
- < 1.0e-07
- 1.1e-07 - 1.0e-06
- 1.1e-06 - 1.0e-05
- 1.1e-05 - 1.0e-04
- 1.1e-04 - 1.0e-03
- 1.1e-03 - 1.0e-02
- 1.1e-02 - 1.0e-01
- 1.1e-01 - 1.0e+00
- 1.1e+00 - 1.0e+01
- 1.1e+01 - 1.0e+02

modelled Ss
- <1E-6
- 1E-6 - 2E-6
- 2E-6 - 5E-6
- 6E-6 - 1E-5
- 1E-5 - 5E-5
- 5E-5 - 1E-4
- 1E-4 - 5E-4
- 5E-4 - 1E-3
- 1E-3 - 5E-3
- 5E-3 - 1E-2

modelled Sy
- < 0.01
- 0.01 - 0.04
- 0.04 - 0.08
- 0.08 - 0.12
- 0.12 - 0.2
- > 0.2

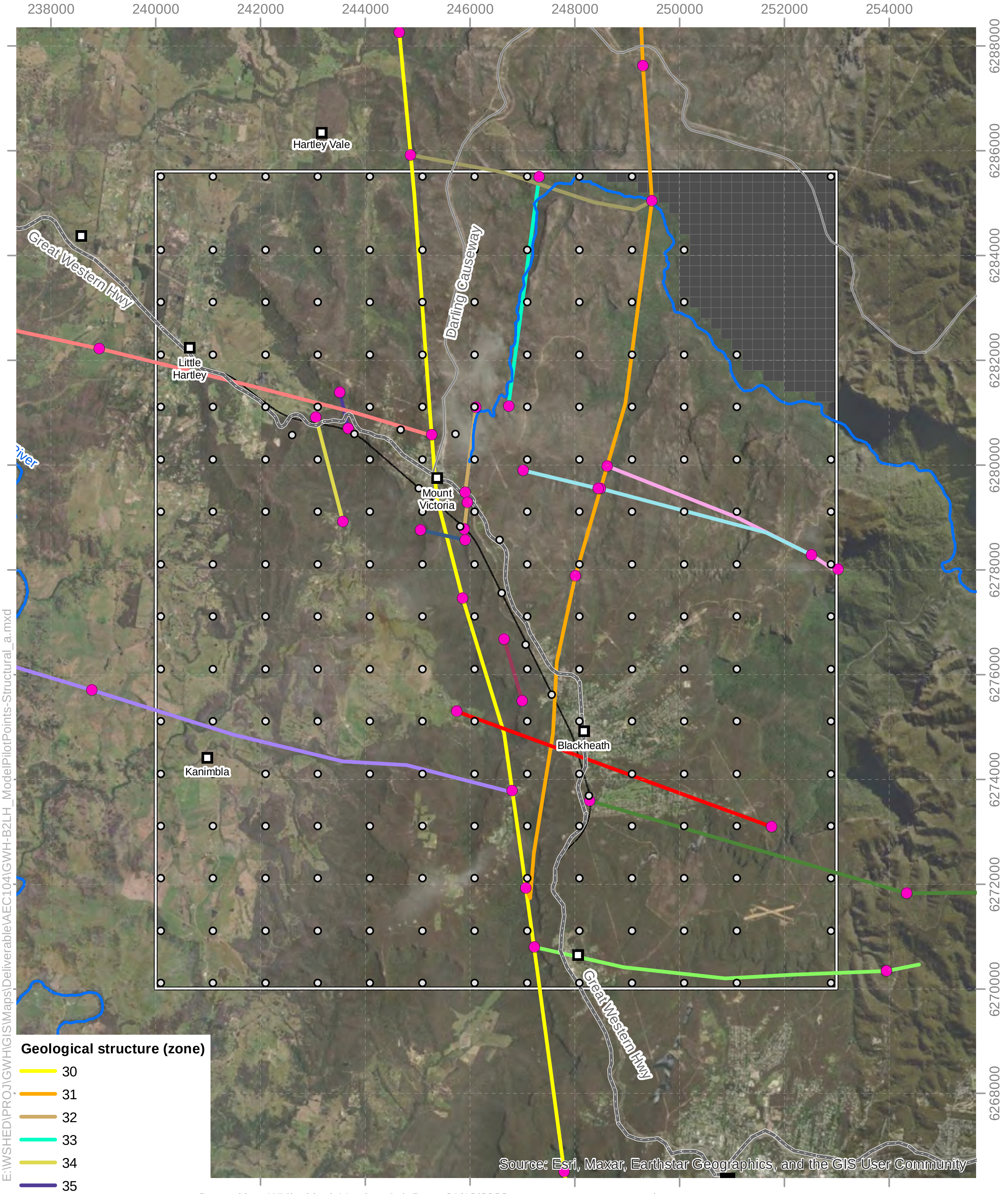
N
0 1 2 3 4 km

Scale: 142,500 @A4
GDA2020 MGA Zone 56

GWH-B2LH

Modelled parameters:
Kx, Kz, Ss, Sy - Layer 17
[Marrangaroo Congl. / Gundangaroo

Figure E-5



Geological structure (zone)

- 30
- 31
- 32
- 33
- 34
- 35
- 36
- 37
- 38
- 39
- 40
- 41
- 42
- 43
- 44
- 45

Created by: WMinchin | Version: A | Date: 01/12/2022

- Model extent
- Main road
- Great Western Highway
- GWH project alignment
- River
- Pilot point --> model Kx,Kz,Sy,Ss
- Structural pilot points
- Model no flow (inactive)

N

0 0.65 1.3 1.95 2.6 km

Scale: 96,000 @A4
GDA2020 MGA Zone 56

WATERSHED HYDROGEO

GWH-B2LH

Location of geological structures and structural pilot points used to assign hydraulic conductivity

Figure E6

Table E1 Parameters used in PESTPP-IES history-matching

Parameter type	Group	Lithology	No. of parameters
Recharge	Global multiplier	global	1
River conductance	Major watercourse catchments	n/a	7
	Minor streams and springs	n/a	4249
			No. of pilot points
Hydraulic conductivity – horizontal (Kx) and Hydraulic conductivity – vertical anisotropy (vka → Kz)	Zone 1: Regolith	Regolith	196
	Zone 21: Swamp	Swamp	24
	Zone 2: Banks Wall Sandstone (upper) / Burralow	Sandstone	19
	Zone 3: Bedding plane shear zone #1	shear zone	54
	Zone 4: Wentworth Falls Claystone	Sandstone	60
	Zone 5: Bedding plane shear zone #2	shear zone	87
	Zone 6: Mt York Claystone	Claystone	71
	Zone 7: Burra Moko Head Sandstone (upper)	Sandstone	86
	Zone 8: Burra Moko Head Sandstone (lower)	Sandstone	98
	Zone 9: Bedding plane shear zone #3	shear zone	111
	Zone 10: Caley Formation (upper units)	Sandstone	105
	Zone 11: Caley Formation (lower units)	Claystone	108
	Zone 12: Wallerawang Subgroup (upper)	Claystone	110
	Zone 13: Wallerawang Subgroup (lower)	Sandstone	117
	Zone 14: Charbon Group (upper)	Sandstone	120
	Zone 15: Long Swamp Formation	Claystone	122
	Zone 16: Cullen Bullen Subgroup	Sandstone	124
	Zone 17: Marrangaroo Congl. / Gundangaroo Fm	Sandstone	135
	Zone 18: Coorongooba Creek Sandstone	Sandstone	144
	Zone 19: Shoalhaven Group	Sandstone	189
	Zone 20: Basement	Sandstone	189
	kxstr: Structural features	structures	38
Specific yield (Sy) and Specific Storage (Ss)	Zone 1: Regolith	Regolith	196
	Zone 21: Swamp	Swamp	24
	Zone 2: Banks Wall Sandstone (upper) / Burralow	Sandstone	19
	Zone 3: Bedding plane shear zone #1	shear zone	54
	Zone 4: Wentworth Falls Claystone	Sandstone	60
	Zone 5: Bedding plane shear zone #2	shear zone	87
	Zone 6: Mt York Claystone	Claystone	71
	Zone 7: Burra Moko Head Sandstone (upper)	Sandstone	86
	Zone 8: Burra Moko Head Sandstone (lower)	Sandstone	98

Parameter type	Group	Lithology	No. of parameters
	Zone 9: Bedding plane shear zone #3	shear zone	111
	Zone 10: Caley Formation (upper units)	Sandstone	105
	Zone 11: Caley Formation (lower units)	Claystone	108
	Zone 12: Wallerawang Subgroup (upper)	Claystone	110
	Zone 13: Wallerawang Subgroup (lower)	Sandstone	117
	Zone 14: Charbon Group (upper)	Sandstone	120
	Zone 15: Long Swamp Formation	Claystone	122
	Zone 16: Cullen Bullen Subgroup	Sandstone	124
	Zone 17: Marrangaroo Congl. / Gundangaroo Fm	Sandstone	135
	Zone 18: Coorongooba Creek Sandstone	Sandstone	144
	Zone 19: Shoalhaven Group	Sandstone	189
	Zone 20: Basement	Sandstone	189
Total parameters used by PESTPP-IES			**13,393**

E:\WSHED\PROJ\GWH\Model\PEST\pilotpoints\PilotPoints_GWHv4_TR013_p3.xlsx

Appendix F: Groundwater model calibration hydrographs

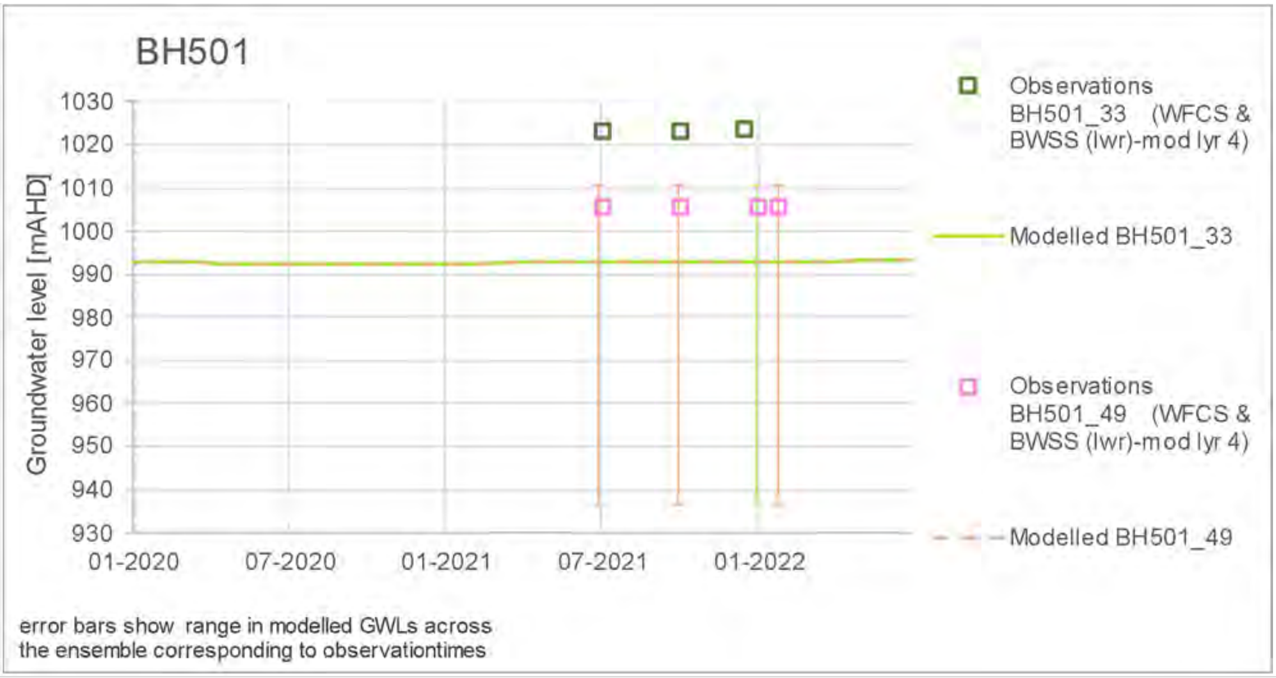
Modelled vs observed groundwater level hydrographs

PEST and GW model run: GWHv4_TR013_p3

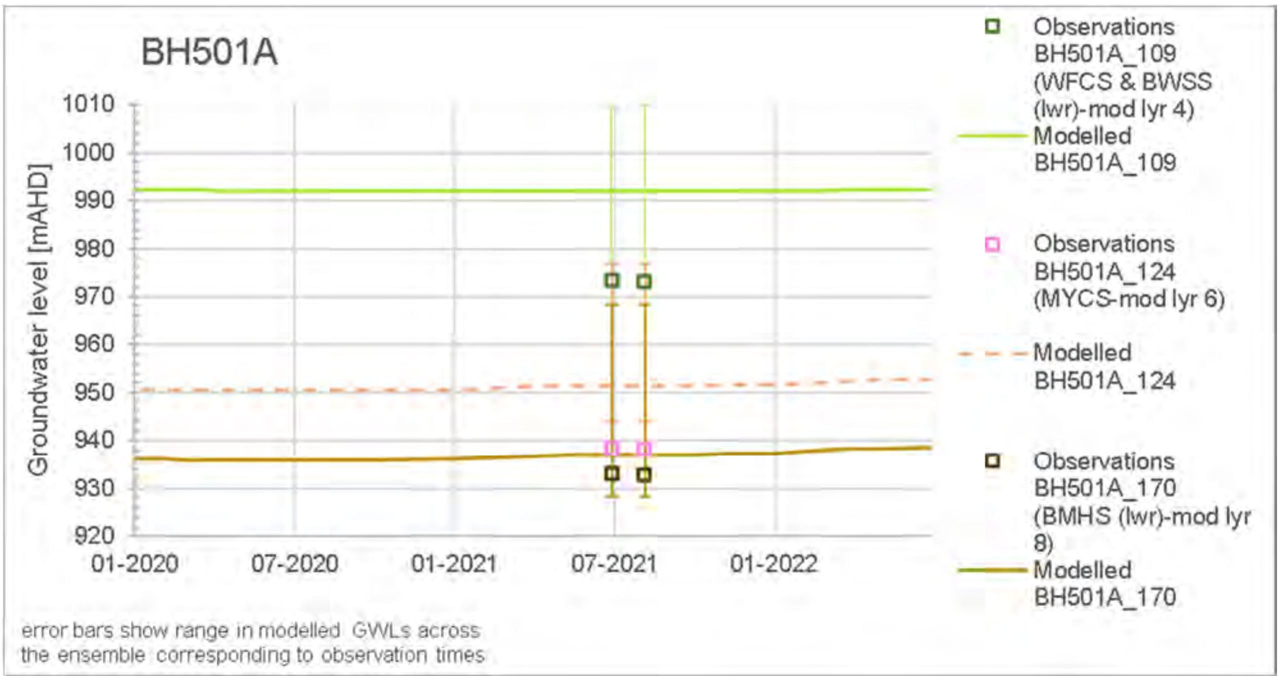
Observations (targets) are hollow symbols.

Lines are modelled GWLs for the 'Base' realisation.

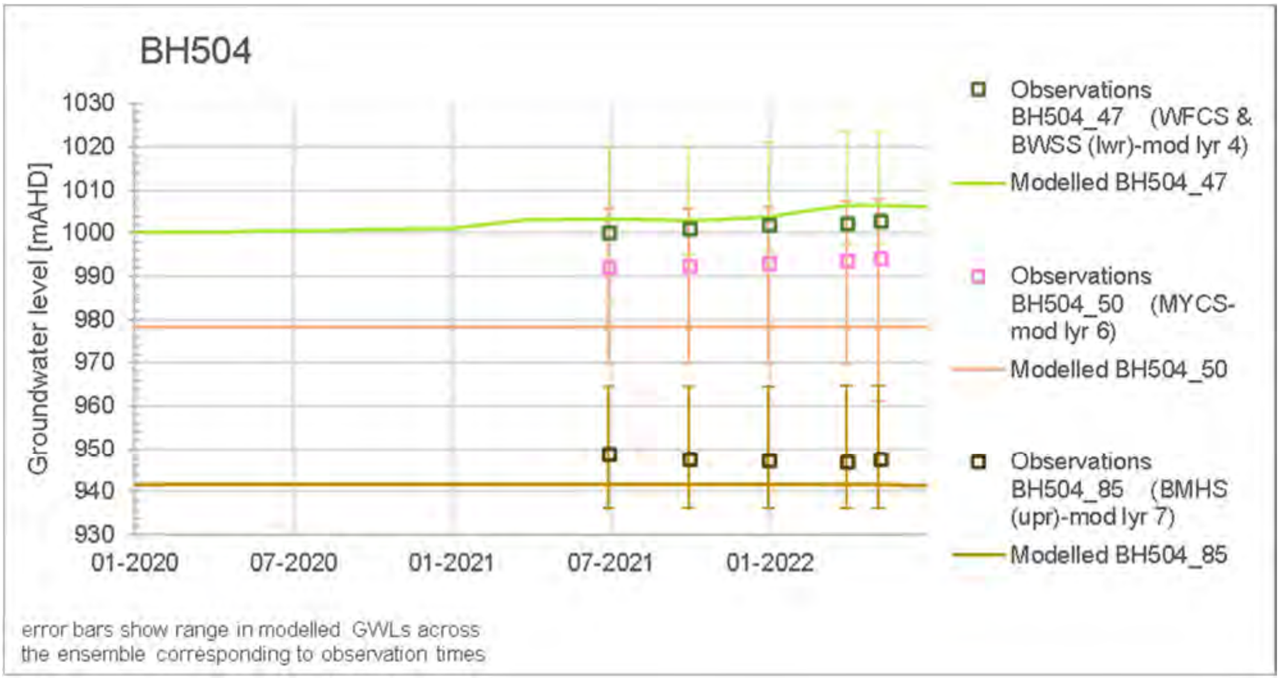
Error bars show the range in modelled GWL from the 300-realisation ensemble corresponding to the time of the observations/targets.



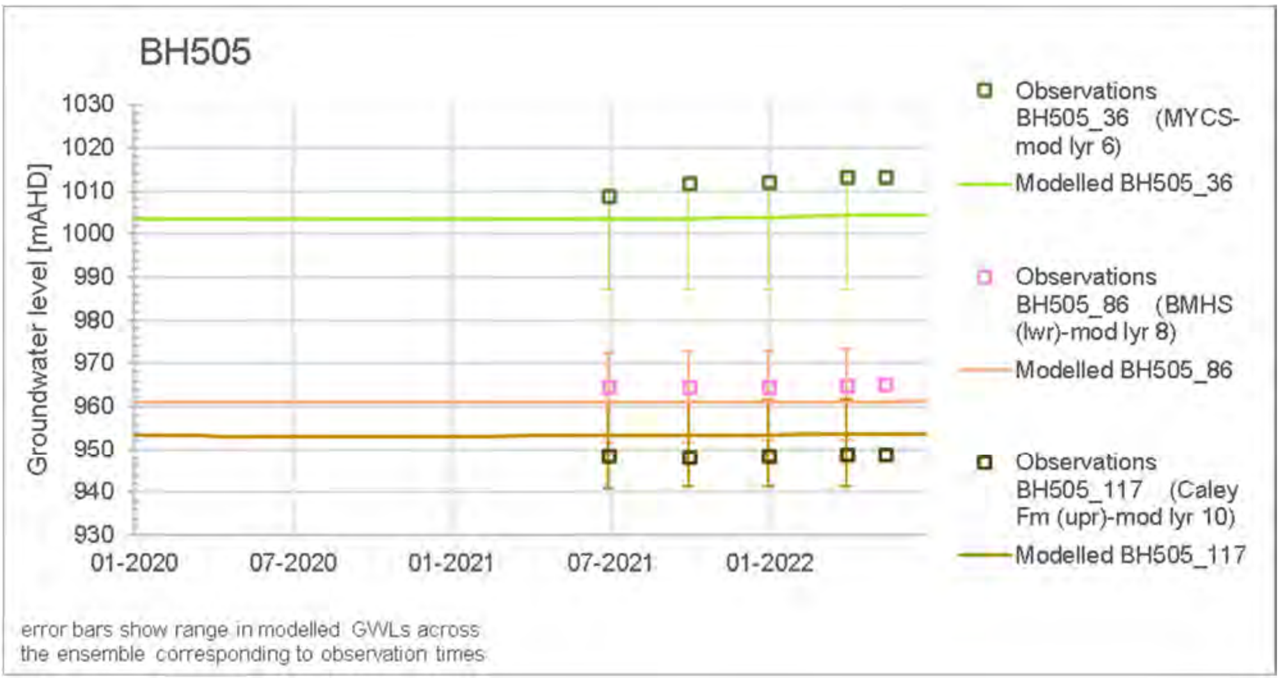
BH501



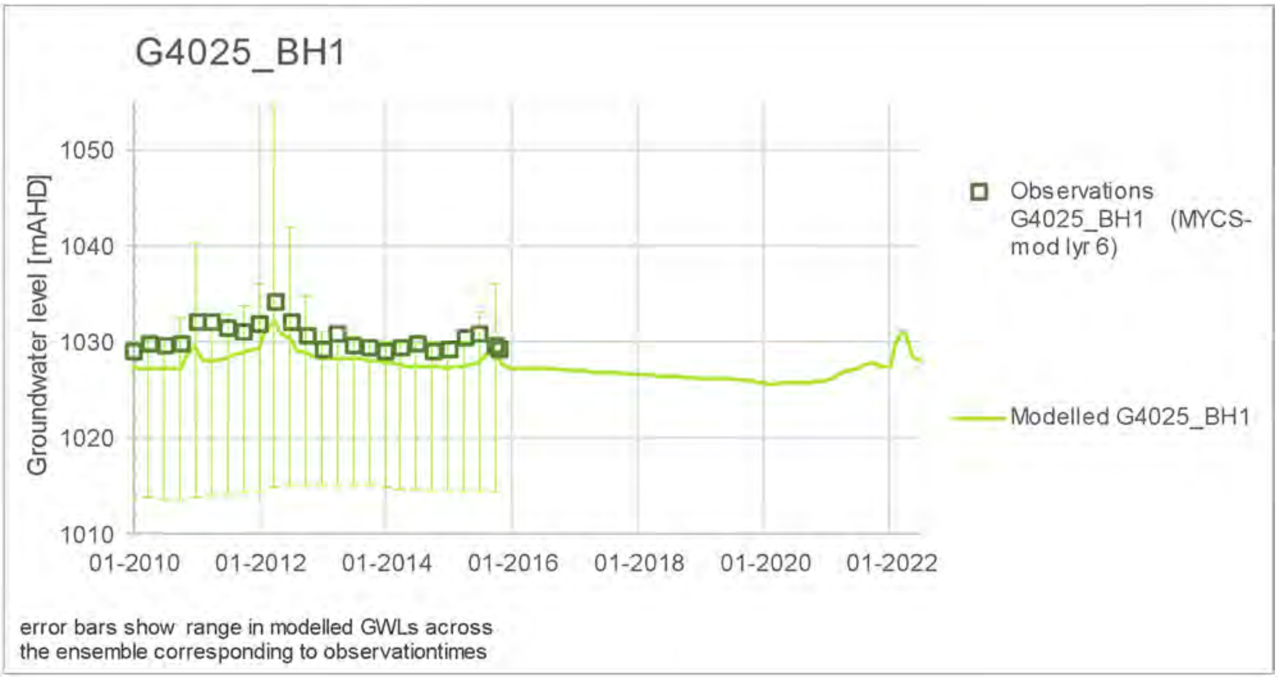
BH501A


BH504
1030
1020
1010
1000
990
980
970
960
950
940
930
Groundwater level [mAHD]
01-2020
07-2020
01-2021
07-2021
01-2022
Observations BH504_47 (WFCS & BWSS (lwr)-mod lyr 4)
Modelled BH504_47
Observations BH504_50 (MYCS-mod lyr 6)
Modelled BH504_50
Observations BH504_85 (BMHS (upr)-mod lyr 7)
Modelled BH504_85
error bars show range in modelled GWLs across the ensemble corresponding to observation times

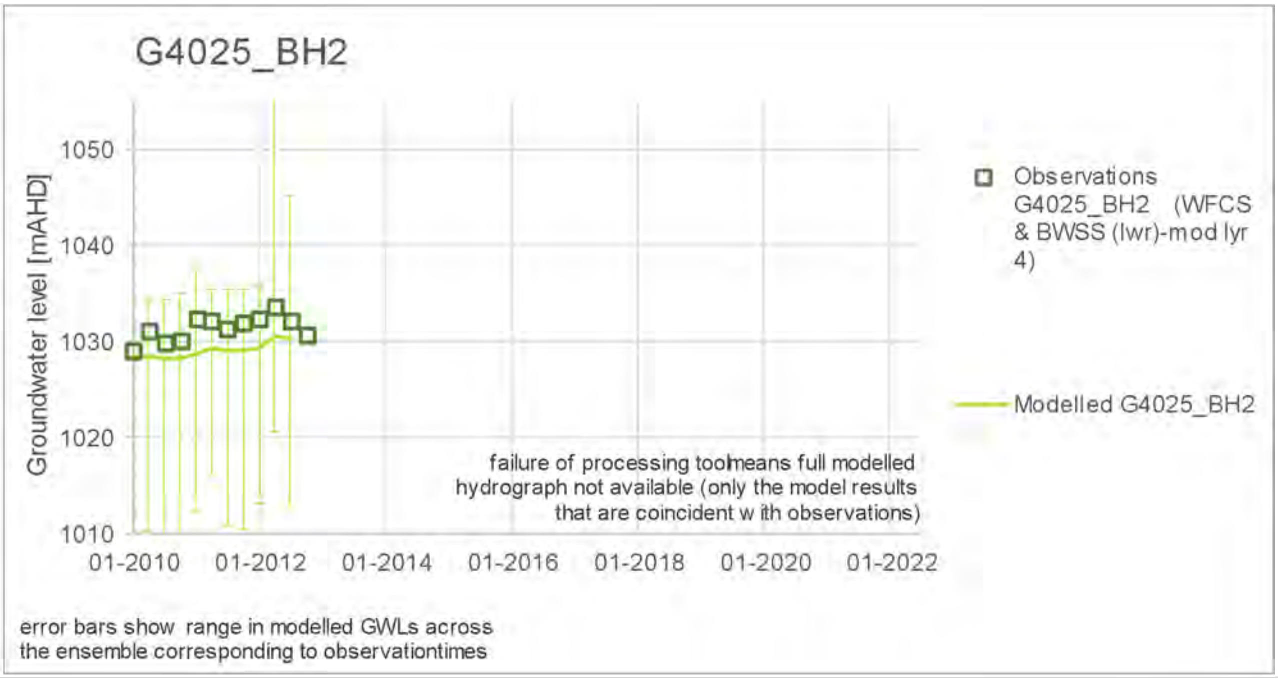
BH504


BH505
1030
1020
1010
1000
990
980
970
960
950
940
930
Groundwater level [mAHD]
01-2020
07-2020
01-2021
07-2021
01-2022
Observations BH505_36 (MYCS-mod lyr 6)
Modelled BH505_36
Observations BH505_86 (BMHS (lwr)-mod lyr 8)
Modelled BH505_86
Observations BH505_117 (Caley Fm (upr)-mod lyr 10)
Modelled BH505_117
error bars show range in modelled GWLs across the ensemble corresponding to observation times

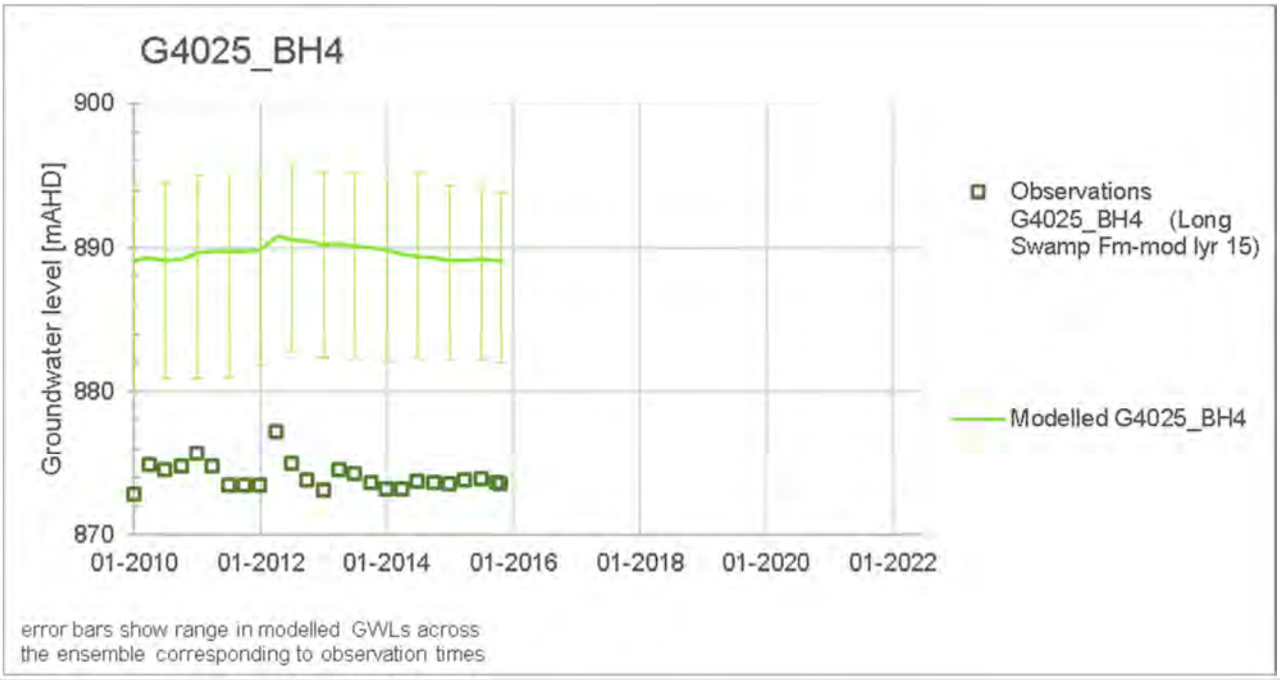
BH505



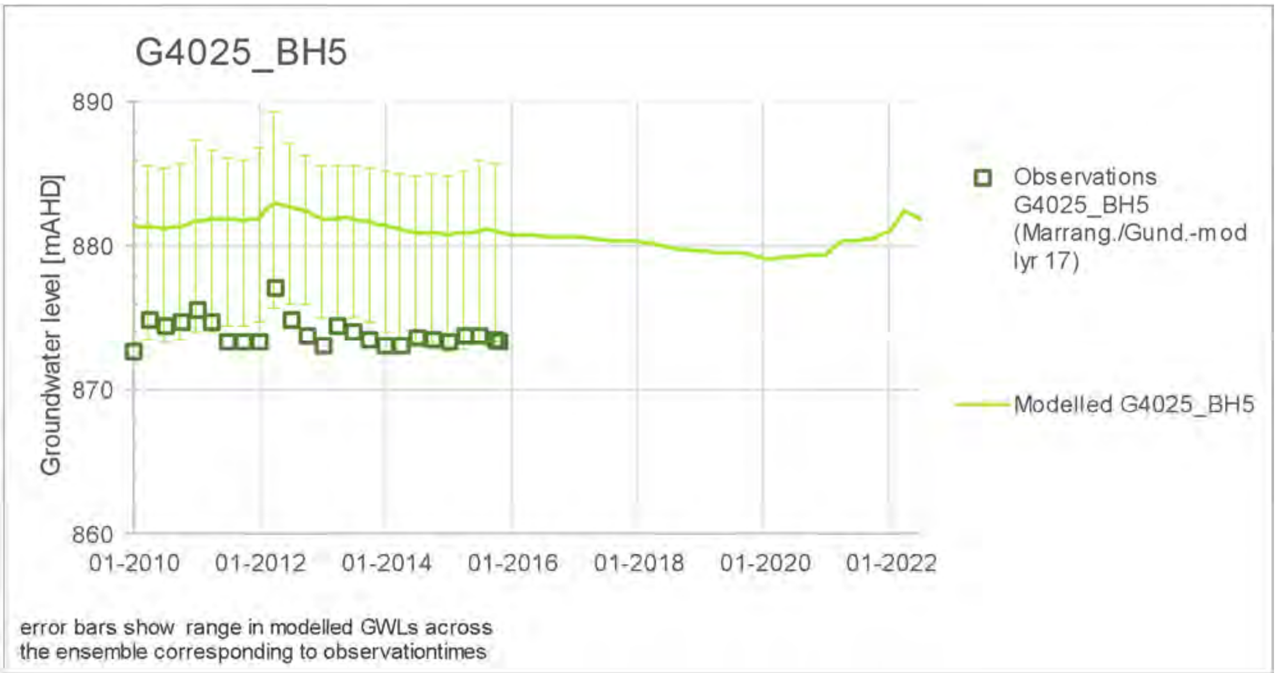
G4025_BH1



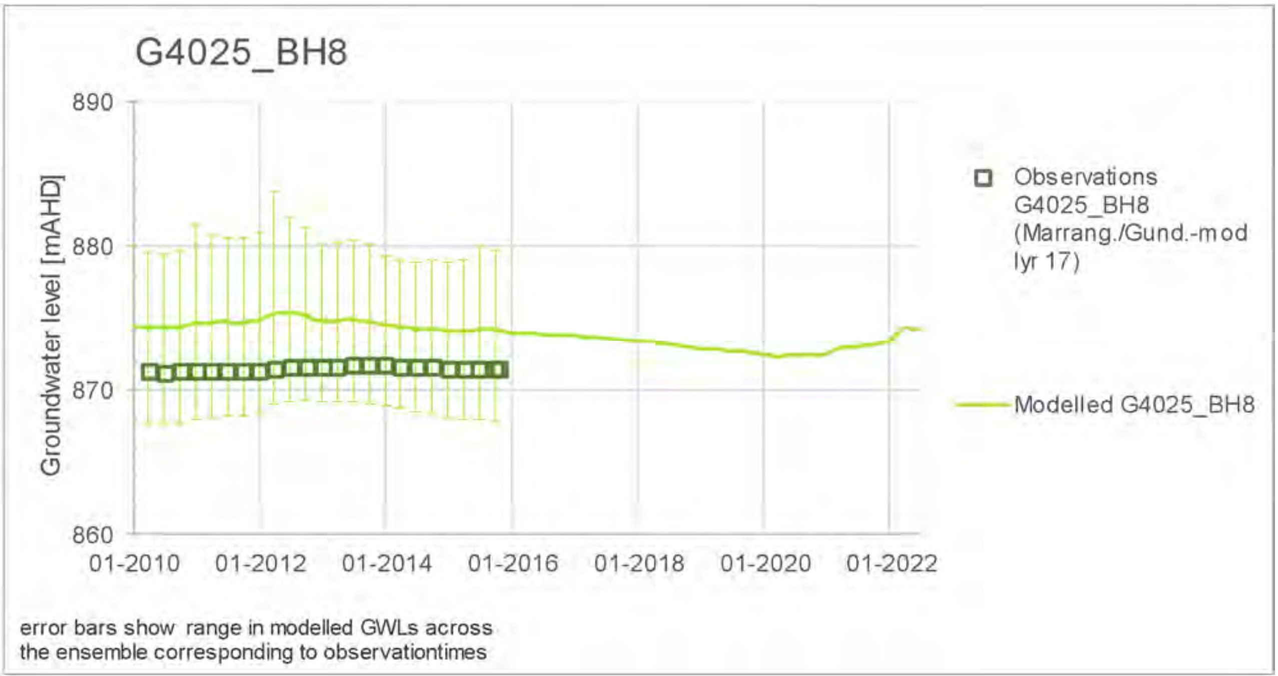
G4025_BH2



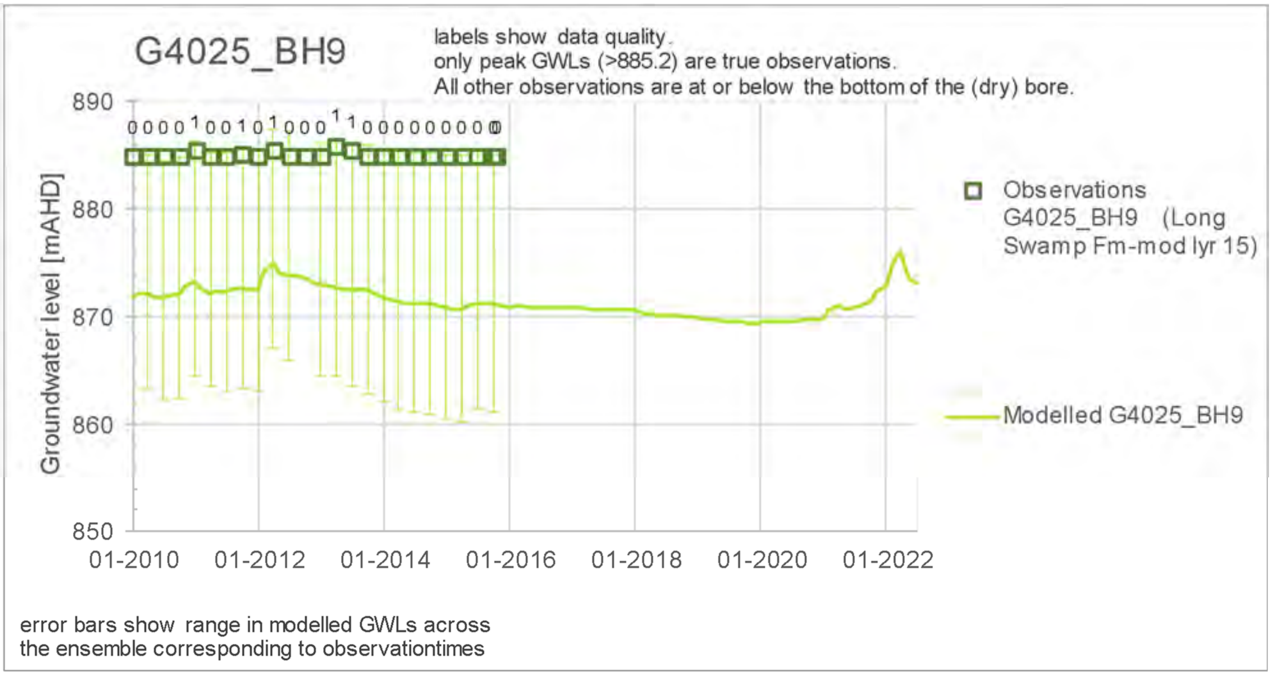
G4025_BH4



G4025_BH5



G4025_BH8



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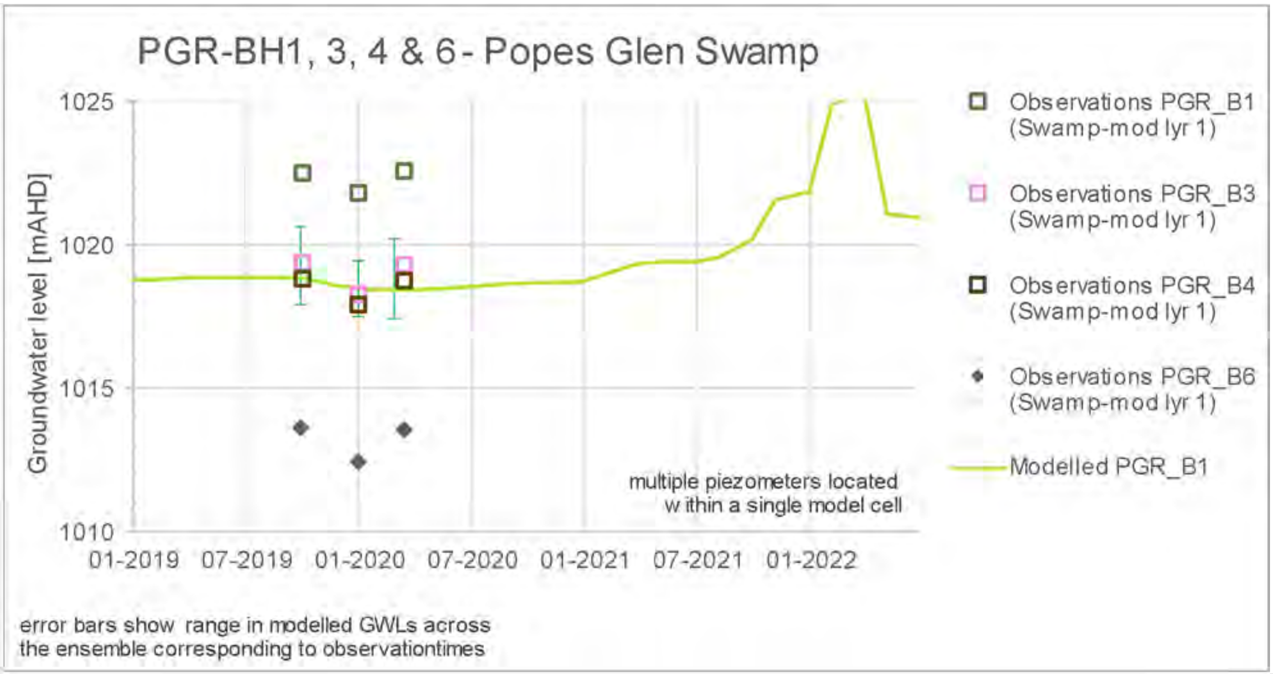
G4025_BH9



Popes Glen Swamp piezometers BH1, 3, 4 and 6

Appendix G: Model Confidence Classification

Table G1: Groundwater model confidence level classification table

Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012)

	Data		Calibration		Prediction		Key indicator	
Class 3	Spatial and temporal distribution of groundwater head observations adequately define groundwater behaviour, especially in areas of greatest interest and where outcomes are to be reported.		Adequate validation is demonstrated. **Noting that it is not widely agreed that setting aside data for verification is the best use of that information.*		Length of predictive model is not excessive compared to length of calibration period.		Key calibration statistics are acceptable and meet agreed targets.	
	Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry. (dataset is being extended)	✓	Scaled RMS error (refer Chapter 5) or other calibration statistics are acceptable.	✓	Temporal discretisation used in the predictive model is consistent with the transient calibration.	✓	Model predictive time frame is less than 3 times the duration of transient calibration. *(for construction period)*	✓
	Reliable metered groundwater extraction and injection data is available.		Long-term trends are adequately replicated where these are important.		Level and type of stresses included in the predictive model are within the range of those used in the transient calibration.		Stresses are not more than 2 times greater than those included in calibration.	
	Rainfall and evaporation data is available.	✓	Seasonal fluctuations are adequately replicated where these are important.		Model validation* suggests calibration is appropriate for locations and/or times outside the calibration model.		Temporal discretisation in predictive model is the same as that used in calibration.	
	Aquifer-testing data to define key parameters		Transient calibration is current, i.e. uses recent data.	✓	Steady-state predictions used when the model is calibrated in steady- state only.		Mass balance closure error is less than 0.5% of total.	✓
	Streamflow and stage measurements are available with reliable baseflow estimates at a number of points.		Model is calibrated to heads and fluxes.				Model parameters consistent with conceptualisation.	✓
	Reliable land-use and soil- mapping data available.		Observations of the key modelling outcomes dataset is used in calibration:				Appropriate computational methods used with appropriate spatial discretisation to model the problem. (but for detailed design, refinement of the mesh to better match construction features should be considered)	✓
			* Groundwater levels	✓				
	Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation.	✓					The model has been reviewed and deemed fit for purpose by an experienced, independent hydrogeologist with modelling experience.	✓
Class 2	Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain.	✓	Validation* is either not undertaken or is not demonstrated for the full model domain.	✓	Transient calibration over a short time frame compared to that of prediction.	✓	Key calibration statistics suggest poor calibration in parts of the model domain.	
	Metered groundwater- extraction data may be available but spatial and temporal coverage may not be extensive.		Calibration statistics are generally reasonable but may suggest significant errors in parts of the model domains).	✓	Temporal discretisation used in the predictive model is different from that used in transient calibration.		Model predictive time frame is between 3 and 10 times the duration of transient calibration. (for long-term post-construction estimates)	✓
	Streamflow data and baseflow estimates available at a few points.		Long-term trends not replicated in all parts of the model domain.		Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration.	✓	Stresses are between 2 and 5 times greater than those included in calibration.	
	Reliable irrigation-application data available in part of the area or for part of the model duration.		Transient calibration to historic data but not extending to the present day.		Validation* suggests relatively poor match to observations when calibration data is extended in time and/or space.		Temporal discretisation in predictive model is not the same as that used in calibration.	
	Aquifer-testing data to define key parameters is available, but limited	✓	Seasonal fluctuations not adequately replicated in all parts of the model domain.	✓			Mass balance closure error is less than 1% of total.	
			Observations of the key modelling outcome data set are not used in calibration (i.e. not available)				Not all model parameters consistent with conceptualisation.	
			(see above for those that are used) > no observations of groundwater drawdown, baseflow or tunnel inflow. > inferred changes in water balance are lower reliability (but countered by uncertainty analysis).	X			Spatial refinement too coarse in key parts of the model domain.	✓
							The model has been reviewed and deemed fit for purpose by an independent hydrogeologist.	
Class 1	Few or poorly distributed existing wells from which to obtain reliable groundwater and geological information.		No calibration is possible.		Predictive model time frame far exceeds that of calibration.		Model is uncalibrated or key calibration statistics do not meet agreed targets.	
	Observations and measurements unavailable or sparsely distributed in areas of greatest interest.		Calibration illustrates unacceptable levels of error especially in key areas.		Temporal discretisation is different to that of calibration.		Model predictive time frame is more than 10 times longer than transient calibration period.	✓
	No available records of metered groundwater extraction or injection.	✓	Calibration is based on an inadequate distribution of data.		Transient predictions are made when calibration is in steady state only.		Stresses in predictions are more than 5 times higher than those in calibration.	✓
	Climate data only available from relatively remote locations.		Calibration only to datasets other than that required for prediction.	✓	Model validation* suggests unacceptable errors when calibration dataset is extended in time and/or space.		Stress period or calculation interval is different from that used in calibration.	
	Little or no useful data on land-use, soils or river flows and stage elevations.						Transient predictions made but calibration in steady state only.	
	No streamflow data available	✓					Cumulative mass-balance closure error exceeds 1% or exceeds 5% at any given calculation time.	
							Model parameters outside the range expected by the conceptualisation with no further justification.	
							Unsuitable spatial or temporal discretisation.	
							The model has not been reviewed.	

Appendix H: Water supply works with predicted >2 m drawdown

Modelled drawdown at Registered Groundwater Works

GW work ID	Purpose	Easting	Northing	Strat. Unit	AIP_status?	Max drawdown [m] during construction (%ile from ensemble)				Max drawdown [m] post-construction (%ile from ensemble)				Max long-term (~2130) drawdown [m] (%ile from ensemble)			
				(modelled)		5th%ile [m]	Median [m]	95th%ile [m]	% probability of >=2m	5th%ile [m]	Median [m]	95th%ile [m]	% probability of >=2m	5th%ile [m]	Median [m]	95th%ile [m]	% probability of >=2m
GW101800	Water Supply	240043	6285091	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW028506	Irrigation	240006	6284336	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW105633	Water Supply	241053	6284234	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW108241	Water Supply	241392	6284374	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW062400	Irrigation	240560	6283920	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW062401	Irrigation	240717	6283831	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW055246	Water Supply	240016	6283011	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW104996	Water Supply	240328	6283055	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW107274	Water Supply	240411	6283174	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW111541	Monitoring	240030	6282723	Shoalhaven Group	non-water supply	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW101757	Water Supply	240175	6282514	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW104995	Water Supply	240625	6282429	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW114791_a	Water Supply	242877	6282528	Burra Moko Head Sst (lwr)	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW114791_b	Water Supply	242877	6282528	Caley Formation (upper units)	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW114791_c	Water Supply	242877	6282528	Caley Formation (lower units)	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW114791_d	Water Supply	242877	6282528	Wallerawang Subgroup (upper)	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW105519	Water Supply	240901	6282218	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW100049	Water Supply	242116	6282213	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW100172	Water Supply	242117	6282213	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW107954	Water Supply	240896	6282133	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW104752	Water Supply	240770	6281826	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW104731	Water Supply	240109	6281627	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW104862	Water Supply	240215	6281758	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW056504	Stock and Domestic	240709	6281272	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW111538	Monitoring	243002	6281003	Marrangaroo / Gundangaroo	non-water supply	0.02	0.13	0.85	0.3%	-0.45	-0.23	-0.03	0%	-0.61	-0.35	-0.11	0%
GW058892	Water Supply	244041	6281176	Caley Formation (upper units)	Water Supply (AIP)	0.00	0.00	0.05	0%	-0.02	0.00	0.01	0%	-0.06	-0.01	0.00	0%
GW100085	Water Supply	244357	6280955	Burra Moko Head Sst (lwr)	non-water supply	0.00	0.04	0.47	0%	-0.09	-0.01	0.04	0%	-0.20	-0.08	-0.02	0%
GW108604	Water Supply	241702	6280469	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.01	0%	0.00	0.00	0.01	0%
GW104994	Water Supply	240201	6280324	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW108681	Water Supply	244360	6280362	Burra Moko Head Sst (upr)	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	-0.02	0.00	0.00	0%
GW108140	Water Supply	240531	6280084	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW058247	Water Supply	244740	6280116	Mt York Claystone	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	-0.02	-0.01	0.00	0%
GW064625	Water Supply	240566	6279850	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW108313	Water Supply	240525	6279986	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW103830	Monitoring	245521	6279813	Banks Wall Sandstone (lower)	non-water supply	0.00	0.01	0.03	0%	0.00	0.00	0.01	0%	-0.07	-0.04	-0.02	0%
GW103831	Monitoring	245521	6279813	Banks Wall Sandstone (lower)	non-water supply	0.00	0.01	0.03	0%	0.00	0.00	0.01	0%	-0.07	-0.04	-0.02	0%
GW103832	Monitoring	245521	6279813	Banks Wall Sandstone (lower)	non-water supply	0.00	0.01	0.03	0%	0.00	0.00	0.01	0%	-0.07	-0.04	-0.02	0%
GW106050	Water Supply	240418	6279725	Basement	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW111533	Monitoring	245959	6279483	Banks Wall Sandstone (lower)	non-water supply	0.00	0.01	0.04	0%	-0.04	-0.01	0.00	0%	-0.13	-0.07	-0.03	0%
GW108737	Water Supply	243236	6278987	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW108737	Water Supply	243236	6278987	Shoalhaven Group	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW067317	Monitoring	250205	6277331	Banks Wall Sandstone (lower)	non-water supply	0.00	0.00	0.01	0%	0.00	0.00	0.01	0%	0.00	0.00	0.00	0%
GW016433	Irrigation	251349	6276990	Banks Wall Sst (upr) / Burralow	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW102214	Water Supply	247491	6276581	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.10	0.84	4.76	22.5%	0.08	0.52	1.46	1.7%	-0.29	-0.12	0.00	0%
GW100157	Water Supply	247536	6275842	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.09	0.68	3.14	12.1%	-0.14	0.21	0.81	0%	-0.49	-0.23	-0.05	0%
GW102030	Water Supply	247859	6275652	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.03	0.17	1.01	1.0%	-0.02	0.10	0.48	0%	-0.36	-0.10	0.05	0%
GW058022	Water Supply	248261	6275738	Banks Wall Sst (upr) / Burralow	Water Supply (AIP)	0.00	0.00	0.05	0%	0.00	0.01	0.06	0%	-0.06	0.00	0.00	0%
GW055396	Water Supply	248379	6275186	Banks Wall Sst (upr) / Burralow	Water Supply (AIP)	0.00	0.00	0.02	0%	0.00	0.00	0.03	0%	-0.06	0.00	0.00	0%
GW111780	Water Supply	248910	6274705	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.00	0.02	0%	0.00	0.01	0.03	0%	-0.05	0.00	0.02	0%
GW063579	Water Supply	249012	6274648	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.00	0.02	0%	0.00	0.01	0.03	0%	-0.04	0.00	0.02	0%
GW072282	Water Supply	249273	6274686	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.00	0.01	0%	0.00	0.01	0.03	0%	-0.02	0.00	0.02	0%
GW061195	Water Supply	249421	6274782	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.00	0.01	0%	0.00	0.01	0.02	0%	-0.02	0.00	0.01	0%
GW058199	Water Supply	248734	6274425	Banks Wall Sst (upr) / Burralow	Water Supply (AIP)	0.00	0.00	0.02	0%	0.00	0.01	0.04	0%	-0.03	0.00	0.03	0%
GW057374	Water Supply	248834	6274551	Banks Wall Sst (upr) / Burralow	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.01	0%	-0.02	0.00	0.01	0%
GW057374	Water Supply	248834	6274551	Banks Wall Sst (upr) / Burralow	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.01	0%	-0.02	0.00	0.01	0%
GW105896	Unknown	248815	6274554	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.00	0.02	0%	0.00	0.01	0.04	0%	-0.06	0.00	0.04	0%
GW107197	Water Supply	249119	6274315	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.00	0.02	0%	0.00	0.02	0.05	0%	-0.02	0.01	0.05	0%
GW057614	Water Supply	248379	6274169	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.01	0.06	0%	-0.04	0.02	0.10	0%	-0.18	-0.02	0.08	0%
GW101569	Water Supply	249683	6273745	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.00	0.03	0%	0.00	0.02	0.08	0%	0.00	0.02	0.08	0%
GW057611	Water Supply	248757	6273531	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.01	0.19	0.64	0%	0.03	0.26	0.71	0%	0.02	0.20	0.60	0%
GW058193	Water Supply	248733	6273469	Banks Wall Sst (upr) / Burralow	Water Supply (AIP)	0.01	0.24	0.79	0.3%	0.02	0.30	0.95	0%	0.01	0.22	0.64	0%
GW058236	Water Supply	248630	6273466	Banks Wall Sst (upr) / Burralow	Water Supply (AIP)	0.02	0.49	1.92	3.7%	0.08	0.52	1.66	4.7%	0.03	0.38	1.21	0%
GW059737	Water Supply	248707	6273468	Banks Wall Sst (upr) / Burralow	Water Supply (AIP)	0.01	0.26	0.82	0.3%	0.02	0.31	0.96	0.7%	0.01	0.23	0.65	0%
GW059727	Unknown	248963	6273537	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.10	0.41	0%	0.02	0.17	0.51	0%	0.01	0.13	0.45	0%
GW072891	Water Supply	248906	6273491	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.14	0.59	0%	0.02	0.22	0.67	0%	0.01	0.17	0.62	0%
GW056581	Water Supply	249017	6273476	Banks Wall Sst (upr) / Burralow	Water Supply (AIP)	0.00	0.08	0.30	0%	0.01	0.12	0.37	0%	0.00	0.09	0.29	0%

Modelled drawdown at Registered Groundwater Works

GW work ID	Purpose	Easting	Northing	Strat. Unit	AIP_status?	**Max drawdown [m] during construction** (%ile from ensemble)				**Max drawdown [m] post-construction** (%ile from ensemble)				**Max long-term (~2130) drawdown [m]** (%ile from ensemble)			
				(modelled)		5th%ile [m]	Median [m]	95th%ile [m]	% probability of >=2m	5th%ile [m]	Median [m]	95th%ile [m]	% probability of >=2m	5th%ile [m]	Median [m]	95th%ile [m]	% probability of >=2m
GW057390	Water Supply	249014	6273569	Banks Wall Sst (upr) / Burralow	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.01	0.02	0%	0.00	0.00	0.02	0%
GW058197	Water Supply	249145	6273511	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.02	0.15	0%	0.01	0.09	0.30	0%	0.01	0.09	0.30	0%
GW108316	Water Supply	248720	6273319	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.07	0.27	0%	0.04	0.18	0.49	0%	0.02	0.17	0.49	0%
GW042543	Irrigation	245162	6272974	Burra Moko Head Sst (upr)	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW061632	Water Supply	246542	6272455	Burra Moko Head Sst (upr)	Water Supply (AIP)	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW075185	Monitoring	246793	6270608	Shoalhaven Group	non-water supply	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
GW108605	Water Supply	241827	6281224	Shoalhaven Group	non-water supply	0.00	0.00	0.01	0%	0.00	0.00	0.01	0%	0.00	0.00	0.01	0%
GW058751	Water Supply	249637	6273400	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.01	0.08	0%	0.00	0.02	0.12	0%	0.00	0.04	0.15	0%
GW102618	Water Supply	248400	6275341	Banks Wall Sandstone (lower)	Water Supply (AIP)	0.00	0.00	0.08	0%	0.00	0.00	0.05	0%	0.00	0.00	0.02	0%

Notes:

+ve values represent modelled drawdown; -ve values represent groundwater mounding.

greyed out entries are not 'water supply' works that require assessment against AIP criteria

E:\WSHED\PROJ\GWH\Model\Runs\GWHv4TR013_p3_forecast\Proc\Heads\RegBores\[Hydrographs_RegisteredBores_GWHv4TR013_p3_forecast_A-B_combined.xlsx]SUMMARY

Annexure C

Project borelogs, standpipe and vibrating wire piezometer installation information

HOLE NO : BH500
FILE / JOB NO : G5331
SHEET : 1 OF 5

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Tennyson Road adjacent to Great Western Highway south of Evans Look Out Road

POSITION : E: 248196.057, N: 6273114.296 (56 GDA2020) SURFACE ELEVATION : 1053.789 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

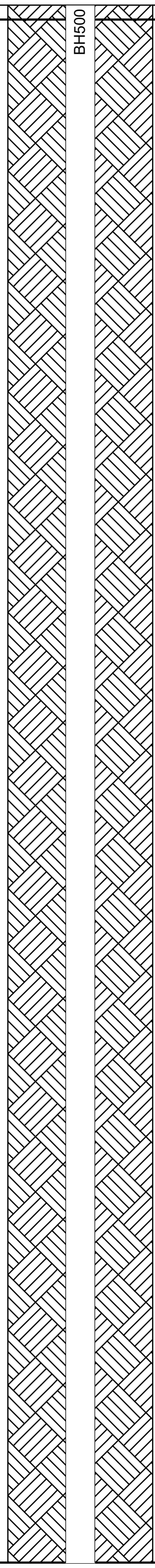
DATE STARTED : 14/9/21 DATE COMPLETED : 20/9/21 DATE LOGGED : 20/9/21 LOGGED BY : BA CHECKED BY : MD

DRILLING / MATERIAL

Drilling & Casing	Water	Ground Water Levels	Depth (m)	Classification Symbol	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic; Secondary and Minor Components)
AD/T, HW Casing (0.0–2.77m)		Not Encountered	0.0–0.55m	CI	SILTY CLAY: brown, medium plasticity, trace fine and medium grained sand
			0.55–1.30m	SC	CLAYEY SAND: grey, medium with fine grained sand, medium and low plasticity clay Sand: grey, medium grained with fine grains, with silt and clay
			1.30–2.00m	CI	SANDY CLAY: grey, medium plasticity
			2.00–2.77m		SANDSTONE AND SILTY SANDSTONE: grey 2.50m: ironstone band, ~50mm thick, sandstone, brown to orange-brown
HQ3 (2.77–8.0m)	0% Polymer LOSS (HW casing at 2.77m)		2.77–4.15m		SANDSTONE: brown, fine and medium grained, bedding at 0-5deg.; moderately weathered, very low - high strength 3.33 to 3.47m: pale grey and grey
		15/09/21, 7.50am (approx. 3.9m)	4.15–5.10m		SANDSTONE: cream, medium with fine grained; moderately weathered, low to extremely high strength 4.97 to 5.10m: ironstone band
			5.10–8.0m		SANDSTONE: brown with some orange-brown, medium and fine grained, colours in lamination and layers, bedding at 55 to 75deg.; moderately weathered, extremely low - very high strength - pale brown layer - below 7.20m, bedding variable from 0 to 75deg and occasional ironstone band, as noted

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH500	Standpipe Piezometer		34.81 m 1018.98 m AHD		



See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Tennyson Road adjacent to Great Western Highway south of Evans Look Out Road

POSITION : E: 248196.057, N: 6273114.296 (56 GDA2020) SURFACE ELEVATION : 1053.789 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 14/9/21 DATE COMPLETED : 20/9/21 DATE LOGGED : 20/9/21 LOGGED BY : BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH500	Standpipe Piezometer		34.81 m 1018.98 m AHD		

Depth (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
8.0	SANDSTONE: brown with some orange-brown, medium and fine grained, colours in lamination and layers, bedding at 55 to 75deg.; moderately weathered, extremely low - very high strength *(continued)*
9.60m	SANDSTONE: brown, medium with fine grained, trace of coarse grains.; moderately weathered, extremely low to very high strength
9.82m	CORE LOSS 0.09m (9.82-9.91)
9.91m	SANDSTONE (IRON CEMENTED): brown with some orange-brown and purple-brown, medium with coarse grained, and fine grains, with/trace fine and fine to medium quartz gravel.; moderately weathered, high - extremely high strength
10.58m	SANDSTONE: cream, medium with fine grained, trace coarse grains.; slightly weathered, medium strength
10.75m	SANDSTONE: grey with some pale grey, cream and red-brown patches, fine grained, bedding predominantly at 12-18deg.; moderately weathered, extremely low to medium strength
11.30m	SANDSTONE: brown, medium with fine grained; moderately weathered, very low to very high strength - occasional ironstone band, as noted
12.53m	SILTY SANDSTONE , SANDY SILTSTONE, SANDSTONE AND SILTSTONE: grey and pale grey, fine grained, bedding predominantly at 0-7deg.; fresh, medium to high strength
13.53m	SANDSTONE: brown with some cream, fine and medium grained, with some layers of fine grained, with trace medium grains, irregular bedding at 55-85deg.; moderately weathered, extremely low to very high strength - occasional ironstone band, as noted
16.0	

DRILLING: HQ3
WATER: 0% Polymer LOSS (HW casing at 2.77m)
GROUND WATER LEVELS: 17/09/21, 7.50am (at approx. 13.1 m)

Piezometer: Grout

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Tennyson Road adjacent to Great Western Highway south of Evans Look Out Road

POSITION : E: 248196.057, N: 6273114.296 (56 GDA2020) SURFACE ELEVATION : 1053.789 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 14/9/21 DATE COMPLETED : 20/9/21 DATE LOGGED : 20/9/21 LOGGED BY : BA CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING: HQ3; WATER: 0% Polymer LOSS (HW casing at 2.77m)); GROUND WATER LEVELS; DEPTH (m)

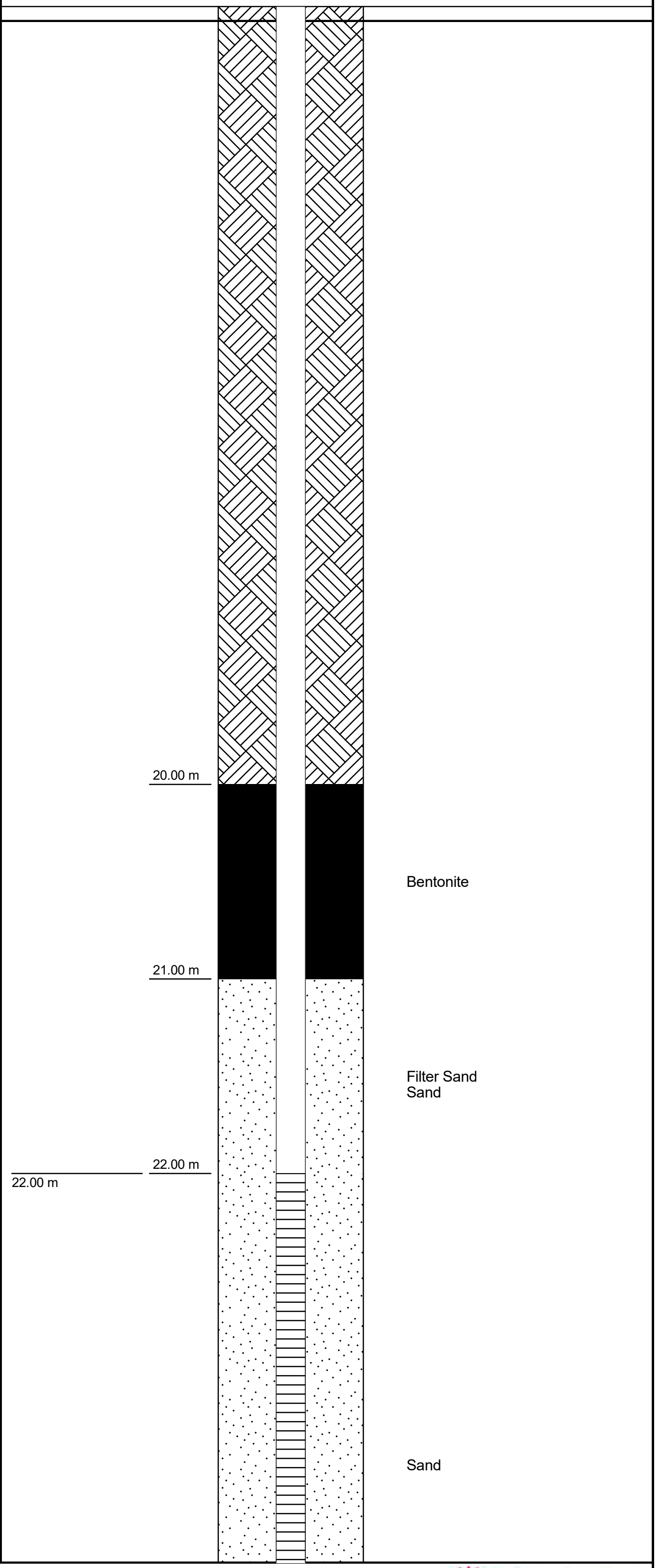
MATERIAL: GRAPHIC LOG; CLASSIFICATION SYMBOL; MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components

Depth	MATERIAL DESCRIPTION
16.0	SANDSTONE: brown with some cream, fine and medium grained, with some layers of fine grained, with trace medium grains, irregular bedding at 55-85deg.; moderately weathered, extremely low to very high strength *(continued)*
17.24m	CORE LOSS 0.62m (17.24-17.86)
17.86m	SANDSTONE: brown, medium grained, with trace fine and coarse grains, occasional trace of fine and medium quartz gravel.; extremely weathered, extremely low strength
	18.26 to 18.30m: clayey sand
18.30m	CORE LOSS 0.50m (18.30-18.80)
18.80m	SANDSTONE: cream, coarse grained, trace medium and fine grains, with fine and medium quartz gravel.; extremely weathered to moderately weathered, extremely low - very high strength
19.10m	SANDSTONE: brown, pale brown and cream, medium with fine grained, trace coarse grains, occasional trace of fine and medium quartz gravel, occasional ironstone bands down to 19.37m as noted.; extremely weathered to moderately weathered, extremely low to very high strength
	- layers of coarse grained with medium grains and trace of fine grains
20.95m	SANDSTONE (GRAVELLY): pale cream-brown, coarse with medium grained, trace of fine grains, medium/coarse to fine quartz gravel.; extremely weathered, extremely low strength
21.77m	CORE LOSS 0.53m (21.77-22.30)
22.30m	CORE LOSS 0.50m (22.30-22.80)
22.80m	CORE LOSS 0.50m (22.80-23.30)
23.30m	CORE LOSS 0.50m (23.30-23.80)
23.80m	CORE LOSS 0.45m (23.80-24.25)

Depth scale: 16.0, 17.0, 18.0, 19.0, 20.0, 21.0, 22.0, 23.0, 24.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH500	Standpipe Piezometer		34.81 m 1018.98 m AHD		



See Explanatory Notes for details of abbreviations & basis of descriptions.

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Tennyson Road adjacent to Great Western Highway south of Evans Look Out Road

POSITION : E: 248196.057, N: 6273114.296 (56 GDA2020) SURFACE ELEVATION : 1053.789 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 14/9/21 DATE COMPLETED : 20/9/21 DATE LOGGED : 20/9/21 LOGGED BY : BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH500	Standpipe Piezometer		34.81 m 1018.98 m AHD		

Drilling & casing: HQ3
Water: 0% Polymer LOSS (HW casing at 2.77m) (to 29.30m); 5% Polymer LOSS (29.30–30.30m); 0% Polymer LOSS (HW casing at 2.77m) (from 30.30m)

Depth (m)	Material Description
24.25m	CORE LOSS 0.45m (23.80-24.25) *(continued)*
24.80m	SANDSTONE: cream with some brown, coarse with medium grained, with medium and fine quartz gravel, occasional layers of medium grained sand with fine grains and trace of coarse grains, trace of fine gravel; extremely weathered, extremely low to very low strength
25.30m	CORE LOSS 0.50m (24.80-25.30)
26.30m	SANDSTONE: cream and brown, medium with fine grained, trace of coarse grains.; extremely weathered, extremely low strength
26.49m	SILTSTONE: pale grey, tuffaceous.; slightly weathered, medium strength
26.60m	SILTY SANDSTONE: with some siltstone laminations.; moderately weathered - slightly weathered, low - medium strength
27.52m	SANDSTONE: cream and brown, medium with fine grained, trace of coarse grains.; extremely weathered, extremely low strength
27.80m	CORE LOSS 0.28m (27.52-27.80) Probable location
28.60m	SANDSTONE: cream, medium with coarse grained, and trace of fine grains, occasional trace of fine and medium quartz gravel.; extremely weathered, extremely low strength
28.80m	CORE LOSS 0.20m (28.60-28.80) Probable location
29.30m	SANDSTONE: cream, medium with coarse grained, and trace of fine grains, occasional trace of fine and medium quartz gravel.; extremely weathered, extremely low strength
29.80m	CORE LOSS 0.50m (29.30-29.80)
31.00m	SANDSTONE: cream with some brown and pale brown, medium with coarse grained, and fine grains, some layers of coarse grains with medium grains and trace of fine grains.; extremely weathered, extremely low strength
31.48m	SILTY SANDSTONE WITH OCCASIONAL SILTSTONE LAYERS UP TO 170MM THICK: cream and cream to pale grey, fine with medium grained; extremely weathered, extremely low to medium strength
31.95m	SANDSTONE: cream, fine with medium grained, trace of silt.; extremely weathered, extremely low strength

Piezometer installation:

From	To	Backfill
	26.00 m	Sand (screen to 25.00 m)
26.00 m	27.00 m	Bentonite
27.00 m		Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Tennyson Road adjacent to Great Western Highway south of Evans Look Out Road

POSITION : E: 248196.057, N: 6273114.296 (56 GDA2020) SURFACE ELEVATION : 1053.789 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 14/9/21 DATE COMPLETED : 20/9/21 DATE LOGGED : 20/9/21 LOGGED BY : BA CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING: HQ3; WATER: 0% Polymer LOSS (HW casing at 2.77m)); GROUND WATER LEVELS; DEPTH (m)

MATERIAL: GRAPHIC LOG; CLASSIFICATION SYMBOL; MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components

Depth to	Material Description
32.30m	CORE LOSS 0.35m (31.95-32.30) *(continued)*
32.43m	SANDSTONE: with ironstone bands of 1 to 20mm thick.; extremely weathered - moderately weathered, extremely low and high strength
32.80m	CORE LOSS 0.37m (32.43-32.80) Location unknown (Bottom of Run - B.O.R).
32.90m	SANDSTONE: with ironstone band of 5 to 40mm thick.; extremely weathered - moderately weathered, extremely low and high strength
33.28m	CORE LOSS 0.38m (32.90-33.28) Location unknown (Bottom of Run - B.O.R).
33.40m	SANDSTONE: with ironstone bands of 3 to 20mm thick.; extremely weathered - moderately weathered, extremely low and high strength
33.51m	SANDSTONE: ironstone band of 110mm thick.; moderately weathered, high and very high strength
33.88m	TUFFACEOUS SILTSTONE: pale grey; slightly weathered, medium to high strength
34.10m	SANDSTONE: pale brown, fine with medium grained, trace of silt.; moderately weathered, medium strength
34.52m	TUFFACEOUS SILTSTONE: cream, pale grey with dark grey patches; slightly weathered, medium - high strength
34.81m	SANDY SILTSTONE , SILTY SANDSTONE, SILTSTONE AND SANDSTONE LAYERS: cream, pale grey and brown, fine grained sand.; moderately weathered - slightly weathered, medium to high strength

BH500 TERMINATED AT 34.81 m
Target depth

Depth scale: 32.0, 33.0, 34.0, 35.0, 36.0, 37.0, 38.0, 39.0, 40.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH500	Standpipe Piezometer		34.81 m 1018.98 m AHD		

Grout

34.81 m

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

NSW GOVERNMENT Transport for NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Evans Look Out road adjacent to Great Western Highway

POSITION : E: 248272.270, N: 6273356.377 (56 GDA2020) SURFACE ELEVATION : 1052.240 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 17/9/21 DATE COMPLETED : 22/9/21 DATE LOGGED : 22/9/21 LOGGED BY : DJ/RH CHECKED BY : MD

DRILLING

Depth (m)	Drilling & Casing	Water	Ground Water Levels
0.0–2.70	AD/T, HW Casing		Not Encountered
2.70	PW Casing		
2.70–8.0	HQ3	0% Water LOSS (casing at 2.50m) to 6.10	
6.10–8.0		20% Water LOSS (casing at 2.50m)	23/09/21 (at 6.10)

MATERIAL

Depth	Classification Symbol	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.00–0.80m	SM	SILTY SAND: grey, pale yellow, fine to medium grained sand, low plasticity silt
0.80–2.70m	SM	SILTY SAND: pale yellow, brown, fine to medium grained sand
2.80m		SANDSTONE: red-brown, fine and medium grained, ironstone bands; highly weathered, medium and high strength
3.00m		SANDSTONE: pale grey and yellow-brown, fine and medium grained, indistinct bedding, some siltstone clasts.; extremely weathered, extremely low strength
		SANDSTONE: pale grey, grey, yellow-brown and purple-brown, fine and medium grained, 0-5deg bedding, some siltstone bands and clasts at 3.04 - 3.50m.; extremely weathered to slightly weathered, extremely low to medium strength
3.79m		SANDSTONE: yellow-brown and pale to dark red-brown and purple-brown, fine to coarse grained, 0-5deg bedding, some ironstone bands <=80mm, trace of quartz gravel <=4mm.; extremely weathered to highly weathered, extremely low to very high strength
4.54m		CORE LOSS 1.56m (4.54-6.10)
6.10m		SANDSTONE: red-brown and dark red-brown, fine to coarse grained, indistinct bedding, ironstone bands; highly weathered, high and very high strength
6.30m		CORE LOSS 1.04m (6.30-7.34)
7.34m		SANDSTONE: yellow-brown, dark red-brown and red-brown with some purple-brown, fine and medium grained, 0-5deg bedding, trace ironstone bands <=40mm.; extremely weathered - highly weathered, very low to very high strength
7.94m		

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH500A	Standpipe		39.11 m 1013.13 m AHD		

BH500A

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH500A
FILE / JOB NO : G5331
SHEET : 2 OF 5

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Evans Look Out road adjacent to Great Western Highway

POSITION : E: 248272.270, N: 6273356.377 (56 GDA2020) SURFACE ELEVATION : 1052.240 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 17/9/21 DATE COMPLETED : 22/9/21 DATE LOGGED : 22/9/21 LOGGED BY : DJ/RH CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING: HQ3; WATER: 20% Water LOSS (casing at 2.50m)); GROUND WATER LEVELS; DEPTH (m) 8.0–16.0

MATERIAL: GRAPHIC LOG; CLASSIFICATION SYMBOL; MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components

Depth	Material Description
	CORE LOSS 0.40m (7.94-8.34) *(continued)*
8.34m	SANDSTONE: red-brown and dark red-brown, fine and medium grained, 0-5deg bedding, trace iron seams.; extremely weathered - highly weathered, extremely low and very low strength
8.50m	CORE LOSS 0.84m (8.50-9.34)
9.34m	CORE LOSS 0.32m (9.34-9.66)
9.66m	SANDSTONE: red-brown and dark red-brown, fine to coarse grained, 0-5deg bedding, some ironstone band seams <=30mm.; highly weathered, extremely low to very high strength
9.92m	SANDSTONE: off-white and pale yellow-grey, fine grained, and fine to medium grained sand, 0-5deg bedding.; moderately weathered to slightly weathered, low to high strength
11.75m	SANDSTONE AND PEBBLY SANDSTONE: pale yellow-grey, fine to coarse grained, angular to sub-rounded quartz pebbles <=10mm, 0-5deg bedding.; highly weathered to slightly weathered, very low to low strength
12.43m	SANDSTONE AND SILTSTONE: off-white, grey, dark red-brown and yellow-brown, fine grained, and fine to medium grained sand with trace of coarse grained sand, 0-60deg current bedding, some ironstone bands and layers <=80mm.; extremely weathered to moderately weathered, extremely low to very high strength
13.00m	CORE LOSS 0.54m (13.00-13.54)
13.54m	SANDSTONE: dark red-brown and brown, fine to coarse grained, 0-5deg bedding, some ironstone layers <=110mm.; extremely weathered to highly weathered, extremely low and very high strength
13.89m	CORE LOSS 0.11m (13.89-14.00)
14.00m	SANDSTONE: pale grey, pale brown-grey and purple-grey with some dark red-brown, fine with medium grained, and coarse grains, 0-5deg bedding, trace of ironstone bands <=70mm and quartz gravel <=5mm.; highly weathered to slightly weathered, low to very high strength
15.40m	CORE LOSS 0.14m (15.40-15.54)
15.54m	CORE LOSS 1.10m (15.54-16.64)

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH500A	Standpipe		39.11 m 1013.13 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH500A
FILE / JOB NO : G5331
SHEET : 3 OF 5

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Evans Look Out road adjacent to Great Western Highway

POSITION : E: 248272.270, N: 6273356.377 (56 GDA2020) SURFACE ELEVATION : 1052.240 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 17/9/21 DATE COMPLETED : 22/9/21 DATE LOGGED : 22/9/21 LOGGED BY : DJ/RH CHECKED BY : MD

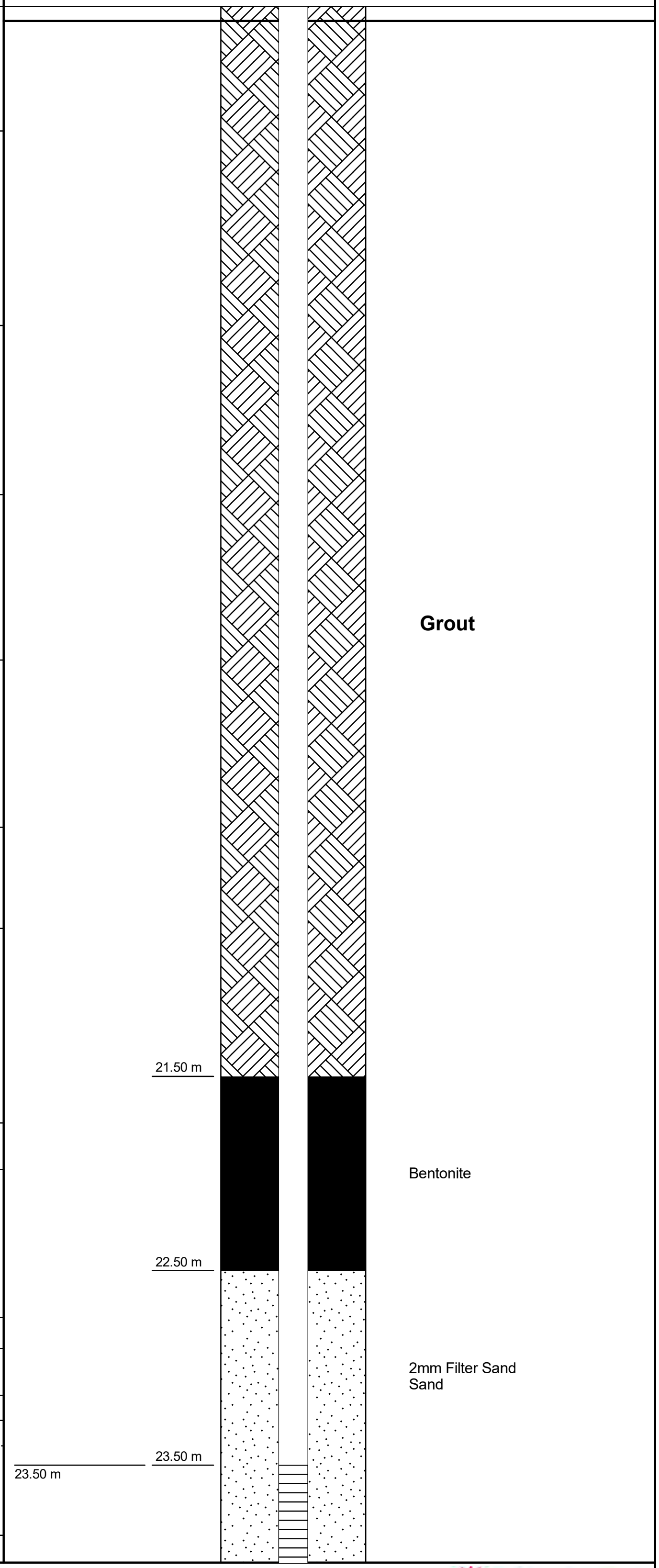
DRILLING: PROGRESS (DRILLING & CASING: HQ3; WATER: 20-5% Water LOSS (casing at 2.50m)); GROUND WATER LEVELS; DEPTH (m)
MATERIAL: GRAPHIC LOG; CLASSIFICATION SYMBOL; MATERIAL DESCRIPTION — Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components

Depth to (m)	Material Description
16.64m	CORE LOSS 1.10m (15.54-16.64) *(continued)*
17.64m	CORE LOSS 1.00m (16.64-17.64)
18.51m	SANDSTONE: pale grey, pale to dark red-brown, yellow-brown and purple-brown, fine grained, 0-5deg bedding, trace of ironstone bands <=55mm.; extremely weathered to slightly weathered, extremely low to high strength
19.36m	SANDSTONE: pale grey, pale to dark red-brown, yellow-brown and purple-brown, fine grained, 0-5deg bedding, trace of ironstone bands <=55mm.; highly weathered to moderately weathered, low to very high strength
20.22m	SANDSTONE: pale grey with some dark red-brown, fine and medium grained, 0-5deg bedding, trace of siltstone clasts and ironstone bands <=45mm.; highly weathered to slightly weathered, low to very high strength
20.74m	CORE LOSS 0.52m (20.22-20.74)
21.74m	CORE LOSS 1.00m (20.74-21.74)
21.98m	SANDSTONE AND CONGLOMERATE: dark red-brown and yellow-brown, fine to coarse grained, sub-rounded quartz gravel <=15mm, predominantly ironstone bands; highly weathered, high and very high strength
22.74m	CORE LOSS 0.76m (21.98-22.74)
22.90m	CONGLOMERATE: dark red-brown and white, fine to coarse grained sand, angular to sub-rounded quartz gravel <=20mm, ironstone bands; highly weathered, very high strength
23.14m	CORE LOSS 0.24m (22.90-23.14)
23.27m / 23.40m	CONGLOMERATE: dark red-brown and white, fine to coarse grained sand, angular to sub-rounded quartz gravel <=20mm, ironstone bands; highly weathered, very high strength
23.86m	SILTSTONE: grey, 0-60deg current bedded, trace of sandstone pockets.; extremely weathered - highly weathered, very low strength
	CONGLOMERATE AND PEBBLY SANDSTONE: pale brown-grey and pale brown, fine to coarse

Depth scale: 16.0, 17.0, 18.0, 19.0, 20.0, 21.0, 22.0, 23.0, 24.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH500A	Standpipe		39.11 m 1013.13 m AHD		



See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Evans Look Out road adjacent to Great Western Highway

POSITION : E: 248272.270, N: 6273356.377 (56 GDA2020) SURFACE ELEVATION : 1052.240 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 17/9/21 DATE COMPLETED : 22/9/21 DATE LOGGED : 22/9/21 LOGGED BY : DJ/RH CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING: HQ3; WATER: 0-5% Polymer LOSS (casing at 2.50m)); GROUND WATER LEVELS; DEPTH (m)

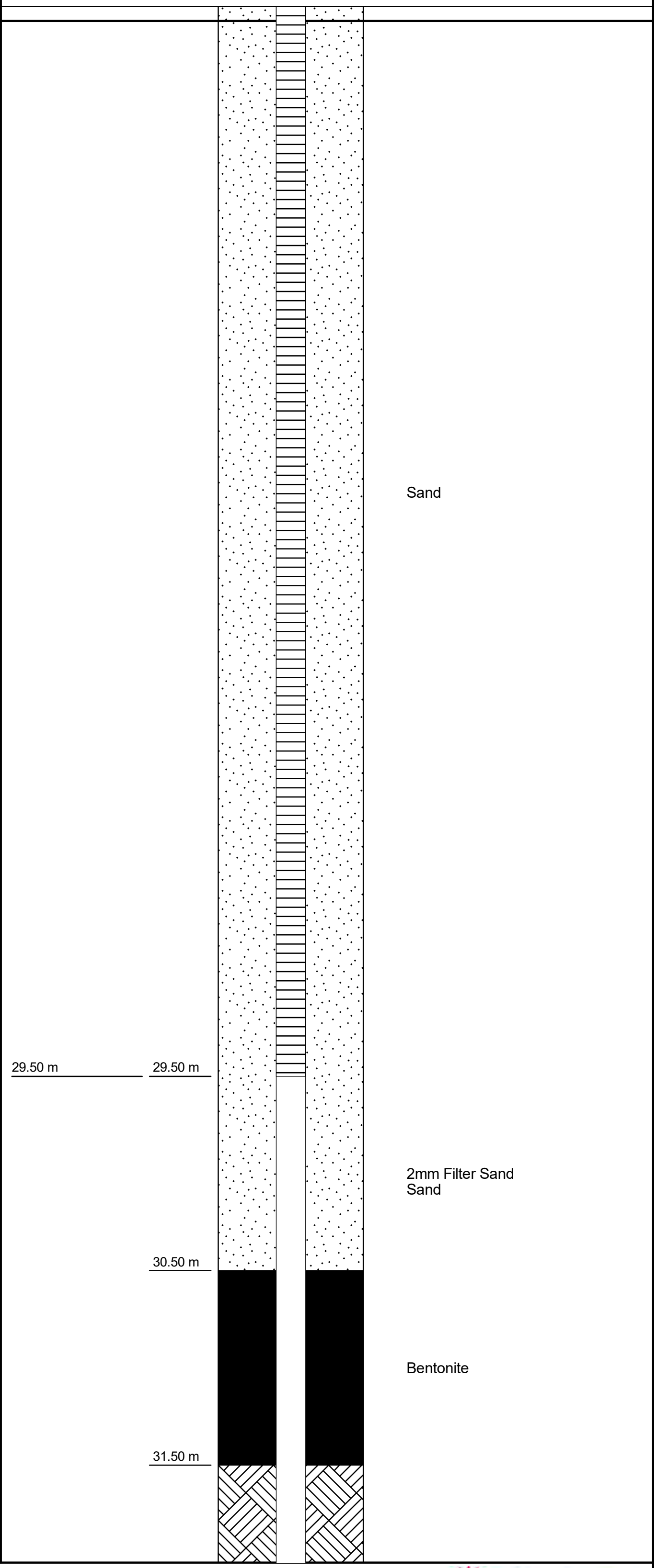
MATERIAL: GRAPHIC LOG; CLASSIFICATION SYMBOL; MATERIAL DESCRIPTION — Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components

Depth (m)	Material Description
24.12m	grained sand, angular to sub-rounded quartz gravel <=20mm, 0-5deg bedding, trace of siltstone and claystone clasts.; highly weathered, very low to low strength
	SILTSTONE AND CONGLOMERATE: grey and pale brown, conglomerate as above with siltstone clasts throughout.; extremely weathered - highly weathered, extremely low and very low strength *(continued)*
	SANDSTONE: pale grey and pale purple-grey with some dark red-brown and yellow-brown, fine grained, 0-5deg bedding, trace of ironstone bands <=30mm.; extremely weathered to slightly weathered, medium and high strength
25.27m	
25.36m	SANDSTONE (CLAYEY): pale brown-grey, some quartz gravel.; extremely weathered to highly weathered, extremely low strength
	CORE LOSS 0.48m (25.36-25.84)
25.84m	
25.93m	CONGLOMERATE AND QUARTZ PEBBLES: white and dark red-brown; highly weathered, extremely low to high strength
	CORE LOSS 1.07m (25.93-27.00)
27.00m	CORE LOSS 0.74m (27.00-27.74)
27.74m	CORE LOSS 1.00m (27.74-28.74)
28.74m	CORE LOSS 1.00m (28.74-29.74)
29.74m	SANDSTONE AND CLAYEY SANDSTONE: pale grey and yellow-brown, fine grained, with trace of medium and coarse grained sand, 0deg bedding.; extremely weathered - highly weathered, extremely low and very low strength
30.00m	CORE LOSS 0.74m (30.00-30.74)
30.74m	
30.90m	SANDSTONE AND CLAYSTONE: pale grey and pale green-grey, fine and medium grained, 0deg bedding.; extremely weathered - highly weathered, extremely low to very low strength
	CORE LOSS 0.84m (30.90-31.74)
31.74m	CORE LOSS 0.20m (31.74-31.94)
31.94m	

Depth scale: 24.0, 25.0, 26.0, 27.0, 28.0, 29.0, 30.0, 31.0, 32.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH500A	Standpipe		39.11 m 1013.13 m AHD		



TFNSW 42.1 LIB.GLB Log RTA PIEZOMETER INSTALLATION LOG G5331 BLACKHEATH TO LITTLE HARTLEY TUNNEL.GPJ <<DrawingFile>> 01/Mar/2022 16:26 10.02.00.04 Datgel Tools

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH500A
FILE / JOB NO : G5331
SHEET : 5 OF 5

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Evans Look Out road adjacent to Great Western Highway

POSITION : E: 248272.270, N: 6273356.377 (56 GDA2020) SURFACE ELEVATION : 1052.240 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 17/9/21 DATE COMPLETED : 22/9/21 DATE LOGGED : 22/9/21 LOGGED BY : DJ/RH CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING: HQ3; WATER: 0-5% Polymer LOSS (casing at 2.50m)); GROUND WATER LEVELS; DEPTH (m) 32.0–40.0

Depth	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components
32.0	SILTSTONE AND SANDY SILTSTONE: grey, with dark red-brown from 31.94 to 32.05m, fine grained sand, 0-5deg bedding.; highly weathered to fresh, medium to high strength *(continued)*
33.00m	SILTY SANDSTONE: grey and pale grey, fine grained, 0-5deg current and disturbed bedding.; fresh, high strength
33.83m	SANDY SILTSTONE AND SILTY SANDSTONE: grey and pale grey, fine grained sand, 0-5deg bedding.; fresh, medium - high strength
34.28m	SANDSTONE: pale grey becoming pale yellow-grey, fine and medium grained, 0-5deg bedding, some silty laminations.; moderately weathered to fresh, medium - high strength
35.05m	SANDSTONE: dark purple-brown, dark red-brown, red-brown and brown, fine to coarse grained, 0-5deg bedding, trace of quartz pebbles, <=5mm, some ironstone bands <=170mm and poorly cemented layers.; extremely weathered to highly weathered, extremely low to very high strength
36.00m	CORE LOSS 0.19m (36.00-36.19)
36.19m	TUFFACEOUS CLAYSTONE: green-grey with some dark red-brown, 0-5deg bedding, trace of fine grained clayey sandstone bands, ironstone sandstone band at 36.19 to 36.23m.; highly weathered to fresh, high to very high strength
36.97m	SILTY SANDSTONE (CLAYEY AND TUFFACEOUS): green-grey and purple-brown, fine grained, 0deg bedding,; moderately weathered to fresh, high strength
37.16m	SANDSTONE: pale to dark purple-brown, yellow-brown, red-brown and pale grey, fine to coarse grained, 0-5deg bedding, trace of tuffaceous claystone pockets.; highly weathered to moderately weathered, low to very high strength
37.77m	CLAYSTONE , SANDY CLAYSTONE AND CLAYEY SANDSTONE: green-grey and pale brown with some dark red-brown and red-brown, fine to coarse grained, 0-5deg bedding, sandstone layer at 38.18 to 38.28m, tuffaceous.; extremely weathered to fresh, low to very high strength
38.34m	CLAYSTONE , SANDY CLAYSTONE AND CLAYEY SANDSTONE: pale green-grey with some dark red-brown, fine and medium grained, with trace of coarse grained sand, 0-5deg bedding, tuffaceous.; highly weathered to slightly weathered, medium to high strength
39.00m	SANDSTONE: pale to dark red-brown, fine to coarse grained, 0-5deg bedding,; moderately weathered, medium strength
39.11m	BH500A TERMINATED AT 39.11 m Target depth

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH500A	Standpipe		39.11 m 1013.13 m AHD		

Grout

39.11 m

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH502
FILE / JOB NO : G5331
SHEET : 1 OF 12

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway at intersection with Hat Hill Road

POSITION : E: 248148.543, N: 6275254.052 (56 GDA2020) SURFACE ELEVATION : 1066.524 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 29/6/21 DATE COMPLETED : 31/8/21 DATE LOGGED : 31/8/21 LOGGED BY : RH/DJ/BA CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING; WATER); GROUND WATER LEVELS; DEPTH (m)

- 0.0–2.60: AD/T, HW Casing
- 2.60–8.0: HQ3, HW Casing; 0% Polymer LOSS (casing at 2.6m)
- Ground water levels: Not Encountered

MATERIAL: GRAPHIC LOG | CLASSIFICATION SYMBOL | MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)

Depth	MATERIAL DESCRIPTION
0.10m	ASPHALT: black, angular aggregate <=14mm.
0.35m	GRAVELLY SAND WITH SOME SILT: brown, fine and medium grained sand, non plastic, angular and sub-angular predominantly sandstone <=20mm gravel, with trace of coarse grained sand.
0.75m	SANDSTONE: yellow-brown, fine grained, and fine to medium grained sand, horizontally bedded.
1.50m	SANDSTONE: yellow-brown, fine grained, and fine to medium grained sand, horizontally bedded.
2.60m	SANDSTONE: yellow-brown, fine grained, and fine to medium grained sand, horizontally bedded.
3.30m	CORE LOSS 0.70m (2.60-3.30)
3.59m	SANDSTONE: dark red-brown with some purple-brown, fine to coarse grained, 0-5deg bedding, ironstone bands; highly weathered, low to high strength
6.30m	CORE LOSS 2.71m (3.59-6.30)
6.74m	CORE LOSS 0.44m (6.30-6.74)
8.00m	SANDSTONE: red-brown, fine and medium grained, with some coarse grained sand, 0-5deg bedding, ironstone bands, trace of quartz pebbles <=5mm.; extremely weathered to highly weathered, low to very high strength

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH502	Standpipe		89.00 m 977.52 m AHD		

BH502

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH502
FILE / JOB NO : G5331
SHEET : 2 OF 12

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway at intersection with Hat Hill Road

POSITION : E: 248148.543, N: 6275254.052 (56 GDA2020) SURFACE ELEVATION : 1066.524 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 29/6/21 DATE COMPLETED : 31/8/21 DATE LOGGED : 31/8/21 LOGGED BY : RH/DJ/BA CHECKED BY : MD

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH502	Standpipe		89.00 m 977.52 m AHD		

DRILLING: PROGRESS (DRILLING & CASING; WATER); GROUND WATER LEVELS; DEPTH (m)
MATERIAL: GRAPHIC LOG; CLASSIFICATION SYMBOL; MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components
PIEZOMETER CONSTRUCTION DETAILS

Drilling & casing: HW Casing (8.0–10.6 m); HQ3; HW Casing
Water: 0% Polymer LOSS (casing at 2.6m) (to 10.6 m); 0% Polymer LOSS (casing at 10.60m)

Depth (m)	Material description
8.00–8.55m	SANDSTONE: red-brown and dark red-brown, fine and medium grained, with trace of coarse grained sand, 0-5deg bedding, trace of quartz pebbles <=10mm, Fe cemented.; highly weathered, high to very high strength
8.55m–9.04m	SANDSTONE: yellow-brown and red-brown, fine and medium grained, with some coarse grained sand, 0-5deg bedding, trace of quartz pebbles <=5mm.; extremely weathered - highly weathered, extremely low to very low strength
9.04m–9.24m	CORE LOSS 0.20m (9.04-9.24)
9.24m–9.92m	SANDSTONE: red-brown and dark red-brown, fine and medium grained, with some coarse grained sand, 0-5deg bedding, trace of quartz pebbles <=4mm, ironstone bands; highly weathered, high and very high strength
9.92m–10.27m	SANDSTONE: yellow-brown and red-brown, fine to medium grained, with some coarse grained sand, 0-5deg bedding, trace ironstone bands <=25mm.; extremely weathered, extremely low strength
10.27m–10.54m	CORE LOSS 0.27m (10.27-10.54)
10.54m–11.33m	SANDSTONE: red-brown and dark red-brown, fine to coarse grained, 0-5deg bedding, trace of quartz pebbles <=3mm, predominantly ironstone bands; highly weathered, high and very high strength
11.33m–11.78m	CORE LOSS 0.45m (11.33-11.78)
11.78m–11.93m	SANDSTONE: yellow-brown, fine and medium grained, with trace of coarse grained sand, 5deg bedding, poorly cemented.; extremely weathered, extremely low strength
11.93m–12.37m	SILTY SANDSTONE: off-white and pale red-brown, fine grained, 0-5deg bedding.; extremely weathered, extremely low to very low strength
12.37m–13.55m	SANDSTONE AND SILTY SANDSTONE: pale to dark red-brown, yellow-brown and off-white with some purple-brown, fine grained, 0-5deg bedding, trace ironstone bands <=40mm.; extremely weathered to moderately weathered, extremely low to very low strength
13.55m–13.74m	CORE LOSS 0.19m (13.55-13.74)
13.74m–13.96m	SANDSTONE: off-white, yellow-brown, dark red-brown, fine grained, 0-5deg bedding, ironstone bands at 13.80 - 13.84m.; extremely weathered to moderately weathered, extremely low to very low strength
13.96m–14.64m	SILTY SANDSTONE AND SANDSTONE: off-white, pale grey and pale purple-grey with some red-brown, fine grained, with trace of medium and coarse grained sand, 0deg bedding, ironstone bands 14.59 - 14.62m.; extremely weathered to slightly weathered, very low to medium strength
14.64m–14.80m	CORE LOSS 0.16m (14.64-14.80)
14.80m–15.15m	SANDSTONE: yellow-brown and red-brown, fine and medium grained, with some coarse grained sand, 0deg bedding, trace of quartz pebbles <=8mm.; extremely weathered, extremely low strength
15.15m–15.58m	SANDSTONE (CLAYEY): off-white and yellow-brown, fine and medium grained, with trace of coarse grained sand, 0-5deg bedding, trace of ironstone bands; extremely weathered to highly weathered, extremely low to very low strength
15.58m–16.0	

Piezometer: Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway at intersection with Hat Hill Road

POSITION : E: 248148.543, N: 6275254.052 (56 GDA2020) SURFACE ELEVATION : 1066.524 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 29/6/21 DATE COMPLETED : 31/8/21 DATE LOGGED : 31/8/21 LOGGED BY : RH/DJ/BA CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING; WATER); GROUND WATER LEVELS; DEPTH (m)
MATERIAL: GRAPHIC LOG; CLASSIFICATION SYMBOL; MATERIAL DESCRIPTION — Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components

Drilling & casing: HQ3; HW Casing
Water: 0% Polymer LOSS (casing at 10.60m)

Depth (m)	Material Description
16.03m	SANDSTONE: yellow-brown and pale to dark red-brown, fine and medium grained, 0-5deg bedding, trace ironstone bands <=40mm.; extremely weathered to highly weathered, extremely low to high strength *(continued)*
	CORE LOSS 1.51m (16.03-17.54)
17.54m	CORE LOSS 0.70m (17.54-18.24)
18.24m	CORE LOSS 1.50m (18.24-19.74)
19.74m	SANDSTONE: pale to dark red-brown and yellow-brown with some off-white, fine to coarse grained, 0-5deg bedding, trace and some quartz pebbles <=20mm, trace ironstone bands and layers <=80mm.; extremely weathered to highly weathered, extremely low to high strength
20.75m	CORE LOSS 0.49m (20.75-21.24)
21.24m	SANDSTONE: pale to dark red-brown and yellow-brown, fine and medium grained, with trace of coarse grained sand, 0-5deg bedding, ironstone layer at 21.31 - 21.50m.; extremely weathered to highly weathered, extremely low to high strength
21.87m	CORE LOSS 0.37m (21.87-22.24)
22.24m	SANDSTONE: off-white and pale yellow-brown, fine and medium grained, with trace of coarse grained sand, 0-5deg bedding, poorly cemented.; extremely weathered, extremely low strength
22.95m	CORE LOSS 1.29m (22.95-24.24)

Depth scale: 16.0, 17.0, 18.0, 19.0, 20.0, 21.0, 22.0, 23.0, 24.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH502	Standpipe		89.00 m 977.52 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

HOLE NO : **BH502**
FILE / JOB NO : G5331
SHEET : 4 OF 12

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway at intersection with Hat Hill Road

POSITION : E: 248148.543, N: 6275254.052 (56 GDA2020) SURFACE ELEVATION : 1066.524 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

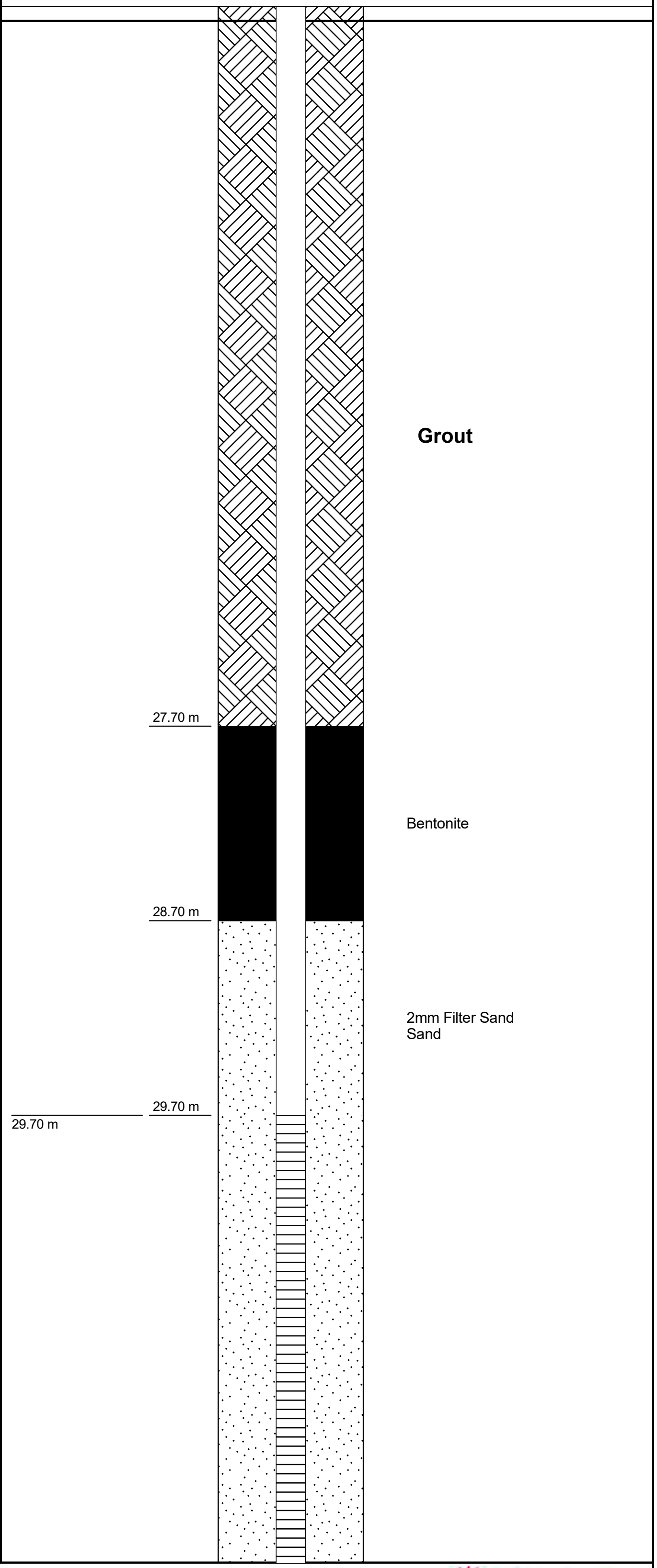
DATE STARTED : 29/6/21 DATE COMPLETED : 31/8/21 DATE LOGGED : 31/8/21 LOGGED BY : RH/DJ/BA CHECKED BY : MD

DRILLING: PROGRESS — DRILLING & CASING: HQ3, HW Casing; WATER: 0% Polymer LOSS (casing at 10.60m)

DEPTH (m)	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components
24.0 – 24.24m	CORE LOSS 1.29m (22.95-24.24) *(continued)*
24.24m – 25.03m	SANDSTONE: yellow-brown and pale to dark red-brown, fine grained, fine to medium grained sand, 0-5deg bedding, some horizontal and vertical ironstone bands <=10mm.; extremely weathered to highly weathered, extremely low - low strength
25.03m – 25.64m	CORE LOSS 0.61m (25.03-25.64)
25.64m – 27.14m	SANDSTONE: yellow-brown and pale to dark red-brown with some grey and off-white, fine and medium grained, with trace of coarse grained sand, 0-5deg bedding, trace ironstone bands and zones <=260mm.; extremely weathered to highly weathered, extremely low to very high strength
27.14m – 27.24m	CORE LOSS 0.10m (27.14-27.24)
27.24m – 28.26m	SANDSTONE: yellow-brown and pale to dark red-brown with some pale grey and off-white, fine and medium grained, becoming fine to coarse grained sand, 0-5deg bedding, ironstone layer at 27.75 - 28.26m.; extremely weathered to highly weathered, extremely low to very high strength
28.26m – 28.74m	CORE LOSS 0.48m (28.26-28.74)
28.74m – 29.10m	SANDSTONE: red-brown and dark red-brown, fine and medium grained, with trace of coarse grained sand, 0-5deg bedding, trace of quartz pebbles <=10mm, predominantly Fe cemented.; highly weathered, very low and very high strength
29.10m – 30.24m	CORE LOSS 1.14m (29.10-30.24)
30.24m – 31.15m	SANDSTONE AND PEBBLY SANDSTONE: pale to dark red-brown, yellow-brown and off-white, fine to coarse grained, angular to sub-rounded quartz pebbles <=15mm, trace ironstone bands and layers <=60mm, claystone pockets at 30.24 - 30.36m, 0-5deg bedding.; extremely weathered to highly weathered, extremely low to very high strength
31.15m – 31.82m	CORE LOSS 0.67m (31.15-31.82)
31.82m – 32.0	CORE LOSS 1.42m (31.82-33.24)

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH502	Standpipe		89.00 m 977.52 m AHD		



PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway at intersection with Hat Hill Road

POSITION : E: 248148.543, N: 6275254.052 (56 GDA2020) SURFACE ELEVATION : 1066.524 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 29/6/21 DATE COMPLETED : 31/8/21 DATE LOGGED : 31/8/21 LOGGED BY : RH/DJ/BA CHECKED BY : MD

DRILLING: Drilling & Casing	DRILLING: Water	Ground Water Levels	Depth (m)	Graphic Log	Classification Symbol	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
HQ3 / HW Casing	0% Polymer LOSS (casing at 10.60m)		32.0			CORE LOSS 1.42m (31.82-33.24) *(continued)*
			33.24m			SANDSTONE AND CLAYEY SANDSTONE: off-white and dark red-brown, fine to coarse grained, 0-5deg bedding, trace and some quartz pebbles <=10mm, trace ironstone bands <=50mm.; extremely weathered - highly weathered, extremely low and very high strength
	10% Polymer LOSS (casing at 10.60m)		33.62m			CORE LOSS 1.12m (33.62-34.74)
			34.74m			SANDSTONE: dark-red-brown, fine to coarse grained, ironstone bands; highly weathered, high and very high strength
			34.88m			CORE LOSS 1.36m (34.88-36.24)
			36.24m			TUFFACEOUS CLAYSTONE: dark red-brown, brown-grey, yellow-brown and grey, 0-5deg bedding, trace of closed joint at 10-45deg.; highly weathered to slightly weathered, low - high strength
						- as above, pale to dark maroon-brown and pale green-grey
			38.98m			SILTSTONE: dark purple-brown and yellow-brown, 0-5deg bedding, trace of fine grained sand, some closed joints at 10-90deg.; highly weathered, medium - high strength
			39.36m			SANDSTONE: yellow-brown, red-brown and dark purple-brown with some pale yellow-grey, fine grained, 0-5deg bedding, trace of sandy siltstone bands, ironstone bands <=50mm.; extremely weathered to moderately weathered, extremely low - high strength
			40.00m			

Depth scale: 32.0, 33.0, 34.0, 35.0, 36.0, 37.0, 38.0, 39.0, 40.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH502	Standpipe		89.00 m 977.52 m AHD		

Depth	Backfill
to 35.70 m	Sand
35.70 m – 36.70 m	2mm Filter Sand Sand
36.70 m – 37.70 m	Bentonite
37.70 m –	**Grout**

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway at intersection with Hat Hill Road

POSITION : E: 248148.543, N: 6275254.052 (56 GDA2020) SURFACE ELEVATION : 1066.524 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 29/6/21 DATE COMPLETED : 31/8/21 DATE LOGGED : 31/8/21 LOGGED BY : RH/DJ/BA CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING: HQ3, HW Casing; WATER: 10% Polymer LOSS (casing at 10.60m)); GROUND WATER LEVELS; DEPTH (m)

MATERIAL: GRAPHIC LOG; CLASSIFICATION SYMBOL; MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components

Depth to (m)	MATERIAL DESCRIPTION
40.25m	SANDSTONE: yellow-brown, fine to coarse grained, 0-5deg bedding.; extremely weathered, extremely low strength
42.24m	CORE LOSS 1.99m (40.25-42.24)
42.89m	SANDSTONE: yellow-brown, red-brown and off-white, fine to coarse grained, 0-5deg bedding, trace of quartz pebbles <=8mm, poorly cemented.; extremely weathered to highly weathered, extremely low to very low strength
43.74m	CORE LOSS 0.85m (42.89-43.74)
44.59m	SANDSTONE: off-white and pale red-brown with some dark red-brown, fine to coarse grained, 0-5deg bedding, Fe cemented layer at 44.47 - 44.59m, predominantly poorly cemented.; extremely weathered to highly weathered, extremely low to very high strength
45.24m	CORE LOSS 0.65m (44.59-45.24)
45.85m	CLAYSTONE , CLAYEY SANDSTONE AND SANDSTONE: pale green-grey with some yellow-brown and purple-brown, fine and medium grained, with trace of coarse grained sand, 0-5deg bedding.; moderately weathered, extremely low - medium strength
46.20m	SANDSTONE: yellow-brown and red-brown, fine to coarse grained, 0-5deg bedding, trace of ironstone bands <=10mm.; extremely weathered to moderately weathered, extremely low and low strength
46.36m	CORE LOSS 0.16m (46.20-46.36)
48.00m	SANDSTONE: off-white, red-brown, yellow-brown and pale yellow-grey, fine to coarse grained, 0-5deg bedding, trace of claystone clasts <=20mm.; extremely weathered to highly weathered, extremely low - low strength

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH502	Standpipe		89.00 m 977.52 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway at intersection with Hat Hill Road

POSITION : E: 248148.543, N: 6275254.052 (56 GDA2020) SURFACE ELEVATION : 1066.524 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 29/6/21 DATE COMPLETED : 31/8/21 DATE LOGGED : 31/8/21 LOGGED BY : RH/DJ/BA CHECKED BY : MD

DRILLING | MATERIAL | PIEZOMETER CONSTRUCTION DETAILS

Depth (m)	Drilling & Casing	Water	Depth to boundary	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
48.0–49.40	HW Casing (to 51.0); HQ3	10% Polymer LOSS (casing at 10.60m)	49.40m	SANDSTONE: off-white, pale red, grey with some red-brown, fine to coarse grained, 0-5deg bedding, trace of quartz pebbles <=4mm, ironstone bands <=10mm.; extremely weathered to moderately weathered, extremely low to low strength
49.40–49.74			49.74m	CORE LOSS 0.34m (49.40-49.74)
49.74–49.91			49.91m	CLAYSTONE: green-grey, 0-5deg bedding, sandstone at 49.86 - 49.91m.; moderately weathered, very low - low strength
49.91–51.24		10% Polymer LOSS to 51.24	51.24m	CORE LOSS 1.33m (49.91-51.24)
51.24–51.85		20% Polymer LOSS	51.85m	CORE LOSS 0.61m (51.24-51.85)
51.85–54.44		20% Polymer LOSS (to ~52.7); 30% Polymer LOSS	54.44m	SANDSTONE: brown, pale yellow, grey, off-white, medium to coarse grained, planar to irregular ironstone bands ~20mm.; extremely weathered - highly weathered, extremely low to very high strength 53.26 - 53.46m: siltstone
54.44–55.94		100% Polymer LOSS	55.94m	CORE LOSS 1.50m (54.44-55.94)

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH502	Standpipe		89.00 m 977.52 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway at intersection with Hat Hill Road

POSITION : E: 248148.543, N: 6275254.052 (56 GDA2020) SURFACE ELEVATION : 1066.524 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 29/6/21 DATE COMPLETED : 31/8/21 DATE LOGGED : 31/8/21 LOGGED BY : RH/DJ/BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH502	Standpipe		89.00 m 977.52 m AHD		

Drilling & Casing	Water	Depth (m)	Depth of boundary	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
HQ3	50% Polymer LOSS	56.0		CORE LOSS 1.06m (55.94-57.00) *(continued)*
		57.0	57.00m	TUFFACEOUS CLAYSTONE: grey; moderately weathered, medium strength
	40% Polymer LOSS		57.35m	SANDSTONE: pale grey, yellow, brown, medium to coarse grained; highly weathered to moderately weathered, extremely low to high strength
		58.0		- as above, grey, off-white, dark brown locally
			58.50m	CORE LOSS 0.44m (58.50-58.94)
	40% Polymer LOSS	59.0	58.94m	CORE LOSS 0.25m (58.94-59.19)
			59.19m	SANDSTONE: pale yellow, brown, grey some pink, fine to coarse grained, planar to distinct curved ironstone bands; highly weathered - moderately weathered, very low strength
		60.0	60.44m	CORE LOSS 0.21m (60.44-60.65)
	20% Polymer LOSS	61.0	60.65m	TUFFACEOUS CLAYSTONE: red-brown, grey; moderately weathered - slightly weathered, medium strength
			61.50m	SANDSTONE: yellow-brown, grey, fine to coarse grained, 0-5deg bedding, trace planar ironstone bands.; moderately weathered, low - medium strength
	30% Polymer LOSS	62.0	61.85m	SILTSTONE: grey to pale grey, 0-5deg bedding, occasional sandy laminations.; moderately weathered, medium strength
		63.0	63.02m	SANDSTONE: brown to orange-brown, medium with fine grained, trace of coarse grains, 0-5deg bedding, occasional patchy current bedding.; moderately weathered, very low to very high strength 63.38 - 63.43m: ironstone bands 63.68 - 64.13m: sandstone as previous with ironstone bands up to 35mm
		64.0		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway at intersection with Hat Hill Road

POSITION : E: 248148.543, N: 6275254.052 (56 GDA2020) SURFACE ELEVATION : 1066.524 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 29/6/21 DATE COMPLETED : 31/8/21 DATE LOGGED : 31/8/21 LOGGED BY : RH/DJ/BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH502	Standpipe		89.00 m 977.52 m AHD		

DRILLING: PROGRESS – DRILLING & CASING: HQ3; WATER: 30% Polymer LOSS

Depth (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
64.13m	SANDSTONE: cream with pale brown, medium with fine grained, trace of coarse grains, 0-8deg bedding.; highly weathered, very low to low strength
65.00m	SANDSTONE: brown, pale brown and some cream, medium and coarse grained, trace of fine grains, occasional layers of coarse grained with/trace of medium grains, with ironstone bands of 2 to 50mm thick.; highly weathered, very low to very high strength
66.20m	CORE LOSS 0.24m (66.20-66.44)
66.44m	SANDSTONE: brown, pale brown and some cream, medium and coarse grained, trace of fine grains, occasional layers of coarse grained with/trace of medium grains, with ironstone bands of 2 to 50mm thick.; highly weathered - moderately weathered, very low - very high strength 66.7 - 66.80m: ironstone band, 100mm thick
67.42m	CORE LOSS 0.42m (67.42-67.84) Location unknown, Bottom of Run (B.O.R)
67.84m	SANDSTONE: brown, pale brown and some cream, Layers of: coarse grained with medium grains; coarse grained with medium and fine grains; coarse and medium grained; medium grained with fine grains and trace of coarse grained, with ironstone bands with variable thickness from 2 to 30mm.; extremely weathered to moderately weathered, extremely low - very high strength 68.18 - 68.23m: sandy siltstone
69.34m	CORE LOSS 0.10m (69.34-69.44) Location unknown, Bottom of Run (B.O.R)
69.44m	SANDSTONE: cream, brown, pale brown, medium to coarse grained, planar to distinct curved ironstone bands; moderately weathered, medium strength
70.15m	SILTSTONE: grey, pale grey, 0-5deg bedding.; moderately weathered, medium - high strength
70.40m	SANDSTONE: pale brown, brown some cream, medium to coarse grained, 0-5deg bedding, local ironstone bands ~10mm thick.; moderately weathered, very low to medium strength

Depth scale: 64.0 – 72.0 m

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

NSW GOVERNMENT Transport for NSW

HOLE NO : BH502
FILE / JOB NO : G5331

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway at intersection with Hat Hill Road

POSITION : E: 248148.543, N: 6275254.052 (56 GDA2020) SURFACE ELEVATION : 1066.524 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 29/6/21 DATE COMPLETED : 31/8/21 DATE LOGGED : 31/8/21 LOGGED BY : RH/DJ/BA CHECKED BY : MD

DRILLING: PROGRESS — DRILLING & CASING: HQ3; WATER: 0-5% Polymer LOSS; GROUND WATER LEVELS

Depth (m)	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components
72.11m – 72.16m	CORE LOSS 0.05m (72.11-72.16)
72.16m – 72.24m	SANDSTONE: pale brown, brown some cream, medium to coarse grained, 0-5deg bedding, local ironstone bands ~10mm thick.; highly weathered, medium strength
72.24m – 72.68m	CLAYSTONE AND SANDY CLAYSTONE: pale green-grey with some purple-brown, red-brown and yellow-brown, fine grained, 0-5deg bedding.; moderately weathered to slightly weathered, medium strength
72.68m – 72.88m	SANDSTONE: pale to dark red-brown, yellow-brown, fine to coarse grained, 0-5deg bedding, with ferruginous bands <=30mm.; highly weathered, very low to medium strength
72.88m – 73.05m	CORE LOSS 0.17m (72.88-73.05)
73.05m – 75.10m	SANDSTONE: off-white, pale to dark red-brown and yellow-brown, fine to coarse grained, 0-15deg cross bedding, trace and some Fe cemented bands <=15mm.; highly weathered to slightly weathered, extremely low and medium strength
75.10m – 75.48m	CLAYSTONE: pale green-grey, 0deg bedding.; slightly weathered, medium strength
75.48m – 75.77m	SANDSTONE: pale to dark red-brown, yellow-brown and purple-brown, fine to coarse grained, 0deg bedding, ironstone bands throughout.; highly weathered, extremely low to very high strength
75.77m – 76.00m	CORE LOSS 0.23m (75.77-76.00)
76.00m – 76.52m	SANDSTONE: red-brown, dark red-brown, yellow-brown and off-white, fine to coarse grained, 0-5deg bedding, with ironstone bands <=80mm.; highly weathered, extremely low to very high strength
76.52m – 76.90m	CORE LOSS 0.38m (76.52-76.90)
76.90m – 79.39m	SANDSTONE: yellow-brown, red-brown, pale yellow-grey, fine to coarse grained, 0-5deg bedding, trace ironstone bands <=20mm to 40mm.; highly weathered to moderately weathered, extremely low and very high strength
79.39m – 79.60m	CLAYSTONE: grey, pale grey, tuffaceous, 0-5deg bedding.; highly weathered to moderately weathered, medium strength
79.60m – 80.00m	SANDSTONE: yellow-brown, red-brown, pale yellow, grey, fine to coarse grained, 0-5deg bedding, planar to distinctly curved ironstone bands.; highly weathered to moderately

Depth scale: 72.0, 73.0, 74.0, 75.0, 76.0, 77.0, 78.0, 79.0, 80.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH502	Standpipe		89.00 m 977.52 m AHD		

Grout

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway at intersection with Hat Hill Road

POSITION : E: 248148.543, N: 6275254.052 (56 GDA2020) SURFACE ELEVATION : 1066.524 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 29/6/21 DATE COMPLETED : 31/8/21 DATE LOGGED : 31/8/21 LOGGED BY : RH/DJ/BA CHECKED BY : MD

DRILLING — PROGRESS: DRILLING & CASING: HQ3; WATER: 0% Polymer LOSS; GROUND WATER LEVELS

MATERIAL

DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components
80.0			weathered, medium to very high strength
			SANDSTONE: yellow-brown, red-brown, pale yellow, grey, medium to coarse grained, 0-5deg bedding, planar to distinctly curved ironstone bands <=20mm to 40mm.; moderately weathered to slightly weathered, low to high strength
82.20			82.20 - 82.30m: as above, with thin layer of claystone and fine grained sandstone
83.42m			SANDSTONE: brown, yellow-brown, red-brown, grey, medium to coarse grained, 0-5deg bedding, planar to distinctly curved ironstone bands <=20mm to 40mm.; moderately weathered to slightly weathered, low to high strength
85.55m			SANDSTONE: grey, brown, pale yellow, red-brown, fine to coarse grained, 0-5deg bedding, planar to distinctly curved ironstone bands <=20mm.; moderately weathered to slightly weathered, medium to high strength
87.16m			SANDSTONE: grey, off-white, yellow-brown, coarse with medium grained, and fine grains, 0-5deg bedding, local ironstone bands <10mm.; moderately weathered to slightly weathered, low strength
88.00m			

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH502	Standpipe		89.00 m 977.52 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

HOLE NO : BH502
FILE / JOB NO : G5331
SHEET : 12 OF 12

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway at intersection with Hat Hill Road

POSITION : E: 248148.543, N: 6275254.052 (56 GDA2020) SURFACE ELEVATION : 1066.524 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 29/6/21 DATE COMPLETED : 31/8/21 DATE LOGGED : 31/8/21 LOGGED BY : RH/DJ/BA CHECKED BY : MD

DRILLING & CASING	WATER	GROUND WATER LEVELS	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components
HQ3	0% Polymer LOSS		88.0 – 89.44			SANDSTONE: grey, off-white, yellow-brown, medium to coarse grained, 0-5deg bedding.; moderately weathered to slightly weathered, low to medium strength
			89.44m			BH502 TERMINATED AT 89.44 m Target depth

Depth scale: 88.0, 89.0, 90.0, 91.0, 92.0, 93.0, 94.0, 95.0, 96.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH502	Standpipe		89.00 m 977.52 m AHD		

Grout

89.00 m

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

NSW GOVERNMENT Transport for NSW

HOLE NO : BH505A
FILE / JOB NO : G5331
SHEET : 1 OF 7

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

DRILLING / MATERIAL

Drilling & Casing: AD/T – HW Casing (0.0–1.0 m); HW Casing (1.0–1.4 m); HW Casing (1.4–2.4 m); HQ3 (1.0–8.0 m)

Water: N/A (0.0–1.0 m); 0% Polymer LOSS (HW casing at 1.10m) (1.0–8.0 m)

Ground water levels: Not Encountered

Depth (m)	Material Description
0.00–0.55m	SILTY SAND: brown, medium and fine grained sand, trace of clay
0.55–1.00m	SANDSTONE: cream, medium with fine grained, trace of coarse grains.
1.00–1.08m	CORE LOSS 0.08m (1.00-1.08)
1.08–1.47m	SANDSTONE: cream, medium with fine grained, trace/with coarse grains.; extremely weathered to highly weathered, extremely low - medium strength
1.47–1.93m	TUFFACEOUS CLAYSTONE: grey; moderately weathered, medium strength
1.93–2.26m	SANDSTONE: cream, medium with fine grained, trace/with coarse grains.; highly weathered, low strength
2.26–5.20m	SANDSTONE: brown and orange-brown, medium and fine grained, with coarse grains, trace of fine quartz gravel, occasional ironstone bands with variable thickness between 1 and 10mm.; extremely weathered to highly weathered, extremely low - very high strength
5.20–5.65m	TUFFACEOUS CLAYSTONE: grey; moderately weathered, medium strength
5.65–7.02m	SANDSTONE: cream, brown and pale brown bands, medium with fine grained, trace of coarse grains, occasionalironstone bands of variable thickness from 1 to 70mm.; extremely weathered to highly weathered, extremely low - medium strength
7.02–7.29m	TUFFACEOUS CLAYSTONE: grey; moderately weathered, medium strength
7.29–8.00m	SANDSTONE: cream, brown and pale brown bands, medium with fine grained, trace of coarse grains, occasional ironstone bands of variable thickness from 1 to 70mm.; extremely weathered to moderately weathered, extremely low to very high strength

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505	Standpipe Piezometer		53.00 m 982.51 m AHD		

BH505

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

NSW GOVERNMENT Transport for NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505	Standpipe Piezometer		53.00 m 982.51 m AHD		

DRILLING: PROGRESS (DRILLING & CASING: HQ3; WATER: 0% Polymer LOSS (HW casing at 1.10m)), GROUND WATER LEVELS

DEPTH (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)	Piezometer
8.0 – 11.55m	SANDSTONE: cream, brown and pale brown bands, medium with fine grained, trace of coarse grains, occasional ironstone bands of variable thickness from 1 to 70mm.; extremely weathered to moderately weathered, extremely low to very high strength *(continued)* 8.52 to 8.61m: sandstone, grey, fine grained 8.85 to 8.92m: tuffaceous claystone	Grout
11.55m – 13.81m	SANDSTONE: brown with pale brown and cream bands, medium with fine grained, and coarse grains, trace of fine quartz gravel, bedding predominantly at 0-10deg.; moderately weathered, very low to high strength 12.60m: occasional fine grained band	Grout
13.81m – 16.00m	SANDSTONE: cream to pale grey, medium with coarse grained, trace of fine grains, trace of fine quartz gravel, occasional ironstone bands of variable thickness from 2 to 10mm, occasional coarse grained bands with medium and fine grains, and occasional fine grained bands.; moderately weathered, low - medium strength - below 14.90m, occasional bands of pale brown and cream	Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH505A
FILE / JOB NO : G5331
SHEET : 3 OF 7

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

DRILLING & CASING	WATER	DEPTH (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)	PIEZOMETER CONSTRUCTION DETAILS
HQ3	5% Polymer LOSS (HW casing at 1.10m)	16.0	SANDSTONE: cream to pale grey, medium with coarse grained, trace of fine grains, trace of fine quartz gravel, occasional ironstone bands of variable thickness from 2 to 10mm, occasional coarse grained bands with medium and fine grains, and occasional fine grained bands.; moderately weathered, extremely low to very high strength	Grout (16.00–19.00 m)
		17.0	17.24 to 17.37m: trace of medium and fine quartz gravel	
		18.0		
		19.0		19.00 m; Bentonite (19.00–20.00 m)
		20.0		20.00 m; 2mm Filter Sand Sand
		21.0	21.31 to 21.36m: sandy siltstone	21.00 m; 21.00 m; Sand
		21.36m	SANDSTONE: cream, brown, pale brown and cream bands, medium and coarse grained, with trace of fine grains, occasional fine grained bands, occasional trace of fine quartz gravel, ironstone bands of variable thickness from 2mm.; moderately weathered, extremely low to very high strength	
		22.0		
		23.0		
		24.0		24.00 m; 24.00 m

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505	Standpipe Piezometer		53.00 m 982.51 m AHD		

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL LOCATION : Great Western Highway verge west of Victoria Falls Road	**HOLE NO : BH505A** FILE / JOB NO : G5331 SHEET : 4 OF 7

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

DRILLING				MATERIAL		
PROGRESS: DRILLING & CASING	PROGRESS: WATER	GROUND WATER LEVELS	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components
HQ3	5% Polymer LOSS (HW casing at 1.10m)		24.0			SANDSTONE: cream, brown, pale brown and cream bands, medium and coarse grained, with trace of fine grains, occasional fine grained bands, occasional trace of fine quartz gravel, ironstone bands of variable thickness from 2mm.; moderately weathered, extremely low to very high strength *(continued)*
			25.0			
			26.0			
			26.69m			CLAYSTONE: grey; moderately weathered, low strength
			27.0			
			27.43m			CLAYSTONE: red-brown, with occasional grey patches of siltstone with sand, no obvious bedding.; fresh, medium to high strength
			28.0			
						28.64 to 28.76m: siltstone, pale grey
			29.0			
			30.0			
			31.0			
			32.0			

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505	Standpipe Piezometer		53.00 m 982.51 m AHD		

Depth	Installation
24.0 – 25.00 m	2mm Filter Sand Sand
25.00 m – 26.00 m	Bentonite
26.00 m – 32.0	**Grout**

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL LOCATION : Great Western Highway verge west of Victoria Falls Road	**HOLE NO : BH505A** FILE / JOB NO : G5331 SHEET : 5 OF 7

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

DRILLING — PROGRESS: DRILLING & CASING; WATER; GROUND WATER LEVELS; DEPTH (m)

MATERIAL — GRAPHIC LOG; CLASSIFICATION SYMBOL; MATERIAL DESCRIPTION: Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components

Depth (m)	Material Description
32.24m	SILTSTONE: grey to pale grey, no obvious bedding, trace of sand.; fresh, high to very high strength
33.30m	CLAYSTONE: red-brown, occasional pale grey siltstone with sand patches, no obvious bedding.; fresh, high strength
37.78m	SILTSTONE: pale grey, with sand.; fresh, medium to very high strength
37.85m	SANDSTONE , SILTY SANDSTONE/SANDY SILTSTONE: pale grey, cream, orange-brown to brown, bands of pale grey fine grained silty sandstone/sandy siltstone, with some bands of cream pebbly sandstone and some bands of orange-brown to brown medium grained sandstone with fine grains and trace of coarse/fine gravel, trace ironstone bands up to 110mm thick.; fresh, low to very high strength
38.83m	CORE LOSS 0.06m (38.83-38.89) Probable location
38.89m	SANDSTONE , SILTY SANDSTONE/SANDY SILTSTONE: pale grey, cream, orange-brown to brown, bands of pale grey fine grained silty sandstone/sandy siltstone, with some bands of cream pebbly sandstone and some bands of orange-brown to brown medium grained sandstone with fine grains and trace of coarse/fine gravel, trace ironstone bands up to 110mm thick.; fresh, low - very high strength
39.50m	39.22 - 39.50m: ironstone band

Depth scale: 32.0, 33.0, 34.0, 35.0, 36.0, 37.0, 38.0, 39.0, 40.0

Water: 5% Polymer LOSS (HW casing at 1.10m) — to approx. 39.35m; 0% Water LOSS — below

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505	Standpipe Piezometer		53.00 m 982.51 m AHD		

Grout to 53m

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

Drilling & Casing	Water	Depth (m)	Boundary	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
	0% Water LOSS	40.0		SANDSTONE: orange-brown and pale grey, fine to medium grained, with quartz gravel up 5mm.; fresh, extremely low to high strength *(continued)*
				41.39 - 41.46m: ironstone band, 70mm thick
				41.55 - 42.12m: corss bedded
	5% Water LOSS			42.54 - 43.18m: distinctly bedded at 15-25deg
				43.17m: ironstone band, 3mm thick
				44.17 - 44.19m: ironstone band, 3mm thick
				44.25 - 44.42m: cross bedded
				44.60 - 44.62m: ironstone band, 20mm thick
				44.96 - 45.11m: claystone band, pale grey, bedding/parting indistinct
	0% Water LOSS		45.45m	CLAYSTONE: pale grey, with sandstone band.; fresh, medium strength
			45.67m	SANDSTONE: orange-brown, fine to medium grained, with fine quartz gravel, with iron staining.; moderately weathered to fresh, low to medium strength
				- below 46.05m, becoming pale grey
				46.52m: band of claystone, 50mm thick
		48.0	48.00m	

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505	Standpipe Piezometer		53.00 m 982.51 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

DRILLING				MATERIAL			PIEZOMETER CONSTRUCTION DETAILS
DRILLING & CASING	WATER	GROUND WATER LEVELS	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components	
	0% Water LOSS		48.0			SANDSTONE: pale grey, fine to medium grained, with fine quartz gravel, bedded at 5-10deg.; moderately weathered to fresh, low to high strength	Grout
			49.0				
			50.0				
			51.0				
			52.0				
			53.0				53.00 m
			54.0			54.00m: claystone band, 0deg, 70mm thick	
						54.30m: claystone band, 0deg, 40mm thick	
			55.0			55.12m: ironstone band, 0deg, 10mm thick	
						55.50 - 55.90m: cross bedded	
			56.0				

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505	Standpipe Piezometer		53.00 m 982.51 m AHD		

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : **BH505B**
FILE / JOB NO : G5331
SHEET : 1 OF 11

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505B	Standpipe Piezometer		83.00 m 952.51 m AHD		

DRILLING (Progress: Drilling & Casing; Water; Ground Water Levels)

- Drilling & Casing: AD/T — HW Casing (0.0–1.00 m); HW Casing (1.0–1.4 m); HW Casing (1.4–2.4 m); HQ3
- Water: N/A (0.0–1.0 m); 0% Polymer LOSS (HW casing at 1.10m)
- Ground Water Levels: Not Encountered

MATERIAL

Depth (m)	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic; Secondary and Minor Components)
0.00–0.55m	SILTY SAND: brown, medium and fine grained sand, trace of clay
0.55–1.00m	SANDSTONE: cream, medium with fine grained, trace of coarse grains.
1.00–1.08m	CORE LOSS 0.08m (1.00-1.08)
1.08–1.47m	SANDSTONE: cream, medium with fine grained, trace/with coarse grains.; extremely weathered to highly weathered, extremely low - medium strength
1.47–1.93m	TUFFACEOUS CLAYSTONE: grey; moderately weathered, medium strength
1.93–2.26m	SANDSTONE: cream, medium with fine grained, trace/with coarse grains.; highly weathered, low strength
2.26–5.20m	SANDSTONE: brown and orange-brown, medium and fine grained, with coarse grains, trace of fine quartz gravel, occasional ironstone bands with variable thickness between 1 and 10mm.; extremely weathered to highly weathered, extremely low - very high strength
5.20–5.65m	TUFFACEOUS CLAYSTONE: grey; moderately weathered, medium strength
5.65–7.02m	SANDSTONE: cream, brown and pale brown bands, medium with fine grained, trace of coarse grains, occasionalironstone bands of variable thickness from 1 to 70mm.; extremely weathered to highly weathered, extremely low - medium strength
7.02–7.29m	TUFFACEOUS CLAYSTONE: grey; moderately weathered, medium strength
7.29m–	SANDSTONE: cream, brown and pale brown bands, medium with fine grained, trace of coarse grains, occasional ironstone bands of variable thickness from 1 to 70mm.; extremely weathered to moderately weathered, extremely low to very high strength

Depth scale: 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0

Piezometer: BH505B — Grout

TFNSW 42.1 LIB.GLB Log RTA PIEZOMETER INSTALLATION LOG G5331 BLACKHEATH TO LITTLE HARTLEY TUNNEL.GPJ <<DrawingFile>> 02/Mar/2022 12:40 10.02.00.04 Datgel Tools

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505B	Standpipe Piezometer		83.00 m 952.51 m AHD		

DRILLING: PROGRESS — DRILLING & CASING: HQ3; WATER: 0% Polymer LOSS (HW casing at 1.10m)

Depth (m)	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
8.0	SANDSTONE: cream, brown and pale brown bands, medium with fine grained, trace of coarse grains, occasional ironstone bands of variable thickness from 1 to 70mm.; extremely weathered to moderately weathered, extremely low to very high strength *(continued)*
	8.52 to 8.61m: sandstone, grey, fine grained
	8.85 to 8.92m: tuffaceous claystone
11.55m	SANDSTONE: brown with pale brown and cream bands, medium with fine grained, and coarse grains, trace of fine quartz gravel, bedding predominantly at 0-10deg.; moderately weathered, very low to high strength
	12.60m: occasional fine grained band
13.81m	SANDSTONE: cream to pale grey, medium with coarse grained, trace of fine grains, trace of fine quartz gravel, occasional ironstone bands of variable thickness from 2 to 10mm, occasional coarse grained bands with medium and fine grains, and occasional fine grained bands.; moderately weathered, low - medium strength
	- below 14.90m, occasional bands of pale brown and cream
16.00m	

PIEZOMETER CONSTRUCTION DETAILS: Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL LOCATION : Great Western Highway verge west of Victoria Falls Road	**HOLE NO : BH505B** FILE / JOB NO : G5331 SHEET : 3 OF 11

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING; WATER); GROUND WATER LEVELS; DEPTH (m)

MATERIAL: GRAPHIC LOG; CLASSIFICATION SYMBOL; MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505B	Standpipe Piezometer		83.00 m 952.51 m AHD		

Drilling & casing: HQ3

Water: 5% Polymer LOSS (HW casing at 1.10m)

Depth (m)	Material Description
16.0	SANDSTONE: cream to pale grey, medium with coarse grained, trace of fine grains, trace of fine quartz gravel, occasional ironstone bands of variable thickness from 2 to 10mm, occasional coarse grained bands with medium and fine grains, and occasional fine grained bands.; moderately weathered, extremely low to very high strength
17.0	17.24 to 17.37m: trace of medium and fine quartz gravel
18.0	
19.0	
20.0	
21.0	21.31 to 21.36m: sandy siltstone
21.36m	SANDSTONE: cream, brown, pale brown and cream bands, medium and coarse grained, with trace of fine grains, occasional fine grained bands, occasional trace of fine quartz gravel, ironstone bands of variable thickness from 2mm.; moderately weathered, extremely low to very high strength
22.0	
23.0	
24.0	

Piezometer: Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

DRILLING & CASING	WATER	DEPTH (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
HQ3	5% Polymer LOSS (HW casing at 1.10m)	24.0	SANDSTONE: cream, brown, pale brown and cream bands, medium and coarse grained, with trace of fine grains, occasional fine grained bands, occasional trace of fine quartz gravel, ironstone bands of variable thickness from 2mm.; moderately weathered, extremely low to very high strength *(continued)*
		26.69m	CLAYSTONE: grey; moderately weathered, low strength
		27.43m	CLAYSTONE: red-brown, with occasional grey patches of siltstone with sand, no obvious bedding.; fresh, medium to high strength
			28.64 to 28.76m: siltstone, pale grey

Depth scale: 24.0, 25.0, 26.0, 27.0, 28.0, 29.0, 30.0, 31.0, 32.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505B	Standpipe Piezometer		83.00 m 952.51 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

DRILLING | MATERIAL | PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505B	Standpipe Piezometer		83.00 m 952.51 m AHD		

Depth (m)	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
32.24m	SILTSTONE: grey to pale grey, no obvious bedding, trace of sand.; fresh, high to very high strength
33.30m	CLAYSTONE: red-brown, occasional pale grey siltstone with sand patches, no obvious bedding.; fresh, high strength
37.78m	SILTSTONE: pale grey, with sand.; fresh, medium to very high strength
37.85m	SANDSTONE , SILTY SANDSTONE/SANDY SILTSTONE: pale grey, cream, orange-brown to brown, bands of pale grey fine grained silty sandstone/sandy siltstone, with some bands of cream pebbly sandstone and some bands of orange-brown to brown medium grained sandstone with fine grains and trace of coarse/fine gravel, trace ironstone bands up to 110mm thick.; fresh, low to very high strength
38.83m	CORE LOSS 0.06m (38.83-38.89) Probable location
38.89m	SANDSTONE , SILTY SANDSTONE/SANDY SILTSTONE: pale grey, cream, orange-brown to brown, bands of pale grey fine grained silty sandstone/sandy siltstone, with some bands of cream pebbly sandstone and some bands of orange-brown to brown medium grained sandstone with fine grains and trace of coarse/fine gravel, trace ironstone bands up to 110mm thick.; fresh, low - very high strength
39.50m	39.22 - 39.50m: ironstone band

Depth scale: 32.0, 33.0, 34.0, 35.0, 36.0, 37.0, 38.0, 39.0, 40.0

Water: 5% Polymer LOSS (HW casing at 1.10m); 0% Water LOSS

Piezometer construction:

Depth	Material
to 38.00 m	Grout
38.00 m – 39.00 m	Bentonite
39.00 m – 40.00 m	2mm Filter Sand Sand

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

DRILLING: Water	Depth (m)	Material Description	Piezometer construction
0% Water LOSS (40.0–42.33)	40.0	SANDSTONE: orange-brown and pale grey, fine to medium grained, with quartz gravel up 5mm.; fresh, extremely low to high strength *(continued)*	40.00 m – Sand
		41.39 - 41.46m: ironstone band, 70mm thick	
		41.55 - 42.12m: corss bedded	
5% Water LOSS (42.33–45.40)		42.54 - 43.18m: distinctly bedded at 15-25deg	
		43.17m: ironstone band, 3mm thick	
		44.17 - 44.19m: ironstone band, 3mm thick	
		44.25 - 44.42m: cross bedded	
		44.60 - 44.62m: ironstone band, 20mm thick	
		44.96 - 45.11m: claystone band, pale grey, bedding/parting indistinct	
0% Water LOSS (45.40–48.00)	45.45m	CLAYSTONE: pale grey, with sandstone band.; fresh, medium strength	
	45.67m	SANDSTONE: orange-brown, fine to medium grained, with fine quartz gravel, with iron staining.; moderately weathered to fresh, low to medium strength	46.00 m
		- below 46.05m, becoming pale grey	46.00 m – 2mm Filter Sand / Sand
		46.52m: band of claystone, 50mm thick	
			47.00 m – Bentonite
	48.00m		48.00 m

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505B	Standpipe Piezometer		83.00 m 952.51 m AHD		

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH505B
FILE / JOB NO : G5331
SHEET : 7 OF 11

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

DRILLING				MATERIAL			PIEZOMETER CONSTRUCTION DETAILS
PROGRESS: DRILLING & CASING	PROGRESS: WATER	GROUND WATER LEVELS	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components	ID: BH505B; Type: Standpipe Piezometer; Stick Up & RL: ; Tip Depth & RL: 83.00 m 952.51 m AHD; Installation Date: ; Static Water Level:
	0% Water LOSS		48.0			SANDSTONE: pale grey, fine to medium grained, with fine quartz gravel, bedded at 5-10deg.; moderately weathered to fresh, low to high strength	Grout
			49.0				
			50.0				
			51.0				
			52.0				
			53.0				
			54.0			54.00m: claystone band, 0deg, 70mm thick	
						54.30m: claystone band, 0deg, 40mm thick	
			55.0			55.12m: ironstone band, 0deg, 10mm thick	
						55.50 - 55.90m: cross bedded	
			56.0				

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505B	Standpipe Piezometer		83.00 m 952.51 m AHD		

DRILLING / MATERIAL

Columns: PROGRESS (DRILLING & CASING, WATER), GROUND WATER LEVELS, DEPTH (m), GRAPHIC LOG, CLASSIFICATION SYMBOL, MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)

Water: 0% Water LOSS

Depth (m)	Material Description
56.0	SANDSTONE: pale grey, fine to medium grained, with fine quartz gravel, bedded at 5-10deg.; moderately weathered to fresh, low to high strength *(continued)*
	57.42m: ironstone band, 0-5deg, 50mm thick
58.24m	SILTSTONE AND SANDSTONE (60:40) INTERLAMINATED: pale grey, siltstone is pale grey, sandstone is pale grey and fine to medium grained, laminated at 0-10deg.; fresh, high strength
	58.24m: ironstone band, 0deg, 20mm thick
59.22m	SANDSTONE: orange-brown, fine to medium grained, with fine quartz gravel.; moderately weathered to fresh, low to high strength
	59.23m: ironstone band, 0deg, 10mm thick
	59.59m: ironstone band, 0deg, 20mm thick
	59.80m: cross-bedded
	- below 61.90m, bedded at 10-20deg
64.0	

Piezometer: Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505B	Standpipe Piezometer		83.00 m 952.51 m AHD		

DRILLING & CASING	WATER	GROUND WATER LEVELS	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)	PIEZOMETER
	0% Water LOSS		64.0 – 67.88m			SANDSTONE: orange-brown, fine to medium grained, with fine quartz gravel.; moderately weathered to fresh, low to high strength *(continued)*	Grout
						- below 67.00m, with iron staining	
						67.10m: ironstone band, 15deg, 30mm thick	
						67.19m: ironstone band, 10deg, 20mm thick	
						67.30m: ironstone band, 10deg, 40mm thick	
			67.88m			67.84m: ironstone band, 5deg, 20mm thick	
			67.88 – 68.23m			CORE LOSS 0.35m (67.88-68.23)	
			68.23m – 72.0			SANDSTONE: orange-brown, pale grey, fine to medium grained, with occasional coarse grained bands, bedded at 5-10deg.; moderately weathered to fresh, extremely low to medium strength	
						68.88m: ironstone band, 0deg, 10mm thick	
						68.92m: ironstone band, 0deg, 20mm thick	
						71.00 - 71.70m: medium to coarse grained sandstone	
						71.83 - 72.00m: medium to coarse grained sandstone band	

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH505B
FILE / JOB NO : G5331
SHEET : 10 OF 11

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°

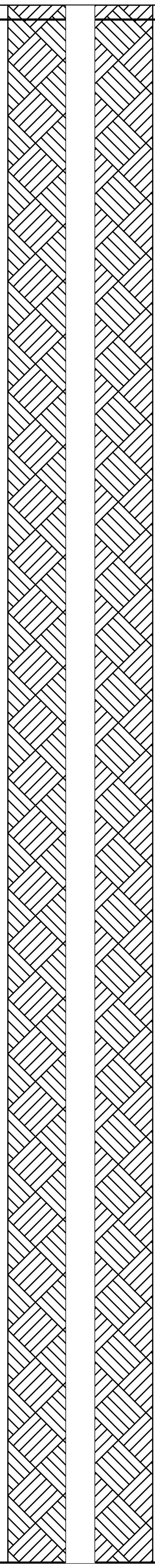
RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

DRILLING: PROGRESS – DRILLING & CASING	DRILLING: PROGRESS – WATER	GROUND WATER LEVELS	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components
	0% Water LOSS		72.0			72.05m CLAYSTONE: pale grey with red bands, bedding indistinct, with sandstone bands.; fresh, medium strength
						72.50m SANDSTONE: pale grey, orange-brown, fine to medium grained; moderately weathered to fresh, medium to very high strength
			73.0			
			74.0			
			75.0			
			76.0			
			77.0			
			78.0			78.47m: ironstone band, 0deg, 20mm thick
			79.0			79.03m: ironstone band, 0deg, 10mm thick
			80.0			

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505B	Standpipe Piezometer		83.00 m 952.51 m AHD		



Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge west of Victoria Falls Road

POSITION : E: 246023.117, N: 6279427.581 (56 GDA2020) SURFACE ELEVATION : 1035.505 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMMACHIO 305 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 30/3/21 DATE COMPLETED : 29/4/21 DATE LOGGED : 30/3/21 LOGGED BY : BA/FI CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING, WATER), GROUND WATER LEVELS, DEPTH (m)

MATERIAL: GRAPHIC LOG, CLASSIFICATION SYMBOL, MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH505B	Standpipe Piezometer		83.00 m 952.51 m AHD		

Water: 0% Water LOSS

Depth (m)	Material Description
80.0	SANDSTONE: pale grey, orange-brown, fine to medium grained; moderately weathered to fresh, medium to very high strength *(continued)*
	- below 81.15m: bedded at 5-15deg
	81.62m: ironstone band, 10deg, 40mm thick
	82.18m: ironstone band, 0-5deg, 40mm thick
	84.10m: claystone band, 0deg, 100mm thick
	84.28m: claystone band, 0deg, 80mm thick
85.00m	SANDSTONE: pale brown and brown with some orange-brown, coarse and medium grained, with trace of fine grains, trace/with fine gravel.; moderately weathered to slightly weathered, medium to high strength
	86.34m: ironstone band, 0deg, 10mm thick
	86.38 - 86.48m: some patchy iron cementation 2 to 8mm
	86.76 - 86.82m: claystone/siltstone
87.02m	SANDSTONE: off-white with pale orange-brown, fine with medium grained; slightly weathered to fresh, medium to very high strength
	87.86 - 87.88m: ironstone band
88.0	

Piezometer: Grout to 83.00 m

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH507
FILE / JOB NO : G5331
SHEET : 1 OF 27

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Drilling & Casing	Water	Ground Water Levels	Depth (m)	Classification Symbol	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic; Secondary and Minor Components)	Piezometer
AD/T – CASING (0.0–1.0)		Not Encountered	0.0–0.25m	SM	SILTY SAND AND SAND: sand is grey, medium plasticity silt; sand is fine grained sand, with silt	BH507 Grout
			0.25–1.00m		SANDSTONE: brown with some yellow brown layers, medium and fine grained	
HQ3 – HW Casing (1.0–8.0)	0% Water LOSS (HW casing at 1.25m)		1.00–1.75m		SANDSTONE: brown with some cream, medium grained, with fine and coarse grains; extremely weathered, extremely low strength	
			1.75–2.60m		CORE LOSS 0.85m (1.75-2.60)	
			2.60–3.12m		SANDSTONE: brown with some cream, medium grained, with fine and coarse grains; extremely weathered, extremely low strength	
			3.12–4.60m		SANDSTONE: cream, medium and coarse grains with fine grains; extremely weathered, extremely low strength	
			4.60–4.76m		SANDSTONE: pale and cream, medium grained, with coarse and fine grains; extremely weathered, extremely low strength	
			4.76–5.25m		CORE LOSS 0.49m (4.76-5.25)	
			5.25–5.68m		SANDSTONE: pale and cream, medium grained, with coarse and fine grains; extremely weathered, extremely low strength	
		07/05/21 07:30	5.68–6.23m		CORE LOSS 0.55m (5.68-6.23)	
			6.23–6.62m		SANDSTONE: pale and cream, medium grained, with coarse and fine grains; extremely weathered, extremely low to very high strength	
		21/05/21 07:30	6.62–6.88m		CORE LOSS 0.26m (6.62-6.88)	
			6.88–8.00m		SANDSTONE: pale and cream, medium grained, with coarse and fine grains; extremely weathered, extremely low to very low strength	

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH507
FILE / JOB NO : G5331
SHEET : 2 OF 27

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING: HQ3, HW Casing; WATER: 0% Water LOSS (HW casing at 1.25m)); GROUND WATER LEVELS: 20/05/21 08:30 (approx. 10.55 m); 24/05/21 09:55 (approx. 12.4 m)

DEPTH (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic; Secondary and Minor Components)
8.00–8.19m	CORE LOSS 0.19m (8.00-8.19)
8.19–8.55m	SANDSTONE: brown, coarse and medium grained, with fine grains, trace of fine gravel; extremely weathered, extremely low strength
8.55–8.68m	CORE LOSS 0.13m (8.55-8.68)
8.68–9.23m	SANDSTONE: brown to orange brown, medium grained, with fine grains, trace of coarse grains; extremely weathered, extremely low to very high strength
9.23–9.86m	SANDSTONE: layers of brown, cream, cream with red brown, predominantly medium grained, with fine grains, but occasional coarse or fine layers; extremely weathered to highly weathered, extremely low to low strength
9.86–10.24m	CORE LOSS 0.38m (9.86-10.24)
10.24–10.50m	SANDSTONE: layers of brown, cream, cream with red brown, predominantly medium grained, with fine grains, but occasional coarse or fine layers; extremely weathered to highly weathered, extremely low to low strength
10.50–14.00m	SANDSTONE: cream with occasional pale brown and pale orange brown, patches and layers, medium grained, with coarse grains and fine grains, occasional trace of fine gravel; extremely weathered to highly weathered, extremely low to very high strength
14.00–14.16m	CORE LOSS 0.16m (14.00-14.16)
14.16–14.25m	SANDSTONE: cream with occasional pale brown and pale orange brown, patches and layers, medium grained, with coarse grains and fine grains, occasional trace of fine gravel; extremely weathered, extremely low strength
14.25–14.63m	CORE LOSS 0.38m (14.25-14.63)
14.63–15.52m	SANDSTONE: cream with occasional pale brown and pale orange brown, patches and layers, medium grained, with coarse grains and fine grains, occasional trace of fine gravel; extremely weathered to highly weathered, extremely low to low strength
15.52m	

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Grout

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING: PROGRESS — DRILLING & CASING: HQ3, HW Casing; WATER: 0% Water LOSS (HW casing at 1.25m)

Depth boundary	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
16.0	SANDSTONE: pale brown with occasional cream with brown or cream layer, predominantly medium and coarse grains, with fine grains, occasional very thin layer of fine grained sandstone, trace of fine gravel; extremely weathered to moderately weathered, extremely low to very high strength *(continued)*
17.74m	17.70-17.74m: ironstone band, 40mm thick.
17.84m	CORE LOSS 0.10m (17.74-17.84)
	SANDSTONE: pale brown with occasional cream with brown or cream layer, predominantly medium and coarse grains, with fine grains, occasional very thin layer of fine grained sandstone, trace of fine gravel; extremely weathered to moderately weathered, extremely low - very high strength 18.22-18.37m: SANDY SILTSTONE: cream to pale grey, fine grained sand. 18.64-18.67m: SANDY SILTSTONE: cream to pale grey, fine grained sand. 18.80m: occasional trace of fine and fine to medium gravel.
19.44m	CORE LOSS 0.22m (19.44-19.66)
19.66m	SANDSTONE: pale brown with occasional cream with brown or cream layer, predominantly medium and coarse grains, with fine grains, occasional very thin layer of fine grained sandstone, trace of fine gravel; extremely weathered with highly weathered, extremely low to very low strength
20.04m	CORE LOSS 0.12m (20.04-20.16)
20.16m	CORE LOSS 0.15m (20.16-20.31)
20.31m	SANDSTONE: pale brown with occasional cream with brown or cream layer, predominantly medium and coarse grains, with fine grains, occasional very thin layer of fine grained sandstone, trace of fine gravel; extremely weathered to moderately weathered, extremely low to very high strength
20.81m	SANDSTONE: brown with cream layers and laminations, medium grained, with coarse grains and trace/with fine grains, sub-vertical bedding; extremely weathered to moderately weathered, extremely low to very high strength 22.12-22.33m: SILTSTONE/CLAYSTONE. 22.48-22.84m: cream with grey carbonaceous layers and laminations.
22.93m	SANDSTONE: cream with some pale brown and brown layers and patches, fine and medium grains, bedding at 0-5deg; extremely weathered to moderately weathered, extremely low / very high strength 23.80-23.86m: SILTSTONE/CLAYSTONE.
24.0	

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

MATERIAL

Depth	Material Description
24.05m	SANDSTONE: pale brown with some cream, medium grained, with fine and coarse grains, trace of fine and fine/medium gravel; extremely weathered, extremely low strength. Below 24.34m: fine and medium grained sandstone.
24.62m	CORE LOSS 0.07m (24.62-24.69)
24.69m	SANDSTONE: pale brown with some cream, medium grained, with fine and coarse grains, trace of fine and fine/medium gravel; extremely weathered to moderately weathered, extremely low to very high strength
26.42m	SILTSTONE: red brown colouring to pale brown/pale grey brown by 27.0m, no obvious bedding; moderately weathered, medium strength
27.76m	SILTSTONE: red brown and pale grey, no obvious bedding; moderately weathered, medium strength
28.00m	CLAYSTONE: red brown, no obvious bedding; moderately weathered, medium to high strength

DRILLING: HQ3 — HW Casing
WATER: 0% Water LOSS (HW casing at 1.25m)
GROUND WATER LEVELS: 03/06/21 07:15 (approx. 24.8m)

DEPTH (m): 24.0, 25.0, 26.0, 27.0, 28.0, 29.0, 30.0, 31.0, 32.0

Piezometer: Grout

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING				MATERIAL		
PROGRESS: DRILLING & CASING	PROGRESS: WATER	GROUND WATER LEVELS	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components
HQ3 HW Casing	0% Water LOSS (HW casing at 1.25m)		32.0			CLAYSTONE: red brown, no obvious bedding; moderately weathered, medium to high strength *(continued)*
			33.0			
			34.0			
			35.0			
			35.45m			SILTSTONE: cream with some red brown and brown, no obvious bedding; moderately weathered, medium to high strength
			35.97m 36.0			SILTY SANDSTONE: pale yellow cream, fine grained, several carbonaceous patches; highly weathered and moderately weathered, low - medium strength
	100% Water LOSS (HW casing at 1.25m)		36.16m			SANDSTONE: brown to orange brown, fine grained, iron cemented; moderately weathered, high strength
			36.55m			SANDSTONE: brown, medium and fine grained, trace ironstone bands; moderately weathered, medium to high strength
		26/05/21	37.00m 37.0			SANDSTONE: brown with black patches and spots throughout, medium grained, with fine grains, trace of coarse grains; moderately weathered, medium to very high strength
	100% Water LOSS (HW casing at 1.25m)		38.0 38.13m			CORE LOSS 0.30m (38.13-38.43)
	100% Water LOSS (HW casing at 1.25m)	02/06/21 07:15	38.43m			SANDSTONE: brown with some pale yellow brown or cream layers, predominantly medium grained with fine grained and trace of coarse grains, occasional trace of fine and fine/medium gravel, bedding predominantly at 0-5deg; moderately weathered, medium to very high strength
			39.0			
		01/06/21 07:30	40.0			

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING & CASING	WATER	DEPTH (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic; Secondary and Minor Components)
HQ3 / HW Casing	100% Water LOSS (HW casing at 38.4m)	40.20m	SANDSTONE: layers of cream, orange brown, pale orange brown and cream, pale brown, variable layers of grain size, coarse grained with fine grains and trace coarse, fine grained with medium grains, medium and coarse grained with fine grains, bedding predominantly at 0-5deg; moderately weathered, medium to very high strength 40.40 and 41.55m: with occasional layer of pale grey, fine grained sandy siltstone between 5mm and 35mm thickness.
	0% Water LOSS (HW casing at 39.9m)	42.33m	SANDSTONE: layers of brown, pale brown, cream, cream with pale brown, medium grained with coarse grains and with/trace fine grains, bedding predominantly at 0-5deg, occasional very thin layers (5-100mm thick) of siltstone or claystone; moderately weathered, very low to high strength 46.70m: some layers with/trace of fine quartz gravel.

Depth scale: 40.0 – 48.0 m

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Grout (to 47.00 m)

Bentonite (47.00 m – 48.00 m)

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

Drilling & Casing	Water	Ground Water Levels	Depth (m)	Graphic Log	Classification Symbol	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic; Secondary and Minor Components)
HQ3 / HW Casing	0% Water LOSS (HW casing at 39.9m)		48.0			SANDSTONE: layers of brown, pale brown, cream, cream with pale brown, medium grained with coarse grains and with/trace fine grains, bedding predominantly at 0-5deg, occasional very thin layers (5-100mm thick) of siltstone or claystone; moderately weathered, very low to high strength *(continued)*
		04/06/21 07:20	50.00m			IRONSTONE / SANDSTONE: ironstone is purple brown with cream flecking, few closed vertical and subvertical fracture; sandstone is iron cemented; moderately weathered, high - very high strength
			50.53m			SANDSTONE: brown with some orange brown layers, layers of medium grains with fine grains and some layers of medium and fine grained with coarse grains; moderately weathered, very low - very high strength 51.55-51.70m: subvertical ironstone band up to 45mm width.
	5-10% Water LOSS (HW casing at 39.9m)		52.46m			SILTSTONE: pale purple; moderately weathered, high strength
			52.71m			SANDSTONE: brown with some orange brown layers, layers of medium grains with fine grains and some layers of medium and fine grained with coarse grains; moderately weathered, low - high strength
			53.27m			CORE LOSS 0.22m (53.27-53.49)
			53.49m			SILTSTONE: red brown with cream and pale purple, few subvertical to vertical closed fractures, majority ironstone bands 2mm to <1mm; moderately weathered, medium - high strength
			55.10m			SILTSTONE: cream with some brown, with sandy siltstone layers and laminations, fine grained sand, bedding variable 0-8deg; moderately weathered, medium to high strength
			56.0			

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

48.00-49.00 m: 2mm Filter Sand / Sand
49.00 m
49.00-55.00 m: Sand
55.00 m
55.00-56.00 m: 2mm Filter Sand / Sand
56.00 m

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING, WATER), GROUND WATER LEVELS, DEPTH (m)
MATERIAL: GRAPHIC LOG, CLASSIFICATION SYMBOL, MATERIAL DESCRIPTION — Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components

Drilling: HQ3 — HW Casing — 5% Water LOSS (HW casing at 39.9m)

Depth (m)	Material Description
56.32m	SANDSTONE: brown with some cream layer, fine and medium grains, patchy traces of coarse grained sand and fine gravel below 56.8m; moderately weathered, low to very high strength
57.59m	SANDSTONE: brown to orange brown, medium grained, with fine grains and trace of coarse grains, bedding at 15deg; moderately weathered, low to very high strength
58.00m	SILTSTONE: cream to pale grey, bedding at 0deg, trace of fine grained sand; moderately weathered, medium to high strength
58.52m	SANDSTONE: cream with some brown layers and patches, medium grained, with fine grains and trace of coarse grains, occasional layer of medium grains with fine grains and trace/with coarse grained sand, bedding variable up to 15deg; moderately weathered to slightly weathered, medium - high strength
60.48m	SANDSTONE: cream, fine grained, with medium grains, bedding at 0-15deg; moderately weathered to slightly weathered, medium - high strength
60.70m	SANDSTONE: cream with some patchy and streaky pale orange brown and pale red brown, variable layers: medium and coarse grains with fine grains, coarse grained with medium grains and trace fine grains, variable bedding 0-15deg; slightly weathered, medium to very high strength

Depth scale: 56.0, 57.0, 58.0, 59.0, 60.0, 61.0, 62.0, 63.0, 64.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Bentonite (to 57.00 m)

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

DRILLING: PROGRESS (DRILLING & CASING, WATER), GROUND WATER LEVELS, DEPTH (m) | MATERIAL: GRAPHIC LOG, CLASSIFICATION SYMBOL, MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic; Secondary and Minor Components) | PIEZOMETER CONSTRUCTION DETAILS

Drilling & casing: HQ3; HW Casing
Water: 5% Water LOSS (HW casing at 39.9m)

Depth (m)	Material Description
64.0	SANDSTONE: cream with some patchy and streaky pale orange brown and pale red brown, variable layers: medium and coarse grains with fine grains, coarse grained with medium grains and trace fine grains, variable bedding 0-15deg; slightly weathered, medium to very high strength *(continued)*
66.62m	SANDSTONE: cream, medium grained, with coarse grains and fine grains, occasional trace of fine gravel, bedding predominantly at 0-5deg, occasional layer of pale grey sandy siltstone and siltstone up to 190mm thickness; moderately weathered to slightly weathered, low - high strength
	69.09-69.35m: fine grained sandstone.
69.35m	SANDSTONE: brown, medium grained, with coarse and fine grains, trace fine gravel; moderately weathered, low to high strength
69.68m	SANDSTONE: cream, medium grained, with coarse grains and fine grains, occasional trace of fine gravel, bedding predominantly at 0-5deg, occasional layer of pale grey sandy siltstone and siltstone up to 190mm thickness; moderately weathered, medium - high strength

Depth scale: 64.0, 65.0, 66.0, 67.0, 68.0, 69.0, 70.0, 71.0, 72.0

Piezometer: **Grout**

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

DRILLING / MATERIAL

Drilling & Casing: HQ3, HW Casing
Water: 5% Water LOSS (HW casing at 39.9m)
Ground Water Levels: 18/06/21 07:20 (approx. 78.7 m); 17/06/21 (approx. 79.8 m)

Depth (m)	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
72.00	SANDSTONE: cream, medium grained, with coarse grains and fine grains, occasional trace of fine gravel, bedding predominantly at 0-5deg, occasional layer of pale grey sandy siltstone and siltstone up to 190mm thickness; moderately weathered, medium - high strength *(continued)*
73.40m	SANDSTONE: cream with pale orange brown, fine and medium grains, bedding predominantly at 0-10deg; moderately weathered to slightly weathered, medium to high strength
74.58m	SILTSTONE: pale grey; moderately weathered to slightly weathered, medium to high strength
74.64m	SANDSTONE: cream with pale orange brown, fine and medium grains, bedding predominantly at 0-10deg; moderately weathered to slightly weathered, medium to high strength
75.90m	SILTSTONE: pale grey; moderately weathered to slightly weathered, medium - high strength
76.24m	SANDSTONE: cream with pale orange brown, medium and coarse grains with fine grains, bedding predominantly at 0-5deg; moderately weathered to slightly weathered, low to very high strength

Piezometer: Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

DRILLING: PROGRESS (DRILLING & CASING: HQ3, HW Casing; WATER: 5% Water LOSS (HW casing at 39.9m)); GROUND WATER LEVELS: 08/06/21 08:15

DEPTH (m)	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components
80.0	SANDSTONE: cream with pale orange brown, medium and coarse grains with fine grains, bedding predominantly at 0-5deg; moderately weathered to slightly weathered, low to very high strength *(continued)*
81.97m	SANDSTONE: brown with some orange brown, coarse grained, with medium grains and trace of fine grains, occasional medium and fine grained layer with trace of coarse grains, trace fine gravel, bedding at 0-15deg; moderately weathered to slightly weathered, low to very high strength 83.23-83.50m: cream.
83.80m	SANDSTONE: cream, medium grained, with coarse and fine grains bedding at 5-15deg; slightly weathered, medium to high strength
85.05m	SANDSTONE: cream with orange brown and brown, medium grained, with fine grains, bedding at 0-5deg; moderately weathered to slightly weathered, high strength
85.17m	SILTSTONE: grey and red brown; moderately weathered to slightly weathered, medium - high strength
85.30m	SANDSTONE: cream with orange brown and brown, medium grained, with fine grains, bedding at 0-5deg; moderately weathered to slightly weathered, medium to very high strength 86.20-86.40m: bedding at 10-15deg.
86.61m	SILTSTONE: grey; slightly weathered, medium to very high strength
87.02m	SILTSTONE: red brown to brown; slightly weathered, extremely low to very high strength
88.0	

Grout

TFNSW 42.1 LIB.GLB Log RTA PIEZOMETER INSTALLATION LOG G5331 BLACKHEATH TO LITTLE HARTLEY TUNNEL.GPJ <<DrawingFile>> 01/Mar/2022 16:29 10.02.00.04 Datgel Tools

See Explanatory Notes for details of abbreviations & basis of descriptions.

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING, WATER), GROUND WATER LEVELS, DEPTH (m)

MATERIAL: GRAPHIC LOG, CLASSIFICATION SYMBOL, MATERIAL DESCRIPTION — Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Drilling & casing: HQ3 — HW Casing

Water: 5% Water LOSS (HW casing at 39.9m) (to approx. 93.2m); 10% Water LOSS (HW casing at 39.9m)

Depth (m)	Material Description
88.0	SILTSTONE: red brown to brown; slightly weathered, extremely low to very high strength *(continued)*
88.62m	SANDSTONE: brown, grey, pale grey, coarse grained, with medium grains, trace fine gravel; moderately weathered, medium to very high strength
89.36m	SILTSTONE: grey; moderately weathered,
89.47m	medium to high strength
	SANDSTONE: brown with some orange brown or cream, with pale brown layers, medium grained with coarse and fine grains, occasional trace of fine gravel, bedding predominantly at 0-5deg; moderately weathered, medium to very high strength
90.10m	CORE LOSS 0.15m (90.10-90.25)
90.25m	SANDSTONE: brown with some orange brown or cream, with pale brown layers, medium grained with coarse and fine grains, occasional trace of
90.60m	fine gravel, bedding predominantly at 0-5deg; moderately weathered, medium to very high strength
	SANDSTONE: layers of brown, pale brown, orange brown and cream, layers of medium grained, with fine grains, medium grained with dine grains and trace coarse grains, fine and medium grained, variable bedding 0-15deg, occasional layer of siltstone and sandy siltstone: grey, bedding predominantly at 0-9deg; moderately weathered, medium to high strength
92.36m	SANDSTONE: grey and pale grey, fine grained, bedding at 0-5deg; moderately weathered, high strength
92.81m	SANDSTONE: brown, medium and fine grained, with occasional layer, with coarse grains, bedding predominantly at 0-5deg; moderately weathered, medium to very high strength 93.58-93.65m: SILTSTONE: 10-15mm thick.
95.26m	SILTSTONE: brown to 95.33m, then grey, bedding predominantly at 0-5deg, a scatter of ?? silty clay throughout; highly weathered to slightly weathered, extremely low to high strength
96.0	

Depth scale: 88.0, 89.0, 90.0, 91.0, 92.0, 93.0, 94.0, 95.0, 96.0

Piezometer: Grout

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

DRILLING / MATERIAL

Drilling & casing: HQ3, HW Casing

Water: 10% Water LOSS (HW casing at 39.9m) to 98.8m; 100% Water LOSS (HW casing at 39.9m) 98.8m to 102.2m; 30% Water LOSS (HW casing at 41.4m) from 102.2m

Ground water levels: 09/06/21 08:00; 10/06/21 09:20

Depth (m)	Material Description
96.0	SILTSTONE: brown to 95.33m, then grey, bedding predominantly at 0-5deg, a scatter of ?? silty clay throughout; highly weathered to slightly weathered, extremely low to high strength *(continued)* 96.40-96.53m: core partially extremely weathered (clayey).
97.68m	SANDY SILTSTONE: grading to silty sandstone/sandy siltstone by 97.76m: pale grey, fine grained sand, bedding at 0-8deg; medium to high strength
98.08m	SILTSTONE: grey, red brown and pale grey layers, bedding at 0-5deg; moderately weathered, medium to high strength
98.34m	SILTY SANDSTONE: brown; moderately weathered, medium to high strength
98.76m	SANDSTONE: brown, medium and fine grains, with some layer of medium and fine grained with coarse grains and trace of fine gravel; moderately weathered, medium strength
100.16m	SANDSTONE: cream to pale grey with brown and orange brown, fine grained, with trace of medium grains; moderately weathered to slightly weathered, extremely low / high strength
100.93m	SANDSTONE: brown, medium grained; slightly weathered, low to medium strength
101.73m	SILTSTONE: with some sandy siltstone and silty sandstone: pale grey and grey, fine grained sand, bedding at 0-5deg; slightly weathered, high strength
102.04m	SANDSTONE: pale brown, fine grained, with medium grains, bedding at 0-5deg; moderately weathered, medium to high strength
102.65m	SILTSTONE: grey, few sandy siltstone layers or laminations, bedding at 0-5deg; moderately weathered, medium to high strength
103.44m	SANDSTONE: pale orange brown with some grey layers or laminations, variable grain size from fine to to coarse grains sand; moderately weathered, low - medium strength
103.85m	
104.0	

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

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RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Drilling progress: HQ3; HW Casing; 30% Water LOSS (HW casing at 41.4m)

Depth (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
104.12m	SILTSTONE: grey; moderately weathered, extremely low to medium strength *(continued)*
104.67m	IRON CEMENTED SANDSTONE: orange brown and brown, fine grained, with/trace medium and coarse grains, few sub-vertical to vertical ironstone zones 2-8mm thick; moderately weathered, extremely low to very high strength
105.05m	SANDSTONE: pale brown, fine grained, with medium grains and trace coarse grains and fine gravel; moderately weathered, medium strength
105.20m	CORE LOSS 0.15m (105.05-105.20)
105.39m	SANDSTONE: pale brown, fine grained, with medium grains and trace coarse grains and fine gravel; moderately weathered, medium strength
	SANDSTONE: orange brown, brown and cream, layers of medium grained with fine grains, coarse grained with medium and fine grains, fine and medium grains, coarse grained with fine gravel, bedding variable 0-55deg; extremely weathered to moderately weathered, extremely low - very high strength
	108.30m: with occasional layer of grey to pale grey, fine grained sandstone.

Depth scale: 104.0, 105.0, 106.0, 107.0, 108.0, 109.0, 110.0, 111.0, 112.0

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Depth (m)	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
12.0	SANDSTONE: orange brown, brown and cream, layers of medium grained with fine grains, coarse grained with medium and fine grains, fine and medium grains, coarse grained with fine gravel, bedding variable 0-55deg; extremely weathered to moderately weathered, extremely low - very high strength *(continued)*
114.21m	SILTSTONE: grey to dark grey, bedding at 0-5deg; slightly weathered to fresh, high to very high strength
118.05m	SILTSTONE: with some sandy siltstone and silty sandstone laminations and layers, grey to dark grey with pale laminations; slightly weathered to fresh, high - very high strength
118.90m	SILTY SANDSTONE: with some sandy siltstone: pale grey, fine grained, current bedding at 0-8deg; slightly weathered to fresh, high to very high strength

Depth scale: 12.0, 13.0, 14.0, 15.0, 16.0, 17.0, 18.0, 19.0, 20.0

Drilling & Casing: HQ3 — HW Casing

Water: 30% Water LOSS (HW casing at 41.4m); 95% Water LOSS (HW casing at 41.4m)

Ground water levels: 25/06/21 07:00; 24/06/21 07:00; 08/07/21

Piezometer: Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH507
FILE / JOB NO : G5331
SHEET : 16 OF 27

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Drilling & casing: HQ3 – HW Casing

Water: 100% Water LOSS (HW casing at 41.4m) (to ~123.2m); 50-60% Water LOSS (HW casing at 41.4m)

Ground water levels: 09/07/21; 17/08/21; 19/08/21; 02/09/21; 25/08/21

Piezometer: Grout

Depth (m)	Material Description
120.0	SILTY SANDSTONE: with some sandy siltstone: pale grey, fine grained, current bedding at 0-8deg; slightly weathered to fresh, high to very high strength *(continued)*
	120.35-120.47m: bedding at 10-15m.
120.53m	SANDSTONE: pale grey with dark grey carbonaceous laminae, fine grained, to 120.92m, then medium and fine grained, bedding at 0-5deg; slightly weathered to fresh, medium to high strength
	At 121.53-121.60m: layers of carbonaceous siltstone.
	At 121.60m: medium grained sandstone with fine grains.
	At 121.74-121.78m: layers of carbonaceous siltstone.
122.47m	SILTSTONE: grey to 122.69m, then siltstone and sandy siltstone, grey and pale grey, fine grained sand, bedding predominantly at 0-5deg; slightly weathered to fresh, high strength
123.47m	SANDSTONE AND SILTY SANDSTONE: pale grey and grey, predominantly fine grained sand, 0-5deg bedding; slightly weathered to fresh, high - very high strength
	At 123.60-123.75m: siltstone and carbonaceous siltstone layers.
124.34m	SANDSTONE: pale grey with grey bands and laminations, fine to coarse grained, becoming predominantly coarse grained sand, 0-5deg bedding, some siltstone and sandy siltstone sands and laminations; slightly weathered to fresh, medium - high strength
	125.20m: with siltstone and claystone laminations throughout.
125.49m	SANDSTONE: pale grey, fine grained, bedding at 0-10deg; slightly weathered to fresh, high - very high strength
125.65m	SANDY SILTSTONE AND SILTY SANDSTONE: siltstone is pale to dark grey bands and laminations; sandstone is fine grained, 0-5deg bedding, trace of siltstone bands; slightly weathered to fresh, high to very high strength
126.10m	SANDSTONE /SILTY SANDSTONE AND SANDY SILTSTONE: pale to dark grey bands and layers, fine grained, bedding at 0-5deg, trace of siltstone and tuffaceous bands, thinly laminated to thinly bedded; fresh, high to very high strength
126.95m	SILTSTONE AND TUFFACEOUS CLAYSTONE: grey-brown and brown-grey, bedding at 0-5deg, trace of vertical and sub-vertical closed joints and fine grained sand; fresh, high strength
127.67m	SILTSTONE: grey and dark grey, bedding at 0deg, trace of fine grained sand; fresh, high strength
128.0	

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING: HQ3, HW Casing; WATER: 50-60% Water LOSS (HW casing at 41.4m); 100% Water LOSS (HW casing at 41.4m)); GROUND WATER LEVELS: 26/08/21, 02/09/21, 03/09/21

DEPTH (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
128.0	128.00m: becoming carbonaceous.
128.19m	COAL: black, bedding at 0-5deg, trace of tuffaceous bands; slightly weathered to fresh, medium - high strength
129.00m	SILTSTONE: grey, bedding at 0-5deg, trace of coal fragments; slightly weathered to fresh, high strength
129.18m	SILTSTONE AND CLAYSTONE: grey, pale grey and pale mauve-grey, bedding at 0-5deg, trace of fine grained sand and closed vertical and sub-vertical joints; slightly weathered to fresh, high to very high strength
132.46m	SILTSTONE AND TUFFACEOUS CLAYSTONE: grey-brown, bedding at 0-5deg, with some current and disturbed bedding, trace of non-tuffaceous layers and bands; slightly weathered to fresh, high to very high strength
133.43m	SILTSTONE AND CLAYSTONE: grey, bedding at 0deg, trace of vertical and sub-vertical closed joints; slightly weathered to fresh, high strength
134.69m	SILTSTONE AND CLAYSTONE: grey-brown and brown-grey with some grey, trace of current bedding <=10deg, some slightly tuffaceous? layers; slightly weathered to fresh, high - very high strength
	135.60m: some siliceous? layers.
136.0	

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

DRILLING: PROGRESS (DRILLING & CASING: HQ3, HW Casing; WATER: 100% Water LOSS (HW casing at 41.4m)), GROUND WATER LEVELS, DEPTH (m)

MATERIAL: GRAPHIC LOG, CLASSIFICATION SYMBOL, MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components

Depth (m)	Material Description
136.0	136.00m: siliceous?
136.12m	CLAYSTONE /SILTSTONE AND CLAYEY SANDSTONE (TUFFACEOUS): pale brown, pale grey-brown and pale brown-grey, fine grained sand particles, 0-5deg bedding; extremely weathered to fresh, extremely low / very high strength
137.48m	SANDSTONE: pale grey with dark bands, fine grained, bedding at 0deg, some siltstone bands and laminations, trace of closed vertical joints; fresh, very high strength
137.95m	SILTSTONE: dark grey, bedding at 0-5deg, trace of fine grained silty sandstone laminations; fresh, very high strength 138.48m: with slightly carbonaceous siltstone bands.
139.20m	TUFFACEOUS CLAYSTONE AND SILTSTONE AND COAL: brown, grey-brown and black, with trace of pale brown, bedding at 0-5deg, with trace of bedding <=40deg, trace of vertical and sub-vertical closed joints, thinly laminated to medium bedded layers; extremely weathered to fresh, extremely low to high strength
140.59m	COAL AND CARBONACEOUS SILTSTONE: black with some pale brown, bedding at 0-5deg, trace of tuffaceous claystone bands <=70mm; moderately weathered to fresh, low to high strength
142.34m	SILTSTONE: grey to brown grey, bedding at 0-5deg (possibly tuffaceous); slightly weathered to fresh, high strength
142.76m	COAL WITH CARBONACEOUS SILTSTONE AND SILTSTONE (TUFFACEOUS): black with some grey and brown grey layers, bedding at 0-5deg; moderately weathered to fresh, extremely low to high strength From 142.76-143.91m: slight hydrocarbon smell.
44.0	

Depth scale: 36.0, 37.0, 38.0, 39.0, 40.0, 41.0, 42.0, 43.0, 44.0

PIEZOMETER CONSTRUCTION DETAILS

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING: PROGRESS — DRILLING & CASING: HQ3, HW Casing; WATER: 100% Water LOSS (HW casing at 41.4m)

Depth (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic; Secondary and Minor Components)
144.30m	CORE LOSS 1.00m (144.30-145.30)
145.30m	SILTSTONE: pale grey with some dark grey carbonaceous laminae and stinge, bedding predominantly at 0-5deg; slightly weathered, medium - high strength
145.75m	SILTSTONE: pale brown-grey, few carbonaceous laminae and stinge, bedding at 0-5deg, possibly tuffaceous; slightly weathered, medium to high strength
146.60m	CORE LOSS 0.46m (146.60-147.06)
147.06m	CARBONACEOUS SILTSTONE: grey with some black layers, with few coal layers up to 30mm thickness; slightly weathered, high strength
147.37m	SILTSTONE: grey, bedding at 0-5deg, slightly carbonaceous; slightly weathered, high to very high strength
147.98m	INTERBEDDED SILTSTONE /CARBONACEOUS SILTSTONE AND SILTY SANDSTONE AND LAMINATED: siltstone is dark grey, grey and pale grey laminations and layers, bedding predominantly at 0-5deg; sandstone is fine grained; slightly weathered, high strength
149.04m	SILTSTONE: grey, slightly carbonaceous, bedding at 0-5deg; slightly weathered, high strength
149.69m	SILTY SANDSTONE: pale grey with some grey and dark grey carbonaceous siltstone laminations; extremely weathered to slightly weathered, extremely low to high strength
150.76m	CARBONACEOUS SILTSTONE: grey, occasional pale grey silty sandstone laminations and layers, bedding predominantly at 0-5deg; slightly weathered to fresh, extremely low - very high strength 150.83-151.05m: coal seams. 151.12-151.23m: coal seams. 151.27-151.31m: possible tuffaceous siltstone.

Depth scale: 44.0, 45.0, 46.0, 47.0, 48.0, 49.0, 50.0, 51.0, 52.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Drilling: HQ3 — HW Casing; Water: 100% Water LOSS (HW casing at 41.4m)

Depth (m)	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
152.0	CARBONACEOUS SILTSTONE: grey, occasional pale grey silty sandstone laminations and layers, bedding predominantly at 0-5deg; slightly weathered to fresh, extremely low - very high strength *(continued)*
	154.11-154.19m: highly carbonaceous siltstone.
155.06m	INTERBEDDED SANDSTONE /SILTY SANDSTONE AND CARBONACEOUS SILTSTONE AND LAMINATED: grey and pale grey, fine and medium grained, bedding at 0-5deg; slightly weathered to fresh, high to very high strength
155.54m	CARBONACEOUS SILTSTONE: grey, bedding at 0-5deg, occasional sandy siltstone laminations; slightly weathered to fresh, high to very high strength
156.18m	COAL AND CARBONACEOUS SILTSTONE: dark grey and black, bedding at 0-5deg, trace of tuffaceous claystone clasts, very strong hydrocarbon aroma; extremely weathered to fresh, extremely low to high strength
156.73m	TUFFACEOUS CLAYSTONE: brown and pale brown, bedding at 0-5deg, trace of fine grained sand particles; slightly weathered to fresh, medium - high strength
157.37m	CARBONACEOUS SILTSTONE AND COAL: dark grey and black, bedding at 0-5deg, slight hydrocarbon aroma; fresh, high strength
157.92m	SANDY CLAYSTONE AND TUFFACEOUS CLAYSTONE: grey, brown-grey, pale brown and brown, fine grained sand particles, bedding at 0-5deg; fresh, medium to high strength
158.40m	CARBONACEOUS SILTSTONE: dark grey and dark grey-brown, bedding at 0-5deg, trace of tuffaceous and coal laminations; fresh, high strength
158.69m	SILTSTONE /SANDY SILTSTONE AND SILTY SANDSTONE: siltstone is dark grey and grey; sandstone is fine grained, bedding at 0-5deg, trace of coal laminations and lenticles, thinly laminated to very thinly bedded; fresh, high strength
159.90m	
160.0	

Piezometer: Grout

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING; WATER), GROUND WATER LEVELS, DEPTH (m) | MATERIAL: GRAPHIC LOG, CLASSIFICATION SYMBOL, MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components | PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Drilling & casing: HQ3; HW Casing
Water: 100% Water LOSS (HW casing at 41.4m)

Depth (m)	Material Description
160.0	SANDSTONE AND SILTSTONE /SANDY SILTSTONE: pale to dark grey bands, layers and laminations, predominantly fine grained sand, with trace and some medium grained sand, bedding at 0-5deg, trace of carbonaceous siltstone bands and laminations, thinly laminated to thinly bedded layers; fresh, low to high strength *(continued)*
	161.60m: fine and medium grained sand, with trace of coarse grained sand.
162.56m	SANDSTONE: grey, with some pebbly sandstone, variable fine to coarse grained sand, current bedding at 0-10deg, angular to sub-rounded lithic pebbles <=4mm, trace of siltstone bands and coal lenticles; fresh, medium to high strength
163.63m	SILTSTONE /CARBONACEOUS SILTSTONE AND COAL: dark grey, black and grey-brown, bedding at 0-5deg, some tuffaceous siltstone interbedding, trace of tuffaceous claystone bands and vertical closed joints; fresh, high to very high strength
165.33m	SANDY SILTSTONE /SILTSTONE AND CARBONACEOUS SILTSTONE: dark grey and black, with trace of pale grey, fine grained sand, bedding at 0-5deg, trace of sandstone bands and laminations; fresh, high strength
166.04m	SANDSTONE AND SILTSTONE: pale to dark grey bands and laminations, predominantly fine grained sand, bedding at 0-5deg, trace of carbonaceous siltstone laminations, laminated to very thinly bedded; fresh, medium strength
166.69m	SILTSTONE /CARBONACEOUS SILTSTONE AND COAL: dark grey and black, bedding at 0-5deg, trace of fine grained sandstone bands and laminations; fresh, high strength
167.00m	SANDSTONE AND SILTY SANDSTONE: pale grey and grey with some dark grey bands, fine and medium grained, bedding at 0-5deg, trace some siltstone bands and laminations; fresh, medium to high strength
167.91m	

Depth scale: 160.0, 161.0, 162.0, 163.0, 164.0, 165.0, 166.0, 167.0, 168.0

Piezometer: Grout

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING: HQ3, HW Casing; WATER: 100% Water LOSS (HW casing at 41.4m)); GROUND WATER LEVELS; DEPTH (m)

MATERIAL: GRAPHIC LOG; CLASSIFICATION SYMBOL; MATERIAL DESCRIPTION — Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components

Depth (m)	Boundary	Material Description
68.0		SILTY SANDSTONE AND SILTSTONE /SANDY SILTSTONE: grey and dark grey bands of laminations, fine grained, bedding at 0deg, with some current and disturbed bedding, thinly laminated and laminated; fresh, high strength *(continued)*
	168.52m	SILTSTONE AND CARBONACEOUS SILTSTONE: dark grey and black, bedding at 0-5deg, some tuffaceous claystone bands; fresh, high strength
69.0	168.72m	SANDSTONE AND SILTY SANDSTONE: pale grey with grey and dark grey bands and laminations, fine grained, bedding at 0-5deg, with some current and disturbed bedding, trace and some siltstone and carbonaceous siltstone bands and laminations and sandy siltstone interbedding, lithic?; fresh, medium to high strength
70.0		
71.0	171.36m	SILTY SANDSTONE AND SANDY SILTSTONE: pale to dark grey bands and laminations, fine grained sand, cross bedding at 0-5deg, with some disturbed and burrowed bedding, trace of siltstone bands and laminations, thinly laminated to very thinly bedded, trace of calcite? sealed vertical and sub-vertical joints, lithic?; fresh, high strength
72.0		
73.0	172.97m	SILTSTONE /SANDY SILTSTONE AND SILTY SANDSTONE: siltstone is pale to dark grey bands and laminations, with trace of red-brown; sandstone is fine grained, bedding at 0-5deg, thinly laminated to very thinly bedded, trace of vertical and sub-vertical calcite? sealed joints; slightly weathered to fresh, high to very high strength
	173.66m	SILTSTONE AND SANDY SILTSTONE: pale to dark grey bands and laminations, with some silty sandstone, fine grained sand, bedding at 0-5deg, predominantly thinly laminated and laminated, trace of vertical and sub-vertical calcite? sealed joints; fresh, high strength
74.0		
75.0		175.00m: with some laminite, trace of very thinly and thinly bedded layers, varying percentages of siltstone, sandy siltstone and silty sandstone.
76.0		

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING, WATER), GROUND WATER LEVELS, DEPTH (m)
MATERIAL: GRAPHIC LOG, CLASSIFICATION SYMBOL, MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Drilling: HQ3; HW Casing
Water: 100% Water LOSS (HW casing at 41.4m)

Depth scale: 176.0, 177.0, 178.0, 179.0, 180.0, 181.0, 182.0, 183.0, 184.0

Depth	Material Description
176.25m	SILTSTONE: dark grey, with trace of pale grey and dark brown, bedding at 0-5deg, trace of fine grained sandy siltstone and silty sandstone bands and laminations, trace of vertical and sub-vertical closed joints; fresh, high to very high strength
177.61m	At 177.48-177.61m: brown tuffaceous claystone layer.
	SILTSTONE: dark grey with pale grey laminations and trace of dark grey-brown, bedding at 0-5deg, with trace of cross bedding <=10deg, some vertical and sub-vertical closed joints; fresh, high strength
	179.60m: dark grey with trace of pale grey laminations.
	180.60m: becoming slightly siliceous.
181.24m	SILTSTONE , CLAYSTONE AND TUFFACEOUS SANDSTONE: pale grey and pale brown, bedding at 0deg, fine and medium grained sand particles, trace of closed vertical joints; fresh, medium to high strength
181.78m	SILTSTONE: dark grey with trace of pale grey laminations, bedding at 0deg, some closed vertical and sub-vertical joints; fresh, high strength
	182.49m: trace of closed vertical and sub-vertical joints, trace of pale brown tuffaceous claystone bands <=10mm.
184.00m	

Piezometer: Grout

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING | MATERIAL | PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Depth (m)	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
184.0	SILTSTONE: dark grey with pale grey, bedding at 0deg, trace of pale brown tuffaceous claystone bands <=30mm and closed vertical and sub-vertical joints; fresh, medium to very high strength
185.0	185.00m: some slightly carbonaceous interbedding, dark grey and black.
186.60	186.60m: trace of fine grained sandstone laminations, brown tuffaceous
187.02	187.02-187.17m: sandy siltstone layer.
187.17m	SILTSTONE /SANDY SILTSTONE: pale to dark grey, predominantly fine grained sand with trace of medium grained sand, bedding at 0deg, with some current and disturbed bedding, trace of pale brown tuffaceous claystone bands <=35mm, thinly laminated to very thinly bedded; fresh, medium - high strength
189.0	189.00m: with some carbonaceous bands and laminations.
189.60	189.60m: thinly laminated.
189.86m	SILTSTONE AND CARBONACEOUS SILTSTONE: dark grey and black with some pale grey laminations, bedding at 0deg, initially some becoming trace of fine grained silty sandstone laminations, trace of vertical and sub-vertical closed joints; fresh, high strength
190.53m	SILTY SANDSTONE AND SANDY SILTSTONE: pale to dark grey layers, bands and laminations, fine grained, bedding at 0-5deg, with trace of current bedding, some vertical and sub-vertical close joints, thinly laminated to very thinly bedded; fresh, high strength
191.36m	COAL: dark grey-brown and black, bedding at 0-5deg, some vertical and sub-vertical closed joints; fresh, high / very high strength At 191.36m: 20mm tuffaceous claystone band.
191.84m	
192.0	

Drilling: HQ3; HW Casing
Water: 100% Water LOSS (HW casing at 41.4m)
Ground water levels: 31/08/21 (at approx. 186.0 m)

Piezometer: Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH507
FILE / JOB NO : G5331
SHEET : 25 OF 27

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

Depth (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
192.0 – 192.27m	CARBONACEOUS SILTSTONE AND CARBONACEOUS SANDY SILTSTONE: black, fine grained sand, bedding at 0deg, trace of silty sandstone interbedding and closed vertical joints; fresh, medium to high strength *(continued)*
192.27 – 192.55m	SANDY SILTSTONE AND SILTY SANDSTONE: siltstone is pale to dark grey bands and laminations; sandstone is fine grained, bedding at 0-5deg, thinly laminated; fresh, high strength
192.55 – 193.00m	SILTY SANDSTONE: pale grey and brown-grey, fine grained, bedding at 0deg, trace of siltstone laminations; fresh, high strength
193.00 – 194.10m	SILTY SANDSTONE: pale grey with some grey and dark grey, fine grained, bedding at 0-10deg, trace of sandy siltstone laminations; fresh, high strength
194.10 – 195.04m	SILTY SANDSTONE AND SANDY SILTSTONE /SILTSTONE: pale to dark grey bands and laminations, fine grained, bedding at 0-5deg, with some current and disturbed bedding, thinly laminated to very thinly bedded; fresh, high strength
195.04 – 196.17m	SILTSTONE: pale to dark grey bands and laminations, bedding at 0deg, trace of fine grained silty sandstone laminations, thinly laminated to laminated, carbonaceous siltstone and coal at 196.08-196.17m, trace of closed sub-vertical joints; fresh, high strength
196.17 – 196.76m	SILTY SANDSTONE AND SANDY SILTSTONE: pale grey with trace of grey and dark grey, fine grained, bedding at 0-5deg, with current and disturbed bedding throughout, trace of minor faulting? and calcite sealed joints; fresh, low - medium strength
196.76 – 196.99m	SILTY SANDSTONE: grey, fine grained, bedding at 0-5deg; fresh, medium - very high strength
196.99 – 198.10m	SILTSTONE /SANDY SILTSTONE AND SILTY SANDSTONE: siltstone is pale to dark grey bands and laminations; sandstone is fine grained, bedding at 0-5deg, with some disturbed bedding, thinly laminated to very thinly bedded; fresh, medium to high strength
198.10 – 199.13m	SILTY SANDSTONE AND SANDY SILTSTONE: grey, dark grey and dark grey-brown, fine grained, bedding at 0deg, trace of vertical and sub-vertical closed joints; fresh, medium to high strength 198.59-198.74m: siltstone layer.
199.13 – 199.57m	SILTSTONE: dark grey, bedding at 0deg, trace of closed sub-vertical joints; fresh, high strength
199.57 – 199.74m	CLAYSTONE AND TUFFACEOUS SANDSTONE: claystone is pale brown and grey brown; sandstone is fine grained, bedding at 0deg; fresh, medium strength
199.74 – 200.00m	

Drilling: HQ3; HW Casing. Water: 100% Water LOSS (HW casing at 41.4m)

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

NSW GOVERNMENT Transport for NSW

HOLE NO : BH507
FILE / JOB NO : G5331
SHEET : 26 OF 27

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Eltham Park Avenue Mt Victoria

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Drilling: HQ3, HW Casing. Water: 100% Water LOSS (HW casing at 41.4m). Ground water levels: 06/09/21 (at ~201.1 m), 07/09/21 (at ~207.1 m).

Piezometer: Grout

Depth (m)	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
200.00	SILTSTONE: dark grey, bedding at 0deg, trace of fine and medium grained sandstone pockets; fresh, medium strength
200.39m	SILTSTONE /CARBONACEOUS SILTSTONE AND SANDSTONE: siltstone is pale to dark grey and black; sandstone is fine and medium grained, with trace of coarse grained sand, bedding at 0deg, with current and disturbed bedding throughout; fresh, medium to high strength
	SANDSTONE: pale grey with some dark grey laminations, fine and medium grained, bedding at 0deg, some carbonaceous siltstone laminations, trace of vertical closed joints; fresh, high strength
	20.15m: with numerous siltstone laminations throughout, predominantly fine grained sand, some current and disturbed bedding, thinly laminated and laminated.
202.09m	SANDSTONE /SILTY SANDSTONE AND SANDY SILTSTONE /SILTSTONE: pale to dark grey bands and laminations, fine grained, bedding at 0-5deg, thinly laminated and laminated; fresh, high strength
202.65m	SILTSTONE: dark grey and black with trace of pale grey, bedding at 0deg, trace of fine grained sandy siltstone and silty sandstone bands and laminations, trace of closed vertical joints and slightly carbonaceous interbedding; fresh, medium to high strength
	203.96m: some fine grained silty sandstone and sandy siltstone bands of laminations.
	204.50m: siltstone with trace of fine grained silty sandstone laminations.
205.62m	SILTY SANDSTONE: pale to dark grey, fine and medium grained, bedding at 0-5deg, slightly carbonaceous; fresh, high strength
205.78m / 205.90m	CARBONACEOUS SILTSTONE: black, bedding at 5deg, some vertical closed joints; fresh, high strength
	SILTSTONE /SANDY SILTSTONE AND SILTY SANDSTONE /TUFFACEOUS SILTSTONE, SANDY SILTSTONE/SILTY SANDSTONE: pale to dark grey and pale brown bands and layers, fine grained sand, bedding at 0-10deg, with some current and disturbed bedding, thinly laminated to thinly bedded, trace of closed vertical and sub-vertical joints; fresh, high to very high strength
207.36m	SILTSTONE /SANDY SILTSTONE AND SILTY SANDSTONE: siltstone is pale grey with some grey; sandstone is fine grained, bedding at 0-5deg, with some current and disturbed bedding, closd vertical and sub-vertical joints throughout; fresh, high to very high strength
208.00m	

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL LOCATION : Eltham Park Avenue Mt Victoria	**HOLE NO : BH507** FILE / JOB NO : G5331 SHEET : 27 OF 27

POSITION : E: 244259.128, N: 6280575.331 (56 GDA2020) SURFACE ELEVATION : 1072.000 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 4/5/21 DATE COMPLETED : 7/9/21 DATE LOGGED : 4/5/21 LOGGED BY : BA CHECKED BY : MD

DRILLING & CASING	WATER	DEPTH (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
HQ3 / HW Casing	100% Water LOSS (HW casing at 41.4m)	208.0	SILTSTONE AND SANDY SILTSTONE: pale grey with some grey, fine grained sand, 0-5deg bedding, closed vertical and sub-vertical joints throughout; fresh, high to very high strength
		208.75m	CLAYSTONE: brown-grey and grey, bedding at 0deg, some closed vertical joints; fresh, medium - high strength
		209.00m	SILTSTONE AND SANDY SILTSTONE: dark grey and black, fine grained sand, bedding at 0deg, trace of closed sub-vertical and vertical joints; fresh, high strength
		210.00m	At 209.94-210.00m: carbonaceous siltstone and coal.
			BH507 TERMINATED AT 210.00 m Target depth

Depth scale: 208.0, 209.0, 210.0, 211.0, 212.0, 213.0, 214.0, 215.0, 216.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH507	Standpipe		210.00 m 862.00 m AHD		

Grout (to 210.00 m)

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH622
FILE / JOB NO : G5331
SHEET : 1 OF 6

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge near point to point gantry

POSITION : E: 242454.830, N: 6280909.730 (56 GDA2020) SURFACE ELEVATION : 875.559 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 5/10/21 DATE COMPLETED : 14/10/21 DATE LOGGED : 14/10/21 LOGGED BY : DJ CHECKED BY : MD

DRILLING: Drilling & Casing	DRILLING: Water	Ground Water Levels	Depth (m)	Classification Symbol	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
AD/T, HW Casing (0.0–1.80)		Not Encountered	0.0–0.90	CI	GRAVELLY CLAY: pale yellow, yellow-brown, grey, medium plasticity, fine to coarse gravel
			0.90–1.80	CI-CH	SANDY CLAY: pale yellow, grey, medium to high plasticity, fine grained sand, trace gravel
HQ3 (1.80–8.0)	0% Water LOSS		1.80–2.31		CORE LOSS 0.51m (1.80-2.31)
			2.31–2.80	GC	CLAYEY GRAVEL: pale yellow, grey, fine to coarse gravel, medium plasticity clay
			2.80–3.24		SANDSTONE: pale yellow, grey, off-white, medium to coarse grained; highly weathered, very low strength
			3.24–3.48		CORE LOSS 0.24m (3.24-3.48)
			3.48–6.70		SILTSTONE: pale yellow, pale grey, yellow-brown, horizontally bedded.; highly weathered to moderately weathered, extremely low - very low strength - as above with dark grey layers (at ~5.0 m)
			6.70–8.0		SHALE /SILTSTONE: dark grey, pale grey, bedding 0-5deg.; highly weathered to moderately weathered, extremely low to very low strength

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH622	Standpipe Piezometer		42.50 m 833.06 m AHD		

Grout (0.0–8.0 m)

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH622
FILE / JOB NO : G5331
SHEET : 2 OF 6

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge near point to point gantry

POSITION : E: 242454.830, N: 6280909.730 (56 GDA2020) SURFACE ELEVATION : 875.559 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 5/10/21 DATE COMPLETED : 14/10/21 DATE LOGGED : 14/10/21 LOGGED BY : DJ CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING: HQ3; WATER: 0% Water LOSS); GROUND WATER LEVELS

DEPTH (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic; Secondary and Minor Components)
8.0	SHALE /SILTSTONE: dark grey, pale grey, bedding 0-5deg.; highly weathered to moderately weathered, extremely low to very low strength *(continued)*
8.71m	LAMINITE: dark grey, pale yellow, yellow-brown, grey; moderately weathered to fresh, low to medium strength
10.00m	SILTSTONE: dark grey to black, thinly interbedded with sandstone, bedding 0-5deg.; fresh, medium strength
13.80m	LAMINITE: dark grey, grey, thinly interbedded and interlaminated siltstone and fine grained sandstone, bedding 0-5deg.; fresh, medium strength
14.91m	COAL: dark grey to black, fractured.; fresh, very low strength
15.18m	SILTSTONE: dark grey, grey, thinly interlaminated with sandstone, horizontal bedding.; moderately weathered to fresh, medium strength

Depth scale: 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15.0, 16.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH622	Standpipe Piezometer		42.50 m 833.06 m AHD		

Grout

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge near point to point gantry

POSITION : E: 242454.830, N: 6280909.730 (56 GDA2020) SURFACE ELEVATION : 875.559 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 5/10/21 DATE COMPLETED : 14/10/21 DATE LOGGED : 14/10/21 LOGGED BY : DJ CHECKED BY : MD

DRILLING / MATERIAL

DRILLING & CASING: HQ3

WATER: 0% Water LOSS (16.0–18.05 m); 100% Water LOSS (18.05–24.0 m)

Depth (m)	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
16.00	SILTSTONE: dark grey, grey, thinly interlaminated with sandstone, horizontal bedding.; moderately weathered to fresh, medium strength *(continued)*
16.70m	COAL: dark grey to black, fractured.; moderately weathered, very low strength
17.35m	SANDSTONE: grey, pale yellow, dark grey, fine grained, thinly interlaminated with siltstone, horizontal bedding.; moderately weathered, medium strength
17.68m	COAL: dark grey to black, fractured, with carbonaceous siltstone 18.00m.; moderately weathered, very low to medium strength
18.35m	LAMINITE: dark grey, grey, 70% fine grained sandstone interlaminated with 30% siltstone, horizontal bedding.; moderately weathered, medium strength
20.15m	SANDSTONE WITH CONGLOMERATE: pale yellow, grey, medium to coarse grained; highly weathered to moderately weathered, extremely low to medium strength
23.45m	COAL /CARBONACEOUS SILTSTONE: black; moderately weathered, very low strength

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH622	Standpipe Piezometer		42.50 m 833.06 m AHD		

Depth	Backfill
16.00 – 22.00 m	**Grout**
22.00 – 23.00 m	Bentonite
23.00 – 24.00 m	2mm Filter Sand Sand

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH622
FILE / JOB NO : G5331
SHEET : 4 OF 6

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge near point to point gantry

POSITION : E: 242454.830, N: 6280909.730 (56 GDA2020) SURFACE ELEVATION : 875.559 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 5/10/21 DATE COMPLETED : 14/10/21 DATE LOGGED : 14/10/21 LOGGED BY : DJ CHECKED BY : MD

DRILLING: PROGRESS (DRILLING & CASING: HQ3; WATER: 100% Water LOSS), GROUND WATER LEVELS, DEPTH (m) 24.0–32.0

Depth	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
24.19m	COAL /PEAT: black, soil properties.; extremely weathered, extremely low strength
24.40m	CARBONACEOUS SILTSTONE: black; moderately weathered - slightly weathered, medium strength
24.81m	SILTSTONE: grey, horizontal bedding.; slightly weathered, medium strength
25.40m	LAMINITE: dark grey, grey, 80% siltstone, 20% fine grained sandstone, horizontal bedding.; slightly weathered to fresh, medium - high strength
26.41m	SILTSTONE: dark grey, black, grey, thinly laminated fine grained sandstone, horizontal bedding.; slightly weathered to fresh, low strength
26.86m	SANDSTONE: grey with dark grey, fine grained, thinly laminated siltstone, horizontal bedding.; slightly weathered to fresh, medium strength
27.81m	LAMINITE: dark grey, black, grey, 70% siltstone, 30% fine grained sandstone.; slightly weathered to fresh, medium strength
28.43m	SANDSTONE: grey with dark grey, fine to medium grained, thinly laminated siltstone, trace conglomerate, horizontally bedded.; slightly weathered, medium strength
31.52m	CORE LOSS 0.21m (31.52-31.73)
31.73m	LITHIC SANDSTONE: grey, off-white, dark grey, coarse grained; moderately weathered, low strength

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH622	Standpipe Piezometer		42.50 m 833.06 m AHD		

Depth	Backfill
24.00 m – 28.00 m	Sand
27.00 m – 28.00 m	2mm Filter Sand Sand
28.00 m – 29.00 m	Bentonite
29.00 m –	**Grout**

27.00 m

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

HOLE NO : BH622
FILE / JOB NO : G5331
SHEET : 5 OF 6

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge near point to point gantry

POSITION : E: 242454.830, N: 6280909.730 (56 GDA2020) SURFACE ELEVATION : 875.559 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST
DATE STARTED : 5/10/21 DATE COMPLETED : 14/10/21 DATE LOGGED : 14/10/21 LOGGED BY : DJ CHECKED BY : MD

DRILLING — PROGRESS (DRILLING & CASING: HQ3; WATER: 100% Water LOSS); GROUND WATER LEVELS; DEPTH (m)

MATERIAL — GRAPHIC LOG; CLASSIFICATION SYMBOL; MATERIAL DESCRIPTION: Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components

Depth (m)	MATERIAL DESCRIPTION
32.0	LITHIC SANDSTONE: grey, off-white, dark grey, coarse grained; moderately weathered, low strength *(continued)*
32.42m	LITHIC SANDSTONE: grey, off-white, fine to coarse grained, carbonate cementation; moderately weathered, extremely low to medium strength
33.00m	INTERBEDDED SILTSTONE AND SANDSTONE (50:50%): siltstone is thin laminations, bedding 0-5deg, with carbonaceous siltstone from 34.24 - 34.28m, 34.35 - 34.38m.; sandstone is fine grained; slightly weathered - fresh, low to medium strength
34.38m	SILTY SANDSTONE: grey, fine grained sand, bedding 0-5deg, very thin lamination of carbonaceous siltstone.; fresh, high strength
37.14m	INTERBEDDED SILTSTONE WITH SANDSTONE: siltstone is dark grey, grey, bedding 0-5deg, thin lamination of carbonaceous siltstone.; sandstone is fine grained; fresh, high strength
38.19m	SANDY SILTSTONE: grey, fine grained sand, thin lamination of carbonaceous siltstone.; fresh, high strength
40.00m	

Depth scale: 32.0, 33.0, 34.0, 35.0, 36.0, 37.0, 38.0, 39.0, 40.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH622	Standpipe Piezometer		42.50 m 833.06 m AHD		

Grout

See Explanatory Notes for details of abbreviations & basis of descriptions.

HOLE NO : BH622
FILE / JOB NO : G5331
SHEET : 6 OF 6

PROJECT : BLACKHEATH TO LITTLE HARTLEY TUNNEL
LOCATION : Great Western Highway verge near point to point gantry

POSITION : E: 242454.830, N: 6280909.730 (56 GDA2020) SURFACE ELEVATION : 875.559 (AHD) ANGLE FROM HORIZONTAL : 90°

RIG TYPE : COMACCHIO 405 MOUNTING : Track CONTRACTOR : TERRATEST

DATE STARTED : 5/10/21 DATE COMPLETED : 14/10/21 DATE LOGGED : 14/10/21 LOGGED BY : DJ CHECKED BY : MD

DRILLING & CASING	WATER	GROUND WATER LEVELS	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components
HQ3	100% Water LOSS		40.0 – 42.50			INTERBEDDED SANDSTONE AND SILTSTONE: grey, dark grey, fine grained, bedding 0-5deg, thin lamination of carbonaceous siltstone.; fresh, high strength
			42.50m			BH622 TERMINATED AT 42.50 m Target depth

Depth scale: 40.0, 41.0, 42.0, 43.0, 44.0, 45.0, 46.0, 47.0, 48.0

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
BH622	Standpipe Piezometer		42.50 m 833.06 m AHD		

Grout (to 42.50 m)

See Explanatory Notes for details of abbreviations & basis of descriptions.

TRANSPORT FOR NSW

PIEZOMETER INSTALLATION LOG

Transport for NSW

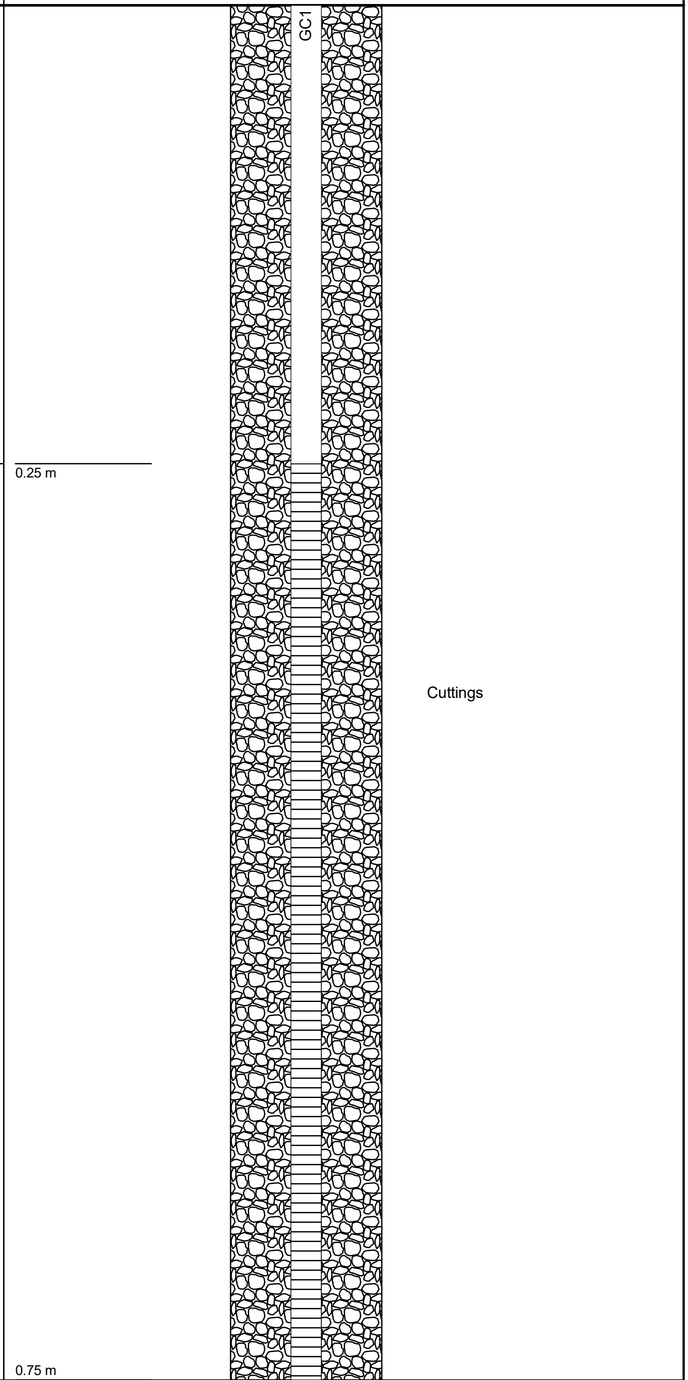
Hole ID: GC1

CLIENT :		POSITION : B6 Lake Medlow Trail-Greves Creek	Sheet : 1 OF 1
CONTRACTOR :		EASTING : 248955.0 m	STATUS :
PROJECT : Blackheath to Little Hartley TUNNEL		NORTHING : 6273076.0 m	LOGGED BY : DJ
LOCATION :		COORD. SYS. : GDA2020 56	DRILL DATE : 20/12/2021
PROJECT No. : G5331		GROUND RL : 1010.00 m AHD	

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
GC1	Standpipe Piezometer		0.75 m 1009.25 m AHD		

Method	Drilling Water	Depth (m)	Elevation (m AHD)	Graphic Log	Soil / Rock Description
HA					SILTY CLAY
					CLAYEY SAND: dark grey, black, fine grained sand, low plasticity clay, increasing sand content with depth
		0.5	1009.5		
					GC1 TERMINATED AT 0.75 m Target depth



RIG :	CHECKED BY : MD	REMARK	
INCLINATION :	CHECKED DATE : 12/05/2022		
AZIMUTH :	APPROVED BY :		
HOLE DIA. :	APPROVED DATE :		

PIEZOMETER INSTALLATION LOG

Hole ID : GC2

CLIENT :		POSITION : B6 Lake Medlow Trail-Greves Creek	Sheet : 1 OF 1
CONTRACTOR :		EASTING : 249473.0 m	STATUS :
PROJECT : Blackheath to Little Hartley Tunnel		NORTHING : 6272907.0 m	LOGGED BY : DJ
LOCATION :		COORD. SYS. : GDA2020 56	DRILL DATE : 20/12/2021
PROJECT No. : G5331		GROUND RL : 976.00 m AHD	

PIEZOMETER CONSTRUCTION DETAILS

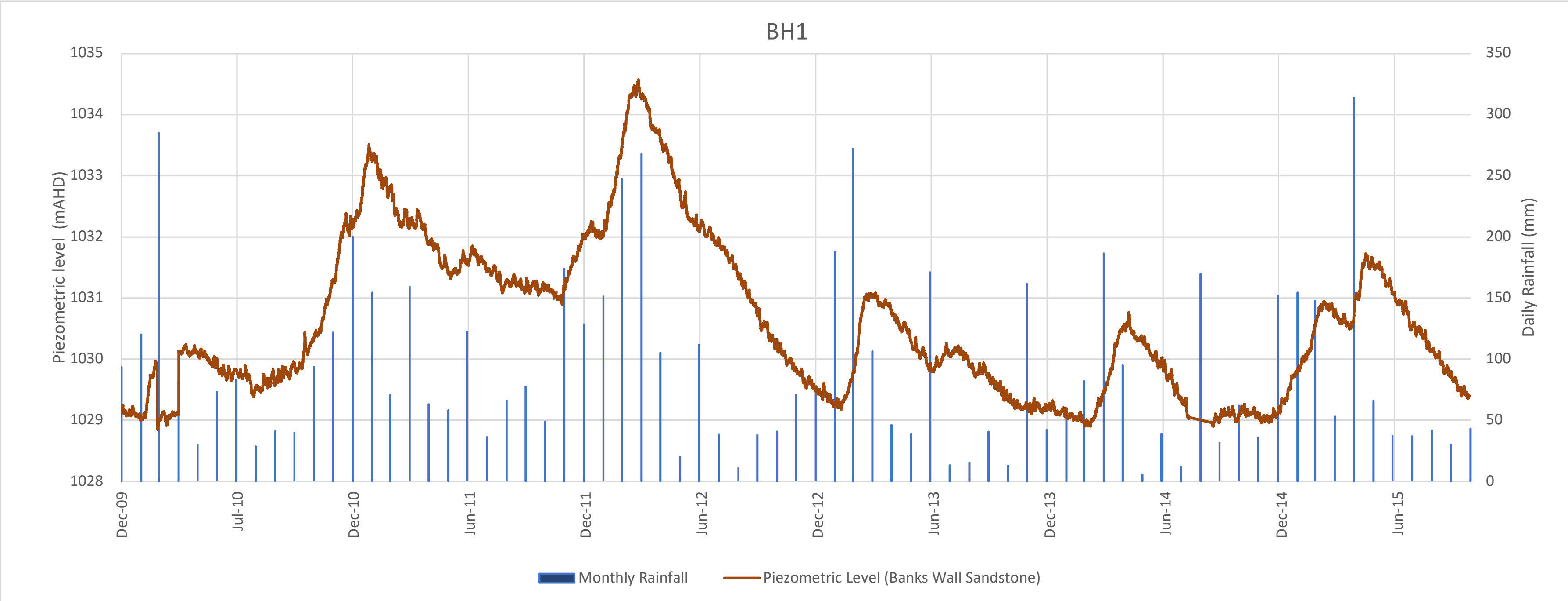
ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
GC2	Standpipe Piezometer		0.80 m 975.20 m AHD		

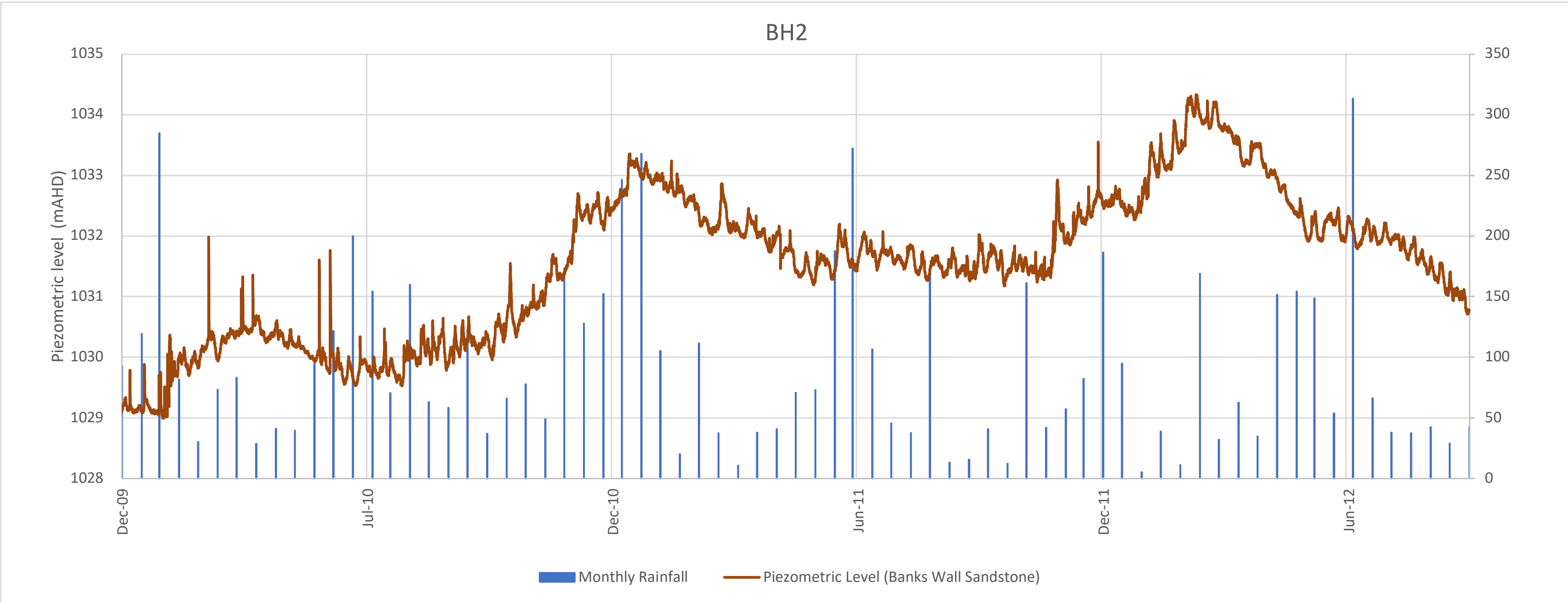
Method	Drilling Water	Depth (m)	Elevation (m AHD)	Graphic Log	Soil / Rock Description	Piezometer
HA					SILTY CLAY (Peat	GC2; Cuttings
					CLAYEY SAND: dark grey, black, fine grained sand, low plasticity clay, increasing sand content with depth	0.30 m
		0.5	975.5			
						0.80 m
					GC2 TERMINATED AT 0.80 m Target depth	

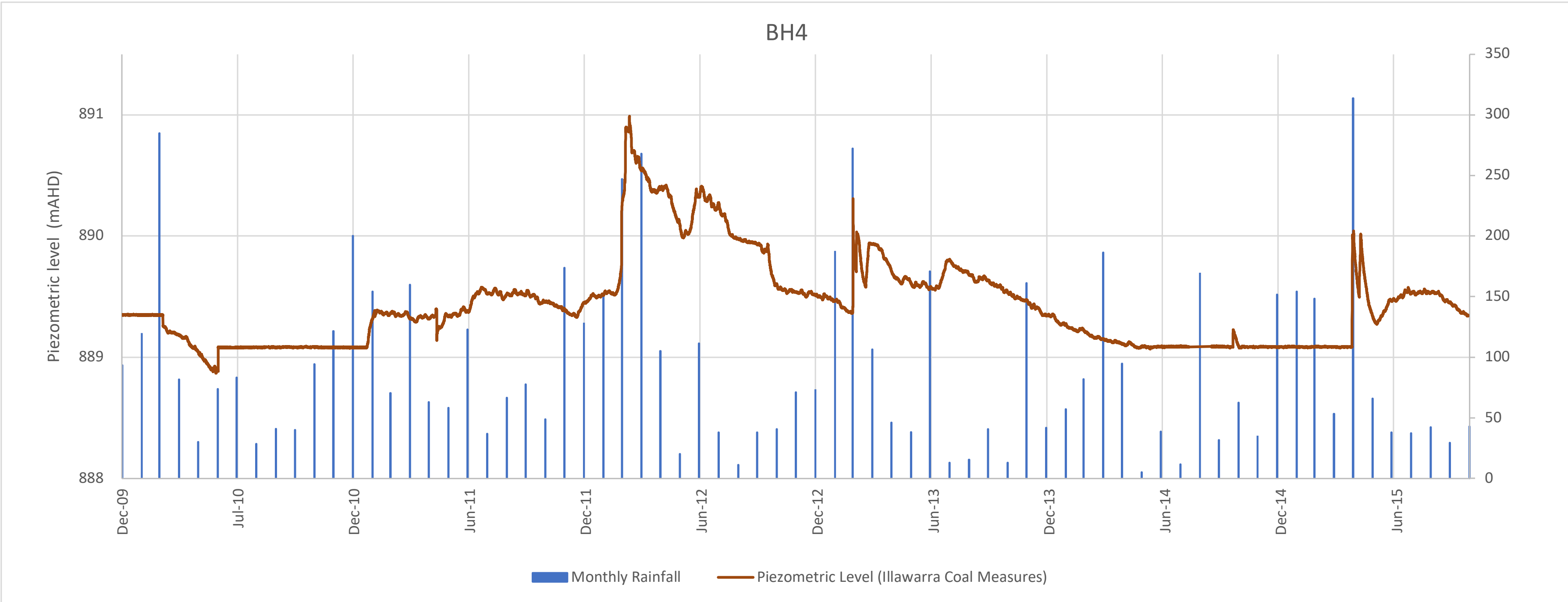
RIG :	CHECKED BY : MD	REMARK	
INCLINATION :	CHECKED DATE : 12/05/2022		
AZIMUTH :	APPROVED BY :		
HOLE DIA. :	APPROVED DATE :		

Annexure D

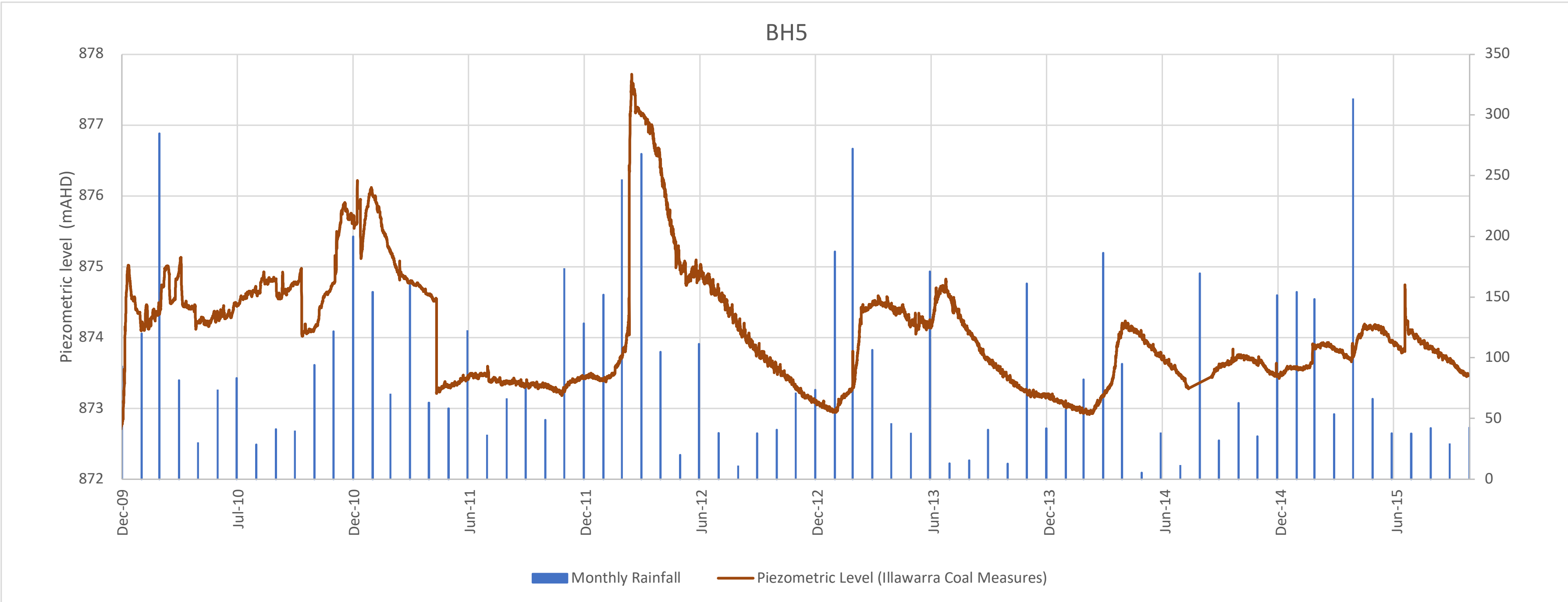
Hydrographs

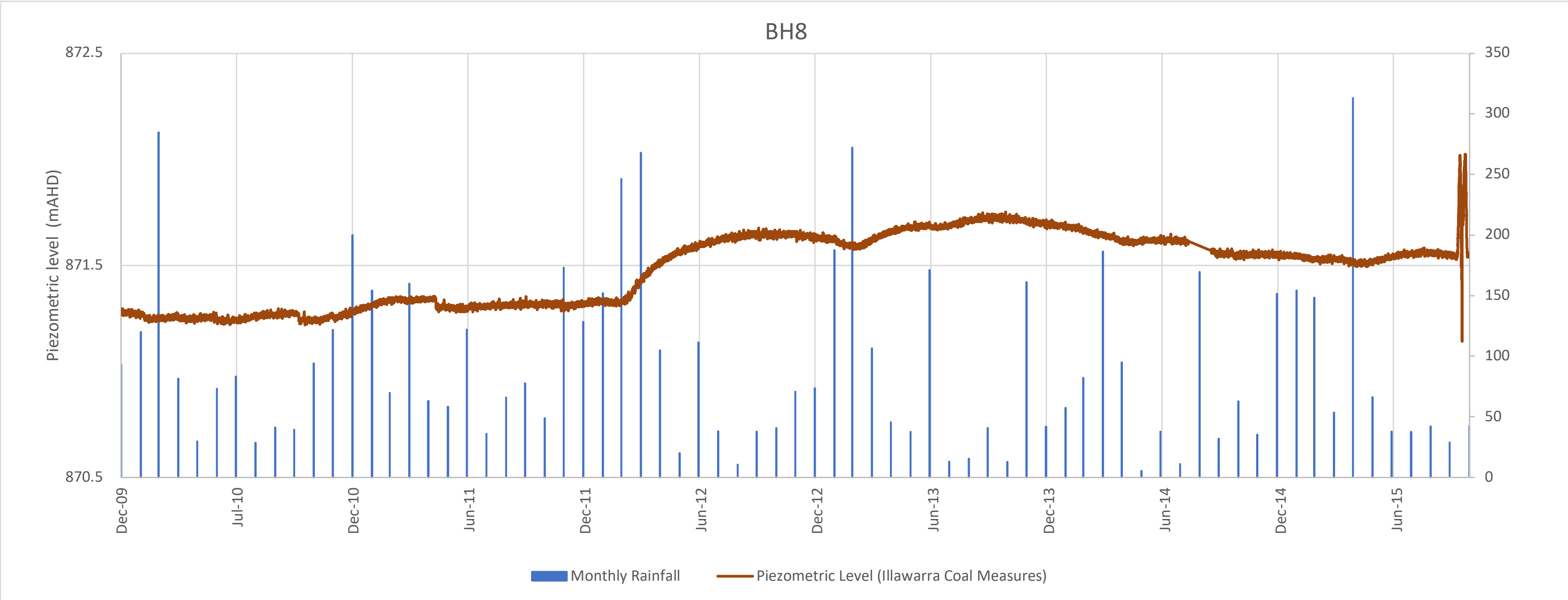

BH1
1035
1034
1033
1032
1031
1030
1029
1028
Piezometric level (mAHD)
350
300
250
200
150
100
50
0
Daily Rainfall (mm)
Dec-09
Jul-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
Monthly Rainfall
Piezometric Level (Banks Wall Sandstone)


BH2
Piezometric level (mAHD)
1035
1034
1033
1032
1031
1030
1029
1028
350
300
250
200
150
100
50
0
Dec-09
Jul-10
Dec-10
Jun-11
Dec-11
Jun-12
Monthly Rainfall
Piezometric Level (Banks Wall Sandstone)

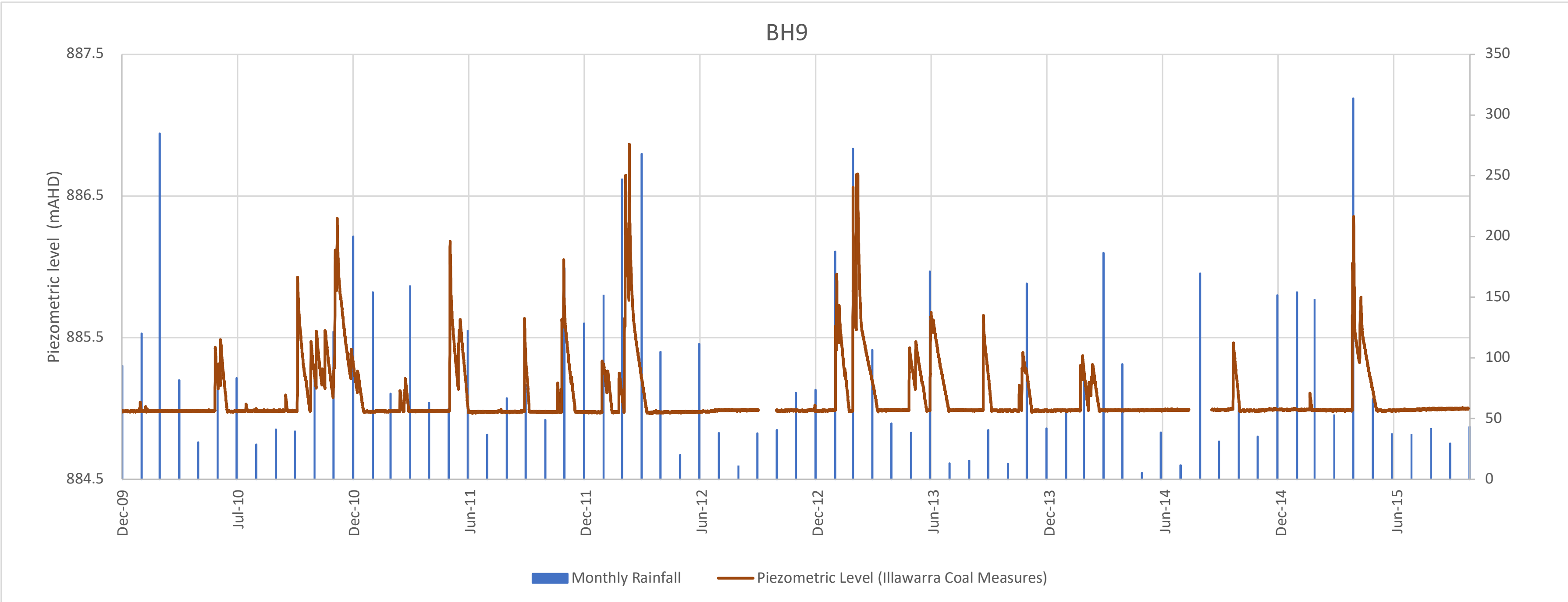


BH4
Piezometric level (mAHD)
891
890
889
888
350
300
250
200
150
100
50
0
Dec-09
Jul-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
Monthly Rainfall
Piezometric Level (Illawarra Coal Measures)

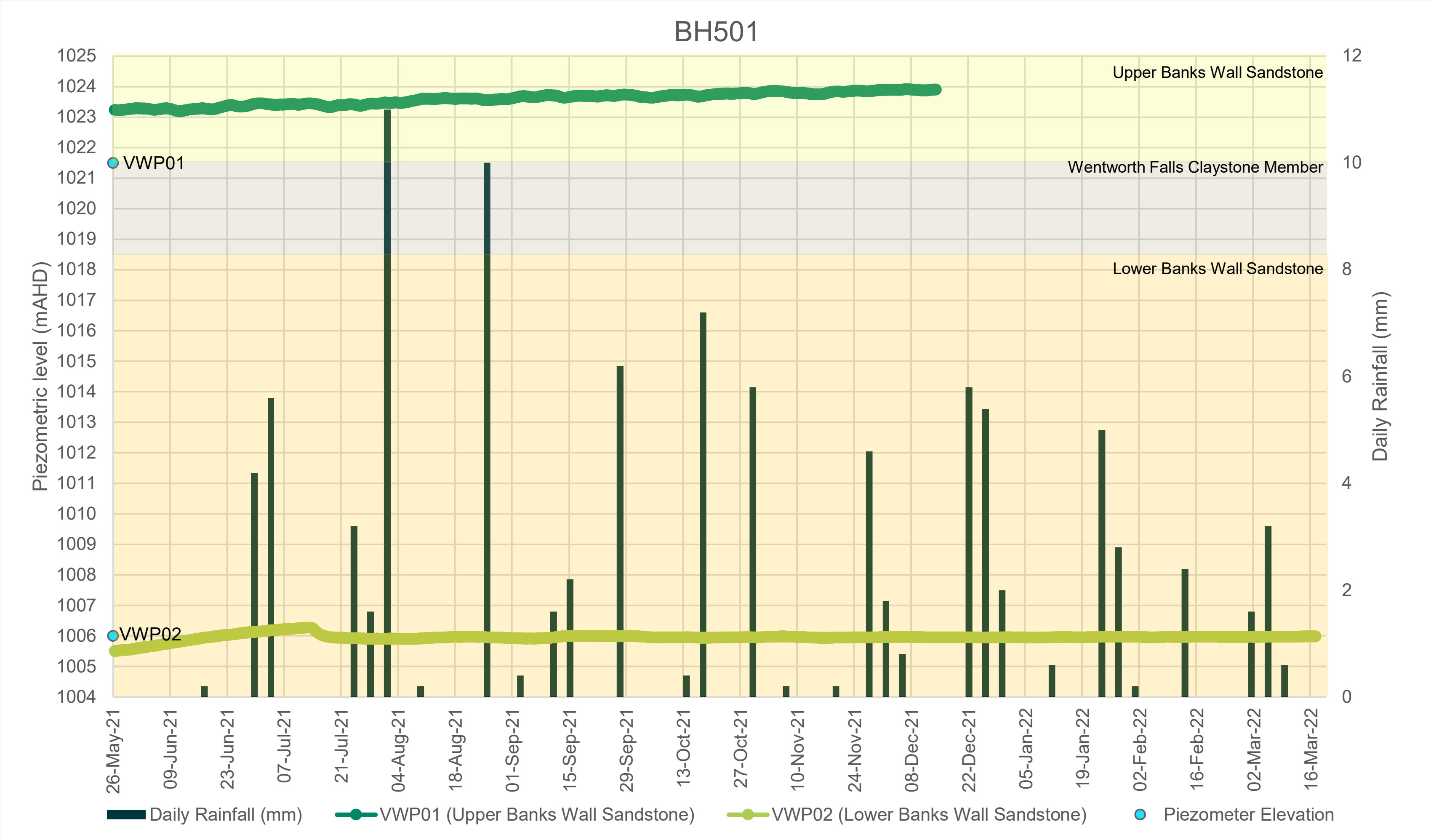

BH5
Piezometric level (mAHD)
878
877
876
875
874
873
872
350
300
250
200
150
100
50
0
Dec-09
Jul-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
Monthly Rainfall
Piezometric Level (Illawarra Coal Measures)

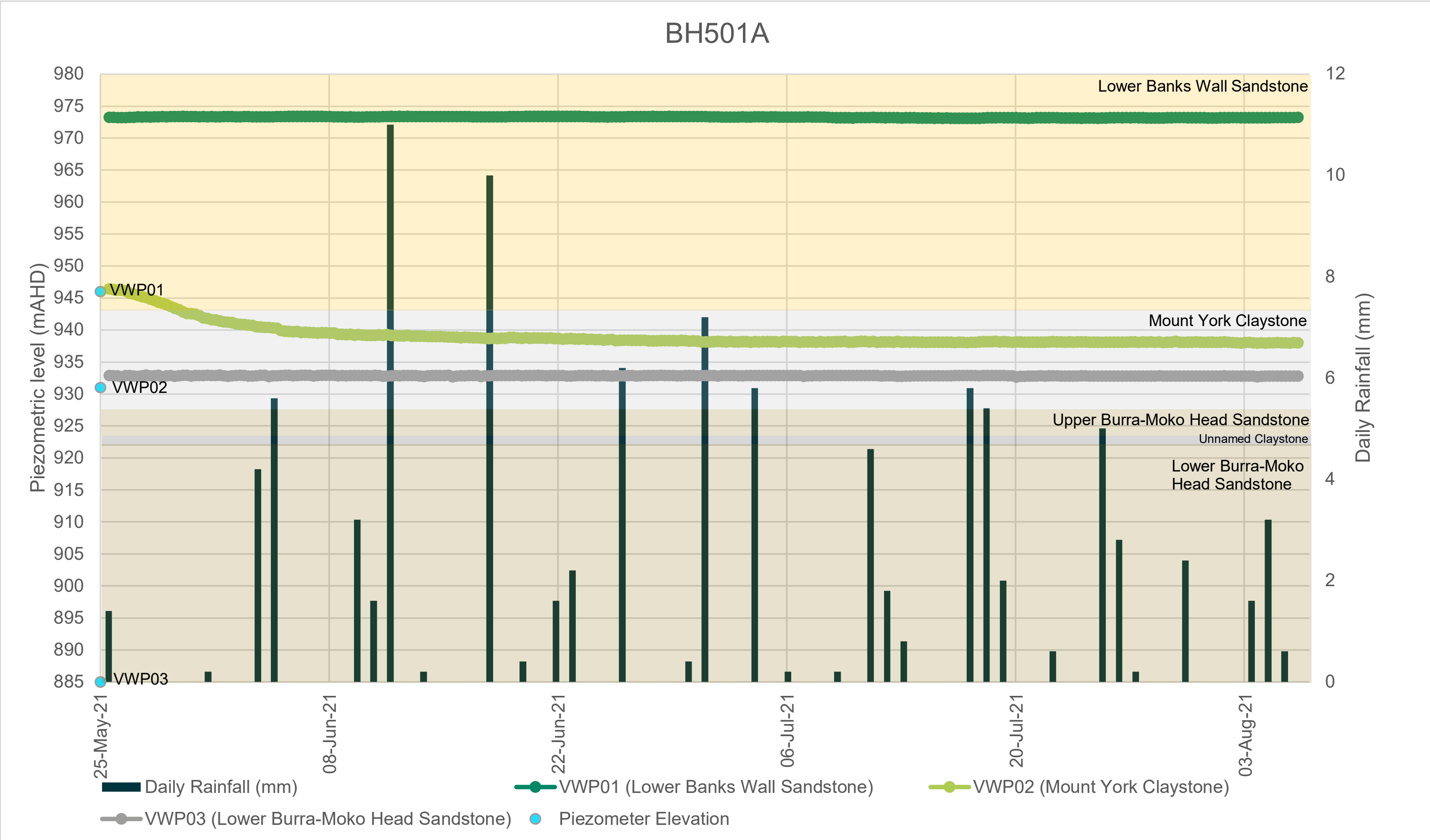


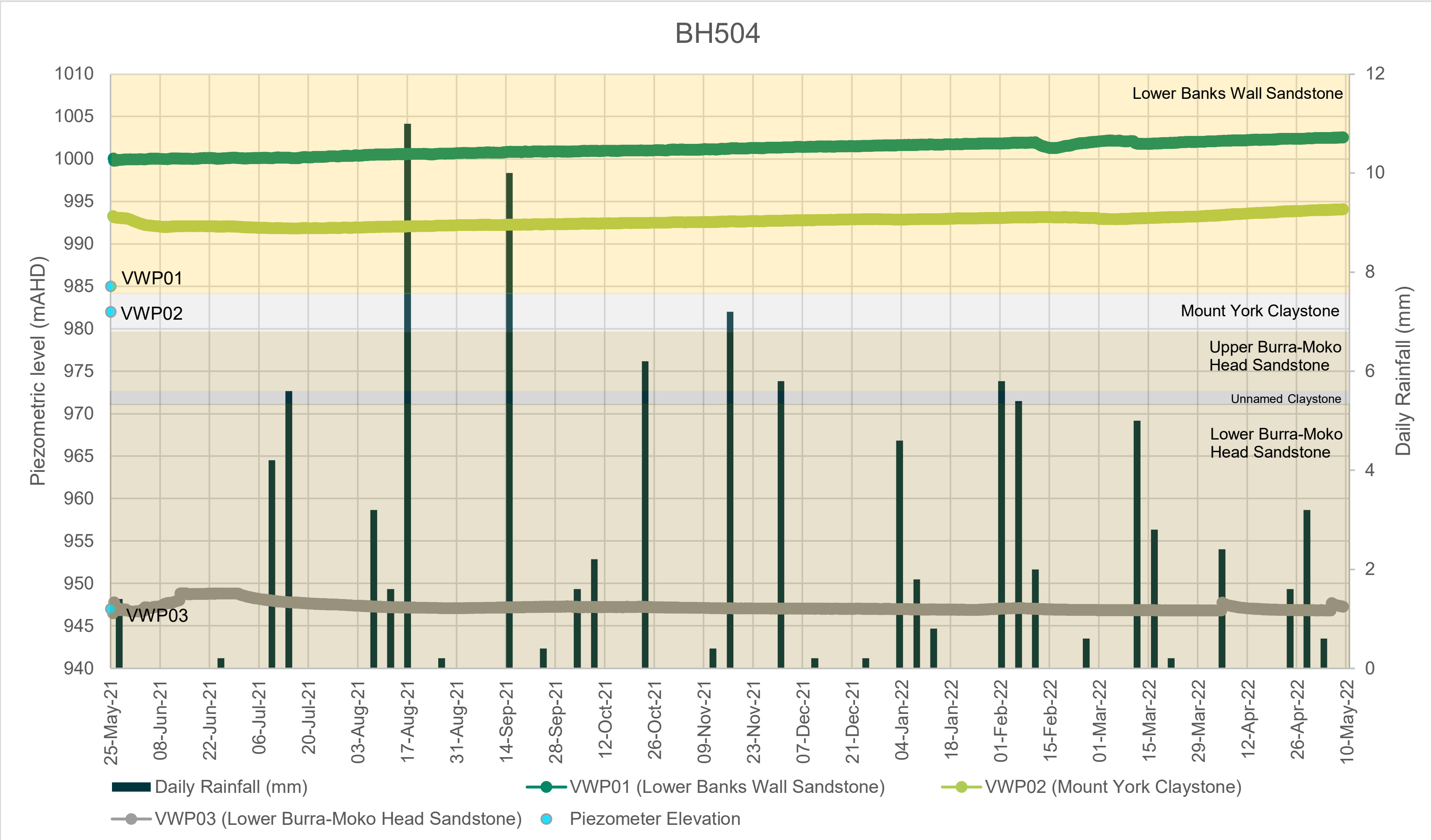
BH8
872.5
871.5
870.5
Piezometric level (mAHD)
350
300
250
200
150
100
50
0
Dec-09
Jul-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
Monthly Rainfall
Piezometric Level (Illawarra Coal Measures)



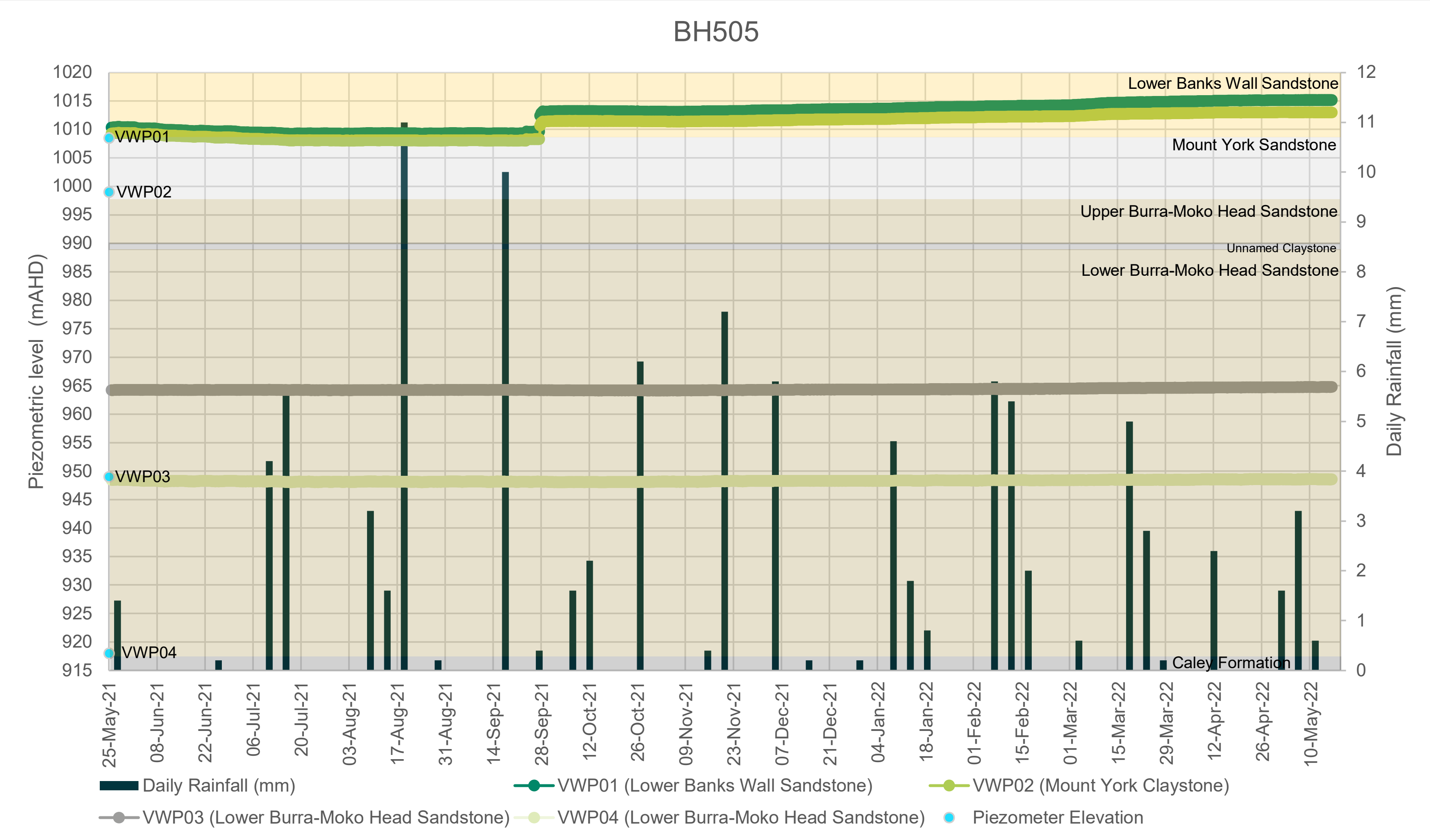
BH9
Piezometric level (mAHD)
887.5
886.5
885.5
884.5
350
300
250
200
150
100
50
0
Dec-09
Jul-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
Monthly Rainfall
Piezometric Level (Illawarra Coal Measures)


BH501
Upper Banks Wall Sandstone
Wentworth Falls Claystone Member
Lower Banks Wall Sandstone
VWP01
VWP02
Piezometric level (mAHD)
Daily Rainfall (mm)
1025
1024
1023
1022
1021
1020
1019
1018
1017
1016
1015
1014
1013
1012
1011
1010
1009
1008
1007
1006
1005
1004
12
10
8
6
4
2
0
26-May-21
09-Jun-21
23-Jun-21
07-Jul-21
21-Jul-21
04-Aug-21
18-Aug-21
01-Sep-21
15-Sep-21
29-Sep-21
13-Oct-21
27-Oct-21
10-Nov-21
24-Nov-21
08-Dec-21
22-Dec-21
05-Jan-22
19-Jan-22
02-Feb-22
16-Feb-22
02-Mar-22
16-Mar-22
Daily Rainfall (mm)
VWP01 (Upper Banks Wall Sandstone)
VWP02 (Lower Banks Wall Sandstone)
Piezometer Elevation


BH501A
Piezometric level (mAHD)
Daily Rainfall (mm)
980
975
970
965
960
955
950
945
940
935
930
925
920
915
910
905
900
895
890
885
12
10
8
6
4
2
0
Lower Banks Wall Sandstone
Mount York Claystone
Upper Burra-Moko Head Sandstone
Unnamed Claystone
Lower Burra-Moko Head Sandstone
VWP01
VWP02
VWP03
25-May-21
08-Jun-21
22-Jun-21
06-Jul-21
20-Jul-21
03-Aug-21
Daily Rainfall (mm)
VWP01 (Lower Banks Wall Sandstone)
VWP02 (Mount York Claystone)
VWP03 (Lower Burra-Moko Head Sandstone)
Piezometer Elevation



BH504
Piezometric level (mAHD)
Daily Rainfall (mm)
1010
1005
1000
995
990
985
980
975
970
965
960
955
950
945
940
12
10
8
6
4
2
0
Lower Banks Wall Sandstone
Mount York Claystone
Upper Burra-Moko Head Sandstone
Unnamed Claystone
Lower Burra-Moko Head Sandstone
VWP01
VWP02
VWP03
25-May-21
08-Jun-21
22-Jun-21
06-Jul-21
20-Jul-21
03-Aug-21
17-Aug-21
31-Aug-21
14-Sep-21
28-Sep-21
12-Oct-21
26-Oct-21
09-Nov-21
23-Nov-21
07-Dec-21
21-Dec-21
04-Jan-22
18-Jan-22
01-Feb-22
15-Feb-22
01-Mar-22
15-Mar-22
29-Mar-22
12-Apr-22
26-Apr-22
10-May-22
Daily Rainfall (mm)
VWP01 (Lower Banks Wall Sandstone)
VWP02 (Mount York Claystone)
VWP03 (Lower Burra-Moko Head Sandstone)
Piezometer Elevation



Note: A change of frequency for VWP01 and VWP02 noted at BH505 around 28 September 2021. Pressure may be due to landslide occurrence that happened at a bridge approximately 60 metres from the bore.

Annexure E

Project specific packer testing data

Bore ID	Test Depth (metres)	Geological Unit	Flow Pattern	Houlsby Lugeon Value	Hydraulic Conductivity (metres/day)
BH500	5.0-14.8	Banks Wall Sandstone	Dilation	0.23	1.99×10^{-4}
BH500	14.5-23.8	Banks Wall Sandstone	Dilation	0.52	4.49×10^{-4}
BH500	17.2-34.8	Banks Wall Sandstone	Dilation	0.59	5.10×10^{-4}
BH500A	4.4-14	Banks Wall Sandstone	Dilation	0.17	1.47×10^{-4}
BH500A	13.5-27	Banks Wall Sandstone	Laminar Flow	0.22	1.90×10^{-4}
BH500A	25.2-39.11	Banks Wall Sandstone	Wash Out	1	8.64×10^{-4}
BH501	9.5-15.2	Banks Wall Sandstone	Void Filling	2.2	1.90×10^{-3}
BH501	14-21.2	Banks Wall Sandstone	Laminar Flow	0.37	3.20×10^{-4}
BH501	21-28.2	Banks Wall Sandstone	Turbulent Flow	0.92	7.95×10^{-4}
BH501	28-36.2	Banks Wall Sandstone	Dilation	0.32	2.76×10^{-4}
BH501	36-45.2	Banks Wall Sandstone	Void Filling	0.13	1.12×10^{-4}
BH501	45-57.2	Banks Wall Sandstone	Turbulent Flow	0.22	1.90×10^{-4}
BH501	57-72.2	Banks Wall Sandstone	Turbulent Flow	0.15	1.30×10^{-4}
BH501A	90.2-105.2	Banks Wall Sandstone	Dilation	0.16	1.38×10^{-4}
BH501A	105-117.2	Banks Wall Sandstone	Dilation	0.07	6.05×10^{-5}
BH501A	117-126.9	Mt York Claystone	Dilation	0.001	8.64×10^{-7}
BH501A	126.5-141.95	Burra Moko Head Sandstone	Turbulent Flow	0.06	5.18×10^{-5}
BH501A	170-185.21	Burra Moko Head Sandstone	Void Filling	0.04	3.46×10^{-5}
BH502	37.5-43.74	Banks Wall Sandstone	Turbulent Flow	1.2	1.04×10^{-3}
BH502	62-69.44	Banks Wall Sandstone	Turbulent Flow	2.8	2.42×10^{-3}
BH502	70.6-78.16	Banks Wall Sandstone	Dilation	0.3	2.59×10^{-4}
BH502	77.1-84.1	Banks Wall Sandstone	Dilation	0.03	2.59×10^{-5}
BH502	83.8-89.9	Banks Wall Sandstone	Laminar Flow	0.06	5.18×10^{-5}
BH503	33-42.9	Banks Wall Sandstone	Dilation	0.5	4.32×10^{-4}
BH503	42.5-56.45	Banks Wall Sandstone	Dilation	6.7	5.79×10^{-3}
BH503	56-69.9	Banks Wall Sandstone	Dilation	0.6	5.18×10^{-4}
BH503	69-84.9	Banks Wall Sandstone	Turbulent Flow	0.03	2.59×10^{-5}
BH503	84-99.7	Banks Wall Sandstone	Dilation, termination at stage 3 due to leakage	0.05	4.32×10^{-5}
BH503	99-111.7	Banks Wall Sandstone	Dilation	0.21	1.81×10^{-4}
BH503	111-123.95	Banks Wall Sandstone	Laminar Flow	0.1	8.64×10^{-5}
BH503	123.8-138.84	Banks Wall Sandstone	Dilation	0.1	8.64×10^{-5}
BH504	35.06-45.34	Banks Wall Sandstone	Turbulent Flow	0.06	5.18×10^{-5}

BH504	45-57.34	Mt York Claystone	Turbulent Flow	0.07	$6.05x10^{-5}$
BH504	57.03-69.36	Burra Moko Head Sandstone	Turbulent Flow	0.76	$6.57x10^{-4}$
BH504	69-81.48	Burra Moko Head Sandstone	Dilation	0.06	$5.18x10^{-5}$
BH504	81.03-93.48	Burra Moko Head Sandstone	Laminar Flow	0.07	$6.05x10^{-5}$
BH505	27.3-31.8	Mt York Claystone	Dilation	0.33	$2.85x10^{-4}$
BH505	31.2-45.44	Burra Moko Head Sandstone	Laminar Flow	0.08	$6.91x10^{-5}$
BH505	45.2-57.4	Burra Moko Head Sandstone	Turbulent Flow	0.13	$1.12x10^{-4}$
BH505	57.2-72.34	Burra Moko Head Sandstone	Laminar Flow	0.27	$2.33x10^{-4}$
BH505	71-87.4	Burra Moko Head Sandstone	Laminar Flow	0.03	$2.59x10^{-5}$
BH505	87-102.3	Burra Moko Head Sandstone	Laminar Flow	0.08	$6.91x10^{-5}$
BH505	102-117.32	Burra Moko Head Sandstone	Dilation	0.12	$1.04x10^{-4}$
BH505	117.0-132.36	Caley Formation	NA (no water intake)	-	-
BH506	25-39.8	Mt York Claystone	Turbulent Flow	0.27	$2.33x10^{-4}$
BH506	39-54.87	Burra Moko Head Sandstone	Turbulent Flow	0.84	$7.26x10^{-4}$
BH506	67-81.46	Burra Moko Head Sandstone	Wash Out	27	$2.33x10^{-2}$
BH506	100-110.36	Caley Formation	Dilation	2.8	$2.42x10^{-3}$
BH506	110.2-120.64	Caley Formation	Wash Out	0.2	$1.73x10^{-4}$
BH506	120.5-133.72	Caley Formation	Dilation	5.8	$5.01x10^{-3}$
BH506	133.5-143.2	Caley Formation	Turbulent Flow	4.5	$3.89x10^{-3}$
BH506	146-152.24	Illawarra Coal Measures	Dilation	0.04	$3.46x10^{-5}$
BH506	152-162.64	Illawarra Coal Measures	Dilation	0.02	$1.73x10^{-5}$
BH506	162-171.62	Illawarra Coal Measures	Dilation	0.02	$1.73x10^{-5}$
BH507	36-37.83	Burra Moko Head Sandstone	Dilation	94	$8.12x10^{-2}$
BH507	42.5-53.5	Burra Moko Head Sandstone	Dilation	0.91	$7.86x10^{-4}$
BH507	164.1-171.1	Illawarra Coal Measures	Dilation	0.24	$2.07x10^{-4}$
BH507	170.8-180.1	Illawarra Coal Measures	Dilation	3.6	$3.11x10^{-3}$
BH507	182-189.6	Illawarra Coal Measures	Dilation	0.27	$2.33x10^{-4}$
BH507	189-198.1	Illawarra Coal Measures	Dilation	1.2	$1.04x10^{-3}$
BH507	197.8-207.1	Illawarra Coal Measures	Dilation	0.24	$2.07x10^{-4}$
BH606	31.0-40.1	Banks Wall Sandstone	Turbulent Flow	0.24	$2.07x10^{-4}$
BH606	49.0-62.62	Banks Wall Sandstone	Laminar Flow	0.04	$3.46x10^{-5}$
BH614	6.0-15.2	Banks Wall Sandstone	Dilation	0.59	$5.10x10^{-4}$
BH614	15.0-27.15	Banks Wall Sandstone	Laminar Flow	0.16	$1.38x10^{-4}$
BH614	105.0-114.05	Burra-Moko Head Sandstone	Laminar Flow	0.28	$2.42x10^{-4}$
BH614	113.8-123.1	Caley Formation	NA (no water intake)	-	-
BH614	122.8-132.15	Illawarra Coal Measures	Laminar Flow	0.008	$6.91x10^{-6}$

BH614	131.7-140.82	Illawarra Coal Measures	Dilation	1.8	$1.56x10^{-3}$
BH622	5-12.04	Illawarra Coal Measures	Laminar Flow	0.14	$1.21x10^{-4}$
BH622	10.8-24	Illawarra Coal Measures	Turbulent Flow	57	$4.92x10^{-2}$
BH622	23-33	Illawarra Coal Measures	Dilation	4.1	$3.54x10^{-3}$
BH622	32.5-42.5	Illawarra Coal Measures	Dilation	11	$9.50x10^{-3}$
BH610	75.1-85.1	Banks Wall Sandstone	Laminar Flow	< 1	$4.32x10^{-4}$
BH610	80.1-87.2	Mt York Claystone	Laminar Flow	< 1	$4.32x10^{-4}$
BH610	87-93.3	Mt York Claystone	Laminar Flow	< 1	$4.32x10^{-4}$
BH610	93-99.3	Burra-Moko Head Sandstone	Laminar Flow	< 1	$4.32x10^{-4}$
BH610	99-105.3	Burra-Moko Head Sandstone	Void Filling	< 1	$4.32x10^{-4}$
BH610	105-111.3	Burra-Moko Head Sandstone	Void Filling	< 1	$4.32x10^{-4}$
BH610	111-117.4	Burra-Moko Head Sandstone	Void Filling	< 1	$4.32x10^{-4}$
BH610	117-123.3	Burra-Moko Head Sandstone	Void Filling	< 1	$4.32x10^{-4}$
BH610	123-129.1	Burra-Moko Head Sandstone	Void Filling	< 1	$4.32x10^{-4}$
BH610	129-135.1	Burra-Moko Head Sandstone	Laminar Flow	< 1	$4.32x10^{-4}$
BH610	135-141.5	Burra-Moko Head Sandstone	Laminar Flow	< 1	$4.32x10^{-4}$
BH611	81-87.5	Mt York Claystone	Laminar Flow	< 1	$4.32x10^{-4}$
BH611	86.5-93.6	Burra-Moko Head Sandstone	Laminar Flow	< 1	$4.32x10^{-4}$
BH611	92.5-99.5	Burra-Moko Head Sandstone	Laminar Flow	< 1	$4.32x10^{-4}$
BH611	98.5-105.56	Burra-Moko Head Sandstone	Wash Out	22	$1.90x10^{-2}$
BH611	105-111.5	Burra-Moko Head Sandstone	Void Filling	< 1	$4.32x10^{-4}$
BH611	111-117.7	Burra-Moko Head Sandstone	Void Filling	5	$4.32x10^{-3}$
BH611	117-123.7	Burra-Moko Head Sandstone	Laminar Flow	< 1	$4.32x10^{-4}$
BH612	89-94.4	Burra-Moko Head Sandstone	Turbulent Flow	1.4	$1.21x10^{-3}$
BH623	7-13	Illawarra Coal Measures	Laminar Flow	< 1	$4.32x10^{-4}$
BH623	12-17.5	Illawarra Coal Measures	Wash Out	10	$8.64x10^{-3}$
BH623	16.5-21.5	Berry Siltstone	Laminar Flow	24	$2.07x10^{-2}$
BH634	18-23	Illawarra Coal Measures	Laminar Flow	27	$2.33x10^{-2}$
BH634	25.8-30.8	Illawarra Coal Measures	Laminar Flow	4	$3.46x10^{-3}$
BH634	30-35.4	Illawarra Coal Measures	Laminar Flow	3	$2.59x10^{-3}$
BH635	42-48.6	Illawarra Coal Measures	Void Filling	3	$2.59x10^{-3}$
BH635	48-55.1	Berry Siltstone	Void Filling	4	$3.46x10^{-3}$
BH636	11-13.1	Berry Siltstone	Laminar Flow	3	$2.59x10^{-3}$
BH636	13-16.5	Berry Siltstone	NA	-	-
BH636	16.5-20.26	Berry Siltstone	NA	-	-

Notes: Where lugeon values are recorded as <1, a lugeon value of 0.5 has been used to convert to cm/day.
Source: Transport (2022) and JAJV (2022)

Annexure F

Registered groundwater bore information

Bore ID	Date drilled	Purpose	Status reported by AGE	Status reported by WaterNSW	Distance from project (km)	Depth (m)	SWL (m)	Salinity description	Cumulative Recorded yield (L/s)	Screened interval (m)	Screened geology
GW016433	1/01/1947	Irrigation	Unknown	Unknown	3.98	22.8	-	-	-	-	-
GW020495	-	Irrigation	Functioning	Functioning	2.79	7	-	-	-	-	-
GW028506	-	Irrigation	Unknown	-	2.61	9.1	-	-	-	-	-
GW042543	1/10/1975	Irrigation	Unknown	Unknown	2.58	60.9	4.8	-	0.07	-	-
GW055246	1/05/1981	Stock/ domestic	Unknown	Functioning	1.39	38.1	15.2		0.53	16.7-30.4	Shale
GW055390	-	Domestic	Unknown	Functioning	4.51	14	-	-	0.13	3.0-11.0	Sandstone
GW055396	1/05/1981	Domestic	Unknown	Functioning	0.52	32	7.5	-	4.5	6.5-10	-
GW055902	1/03/1982	Domestic	Unknown	-	4.6	64	34	Fresh	0.15	-	-
GW056504	1/09/1981	Stock	Unknown	Functioning	0.57	60.9	41.1	-	0.3	-	-
GW056581	1/03/1982	Domestic	Unknown	Functioning	0.7	43	26	-	0.61	26-43	Sandstone
GW057374	1/11/1982	Domestic	Unknown	Unknown	0.75	57	42	-	0.16	18-57	Sandstone
GW057390	1/12/1982	Domestic	Unknown	Functioning	0.693	44	20	-	0.6	20-44	Sandstone
GW057611	1/04/1983	Domestic	Unknown	Functioning	0.44	30	-	-	0.5	20-30	Sandstone
GW057614	1/09/1982	Domestic	Unknown	Functioning	0.2	66	60	-	0.11	50-66	Sandstone
GW058022	1/02/1983	Domestic	Unknown	Functioning	0.66	60	35	-	0.08	40.0-60.0	Sandstone
GW058134	1/11/1983	Domestic	Unknown	Functioning	4.6	40.6	-	-	0.3	12.5-40.6	Sandstone
GW058193	1/01/1983	Domestic	Unknown	Functioning	0.42	33	15	-	0.6	10-33	Sandstone
GW058197	1/04/1982	Domestic	Unknown	Functioning	0.83	46	35	-	0.38	30-45	Sandstone
GW058199	1/10/1982	Domestic	Unknown	Functioning	0.62	33	25	-	0.3	25-33	Sandstone
GW058236	1/12/1982	Domestic	Unknown	Functioning	0.31	31	18	-	0.5	15-30	Sandstone
GW058247	1/11/1983	Domestic	Unknown	Functioning	0.21	50	40.6	-	0.02	-	-
GW058751	1/11/1982	Domestic	Unknown	Functioning	1.33	61	-	-	0.19	48.8-61	Sandstone

Bore ID	Date drilled	Purpose	Status reported by AGE	Status reported by WaterNSW	Distance from project (km)	Depth (m)	SWL (m)	Salinity description	Cumulative Recorded yield (L/s)	Screened interval (m)	Screened geology
GW058892	1/12/1981	Stock/ domestic	Unknown	Functioning	0.62	83.8	-	-	0.1	-	-
GW059727	1/12/1982	Unknown	Functioning	Unknown	0.65	66	-	-	0.15	-	-
GW059737	1/03/1983	Domestic	Unknown	Functioning	0.39	30	-	-	0.35	10-30	Sandstone
GW061195	1/08/1985	Stock/ domestic	Unknown	Functioning	1.38	53.1	31.2	-	0.13	50-53.1	Sandstone
GW061436	1/01/1986	Stock/ domestic	Unknown	Functioning	4.54	46.8	-	-	0.29	43.7-46.8	Sandstone
GW061451	1/01/1986	Stock/ domestic	Unknown	Functioning	2.29	15.6	46.8	-	0.07	43.7-46.8	Sandstone
GW061488	1/02/1986	Stock/ domestic	Unknown	Cancelled	4.52	18.7	-	-	0.6	15.6-18.7	Sandstone
GW061632	1/02/1986	Domestic	Unknown	Functioning	1.13	93.7	68.7	-	0.05	-	-
GW062400	1/08/1985	Irrigation	Unknown	-	2.09	56.7	-	-	0.08	-	-
GW062401	1/08/1985	Irrigation	Unknown	Unknown	1.98	30.5	-	Fresh	3.14	6.1-27.4	Shale
GW063579	1/01/1987	Stock/ domestic	Unknown	Functioning	0.95	49	18	-	0.5	-	-
GW064060	1/03/1987	Stock/ domestic	Unknown	Unknown	4.73	30	-	-	0.45	28.1-30.0	Sandstone
GW064625	1/02/1988	Stock/ domestic	Unknown	Functioning	1.97	40.2	6.1	Fresh	0.09	-	-
GW067317	-	Monitoring	Functioning	Unknown	3.11	65		-	0.15	62-65	Sandstone
GW069005	5/11/1991	Stock/ domestic	Unknown	Unknown	4.59	93.7	-	-	0.14	-	-
GW072282	15/12/1994	Stock/ domestic	Unknown	Unknown	1.21	59.3	-	-	0.44	56.2-59.3	Sandstone
GW072310	26/05/1994	Stock/ domestic	Functioning	Functioning	3.05	83.8	9.1	Fresh	0.25	-	-
GW072891	7/12/1994	Domestic	Unknown	Unknown	0.59	50	-	-	0.3	46.2-50	Sandstone

Bore ID	Date drilled	Purpose	Status reported by AGE	Status reported by WaterNSW	Distance from project (km)	Depth (m)	SWL (m)	Salinity description	Cumulative Recorded yield (L/s)	Screened interval (m)	Screened geology
GW075184	31/01/2006	Monitoring	Functioning	Unknown	4.85	141	25.5	-	-	-	-
GW075185	1/02/2006	Monitoring	Functioning	Unknown	1.62	187	11	-	-	-	-
GW100049	31/07/1990	Domestic	Functioning	Abandoned	0.82	31.2	-	-	0.45	28-31.2	Sandstone
GW100085	14/06/1991	Stock/ domestic	Abandoned	Unknown	0.6	93.7	-	-	-	-	-
GW100120	7/11/1991	Stock/ domestic	Functioning	Functioning	4.29	51.8	30.4	Fresh	0.43	30.4-51.8	Sandstone
GW100157	22/05/1991	Stock/ domestic	Functioning	Functioning	0.05	62.5	44	-	0.2	56-62.5	Sandstone
GW100172		Stock/ domestic	Functioning	Functioning	0.82	100.6	-	-	-	-	-
GW100224	7/06/1993	Stock/ domestic	Functioning	Functioning	4.46	47	-	-	-	-	-
GW100239	26/06/1983	Stock/ domestic	Functioning	Unknown	4.61	46.8	34	-	0.01	43-46.8	Sandstone
GW100240	8/07/1993	Stock/ domestic	Functioning	Functioning	4.64	59.3	-	-	0.05	53.0-59.3	Sandstone
GW100545	11/03/1997	Stock/ domestic	Functioning	Unknown	4.51	62.5	-	-	0.51	56.2-62.5	Sandstone
GW100888	1/01/1982	Domestic	Unknown	Functioning	4.83	40	12	-	-	-	-
GW101228	10/02/1998	Stock/ domestic	Functioning	Functioning	4.93	59.3	-	-	0.52	54.6-59.3	Sandstone
GW101569	28/10/1991	Stock/ domestic	Unknown	Functioning	1.376	37.5	25	-	0.6	32.8-37.5	Sandstone
GW101641	6/01/1994	Stock/ domestic	Unknown	Functioning	4.74	68.75	-	-	0.6	64.0-68.75	Sandstone
GW101757	26/10/1995	Stock/ domestic	Unknown	Functioning	0.91	36	9	-	1	28-34	Shale
GW101800	19/12/1994	Stock/ domestic	Unknown	Functioning	3.33	37.2	5.95	Fresh	2.145	-	-

Bore ID	Date drilled	Purpose	Status reported by AGE	Status reported by WaterNSW	Distance from project (km)	Depth (m)	SWL (m)	Salinity description	Cumulative Recorded yield (L/s)	Screened interval (m)	Screened geology
GW102030	14/07/1998	Stock/ domestic	Unknown	Unknown	0.26	78	15	Fresh	0.33	-	-
GW102214	1/01/1998	Domestic	Functioning	Functioning	0.35	62.5	-	-	0.9	56.2-62.5	Sandstone
GW102618	17/10/1997	Stock/ domestic	Unknown	Functioning	0.61	93.7	71.8	-	0.3	87.5-93.7	Sandstone
GW103203	30/06/2000	Stock/ domestic	Unknown	Functioning	4.66	78.2	-	-	0.11	73.4-78.2	Sandstone
GW103528	21/03/2001	Stock/ domestic	Functioning	Functioning	4.18	36	10		0.35	29.5-35.5	Sandstone
GW103693	1/11/1999	Domestic	Functioning	Cancelled	4.01	76	7.8	-	-	58-64	Shale
GW103830	11/04/1991	Monitoring	Unknown	Unknown	0.5	3.3	-	-	-	-	-
GW103831	16/07/2001	Monitoring	Unknown	Unknown	0.5	2.5	-	-	-	-	-
GW103832	11/04/1991	Monitoring	Unknown	Unknown	0.5	3.35	-	-	-	-	-
GW104731	10/01/2003	Domestic	Functioning	Functioning	0.75	42	6	-	0.38	30-36	Shale
GW104752	10/05/1999	Domestic	Functioning	Functioning	0.07	46	6	-	0.15	12-13	Sandstone
GW104862	8/02/2003	Stock/ domestic	Functioning	Functioning	0.6	48	16.5	-	0.5	36-42	Shale
GW104879	4/03/2003	Monitoring	Proposed	Unknown	3.96	90	-	-	-	-	-
GW104880	3/03/2003	Monitoring	Proposed	Unknown	4.01	200	-	-	-	-	-
GW104994	20/01/2002	Stock/ domestic	Functioning	Functioning	1.61	62	-	-	0.3	-	-
GW104995	28/11/2003	Stock/ domestic	Functioning	Functioning	0.6	64	6	-	0.51	51-52	Shale
GW104996	20/08/2001	Stock/ domestic	Functioning	Functioning	1.29	37	6	-	1.63	12-30	Shale
GW105519	14/10/2003	Domestic	Unknown	Functioning	0.36	39	5	-	2.51	8-33	Shale
GW105633	23/10/2003	Domestic	Functioning	Functioning	2.37	100	38	-	0.25	-	-

Bore ID	Date drilled	Purpose	Status reported by AGE	Status reported by WaterNSW	Distance from project (km)	Depth (m)	SWL (m)	Salinity description	Cumulative Recorded yield (L/s)	Screened interval (m)	Screened geology
GW057374	1/11/1982	General use	Unknown	-	0.75	57	42	-	0.16	18-57	Sandstone
GW105881	9/05/2005	Stock/ domestic	Unknown	Functioning	1.5	-	-	-	-	-	-
GW105896	10/05/2005	Domestic	Unknown	Functioning	0.73	-	-	-	-	-	-
GW105907	12/05/2005	Domestic	Unknown	Functioning	3.43	-	-	-	-	-	-
GW106050	5/01/2002	Stock/ domestic	Functioning	Functioning	2.16	180	70	-	1.12	-	-
GW106303	11/08/2005	Stock/ domestic	Unknown	Functioning	4.03	-	-	-	-	-	-
GW106704	14/12/2002	Industrial/ domestic	Unknown	Functioning	4.37	60	0.32	-	0.4	48.0-60.0	Shale
GW107197	25/11/2003	Stock/ domestic	Functioning	Functioning	0.96	47	12	-	-	44-47	Sandstone
GW107274	7/01/2004	Stock/ domestic	Functioning	Functioning	1.37	164	84	-	1.65	18-36	Sandstone
GW107954	29/10/2005	Stock/ domestic	Functioning	Functioning	0.27	50	30	-	0.75	-	-
GW108140	1/01/2002	Domestic	Unknown	Functioning	1.79	50	38	-	17.8*	-	-
GW108241	2/07/2007	Stock/ domestic	Unknown	Cancelled	2.59	89	15	-	-	-	-
GW108313	1/01/2004	Stock/ domestic	Unknown	Functioning	1.89	52	16	-	0.5	-	-
GW108316	28/11/2006	Domestic	Functioning	Functioning	0.42	60	-	-	0.5	56-62	Sandstone
GW108604	12/02/2008	Stock/ domestic	Functioning	Unknown	0.8	102	-	-	-	-	-
GW108605	23/10/2006	Stock/ domestic	Abandoned	Unknown	0.09	145	-	-	-	-	-
GW108681	16/12/1989	Domestic	Functioning	Functioning	0.15	40	-	-	0.5	37-40	Sandstone

Bore ID	Date drilled	Purpose	Status reported by AGE	Status reported by WaterNSW	Distance from project (km)	Depth (m)	SWL (m)	Salinity description	Cumulative Recorded yield (L/s)	Screened interval (m)	Screened geology
GW108737.1.1	22/01/2007	Stock/ domestic	Functioning	Functioning	1.57	49	12	-	0.49	23-28 38-44	Sandstone
GW109281	1/09/2008	Monitoring	Unknown	Unknown	4.28	3.3	-	-	-	-	-
GW109283	1/09/2008	Monitoring	Unknown	Unknown	4.39	4	-	-	-	-	-
GW109284	1/09/2008	Monitoring	Unknown	Unknown	4.28	3.3	-	-	-	-	-
GW109285	1/09/2008	Monitoring	Unknown	Unknown	4.23	4.5	-	-	-	-	-
GW109286	1/09/2008	Monitoring	Unknown	Unknown	4.31	1.9	-	-	-	-	-
GW109287	1/09/2008	Monitoring	Unknown	Unknown	4.37	2.9	-	-	-	-	-
GW109288	2/09/2008	Monitoring	Unknown	Unknown	4.27	4.5	-	-	-	-	-
GW112424	19/09/2009	Stock/ domestic	Functioning	Functioning	3.32	37	-	-	0.17	30-37	Sandstone
GW111530	23/05/2011	Monitoring	Functioning	Functioning	3.76	14	-	-	-	11-14	Granite
GW111533	7/06/2011	Monitoring	Functioning	Functioning	0.54	17.3	-	-	-	14.3-17.2	Claystone
GW111532	2/06/2011	Monitoring	Functioning	Functioning	4.96	12.35	-	-	-	9.3-12.3	Granite
GW111538	3/08/2011	Monitoring	Functioning	Functioning	0.18	17.78	-	-	-	-	-
GW111541	27/05/2011	Monitoring	Functioning	Functioning	1.19	12.4	-	-	-	9.4-12.4	Siltstone
GW111780	7/11/2005	Domestic	Functioning	Functioning	0.86	63	-	-	-	58-63	-
GW114520	14/02/2014	Domestic	Functioning	Functioning	4.05	100	8	-	0.22	-	-
GW114564	1/04/2014	Stock/ domestic	Functioning	Functioning	4.29	17	3	-	-	5.5-11.5	Sandstone
GW114791	24/02/2014	Stock/ domestic	Functioning	Functioning	1.51	122	93	-	0.05	42-54 60-66 72-78 84-108	Sandstone
GW115835	23/07/2018	Domestic	Functioning	Functioning	2.83	96	48	-	0.5	86-96	Sandstone

Bore ID	Date drilled	Purpose	Status reported by AGE	Status reported by WaterNSW	Distance from project (km)	Depth (m)	SWL (m)	Salinity description	Cumulative Recorded yield (L/s)	Screened interval (m)	Screened geology
GW116096	28/11/2018	Unknown	Functioning	-	4.67	65	-	-	-	-	-

*Potentially a false reading. Value has been excluded from report