Appendix

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Appendix N

Groundwater

January 2020

Roads and Maritime Services

Western Harbour Tunnel and Warringah Freeway Upgrade

Technical working paper: Groundwater

January 2020

Prepared for

Roads and Maritime

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Contents

List of Tables

List of Figures

Appendices

Glossary of terms and abbreviations

Acronym	Meaning
AIP	Aquifer Interference Policy
ANZECC	Australian and New Zealand Environment Conservation Council
ASRIS	Australian Soil Resource Information System
ASS	Acid sulfate soils
BOM	Bureau of Meteorology
BSAL	Biophysical Strategic Agricultural Land
CEMP	Construction Environment Management Plan
CRD	Cumulative rainfall deviation
DPIE	Department of Planning, Industry and Environment
EC	Electrical conductivity
EIS	Environmental impact statement
EMP	Environmental Management Plan
EPBC	*Environment Protection and Biodiversity Conservation Act 1999* (Cth)
GDE	Groundwater dependent ecosystem
IMT	Immersed tube tunnel
LEP	Local Environmental Plan
mAHD	Metres Australian Height Datum
mBGL	Metres below ground level
NES	National Environmental Significance
NSW WQO	NSW Water Quality Objectives
NWQMS	National Water Quality Management Strategy
Project (the project)	Western Harbour Tunnel and Warringah Freeway Upgrade
SEARs	Secretary’s environmental assessment requirements
TDS	Total dissolved solids
VWP	Vibrating wire Piezometer
WAL	Water Access Licence
WSP	Water Sharing Plan

Executive summary

Context

The Western Harbour Tunnel and Beaches Link program of works is a NSW Government initiative to provide additional road network capacity across Sydney Harbour and to improve connectivity with Sydney's northern beaches. The Western Harbour Tunnel and Beaches Link program of works includes:

- The Western Harbour Tunnel and Warringah Freeway Upgrade project comprises a new tolled motorway tunnel connection across Sydney Harbour, and an upgrade of the Warringah Freeway to integrate the new motorway infrastructure with the existing road network and to connect to the Beaches Link and Gore Hill Freeway Connection project
- The Beaches Link and Gore Hill Freeway Connection project comprises a new tolled motorway tunnel connection from the Warringah Freeway to Balgowlah and Frenchs Forest and upgrade and integration works to connect to the Gore Hill Freeway.

Roads and Maritime Services (Roads and Maritime) is seeking approval under Division 5.2, Part 5 of the *Environmental Planning and Assessment Act 1979* to construct and operate the Western Harbour Tunnel and Warringah Freeway Upgrade (the project), which would comprise two main components:

- A new crossing of Sydney Harbour involving twin tolled motorway tunnels connecting the WestConnex M4-M5 Link at Rozelle and the existing Warringah Freeway at North Sydney (the Western Harbour Tunnel)
- Upgrade and integration works along the existing Warringah Freeway, including allowance for connections to the Beaches Link and Gore Hill Freeway Connection project (the Warringah Freeway Upgrade).

Scope

This report assesses the risks related to groundwater for the project and has been prepared to support and inform the associated environmental impact statement.

The majority of the construction footprint would be located underground within the mainline tunnels. However, surface areas would be required to support tunnelling activities and to construct the tunnel connections, tunnel portals and operational facilities. The project would be constructed mainly with roadheaders with an immersed tube tunnel installed within Sydney Harbour.

The project tunnels would be designed and constructed to:

- Drain in areas where groundwater inflows are predicted to be less than one litre per second per kilometre
- Divert inflows away from the tunnel roof and towards the base of the tunnel in areas of higher groundwater inflows
- Reduce inflows in areas next to immersed tube tunnel sections beneath Sydney Harbour.

This report assesses the potential impacts upon groundwater pressure, level and quality that may occur as a result of the construction and operation of the project.

Policy setting

Impacts have been assessed against relevant legislation and guidelines to determine whether they are acceptable, or if management and mitigation measures were required. Key guidelines were the NSW Aquifer Interference Policy (AIP) and the Water Sharing Plans (WSP) for the Greater Metropolitan Region Groundwater Sources and the Greater Metropolitan Region Unregulated River Water Sources. These documents outline how groundwater and connected surface water values should be assessed for new developments.

Methodology

The assessment of potential impacts related to groundwater arising from the project has been implemented as follows:

- Characterisation of the existing environment including climate, topography, geology, and groundwater occurrence, quality and use, including groundwater dependent ecosystems (GDEs)
- Review of similar assessments and previous tunnelling projects in the Sydney region
- Project-specific field investigations including drilling, permeability testing, monitoring bore installation, and water level and quality monitoring
- Development of a three dimensional conceptual hydrogeological model describing groundwater flow
- Groundwater numerical modelling 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 related impacts to satisfy the minimal impact considerations of the AIP and to address groundwater related issues raised in the Secretary's environmental assessment requirements (SEARs)
- Assessment of potential settlement related impacts
- Recommendations for monitoring and management of identified impacts and risk, including mitigation measures as appropriate.

Potential impacts were assessed by modelling tunnel inflows for all project components and groundwater drawdown in aquifer layers above these components. Drawdown was predicted at the water table and in the intermediate model layers. The modelling results should be considered as a conservative assessment, since it has assumed a single layer such that the water table is in direct connection with the tunnel. In reality, data indicates the potential for multiple water tables, or disconnected aquifers that, if present, would act to attenuate the propagation of depressurisation and drawdown. In these areas the predicted water table decline is expected to be an over-estimate.

Potential impacts are considered both during construction and during the first one hundred years of the operational lifetime of the project.

The Beaches Link and Gore Hill Freeway Connection and the M4-M5 Link projects are in the vicinity of the Western Harbour Tunnel and Warringah Freeway Upgrade project. Together these projects could result in greater cumulative impacts on groundwater levels and flow. The impact assessment has therefore reported on impacts due to the Western Harbour Tunnel project only as well as total cumulative impact.

Potential impacts

Groundwater drawdown from tunnel dewatering has the potential to impact the surrounding environment and groundwater users by reducing the availability or quality of groundwater. Potential impacts that may arise due to changes in groundwater flow conditions include:

- Reduced water supply to registered groundwater users (both holders of water access licences and stock and domestic users)
- Induced migration of contaminated groundwater plumes
- Saline intrusion that reduces the beneficial uses of an aquifer
- Activation of acid sulfate soils (ASS) that reduces the beneficial uses of the aquifer
- Ground surface settlement.

No groundwater dependent ecosystems (GDEs), baseflow dependent surface water systems or groundwater dependent culturally significant sites were identified in the project area. Impacts on potential baseflow in Whites

Creek have not been considered as the creek is a concrete-lined stormwater drain and would not be baseflow dependent.

Potential impacts during construction

Potential impacts during construction of the project are expected to include:

- Up to three metres of water table drawdown is predicted to occur at bore GW109209 recorded as being used for domestic purposes, which exceeds the AIP minimal impact levels. Monitoring would be necessary if this bore is found to be viable and make good provisions would apply if impacts are realised.
- Up to two metres drawdown is predicted to occur at bore GW107764, the use of which is recorded as being unknown, however could be used for water supply. This impact is within minimal impact levels specified in the Aquifer Interference Policy. Make good provisions would not be necessary, however, monitoring is recommended if this bore is found to viable.
- Drawdown of less than one metre is predicted to occur at bore GW108991, the use of which is recorded as being for water supply. This impact is within minimal impact levels specified in the Aquifer Interference Policy. GW108991 is recorded as being 168m deep and is likely drawing water from the Hawkesbury Sandstone beneath the tunnel alignment. It is not anticipated that supply from the bore would be impacted. Make good provisions would not be necessary, however, monitoring is recommended if this bore is found to be viable.
- Drawdown resulting in potential baseflow reductions at Flat Rock Creek and Quarry Creek. Water table drawdown is predicted at areas of environmental interest for contamination, including Easton Park and White Bay Power Station. No water quality impacts to groundwater users are expected during construction however due to the absence of groundwater bores situated between the project alignment and the contaminated sites.
- In respect to the ‘cumulative scenario’ at the end of construction (ie the presence of the Western Harbour Tunnel and Warringah Freeway upgrade in addition to other large infrastructure projects situated adjacent or nearby), groundwater drawdown would be considerably greater in the Rozelle area compared with the ‘project only’ scenario. Given the number of underground tunnels associated with the M4-M5 Link project situated nearby, maximum expected drawdown near the Rozelle dive structure is predicted to be about 40 metres, while at Easton Park (an area of environmental interest for contamination) to the north-east, cumulative drawdown is expected to be 38 metres. Groundwater drawdown at Whites Bay Power Station (area of environmental interest for contamination) is also predicted to be up to 12 metres during this period. North of the harbour, maximum water table drawdown of about 10 metres would occur at the northern dive structure, while areas above the mainline alignment in North Sydney and Waverton are predicted to have a maximum drawdown of five metres. A maximum cumulative drawdown of 18 metres occurs above the North Sydney Metro Station.
- The predicted migration of the saline interface is not considered significant and, as such, impacts on groundwater users, or the beneficial use of the aquifer are not expected.
- Given the absence of groundwater-dependent ecosystems, other sensitive environments and groundwater users in proximity to the project, no impacts, particularly in respect to the activation of acid-sulfate soils (ASS) are expected on such receivers during construction.
- All project components (with the exception of the access declines at Victoria Road and Berrys Bay) are expected to experience ground surface settlement impacts of over 10 millimetres. However, maximum long-term surface settlement of over 40 millimetres around the Warringah Freeway portal, and up to approximately 40 millimetres along parts of the alignment of the main line tunnels between the Western Harbour crossing and the Warringah Freeway. All other project components are anticipated to be subject to total settlement measurements of 30 millimetres or less. A number of buildings are predicted to experience very slight to slight aesthetic damage from long-term ground surface settlement.

- Average groundwater inflows are predicted to be between 0.34 and 0.48 litres per second per kilometre, or 0.51 to 0.75 megalitres per day. Peak inflows are expected to occur in 2022. Predicted inflows do not exceed the design criteria of one litre per second per kilometre.

Potential impacts during operation

Potential long-term impacts after 100 years of project operation include:

- Up to four metres water table drawdown at the domestic bore GW109209, which exceeds the AIP minimal impact levels. Monitoring would be necessary if this bore is found to be viable and make good provisions would apply if impacts are realised
- Up to two metres water table drawdown is predicted to occur at bore GW107764 and up to one metre of water pressure drawdown is predicted to occur at bore GW10899. GW107764 is recorded as being of unknown use, however could be used for water supply. GW10899 is recorded as being used for water supply but is likely drawing water from below the depth of the tunnel. Potential impacts are within minimal impact levels specified in the Aquifer Interference Policy. Make good provisions would not be necessary, however, monitoring is recommended if these bores are found to viable
- Drawdown resulting in potential baseflow reductions at Flat Rock Creek and Quarry Creek
- Water table drawdown is predicted at areas of environmental interest for contamination, including Rozelle Rail Yards, Easton Park, Waverton Park and White Bay Power Station. This level of drawdown may cause migration of contaminant plumes however; there are not groundwater-dependent eco-systems, baseflow watercourses or groundwater users situated between the tunnels and the vicinity of any areas of environmental interest for contamination, therefore impacts are unlikely
- After 100 years of operation, predicted drawdown magnitudes are similar to end of construction, with a maximum drawdown of about 40 metres in Rozelle (particularly Easton Park, an area of environmental interest for contamination). There is recovery of drawdown in the vicinity of the Victoria Road access decline, with a corresponding recovery in drawdown to the west. There is also a minor propagation of drawdown towards Birchgrove. North of the harbour maximum predicted drawdown above the alignment increases to about five metres in Waverton (including Waverton Park, an area of environmental interest for contamination) and North Sydney, and a minor propagation of drawdown extent away from the alignment
- The predicted migration of the saline interface is considered negligible after 100 years of operation and, as such, impacts on groundwater users, or the beneficial use of the aquifer are not expected
- Cumulative drawdown of up to 15 metres is predicted in ASS risk areas close to Rozelle Rail Yards and up to three metres near Birchgrove Park during operation (ie year 2126), as such there is the potential for activation of ASS. However, no impacts to GDEs, sensitive environments or groundwater users from ASS are expected
- Ground settlement during operation is not expected to exceed that which occurred during construction
- Average groundwater inflow predictions of 0.36 litres per second per kilometre declining to 0.31 litres per second per kilometre after 100 years of operation. Annual total groundwater inflow predictions of up to 203 megalitres per year declining to 180 ML after 100 years of operation. Predicted inflows do not exceed the design criteria of one litre per second per kilometre.

Management measures

Construction

Safeguards will be implemented to minimise and manage impacts during construction. The project construction environmental management plan will include a groundwater monitoring regime for the construction phase taking into consideration the groundwater monitoring being carried out for the M4 M5 Link and the Beaches Link and Gore Hill Connection projects. The monitoring regime will include:

- Continuation of groundwater levels and groundwater quality monitoring within the currently installed project monitoring network to inform the update and refinement of the groundwater model
- If bores GW109209 and GW107764 are found to be viable, installation of water level logger and EC logger and/or periodic manual measurements to obtain a baseline for assessing potential drawdown impacts with respect to static and pumping water levels
- Monitoring of groundwater levels and quality beneath high risk sites for contamination prior and during construction. This includes monitoring of the existing Hawkesbury Sandstone groundwater monitoring bore installed as part of the M4-M5 Link Groundwater Impact Assessment (AECOM, 2017), and monitoring at the Rozelle Rail Yards construction support site
- Monitoring of areas of high risk for saline intrusion near Sydney Harbour
- Monitoring the quality and quantity of groundwater inflows into tunnels during construction
- Quantity and quality of the treated wastewater discharges from the construction wastewater treatment plants.

Operation

Measures will be included in the project operational environmental management plan to manage operational impacts. Groundwater inflows and water table drawdown monitoring will be developed in consultation with the EPA and DPI Water. Operational monitoring will include:

- Monitoring the quality and quantity of groundwater inflows into tunnels next to Sydney Harbour and beneath high risk sites for contamination
- Monitoring quantity and quality of the treated wastewater discharges from the Rozelle wastewater treatment plant
- In addition, ongoing settlement monitoring will be carried out as per the independent property impact assessment panel requirements.

1. Introduction

This section provides an overview of the Western Harbour Tunnel and Warringah Freeway Upgrade (the project), including its key features and location. It also outlines the Secretary's environmental assessment requirements addressed in this technical working paper.

1.1 Overview

The Greater Sydney Commission's *Greater Sydney Region Plan – A Metropolis of Three Cities* (Greater Sydney Commission, 2018) proposes a vision of three cities where most residents have convenient and easy access to jobs, education and health facilities and services. In addition to this plan, and to accommodate for Sydney's future growth the NSW Government is implementing the *Future Transport Strategy 2056* (Transport for NSW, 2018), a plan that sets the 40 year vision, directions and outcomes framework for customer mobility in NSW. The Western Harbour Tunnel and Beaches Link program of works is proposed to provide additional road network capacity across Sydney Harbour and to improve transport connectivity with Sydney's northern beaches. The Western Harbour Tunnel and Beaches Link program of works include:

- The Western Harbour Tunnel and Warringah Freeway Upgrade project which comprises a new tolled motorway tunnel connection across Sydney Harbour, and an upgrade of the Warringah Freeway to integrate the new motorway infrastructure with the existing road network and to connect to the Beaches Link and Gore Hill Freeway Connection project
- The Beaches Link and Gore Hill Freeway Connection project which comprises a new tolled motorway tunnel connection across Middle Harbour from the Warringah Freeway and Gore Hill Freeway to Balgowlah and Killarney Heights and including the surface upgrade of Wakehurst Parkway from Seaforth to Frenchs Forest and upgrade and integration works to connect to the Gore Hill Freeway at Artarmon.

A combined delivery of the Western Harbour Tunnel and Beaches Link program of works would unlock a range of benefits for freight, public transport and private vehicle users. It would support faster travel times for journeys between the Northern Beaches and south, west and north-west of Sydney Harbour. Delivering the program of works would also improve the resilience of the motorway network, given that each project provides an alternative to heavily congested harbour crossings.

1.1 The project

Roads and Maritime is seeking approval under Division 5.2, Part 5 of the Environmental Planning and Assessment Act 1979 to construct and operate the Western Harbour Tunnel and Warringah Freeway Upgrade, which would comprise two main components:

- A new crossing of Sydney Harbour involving twin tolled motorway tunnels connecting the M4-M5 Link at Rozelle and the existing Warringah Freeway at North Sydney (the Western Harbour Tunnel)
- Upgrade and integration works along the existing Warringah Freeway, including infrastructure required for connections to the Beaches Link and Gore Hill Freeway Connection project (the Warringah Freeway Upgrade).

Key features of the Western Harbour Tunnel component of the project are shown in Figure 1-1 and would include:

- Twin mainline tunnels about 6.5 kilometres long and each accommodating three lanes of traffic in each direction, connecting the stub tunnels from the M4-M5 Link at Rozelle to the Warringah Freeway and to the Beaches Link mainline tunnels at Cammeray. The crossing of Sydney Harbour between Birchgrove and Waverton would involve a dual, three lane, immersed tube tunnel
- Connections to the stub tunnels at the M4-M5 Link project in Rozelle and to the mainline tunnels at Cammeray (for a future connection to the Beaches Link and Gore Hill Freeway Connection project)

- Surface connections at Rozelle, North Sydney and Cammeray, including direct connections to and from the Warringah Freeway (including integration with the Warringah Freeway Upgrade), an off ramp to Falcon Street and an on ramp from Berry Street at North Sydney
- A ventilation outlet and motorway facilities (fitout and commissioning only) at the Rozelle Interchange
- A ventilation outlet and motorway facilities at the Warringah Freeway in Cammeray
- Operational facilities including a motorway control centre at Waltham Street, within the Artarmon industrial area and tunnel support facilities at the Warringah Freeway in Cammeray
- Other operational infrastructure including groundwater and tunnel drainage management and treatment systems, signage, tolling infrastructure, fire and life safety systems, lighting, emergency evacuation and emergency smoke extraction infrastructure, CCTV and other traffic management systems.

Key features of the Warringah Freeway Upgrade component of the project are shown in Figure 1-2 and would include:

- Upgrade and reconfiguration of the Warringah Freeway from immediately north of the Sydney Harbour Bridge through to Willoughby Road at Naremburn
- Upgrades to interchanges at Falcon Street in Cammeray and High Street in North Sydney
- New and upgraded pedestrian and cyclist infrastructure
- New, modified and relocated road and shared user bridges across the Warringah Freeway
- Connection of the Warringah Freeway to the portals for the Western Harbour Tunnel mainline tunnels and the Beaches Link tunnels via on and off ramps, which would consist of a combination of trough and cut and cover structures
- Upgrades to existing roads around the Warringah Freeway to integrate the project with the surrounding road network
- Upgrades and modifications to bus infrastructure, including relocation of the existing bus layover along the Warringah Freeway
- Other operational infrastructure, including surface drainage and utility infrastructure, signage, tolling, lighting, CCTV and other traffic management systems.

A detailed description of the project is provided in Chapter 5 (Project description) and construction of the project is described in Chapter 6 (Construction work) of the environmental impact statement. The project alignment at the Rozelle Interchange shown in Figure 1-1 and Figure 1-3 reflects the arrangement presented in the environmental impact statement for the M4-M5 Link, and as amended by the proposed modifications. The project would be constructed in accordance with the now finalised M4-M5 Link detailed design (refer to Section 2.1.1 of Chapter 2 (Assessment process) of the environmental impact statement for further details).

The project does not include ongoing motorway maintenance activities during operation or future use of residual land occupied or affected by project construction activities, but not required for operational infrastructure. These would be subject to separate planning and approval processes at the relevant times.

Subject to the project obtaining planning approval, construction is anticipated to commence in 2020 and is expected to take around six years to complete.

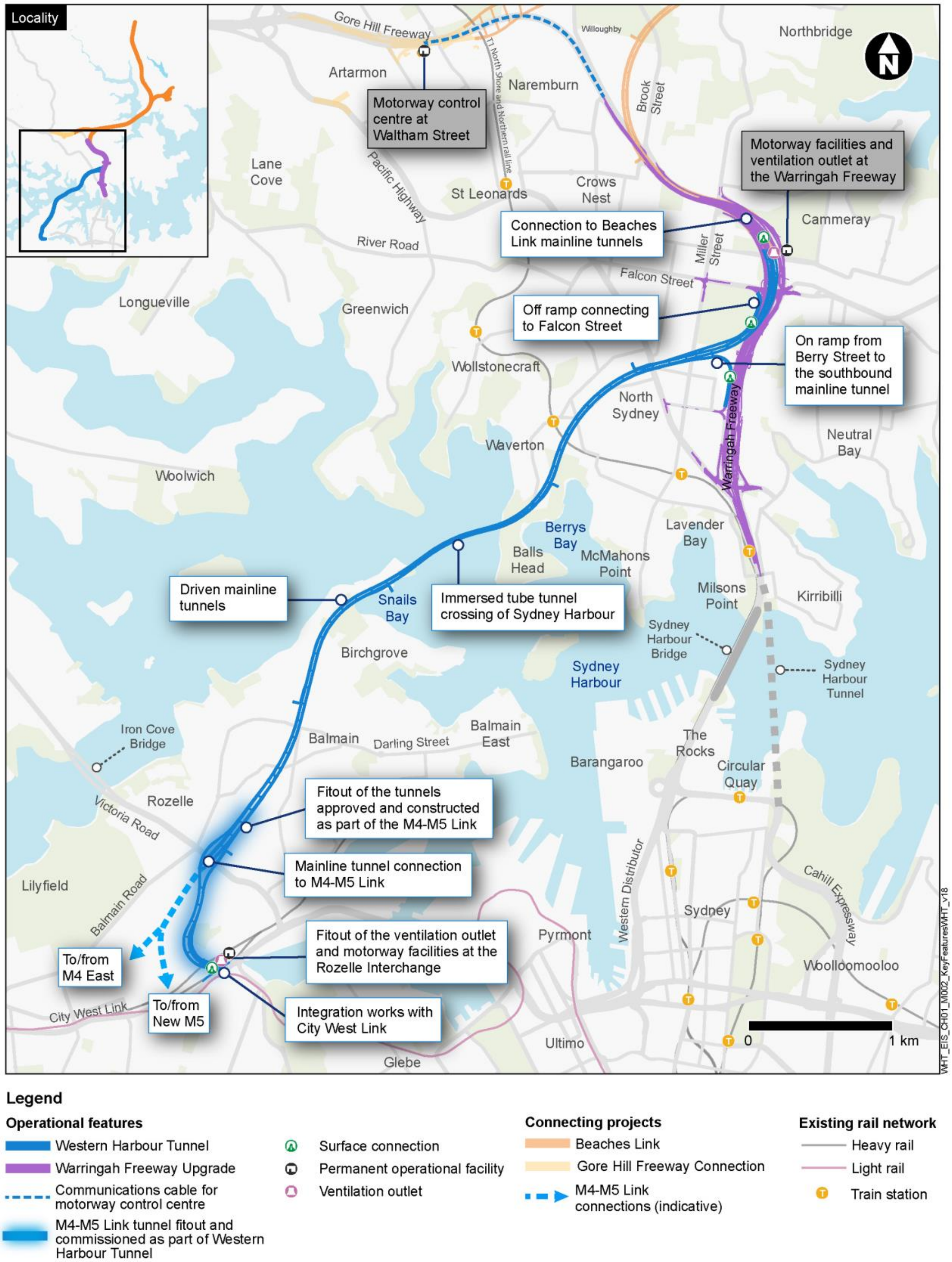
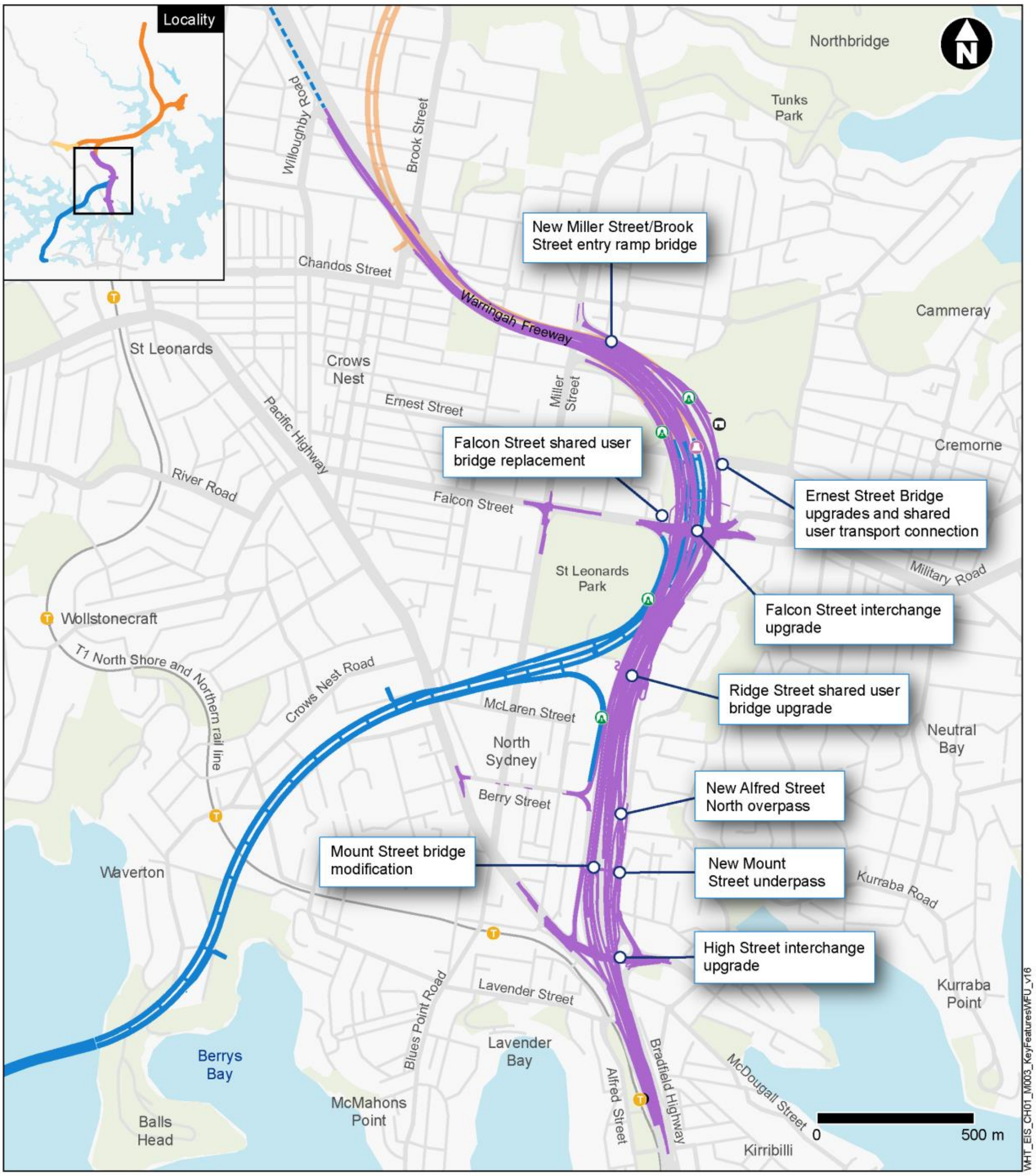


Figure 1-1 Key features of the Western Harbour Tunnel component of the project



Legend

Operational features
- Warringah Freeway Upgrade
- Western Harbour Tunnel
- Communications cable for motorway control centre
- Surface connection
- Permanent operational facility
- Ventilation outlet

Connecting projects
- Beaches Link

Existing rail network
- Heavy rail
- Train station

Figure 1-2 Key features of the Warringah Freeway Upgrade component of the project

1.2 Key construction activities

The area required to construct the project is referred to as the construction footprint. The majority of the construction footprint would be located underground within the mainline tunnels. However, surface areas would be required to support tunnelling activities and to construct the tunnel connections, tunnel portals and operational ancillary facilities.

Key construction activities would include:

- Early works and site establishment, with typical activities being property acquisition and condition surveys, utilities installation, protection, adjustments and relocations, installation of site fencing, environmental controls (including noise attenuation and erosion and sediment control) and traffic management controls, vegetation clearing, earthworks and demolition of structures, establishment of construction support sites including acoustic sheds and associated access decline acoustic enclosures (where required), construction of minor access roads and the provision of property access, temporary relocation of pedestrian and cycle paths and bus stops, temporary relocation of swing moorings within Berrys Bay, and relocation of the historic vessels.
- Construction of Western Harbour Tunnel, with typical activities being excavation of tunnel construction accesses, construction of driven tunnels, cut and cover and trough structures and construction of cofferdams, dredging activities in preparation for the installation of immersed tube tunnels, casting and installation of immersed tube tunnels and civil finishing and tunnel fitout
- Construction of operational facilities comprising of a motorway control centre at Waltham Street in Artarmon, motorway and tunnel support facilities, ventilation outlets at the Warringah Freeway in Cammeray, construction and fitout of the project operational facilities that form part of the M4-M5 Link Rozelle East Motorway Operations Complex, a wastewater treatment plant at Rozelle and the installation of motorway tolling infrastructure
- Construction of the Warringah Freeway Upgrade, with typical activities being earthworks, bridgeworks, construction of retaining walls, stormwater drainage, pavement works and linemarking and the installation of road furniture, lighting, signage and noise barriers
- Testing of plant and equipment, and commissioning of the project, backfill of access declines, removal of construction support sites, landscaping and rehabilitation of disturbed areas and removal of environmental and traffic controls.

Temporary construction support sites would be required as part of the project (refer to Figure 1 3), and would include tunnelling and tunnel support sites, civil surface sites, cofferdams, mooring sites, wharf and berthing facilities, laydown areas, parking and workforce amenities. Construction support sites for Western Harbour Tunnel would include:

- Rozelle Rail Yards (WHT1)
- Victoria Road (WHT2)
- White Bay (WHT3)
- Yurulbin Point (WHT4)
- Sydney Harbour south cofferdam (WHT5)
- Sydney Harbour north cofferdam (WHT6)
- Berrys Bay (WHT7)
- Berry Street north (WHT8).
- Ridge Street north (WHT9)
- Cammeray Golf Course (WHT10)
- Waltham Street (WHT11).

During the construction of the Warringah Freeway Upgrade, smaller construction support sites would be required to support the construction works (as shown on Figure 1 3). These include:

- Blue Street (WFU1)
- High Street south (WFU2)
- High Street north (WFU3)
- Arthur Street east (WFU4)
- Berry Street east (WFU5)
- Ridge Street east (WFU6)
- Merlin Street (WFU7)
- Cammeray Golf Course (WFU8)
- Rosalind Street east (WFU9).

A detailed description of construction works for the project is provided in Chapter 6 (Construction work) of the environmental impact statement.

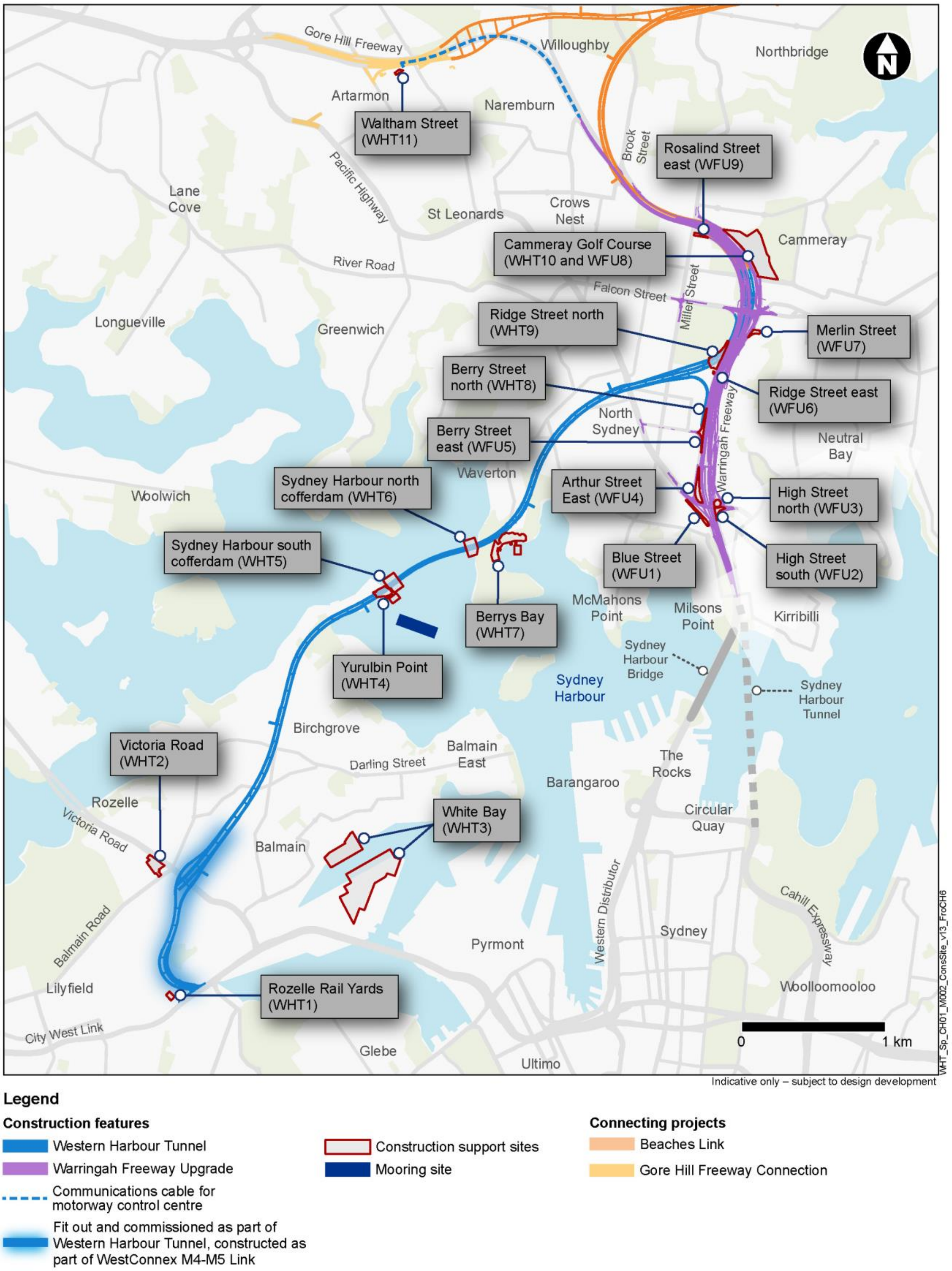


Figure 1-3 Overview of construction support sites

1.3 Project location

The project would be located within the Inner West, North Sydney and Willoughby local government areas, connecting Rozelle in the south with Naremburn in the north.

Commencing at the Rozelle Interchange, the mainline tunnels would pass under Balmain and Birchgrove, then cross Sydney Harbour between Birchgrove and Balls Head. The tunnels would then continue under Waverton and North Sydney, linking directly to the Warringah Freeway to the north of the existing Ernest Street bridge.

The motorway control centre would be located at Waltham Street, Artarmon, with a trenched communications link connecting the motorway control centre to the Western Harbour tunnel along the Gore Hill Freeway and Warringah Freeway road reserves.

The Warringah Freeway Upgrade would be carried out on the Warringah Freeway from around Fitzroy Street at Milsons Point to around Willoughby Road at Naremburn. Upgrade works would include improvements to bridges across the Warringah Freeway, and upgrades to surrounding roads.

1.4 Purpose of this report

This report has been prepared to support the environmental impact statement for the project and to address the environmental assessment requirements of the Secretary of the Department of Planning, Industry and Environment ('the Secretary's environmental assessment requirements').

This report assesses the potential groundwater pressure, level and quality related impacts that may occur as a result of the construction and operation of the project. Tunnel dewatering can lead to groundwater drawdown, which has the potential to impact the surrounding environment by reducing the availability of water for Groundwater Dependent Ecosystems (GDE), reducing baseflow contributions to surface water courses and reducing the availability of water for local groundwater users.

This assessment also seeks to establish the presence of potentially contaminated groundwater as tunnel inflows in such areas have the potential to lead to human health risks and the requirements and potential impacts of water disposal need to be assessed accordingly.

A summary of the relevant guidelines and legislation is provided in Section 3.

1.5 Secretary's environmental assessment requirements

The Secretary's environmental assessment requirements relating to groundwater, and where these requirements are addressed in this report are outlined in Table 1-1.

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

Requirement (specific assessment requirements in addition to the general requirement above)	Where addressed
1. The Proponent must describe (and map) the existing hydrological regime for any surface and groundwater resource (including reliance by users and for ecological purposes and groundwater dependent ecosystems) likely to be impacted by the project, including rivers, streams, wetlands and estuaries as described in Appendix 2 of the Framework for Biodiversity Assessment – NSW Biodiversity Offsets Policy for Major Projects (Department of Premier and Cabinet (Heritage), 2014).	A description of groundwater resources is presented in Section 5 of this report Refer to Technical working paper: Surface water (Jacobs, 2020a) for a description of waterways and catchments and Technical working paper: Biodiversity Development Assessment (Arcadis, 2020) for a description on groundwater dependent ecosystems.
2. The Proponent must prepare a detailed water balance for ground and surface water including the proposed intake and discharge locations (including mapping of these locations), volume, frequency and duration for both the construction and operational phases of the project.	Refer to Technical working paper: Surface water for a detailed water balance and further information regarding proposed intake and discharge locations.
3. The Proponent must assess (and model if appropriate) the impact of the construction and operation of the project and any ancillary facilities (both built elements and discharges) on surface and groundwater hydrology in accordance with the current guidelines, including: (a) natural processes within rivers, wetlands, estuaries, marine waters and floodplains that affect the health of the fluvial, riparian, estuarine or marine system and landscape health (such as modified discharge volumes, durations and velocities), aquatic connectivity, water dependent fauna and flora and access to habitat for spawning and refuge; (b) impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, barriers to flows, implications for groundwater dependent surface flows, ecosystems and species, groundwater users and the potential for settlement; (c) changes to environmental water availability and flows, both regulated/licensed and unregulated/rules-based sources including the stormwater harvesting scheme implemented by North Sydney Council at the storage dam at Cammeray Golf Course; (d) direct or indirect increases in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses; (e) 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	Section 6 of this report for construction stage. Refer to Technical working paper: Flooding (Lyall and Associates, 2020) for assessment of impact on flood behaviour including volumes, durations and velocities. Refer to Technical working paper: Marine Water Quality (Cardno, 2020) and Technical working paper: Biodiversity development assessment report (Arcadis, 2020) for assessment of impact on aquatic connectivity, water dependent fauna and flora and access to habitat for spawning and refuge

Requirement (specific assessment requirements in addition to the general requirement above)	Where addressed
options) and on the conveyance capacity of existing stormwater systems where discharges are proposed through such systems; and (f) measures to mitigate the impacts of the proposal and manage the disposal of produced and incidental water.	
4. The assessment must provide details of the final landform of the sites to be excavated or modified (eg portals), including final void management and rehabilitation measures.	Refer to EIS Chapter 5 project description. The management of voids (shafts and access declines) is detailed in Chapter 6 (Construction work).
5. The Proponent must identify any requirements for baseline monitoring of hydrological attributes.	Section 7.3 of this report
6. The assessment must include details of proposed surface and groundwater monitoring.	Section 7.3 of this report Refer to Refer to Technical working paper: Surface water (Jacobs, 2020a) for construction and operational surface water monitoring.
7. The Proponent must identify design approaches to minimise or prevent drainage of alluvium in the palaeochannels.	Section 5.3 of this report
1. The Proponent must: (a) describe the background conditions for any surface or groundwater resource likely to be affected by the development (b) state the ambient NSW Water Quality Objectives (NSW WQO) (as endorsed by the NSW Government [see www.environment.nsw.gov.au/ieo/index.htm]) and environmental values for the receiving waters (including groundwater where appropriate) relevant to the project and that represent the community's uses and values for those receiving waters, including the indicators and associated trigger values or criteria for the identified environmental values in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government; (c) identify and estimate the quality and quantity of all pollutants that may be introduced into the water cycle by source and discharge point and describe the nature and degree of impact that any discharge(s) may have on the	A description of groundwater resources is presented in Section 5 of this report The water quality guidelines and objectives applied in the assessment of surface water quality are presented in Technical working paper: Surface water (Jacobs, 2020a) The water quality guidelines and objectives applied in the assessment of marine surface water quality are presented in Technical working paper: Marine water quality (Cardno 2020). Existing groundwater quality is described in Section 5.5. Discharge points and quantities are described in Technical working paper: Surface water (Jacobs, 2020a), Section 5.1 for construction and Section 6.1 for operation. For surface water quality impacts refer to Sections 5 and 6 of Technical working paper: Surface water (Jacobs, 2020a). Marine water quality

Requirement (specific assessment requirements in addition to the general requirement above)	Where addressed
receiving environment, including consideration of all pollutants that pose a risk of non-trivial harm to human health and the environment; (d) identify the rainfall event that the water quality protection measures will be designed to cope with; (e) assess the significance of any identified impacts including consideration of the relevant ambient water quality outcomes; (f) demonstrate how construction and operation of the project (including mitigating effects of proposed stormwater and wastewater management) 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; and - where the NSW WQOs are not currently being met, activities will work toward their achievement over time; (g) justify, if required, why the WQOs cannot be maintained or achieved over time; (h) demonstrate that all practical measures to avoid or minimise water pollution and protect human health and the environment from harm are investigated and implemented; (i) identify sensitive receiving environments (which may include estuarine and marine waters downstream including Quarry Creek and its catchment) and develop a strategy to avoid or minimise impacts on these environments; and (j) identify proposed monitoring locations, monitoring frequency and indicators of surface and groundwater quality.	impacts are presented within Section 5 of Technical working paper: Marine water quality (Cardno 2020). Refer to Section 6 of this report for an assessment of construction and operational impacts
2. The assessment should consider the results of any current water quality studies, as available, in the project catchment.	Refer to Section 5.5.5 of this report

As the SEARs relate to water more generally, several of the requirements are covered in other technical working papers, namely:

- Increased erosion, siltation or reduction of the stability of river banks and watercourses (SEAR 9.3d) may be affected by groundwater drawdown but is more relevant to assessments of surface water runoff and geotechnical stability and is covered in the Technical working paper: Surface water
- Final landform of sites including void management and rehabilitation (SEAR 9.4) is covered in the Technical working paper: Urban design, landscape character and visual impact (WSP & Arup, 2020)

- Identification of the rainfall event that the water quality objectives are designed to cope with (SEAR 10.1d) is covered in the Technical working paper: Surface water (2020a)
- Identification of contamination risks is also covered in the Technical working paper: Contamination (Jacobs, 2020b).

2. Specific aspects of the project relating to groundwater

The project would be constructed mainly with the use of roadheaders with an immersed tube tunnel installed within Sydney Harbour. The following section describes aspects of the construction methodology that are relevant to the assessment of potential impacts upon groundwater.

2.1 Construction methodology

2.1.1 Mined tunnel and lining methods

The mined tunnels would be supported by permanent rock bolts, shotcrete and a cast-in-situ concrete lining system depending on the geotechnical and hydrogeological conditions.

The tunnel lining system would comprise the following three methods:

- Typical drained tunnel lining: About 93 per cent of the tunnel would be drained via a typical drained tunnel lining. This method is proposed where groundwater inflows are considered low (less than one litre per second per kilometre). The lining would comprise of permanent shotcrete
- Drained tunnel with waterproof umbrella: About three per cent of the tunnel is expected to utilise a waterproof umbrella system where there is risk of elevated groundwater inflows due to geological features and defects, or in the vicinity of water courses and portals. The waterproof umbrella would comprise of permanent shotcrete and a waterproof membrane over conduit drains that direct seepage to the floor drains. The crown of three and two lane tunnels would be finished with an inner lining
- Tanked or undrained tunnel lining: About four per cent of the tunnel would be fully lined with a waterproof membrane to control higher potential inflows (greater than one litre per second per kilometre) where the alignment is below sea level next to the immersed tube tunnel harbour crossing. A tanked tunnel system negates the requirement for ongoing draining and dewatering and therefore reduces groundwater drawdown and potential environmental impacts relative to a drained system.

2.1.2 Groundwater collection method

During construction, groundwater inflows would be collected in sumps at the roadheader and at high inflow points. Collected water would be transferred via gravity drains or pumping, as required, to the relevant treatment facility. Following construction and lining of high inflow sections, residual seepage via wick drains would be directed to the tunnel drainage system, where gravity drainage and water transfers would transfer the accumulated seepage to the long term water treatment facilities. During construction, separation would be maintained between the groundwater and contaminated wash water to optimise groundwater treatment.
A shotcrete lining applied to the side walls of the tunnels would minimise groundwater oxidation and hence the formation of iron oxide sludge.

2.1.3 Immersed tube tunnel design

The Sydney Harbour crossing would utilise an immersed tube tunnel design from Birchgrove to Balls Head. The required roadway grading across the harbour would be achieved with a constant 0.5 per cent slope, which would facilitate water drainage. Any water collected within the immersed tube tunnel would be pumped to the designated wastewater treatment plant as described in Section 6.

On completion, the immersed tube tunnel would be fully watertight under the applied external loading including potential sea level rise. Therefore, no inflows are anticipated.

2.1.4 Cavern design

The project includes two mined caverns at North Sydney. Caverns would be situated at diverging and merging areas as well as exit and entry points. The caverns would vary in length and width.

The caverns would be lined with fibre reinforced shotcrete applied to the excavated rock surface. Weep holes would be drilled through the shotcrete layer with attached strip drains to drain groundwater from the surrounding rock mass. A further shotcrete layer would be applied over the strip drains.

2.1.5 Other tunnel elements

Other, more minor, tunnel elements would be established which would include ramps, cross passages, egress passages, ventilation tunnels, breakdown bays, substations and drainage sumps. The construction and groundwater management methodologies employed for these elements would be consistent with practices detailed above for the major tunnel elements. Typically, the other tunnel elements would be drained and, in some cases, would utilise a waterproof umbrella.

2.1.6 Treated wastewater discharge

The project wastewater treatment plants would treat wastewater generated from tunnelling activities to a standard suitable for discharge. The type, arrangement and performance of wastewater treatment plants would be developed and finalised during further design development. Refer to the Technical working paper: Surface Water, and Technical working paper: Marine water quality (Cardno, 2020), for details in discharge criteria for receiving waters.

During construction, the treated wastewater would be discharged to the local stormwater network, watercourses and Sydney Harbour via discharge points associated with each treatment plant, the locations of which are detailed in Table 2-1 and shown on Figure 2-1. Tunnel inflows during the operational stage of the project would be treated at a wastewater treatment plant located at the Rozelle interchange.

Table 2-1 Groundwater drainage to treatment facilities during construction

Wastewater treatment plant location	Discharge point
Construction	
Rozelle Rail Yards (WHT1)	Rozelle Bay via a local stormwater system
Victoria Road (WHT2)	Sydney Harbour via local stormwater system
Yurulbin Point (WHT4)	Direct discharge to Snails Bay
Berrys Bay (WHT7)	Direct discharge to Berrys Bay
Cammeray Golf Course (WHT10)	Willoughby Creek via local stormwater system
Operation	
Rozelle interchange	Rozelle Bay via a local stormwater system

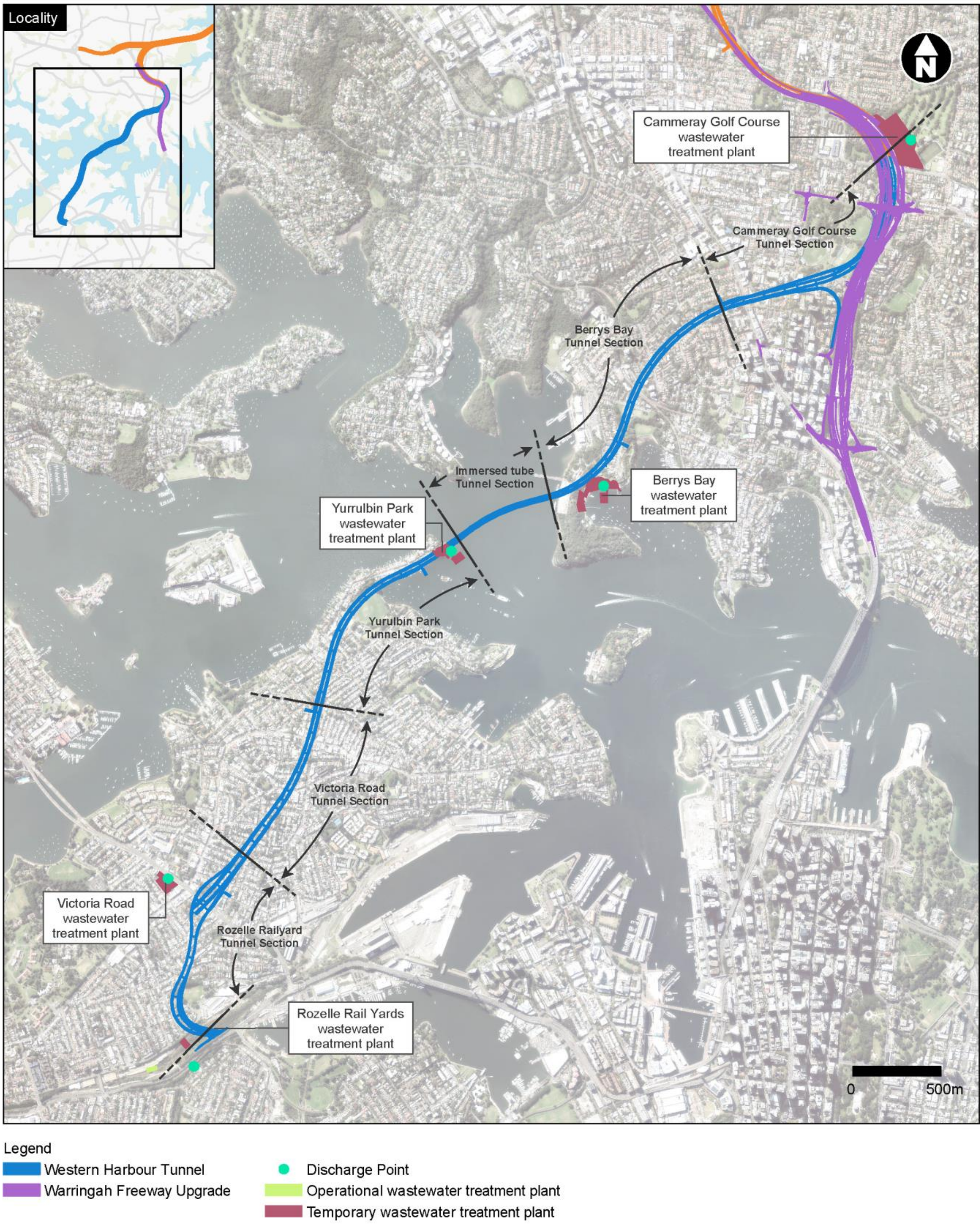


Figure 2-1 Wastewater treatment plants and associated drained sections

3. Groundwater legislation and policy

Commonwealth and State legislation and policies relevant to groundwater management are outlined below.

3.1 Commonwealth legislation and policies

3.1.1 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

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

Approval from the Commonwealth Minister for the Environment is required for:

- An action which has, would have, or is likely to have a significant impact on 'matters of National Environmental Significance' (NES matters). Of most relevance to the project and groundwater, NES matters include Ramsar wetlands of international importance.
- An action by the Commonwealth or a Commonwealth agency which has, would have, or is likely to have a significant impact on the environment
- An action on Commonwealth land which has, would have, or is likely to have a significant impact on the environment
- An action which has, would have, or is likely to have a significant impact on the environment of Commonwealth land, no matter where it is to be carried out.

Impacts on groundwater due to construction and operation of the project may be relevant under the EPBC Act where groundwater is shown to support NES matters, such as wetlands, ecological communities, or water resources. The project could also have a significant impact on the groundwater environment in terms of groundwater levels and quality, which would require approval under the Act.

Impacts on NES matters are assessed through a referral process to the Commonwealth Department of the Environment. If the Commonwealth Minister for the Environment determines that a project is likely to have a significant impact on a NES matter, then the project becomes a controlled action and approval of the Commonwealth Minister for the Environment would be required before groundwater investigations and tunnel construction can start.

3.1.2 National Water Quality Management Strategy

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

The primary document relevant the assessment of groundwater risks for the project is the *Guidelines for Groundwater Quality Protection in Australia* (Australian Government, 2013). This document sets out a high-level risk-based approach to protecting or improving groundwater quality for a range of groundwater beneficial uses (called environmental values), including for aquatic ecosystem protection, primary industries, recreational use, drinking water, industrial water and cultural values. Based on water quality criteria (Section 4.5.5), the highest beneficial use category of groundwater along the project alignment is considered to be use by aquatic ecosystems at groundwater discharge locations.

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

- *Guidelines for Managing Risks in Recreational Water* (National Health and Medical Research Council (NHMRC) 2008)
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, (2000))
- Australian Drinking Water Guidelines (NHMRC/NRMMC, (2011)).

Where these specific water quality objectives are identified, the groundwater component of the water source should meet the guideline values. For the project, this means that the current uses of groundwater or surface water must not be degraded as a result of the construction and operation of the project, for example through installation of contaminated construction materials, chemical spills, wastewater disposal or activation of acid sulfate soils.

3.1.3 National Environment Protection (Assessment of Site Contamination) Measure 1999

The *National Environment Protection (Assessment of Site Contamination) Measure 1999* (the 'NEPM') is a Commonwealth instrument that aims to establish a consistent and sound approach to assessing site contamination for the protection of human health and the environment. The provisions of the NEPM largely relate to contaminated sediments, but also require the impact of contaminated soils on groundwater to be characterised during site assessments. The NEPM refers to the Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) website for numerical health investigation levels of various contaminants, and to NWQMS documents for numerical investigation levels for different beneficial uses.

An extensive list of other guidelines relating to the identification and management of contamination is included in the Technical working paper: Contamination.

3.1.4 Australian Groundwater Modelling Guidelines

The *Australian Groundwater Modelling Guidelines* (SKM & NCGRT, 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 that is underpinned by a progression 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 (ie after conceptualisation and design, after calibration and sensitivity and at completion). Three levels of review are suggested:

- A model appraisal by a non-technical audience to evaluate model results
- A peer review by experienced hydrogeologists and modellers for an in-depth review of the model and results
- A post-audit, critical re-examination of the model when new data is available or the model objectives change.

The guidelines include a detailed description of solute transport modelling where the solute of interest is non-reactive, and for problems relating only to groundwater flow and storage.

The groundwater modelling carried out to assess potential groundwater impacts associated with the project has undergone a third party review by an independent qualified hydrogeologist. The groundwater modelling report is appended in Appendix F.

3.2 New South Wales legislation and policies

3.2.1 Water Act 1912 and Water Management Act 2000

Water resources in NSW are administered under the *Water Act 1912* and the *Water Management Act 2000* by the Department of Planning, Industry and Environment (Water). The *Water Management Act 2000* governs the issue of water access licences and approvals for those water sources (rivers, lakes, estuaries and groundwater) in New South Wales where Water Sharing Plans (WSP) have started. The WSP for the project area has started and the area is therefore governed under the *Water Management Act 2000.*

The *Water Management Act 2000* requires approvals for activities that may impact an aquifer(s). The approval is for activities that intersect groundwater other than water supply bores and may be issued for up to ten years. Part 2 of the *Water Management Act 2000* establishes access licences for the take of water within a particular water management area. The *Water Management (General) Regulation 2011* is the primary regulation instrument under the *Water Management Act 2000*.

Roads and Maritime is exempt as a roads authority under Clause 18(1) of the *Water Management (General) Regulation 2011* from the requirement to hold a water access licence. Roads and Maritime is also exempt under Clause 31(1) of those regulations from the requirement to hold a water use approval. These exemptions are as per Schedule 4, Part 1, clause 2 of the regulations, which pertain to water required for road construction and road maintenance.

3.2.2 Water Sharing Plan

Water Sharing Plans (WSPs) establish rules for sharing water between the environmental needs of the river or aquifer and water users, and also between different types of water use such as town supply, rural domestic supply, stock watering, industry and irrigation. The *Water Act 1912* governs the issue of water licences for water sources in other areas. There are Water Sharing Plans for regulated and unregulated river catchments and groundwater sources in water management areas. The WSP rules are discussed in relation to the project in Section 8.3.

The project would be located within the Sydney Basin Central management zone within the *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources and the Greater Metropolitan Region Groundwater Sources*, both of which started on 1 July 2011. The Metropolitan Coastal Sands management zone is located close to the project area.

The 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). The LTAAEL for the Sydney Central Basin is 45,915 megalitres per year, which is 25 per cent of the estimated annual recharge for the area. Under the WSP there are currently 120 groundwater access licences, with a total licensed volume of 2592 megalitres per year. As such there is up to 43,323 megalitres per year of water available under the LTAAEL, which could be partially consumed by groundwater inflows to the project.

3.2.3 NSW Aquifer Interference Policy

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

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

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

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

The aquifers in the vicinity of the project area are considered to fall in the “less productive porous and fractured rock” category.

The AIP refers to the beneficial use of an aquifer, which is outlined in the *National Water Quality Management Strategy* (NWQMS, 2013); it is noted that within the management strategy the term beneficial use is replaced with environmental value. The beneficial uses are as follows:

- Aquatic ecosystems, comprising the animals, plants and micro-organisms that live in water, and the physical and chemical environment and climatic conditions with which they interact
- Primary industries, including irrigation and general water users, stock drinking water, aquaculture and human consumption of aquatic foods
- Recreation and aesthetic values, including recreational activities such as swimming and boating, and the aesthetic appeal of water bodies
- Drinking water, which is required to be safe to use and aesthetically pleasing
- Industrial water, such as water used for industrial processes including cooling towers, process water or wash water
- Cultural and spiritual values, which may relate to a range of uses and issues of a water source, particularly for indigenous people, including spiritual relationships, sacred sites, customary use, the plants and animals associated with water, drinking water or recreational activities.

Each beneficial use has a unique set of water quality criteria designed to protect the environmental value of the groundwater resource. The NSW Aquifer Interference Policy also requires that for an aquifer interference activity to meet the minimal impact considerations, any change in groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.

Groundwater along the project alignment is likely to be used by aquatic ecosystems, and primary industries to account for small-scale domestic use of groundwater. However, this would vary locally depending on ambient groundwater conditions.

The AIP minimal impact considerations are summarised in Table 3-1. The potential impacts are assessed against the minimal impact considerations in Section 6.

Table 3-1 AIP minimal impact considerations

<table>
<tr><th colspan="2">Minimal impact consideration – less productive porous and fractured rock groundwater source</th></tr>
<tr><td>Water table
1. Less than or equal to 10% 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 2 metre decline cumulatively at any water supply work.
2. If more than 10% 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 2 metre decline cumulatively at any water supply work then make good provisions should apply.</td><td>Water pressure
1. A cumulative pressure head decline of not more than a 2 metre decline, at any water supply work.
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.</td></tr>
<tr><td>Water quality
1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.
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.</td><td>Additional considerations
… any advice provided to a gateway panel, the Planning and Assessment Commission or the Minister for Planning on a State significant development or State significant infrastructure will also consider the potential for:
• acidity issues to arise, for example exposure of acid sulfate soils
• water logging 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.</td></tr>
</table>

Notes: Minister refers to the Minister administering the *Water Management Act 2000*

3.2.4 Groundwater Dependent Ecosystems Policy

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

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

Potential GDEs in the vicinity of the project are discussed in Section 5.5.8.

3.2.5 NSW State Groundwater Quality Protection Policy

The NSW *State Groundwater Quality Protection Policy* (Department of Land and Water Conservation, 1998) is the overarching approach to protecting groundwater quality in NSW and sits under the Commonwealth NWQMS. It provides for the protection of the most sensitive identified beneficial use (environmental value) for a water source through a precautionary approach and risk-based management. It provides guidance on the instruments available for protecting groundwater quality, with an emphasis on using groundwater management plans to manage both quality and quantity aspects together.

3.2.6 NSW Water Quality Objectives

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

3.2.7 Guidelines for the Assessment and Management of Groundwater Contamination

These guidelines are consistent with the *Contaminated Land Management Act 1999* and the *Protection of the Environment Operations Act 1997*, 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 in the event that construction or operation caused contamination of groundwater that impacted environmental values and required remediation.

4. Assessment methodology

4.1 General

The assessment of potential impacts upon groundwater arising from project has been implemented as follows:

- Characterisation of the existing environment including climate, topography, geology, and groundwater occurrence, quality and use, including groundwater dependent ecosystems (GDEs)
- Review of similar assessments and previous tunnelling projects in the Sydney region
- Dedicated field investigations including drilling, permeability testing, monitoring bore installation, and water level and quality monitoring
- Development of a three-dimensional conceptual hydrogeological model
- Groundwater numerical modelling 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 related impacts to satisfy the minimal impact considerations of the AIP and to address groundwater related issues raised in the SEARs
- Recommendations for monitoring and management of identified impacts and risks, including mitigation measures as appropriate.

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

4.2 Desktop assessment

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

4.2.1 Data Collection

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

- The Pinneena database (NSW Government) for groundwater level and quality data at monitoring bores
- The Water Register (www.water.nsw.gov.au/water-licensing/registers) for data on existing groundwater users, including Water Access Licence (WAL) holders and stock and domestic users
- The National Atlas of Groundwater Dependent Ecosystems (the GDE Atlas, www.bom.gov.au/water/groundwater/gde/) to identify the location and groundwater dependence of surface water systems and vegetation
- The NSW EPA list of contaminated sites notified to the EPA (www.epa.nsw.gov.au/your-environment/contaminated-land/notification-policy/contaminated-sites-list)
- Rainfall data from gauging stations in the project area, from the Bureau of Meteorology.

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

4.2.2 Review of previous studies

A range of previous investigation and construction projects provided useful information on geological and hydrogeological properties along the Western Harbour Tunnel and Warringah Freeway Upgrade project area. These included:

- AECOM, 2015. WestConnex New M5 Environmental Impact Statement – Technical working paper: Groundwater Appendix Q, November 2015
- AECOM, 2017. WestConnex M4 – M5 Link Environmental Impact Statement – Technical working paper: Groundwater Appendix T, August 2017
- Coffey Geotechnics, 2012. Geotechnical Interpretative Report. North West Rail Link. Transport for NSW. 18 May 2012
- GHD, 2015. WestConnex M4 East Groundwater Impact Assessment. EIS Appendix R. Prepared for WestConnex Delivery Authority, September 2015
- Hewitt, P., 2005. Groundwater Control for Sydney Rock Tunnels. Geotechnical aspects of tunnelling for infrastructure projects. Sydney: AGS AUCTA
- Jacobs, 2016. Sydney Metro Chatswood to Sydenham, Technical Paper 7: Groundwater Assessment. Prepared for Transport for NSW. May 2016
- WSP | Parsons Brinckerhoff, 2016. HarbourLink – Geotechnical investigations, Preliminary Environmental Assessment, prepared for RMS, June 2016 (final draft).

A number of other general studies on rock properties in the Sydney area and in Hawkesbury Sandstone in particular were also used. These are referenced as appropriate and listed in the reference list in Section 9. Guidelines and management procedures relevant to the protection of groundwater assets are presented in Section 0, which also describes how these guidelines and procedures have been applied to identify implications for tunnel design and groundwater management during the construction and operation phases of development.

4.3 Field assessment

Extensive field work was carried out for the project with monitoring ongoing at the time of writing. The hydrogeological program occurred in conjunction with the geotechnical and contaminated land field program. Results and interpretation of the field work relevant to this groundwater assessment are presented in Section 5.5.

4.3.1 Drilling program

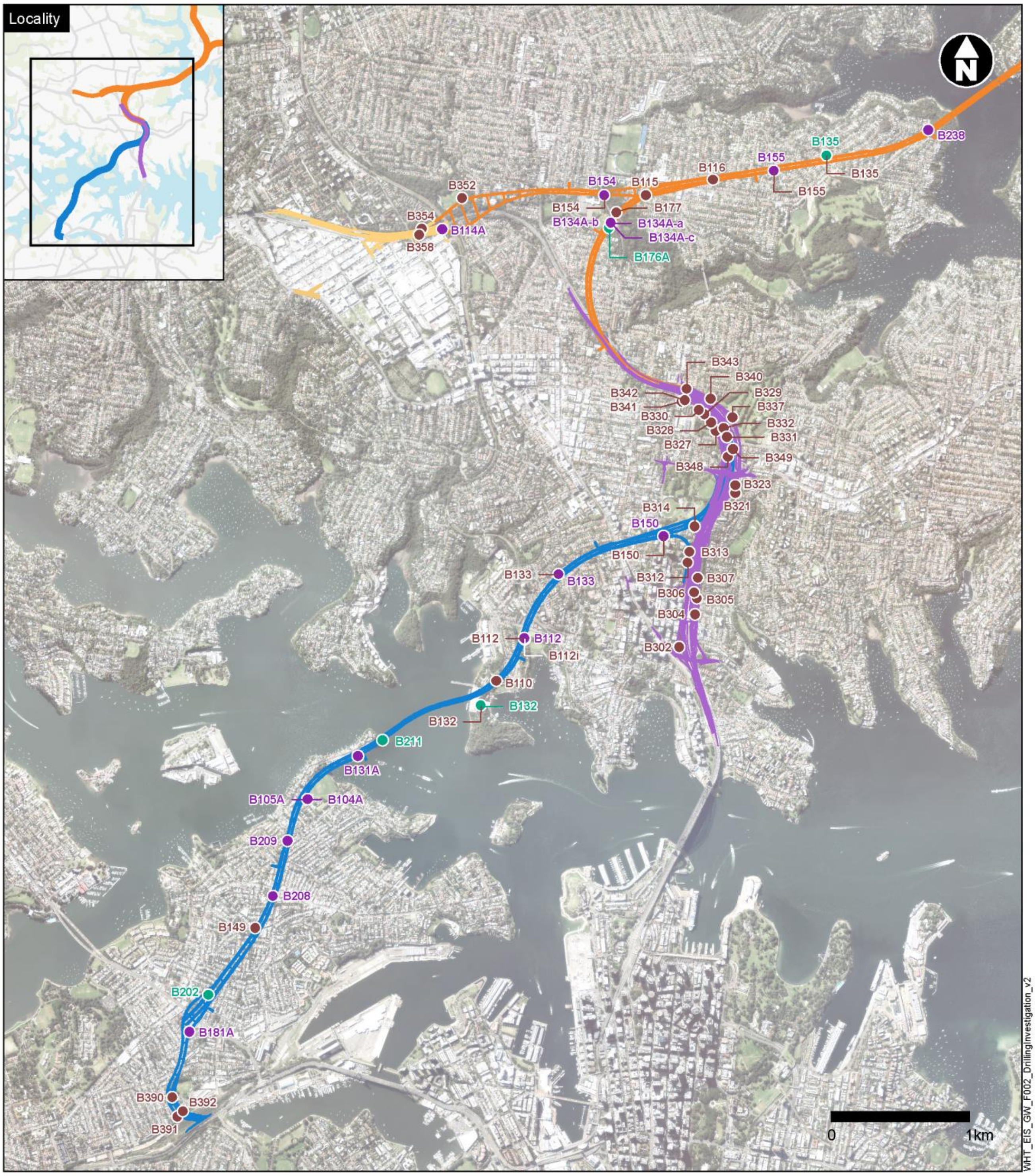
As part of the current investigations a campaign of geotechnical drilling was carried out. The drilling comprised both land-based drilling along the project alignment, and marine-based drilling through the harbour crossing areas. The program incorporated both the Western Harbour Tunnel and Warringah Freeway Upgrade, as well as the Beaches Link and Gore Hill Freeway Connection projects. Lithological and bore completion logs for constructed monitoring bores and vibrating wire piezometer installations are provided in Appendix A and Appendix B of this report.

From the geotechnical investigation boreholes:

- A total of 497 individual packer tests (hydraulic testing for estimating hydraulic conductivity) have been completed at 86 boreholes, comprising
  - 200 useable packer tests from 59 marine boreholes
  - 241 useable packer tests from 27 land boreholes
- Twenty-three boreholes have been installed with groundwater monitoring bores

- Six boreholes have been completed with vibrating wire piezometer installations.

The locations of the investigation sites are shown on Figure 4-1, and the results obtained are discussed in the following sections.



Legend

- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Beaches Link
- Gore Hill Freeway Connection
- Monitoring well
- Packer test
- Vibrating wire piezometer

Figure 4-1 Drilling investigation locations

4.3.1.1 Groundwater bore construction

Groundwater monitoring bores were installed in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (NUDLC, 2012). The standpipes were constructed with 50 millimetres nominal diameter Class 18 PVC pipe, with machine slotted screens with an aperture of 0.5 millimetres. A sand/gravel filter pack was typically extended by 0.5 metres to 2 metres above and below the slotted section. A 0.5 metre to two metre seal of bentonite pellets was placed above the sand/gravel pack and the remaining annulus grouted with a bentonite-cement grout mix. Bores were completed with flush-fitting Gatic type covers (of steel or Class D rated polyethylene) and were developed by either airlifting or pumping.

Groundwater monitoring bores are shown on Figure 4-1. Bore logs and bore construction details are shown in Appendix A and Appendix B of this report.

4.3.1.2 Vibrating wire piezometer installation

Vibrating wire piezometer (VWP) installations are shown in Figure 3-1 and construction details are in Appendix B. The VWP sensors were installed at discrete target intervals with the drill hole fully grouted back to ground surface. The hydrostatic profiles were compiled using the average pore pressure recorded over the monitoring period.

4.3.2 Groundwater level and quality monitoring

Completed monitoring bores have been subject to groundwater water level and quality sampling. Sampling locations are shown in Figure 4-2, and groundwater level results are reported in Section 5.5.2 and quality results are presented in Section 5.5.5.

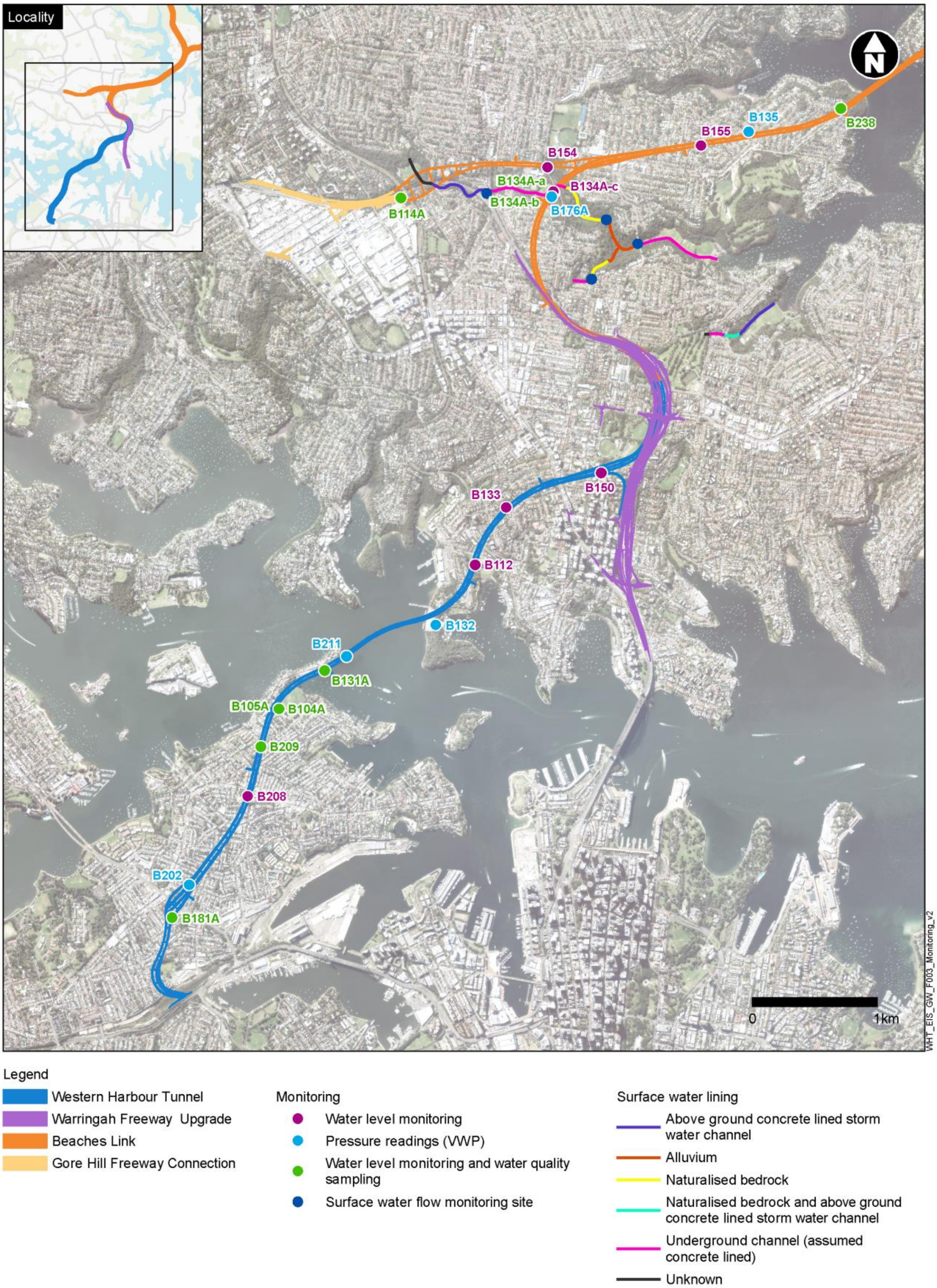


Figure 4-2 Groundwater and surface water monitoring sites

4.4 Groundwater modelling

A groundwater model has been constructed to simulate the project construction and operation. The model has been built using the MODFLOW-USG model code with the Groundwater Vistas 7 Graphical User Interface and employing quadtree grid refinement.

Two separate models have been constructed, referred to as the south model and north model. The models are separated along Sydney Harbour, as the harbour acts as a natural boundary dividing the potential impacts from the project on either side. The Western Harbour Tunnel and Warringah Freeway Upgrade project area is covered by the north model between Sydney Harbour and the Warringah Freeway, and by the south model between Rozelle and Sydney Harbour. The potential impacts discussed in Section 6 rely on the results of both the north and south models.

Employing the dual models allows each model to have a more refined grid, makes more efficient use of the model domain by minimising the number of inactive cells, and the individual models have a faster run time than would be possible had the models been combined into one equally detailed model. Reporting of model development, scenarios and results is included in Appendix F- Groundwater modelling report.

The groundwater modelling predicts drawdown at the water table and in the intermediate model layers. The project tunnels are predominantly in layer 5 of the model and therefore this layer demonstrates the greatest initial drawdown response. Drawdown would then propagate towards the surface, resulting in gradually increasing levels of drawdown in shallower model layers.

The modelling results should be considered as a conservative assessment. The modelling approach assumes a single water table with hydraulic connection to the depth of tunnelling, with the degree of connectivity controlled by the vertical hydraulic conductivity. In reality, the data indicates the potential for multiple water tables, or disconnected aquifers, that if present would act to attenuate the propagation of depressurisation and drawdown. In these areas the predicted water table decline is likely to be an over-estimate.

4.4.1 Saline intrusion

To assess the potential impacts due to saline intrusion, a density dependent flow analysis was carried out along one line section through the region of maximum predicted drawdown in the Rozelle area. A two-dimensional coupled CTRAN/W-SEEP/W groundwater model was developed based on the three-dimensional MODFLOW USG model, described above. Hydraulic parameters assigned to the coupled CTRAN/W-SEEP/W groundwater model were the same as parameters assigned to the three-dimensional MODFLOW USG model. A detailed description of the saline intrusion modelling process is provided in Appendix F.

4.5 Impact assessment

The outputs from the numerical groundwater model combined with hydrogeological interpretation have been applied to assess potential groundwater impacts relating to the dewatering and ongoing operation of the project. Potential impacts are assessed by comparing water level drawdown with the project against the predicted water levels at an equivalent time but without the project.

4.6 Ground settlement assessment

An assessment of ground settlement induced by tunnel excavation due to both stress redistribution in the surrounding ground and groundwater drawdown around drained tunnels has been carried out (Arup and WSP, 2019). The groundwater drawdown predictions have been used to evaluate groundwater drawdown induced settlement. The settlement assessment specifically addresses the following:

- Predicted angular distortion due to settlement
- Settlement impacts to existing buildings and infrastructure

- Settlement impacts on vent tunnels and access declines
- Settlement impacts to heritage items
- Management of settlement impacts.

Arup and WSP (2019) applied the building and structure damage classification shown in Table 4-1.

Table 4-1 Settlement assessment building and structure classification

Damage category[1]	Severity degree	Description	Approximate crack width (mm)	Limiting tensile strain Elim (%)	Maximum slope of ground (angular distortion)[2]	Maximum settlement of building (mm)[2]
0	Negligible	Hairline cracks	<0.1	0 - 0.05	0	0
1	Very slight	Fine cracks that are easily treated during normal decoration. Damage generally restricted to internal wall finishes. Cracks may be visible on external brickwork or masonry.	0.1 to 1	0.05 - 0.075	<1:500	<10
2	Slight	Cracks easily filled. Redecoration probably required. Recurrent cracks can be masked by suitable linings. Crack may be visibly externally and some repointing may be required to ensure weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 - 0.15	1:500 to 1:200	10 to 50
3	Moderate	The cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and window sticking. Service pipes may fracture. Weather-tightness often impaired.	5 to 15 or several (>3)	0.15 - 0.30	1:200 to 1:50	50 to 75
4	Severe	Extensive repair work involving break-out and replacing sections of walls,	15 to 25 but also depends	>0.3	1:200 to 1:50	>75

Damage category[1]	Severity degree	Description	Approximate crack width (mm)	Limiting tensile strain Elim (%)	Maximum slope of ground (angular distortion)[2]	Maximum settlement of building (mm)[2]
		especially over doors and windows. Windows and door frames distorted, floor sloping noticeably1. Walls leaning or bulging noticeably; some loss of bearing in beams. Utilities disrupted.	on number of cracks			
5	Very severe	This requires a major repair job involving partial or complete rebuilding. Beams lose bearing; walls lean badly and require shoring. Windows broken with distortion. Danger of instability.	>25 but also depends on number of cracks	>0.3	>1:50	>75

Notes:

1. Building and structure damage classification after Burland et al (1977) and Boscardin and Cording (1989)
2. Approximate equivalent ground settlements and trough gradients after Rankin (1988).

4.7 Key assumptions

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

- Predicted groundwater inflows and associated impacts are based on the design elements outlined in Section 2.
- With respect to the M4-M5 Link (including the Rozelle Interchange), the assessment is based on the design as approved. The Rozelle Interchange is currently undergoing detailed design and would include a number of design refinements and optimised arrangements which aim to achieve improved construction and operational outcomes or are required to meet the conditions of approval granted for the M4-M5 Link. The outcomes of this detailed design may influence the interface with the project (Western Harbour Tunnel and Warringah Freeway Upgrade). In this case, any required changes to the project that could influence the groundwater assessment would be considered as required (refer to Chapter 2 of the environmental impact statement).
- The existing environment has been characterised based on project specific data and other data available in the public domain. The resulting interpretations are considered to reasonably represent the existing environment and the potential impacts associated with the project
- Field investigations carried out for the project have occurred in tandem with the writing of this report. Any subsequent data that changes the conceptual model or findings of this report would be considered during the further design development stage of the project.

5. Existing environment

The existing environment has been characterised based on a desktop review of publicly available information, as well as the results of field investigations specifically completed for the Western Harbour Tunnel and Warringah Freeway Upgrade, and Beaches Link and Gore Hill Freeway Connection projects.

The conceptualisation of geology and hydrogeology relates to the geological setting and groundwater catchments that the project is situated within, the boundaries of which extend beyond the project boundaries. It is therefore relevant to consider geological and hydrogeological data collected as part of the Beaches Link and Gore Hill Freeway Connection project in the following section.

The purpose of this information is to:

- Understand the existing groundwater regime within which the project would be implemented
- Understand the physical controls on groundwater flow, so that a conceptual model can be developed on which the numerical modelling can be based
- Identify potential receptors that may be impacted by changed groundwater conditions.

5.1 Rainfall and climate

Rainfall data have been obtained from the closest BOM weather stations at Sydney Botanic Gardens (BOM Station 66006), Observatory Hill (BOM Station 66062), and Mosman Council (BOM Station 66184). Station locations are provided in Figure 4-1.

The rainfall record and reliability of data for each of these stations are provided in Table 4-1, with average monthly rainfall provided in Table 4-2. Observatory Hill (BOM Station 66062) has the longest and most complete rainfall record with complete data for 159 years out of 160 years of observation.

Most rainfall occurs in the first half of the year, peaking in June. There is then an abrupt seasonal change with the lowest rainfalls occurring in September. Average annual rainfall is of the order of 1215 to 1230 millimetres per annum across the three stations.

Table 4-2 presents the long-term monthly rainfall record for Observatory Hill (BOM Station 66062) along with the cumulative deviation from mean rainfall (cumulative rainfall deviation or CRD).

The cumulative deviation plot shows four distinct and large scale climatic trends over the 160 years of observation.

Two periods of above average rainfall have occurred, the first from 1858 to 1894, and then again from 1948 to 1992. There was a prolonged period of below average rainfall between 1894 and 1948, and another more recent period of below average rainfall from 1992 to present. These large-scale trends are also overlain by numerous small and intermediate scale fluctuations.

Different types of aquifers have different responses to climatic variation, generally referred to as the groundwater response time. Shallow unconfined aquifers often respond to a small-scale fluctuation including individual rainfall events, whereas deeper regional scale, and semi confined aquifers such as the Hawkesbury Sandstone often show trends that are more aligned to the large-scale variations.

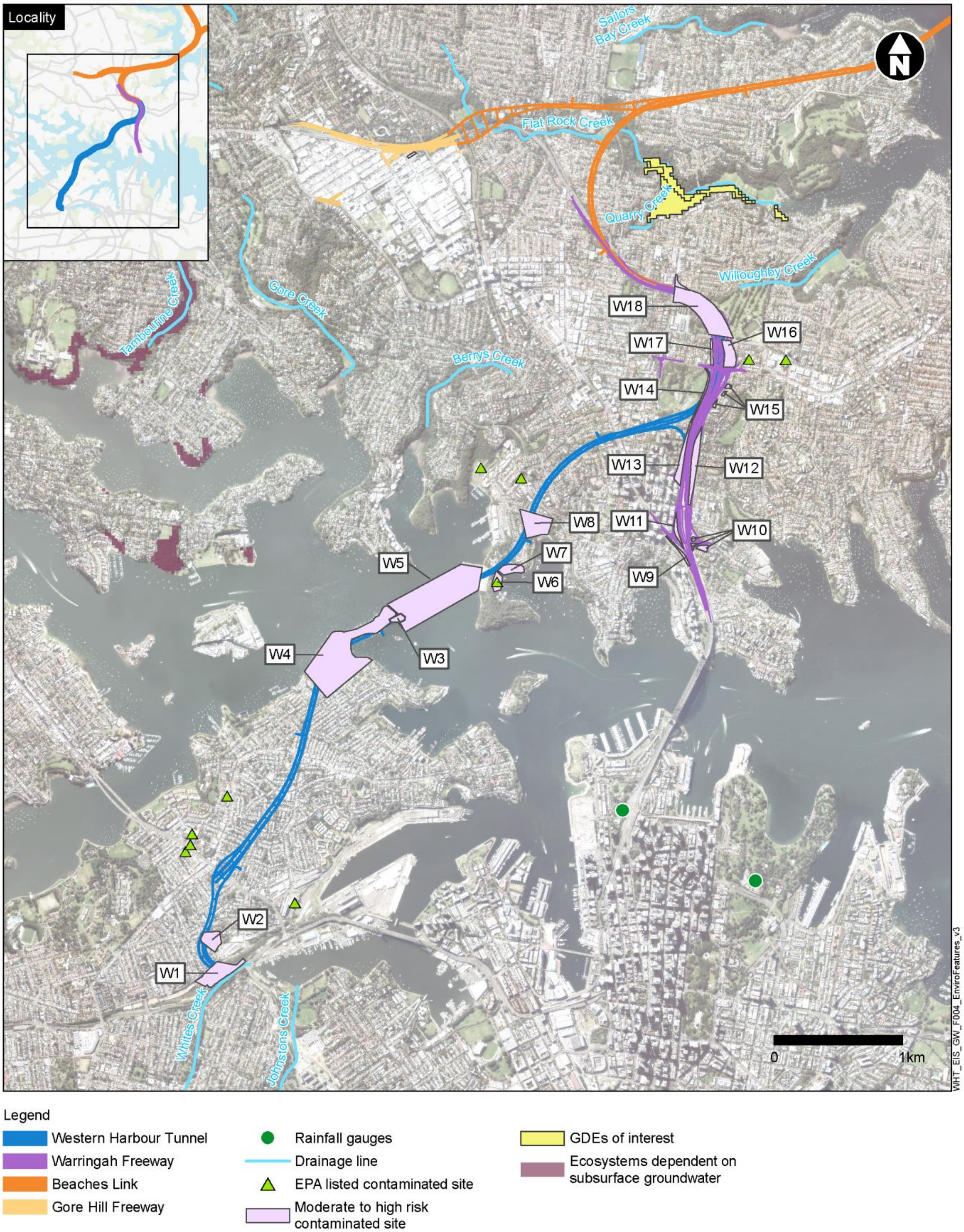


Figure 5-1 Project alignment and environmental features

Table 5-1 Rainfall record and reliability

Station	Rainfall record	Number of years of incomplete data (excluding 2017)
066006 (Botanic Gardens)	133 years (1985 to present)	14 (10.5%)
066062 (Observatory Hill)	160 years (1858 to present)	1 (0.6%)
066184 (Mosman Council)	22 years (1984 to 2007)	12 (54.5%)

Table 5-2 Average rainfall (mm)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
066006	103.6	113.2	134.5	123.1	120.8	135.4	98.2	86.4	68.6	75.2	85.2	82.2	1230.7
066062	102.2	117.6	130.9	128.5	118.6	133.2	97.1	81.1	68.4	76.4	83.8	77.6	1215.7
066184	110.3	139.4	95.7	147.6	123.3	122.8	77.4	76.1	63.0	79.6	111.0	91.8	1231.5

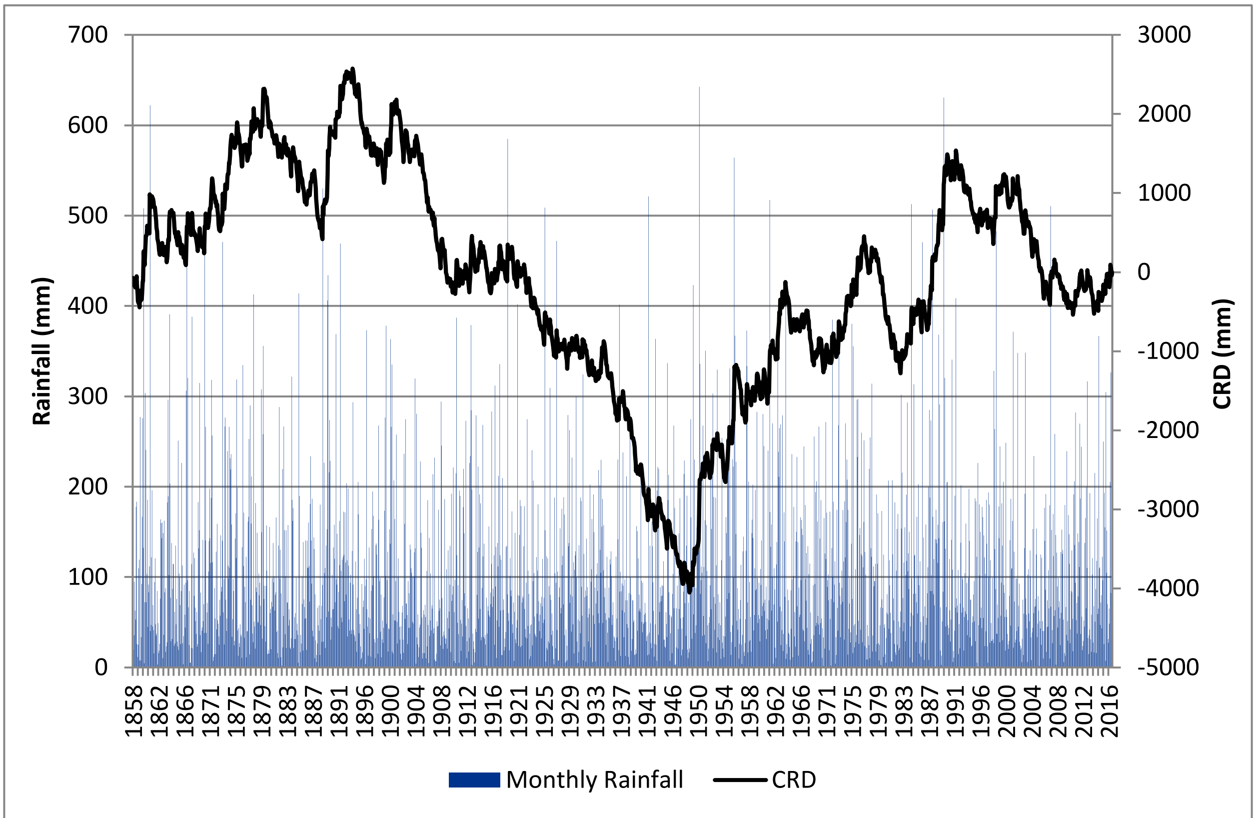


Figure 5-2 Observatory Hill (BOM Station 66062) rainfall

Temperature and evapotranspiration data for Observatory Hill (BOM Station 66062) are provided on Table 4-3. Temperature is available for the same period as rainfall (1958 to present), while evapotranspiration data is only available from 2009.

Mean daily evapotranspiration ranged from 0.7 millimetres in June to 4.3 millimetres in January. Average annual evapotranspiration for the monitoring period is 2.6 millimetres per day or 949 millimetres per annum.

Table 5-3 Temperature and evapotranspiration - Observatory Hill (BOM Station 66062)

Record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Max Temp (°C)	26.0	25.8	24.8	22.5	19.5	17.0	16.4	17.9	20.1	22.2	23.7	25.2	21.8
Mean Min Temp (°C)	8.7	18.8	17.6	14.7	11.6	9.3	8.1	9.0	11.1	13.6	15.7	17.5	13.8
ET (mm)	4.3	3.6	2.8	1.9	1.1	0.7	0.8	1.4	2.3	3.3	4.0	4.5	2.6

5.2 Topography and drainage

Topography and drainage within the project area are presented on Figure 4-3. The main bodies of water relevant to the project are Middle Harbour and Sydney Harbour which are tidally influenced estuaries. The project alignment has one harbour crossing at the Sydney Harbour.

Drainage channels traversing the project footprint are typically highly modified, predominantly concrete lined channels, particularly within the upper reaches, and while having little ecosystem value they provide stability during stormwater overflows.

Willoughby Creek has a semi-natural channel morphology within sections where the presence of bedrock has negated the need for channel stabilisation initiatives, with soil banks present for a small section behind Primrose Park at Cremorne.

At the southern extent of the project alignment is Whites Creek. The complete length of Whites Creek has been modified and the creek is now a stormwater drain with buried pipes in the upper reaches and open concrete channel for the lower one kilometre before discharging to Rozelle Bay. Sydney Water have proposed to naturalise a 420 metre section of Whites Creek from around 200 metres upstream of the outlet at Rozelle Bay. The concept design (Sydney Water, 2016) shows that after the proposed naturalisation the watercourse would continue to have a concrete base and would therefore not interact with groundwater.

The Cammeray Golf Course stormwater storage dam is located next to the Warringah Freeway. The dam forms part of the North Sydney Storm Water Re-use Scheme and receives stormwater runoff from a 94-hectare catchment area which is then used for irrigation on the grass and playing fields at St Leonards Park.

5.3 Geology

The geology of the alignment is dominated by the Hawkesbury Sandstone of the Permo-Triassic age Sydney Basin. In elevated areas the Hawkesbury Sandstone is overlain by the Ashfield Shale of the Wianamatta Group. An intermediate formation between the Hawkesbury Sandstone and the Ashfield Shale, the Mittagong Formation, is sometimes identified but is not mapped along the project alignment. In places the Sydney Basin sediments have been structurally deformed including the presence of faults, dykes, and joint swarms. Geology along the alignment is presented in Figure 5-4 and summarised in Table 5-4.

Table 5-4 Geology along the project alignment

Age	Geological Unit	Description
Quaternary	Fill	Typically comprising waste, emplaced material and engineered fill with a high potential for contamination. Reclaimed land areas are generally located next to the harbour and include parkland, residential, industrial, and open space areas.
	Undifferentiated estuarine and alluvial sediments	Holocene and Pleistocene age, interbedded sands and clays with discontinuous ‘inter-fingered’ lenses of sand and clay. May contain zones of colluvium. May be present as palaeochannel infill deposits.
	Marine sediments	Pleistocene age, primarily clayey sediments with intermittent sand lenses. Possibly containing gas, fissured.
Jurassic	Igneous Intrusion	Dykes
Mid-Triassic	Ashfield Shale	Consists of four variable thickness sub-units of siltstone and laminate.
	Mittagong Formation	Fine grained sandstone, and inter-bedded sandstone/siltstone.
	Hawkesbury Sandstone	Medium to coarse grained, quartzose sandstone. A combination of highly cross-bedded and massive sandstone units with interbedded siltstone.

Source: WSP (2016); AECOM (2015)

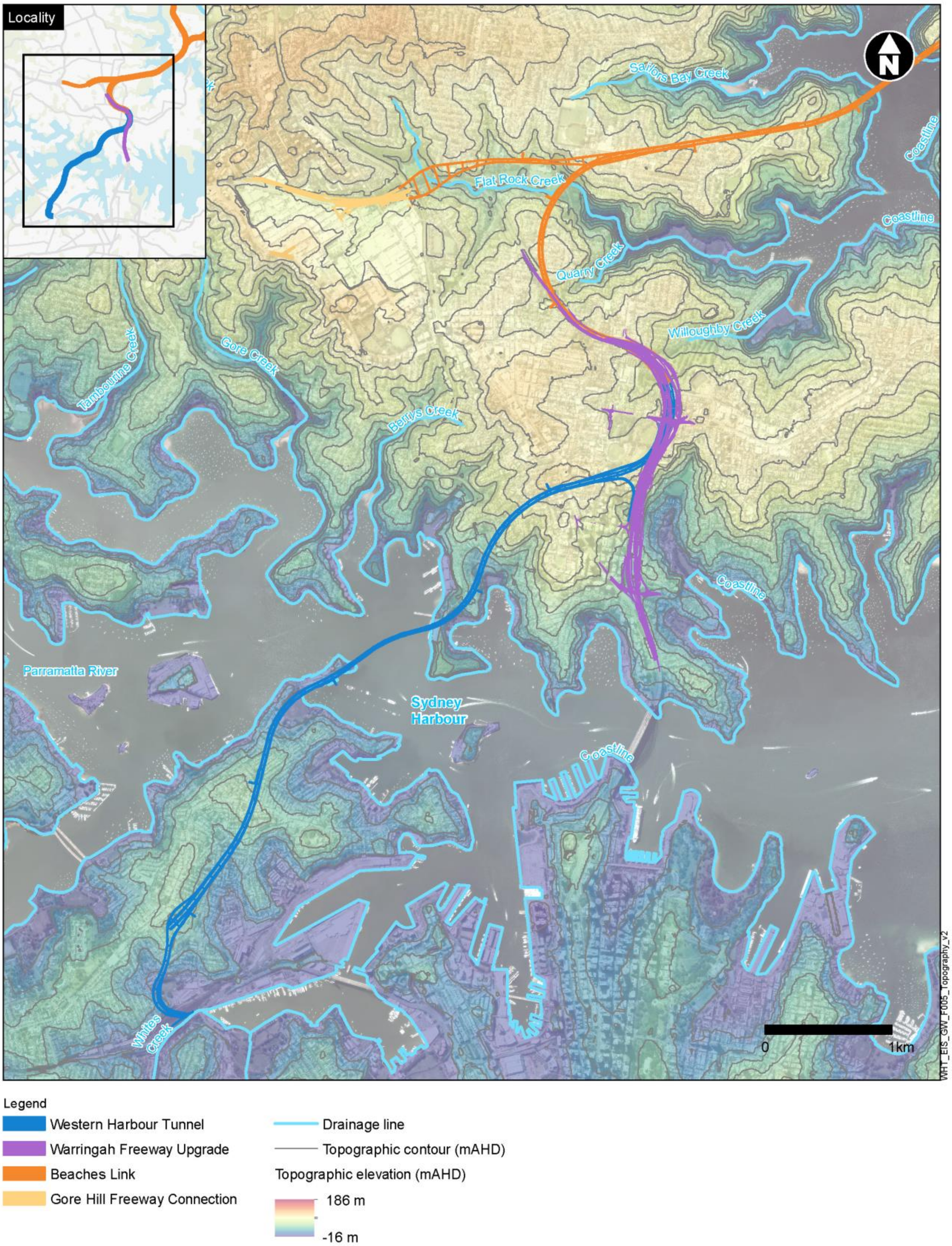


Figure 5-3 Topography and drainage

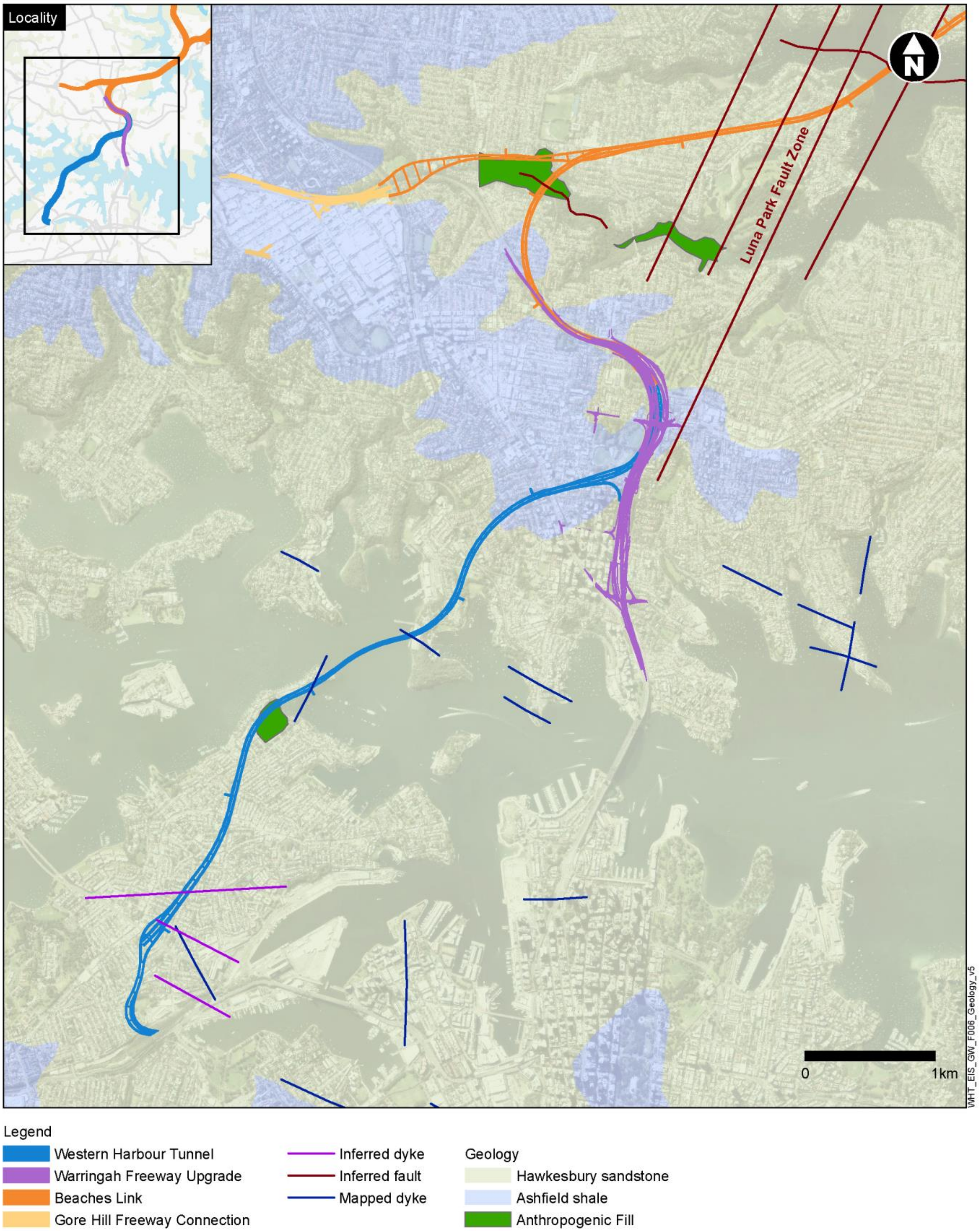


Figure 5-4 Geology along the project alignment

5.3.1 Anthropogenic fill material

In general, a thin layer of fill (less than one metre thick) is commonly encountered in urban areas and is associated with minor modifications to the topography, landscaping and pavement construction. Such fill can be highly variable in composition and compaction.

Thicker deposits of fill are expected towards the mouths of the infilled channels associated with land reclamation, back-filled quarries, landfills, stream capture and urban development in these areas. There is little fill along the Western Harbour Tunnel and Warringah Freeway Upgrade alignments, with occurrences in the vicinity of Whites Creek and at Birchgrove Park. Small areas of fill are also located at Mort Bay Park just east of the project alignment at Birchgrove, and Badangi Reserve just west of the alignment at Waverton.

5.3.2 Palaeochannels

The occurrence of infilled palaeochannels or palaeovalleys is generally limited to beneath the main harbour areas. Some smaller occurrences of palaeochannel-style deposits or basal sands may occur in the larger onshore drainages such Whites Creek. The deeper sediments within the main palaeovalleys are inferred to be of Pleistocene age.

Experience from previous tunnel projects in Sydney indicates that palaeovalleys are critical in tunnel design because the rock mass beneath palaeovalleys is often more structurally complex due to the association with geological structures such as faults and dykes and valley stress relief. Additionally, they can store and transmit large volumes of surface and groundwater resulting in increased groundwater inflow into tunnels and deep excavations.

Palaeovalley geometry along the project alignment is variable and generally increases in width and depth towards the palaeovalley axes in Sydney and Middle Harbours extending to a maximum depth of 85 metres below sea level near South Head at the entrance to Sydney Harbour.

5.3.3 Jurassic Volcanics

Jurassic basaltic dykes intrude the shale and sandstone formations of the Sydney Basin. The dyke orientations are generally consistent with the main structural orientations and typically strike in two dominant directions: either between 90 and 120 degrees or between five and 35 degrees. The dykes are of variable thickness ranging from less than three metres to up to 16 metres wide (AECOM, 2015). Dykes typically act as a hydraulic barrier perpendicular to their orientation and can result in partitioning of groundwater. Dykes can also have elevated permeability parallel to strike resulting from jointing and alteration related to the original intrusion and subsequent weathering. As such they can present a risk to tunnelling. If unmanaged, dykes can result in a potentially hazardous situation as tunnelling through a depressurised aquifer can break through the dyke to encounter a fully pressurised formation. Dykes may also provide a conduit for higher groundwater inflows, especially when in proximity to open water bodies such as Sydney Harbour.

Dykes are known to cross the project alignment at Balls Head, while another dyke also runs parallel with the alignment at Yurulbin Park. Other known dykes are projected to intercept the alignment at Waverton and Rozelle. It is also likely that numerous other unidentified dykes would be encountered. It is difficult to map poorly defined outcrops in an urban environment and therefore the frequency of the occurrence of dykes along a linear feature is difficult to assess.

5.3.4 Ashfield Shale

The Ashfield Shale consists of marine deposits made up of clay, silt and sand that has been mildly deformed and has developed into a laminated shale. It is generally a dark grey to black siltstone/mudstone or laminate (thin alternating layers of siltstone and sandstone). In some parts the shale may become carbonaceous with variable silt and clay particles throughout. The shale grades upwards into partly carbonaceous silty shale with siderite nodules and ironstone bands. The unit is laminated although retains bedding planes at some locations. Structural defects are present in the shale such as faults, fractures and shears (AECOM, 2015).

The Ashfield Shale is only present along the project alignment at ridgelines and outcrops around the area of the Pacific Highway. The Warringah Freeway cuts through the Ashfield Shale, exposing the underlying Hawkesbury Sandstone at Cammeray (refer to Figure 5-4).

Where it outcrops, the shale typically weathers to a stiff to hard clay with medium to high plasticity and the weathered profile generally ranges from three metres to 10 metres in depth. However, it has been noted to reach depths greater than 40 metres in former brick pits (AECOM, 2015).

5.3.5 Mittagong Formation

The Mittagong Formation is composed of a series of interbedded dark shale and sandstone of varying thicknesses and is the unit of change from the Ashfield Shale and underlying Hawkesbury Sandstone.
The shale beds are very similar to the Ashfield Shale, though it is typically no more than 0.5 metres thick while the sandstone beds are up to five metres thick and are fine to medium grained and contain more silt than the Hawkesbury Sandstone (AECOM, 2015). Due to its reduced thickness, the Mittagong Formation rarely outcrops across the Sydney Basin and has been identified to occur at the contact between the Ashfield Shale and Hawkesbury Sandstone in the project area at North Sydney, Crows Nest and Cammeray.

5.3.6 Hawkesbury Sandstone

The Hawkesbury Sandstone was deposited in a fluvial paleo-environment, likely to have been a braided river setting, and as such is highly stratified. The sandstone is ubiquitous across the Sydney Basin and is up to 290 metres thick. The majority of excavations for the Western Harbour Tunnel and Warringah Freeway Upgrade would be within the Hawkesbury Sandstone unit.

Hawkesbury Sandstone is often described as medium to coarse grained and consists of three main depositional environments, namely: massive sandstone facies; cross-bedded or sheet facies; and shale/siltstone interbedded facies. The sheet facies make up about 70 per cent of the unit with primary beds that range in thickness from less than 0.5 metres to greater than five metres but generally occur between one to two metres. Secondary structural features such as joints, fractures and faults are also present.

The sandstone weathers to a clayey sandy soil, typically up to one to two metres in depth. Within the upper ten metres of the profile a duricrust may be present where iron cementation has caused the development of ferricrete or coffee rock, or similarly silica cementation may cause the development of silcrete. Deep orange and red coloured iron staining is characteristic of the Hawkesbury Sandstone that can be concentrated along water bearing fractures and discontinuities (AECOM, 2015).

5.3.7 Structural geology

5.3.7.1 Bedding

Bedding surfaces in the Hawkesbury Sandstone in this part of the Sydney Basin typically dip gently toward the south at up to five degrees (locally up to 10 degrees). Local increases in dip are generally associated with depositional channel structures. Minor siltstone bands or siltstone breccia zones frequently occur in the base of these channel structures. Primary bedding planes are generally spaced between 0.5 and three metres and may be tight to open. Bedding related structures can include clay infills, crushed seams, in-situ weathering, iron-staining and limonite coating (AECOM, 2015).

Laboratory testing has shown that the cross-bedded or sheet facies do not usually represent planes of weakness in fresh or slightly weathered rock. However, in moderately to highly weathered sandstone the cross beds can form surfaces of incipient parting or low shear strength. Both bedding and cross bed partings in the

Hawkesbury Sandstone are typically planar to undulating and rough on a small scale with occasional clay, carbonaceous or mica films and infills (AECOM, 2015).

5.3.7.2 Faults

Figure 5-4 shows the main known structural features in the project area. Within the Sydney region there are four major north to northeast striking fault zones, with the Luna Park Fault Zone being of most significance to the project. Fault zones generally present as joint swarms or brecciated zones and often have associated gauge development. The fault zones have had an important influence on geomorphological development.

These structural features have been recorded at numerous locations within the Sydney Basin and are generally continuous, mappable and relatively predictable, although not always uniformly linear across the Sydney Region (Och et al, 2009).

The Luna Park Fault Zone has been shown to comprise up to three metres wide crushed zones with closely spaced jointing and faulting. The faulting shows normal and reverse movement, as well as strike-slip offset. Extensions of this fault have been identified at stages along a five kilometres strike length. Other occurrences have been identified at Walsh Bay, Darling Island, Star City Casino and Camperdown to the south and Anderson Park to the north (AECOM, 2015).

Joint spacing varies according to stratigraphy, proximity to near-surface weathering and proximity to major geological structures. Assessment of a more regional spread of geotechnical data, from projects such as Sydney Metro North West (previously known as North West Rail Link), WestConnex M4-M5 Link and Sydney Metro City & Southwest, indicates that jointing within the Hawkesbury Sandstone is typically extremely widely spaced (two metres to up to six metres) with zonal occurrences that are usually moderately widely spaced (60 millimetres to 200 millimetres). More widely spaced jointing of up to 25 metres also occurs (AECOM, 2015).

Localised areas of sub-vertical joints may also occur, especially for the north-northeast striking set, with spacing from 0.1 metres to 0.5 metres (eg Luna Park Fault Zone, Martin Place Joint Swarm and General Post Office [GPO] Fault Zone). These localised areas are often associated with preferential groundwater flows, deeper weathered profiles and some discrete faulting and brecciation and have a greater vertical continuity than the general population of joints.

Faults, as with dykes, present risks to tunnelling (from a construction workplace health and safety risk perspective) in that they can act as conduits or as barriers to groundwater flow. Groundwater may exploit these enhanced flow zones and present elevated inflows, or a sudden in-rush potential where barriers to flow, and depressurisation, are penetrated.

Tunnelling itself can enhance, or exacerbate, the inherent permeability of joints or brecciated zones through stress relief and dilation.

5.4 Soils

Soils along the project alignment have been identified from the Soil Landscapes of the Sydney 1:100,000 Sheet (Chapman and Murphy, 1989) and are presented in Figure 5-5.

Residual soils derived from Hawkesbury Sandstone are generally of sandy clay or clayey sand compositions that provide limited resistance to natural erosion. As such, the residual soil profile formed from exposed Hawkesbury Sandstone is generally of limited depth (typically less than about two metres) and are frequently absent or very shallow. The extent of Hawkesbury Sandstone derived soils (ie Gymea and Hawkesbury soil types) is extensive within this project area, occurring from Rozelle to North Sydney.

Residual soils derived from the Ashfield Shale (ie Blacktown soil type) are generally medium and high plasticity clays. These clay soils are more resistant to erosion, and regionally are typically present to depths of three to four metres, and locally up to about 10 metres. Residual soils derived from Ashfield Shale are limited to the North Sydney/ Cammeray area.

The characteristics of the major soil types identified along the alignment soils are summarised in Table 5-5.

Table 5-5 Soil characteristics

Soil Type	Landscape	Characteristics
Gymea	Undulating to rolling rises and low hills on Hawkesbury Sandstone with slopes between ten and 25 per cent and local relief up to 80m. Broad convex crests with moderately inclined slopes and wide benches can be expected within this landscape.	Shallow to moderately deep (30–100cm), on undulating to rolling rises and low hills on Hawkesbury Sandstone. Limitations of this soil landscape include localised steep slopes, high soil erosion hazards, shallow highly permeable soil and very low soil fertility.
Lambert	Undulating to rolling rises and low hills on Hawkesbury Sandstone. Local relief 20-120m, and slopes to slopes 20 per cent. Rock outcrop typically greater than 50 per cent. Broad ridges, gently to moderately inclined slopes, wide rock benches with low broken scarps, small hanging valleys and areas of poor drainage. Open and closed heathland, scrub and occasional low eucalypt open-woodland.	Shallow (<50cm) discontinuous earthy sands and sandy yellow earths on crests and insides of benches; shallow (<20cm) siliceous sands/lithosols on leading edges; shallow to moderately deep (<150cm) leached sands, grey earths, and gleyed podzolic soils in poorly drained areas; localised yellow podzolic soils associated with shale lenses.
Blacktown	Gently undulating rises on Wianamatta Group shales, with slopes less than five per cent and local reliefs up to 30m. Broad rounded crests and ridges with gently inclined slopes can be expected within this landscape.	Strongly acidic and hard setting, and have low fertility, high aluminium toxicity, localised salinity and sodicity, low wet strength, low permeability, and low available water holding capacity. These soils are considered to have a high capability for urban development and require appropriate foundation design if this occurs.
Disturbed terrain	Level plain to hummocky terrain extensively disturbed by human activity by complete disturbance, removal or burial of soils. Slopes are typically less than five per cent and local relief less than ten metres. Landfilling with soil, rocks, building and waste material can be expected within this landscape.	Cap of sandy loam over compacted clay or waste materials and may by strongly acidic to strongly alkaline. Some limitations include low fertility, low wet strength, low availability water capability, high permeability, localised toxicity/acidity and/or alkalinity. These soils are considered a potential mass movement hazard depending on nature of fill material.
Hawkesbury	Rugged, rolling to very steep hills on Hawkesbury Sandstone, with slopes greater than 25 per cent and local reliefs up to 200m. Narrow crests and ridges, narrow incised valleys with steeped sided slopes can be expected within this landscape.	Shallow (<50cm) discontinuous lithosols/siliceous sands associated with rock outcrops, with earthy sands and some yellow podzolic soils on the inside of benches and along rock joints and fractures. Limitations are described as extreme soil erosion hazard, mass movement hazard and steep slopes.

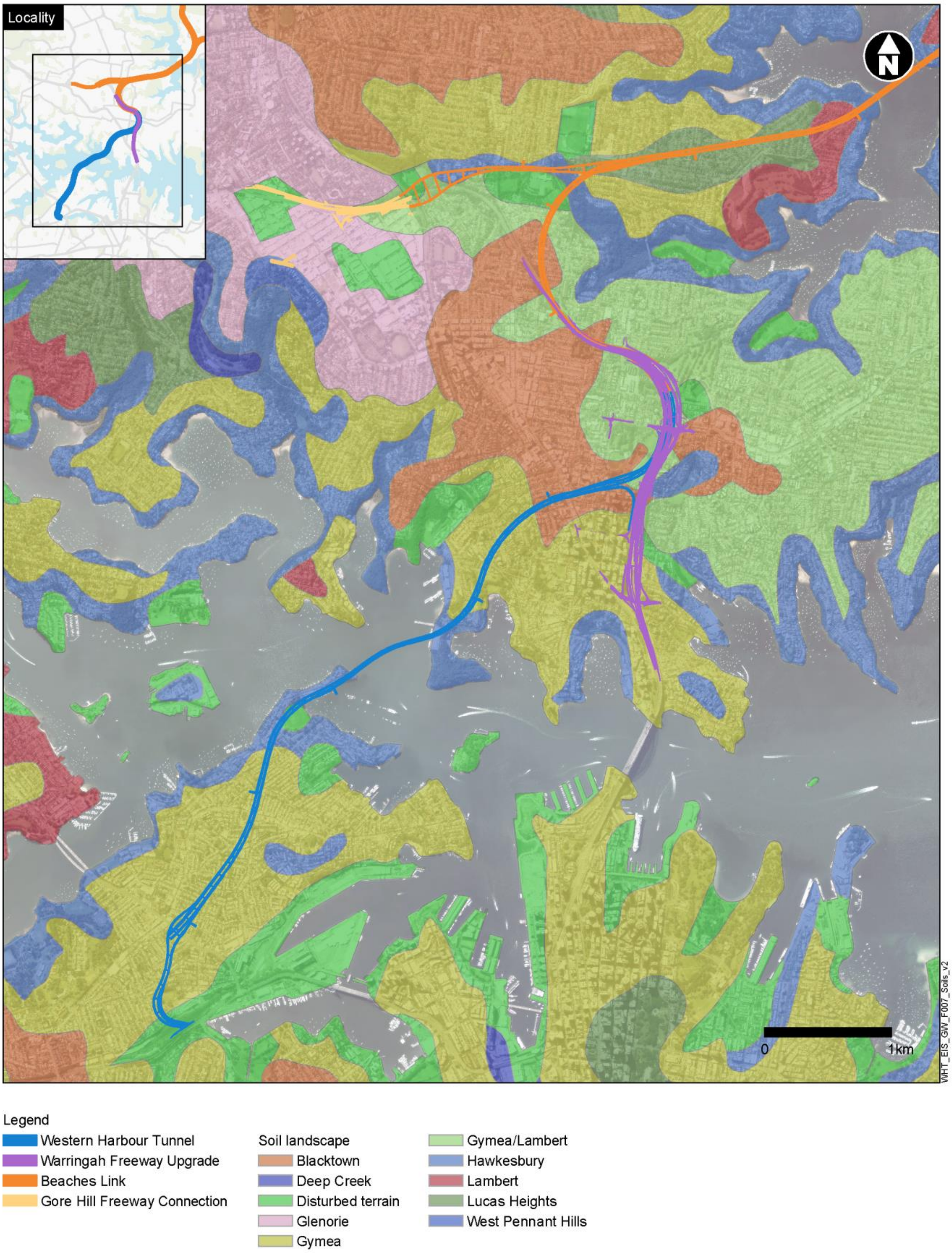


Figure 5-5 Soils along the project alignment

5.4.1 Acid sulfate soils

Acid sulfate soils (ASS) are naturally occurring soils, commonly associated with low lying areas of fine grained sediments and typically occurring in lacustrine, estuarine, or swamp-type environments.
Sediment accumulations within the harbours would also have an elevated risk of ASS. For acid sulfate soils to exist, the soils need to be saturated (anoxic) and contain sulfide minerals, the most common of which is pyrite. Disturbing ASS and exposing it to oxygen results in sulfide oxidation and acidification that can have environmental and flow-on impacts. Acidification of groundwater can result in the mobilisation of arsenic and heavy metals previously bound in the aquifer formation. Potential impacts of acidification and mobilisation of heavy metals include:

- Increased toxicity and loss of biodiversity in wetlands and waterways
- Groundwater contamination
- Reduced agricultural productivity
- Corrosion of concrete and steel infrastructure.

Acid drainage can also occur from hard rock formations that contain sulfide minerals, such as are likely to be present in the black shale units of the Ashfield Shale, and possibly in some finer grained units of the Hawkesbury Sandstone.

Acid sulfate soils (ASS) risk maps from the CSIRO Australian Soil Resource Information System (ASRIS) database were reviewed to ascertain the probability of ASS being present across the project area. The ASS risk maps classify the risk of encountering ASS and, where previously identified, map actual acid sulfate soils (AASS). Based on this information, the generalised ASS probability across the project area has been assessed as follows:

- Lilyfield to Snails Bay – B3 low probability/low confidence
- Balls Head to Crow's Nest – C4 extremely low probability/very low confidence.

A review of the ASS risk maps from the *Leichhardt Local Environmental Plan 2013* indicated that the project is located within areas of predominantly Class 5 ASS risk with isolated areas of Class 1 (Rozelle Rail Yards) and Class 2 (Birchgrove Park) ASS risk (unclassified). The *North Sydney Local Environmental Plan 2013* does not contain ASS risk maps.

Land next to watercourses, such as Whites Creek, are identified as having a high probability of being acid sulfate soils.

Acid sulfate soils risks along the project alignment are presented in Figure 5-6.

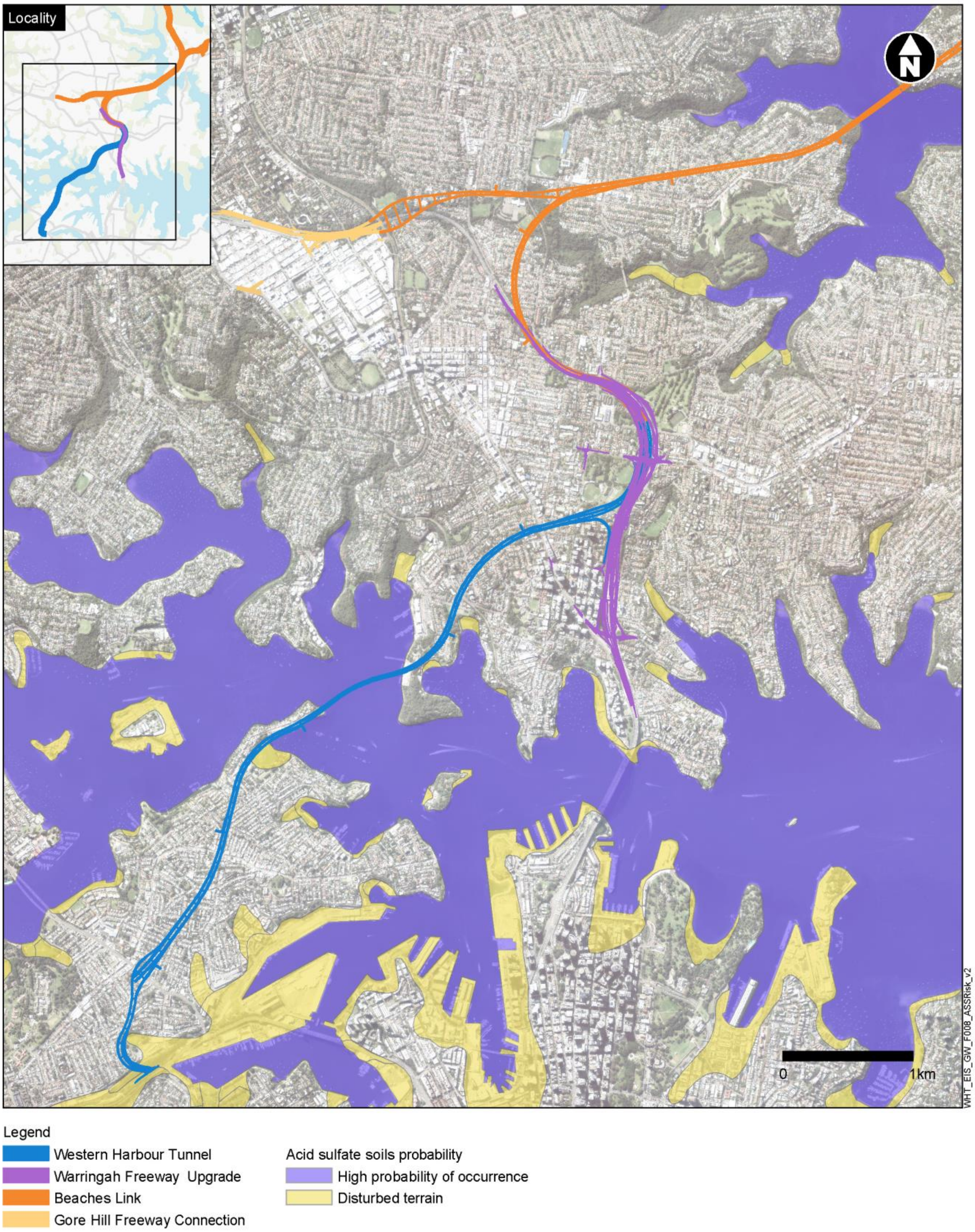


Figure 5-6 Acid sulfate soil risk

5.5 Hydrogeology

For the most part, tunnel excavation would occur through the Hawkesbury Sandstone, although some construction in the Ashfield Shale is expected around the Warringah Freeway at the northern end of the Western Harbour Tunnel (refer to Figure 5-4). At the Sydney Harbour crossing, the project tunnels comprise immersed tubes with submarine excavation of the harbour and Pleistocene sediments.

Localised fill and or Quaternary sediment may occur overlying the project alignment. Key occurrences that may influence or be influenced by the project tunnels are at Birchgrove Park, Waverton Park and Whites Creek. This section describes the hydrogeological units and aquifer/aquitard properties that are likely to be encountered during tunnel excavations.

5.5.1 Groundwater occurrence

The most extensive aquifer in the project area is the Hawkesbury Sandstone aquifer, which is up to 250 metres thick in the Sydney region and outcrops over most of the project alignment. The sandstone is an unconfined aquifer at surface and may become increasingly confined with depth due to the highly-stratified nature of the formation. Some units within the Hawkesbury Sandstone can exhibit remnant primary porosity, however, groundwater movement is typically controlled by secondary permeability and bedding.

The Hawkesbury Sandstone has a highly variable hydraulic conductivity, typically in the range 10^{-3} to 10^{-1} metres per day. The highly-stratified nature of the sandstone and the presence of interbedded shales can also result in multiple aquifer and aquitard zones within the sandstone.

The Hawkesbury Sandstone is overlain in places by the finer grained unit of the Ashfield Shale and Mittagong Formation which are generally considered to be aquitards, however, secondary permeability can exist. When highly fractured, the hydraulic conductivity of the Ashfield Shale can be higher than in more uniform massive shale, but as it weathers to clay, it remains a very low conductivity material and as such behaves as an aquitard.

Unconsolidated alluvial materials, of Quaternary and Holocene age, occupy palaeo-topographic depressions in the underlying bedrock surface. The alluvial materials are predominantly composed of silty to peaty quartz sand, silt and clay, and where saturated, can comprise localised unconfined aquifers.

Due to the highly-developed nature and history of the project area, some of the site is overlain by man-made fill. This can act as a water-bearing unit supporting perched water systems but with very high variability and unpredictability. The hydraulic properties of the fill are determined by the materials used for the fill as well as how it was laid. Much like an alluvial layer, the fill is anticipated to behave as an unconfined aquifer or aquitard, and can potentially be a source of contamination, particularly if used for landfill and metropolitan waste.

The most significant areas of fill along the project alignment are at Birchgrove Park and Waverton Park where fill is noted as potentially containing harbour dredging debris comprising estuarine sand and mud, and demolition rubble, as well as industrial and domestic waste.

5.5.2 Groundwater levels and flow

The regional water table across the project area typically mimics topography and flows from areas of high topographic relief to areas of low topographic relief, ultimately discharging to the surface drainage features and harbour.

The depth to water table is highly variable and can range from close to ground surface in low lying areas and to 100 metres below ground surface at elevated ridgelines. Localised perched water tables may also occur, as well as multiple water tables resulting from the highly-stratified nature of the Hawkesbury Sandstone.

A composite water table contour map along the project alignment has been compiled and is presented in Figure 5-7. These contours have been created using monitoring data for the project, as well as water levels from the DPI Water Pinneena database, and water levels obtained from other nearby projects, including Sydney Metro, the M4-M5 Link, and the Northern Beaches Hospital upgrade.

The contours present a composite of water levels from various data sources and times and as such provide a general overview of key groundwater flow directions and trends along the alignment. Where available data is in time-series, average water levels have been applied.

The water level contours shown in Figure 5-7 confirm the general trend of the water table mimicking topography, with groundwater flow from elevated areas (recharge) toward the harbour and major drainages (discharge).

Deeper groundwater flow would be less controlled by topography and more influenced by the regional structure and stratigraphy of the Sydney Basin. Regional groundwater flow is inferred to be in an east to south-easterly direction towards Port Jackson and the Tasman Sea. There is also localised structurally controlled flow towards surface water features.

Monitoring bore hydrographs

Hydrographs from groundwater monitoring bores along the project alignment are provided in Figure 5-8, and bore locations are shown in Figure 4-2.

The hydrographs are presented as both elevations, in metres above Australian Height Datum (mAHD), and depths below ground level.

Groundwater elevations range from highs of about 68 mAHD at monitoring bore B150 in North Sydney and 37 mAHD at monitoring bore B133 at Waverton, to close to sea level near to the harbour areas. Monitoring bore B104A at Birchgrove Park shows a water level of about 1.5 mAHD while B131A, on the Birchgrove peninsula, fluctuates at around 0 mAHD. B131A also shows a strong tidal oscillation.

B105A, also located at Birchgrove Park, shows a water level that is below sea level. Following a period of fluctuation, B105A has stabilised at about 3 to 4 mAHD. This may be indicative of low permeability and slow recovery following bore development and purging. B105A shows a small scale tidal oscillation overprinted by larger scale fluctuations that are currently not explained.

Outside of induced fluctuations, due to purging, sampling, and development, monitoring bores B154 and B209 show gradual declining trends, while B104A, B105A, B131A, and B181A show trends of rising water levels. Responses to rainfall events are observed at a number of the monitoring bores. B112 shows the most pronounced rainfall response with smaller responses observed at B154 and B209.

Vibrating Wire Piezometers

Three vibrating wire piezometer installations (VWP) have been installed along the project alignment at the locations shown in Figure 4-1. The VWPs record pore water pressures at various intervals below ground and can provide insights into vertical hydraulic gradients and discretisation within the aquifer.

At time of writing, data was available for one VWP, B132. The VWP installation is summarised below, with the hydrographs presented in Figure 5-9.

B132 is located on Balls Head in proximity to Sydney Harbour. Four sensors are installed at 10.4, -8.9, -28.6, and -74.2 mAHD. The upper-most sensor, sensor 4 at 10.4 mAHD, is above the water table and unsaturated. Sensors 1 to 3 display a general lining trend that may be a long-term equilibration with natural formation pressure following installation, with the regression at the deepest sensor (VWP1) being most pronounced.

VWP 2 plots consistently lower than VWP 3, by around 0.5 metres, possibly indicating that it is actually installed shallower than recorded.

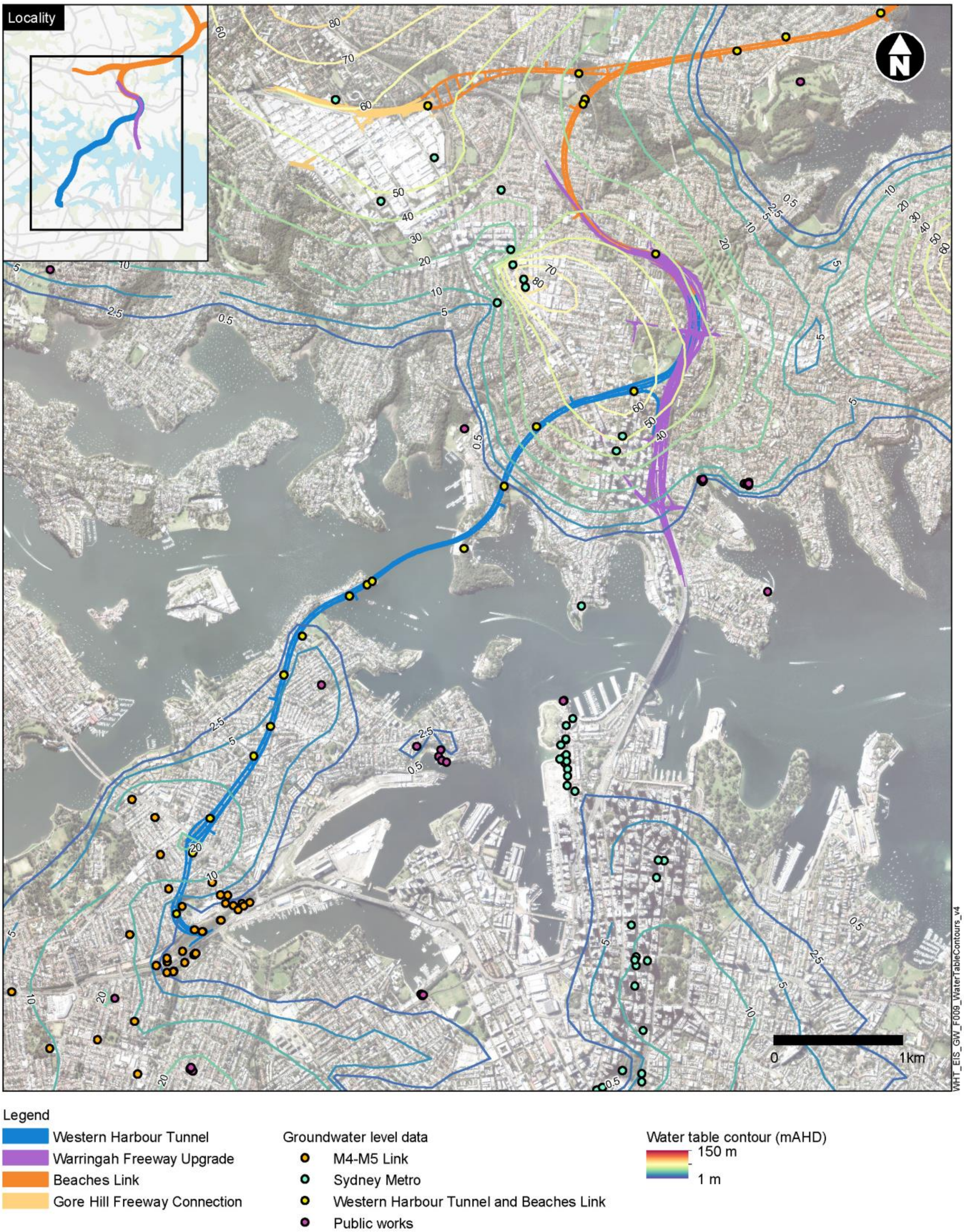
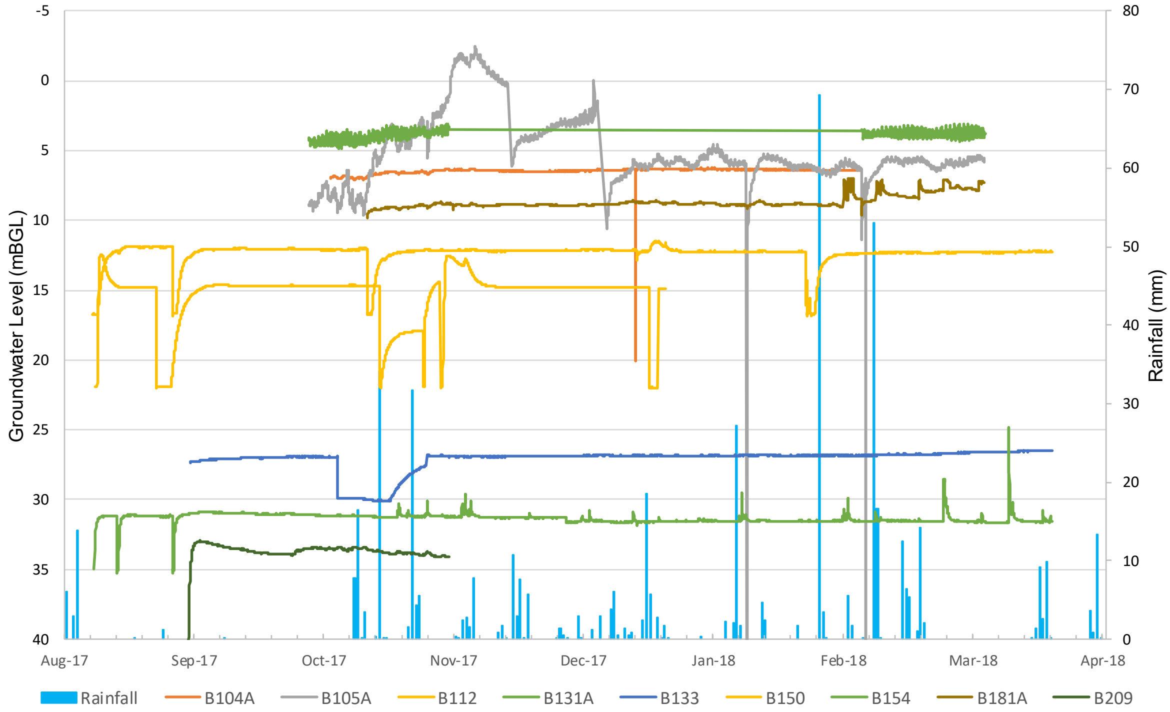


Figure 5-7 Composite water table contours



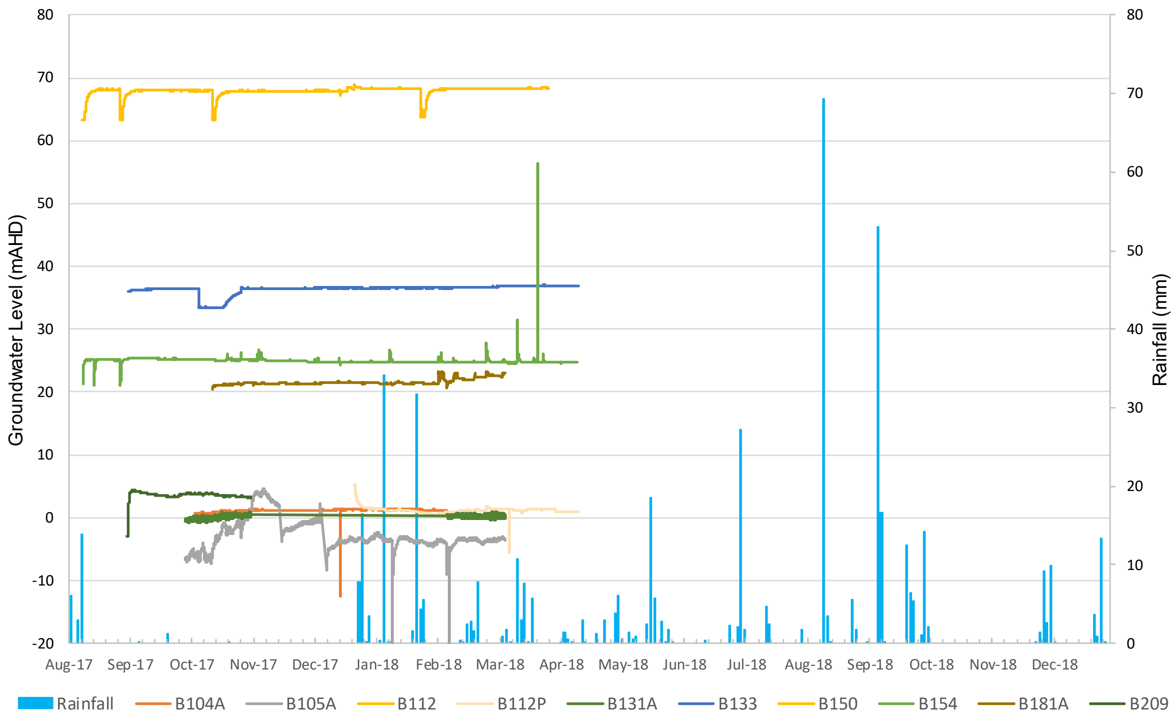


Figure 5-8 Monitoring bore hydrographs

The hydrographs show a strong tidal response implying direct hydraulic connection with the harbour. Tidal loading can also lead to such a response, however, given the proximity to Sydney Harbour and the enhanced hydraulic conductivity of the Hawkesbury Sandstone beneath and next to the Harbour (refer to Figure 5-14), it is considered that that there is direct hydraulic connectivity.

The amplitude of tidal fluctuations at VWP 2 is greater than at VWP 1 and 3, suggesting that VWP 2 is installed in a layer of locally higher hydraulic conductivity that is connected to either the harbour or harbour sediments. This is consistent with packer testing results which record an elevated permeability of 1.12 metres per day over this interval.

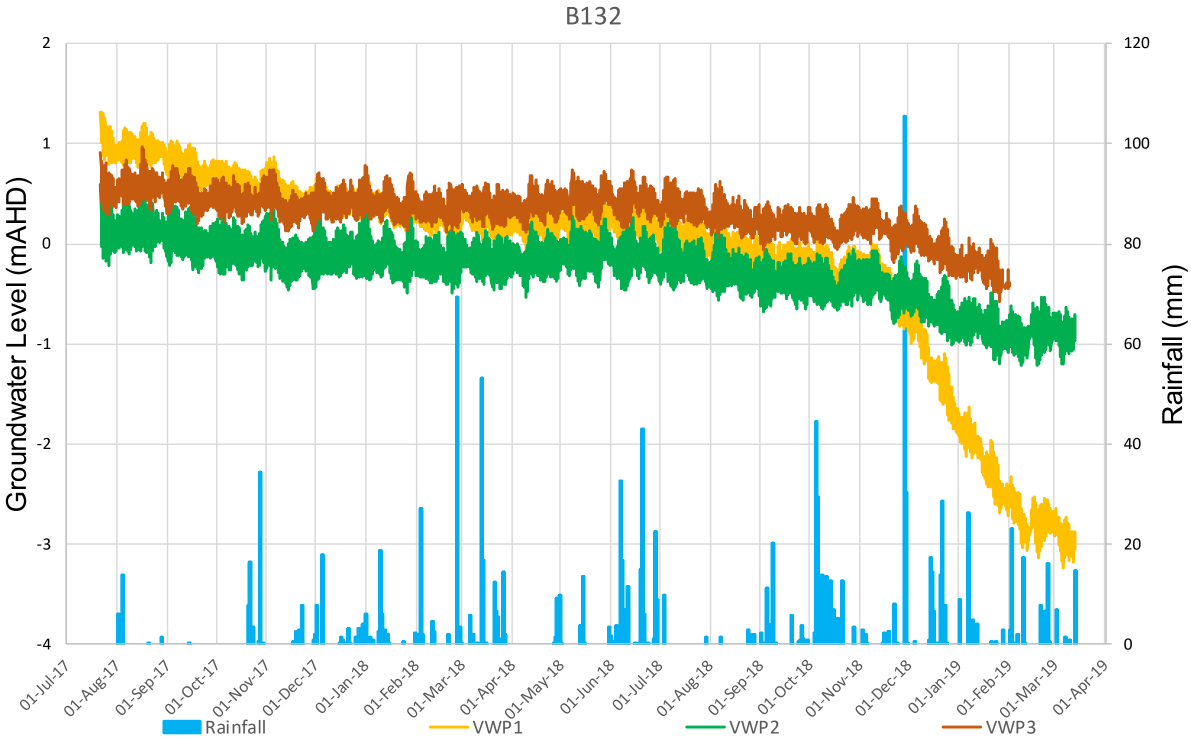


Figure 5-9 Vibrating Wire Piezometer hydrographs

5.5.3 Recharge and discharge

The primary recharge mechanism to the groundwater systems is direct rainfall infiltration. The proportion of net rainfall recharging the groundwater systems depends largely on the characteristics of the surface geology, soils, the land use and depth to the water table. Recharge is expected to be lower in areas where the surface is covered by shale and residual clays with a low hydraulic conductivity and specific yield. This leads to relatively low recharge rates compared to areas where Hawkesbury Sandstone outcrops.

Historically, the majority of groundwater recharge would have been via diffuse infiltration of rainfall over areas of Hawkesbury Sandstone outcrop/subcrop, and from runoff from water courses overlying the Hawkesbury Sandstone. Most of the area in the vicinity of the project alignment has been developed and contemporary groundwater recharge is reliant on areas of remnant vegetation, and park and grassed areas. In parks and playing fields recharge is often enhanced through irrigation. Enhanced recharge also arises from infiltration basins.

Given the hydraulic properties of the Hawkesbury Sandstone, highly stratified and typically of low bulk hydraulic conductivity, the groundwater response time for the system is likely to be measured in decades if not centuries. It is possible that, away from any major groundwater stresses, the groundwater system would still be equilibrating to the new urbanised recharge regime.

Groundwater discharge would be through outflow to the harbour and evapotranspiration in low lying areas. The evapotranspiration rate depends on land use and depth to groundwater. In areas where the water table is shallow and within the rooting depth of vegetation evapotranspiration can be a large component of the water balance.

Extraction of groundwater through existing bores in the project area may also be considered a mechanism of discharge from the groundwater systems. This is expected to be minor and is discussed in Section 5.5.6. Groundwater would also continuously drain into existing underground workings such as unlined tunnels.

Regional groundwater through-flow is also considered a discharge mechanism for groundwater systems in the project area, with regional groundwater flow inferred to be toward the east to south-east.

5.5.4 Hydraulic properties

The Hawkesbury Sandstone presents as a dual porosity aquifer with some remnant interstitial porosity, where not entirely overprinted by silicic and/or carbonate cementation. Secondary porosity is in the form of fracturing, which in turn can also be subject to infilling, either through mineral precipitation, or the chemical or mechanical development of clays and finer grained material. However, for the purposes of this groundwater assessment it is the bulk hydraulic properties, incorporating both primary and secondary permeability, that are of interest.

5.5.4.1 Hydraulic conductivity

Hydraulic conductivity is one of the key parameters that controls drawdown in response to tunnel inflows. Information on hydraulic properties is available from numerous previous tunnelling projects in the Sydney region that have included detailed field investigations, including permeability testing. Key tunnelling projects and associated permeability testing data are summarised in Table 5-6.

From Table 5-6 it is apparent that despite the Ashfield Shale being considered an aquitard relative to the Hawkesbury Sandstone, the range of horizontal hydraulic conductivity values derived from testing is very similar between the two formations, and, as shown from the New M5 and M4 East investigations, the Ashfield Shale and Hawkesbury Sandstone displayed identical median hydraulic conductivity values. From the M4-M5 Link, the maximum, and arithmetic mean hydraulic conductivity values of the Hawkesbury Sandstone were found to be an order of magnitude greater that the Ashfield Shale, while harmonic mean results return very similar values.

Table 5-6 Hydraulic conductivity values derived from other investigations (m/day)

Source	Ashfield Shale (m/day)	Mittagong Formation (m/day)	Hawkesbury Sandstone (m/day)	Method
WestConnex New M5 groundwater assessment (AECOM, 2015)	<0.0001 to 0.07 Median = 0.003 n = 6	<0.0001 to 0.9 Median = 0.01 n = 10	<0.0001 to 4.3 Median = 0.003 n = 205	Packer tests (n=221) Depth range 10 to 80m
Sydney Metro groundwater assessment (Jacobs, 2016)	<0.0086 to 0.05 n = 3 Depth range 12 to 29m	<0.0086 to 0.52 n = 15 Depth range 7 to 33m	<0.0086 to >0.86 n = 53 Depth range 12 to 46m	Packer tests (n=72)

Source	Ashfield Shale (m/day)	Mittagong Formation (m/day)	Hawkesbury Sandstone (m/day)	Method
North West Rail Link (Hewitt, 2005)	No data	No data	Mean (near surface) = 0.1 Mean (50 metre depth) = 0.002	Packer tests (n=363)
M4 East groundwater assessment (GHD, 2015)	0.00022 to 0.73 Median = 0.011 n = 75 Depth range 10 to 40m	No data	0.00043 to 1.7 Median = 0.011 n = 83 Depth range 10 to 50m	Packer tests (n=158)
M4 – M5 Link groundwater assessment (AECOM, 2017)	0.0086 to 0.12 Arithmetic Mean = 0.017 Harmonic mean = 0.010 n = 24	No data	0.0086 to 1.17 Arithmetic Mean = 0.1 Harmonic mean = 0.012 N = 181	Packer tests (n = 205)
Beaches Link and Gore Hill Freeway Connection*	No data	No data	*Land based* 4.0E-06 to 2.25 Mean = 0.053 Median = 0.001 *Marine* 1.4E-04 to 4.04 Mean = 0.187 Median = 0.017	Packer Tests (n=300)

Notes: n – number of tests. * - as reported in Appendix F. Groundwater Modelling Report

A regional analysis of packer test data carried out in the Hawkesbury Sandstone across the Sydney Basin by Tammetta and Hawkes (2009) indicated a trend of decreasing hydraulic conductivity with depth below ground surface which was attributed to less frequent fracture spacing and increasing lithostatic pressure with depth. Data from Tammetta and Hawkes are provided on Figure 5-10.

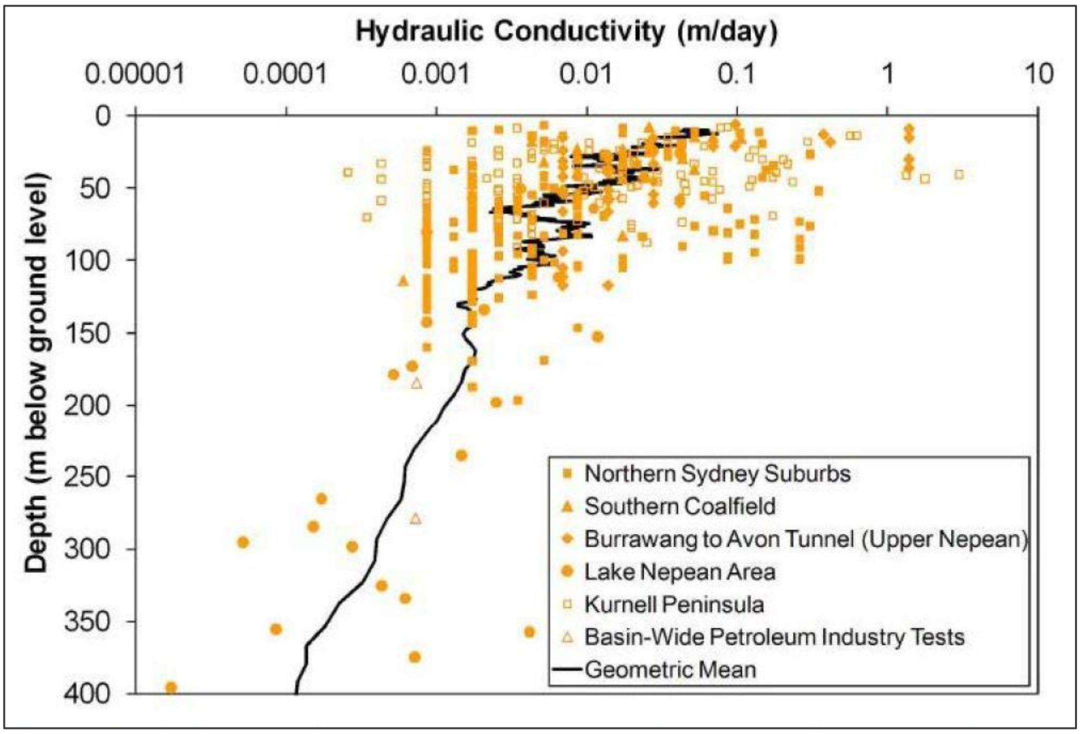


Figure 5-10 Tammetta and Hawkes (2009) hydraulic conductivity from packer testing in Sydney Basin

5.5.4.2 Project Permeability Testing

Packer testing to determine formation hydraulic conductivity was conducted on 74 individual boreholes across the combined Western Harbour Tunnel and Warringah Freeway Upgrade and Beaches Link and Gore Hill Freeway Connection projects, consisting of 491 individual packer tests. The majority of holes drilled were either in the Hawkesbury Sandstone, or overlying sediments or fill. A small number of holes were initiated in either the Ashfield Shale or Mittagong Formation, but these typically only comprised a thin veneer and were not subject to any permeability testing.

Packer testing results are summarised in Table 5-7, and the combined Western Harbour Tunnel and Warringah Freeway Upgrade and Beaches link and Gore Hill Freeway Connection permeability results are plotted against depth below ground level and harbour floor, and against elevation in Figure 5-11 and Figure 5-12. Details of packer testing test intervals and interpreted hydraulic conductivity values are provided in Appendix C.

Figure 5-11 and Figure 5-12 show the permeability results for the Hawkesbury Sandstone in the vicinity of the project to be highly variable, typically ranging from 0.0001 to 2 metres per day. From the results there appears to be an upper permeability bound that diminishes with depth and the results are consistent with those assessed by Tammetta and Hawkes (2009).

The cumulative distribution of packer testing results for land-based and marine-based packer tests are plotted on Figure 5-13. From Figure 5-13 it is apparent that the permeability results from the marine-based testing are typically 1 to 1.5 orders of magnitude greater that the land-based permeability values. This is inferred to reflect the increased occurrence and concentration of structure associated with the harbour areas.

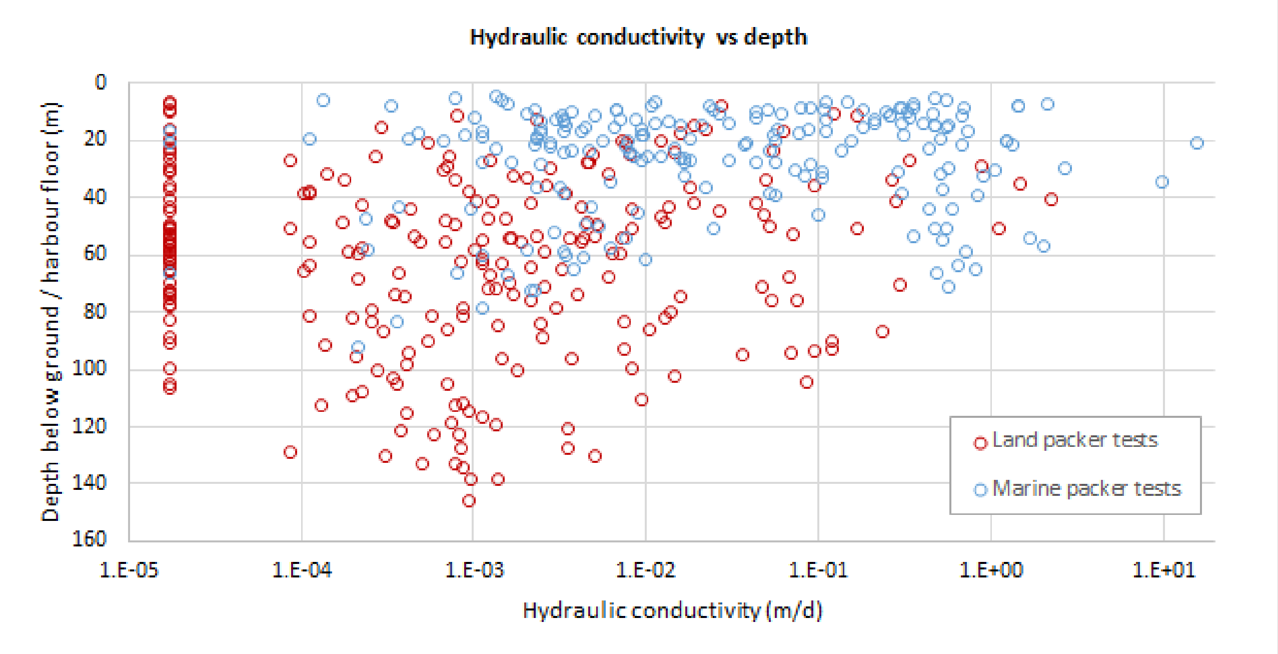


Figure 5-11 Hydraulic conductivity versus depth

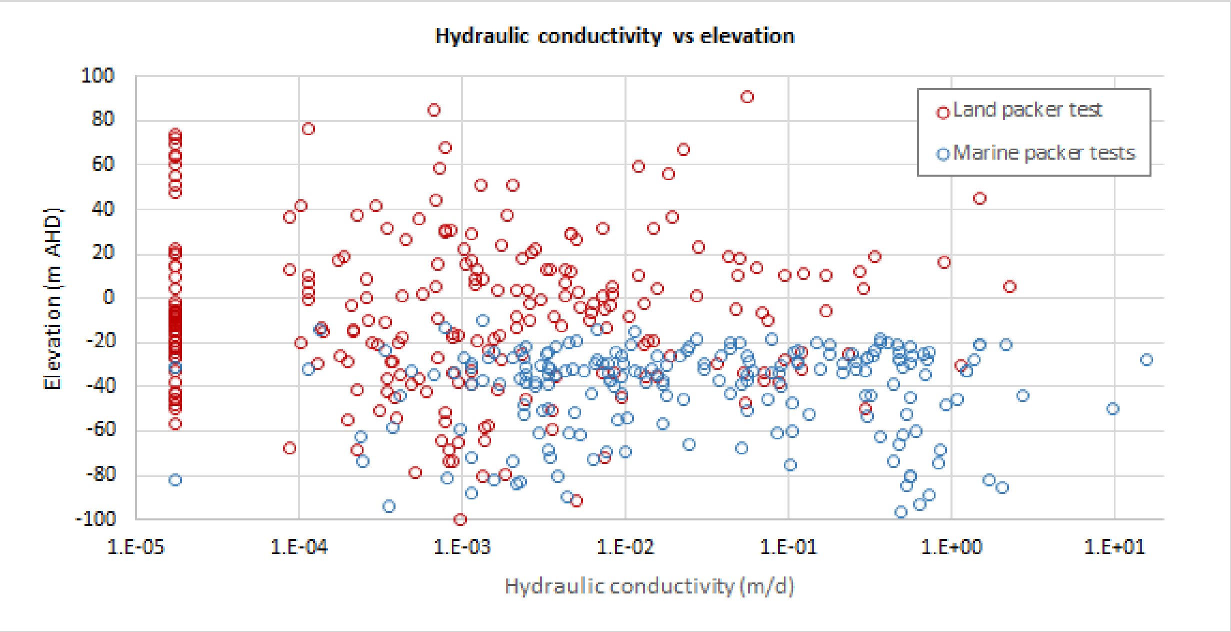


Figure 5-12 Hydraulic conductivity versus elevation

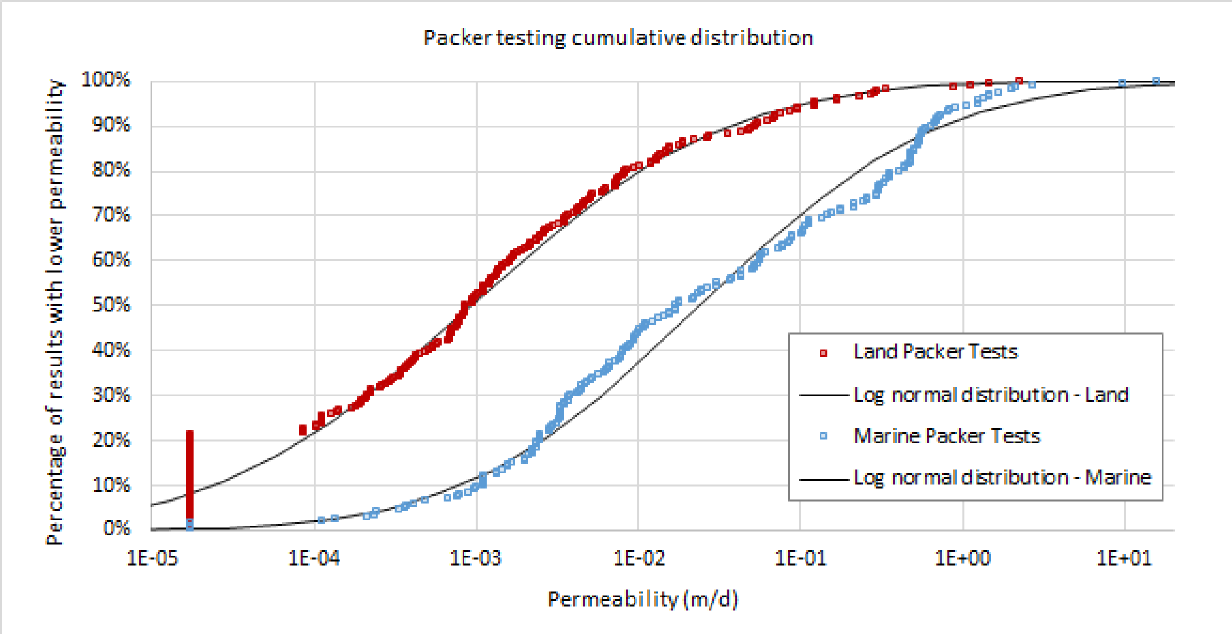


Figure 5-13 Packer testing cumulative distribution

Table 5-7 provides a summary of the packer testing carried out along the project alignment. Testing comprised a total of 49 land-based packer tests and 142 marine-based packer tests. A further 192 land-based packer tests and 108 marine-based packer tests were carried out for the Beaches Link and Gore Hill Freeway Connection project.

Table 5-7 Packer testing summary and hydraulic conductivity in the Hawkesbury Sandstone

Test Location	Number of tests	Minimum Hydraulic Conductivity (m/d)	Maximum Hydraulic Conductivity (m/d)	Mean Hydraulic Conductivity (m/d)	Median Hydraulic Conductivity (m/d)
All land based tests	49	1.1E-05	0.17	0.015	0.0012
Rozelle to Birchgrove	18	5.1E-05	0.05	0.006	0.002
Waverton	31	1.1E-05	0.17	0.021	0.001
Sydney Harbour marine	142	2.8E-05	15.72	0.454	0.026

Notes: to enable statistical analysis utilising all data, all packer tests that retuned results below the sensitivity of the equipment (1x109m/s or 8.64x10-5m/d) have been assigned a representative low hydraulic conductivity value of 2x10-10m/s (1.73x10-5m/d).

Comparison of mean and median hydraulic conductivity values indicate that the elevated mean values are being skewed by a small number of higher permeability results. The range of test results is significant and covers several orders of magnitude. The average hydraulic conductivity for the land-based Hawkesbury Sandstone is 0.015 metres per day compared to the median values of 0.0012 metres per day. As indicated by the cumulative distribution shown in Figure 5-13, the median marine hydraulic conductivity is an order of magnitude greater than the land based value. The derived hydraulic conductivity values are generally in agreement with the range of values from previous investigations as summarised in Table 5-6.

5.5.4.3 Permeability distribution and structural influence

Plots of packer testing results along the section of the Western Harbour Tunnel and Warringah Freeway Upgrade and Beaches Link and Gore Hill Freeway Connection alignments are shown in Figure 5-14. Also shown in Figure 5-14 are drilling water returns observed during the drilling of the holes. There is a close correlation between the areas of elevated permeability and the areas of water loss (low return). Areas of elevated permeability and water loss within the Hawkesbury Sandstone are inferred to be structurally controlled and primarily occur in the vicinity of the harbours and at Flat Rock Creek. Two secondary areas of elevated permeability also occur to the north of Sydney Harbour and Middle Harbour.

5.5.4.4 Sydney Harbour

The main structural zones, or areas of enhanced permeability along the project alignment, are nearby and underlying Sydney Harbour. This is to be expected as it is inferred that the underlying structural control has resulted in the palaeo-drainages in which the harbour is now located. The influence of structure on permeability in the harbour areas is also supported by the order of magnitude increase of mean hydraulic conductivities associated with the sub-harbour lithologies with respect to those away from the harbour, as indicated in Figure 5-13.

The average permeability derived from packer testing at Sydney Harbour was 0.45 metres per day, with a median value of 0.026 metres per day. A maximum hydraulic conductivity value of 15.7 metres per day was returned from testing at Sydney Harbour. One other inferred structural zone on the project alignment is associated with an ancillary structure located to the north of Sydney Harbour.

The elevated permeability to the north of Sydney Harbour, in the vicinity of Waverton Park, is not associated with any mapped structures. Borehole B221 returned elevated permeability results of the order of 0.12 to 0.16 metres per day between eight and 13 metres that are associated with shallow sandstone regolith beneath Waverton Park. The project alignment in this location is about 15 to 20 metres below ground level.

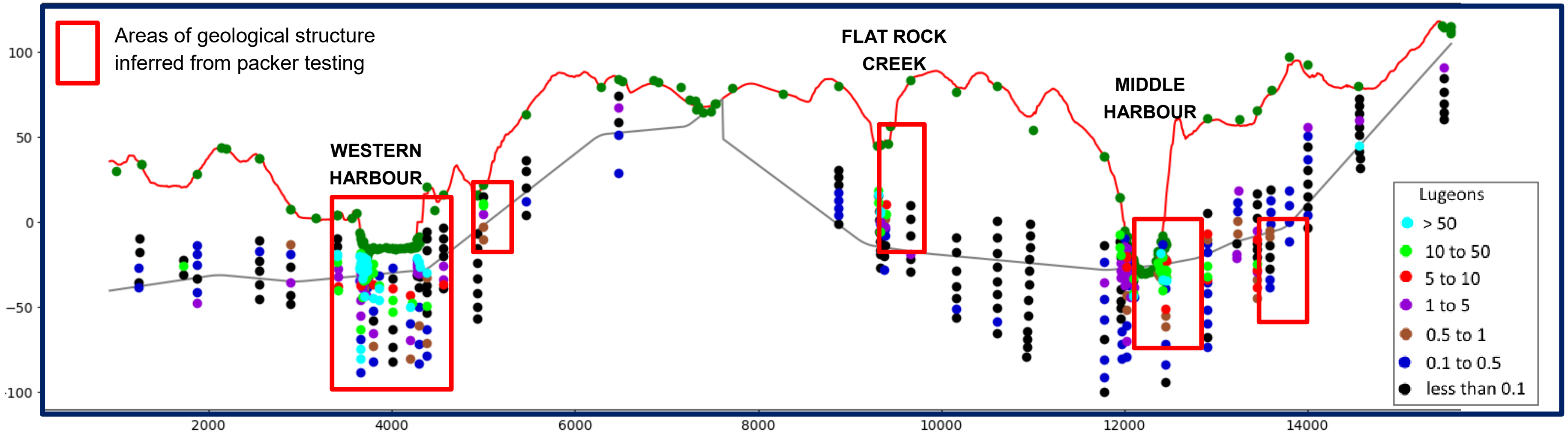


Figure 5-14a Inferred structural zones from drilling and packer testing

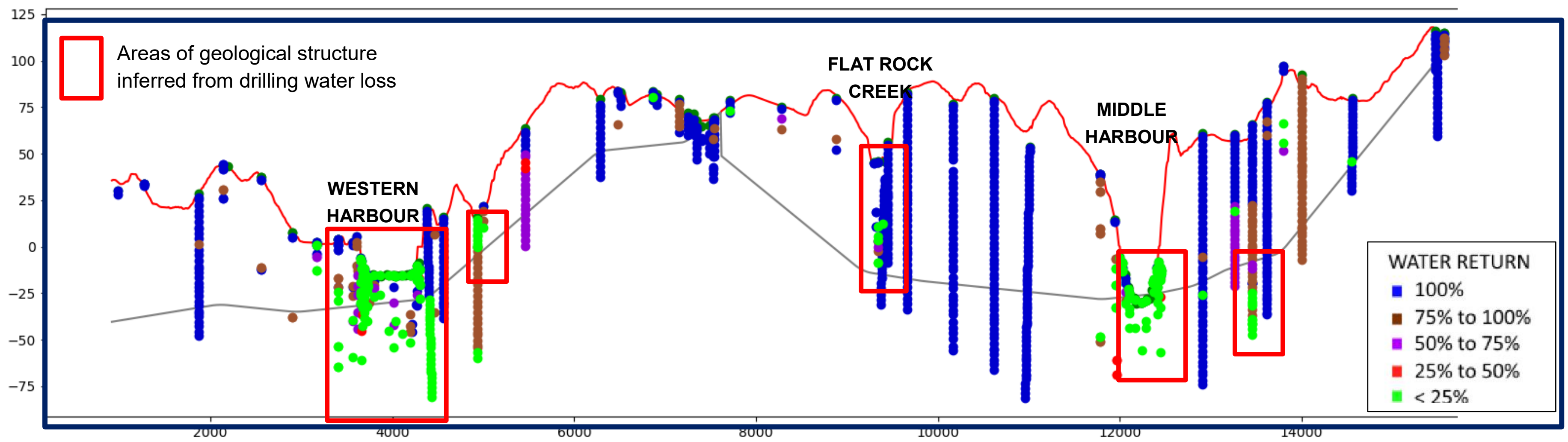


Figure 5-14b Inferred structural zones from drilling and packer testing

5.5.4.5 Dykes

Dykes in the Sydney region are typically highly weathered and represent barriers to groundwater flow across the dyke. Fracturing during intrusion can often result in a zone of marginally increased permeability parallel to strike in the surrounding country rock.

Borehole B202, located in Rozelle, was drilled to intersect the Great Sydney Dyke. The bore intersected the dyke from 92.5 to 95.15 metres below ground level, with the dyke logged as consisting of moderately weathered to highly weathered dolerite. The surrounding sandstone was noted as having increased jointing and shearing associated with the intrusion, with the lower sandstone contact logged as extremely weathered. Anecdotally, the dyke was noted as being very clayey and the drill hole would not stay open to allow the installation of vibrating wire piezometer sensors below the dyke.

5.5.4.6 Vertical hydraulic conductivity

No specific data is available on the vertical hydraulic conductivity along the alignment, however, given the highly-stratified nature of the formations, and the indications of perched and/or multiple water tables (refer to Section 5.5.2), a strong vertical anisotropy is expected.

5.5.4.7 Specific storage

Values for specific storage have been derived from geotechnical rock strength testing data. Specific storage is a product of the formation compressibility and the specific weight of water, where formation compressibility is derived from Young's Modulus and Poisson's Ratio.

Rock strength characteristics are available for 36 core samples from land-based investigations and from depths ranging from 1.5 to 120 metres below ground level. The majority of core samples are of Hawkesbury Sandstone, with one sample each also from laminate, shale breccia, and basalt. Derived values for specific storage are summarised on Table 5-8.

Table 5-8 Formation specific storage

Lithology	Number of tests	Depth range (mBGL)	Mean specific storage (m^{-1})	Median specific storage (m^{-1})
Hawkesbury Sandstone - Massive	9	6-120	1.32E-06	9.13E-07
Hawkesbury Sandstone - Bedded	24	1.5-105	2.22E-06	9.85E-07
Basalt	1	82	5.53E-07	5.53E-07
Laminite	1	57	3.55E-06	3.55E-06
Shale Breccia	1	7	2.35E-06	2.35E-06

Average and median values for specific storage for the Hawkesbury Sandstone are in close agreement, indicating a fairly uniform distribution of results with an average specific storage for the Hawkesbury Sandstone overall of 1.9×10^{-6} m^{-1}.

Specific storage derived from rock strength data should be considered a lower bound, as specific storage would be influenced by fracturing and discontinuity which typically would not be represented in the core samples. Values for specific storage of 5×10^{-6} to 1×10^{-5} m^{-1} are considered reasonable depending on the degree of weathering and fracturing.

5.5.4.8 Specific yield

The specific yield of a material is a measure of the amount of water that would readily drain under gravity. Typical values of specific yield for unconsolidated sands and gravel are typically high in the order of 15 to 25 per cent. For sandstone it is much less, often of the order of five per cent for unconsolidated sandstone and further reducing with consolidation/cementation. An approximation of half of the total porosity for sandstone is considered reasonable.

Porosity has not been recorded for the core samples, however, total water content was reported, which if the core was saturated would be equivalent to the porosity. The average water content for all core samples (disregarding extreme outliers) was 4.6 per cent, while for samples below 50 metres was 4.5 per cent. Based on these results, representative values of specific yield for the Hawkesbury Sandstone of the order of two to five per cent are considered reasonable, depending on degree of weathering and jointing.

5.5.5 Groundwater quality

Project specific groundwater quality monitoring has been conducted from a series of standpipe piezometers installed in the Hawkesbury Sandstone. While there are some surficial deposits of Ashfield Shale and Mittagong Formation in the North Sydney and Cammeray areas, these units are minor in their thickness and extent and, as such, it is considered that any groundwater associated with these formations would not interact with the project.

The groundwater quality in the Hawkesbury sandstone is typically low salinity and of neutral to slightly acidic pH. This is due to the sandstone being dominated by clean quartz/feldspar sand grains. Groundwater contained within the Ashfield shale unit is generally poorer quality than the Hawkesbury sandstone, due to its high clay mineral content, giving rise to a higher salinity.

A summary of general water quality information from previous tunnelling projects in the Sydney area is provided in the groundwater assessment for the Sydney Metro Chatswood to Sydenham Line (Jacobs, 2016). Groundwater inflows to existing underground services were reported as being typically high in iron, and possibly containing manganese, or other contaminants, having a relatively high salinity (as total dissolved salts) and being slightly acidic. Typical parameters from existing tunnel projects were reported as follows (Jacobs, 2016):

- Energy Australia Cable Tunnel: iron 110 milligrams per litre; total dissolved solids (TDS) 10,000 milligrams per litre; pH 5.9
- Sydney Harbour Tunnel: iron 40 milligrams per litre
- Epping to Chatswood Railway: iron 90 milligrams per litre; TDS 1300 milligrams per litre average to 6000 milligrams per litre; pH 5.9
- Cross City Tunnel: iron 50 milligrams per litre.

It is noted that tunnelling projects close to or underlying harbour areas would potentially capture much more saline groundwater and have potential to induce the ingress of saline to brackish groundwater into previously fresher aquifers.

Water quality data collected from previous tunnelling assessments are summarised in Table 5-9.

Table 5-9 Sydney tunnel investigations water quality

Tunnel / formation	TDS (mg/L)	EC (µS/cm)	pH	Number of samples
Sydney Metro Chatswood to Sydenham (Jacobs, 2016)				
Ashfield Shale	269 - 536	402 - 800	4.9 - 5.1	3
Mittagong Formation	265 - 350	396 - 522	4.7 - 5.6	4
Hawkesbury Sandstone	147 - 574	220 - 856	5.2 - 6.8	6
M4 East (GHD, 2015)				
All units	490 - 12,000	760 - 20,000	4.3 - 7.6	27
Unconsolidated sediments	780 - 2300	990 - 3300	-	-
Ashfield Shale	1000 - 12,000	1600 - 20,000	-	-
Hawkesbury Sandstone	490 - 1100	760 - 1700	-	-
New M5 (AECOM, 2015)				
Ashfield Shale	4250 (mean)	-	6.2 (average)	3
Hawkesbury Sandstone	3190 (mean)	-	7.5 (average)	11

Routine monthly groundwater quality monitoring for the project started in October 2017 and would be ongoing during construction and into the operational phase of the project. Groundwater quality data has so far been reported from six sampling events at eight standpipe piezometers. Details of the monitoring sites are shown in Table 5-10 and the locations are shown on Figure 4-1. Full analytical results are provided in Appendix D.

Table 5-10 Groundwater quality sampling

Bore ID	Location (Figure 4-1)	Monitored formation	Number of samples	Comments
B104A	Birchgrove	Hawkesbury Sandstone	5	Metals results considered unreliable due to high pH[1]
B105A	Birchgrove	Hawkesbury Sandstone	5	Complete results
B112P	Waverton	Hawkesbury Sandstone	8	Complete results
B131A	Birchgrove	Hawkesbury Sandstone	5	Complete results
B150P	North Sydney	Hawkesbury Sandstone	7	Complete results
B181A	Rozelle	Hawkesbury Sandstone	6	Complete results
B208	Balmain	Hawkesbury Sandstone	5	Metals results considered unreliable due to high pH[1]

Bore ID	Location (Figure 4-1)	Monitored formation	Number of samples	Comments
B390	Rozelle	Hawkesbury Sandstone	7	Complete results

Note 1: Bores with pH > 8.5 are considered likely to have been impacted by an alkaline source, most likely grout contamination during installation.

The groundwater quality monitoring program provided data for the analytes shown in Table 5-11.

Table 5-11 Groundwater quality analytes

Category	Suite of analytes	
Physico-Chemical parameters (Lab)	Electrical conductivity (EC) pH	Total Dissolved Solids (TDS)
Major ions	Bicarbonate Calcium Carbonate Chloride	Fluoride Phosphorus Potassium Sulfate
Dissolved metals and minor / trace elements	Arsenic Barium Boron Cadmium Chromium Cobalt Copper	Iron Lead Manganese Mercury Nickel Zinc
Nutrients	Ammonia Nitrate Nitrite	Reactive and total phosphorus Total Kjeldhal nitrogen Total nitrogen
Hydrocarbons	Monocyclic aromatic hydrocarbons (MAH) Polycyclic aromatic hydrocarbons (PAH)	Total petroleum hydrocarbons (TPH)

5.5.5.1 Groundwater quality results

From review of the project specific data available the following findings have been made.

Physicochemical parameters

Electrical Conductivity (EC) laboratory measurements ranged from 392 µS/cm at B150P to 37,100 µS/cm at B131A. The variation shown in the data represents proximity to the harbour with the closest bores showing greater influence from proximity to the saline interface. The EC recorded at B131A more or less correlates with seawater salinity.

Anomalously high pH values have been obtained at B104A and B208, with extremely alkaline values in the range 11 to 12 pH units. These values are not considered to be representative of Hawkesbury Sandstone. pH can be naturally influenced by a number of factors, most notably geochemistry, saline intrusion, rainfall recharge and contamination. Bores that displayed a pH of greater than 8.5 were considered to indicate potential influence from an alkaline source, most likely contamination from the grout used in construction. As such, pH data from B104A and B208 have been discounted from this assessment. The remaining pH data set ranges from 4.1 at B181A to 8.0 at B105A.

Major ions

The relative concentrations of major ions have been plotted on a Piper diagram on Figure 5-15 to assess the hydrogeochemical distribution of major ions to aid in the identification of water types based on bore location. All bores sampled are constructed in the Hawkesbury sandstone. The majority of samples show a dominance of sodium and chloride indicating relatively mature groundwater with little recharging influence. B131A is indicative of seawater, both in major ion composition and salinity. No other bores show any significant saline influences.

B181A plots separately in the anion field and is more sulfate dominant than chloride dominant. B181A is also the most acidic of the samples with an average pH of 4.8. The low pH and elevated sulfate may be indicative of natural oxidation of sulphide minerals, possibly from shales, in this area.

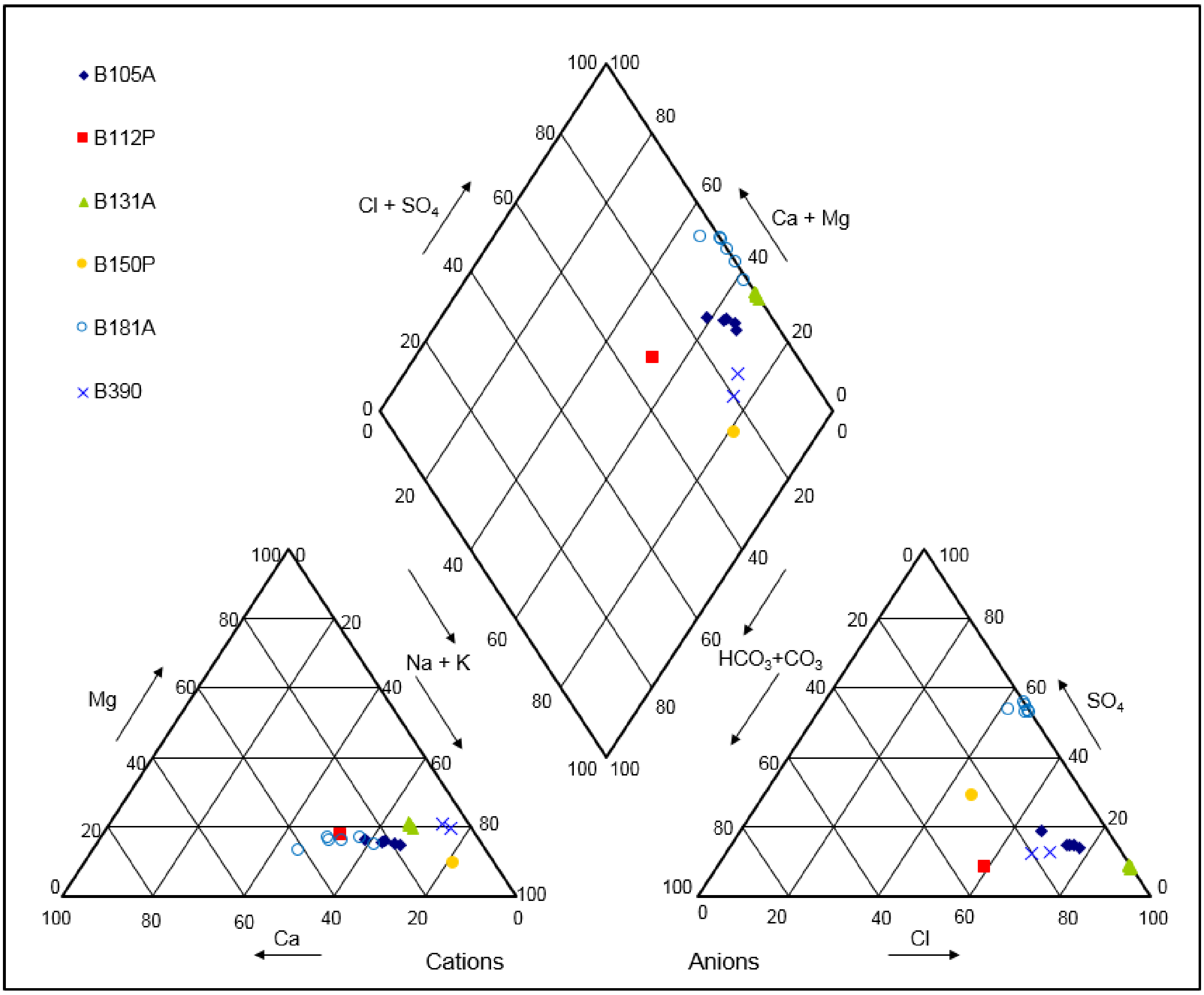


Figure 5-15 Groundwater Piper diagram

Heavy metals

Dissolved metal concentrations have been compared against the ANZECC 2000 guidelines for marine and freshwater (95 per cent level of protection). Data considered unreliable due to high pH (refer to Table 4-10) has been omitted from this analysis. A summary of exceedances of freshwater and marine guideline values is provided as follows and the full results are shown in Appendix D.

- Boron exceeded the freshwater guideline value of 0.37 mg/L in all samples collected from B131A, as well as from samples collected from B150P and B390. These bores are located on the shoreline at Birchgrove, near Berrys Bay, and at Rozelle Rail Yards, respectively. The water quality would be heavily influenced by seawater intrusion at Birchgrove and Berrys Bay
- Cobalt met or exceeded the marine guideline value of 0.001 mg/L in all samples collected from B112P, B131A, B150P, B181A and B390
- Copper showed exceedances of the freshwater and marine guideline values in samples collected from B104A, B112P, B181A, B208A and B390

Hydrocarbons

- Positive results for total petroleum hydrocarbons (TPH) and total recoverable hydrocarbons (TRH) are noted at B104A, B131A, B181A, B208A and B390
- Positive results for benzene, toluene, ethylbenzene, and xylene (BTEX) are noted at B104A, B105A, B131A, B150P and B208A.

5.5.5.2 Potential areas of contamination

From the data available, the groundwater quality at B131, situated on the Birchgrove peninsula, is shown to be relatively poor with high levels of sulfate, ammonia and hydrocarbons. Groundwater at this location would be heavily influenced by seawater but may also be influenced by any contamination from the fill material beneath Birchgrove Park. Positive results for BTEX, TRH and TPH are almost ubiquitous throughout the monitoring results suggesting that the hydrocarbons may have been introduced during the drilling or sampling.

The Technical working paper: Contamination notes that this area contains fill material comprising slag and ash furnace waste from historical harbour-side industry. Other areas of potential contamination in the project area are discussed in Section 5.6.

5.5.5.3 Saline interface

Where aquifers exist in coastal areas, or next to saline water bodies, a natural hydraulic gradient typically exists towards the coast as groundwater discharges into the sea. Because seawater is denser than fresh water, density driven flow results in a gradual increase in the density and salinity of groundwater with depth close to coast as saline water underlies the fresh groundwater. The boundary, or interface, between the fresh and saline water exists in a state of dynamic equilibrium, moving with the seasonal variations of the water table and daily tidal fluctuations. These movements result in an interface which is a transition zone of mixed salinity.

The Ghyben-Herzberg relationship for estimating the location of the interface is based on the density equilibrium of fresh and saline water in a porous aquifer. The approximation assumes a zero head of fresh water at the coast, a sharp boundary between fresh and saline water, and no groundwater flow. Assuming total dissolved solids of 25,000 milligrams per litre for saline water and negligible concentration of dissolved solids for fresh water, the approximation indicates that the vertical position of the saline interface would be about 40 metres below sea level for every one metre of freshwater above sea level.

However, due to geological variability, and the highly-stratified nature of the Hawkesbury Sandstone, the location of the fresh water to saline water interface, with respect to distance from the harbour and water table elevation, is likely to be fairly irregular and difficult to predict.

The drawdown of freshwater at the coast has the potential to result in saline ingress to the aquifer or the vertical migration of the zone of interface. Similarly, depressurisation or drawdown away from the coast can also induce localised upwelling, or up-coning, of the saline interface in the areas of depressurisation.

The modelled location of the existing saline interface has been assessed based on the Ghyben-Herzberg relationship and is shown in Appendix F. This approximation has been used to represent the baseline condition for the two-dimensional saline intrusion modelling carried out to predict saline intrusion impacts (refer to Section 5).

5.5.6 Groundwater users

The Hawkesbury sandstone has been historically utilised as a water supply in the Sydney area with useful yields possible particularly when fractures or joints are intersected. Details of groundwater works, sourced from the DPI Water Pinneena database and the Bureau of Meteorology Groundwater Explorer, are provided in Table 5-12. There were no Water Access Licence (WAL) users identified within 2.5 kilometres of the project. The location of groundwater works within 2.5 kilometres of the alignment are shown on Figure 5-16. There are 24 registered groundwater works (bores) within a one kilometre radius of the project alignment. Of the 24 bores within one kilometre of the alignment:

- Twenty-one bores are recorded as being installed for, monitoring (20), or unknown (one) purposes
- Three bores are recorded as being installed for abstractive use for; irrigation (one), and water supply (two)
- Of the bores installed for abstractive use:
  - GW023150.1.1 is located in Cremorne and is about 750 metres from the alignment. GW023150.1.1 is recorded as being only 1.8 metres deep, which may be erroneous, and is recorded as being used for irrigation. Surface geology in the area is Hawkesbury Sandstone
  - GW108991.1.1 is located in Waverton, about 410 metres from the alignment. GW108991.1.1 is used for water supply and is 168 metres deep and installed in the Hawkesbury Sandstone
  - GW109209.1.1 is located in Birchgrove about 270 metres from the project alignment. GW109209.1.1 is installed to a depth of 4.5 metres and utilises a spear point system (suction pumping for low yield shallow groundwater abstraction) for the purposes of water supply. The geological map shows the area as on the margins of an area of fill, or potentially alluvium, underlain by Hawkesbury Sandstone.

Table 5-12 Groundwater works

Bore ID	Bore Depth (m)	Drilled date	Purpose	Status
GW109604.1.1	1.7	6/05/2003	Monitoring	Unknown
GW109601.1.1	2	2/05/2003	Monitoring	Unknown
GW109591.1.1	2	5/09/2003	Monitoring	Unknown
GW109651.1.1	2.5	27/05/2008	Monitoring	Unknown
GW109589.1.1	2.9	30/04/2003	Monitoring	Unknown
GW105416.1.1	3.5	11/08/2003	Monitoring	Unknown
GW105415.1.1	3.5	11/08/2003	Monitoring	Unknown
GW105414.1.1	3.5	11/08/2003	Monitoring	Unknown
GW105413.1.1	3.5	11/08/2003	Monitoring	Unknown
GW109605.1.1	4	6/05/2003	Monitoring	Unknown
GW109593.1.1	4	2/05/2003	Monitoring	Unknown
GW109590.1.1	4.4	30/04/2003	Monitoring	Unknown
GW103997.1.1	4.5	26/08/1998	Monitoring	Unknown
GW109592.1.1	4.5	5/09/2003	Monitoring	Unknown
GW102671.1.1	4.8	1/07/1993	Monitoring	Unknown
GW109603.1.1	5	1/05/2003	Monitoring	Unknown
GW109600.1.1	6.5	2/05/2003	Monitoring	Unknown
GW109602.1.1	8.3	2/05/2003	Monitoring	Unknown
GW102672.1.1	9	1/07/1993	Monitoring	Unknown
GW102655.1.1	25	15/05/1992	Monitoring	Unknown
GW107764.1.1	0	22/01/2007	Unknown	Unknown
GW109209.1.1	4.5	13/08/2008	Water supply	Unknown
GW108991.1.1	168	8/07/2008	Water supply	Unknown
GW023150.1.1	1.8	1/01/1966	Irrigation	Unknown

Source: DPI Water Pinneena database, BoM Groundwater Explorer.

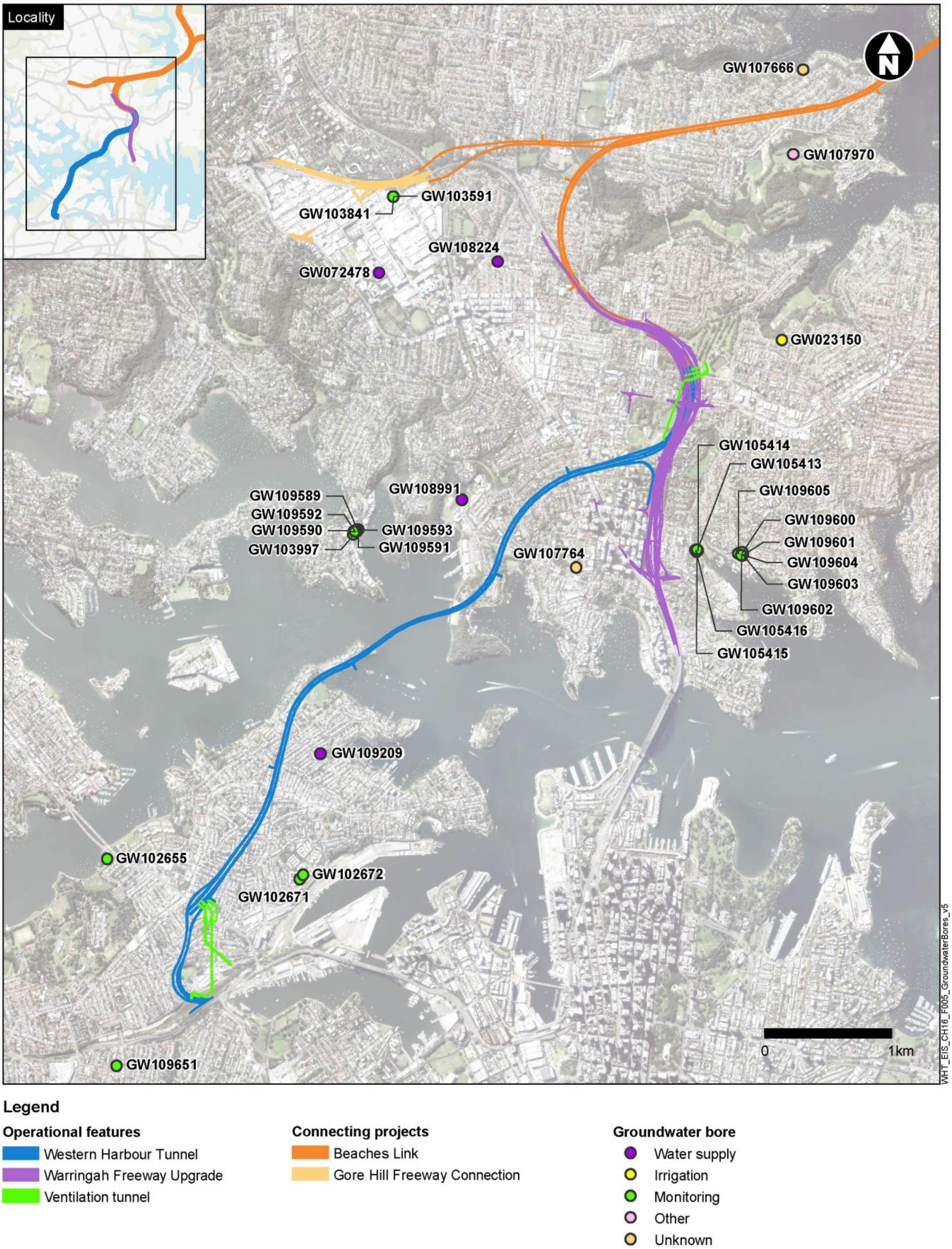


Figure 5-16 Registered groundwater bores

5.5.7 Existing and proposed tunnels

Numerous other existing and proposed tunnels occur and are planned in the Sydney area, where these tunnels are drained and have an ongoing water take they would need to be considered for potential cumulative impacts.

Known inflows to existing tunnels and predicted inflows to proposed tunnels are provided in Table 5-13. It is noted that the Sydney Metro Chatswood to Sydenham (Jacobs, 2016) is proposed as a fully tanked construction for the main tunnel alignment and as such would have negligible inflows.

Where these tunnels fall within the model domain (refer to Section 6) they would be included as groundwater stresses for the purpose of assessing cumulative impacts.

Table 5-13 Sydney tunnel inflows

Tunnel	Year opened	Type	Width (m)	Length (km)	Reported / predicted inflow (L/s/km)	Total inflow (L/s)	Reference
Existing tunnels – inflows							
Eastern Distributor	1999	Twin – three lane, double deck	12	1.7	1	1.7	Hewitt 2005
Northside Storage Tunnel	2000	Stormwater storage	6	20.0	0.9	18	Coffey 2012
M5 East	2001	Twin – two lane	8	3.8	0.9	3.42	Tammetta and Hewitt 2004
Cross City	2005	Twin – two lane	8	2.1	>3	6.3	Hewitt 2005
Lane Cove	2007	Twin – three lane	9	3.6	0.6	2.16	Coffey 2012
Epping to Chatswood	2009	Twin rail	7.2	13.0	0.9	11.7	Best and Parker 2005
Proposed tunnels – predicted inflows							
M4 East	2020[1]	Twin – three lane	-	5.5 each	1.5	17	GHD 2015
New M5	2020[1]	Twin – three lane	14.1-20.6	9	0.63 to 0.67	12.9	AECOM 2015
Sydney Metro Chatswood to Sydenham	2020[1]	Twin rail - tanked	-	15.5	negligible	negligible	Jacobs 2016

Note 1: Assumed completion of tunnelling.

5.5.8 Groundwater dependent ecosystems

Groundwater dependent ecosystems (GDEs) are ecological communities that are dependent, either entirely or in part, on the presence of groundwater for their health or survival. The NSW DPI Water Risk Assessment Guidelines for Groundwater Dependent Ecosystems (Serov et al, 2012) adopts the definition of a GDE as:

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

GDEs might rely on groundwater for the maintenance of some or all of their ecological functions, and that dependence can be variable, ranging from partial and infrequent dependence, ie seasonal or episodic, to total continual dependence.

The Technical working paper: Biodiversity Development Assessment assessed an area within a 500 metre buffer around the project using the Bureau of Meteorology's groundwater dependent ecosystem atlas (BOM, 2018). The search identified that the northern extent of the Warringah Freeway is upstream of a 'moderate to high potential' terrestrial GDE (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sand Forest) located in the lower reaches of Flat Rock Creek and along Quarry Creek. This site is located around 400 metres north-east of the Warringah Freeway Upgrade (refer to Figure 5-1).

High priority GDEs are identified in the Water Sharing Plan for the water source in which they reside and are regulated under the NSW Aquifer Interference Policy. No high priority GDEs are identified in the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources in the vicinity of the project alignment.

5.5.9 Wetlands of international importance

A search of the Department of the Environment and Energy Protected Matters Search Tool found one wetland of international importance 17 kilometres south of the project: Towra Point Nature Reserve.

Towra Point Nature Reserve covers 603 hectares and is located on the southern shores of Botany Bay, on the Kurnell Peninsula. The reserve was listed as a Ramsar site (ie a Wetlands of International Importance) in 1984.

5.5.10 Groundwater surface water interaction

Groundwater surface water interaction along the project alignment is expected to be very limited due to the typically large depth to groundwater over the majority of the alignment. There is potential for groundwater contribution to streamflow as base flow in low lying areas or deeply incised channels. Shallow or perched groundwater systems may also discharge to surface water via shallow fracture networks.

The only significant drainage along the project alignment is Whites Creek. The complete length of Whites Creek has been modified and the creek is now a stormwater drain with buried pipes in the upper reaches and open concrete channel for the lower one kilometre before discharging to Rozelle Bay. Given the highly-disturbed nature of Whites Creek and lining as a stormwater drain, no groundwater related impacts are expected from the dive or tunnelling at the southern end of the project.

There are two smaller drainage channels, Quarry Creek and Willoughby Creek, situated to the north east of the Warringah Freeway Upgrade. Quarry Creek is a small natural estuarine tributary of Flat Rock Creek which drains the Cammeray area and has a history of being quarried for sandstone. The creek has steep embankments on both sides now densely vegetated by exotic species and has limited accessibility.

Willoughby Creek is a small modified concrete and rock channel which drains the suburbs of Neutral Bay and Cammeray directly into Willoughby Bay at Cremorne. The development of impervious surfaces within the catchment has increased the volume and rate of runoff, which has in turn necessitated flood mitigation measures primarily in the mid and upper catchment. Semi-natural channel morphology exists within sections where the presence of bedrock has negated the requirement for channel stabilisation initiatives.

5.5.11 Culturally significant sites

The *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011* specifies distance rules for water supply works near groundwater dependent culturally significant sites. The Department of Premier and Cabinet (Heritage) maintains an inventory of Aboriginal Places and the State Heritage Register. There are no Aboriginal Places listed in the project area, and all State Heritage Register sites are buildings and other built infrastructure that is not groundwater dependent. The presence of culturally significant sites is discussed in detail in the Technical working paper: Cultural Heritage Assessment Report (Jacobs, 2020c) and the Technical working paper: Non-Aboriginal Heritage (Jacobs, 2020d). Using the Aboriginal Heritage Information Management System (AHIMS), four Aboriginal sites have been identified in the area expected to be subject to groundwater drawdown. These are:

- Waverton Park Cave (45-6-2181)
- Waverton Park (45-6-1270)
- Coal Loader 1 (45-6-2762)
- Whale Rock (45-6-0026).

These Aboriginal heritage sites have no reliance on groundwater. The non-Aboriginal Heritage sites include buildings and infrastructure such as sewer vents, power stations, railway stations and sporting ovals. None of these are groundwater dependent.

5.5.12 Sensitive receiving environments

The Technical working paper: Surface Water identifies Flat Rock Creek and Quarry Creek as sensitive receiving environments relevant to the project in areas downstream of the project alignment. Flat Rock Creek becomes tidally influenced estuarine habitat where Quarry Creek tributary meets Flat Rock Creek. Emergent macrophytes, bank undercutting, dense overhanging vegetation and instream woody debris were identified as potential fish refuge.

5.6 Areas of environmental interest for contamination

Areas of environmental interest for contamination along the alignment are discussed in detail in the Technical working paper: Contamination. Each of the areas was given a risk ranking from low to high to indicate the potential for contamination. A further assessment has been made as to whether the contamination is likely to be surficial or present at depth. The sites that are considered to have potentially contaminated groundwater are those where there is a moderate or high contamination risk that is likely to be present at depth and the depth to groundwater is estimated to be less than ten metres. Where the depth to groundwater is estimated to be greater than ten metres it is considered that the relatively low hydraulic properties of the Hawkesbury Sandstone would result in a low risk of contaminants reaching the groundwater.

The marine sediments of the Sydney Harbour crossing were noted as high risk, however, from a groundwater perspective, given the immersed tube design, the harbour sediments are not considered to pose a significant risk to groundwater inflow or to tunnel dewatering. The only other high risk areas are the Rozelle Rail Yards, which contain fill from former industry in the area. Areas of interest with moderate or high risk ranking, and that are considered relevant to the groundwater assessment are reproduced in Table 4-14. Several unsealed areas next to the Warringah Freeway were identified as having potential for deposition of vehicle particulates, but these would not be expected to affect groundwater quality.

The NSW Environment Protection Authority (EPA) maintains a ‘list of contaminated sites notified to the EPA’ on their website. These are sites of which the EPA has been notified about the likely contamination by the site owners, who may have carried out some investigation or remediation. They include retail and industrial sites such as service stations, power stations, and bus and train depots, as shown on Figure 5-17. The EPA list does not specify whether the contamination is of soil, groundwater, or both, and there is no knowledge on whether a contaminant plume exists at the sites. As listed sites however, these are the contaminant sources referred to in the Water Sharing Plan for the Greater Metropolitan Region (2011) which a water supply work (in this case the tunnel) must be located at least 250 metres away from any associated contaminant plume in order to obtain Ministerial approval.

Table 5-14 Areas of environmental interest for contamination

Area of environmental interest	Reference (Figure 4-16)	Potential contamination source	Potential contamination distribution	Risk of soil contamination	Risk of existing groundwater contamination
Rozelle Rail Yards	W1	Residuals from historical railway usage and historical demolition of on-site structures	Surface and depth (depth distribution associated with potential underground storage tanks, and depth of infilling).	High – known contamination/ excavation activities within potential contamination distribution range (laterally and vertically).	High – contaminated groundwater identified as part of M4-M5 Link environmental impact statement (AECOM, 2017), which documents contamination as being relatively minor and limited to exceedances of: • Zinc and copper in one location • Zinc in one other location • TRH, naphthalene and Bis(2-ethylhexyl) phthalate in one location.
		Potential infill of former creek line and adjoining low lying areas	Surface and depth (depth distribution associated with depth of infilling. Infilling materials could comprise historical furnace waste from harbour-side industry).	High – known contamination/ excavation activities within potential contamination distribution range (laterally and vertically).	
Easton Park - Corner Denison Street and Lilyfield Road, Rozelle	W2	Potential infill of former creek line and adjoining low lying areas	Surface and depth (depth distribution associated with depth of infilling. Infilling materials could comprise historical furnace waste from harbour side industry)	Moderate - possible contamination / excavation activities within site footprint and within potential contamination distribution range (laterally and vertically – surface works only). Potential contamination distribution unlikely to impact upon tunnelling (based on depth to tunnel).	Low – groundwater quality analysis at B390 and as documented in M4-M5 environmental impact statement (AECOM, 2017) does not indicate potential contamination
Yurulbin Park, Birchgrove	W3	Slag and ash fill material (historical furnace waste from harbour-	Surface	Moderate - possible contamination / excavation activities within	Moderate – groundwater quality analysis at B131 indicates slightly elevated EC, sulfate, ammonia and phosphorous.

Area of environmental interest	Reference (Figure 4-16)	Potential contamination source	Potential contamination distribution	Risk of soil contamination	Risk of existing groundwater contamination
		side industry), historical industrial land use, demolition of on-site buildings / structures.)		site footprint and within potential contamination distribution range (laterally and vertically – surface works only). Potential contamination distribution unlikely to impact upon tunnelling (based on depth to tunnel).	
Birchgrove Peninsula and Park - Louisa Road, Birchgrove	W4	Slag and ash fill material (historical furnace waste from harbour-side industry)	Surface	Moderate - possible contamination / excavation activities within site footprint and within potential contamination distribution range (laterally and vertically – surface works only). Potential contamination distribution unlikely to impact upon tunnelling (based on depth to tunnel).	Low – groundwater quality analysis at B104a and B105a does not indicate potential contamination
Wharf - Balls Head Drive, Waverton	W6	Commercial/industrial marine land use (current and/or historic)	Surface	Moderate - possible contamination / excavation activities within site footprint and within potential contamination distribution range (laterally and vertically – surface works only). Potential	Moderate – depth to groundwater estimated to be <5mbgl therefore contaminant migration to groundwater is possible

Area of environmental interest	Reference (Figure 4-16)	Potential contamination source	Potential contamination distribution	Risk of soil contamination	Risk of existing groundwater contamination
				contamination distribution unlikely to impact upon tunnelling (based on depth to tunnel).	
Former bulk fuel storage - Balls Head Road, Waverton	W7	Above ground storage of fuels	Surface	Moderate - possible contamination / excavation activities within site footprint and within potential contamination distribution range (laterally and vertically – surface works only). Potential contamination distribution unlikely to impact upon tunnelling (based on depth to tunnel).	Moderate – depth to groundwater estimated to be <5mbgl therefore contaminant migration to groundwater is possible
Waverton Park – Woolcott Road, Waverton	W8	Infill/reclamation next to shore line	Surface and depth. (Depth distribution associated with depth of infilling.)	High - known contamination (TRH)/ tunnel below site footprint. Potential for contamination migration to tunnel.	Moderate – known contamination with potential for migration to groundwater
NSW EPA regulated/notified Sites					
Rozelle - Whites Bay Power Station	Robert Street	Other industry	Unknown	High – regulated/notified site	Moderate – known contamination with potential for migration to groundwater
Rozelle – 7-Eleven service station	178–180 Victoria Road	Service station	Surface and depth	High – regulated/notified site	Low – site has a small footprint and groundwater is estimated to be >10mbgl therefore

Area of environmental interest	Reference (Figure 4-16)	Potential contamination source	Potential contamination distribution	Risk of soil contamination	Risk of existing groundwater contamination
					contamination is unlikely to have reached groundwater
Rozelle – Caltex service station	121 Victoria Road	Service station	Surface and depth	High – regulated/notified site	Low – site has a small footprint and groundwater is estimated to be >10mbgl therefore contamination is unlikely to have reached groundwater
Rozelle – Kennards storage	15–39 Wellington Street	Other petroleum	Surface and depth	High – regulated/notified site	Low – site has a small footprint and groundwater is estimated to be >10mbgl therefore contamination is unlikely to have reached groundwater
Rozelle – BP service station	Corner Darling Street and Thornton Street	Service station	Surface and depth	High – regulated/notified site	Low – site has a small footprint and groundwater is estimated to be >10mbgl therefore contamination is unlikely to have reached groundwater
Neutral Bay – Caltex service station	16–38 Military Road	Service station	Surface and depth	High – regulated/notified site	Low – site has a small footprint and groundwater is estimated to be >10mbgl therefore contamination is unlikely to have reached groundwater
Neutral Bay – Shell service station	200–204 Ben Boyd Road	Service station	Surface and depth	High – regulated/notified site	Low – site has a small footprint and groundwater is estimated to be >10mbgl therefore contamination is unlikely to have reached groundwater
Waverton – Oyster Cove AGL	2 King Street	-	Unknown	High – regulated/notified site	Low – site has a small footprint and groundwater is estimated to be >10mbgl therefore contamination is unlikely

Area of environmental interest	Reference (Figure 4-16)	Potential contamination source	Potential contamination distribution	Risk of soil contamination	Risk of existing groundwater contamination
					to have reached groundwater
Waverton - Berry's Bay Woodley's Marina	1 Balls Head Drive	Unknown	Unknown	Low – not regulated	Low – not regulated and site has a small footprint
Waverton – SRA land	95 Bay Road	Unknown	Unknown	Low – not regulated	Low – not regulated, small footprint and groundwater is estimated to be >10mbgl therefore contamination is unlikely to have reached groundwater

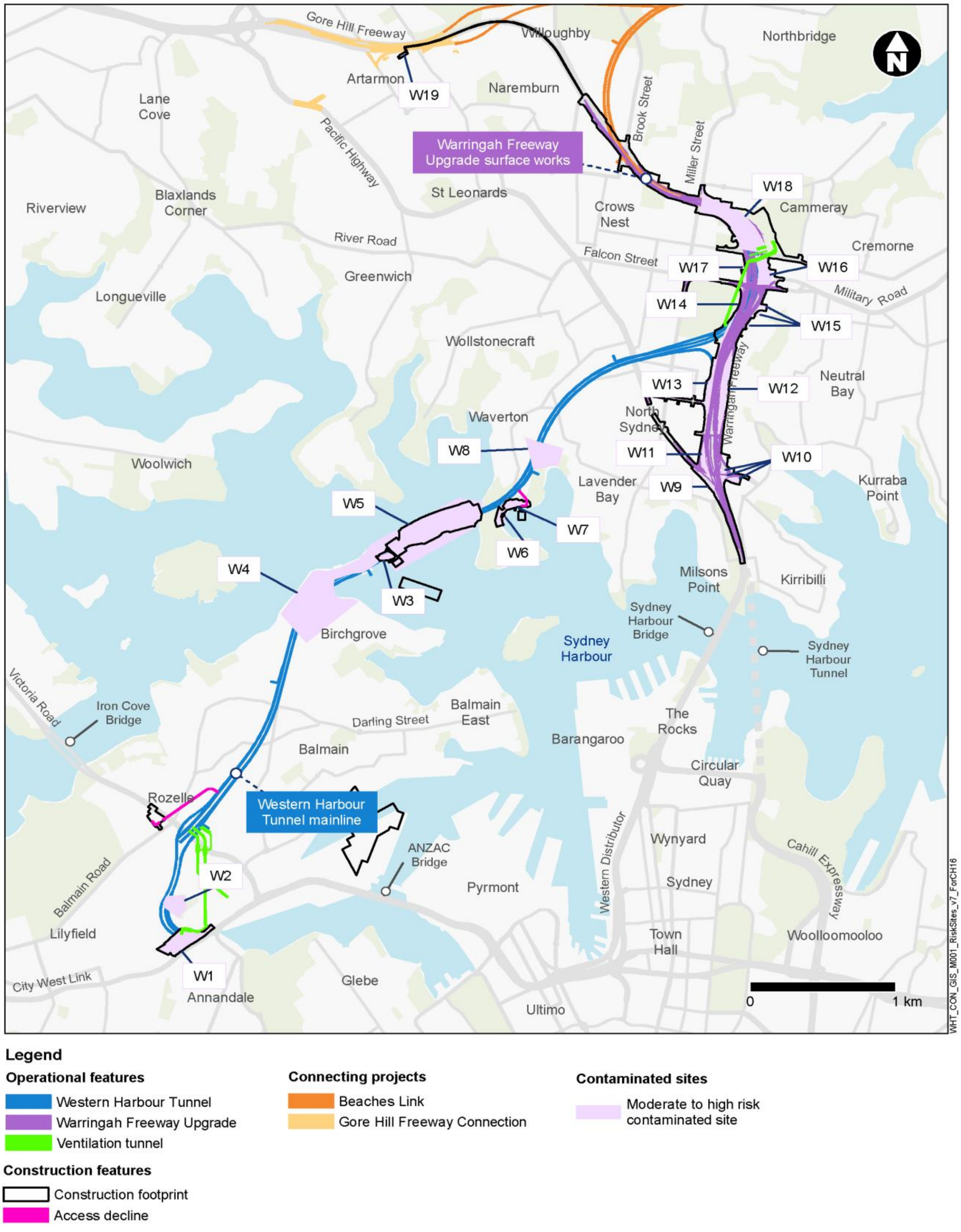


Figure 5-17 Areas of environmental interest for contamination within 500 metres of the project

6. Impact assessment

This section documents the potential groundwater inflows into the project tunnels, groundwater drawdown in connected aquifers as well as the potential impacts on receptors as a result of changed groundwater conditions. The impact assessment outlined below examines these areas to assess the likelihood and extent of potential impacts on relevant identified receptors.

The potential impacts on groundwater conditions and likely receptors affected are as follows:

- Groundwater users (both Water Access Licences and stock and domestic use)
- Groundwater dependent ecosystems (GDEs) and sensitive environments
- Reduction in baseflow in potentially connected surface water systems
- Induced migration of contaminated groundwater plumes
- Saline intrusion that reduces the beneficial uses of an aquifer
- Activation of acid sulfate soils (ASS) that reduces the beneficial uses of the aquifer.

Four culturally significant sites were identified in the Waverton area however, they are all surface features and are not groundwater dependent. Therefore, they are not considered any further in the impact assessment outlined below.

Potential impacts are considered both during construction (Section 6.1) and during the operational lifetime of the project (Section 6.2).

The groundwater modelling described in Section 4.4 and Appendix F predicts drawdown at the water table and in the intermediate model layers. As most potential receptors are associated with the water table, drawdown at the water table is the key issue when assessing potential impacts on receptors.

6.1 Assessment of construction impacts

Subject to planning approval, construction of the project is planned to start in 2021, with completion of tunnel construction in 2024 and project completion in 2026. The tunnel construction schedule would be:

- 2021 – site establishment and Warringah Freeway Upgrade commencement
- 2022 – tunnel construction begins
- 2026 – project fit out and commissioning complete.

For the Sydney Harbour crossing, tunnel excavation and construction occur in close sequence, first for the southern part of the project, then for the northern part of the project. Structures to mitigate inflows and drawdown (such as grout curtains) would be installed soon after excavation. Tanking of the tunnel either side of the harbour crossing would commence in late 2022 / early 2023, with tanking to take place progressively as the tunnel is developed.

6.1.1 Tunnel inflows

In general, maximum inflows would occur into the project tunnels when excavation is complete and measures to mitigate inflows (such as tanked sections) have not yet been installed. Greatest inflows are predicted to occur around the harbour crossing prior to the structure being tanked in late 2022 / early 2023.

Average inflows are presented for each year during the construction phase, as shown in Table 6-1. Peak inflows of almost 0.48 litres per second per kilometre averaged over the whole Western Harbour Tunnel would occur in 2022. Inflows for each tunnel component are included in Appendix E and show that the largest inflows occur for most tunnel components on the south side of Sydney Harbour in 2022 and 2023. North of the harbour inflows are lower.

Total inflows over the construction period would be 1310 megalitres, with annual inflows during construction peaking at 272 megalitres per year in 2022. The long term average annual extraction limit (LTAAEL) for the Sydney Central Basin is 45,915 megalitres per year and current groundwater access licences equate to 2592 megalitres per year, leaving around 43,323 megalitres per year of unassigned water. The predicted peak annual tunnel inflows would be less than one per cent of the water unassigned under the LTAAEL.

As shown in Table 6-1, project wide average inflows for each year of construction are below the design criteria of one litre per kilometre per second that Roads and Maritime have adopted as an acceptable inflow for the project. Planned measures to collect and dispose of tunnel inflows during construction are summarised in Section 2.1.6.

Table 6-1 Summary of modelled average tunnel inflows during construction

	Rozelle to Sydney Harbour	Sydney Harbour to Warringah Freeway	Entire project		Total annual inflows (ML/ year)
Year	L/s/km	L/s/km	L/s/km	ML/day	
2021	0.441	0.244	0.343	0.510	186
2022	0.727	0.228	0.478	0.746	272
2023	0.631	0.210	0.421	0.654	239
2024	0.584	0.189	0.386	0.602	220
2025	0.568	0.182	0.375	0.584	213
2026	0.548	0.161	0.355	0.557	203

Tunnel inflows would be collected, treated at the construction wastewater treatment plants and disposed as described in Section 2.1.6. Refer to Technical working paper: Surface water and Technical working paper: Marine water quality for an assessment of potential impacts of treated wastewater discharges into fresh and marine receiving waters, respectively.

6.1.2 Drawdown

Water table drawdown would occur because groundwater would flow into the project tunnels and lower pressure (and groundwater levels) in the surrounding aquifer. This section assesses the predicted water table drawdown caused by project components and also considers the cumulative impacts with other existing and proposed construction projects. The M4-M5 Link project is likely to contribute to drawdown between now and the completion of the Western Harbour Tunnel and Warringah Freeway Upgrade project. The Sydney Metro Chatswood to Sydenham tunnel construction takes place from 2018 to 2020 and is a fully lined tunnel therefore the contribution to the cumulative impacts would be relatively small. Overall impacts to receptors would be a result of the combined drawdown from these projects.

This section reports impacts according to the following modelled scenarios detailed in Section 6.1 of the modelling report shown in Appendix F:

- Western Harbour Tunnel and Warringah Freeway Upgrade project only (this represents the incremental additional impact due to the project assuming that the M4-M5 Link, Sydney Metro Chatswood to Sydenham and Beaches Link and Gore Hill Freeway Connection projects would go ahead)
- Cumulative scenario. This represents the Western Harbour Tunnel and Warringah Freeway Upgrade project together with the M4-M5 Link, Sydney Metro Chatswood to Sydenham and Beaches Link and Gore Hill Freeway Connection project. This represents the cumulative or total impact due to all four projects.

6.1.2.1 Western Harbour Tunnel and Warringah Freeway Upgrade only

Figure 6-1 indicates water table drawdown at the end of tunnel construction (2026) would be up to about 20 metres above the Rozelle ventilation tunnels, and 15 metres in the vicinity of Victoria Road. Accentuated drawdown of up to 18 metres is also predicted above the Victoria Road access decline. Drawdown propagation is predicted to be limited, with the two metre drawdown contour extending about 650 metres from the tunnel's centreline, largely attenuated by proximity to the harbour. North of the harbour, predicted water table drawdown is less, with a maximum drawdown of three metres predicted in Waverton and North Sydney. In the northern area, the two metre drawdown contour extends up to about 350 metres from the tunnel centrelines. The majority of drawdown is attributed to unlined ancillary structures (Rozelle ventilation tunnels and Victoria Road access decline).

6.1.2.2 Cumulative drawdown

The predicted cumulative drawdown in the water table would be considerably greater in the Rozelle area compared with the project only case, as shown in Figure 6-2. The maximum expected drawdown near the Rozelle dive structure is predicted to be about 40 metres. Half of this drawdown (20 metres) can be attributed to the Western Harbour Tunnel, however, the cumulative influence generally results in more significant drawdown regionally.

At Easton Park near the WHT ramps, project only drawdown is predicted to be of the order of three metres, whereas cumulative drawdowns of up to 38 metres is predicted. There is also a corresponding greater lateral propagation of predicted drawdown in the cumulative scenario, with the two metre drawdown contour extending up to 1.4 kilometres to the west of the alignment in the Rozelle/Lilyfield area.

North of the harbour, maximum water table drawdown of about 10 metres would occur at the northern dive structure of the Western Harbour Tunnel at the Warringah Freeway. In the North Sydney and Waverton areas a maximum drawdown of about five metres is predicted above the alignment. A maximum cumulative drawdown of 18 metres occurs above the North Sydney Metro Station. North of Sydney Harbour, the two metre drawdown contour would extend up to about 500 metres from the tunnel centreline in the North Sydney area.

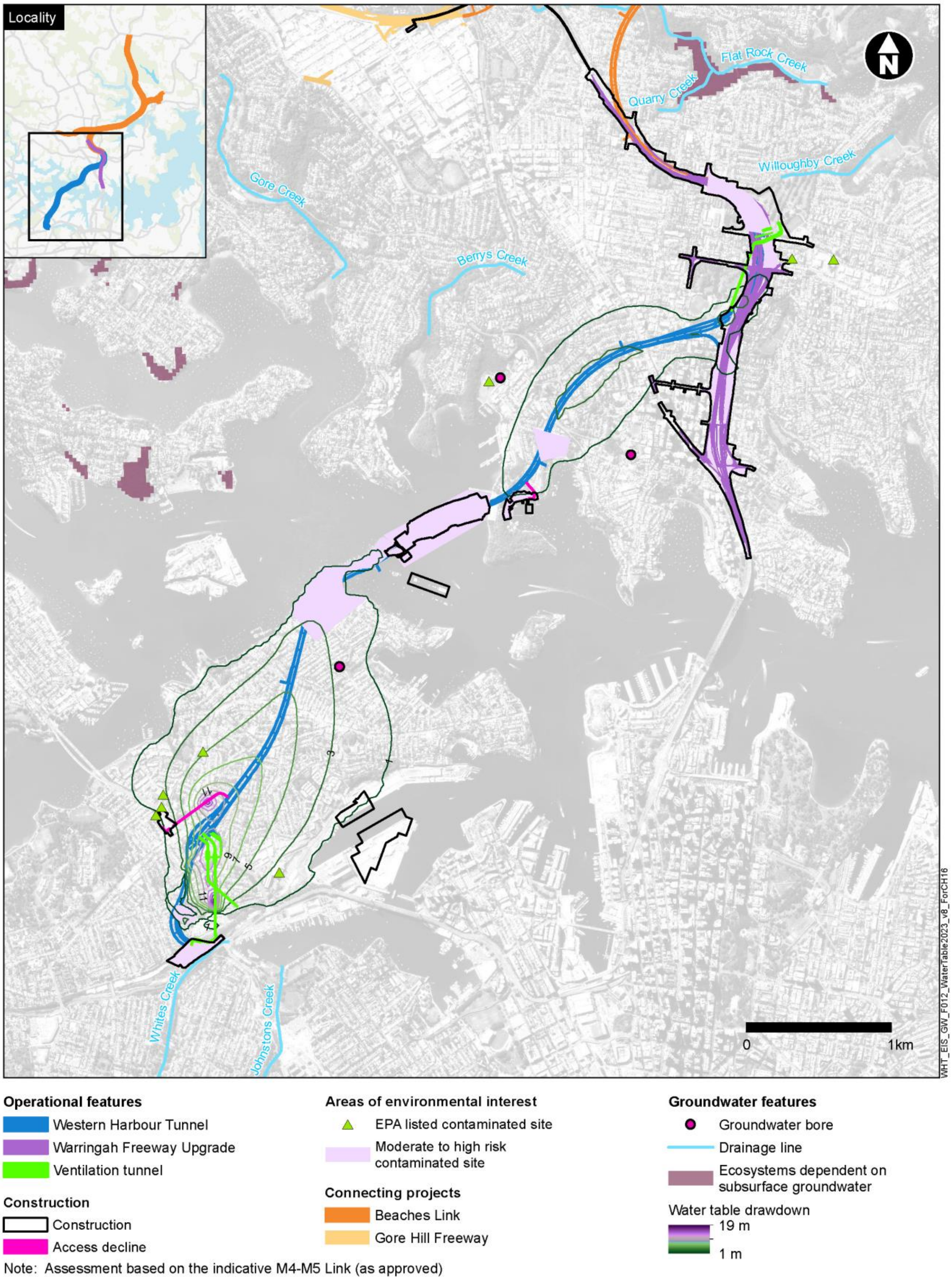


Figure 6-1 Predicted drawdown in the water table at the end of tunnel construction (project only)

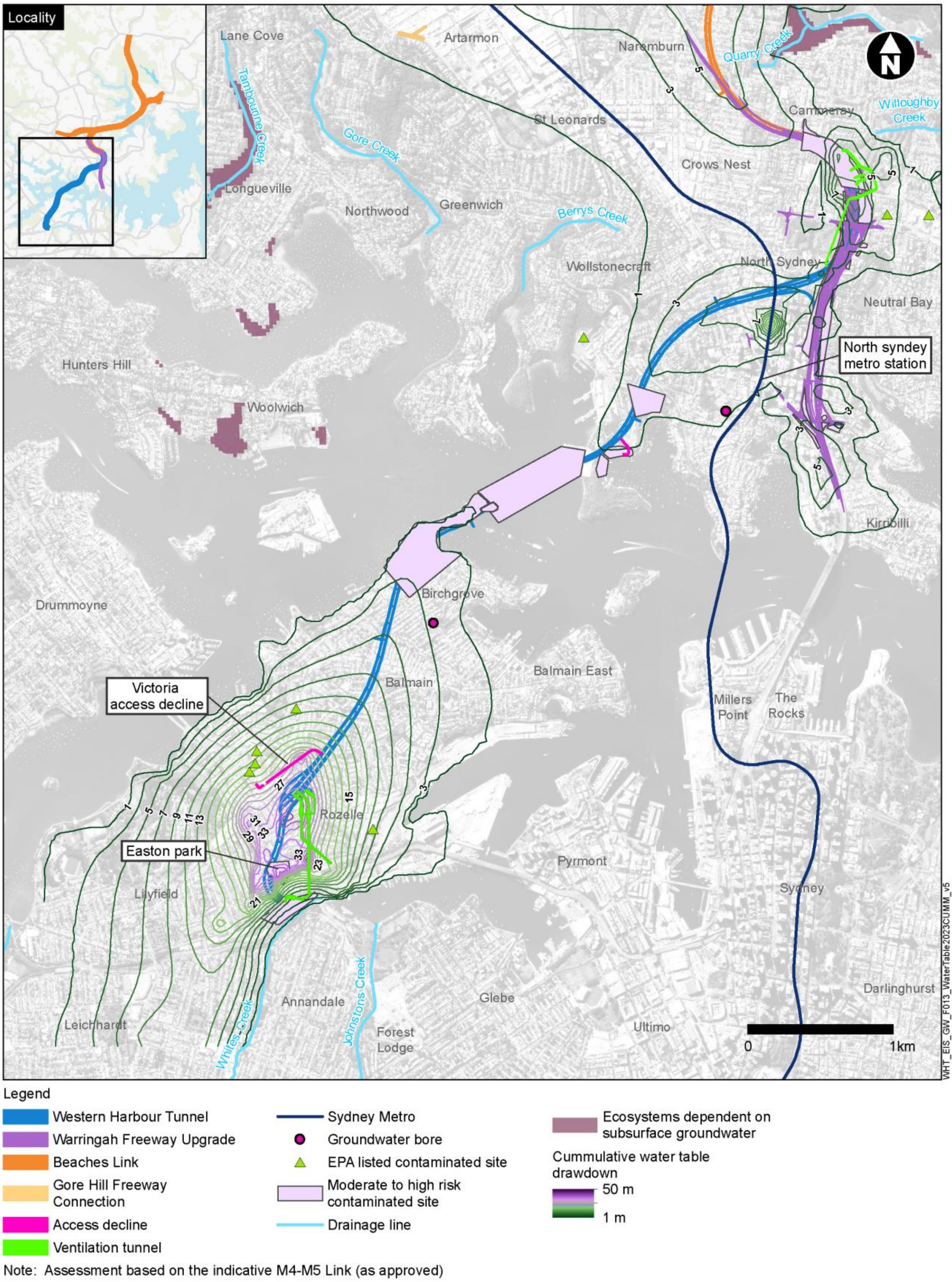


Figure 6.2 Predicted drawdown in the water table at the end of tunnel construction (cumulative)

6.1.3 Potential impacts

Potential impacts resulting from the predicted drawdown of the water table are discussed in the following sections. Predicted drawdown at each receptor is rounded up to the nearest metre and assessed against the *NSW Aquifer Interference Policy* (AIP) requirements. There are no licenced groundwater users or groundwater dependent culturally sensitive sites within the predicted drawdown extents, therefore these are not discussed below.

There are no culturally sensitive sites that are groundwater dependent in the area of drawdown and therefore are not considered within the impact assessment below. Potential settlement of the groundwater surface may affect their integrity however, and as such these receptors are considered in respect to such potential impacts in Section 6.1.3.8.

Whites Creek is within the drawdown extents but is a lined stormwater drain and as such would not be dependent on groundwater baseflow. The creek is to be rehabilitated by Sydney Water and is largely expected to remain as a lined stormwater drain that is unlikely to be baseflow dependent. Due to the absence of groundwater interaction, it is not considered further in this section.

The potential impacts associated with drawdown due to the project are discussed below.

6.1.3.1 Saline intrusion

Drawdown in onshore aquifers reduces the hydraulic pressure near the coast and allows seawater to intrude into fresh aquifers. The intrusion of saline water can reduce the beneficial uses of the aquifer, and potentially impact existing groundwater users. The AIP requires that any change in groundwater quality (for example caused by saline intrusion) should not lower the beneficial use of the groundwater beyond 40 metres from the activity.

Groundwater modelling shows that predicted drawdown reaches Sydney Harbour, which would allow some movement of saline water into the aquifer. This could increase salinity in the fresh parts of the Hawkesbury Sandstone aquifer and potentially impact the beneficial uses of the aquifer. As this quality impact occurs more than 40 metres from the tunnel, it exceeds the criteria in the AIP.

The two-dimensional modelling conducted to assess the impacts of saline intrusion (refer to Appendix F) predicts that the onset of saline intrusion would be very slow within the Hawkesbury Sandstone due to the hydraulic conductivity of the formation. Both the lateral and upward movement of the saline interface along the modelled cross-section would be negligible over the construction period of the project.

Continuation of the current monitoring program would allow identification of groundwater depressurisation and saline intrusion effects as construction progresses. The monitoring of groundwater inflow quality would allow quantification of salt loads and variation over time.

6.1.3.2 Groundwater users

Where existing groundwater users are using bores that target the water table, the water table drawdown has been considered in respect to potential impacts. Where bores are targeting deeper horizons, the drawdown in layer five of the model has been considered to assess the potential impacts. This is a conservative approach as layer five represents the largest drawdown of all model layers as this is the layer in which the tunnel is situated.

The predicted water table drawdown at the three existing groundwater bores that are potentially being used for water supply is shown in Table 6-2. The Minimal Impact Considerations in the AIP are a cumulative water level decline of no more than two metres and this requirement is not met for GW109209, but it is met for GW107764 and GW108991.

GW109209 penetrates to a depth of around 4.5 metres (17 metres Australian Height Datum) while water level monitoring at nearby groundwater monitoring bores (B104 and B209) show water levels of around two to three metres Australian Height Datum, which would be around 14 metres below the base of GW109209. It is expected that this bore is accessing a shallow perched groundwater system that may not be connected to the regional water table.

Site inspection would be carried out at these three bores to confirm their current viability, and if viable, monitoring would be carried out for baseline data as well as during and post construction. Any loss in yield from bores where the drawdown impact is over two meters would require the implementation of make good provisions as discussed in Section 7.

Table 6-2 Predicted drawdown at existing bores at the end of construction

Receptor	Location	Drawdown – project only	Drawdown – cumulative
GW109209	Birchgrove	2-3m	2-3m
GW108991	Wollstonecraft	<1m	<1m
GW107764	North Sydney	<1m	1-2m

6.1.3.3 Areas of environmental interest for contamination

The following potential impacts would arise from areas of environmental interest for contamination:

- Where there is existing groundwater contamination, altered hydraulic gradients may change the speed and direction of contaminant migration. Lowered water table due to dewatering drawdown may act to disconnect the contaminant plume from the contaminant source
- Where there is existing soil contamination that has not yet migrated to the water table, lowering of the water table due to dewatering drawdown would act to mitigate, or delay, the potential for contamination to migrate to groundwater.

Drawdown at areas of environmental interest for contamination has been considered with respect to the water quality guidelines from the AIP, which state that the beneficial use of the groundwater source 40 metres away from the activity must not be reduced.

Predicted drawdown at areas of environmental interest for contamination with moderate to high risk within 500 metres of the project alignment is summarised in Table 6-3.

Table 6-3 Predicted drawdown at areas of environmental interest for contamination at the end of construction

Areas of environmental interest for contamination	Reference (Figure 5-17)	Risk of existing groundwater contamination	Drawdown - Project only 2026 (m)	Drawdown – Cumulative 2026 (m)
Rozelle Rail Yards	W1	High	<1	1 to 9
Easton Park – Corner Denison Street and Lilyfield, Rozelle	W2	Moderate	1 to 5	16 to 37
Yurulbin Park, Birchgrove	W3	Moderate	<1	<1
Waverton Park – Woolcott Road, Waverton	W8	High	<1	1 to 2

Areas of environmental interest for contamination	Reference (Figure 5-17)	Risk of existing groundwater contamination	Drawdown - Project only 2026 (m)	Drawdown – Cumulative 2026 (m)
NSW EPA regulated/notified Sites				
Rozelle - Whites Bay Power Station	Site 1	Moderate	2 to 4	7 to 12

Source: 1) NSW EPA list of contaminated sites notified to the EPA; 2) Technical working paper: Contamination.

Drawdown would be generally minor at most areas of environmental interest for contamination in the project only case and, given the relatively low hydraulic properties of the Hawkesbury Sandstone, would not be expected to cause migration of contaminants during the construction period.

The cumulative water table drawdown in areas of environmental interest for contamination around Rozelle would be largely due to the effect of the M4-M5 Link project and indicates that there is a risk of contaminants migrating. The potential for migration would depend on whether or not the contamination has reached the water table, the aquifer permeability at the contaminant location, and the hydraulic gradient at the site. Contaminant migration caused by drawdown from the tunnel may degrade water quality more than 40 metres from the tunnel and does not meet the Level 1 Minimal Impact criteria of the AIP. However, there are no GDEs, baseflow dependent watercourses or groundwater bores situated between the project alignment and contaminated sites. The viability of these receptors is not expected to be impacted, which satisfies the AIP.

Any migration of contaminants would be towards the tunnel where all water would be collected and treated. Given the hydraulic properties of the Hawkesbury Sandstone and the additional dilution that would occur if contaminants are mobilised, the risk of contaminant migration impacting underground structures due to drawdown associated with the project is considered negligible.

6.1.3.4 Groundwater dependent ecosystems and sensitive environments

There are no groundwater dependent ecosystems or sensitive environments in the area of predicted drawdown, as shown in Figure 6-1 and Figure 6-2. The closest listed Ramsar wetland of international importance is the Towra Point Nature Reserve, located 17 kilometres south of the project. Towra Point Nature Reserve is outside the area of predicted impact and would not be impacted.

6.1.3.5 Surface water systems

The baseflow impacts have been compared against the indicative flow measurements to assess the potential impact to total flow. The nature of the watercourse substrate has been ascertained during ground truthing. Whites Creek is known to be concrete lined within the area of predicted drawdown and would not be reliant on groundwater baseflow. Therefore, there are no baseflow dependent surface water systems within the area of predicted water table drawdown during the construction phase, for the project only scenario, as shown in Figure 6-1.

The predicted reduction in baseflow to Flat Rock Creek at the end of construction (2026) is 549 kilolitres per day, which represents an 83 per cent reduction in baseflow.

The predicted baseflow impact to Quarry Creek at the end of construction is a reduction of 13 kilolitres per day, which equates to a total flow reduction of around 27 per cent.

No drawdown is predicted beneath Willoughby Creek, in addition, ground truthing has shown that the upper reaches of the Willoughby Creek are lined (refer to Figure 4-2) and therefore would not be impacted by groundwater drawdown.

With respect to the predicted baseflow reductions, the following points are noted:

- Groundwater modelling assumes continuous saturation between the tunnel horizon and the shallow water table. In reality the system would be stratified, possibly with disconnected aquifer horizons. The predicted maximum drawdowns are therefore unlikely to be realised and the predicted reduction in base flows are therefore conservative
- Portions of the upper reaches of Flat Rock Creek are highly altered, including concrete lining and tunnel sections. This lining of the creek bed would largely attenuate any drawdown-related impacts and baseflow reductions.

6.1.3.6 Risk of activation of acid sulfate soils

Areas at high risk of acid sulfate soil (ASS) activation are where drawdown causes soil and rock with high concentrations of sulfide minerals (predominantly pyrite and pyrrhotite) to be exposed to oxygen. Activation of ASS has potential to alter groundwater quality by lowering pH and elevating heavy metal content. The Hawkesbury Sandstone would not pose a high risk of acid generation. Key areas of ASS risk are associated with the sediments beneath the Rozelle Rail Yards, Birchgrove Park, Waverton Park and the sediments of Sydney Harbour. Table 6-4 summarises predicted drawdown at these locations.

Table 6-4 Predicted drawdown in areas of ASS risk at the end of construction (2026)

Location	Drawdown – project only (m)	Drawdown – cumulative (m)
Rozelle Rail Yards	<1	1 – 15
Birchgrove Park	2 – 3	2 – 3
Waverton Park	<1	<1
Sydney Harbour[1]	N/A	N/A

Note 1: Groundwater drawdown beneath Sydney Harbour is not applicable due to the constant head of water in the harbour.

While predicted drawdown at Rozelle Rail Yards and Birchgrove Park indicates a risk of ASS activation, mobilisation of heavy metals is not expected to discharge to any surface water features or other groundwater users.

Should soils/sediments in proximity to the Rozelle Rail Yards and Birchgrove Park or within Sydney Harbour, White Bay and/or Berrys Bay require excavation to facilitate construction, these sediments would be assessed for the presence of ASS prior to excavation. Should ASS be identified, an appropriate ASS management plan would be developed in accordance in the ASSMAC (1998) guidelines.

There are no groundwater dependent ecosystems, culturally significant sites or groundwater users in the areas of anticipated ASS, so these receptors would not be impacted. Poorer quality groundwater may affect the quality of inflows to the tunnels leading to a potential human health risk. This risk would be managed through inflow water quality monitoring and the water collection and treatment process.

6.1.3.7 Impacts on groundwater quality from tunnel materials

Potential impacts on groundwater quality due to saline intrusion, mobilisation of contaminants and potential acidification have been discussed in the previous sections.

Components of the tunnel structures may have potential to impact groundwater quality in the surrounding aquifer. Potential sources of contamination include:

- Drilling/cutting fluids at the roadheader/tunnel boring machine
- 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.

These potential contaminant sources are considered to be low risk. Even if contamination to groundwater was to occur during tunnel construction, the likelihood of the contaminated groundwater migrating away from the tunnels is very low, since the tunnel acts as a drain and groundwater flows towards it, rather than away from it. Furthermore, it is expected that this risk would be mitigated through the implementation of pollution control strategies as part of the construction environmental management plan (CEMP) (refer to Section 7.1).

6.1.3.8 Potential for settlement

Settlement of the ground surface may occur due to:

- Tunnel excavation causing the redistribution of stresses in the rock mass
- Tunnel inflows causing groundwater drawdown and depressurisation of aquifers.

Settlement assessment was carried out by Arup and WSP (2019). Assessment of settlement damage to infrastructure considered the maximum predicted settlement and surface angular distortion at infrastructure locations.

All project components are expected to experience ground surface settlement impacts of over 10 millimetres. The tanked section of the mainline tunnels alignment from Rozelle to the Western Harbour Tunnel and the Warringah Freeway portal are expected to experience long-term surface settlement of between 55-60 and 50-55 millimetres respectively, such long-term surface settlement would be considered to have a severity degree of ‘moderate’. All other project components are anticipated to be subject to total long-term settlement measurements of 40 millimetres or less, considered to be of ‘slight’ degree of severity. A number of buildings are predicted to experience very slight to slight aesthetic damage from long-term ground surface settlement.

The predicted angular distortion slightly exceeds 1:500 (see Table 4-1 for more information) at the Warringah Freeway portal and at the location where the tunnel crosses Sydney Harbour. Further to this, the only asset expected to experience an angular distortion greater than 1:500 is the existing Ernest Street Bridge located within the Warringah Freeway corridor.

Arup and WSP (2019) identified 106 buildings across the Western Harbour Tunnel and Warringah Freeway Upgrade project where the expected degree of impact severity was ‘very slight’. No other buildings are expected to be more severely impacted by the project.

With regards to identified services or other infrastructure elements, angular distortion was assessed to exceed 1:500 (although be within approximately 1:500 – 1:200) for some 132kV transmission cables located at a depth of approximately 1.2m in Cammeray as well as an existing 3251 x 2426 sewer situated at a depth of 63m approximately in the same area. Maximum long-term surface settlement for these and all other infrastructure elements is considered to be 45 millimetres or less, a degree of severity considered to be ‘slight’ (Table 4-1).

It was assessed that identified heritage structures would not exceed slight severity of impact (maximum settlement of 50 millimetres or angular distortion greater than 1:200, see Table 4-1 for more information). Maximum ground surface settlement was anticipated to be 40 millimetres or less while angular distortion is expected to be 1:200 or less at all identified heritage sites.

Refer to Section 7.1 for proposed measures to manage predicted ground surface settlement impacts.

6.1.3.9 Reduced groundwater recharge

The conversion of pervious areas to impervious areas during construction has the potential to reduce infiltration of rainfall or surface flow and to reduce recharge. The construction period is not considered of sufficient duration to impact aquifer recharge rates and most of the pervious surfaces created would be converted back to unpaved areas. The impacts due to the permanent changes are discussed in Section 5.5.3.

6.2 Assessment of operational impacts

Subject to project approval, the operation of the project is planned to start following completion in 2026. The assessment of operational impacts considers potential impacts at the commencement of operation and at around 100 years into the operational lifetime of the project.

6.2.1 Tunnel inflows

Inflows to the completed drained sections of the project tunnels were calculated for two time periods during the operational phase, as shown in Table 6-5. Inflows would diminish over time as the hydraulic gradient towards the tunnels flattens and the system approaches equilibrium. Peak operational inflows of 0.36 litres per second per kilometre averaged over the whole project are predicted to occur at the beginning of operation. After 100 years of operation, modelled inflows are predicted to decline to 0.32 litres per second per kilometre. Predicted inflows remain below the one litre per second per kilometre design criteria throughout the modelled period. Planned measures to collect, treat and dispose of tunnel inflows are summarised in Section 2.1.6.

Annual inflows during operation are predicted to be relatively uniform, with 203 megalitres per year in the first year of operation (2026) and 180 megalitres per year after 100 years. The long-term average annual extraction limit (LTAAEL) for the Sydney Central Basin is 45,915 megalitres per year and current groundwater access licences equate to 2592 megalitres per year, leaving around 43,323 megalitres of unassigned water. The predicted peak annual tunnel inflows would be less than one per cent of the water unassigned under the LTAAEL.

Table 6-5 Summary of modelled average tunnel inflows during operation

	Rozelle to Sydney Harbour	Sydney Harbour to Warringah Freeway	Entire project		Total annual inflows
Year	L/s/km	L/s/km	L/s/km	ML/day	ML/ year
2026	0.548	0.161	0.355	0.557	203
2126	0.486	0.143	0.314	0.493	180

During operation, tunnel inflows would be collected, treated at the Rozelle wastewater treatment plant which would be located at the Rozelle interchange and discharged into the local stormwater system and ultimately Rozelle Bay as described in Section 2.1.6. Refer to Technical working paper: Marine water quality for an assessment of potential impacts from treated tunnel inflow discharges from the Rozelle wastewater treatment plant into Rozelle Bay.

6.2.2 Drawdown

This section assesses the drawdown of the water table caused by the operation of the project and also considers the cumulative impacts with the M4-M5 Link, Sydney Metro Chatswood to Sydenham, and Beaches Link and Gore Hill Freeway Connection projects. Drawdown is reported for 2126, after around 100 years of operation.

This section reports impacts according to the following modelled scenarios detailed in Section 7.1 of the modelling report shown in Appendix F:

- Western Harbour Tunnel and Warringah Freeway Upgrade project only (this represents the incremental additional impact due to the project with the M4-M5 Link and the Sydney Metro Chatswood to Sydenham projects which have been approved)
- Western Harbour Tunnel and Warringah Freeway Upgrade project together with the M4-M5 Link, Sydney Metro Chatswood to Sydenham and Beaches Link and Gore Hill Freeway Connection projects (this represents the cumulative or total impact due to all four projects).

6.2.2.1 Western Harbour Tunnel and Warringah Freeway Upgrade only

Water table drawdown at the commencement of operation is the same as at the end of construction (Section 6.1.2) and as such no further assessment has been carried out.

After 100 years of operation, predicted drawdown magnitudes are similar to end of construction. There is recovery of drawdown in the vicinity of the Victoria Road access decline, with a corresponding recovery in drawdown to the west. There is also a minor propagation of drawdown towards Birchgrove and Balmain (refer to Figure 6-3). North of the harbour maximum predicted drawdown above the alignment increases to about five metres in Waverton and North Sydney, and a minor propagation of drawdown extent away from the alignment.

Potential impacts on receptors in the areas of drawdown are discussed in Section 6.2.3.

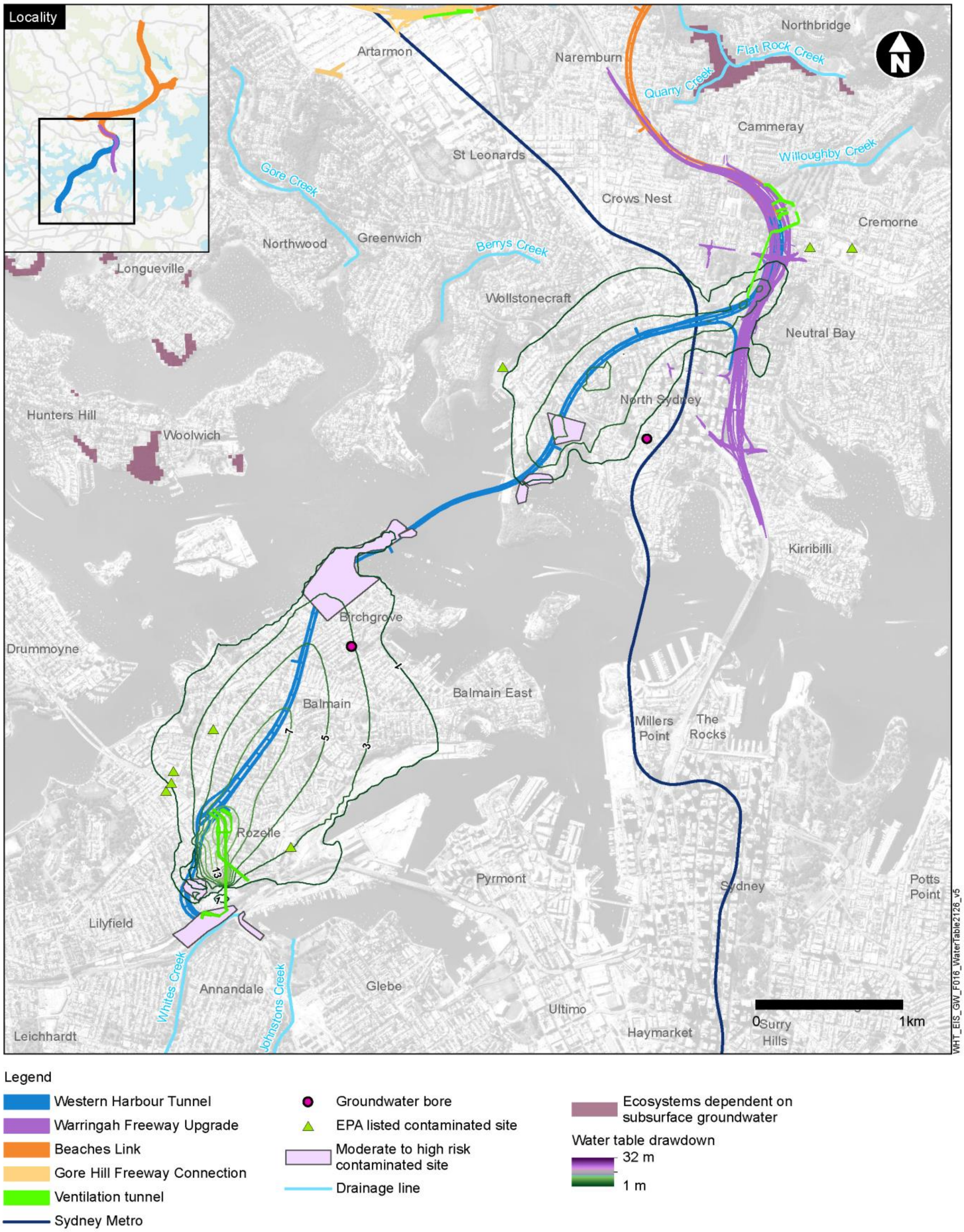


Figure 6-3 Predicted drawdown in the water table after 100 years of operation (2126) (project only)

6.2.2.2 Cumulative drawdown

In 2026, the predicted cumulative drawdown at the water table is as per the predicted drawdown at end of construction (Section 6.1.2.2).

After 100 years of operation, the magnitude of drawdown is similar to that at end of construction, with a maximum drawdown of about 40 metres in Rozelle. As with the project only scenario, there is a recovery in water level at the location of the Victoria Road access decline, and a slight propagation of extent of drawdown away from the alignment (Figure 6-4). North of the harbour there is minor increase in the magnitude of drawdown above the alignment, however there are minor variations in the extent of propagation.

As with the end of construction, cumulative drawdown is dominated by drawdown around the North Sydney Metro Station, and with extended drawdown to the north due to the Beaches Link and Gore Hill Freeway Upgrade project.

Potential impacts on receptors in the drawdown area of influence are discussed in Section 6.2.3.

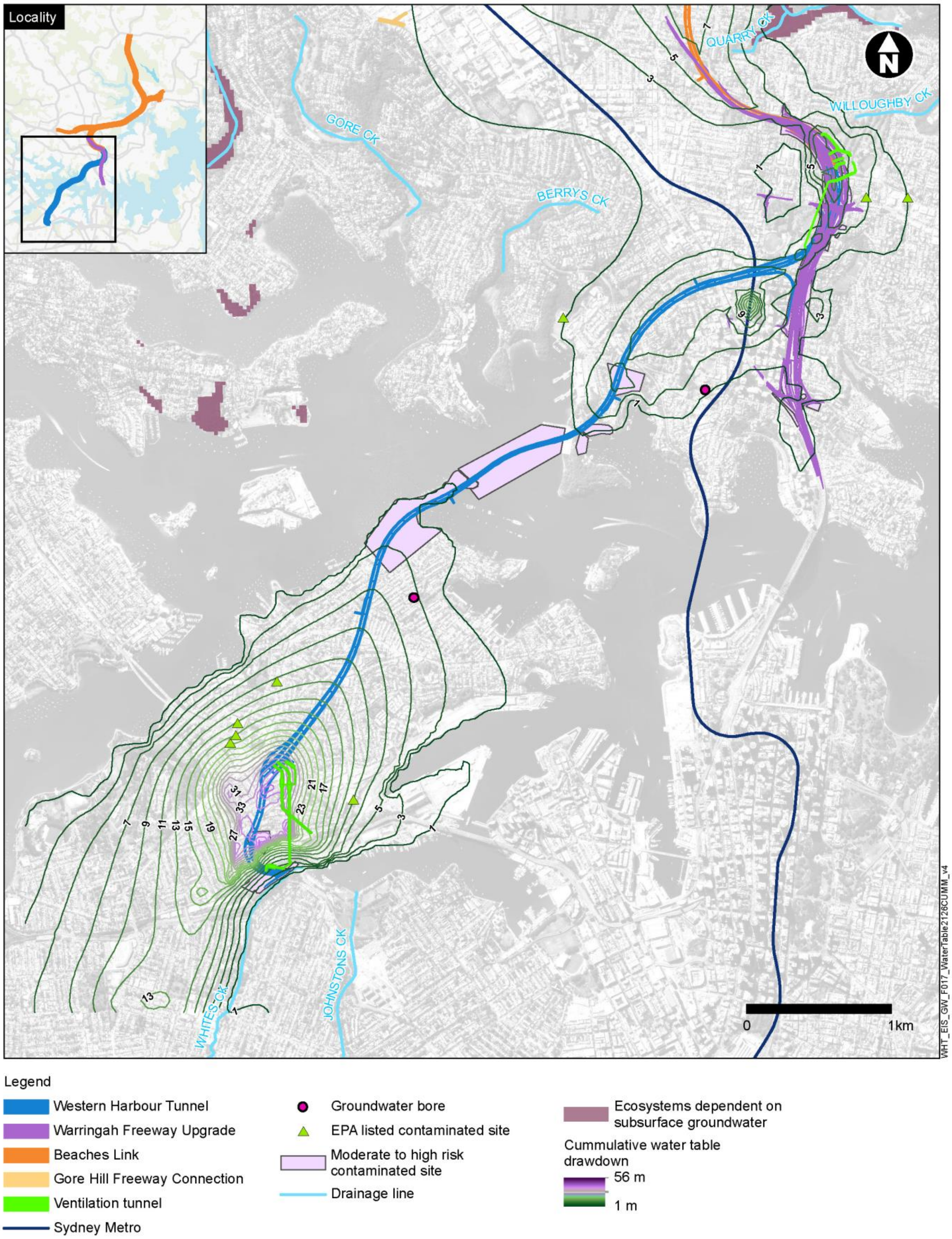


Figure 6-4 Predicted drawdown in the water table after 100 years of operation (2126) (cumulative)

6.2.3 Potential impacts

Potential impacts resulting from the predicted drawdown of the water table are discussed in the following sections.

Drawdown for each receptor is rounded up to the nearest metre and assessed against the *NSW Aquifer Interference Policy* (AIP) requirements. There are no WAL bores or groundwater dependent culturally sensitive sites within the predicted drawdown extents, therefore drawdown from the project would not affect these receptors and they have not been assessed further. There are no culturally sensitive sites that are groundwater dependent in the area of drawdown, however potential impacts relating to the settlement of the ground surface may affect their integrity, which is considered in Section 6.1.3.8.

Whites Creek is within the drawdown extents but is a lined stormwater drain and as such would not be dependent on groundwater baseflow. The creek is to be rehabilitated by Sydney Water and is largely expected to remain as a lined stormwater drain that is unlikely to be baseflow dependent. Due to the absence of groundwater interaction, it is not considered further in this section.

The receptors that may be impacted by drawdown associated with the project are discussed below.

6.2.3.1 Saline intrusion

The two-dimensional modelling conducted to assess the impacts of saline intrusion (refer to Appendix F) predicts that the onset of saline intrusion is very slow within the Hawkesbury Sandstone due to the low hydraulic conductivity of the formation. Modelling predicts that the maximum lateral movement of the saline interface inland after 100 years of project operation would be around 150 metres, which occurs at a depth of around 80 metres. In the upper portion of the aquifer (above 50 metres AHD), the mixing zone is predicted to migrate inland by up to around 30 metres. The predicted migration of the saline interface is negligible and impacts on other groundwater users, groundwater dependent ecosystems, or the beneficial use of the aquifer are not expected.

6.2.3.2 Groundwater users

Where existing groundwater users are using bores that target the water table, the water table drawdown has been considered. Where bores are targeting deeper horizons, the drawdown in layer five of the model has been considered to assess the impacts. This is a conservative approach as layer five represents the largest drawdown of all model layers as this is where the tunnel is situated.

The predicted water table drawdown at the three existing groundwater bores that are potentially being used for water supply is shown in Table 6-6.

Drawdown at the domestic bore GW109209 in Birchgrove is predicted to be up to three metres in 2026 and up to four metres in 2126. Drawdown of up to two metres at bores GW107764 and GW108991 is predicted in 2126 for the cumulative scenario.

Predicted drawdown at GW109209 would exceed the Level 1 Minimal Impact considerations in the AIP. It is expected that GW109209 is accessing a shallow perched groundwater system that may not be connected to the water table. If this is the case, then the bore would not be affected by drawdown. If this bore is accessing the water table, the predicted drawdown may result in loss of production.

Predicted drawdowns at GW107764 and GW108991 are less than the Level 1 Minimal Impact criteria of two metres.

A site inspection would be carried out to confirm the current viability of all three bores, and if viable, monitoring would be carried out during and post construction to assess a water level response due to dewatering.

Monitoring can cease if analysis determines that these bores would not be impacted. Any loss in yield from the bores would require the implementation of make good provisions as discussed in Section 7.2.

Table 6-6 Predicted drawdown at existing users during operational phase

Receptor	Location	Drawdown – project only 2026	Drawdown – project only 2126	Drawdown – cumulative 2026	Drawdown – cumulative 2126
Domestic bores					
GW109209	Birchgrove	2-3m	3-4m	2-3m	3-4m
GW108991	Wollstonecraft	<1m	1m	<1m	1-2m
GW107764	North Sydney	<1m	<1m	1-2m	1-2m

6.2.3.3 Areas of environmental interest for contamination

Predicted drawdown at areas of environmental interest for contamination within 500 metres of the project alignment is summarised in Table 6-7.

Table 6-7 Predicted drawdown at areas of environmental interest for contamination during operation

Areas of environmental interest for contamination	Reference (Figure 5-17)	Risk of existing groundwater contamination	Drawdown - project only 2026 (m)	Drawdown - project only 2126 (m)	Drawdown – cumulative 2026 (m)	Drawdown – cumulative 2126 (m)
Rozelle Rail Yards	W1	High	<1	<1	1 to 9	1 to 9
Easton Park – Corner Denison Street and Lilyfield, Rozelle	W2	Moderate	1 to 5	1 to 5	16 to 38	16 to 39
Yurulbin Park, Birchgrove	W3	Moderate	<1	<1	<1	<1
Waverton Park – Woolcott Road, Waverton	W8	High	<1	<1	1 to 2	3 to 5
NSW EPA regulated/notified sites						
Rozelle - White Bay Power Station	Site 1	Moderate	2 to 4	2 to 5	7 to 12	7 to 13

There is potential for contaminants to migrate and reduce the beneficial uses of groundwater due to drawdowns and increased hydraulic gradients at some areas of environmental interest for contamination, particularly in the cumulative drawdown scenarios. Predicted long-term drawdown at areas of environmental interest for contamination around the Rozelle dive structure would be substantial and there would be a risk of contaminants migrating if contaminants have reached the water table. The distance of migration would depend on whether the contamination has reached the water table, the aquifer permeability at the contaminant location, and the hydraulic gradient at the site.

If contamination associated with these sites has reached the water table, then migration caused by drawdown from the tunnel could degrade water quality more than 40 metres from the tunnel, and the Level 1 Minimal Impact criteria of the AIP would not be satisfied. However, there are no GDEs or baseflow dependent watercourses in the area of drawdown, and the groundwater users (GW107764, GW108991 and GW109209) are not situated between the tunnels and any contaminated sites therefore, impacts due to mobilised contamination are not expected.

Any migration of contaminants would be towards the tunnel where all water would be collected and treated at the Rozelle wastewater treatment plant. Given the hydraulic properties of the Hawkesbury Sandstone and the additional dilution that would occur if contaminants are mobilised, the risk of contaminant migration impacting underground structure due to drawdown associated with the project is considered negligible.

6.2.3.4 Groundwater dependent ecosystems and sensitive environments

There are no groundwater dependent ecosystems in the area of predicted drawdown, as shown in Figure 6-3 and Figure 6-4. The closest listed Ramsar wetland of international importance is the Towra Point Nature Reserve, located 17 kilometres south of the project. Towra Point Nature Reserve would not be impacted by the project.

6.2.3.5 Surface water systems

The Whites Creek channel is concrete lined (refer to Figure 4-2) and for this reason does not rely on groundwater baseflow. Quarry Creek and Flat Rock Creek are outside the predicted area of drawdown for the project only case, as shown in Figure 6-3. The predicted water table drawdown beneath the GDE is predicted to be typically less than one metre for the majority of the GDE area.

The predicted reduction in baseflow to Flat Rock Creek is 549 kilolitres per day (an 83 per cent reduction in baseflow) at the beginning of operation in December 2026 and 433 kilolitres per day (an 86 per cent reduction) after about 100 years of operation.

The predicted reduction in baseflow to Quarry Creek changes from 13 kilolitres per day (a 26 per cent reduction in baseflow) at the beginning of operation to 15 kilolitres per day (a 42 per cent reduction) after about 100 years of operation.

Drawdown is predicted to be negligible beneath Willoughby Creek. In addition, ground truthing has shown that upper reaches of the Willoughby Creek is lined (refer to Figure 4-2) and therefore would not be impacted by groundwater drawdown.

With respect to the predicted baseflow reductions, the following points are noted:

- Groundwater modelling assumes continuous saturation between the tunnel horizon and the shallow water table. In reality the system would be more stratified, possibly with disconnected aquifer horizons. The predicted maximum drawdowns are therefore unlikely to be realised and the predicted reduction in base flows are therefore conservative.
- Portions of the upper reaches of Flat Rock Creek are highly altered, including concrete lining and tunnel sections. This lining of the creek bed would largely attenuate any drawdown related impacts and baseflow reductions

6.2.3.6 Risk of activation of acid sulfate soils

Areas at high risk of acid sulfate soils (ASS) activation are where drawdown causes soil and rock with high concentrations of sulphide minerals (predominantly pyrite and pyrrhotite) to be exposed to oxygen.
The Hawkesbury Sandstone is not considered to pose a high risk of acid generation. Key areas of ASS risk are associated with the sediments beneath Rozelle Rail Yards, Birchgrove Park, and the sediments of Western Harbour. Table 6-8 summarises predicted drawdown at these locations.

Table 6-8 Predicted drawdown in areas of ASS risk during operation (2026 and 2126)

Location	Drawdown – project only, 2026	Drawdown – project only, 2126	Drawdown – cumulative, 2026	Drawdown – cumulative, 2126
Rozelle Rail Yards	<1m	<1m	1 – 15m	1 – 15m
Birchgrove Park	2 – 3m	2 – 3m	2 – 3m	2 – 3m
Sydney Harbour[1]	N/A	N/A	N/A	N/A

Note: 1. Groundwater drawdown beneath Sydney Harbour is not applicable due to the constant head of water in the harbour.

The predicted drawdown at Birchgrove Park and Rozelle Rail Yards (in the cumulative scenario only) indicates there is potential for acid generation and mobilisation of heavy metals. There are no baseflow dependent streams, groundwater users, GDEs or culturally significant sites in these areas hence impacts are not expected.

Activation of ASS has potential to alter groundwater quality by lowering pH and elevating heavy metal content. There are no GDEs, baseflow dependent streams, culturally significant sites or groundwater users in the area of anticipated ASS, hence impacts on these matters are not anticipated. However poorer quality groundwater could have implications for the integrity of underground structures and for the tunnel structure itself, due to increased acidity. The high acidity and associated heavy metal content would also affect the quality of groundwater inflow to the tunnels which would be managed through the Rozelle wastewater treatment plan treatment and disposal processes.

6.2.3.7 Impacts on groundwater quality from tunnel materials

Potential impacts on groundwater quality due to saline intrusion, mobilisation of contaminants and potential acidification have been discussed in the previous sections.

During tunnel operation, no other adverse impacts on groundwater quality are expected because all water within the tunnel would be collected and treated at the Rozelle wastewater treatment plant. In the event that contamination was to occur, the likelihood of the contaminated groundwater migrating away from the tunnel is very low, since the tunnel would act as a drain and groundwater would flow towards rather than away from it.

6.2.3.8 Potential for settlement

Settlement of the ground surface may occur due to:

- Tunnel excavation causing the redistribution of stresses in the rock mass
- Tunnel inflows causing groundwater drawdown and depressurisation of aquifers.

Areas of groundwater level drawdown assessed to induce ground settlement during operation are consistent with those predicted during construction. Ground settlement during operation is not expected to exceed that experienced during the construction phase. Ground settlement impacts are outlined in Section 6.1.3.8.

6.2.3.9 Reduced groundwater recharge

The conversion of pervious areas to impervious areas has the potential to reduce infiltration of rainfall or surface flow and to reduce groundwater recharge.

Permanent infrastructure at Rozelle and the Warringah Freeway Upgrade would lead to an increase in impervious surfaces. The impact to groundwater recharge has been quantified based on the increased impervious area, the average annual rainfall (refer to Section 5.1) and the Hawkesbury Sandstone recharge rate of three per cent that has been applied in the groundwater modelling.

The results for Rozelle are displayed as percentage reduction to the southern modelled zone bounded by Sydney Harbour to the north and the results for the Warringah Freeway Upgrade are displayed as percentage reduction to the modelled zone bounded by Sydney Harbour to the south and Middle Harbour to the north (refer to Appendix F for groundwater model domains). The results shown in Table 6-9 indicate that the reduction in groundwater recharge would be negligible.

Table 6-9 Estimated groundwater recharge reduction

Location	Existing impervious area (ha)	Increase in impervious area (ha)	Increase impervious area (%)	Groundwater recharge reduction (kL/yr)	Groundwater recharge reduction %
Rozelle	2.61	0.55	21%	203	0.04%
Warringah Freeway Upgrade	42.93	3	7%	1107	0.03%

6.2.3.10 Impacts due to ancillary facilities and infrastructure

Ancillary infrastructure has the potential to interact with groundwater in cases where construction or foundations penetrate to below the water table. Surface infrastructure such as the Rozelle wastewater treatment plant, utility adjustments and ventilation facilities would not penetrate to sufficient depth to interact with the water table and are not expected to impact groundwater.

Deeper infrastructure such as tunnel portals and ventilation shafts can impact groundwater as they would require dewatering during construction and operation and increase the overall footprint of the project, which can impede groundwater movement. This infrastructure has been included in the groundwater model and any associated impacts are considered and discussed collectively throughout Section 6.

6.2.3.11 Barriers to groundwater flow

Infrastructure installed below the water table can impede the natural movement of groundwater by creating a barrier to flow, causing mounding behind the barrier. Where groundwater moves through discrete or poorly connected horizons it is possible that a barrier could cause a permanent flow disruption through compartmentalisation. The groundwater modelling indicates some degree of connectivity throughout the full thickness of the modelled portion of the aquifer and groundwater is not expected to become compartmentalised due to the project.

The proposed tunnel design for the project is predominantly drained, where groundwater would enter the tunnel and, as such, the tunnel would not represent a physical barrier to flow. In some areas where inflows are enhanced due to highly permeable zones, there would be design measures such as grouting to reduce the bulk hydraulic conductivity or the use of lining methods such as waterproof umbrellas to divert groundwater flow around the crown of the tunnel. Such design measures would be localised and would permit groundwater movement around the barrier.

The undrained portions of the tunnel are planned to be within the immediate vicinity of the Sydney Harbour crossing and are therefore localised. Given the naturally enhanced permeability is this area and the proximity to the coast, groundwater would be able to migrate around these sections and, as such, the undrained sections are not considered to represent an impediment to groundwater flow.

The groundwater drawdown caused by tunnel dewatering would locally affect groundwater movement by altering the natural head gradient and in some cases reversing the gradient as groundwater is diverted to tunnel. This represents a hydraulic barrier to groundwater movement and the groundwater modelling indicates that this effect extends upwards from the tunnel to the ground surface. Groundwater movement below the tunnel alignment would be largely unaffected except for some minor disturbance in the immediate vicinity of the tunnel.

6.2.3.12 Final landform

Impacts to final landform can occur due to settlement of the land surface due to dewatering. This is most pronounced in alluvial sediments but can also occur in consolidated lithologies.

Impacts on the final landform due to settlement would be negligible.

Other impacts to landform can occur due to baseflow reduction to water courses leading to geomorphological changes. Potential impacts to geomorphology are discussed in the EIS Technical working paper: Surface Water.

7. Impact management measures

This section presents measures to mitigate and minimise the potential impacts identified in previous sections for both the construction and operational phases of the project.

7.1 Management of construction impacts

Measures to be included in the relevant management plan to be developed in respect to the project's construction would address potential impacts such as those outlined below (Table 7-1). There are no GDEs, baseflow dependent surface water courses or groundwater dependent culturally significant sites within the project area. Reduced recharge as a result of creation of impervious surface during construction is considered negligible. The potential for impacts associated with saline intrusion and contamination of groundwater by tunnel infrastructure is also unlikely during the construction period. These risks are not considered to require management during construction and are not included in Table 7-1.

Table 7-1 Summary of potential groundwater impacts during construction and required management measures

Potential impact	Mitigation and management measure
Groundwater modelling update	As more information becomes available through ongoing groundwater monitoring, groundwater modelling will be updated to refine the predictions documented in this technical working paper. Inflow predictions will be updated during further design development and operational inflow and impacts predictions will be updated at the end of the construction period. If refined predictions indicate that impacts would be greater than the impacts documented in this technical working paper, feasible and reasonable mitigation measures will be implemented.
Groundwater inflows and water table drawdown	Groundwater inflows are predicted to result in water table drawdown of up to 20 metres during construction. Where feasible and reasonable, groundwater drawdown will be managed by reducing inflows through the following measures: • Where inflows exceed 1L/s/km, particularly at excavated tunnel sections in proximity to Sydney Harbour, appropriate waterproofing measures will be implemented. Measures can range from a spray-on membrane to grouting or installation of a sheet membrane • A tunnelling procedure that details a methodology to determine when and what type of waterproofing is required to be installed will be implemented. Procedures to be considered will include: - Pre-excavation pressure grouting in locations identified that could produce substantial inflows to reduce groundwater inflows to an acceptable level - Post grouting (ie grouting carried out post excavation) within one month of excavation to further reduce groundwater inflows. Groundwater inflows into the tunnels will be monitored during construction and compared to predictions from the updated groundwater model. If required, the groundwater model will be updated based on the results of the monitoring and proposed management measures to minimise groundwater inflows will be adjusted accordingly to ensure that groundwater inflow performance criteria are met.

Potential impact	Mitigation and management measure
Drawdown impact on existing groundwater users	Water table drawdown at bore GW109209 is predicted to be three metres. If this bore is connected to the water table, the predicted impact would exceed the minimal impact considerations of the *NSW Aquifer Interference Policy* (DPI Water, 2012). Water table drawdown at bore GW107764 is predicted to be two metres (cumulative scenario) and at GW108991 water table drawdown is predicted to be less than one metre, which satisfies the minimal impact considerations of the AIP. Site inspection will be carried out to confirm the current viability of these bores. If viable, the bores will be monitored throughout the construction phase or until analysis can confidently determine that these bores will not be impacted or preventative make good measures are implemented. If loss of yield results from tunnel dewatering, make good measures would include lowering the pump, installing a deeper bore or connection to an alternative water supply.
Drawdown impact on surface water systems	Groundwater modelling predicts baseflow reductions at Flat Rock Creek and Quarry Creek. Monitoring of surface water flows will be implemented at these locations to provide a more detailed data set for model calibration to baseflow, and to allow for identification of potential baseflow reduction due to groundwater drawdown.
Drawdown causing migration of contaminant plumes and reduction in beneficial uses of the aquifer	As discussed in the Technical working paper: Contamination, to further quantify the risk from groundwater contamination to construction and/or operation of the project (including dewatering), further investigations are required at Rozelle Rail Yards, Easton Park at Lilyfield Road Rozelle, Yurulbin Park and Waverton Park. If contamination risks are established, appropriate design (eg tanking) and/or management (eg treatment) measures would be implemented to remove or suitably reduce the associated risk. The following groundwater contamination management measures will be implemented: • Monitoring of groundwater levels and quality prior to and during construction. This includes monitoring of the existing project groundwater monitoring network (plus one Hawkesbury Sandstone groundwater monitoring bore installed as part of the M4-M5 Link Groundwater Impact Assessment (AECOM, 2017) at each of the Rozelle Rail Yards and the Rozelle foreshore sites) • Confirmation / characterisation of the groundwater contamination status at these sites • Where contamination is found to be present: - Modelling/mass balance analysis to assess likely quality of groundwater inflows with establishment of trigger levels relating to human health risk - Monitoring of the quality and quantity of groundwater inflows to tunnels for comparison against modelled predictions and human health risk trigger levels. Where the potential for groundwater contamination due to project processes/activities is identified, appropriate mitigation/management measures will be implemented where feasible and reasonable.
Drawdown causing oxidation of ASS and increasing acidity and	Sediments within Sydney Harbour will be assessed for the presence of ASS (actual or potential) before sediment excavation commences. Should ASS be identified, appropriate ASS management measures will be developed and

Potential impact	Mitigation and management measure
heavy metal contamination, reducing beneficial uses of the aquifer, poorer quality tunnel inflows, health issues for users of underground structures, and impacts on integrity of underground structures	implemented in accordance with the ASSMAC (1998) *Acid Sulfate Soil Assessment Guidelines*. ASS waste (where generated) will be managed in accordance with the NSW EPA (2014) *Waste Classification Guidelines*. If potential for acidification is deemed a high risk, the groundwater drawdown and quality will be monitored in areas of high risk during construction. Remedial or mitigating measures to prevent or contain contaminant migration will be implemented which may include bunding or treatment ponds.
Contamination due to leakage or spills	Emergency spill measures will be developed to avoid and manage accidental spillages of fuels, chemicals, and fluids to minimise the risk of human health impacts and contamination of groundwater.
Ground surface settlement	The following measures will be implemented to manage settlement impacts: • Detailed predictive settlement models will be development in greater detail for areas of concern to guide tunnel design and construction methodology, including the selection of options to minimise settlement where required. • Building/structure condition survey will be prepared for properties (and heritage assets) with the zone of influence of tunnel settlement (for example the 5 millimetre predicted surface settlement contour and within 50 metres of surface works) prior to the commencement of construction. Agreements with utility and infrastructure owners will be prepared before tunnel construction starts identifying acceptable limits of settlement, settlement monitoring and actions in the event that settlement limits are exceeded.

7.2 Management of operational impacts

Measures to be included in the relevant management plan to be developed in respect to the project's operation would address potential impacts such as those outlined below (Table 7-2). There are no GDEs, baseflow dependent surface water courses or groundwater dependent culturally significant sites within the project area. Reduced recharge as a result of creation of impervious surface is considered negligible. Impacts due to settlement are considered negligible and the potential for groundwater contamination by tunnel infrastructure is also unlikely. Therefore, these risks do not require management during operation and are not included in Table 7-2.

Table 7-2 Summary of potential groundwater impacts during operation and required management measures

Potential Impact	Management measure
Groundwater inflows causing water table drawdown	The operational groundwater inflows and water table drawdown monitoring requirements will be established based on updated groundwater modelling informed by groundwater monitoring data collected during further design development and construction stages. Operational groundwater monitoring requirements will be developed in consultation with the EPA and DPI Water.

7.3 Groundwater monitoring program

7.3.1 Construction

The relevant management plan to be developed in respect to the project's construction will include a groundwater monitoring regime for the construction phase taking into consideration the groundwater monitoring being carried out for the M4-M5 Link and/or any other large infrastructure project in the vicinity of the project. The monitoring regime will include:

- Continuation of groundwater levels and groundwater quality monitoring within the currently installed project monitoring network to inform the update and refinement of the groundwater model
- If bores GW109209, GW108991 and GW107764 are found to be viable, installation of water level logger and EC logger and/or periodic manual measurements to obtain a baseline for assessing potential drawdown impacts with respect to static and pumping water levels
- Monitoring of groundwater levels and quality beneath high risk sites for contamination prior to and during construction. This includes monitoring of the existing Hawkesbury Sandstone groundwater monitoring bore installed as part of the M4-M5 Link Groundwater Impact Assessment (AECOM, 2017), and monitoring at the Rozelle Rail Yards construction support site
- Monitoring the quality and quantity of groundwater inflows into tunnels during construction
- Monitoring the quantity and quality of the treated wastewater discharges from the construction wastewater treatment plants
- Ongoing settlement monitoring will be carried out as per the independent property impact assessment panel requirements.

7.3.2 Operation

As noted in Table 7-2, operational monitoring of groundwater inflows and water table drawdown will be developed in consultation with the EPA and DPI Water.

Operational monitoring will be part of the project relevant management plan to be developed in respect to the project's operation and will include:

- Monitoring the quality and quantity of groundwater inflows into tunnels next to Sydney Harbour and beneath high risk sites for contamination
- Monitoring quantity and quality of the treated wastewater discharges from the Rozelle wastewater treatment plant.

8. Policy compliance

8.1 Aquifer Interference Policy

8.1.1 Approval requirements

The NSW Aquifer Interference Policy (AIP) is the NSW Government policy that clarifies the licensing and assessment requirements for aquifer interference activities under the *Water Management Act 2000*. It sets out the information that would be required by the Minister to assess the project and provide advice under the *Environmental Planning and Assessment Act 1979*. Compliance with the policy forms the basis of this impact assessment and the development of mitigation measures for the project.

The AIP supports the requirements of the *Water Management Act 2000* to ensure that the granting of water licences and approvals results in 'no more than minimal harm' to any water source or dependent ecosystems. It also provides clear guidance on the predicted level of impact associated with an interference activity that would be considered acceptable by the Minister. Ministerial approval is based on the proponent's ability to account for the take of water, prevent the take of water as far as possible, meet the minimal impact considerations, and employ remedial actions for unacceptable impacts.

8.1.2 Minimal impact considerations

The AIP sets out minimal impact considerations that aim to maintain water levels, water pressure and water quality in aquifers in order to protect the groundwater resource, as well as connected water sources, groundwater users, culturally significant sites and the environment.

The project tunnels would be predominantly located within the Hawkesbury Sandstone, which is classified as:

- A 'less productive aquifer' because yields are generally less than five litres per second
- A porous rock aquifer.

The minimal impact considerations for this aquifer type are summarised in Table 8-1, together with the response developed in this impact assessment.

Table 8-1 Minimal impact consideration for a 'less productive porous or fractured rock aquifer'

Minimal impact considerations	Response
<u>**Water table**</u> 1. Less than or equal to 10% 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 2 metre decline cumulatively at any water supply work.	Schedule 4 of the *Greater Metropolitan Regional Groundwater Sources Water Sharing Plan* identifies that within the Hawkesbury Sandstone and Ashfield Shale there are: a) No listed high priority groundwater dependent ecosystems (refer to Section 5.5.8) b) No listed high priority culturally significant sites (refer to Section 5.5.11) Groundwater modelling has predicted that water table drawdown at bores GW109209 and GW107764 would be two metres or greater (refer to Section 6). Impact minimisation measures are discussed below.
2. If more than 10% cumulative variation in the water table, allowing for typical climatic post-	Water table drawdown is predicted to be up to three metres at bore GW109209, up to two metres at GW107764, and one metre at GW108991.

Minimal impact considerations	Response
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 2 metre decline cumulatively at any water supply works then make good provisions should apply.	The approach to 'make good' the potential impacts would be to first confirm whether the bores still exist and are in a usable condition, and if so, to undertake monitoring and/or further modelling. If impacts are realised, then 'make good' options would be discussed with the owner. Make good provisions would include provision of alternative water supplies (such as mains water), replacing the bore with a deeper bore, or compensation for additional pumping costs.
<u>Water pressure</u> 1. A cumulative pressure head decline of not more than a 2 metre decline, at any water supply works.	Investigation and mitigation measures to address impacts at bores GW109209, GW108991 and GW107764 have been proposed
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.	The current viability of the bores is uncertain but if it is proven, monitoring would be carried out and if impacts are realised, the make good provisions would be applied to either maintain the long-term viability of the bores or to provide an alternative access or compensation.
<u>Water quality</u> 1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	Impacts to groundwater quality associated with the project would be minor, and as the tunnel inflows create a hydraulic gradient towards the tunnel, any contamination mobilised or caused by the works would flow towards the tunnel rather than away from it. Contaminants associated with the project would therefore remain within 40 metres of the tunnel. Drawdown caused by the project may cause contamination of groundwater more than 40 metres away from the tunnel due to: • Inland migration of the saline interface • Migration of contaminated groundwater from existing contaminated sites into areas of fresher groundwater • Potential activation of ASS These processes mean that this requirement of the AIP would not be satisfied. Impact minimisation measures are discussed below.
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	Intrusion of saline water from the coast into fresher groundwater, and migration of already contaminated groundwater, would not impact the long-term viability of dependent ecosystems or significant sites.

Minimal impact considerations	Response
the dependent ecosystem, significant site or affected water supply works.	If impacted, bores GW109209, GW108991 and GW107764 would be affected by reduced yields before any groundwater quality impacts occur. The make good provisions discussed above would be implemented to provide an alternative water source or compensate the user.
<u>Additional Considerations</u> … any advice provided to a gateway panel, the Planning and Assessment Commission or the Minister for Planning on a State significant development or State significant infrastructure will also consider the potential for: • Acidity issues to arise, for example exposure of acid sulfate soils; • Water logging 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.	The level of predicted drawdown is sufficient to cause activation of ASS if present. No work has been carried out so far to identify and test the acid generating potential of soil and rock in the project area. If ASS are identified, measures to mitigate impacts would be needed. There is no risk of water logging or water table rise since the tunnel would be drained during both construction and operation. The only tanked structures would be a short distance either side of the harbour. Waterlogging or damming of groundwater flow would not occur since the hydraulic gradient by that time would cause flow towards the drained sections of the tunnel around Rozelle/Balmain in the south, and Waverton in the north.

The difference between drawdown at the receptors caused by the project only scenario as opposed to cumulative drawdown is minor, since the only receptors (bores GW109209, GW108991 and GW107764) are located some distance from the M4-M5 project and the Sydney Metro Chatswood to Sydenham would be tanked. Impacts on the receptors can therefore be largely attributed to the project.

8.2 Licensing

The AIP clarifies the licensing requirements for any aquifer interference activities that interfere or take water from an aquifer. Components of the project constitute aquifer interference activities as the drained tunnels would allow groundwater ingress which would be collected and disposed. These groundwater inflows remove water from the aquifer and must be accounted for within the extraction limits of the Water Sharing Plan (WSP).

In general, a water licence is required for the removal of water from an aquifer. However, road authorities such as Roads and Maritime are exempt from the requirement to hold a licence for the take of water under Schedule 4, Part 1, clause 2 of the *Water Management (General) Regulation 2011*. Although a licence is not required for the project, Roads and Maritime must still satisfy the requirements of licensing set out in the Greater Metropolitan Region Water Sharing Plan 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 to ensure compliance with licenced volumes, and with the established limits for the aquifer as stated in the WSP. Inflow volumes and the methods used to predict them have been outlined in sections 3 to 6 of this report.

The total inflow to the project is predicted to be 1310 megalitres during construction, with annual inflows during construction peaking at 272 megalitres per year in 2022. The inflow during operation peaks at 203 megalitres per year in 2026 and declines to 180 megalitres per year by 2126. The inflows generated by the project would need to be assigned to the project through an annual allocation of unassigned water under the WSP, or by purchasing an existing entitlement if there is insufficient unassigned water. There is currently about 43,323 megalitres per year unassigned under the LTAAEL. Annual inflows for the Western Harbour Tunnel and Warringah Freeway Upgrade would be less than one per cent of the unassigned water.

8.3 Water Sharing Plan

All groundwater and surface water in the project area is managed through the *Greater Metropolitan Region Water Sharing Plan* (WSP). The 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 (first/second order streams), and near other licenced bores. The groundwater source relevant to the project is the Sydney Basin Central groundwater source.

The WSP contains provisions for allocation of water to construction projects such as the project through a volume of 'unassigned water' or through the ability to purchase an entitlement where groundwater is available under the LTAAEL. Roads and Maritime is exempt from the requirement to hold a water access licence for the project, under Schedule 4, Part 1, clause 2 of the *Water Management (General) Regulation 2011*. The rules outlined in the WSP are still likely to apply in order to obtain Ministerial approval of the project. Relevant rules from the WSP are summarised in Table 8-2, with the response developed through this EIS.

Table 8-2 Relevant rules from the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011

WSP rule	Response
Part 7 – Rules for granting access licences	Roads and Maritime are exempt from the requirement to hold a licence for the take of water during construction and operation of major projects under Schedule 4, Part 1, clause 2 of the *Water Management (General) Regulation 2011*. The *Water Management Act 2000* requires that road authorities obtain a water supply work approval for groundwater ingress to tunnels. The inflow volume of up to 272 ML/year during construction, and up to 203 ML/year during operation needs to be assigned under the LTAAEL.
Part 8 – Rules for managing access licences	Refer to the Part 7 response
Part 9 – 39: Distance restrictions to minimise interference between supply works	The approval process would determine distance restrictions to minimise interference between water supply works. There are three bores (GW109209, GW108991 and GW107764) that may be impacted by drawdown, and if viable, make good provisions would be applied to maintain access.
Distance restriction from the property boundary is 50 m	The project is within 50 metres of property boundaries and would result in drawdown at nearby properties. This is considered acceptable as the tunnels are predominantly at depth below properties and there is a reticulated water supply to those properties. The project would therefore not impact water supply to nearby properties. There is the potential for surface settlement of greater than 40 millimetres in some areas (mainly at the Warringah Freeway portal) and angular distortions greater than 1:500, may occur at properties

WSP rule	Response
	within 50 metres of the project, which may result in aesthetic damage to buildings.
Distance restriction from an approved water supply work is 100 m	There are no approved water supply works within 100 metres of the project. Supply bores GW109209, GW108991 and GW107764 are within the area of drawdown, but make good provisions would apply, as discussed above.
Distance restriction from a Department observation bore is 200 metres	The Department of Planning, Industry and Environment (Regions, Industry, Agriculture & Resources) does not have any observation bores within 200 metres of the project, or within the area of drawdown surrounding the project.
Distance restriction from an approved work nominated by another access license is 400 m.	There are no approved works nominated by another access licence within 400 metres of the project.
Distance restriction from an approved water supply work nominated by a local water utility or major utility access licence is 1000 m	There are no water supply works nominated by water utilities within 1000 metres of the project, or within the area of drawdown surrounding the project.
Part 9 – 40 Rules for water supply works located near contaminated sources	In addition to the moderate to high risk areas of environmental interest for contamination identified in Technical working paper: Contamination, EPA notified contaminated sites have been identified within the area of predicted drawdown around the project which are captured under the description of contaminated sites in Schedule 3 of the WSP. A water supply works approval must not be granted within: • 250 metres of contaminant plumes associated with these sites • 250-500 metres of these sites as long as no drawdown would occur within 250 metres of the contaminant plume • At a specified distance more than 500 metres of a contaminant plume if needed to protect the water source and users. The presence of contaminant plumes at these sites has not been assessed. However, the risk of groundwater contamination has been assessed and is considered to be low. Approval can be granted for water supply works within the specified distance of contaminated sites as long as the water source, dependent ecosystems, and public health and safety are not threatened. There is no risk to GDEs or groundwater users as they are not present in the area of drawdown, with the possible exception of bores GW109209, GW108991 and GW107764, as discussed above.
Part 9 – 41 Rules for water supply works located near sensitive environmental areas	The project is outside the required distance for the following sensitive environmental areas: 1. 200 metres of a high priority groundwater dependent ecosystem 2. 500 metres of a karst groundwater dependent ecosystem 3. 40 metres from a lagoon or escarpment (section 5).

WSP rule	Response
	The project is within 40 metres of a first/second order stream (Whites Creek), but as it is more than 30 metres deep and within the underlying parent material it satisfies the requirements of the WSP.
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	As the potential supply bores GW109209, GW108991 and GW107764 and the contaminated sites are within restricted distances, the proponent must not take more water than specified in the water access licence. Although the Roads and Maritime is exempt from having to hold a water access licence, Ministerial approval may still specify an allowable extraction volume (or inflow rates) for the project to protect the bore user and avoid contaminant migration.
Part 10 – Access dealing rules	Refer to the Part 7 response

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Appendix A. Bore logs

PIEZOMETER CONSTRUCTION

HOLE NO : B106A_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Birchgrove - Yurulbin Park

POSITION : E: 332168.1, N: 6253322.9 (56 MGA94) | SURFACE ELEVATION : 2.68 (AHD) | ANGLE FROM HORIZONTAL : 68° AT 330°

RIG TYPE : Comacchio 305 | MOUNTING : Track | CONTRACTOR : Groundtest

DATE STARTED : 11/10/17 | DATE COMPLETED : 27/10/17 | DATE LOGGED : 27/10/17 | LOGGED BY : MB | CHECKED BY : GS

DRILLING

PROGRESS: DRILLING Casing & CASING; WATER; GROUND WATER LEVELS

- ADT / HW Casing: 0.0 – approx. 2 m
- HQ3: to 95.80 m
- Water: (GWNO); 0% LOSS; 0% LOSS; 0% LOSS; 10% LOSS; 10% LOSS; 40% LOSS; 100% LOSS

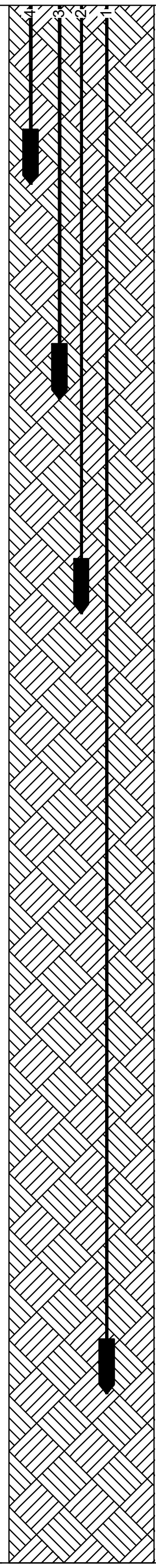
MATERIAL

Depth (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.0 – 0.80m	FILL
0.80m – 13.69m	SANDSTONE
13.69m – 15.40m	SILTSTONE
15.40m – 39.40m	SANDSTONE
39.40m – 39.45m	CORE LOSS 0.05m (39.40-39.45)
39.45m – 46.08m	SANDSTONE
46.08m – 46.13m	CORE LOSS 0.05m (46.08-46.13)
46.13m – 67.00m	SANDSTONE
67.00m – 67.20m	CORE LOSS 0.20m (67.00-67.20)
67.20m – 84.23m	SANDSTONE
84.23m – 84.38m	CORE LOSS 0.15m (84.23-84.38)
84.38m – 95.80m	SANDSTONE

B106A_w TERMINATED AT 95.80 m
Target depth
Imaging completed (ATV and OTV)
4x VWPs installed

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
4	Vibrating Wire Piezometer		11.00 m -7.52 m AHD	25/10/2017	
3	Vibrating Wire Piezometer		24.20 m -19.76 m AHD	25/10/2017	
2	Vibrating Wire Piezometer		37.40 m -32.00 m AHD	25/10/2017	
1	Vibrating Wire Piezometer		85.40 m -76.50 m AHD	25/10/2017	



VWPs installed in full cement/bentonite grout mix

This report of standpipe installation must be read in conjunction with accompanying notes and abbreviations. The geotechnical log is a summary only and the detailed log should be referred to for strata details and any core loss zones.

Golder Associates | Douglas Partners Geotechnics / Environment / Groundwater

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Engineering Log

PIEZOMETER No. B112

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** KW/LB	**Checked by:** PV
Location: Waverton Park - Waverton		**Start Date:** 16/06/2017	**End Date:** 30/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 333240.4 m	**RL:** 15.99 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:** 6254091.1 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Grass

Field Data | **Rock Description** | **Piezometer Details**

Method | Core Run | TCR (%) | RQD (%) | Ground Water | Reduced Level (m) | Depth (m) | Graphic Log

Summary Geology
(refer to geological log for full descriptions)

Defect Spacing (mm): 20 40 100 300 1000

Construction details:	Standpipe Piezometer, 3 m slotted screen, sump
Remarks:	Class 18 PVC 50 mm ID
Casing Top RL:	15.93 m AHD
Casing Top:	0.1 mBGL
Casing Base:	66.5 mBGL
Response Zone Top RL:	-46.51 m AHD
Response Zone Base RL:	-49.51 m AHD
Length of Response Zone:	3.00 m
Instrument Details:	TD-Diver (Manual) at -5.97 mAHD, Baro-Diver
Installation Date:	29/06/2017
Development Date:	24/08/2017

Reduced Level RL (m)

Method	Core Run	TCR (%)	RQD (%)	Summary Geology
HQ3	R1	100	56	SANDSTONE, medium, pale grey
HQ3	R2	100	85	MUDSTONE
				SANDSTONE
HQ3	R3	100	100	SANDSTONE, fine to medium, pale grey to grey
				SANDSTONE, medium, pale grey
HQ3	R4	100	100	SANDSTONE, fine to medium, grey
				SANDSTONE, medium, pale grey
HQ3	R5	100	100	
HQ3	R6	100	99	

Depth (m): 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 22.0, 24.0, 26.0, 28.0, 30.0

Reduced Level (m): 14.0, 12.0, 10.0, 8.0, 6.0, 4.0, 2.0, 0.0, -2.0, -4.0, -6.0, -8.0, -10.0, -12.0

Length 0.0 to 0.0 m — GATIC COVER

Length 0.0 to 59.5 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Client: RMS		**Project No:** 60537922			
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** KW/LB		**Checked by:** PV	
Location: Waverton Park - Waverton		**Start Date:** 16/06/2017		**End Date:** 30/06/2017	
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 333240.4 m		**RL:** 15.99 m	
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:** 6254091.1 m		**Ver. Datum:** AHD	
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56		**Surface:** Grass	

Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 15.93 m AHD
Casing Top: 0.1 mBGL
Casing Base: 66.5 mBGL

Response Zone Top RL: -46.51 m AHD
Response Zone Base RL: -49.51 m AHD
Length of Response Zone: 3.00 m

Instrument Details: TD-Diver (Manual) at -5.97 mAHD, Baro-Diver

Installation Date: 29/06/2017
Development Date: 24/08/2017

Field Data / Rock Description

Summary Geology (refer to geological log for full descriptions)

Method	Core Run	TCR (%)	RQD (%)	Ground Water	Reduced Level (m)	Depth (m)	Summary Geology
HQ3	R7	100	100		-16.0	32.0	SANDSTONE, medium, pale grey *continued*
	R8	100	99		-18.0	34.0	
					-20.0	36.0	BRECCIA
	R9	100	100		-22.0	38.0	SANDSTONE, fine to medium, pale grey to grey
					-24.0	40.0	SANDSTONE, fine, grey
	R10	100	100		-26.0	42.0	SANDSTONE, medium, grey to pale grey
							SANDSTONE, fine to medium, grey
	R11	100	100		-28.0	44.0	SANDSTONE, medium, grey to pale grey
	R12	100	97		-30.0	46.0	SANDSTONE, medium, pale grey to grey
					-32.0	48.0	SANDSTONE, fine to medium, grey to pale grey
	R13	100	100		-34.0	50.0	SANDSTONE, medium, pale grey
					-36.0	52.0	SANDSTONE, fine, pale grey
	R14	100	100		-38.0	54.0	SANDSTONE, medium, pale grey
	R15	100	99		-40.0	56.0	
							LAMINITE
	R16	100	99		-42.0	58.0	SANDSTONE, medium, pale grey
						60.0	

Defect Spacing (mm): 20, 40, 100, 300, 1000

Piezometer construction:
- Length 0.0 to 59.5 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)
- Length 59.5 to 60.5 m —

Reduced Level RL (m): -16.0, -18.0, -20.0, -22.0, -24.0, -26.0, -28.0, -30.0, -32.0, -34.0, -36.0, -38.0, -40.0, -42.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** KW/LB	**Checked by:** PV
Location: Waverton Park - Waverton		**Start Date:** 16/06/2017	**End Date:** 30/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 333240.4 m	**RL:** 15.99 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:** 6254091.1 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Grass

Field Data | **Rock Description** | **Piezometer Details**

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 15.93 m AHD
Casing Top: 0.1 mBGL
Casing Base: 66.5 mBGL

Response Zone Top RL: -46.51 m AHD
Response Zone Base RL: -49.51 m AHD
Length of Response Zone: 3.00 m

Instrument Details: TD-Diver (Manual) at -5.97 mAHD, Baro-Diver

Installation Date: 29/06/2017
Development Date: 24/08/2017

Summary Geology (refer to geological log for full descriptions)

Method	Core Run	TCR (%)	RQD (%)	Depth (m)	Summary Geology
HQ3	R17	100	100	62.0	SANDSTONE, medium, grey
	R18	100	100		SANDSTONE, fine, grey
	R19	100	100	64.0	SANDSTONE, medium, pale grey
					SANDSTONE, fine to medium, pale grey
	R20	100	100	66.0–68.0	SANDSTONE, medium, pale grey
	R21	100	100	70.0	
	R22	100	100	72.0	
	R23	100	100	74.0	SANDSTONE, medium to coarse, pale grey to brown-grey
					SANDSTONE, fine to medium, pale grey
	R24	100	100	76.0	

Defect Spacing (mm): 20, 40, 100, 300, 1000

Interval	Installation
Length 59.5 to 60.5 m	BENTONITE SEAL (PELLETS)
Length 60.5 to 62.5 m	2mm FILTER SAND
Length 62.5 to 65.5 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 65.5 to 66.5 m	2mm FILTER SAND (SUMP/PVC CAP)
Length 66.5 to 76.1 m	BENTONITE SEAL (PELLETS)

B112 terminated at 76.09 m.

Depth (m): 62.0, 64.0, 66.0, 68.0, 70.0, 72.0, 74.0, 76.0, 78.0, 80.0, 82.0, 84.0, 86.0, 88.0, 90.0

Reduced Level RL (m): -46.0, -48.0, -50.0, -52.0, -54.0, -56.0, -58.0, -60.0, -62.0, -64.0, -66.0, -68.0, -70.0, -72.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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Engineering Log

PIEZOMETER No. B112P

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** MC/AM	**Checked by:** -
Location: Waverton Park - Waverton		**Start Date:** 19/12/2017	**End Date:** 22/12/2017
Driller: Terratest	**Hole Diameter:** 99 mm	**Easting:** 333230.4 m	**RL:** 15.94 m
Drill Rig: Comacchio 450P	**Inclination:** -90°	**Northing:** 6254078.3 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H	**Surface:** Grass

Field Data | **Rock Description** | **Piezometer Details**

Method | Core Run | TCR (%) | RQD (%) | Ground Water | Reduced Level (m) | Depth (m) | Graphic Log

Summary Geology (refer to geological log for full descriptions)

Defect Spacing (mm): 20 40 100 300 1000

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 15.89 m AHD
Casing Top: 0.1 mBGL
Casing Base: 70.0 mBGL

Response Zone Top RL: -46.56 m AHD
Response Zone Base RL: -49.56 m AHD
Length of Response Zone: 3.00 m

Instrument Details: TD-Diver (Manual) at -6.01 mAHD, Baro-Diver

Installation Date: 22/12/2017
Development Date: 25/01/2018

Reduced Level RL (m)

Method: HA (0.0–1.5 m); ADT (1.5–15.8 m); RT (15.8–16.2 m); WB (16.5–30.0 m)

Depth (m)	Summary Geology
16.5	SANDSTONE, medium, pale grey
	MUDSTONE
	SANDSTONE
	SANDSTONE, fine to medium, pale grey to grey
	SANDSTONE, medium, pale grey
	SANDSTONE, fine to medium, grey
22.4	SANDSTONE, medium, pale grey

Piezometer details:
- Length 0.0 to 0.0 m — GATIC COVER
- Length 0.0 to 0.4 m — CONCRETE ROAD BOX
- Length 0.4 to 7.7 m — BENTONITE
- Length 7.7 to 53.0 m — BENTONITE

Depth scale: 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 22.0, 24.0, 26.0, 28.0, 30.0
Reduced Level scale: 14.0, 12.0, 10.0, 8.0, 6.0, 4.0, 2.0, 0.0, -2.0, -4.0, -6.0, -8.0, -10.0, -12.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

AECOM coffey

PIEZOMETER No. **B112P**

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	MC/AM	**Checked by:**	-
Location:	Waverton Park - Waverton	**Start Date:**	19/12/2017	**End Date:**	22/12/2017
Driller: Terratest	**Hole Diameter:** 99 mm	**Easting:**	333230.4 m	**RL:**	15.94 m
Drill Rig: Comacchio 450P	**Inclination:** -90°	**Northing:**	6254078.3 m	**Ver. Datum:**	AHD
	Bearing: N/A	**Hor. Proj/Dat:**	MGA94/GDA94-56H	**Surface:**	Grass

Field Data / Rock Description / Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 15.89 m AHD
Casing Top: 0.1 mBGL
Casing Base: 70.0 mBGL

Response Zone Top RL: -46.56 m AHD
Response Zone Base RL: -49.56 m AHD
Length of Response Zone: 3.00 m

Instrument Details: TD-Diver (Manual) at -6.01 mAHD, Baro-Diver

Installation Date: 22/12/2017
Development Date: 25/01/2018

Columns: Method | Core Run | TCR (%) | RQD (%) | Ground Water | Reduced Level (m) | Depth (m) | Graphic Log | Summary Geology (refer to geological log for full descriptions) | Defect Spacing (mm) (20, 40, 100, 300, 1000) | Reduced Level RL (m)

Method: WB

Depth (m)	Reduced Level (m)	Summary Geology
(from ~31.0)		SANDSTONE, medium, pale grey *continued*
32.0	16.0	
34.0	18.0	
36.0	20.0	BRECCIA
~36.6		SANDSTONE, fine to medium, pale grey to grey
38.0	22.0	
40.0	24.0	SANDSTONE, fine, grey
~40.3		SANDSTONE, medium, grey to pale grey
42.0	26.0	
~43.3		SANDSTONE, fine to medium, grey
44.0	28.0	SANDSTONE, medium, grey to pale grey
46.0	30.0	SANDSTONE, medium, pale grey to grey
~47.5		SANDSTONE, fine to medium, grey to pale grey
48.0	32.0	
50.0	34.0	SANDSTONE, medium, pale grey
52.0	36.0	SANDSTONE, fine, pale grey
~52.4		SANDSTONE, medium, pale grey
54.0	38.0	
56.0	40.0	
~56.6		LAMINITE
58.0	42.0	SANDSTONE, medium, pale grey
60.0		

Piezometer details:

Interval	Material
Length 7.7 to 53.0 m	BENTONITE
Length 53.0 to 60.0 m	BENTONITE SEAL (PELLETS)

Reduced Level RL (m): -16.0, -18.0, -20.0, -22.0, -24.0, -26.0, -28.0, -30.0, -32.0, -34.0, -36.0, -38.0, -40.0, -42.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** MC/AM	**Checked by:** -
Location: Waverton Park - Waverton		**Start Date:** 19/12/2017	**End Date:** 22/12/2017
Driller: Terratest	**Hole Diameter:** 99 mm	**Easting:** 333230.4 m	**RL:** 15.94 m
Drill Rig: Comacchio 450P	**Inclination:** -90°	**Northing:** 6254078.3 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H	**Surface:** Grass

Field Data | **Rock Description** | **Piezometer Details**

Columns: Method, Core Run, TCR (%), RQD (%), Ground Water, Reduced Level (m), Depth (m), Graphic Log, Summary Geology (refer to geological log for full descriptions), Defect Spacing (mm) (20, 40, 100, 300, 1000), Reduced Level RL (m)

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 15.89 m AHD
Casing Top: 0.1 mBGL
Casing Base: 70.0 mBGL

Response Zone Top RL: -46.56 m AHD
Response Zone Base RL: -49.56 m AHD
Length of Response Zone: 3.00 m

Instrument Details: TD-Diver (Manual) at -6.01 mAHD, Baro-Diver

Installation Date: 22/12/2017
Development Date: 25/01/2018

Method: WB

Depth (m)	Summary Geology
to ~62.0	SANDSTONE, medium, grey
~62.5	SANDSTONE, fine, grey
~62.5 – 64.3	SANDSTONE, medium, pale grey
~64.3 – 66.9	SANDSTONE, fine to medium, pale grey
~66.9 – 70.0	SANDSTONE, medium, pale grey

Length	Piezometer Detail
Length 60.0 to 62.5 m	2mm FILTER SAND
Length 62.5 to 65.5 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 65.5 to 70.0 m	2mm FILTER SAND (SUMP/PVC CAP)

B112P terminated at 70.00 m.

Depth scale (m): 62.0, 64.0, 66.0, 68.0, 70.0, 72.0, 74.0, 76.0, 78.0, 80.0, 82.0, 84.0, 86.0, 88.0, 90.0

Reduced Level (m): -46.0, -48.0, -50.0, -52.0, -54.0, -56.0, -58.0, -60.0, -62.0, -64.0, -66.0, -68.0, -70.0, -72.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B128

Sheet: 1 of 1

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** LW	**Checked by:** RR
Location: Balgowlah Cycleway - North Sydney		**Start Date:** 2/08/2017	**End Date:** 3/08/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 338485.8 m	**RL:** 30.28 m
Drill Rig: Comacchio 305	**Inclination:** -90°	**Northing:** 6259593.0 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Grass

Field Data | **Rock Description** | **Piezometer Details**

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 30.21 m AHD
Casing Top: 0.1 mBGL
Casing Base: 19.0 mBGL

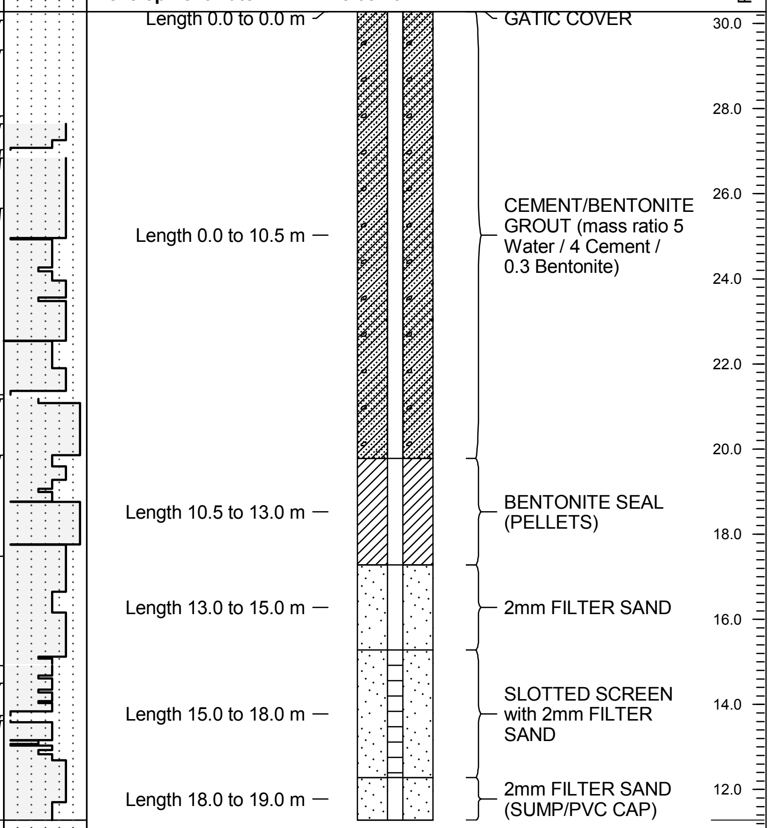
Response Zone Top RL: 15.28 m AHD
Response Zone Base RL: 12.28 m AHD
Length of Response Zone: 3.00 m

Instrument Details: TD-Diver (Manual) at 21.91 mAHD

Installation Date: 7/08/2017
Development Date: 25/08/2017

Method	Core Run	TCR (%)	RQD (%)	Summary Geology (refer to geological log for full descriptions)
HA				SAND, fine to medium
ADT				Clayey SAND, fine to coarse
				SAND, fine to coarse
HQ3	R1	100	100	SANDSTONE
				SANDSTONE, fine to medium, pale grey-brown
	R2	100	90	NO CORE
	R3	90	94	SANDSTONE, fine to medium, pale grey-brown
				SANDSTONE, fine to coarse, pale grey-brown
	R4	90	90	NO CORE
				SANDSTONE, fine to coarse, pale grey-brown
	R5	95	94	SANDSTONE, fine to coarse, pale brown-grey
	R6	95	97	SANDSTONE, fine to medium, pale grey
				SANDSTONE, fine to medium, pale grey
	R7	95	82	SANDSTONE, fine to coarse, pale grey
				NO CORE
				SANDSTONE, fine to coarse, pale grey

Ground Water: 25/08/2017



B128 terminated at 19.00 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

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PIEZOMETER No. B132

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	KW	**Checked by:**	PV/RR
Location:	Balls Head Drive - Waverton	**Start Date:**	19/06/2017	**End Date:**	6/07/2017
Driller:	Terratest	**Hole Diameter:** 96 mm	**Easting:** 332923.5 m	**RL:**	20.56 m
Drill Rig:	Comacchio 405	**Inclination:** -59°	**Northing:** 6253603.3 m	**Ver. Datum:**	AHD
		Bearing: 340°	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:**	Road surface

Piezometer Details

Construction details: Vibrating Wire Piezometer
Remarks: VWP sensor in slotted Class 18 PVC 50 mm ID
Casing Top RL: -
Casing Top: -
Casing Base: -
Response Zone Top RL: -
Response Zone Base RL: -
Length of Response Zone: -
Instrument Details: VWP1 at -74.2 mAHD, VWP2 at -28.26 mAHD, WWP3 at -8.9 mAHD, VWP4 at 10.40 mAHD
Installation Date: 6/08/2017
Development Date: -

Method	Core Run	TCR (%)	RQD (%)	Depth (m)	Rock Description – Summary Geology (refer to geological log for full descriptions)
HA				0.0–1.5	ASPHALTIC CONCRETE, black
					Fill, yellow-brown
HQ3	R1	100	81		SANDSTONE, fine to coarse grained, grey and orange-brown
	R2	100	100		SANDSTONE, fine to coarse grained, yellow and orange-brown
					SANDSTONE
					SANDSTONE, fine to coarse grained, yellow, orange-brown and pale grey
	R3	100	98		SANDSTONE, pale grey
					SANDSTONE, fine to coarse grained, red and yellow-brown
	R4	100	94		SANDSTONE, fine to coarse grained, yellow-brown and purple
					SANDSTONE, fine to coarse grained, pale grey
	R5	100	94		SANDSTONE, fine to coarse grained, red-brown, yellow-brown and purple-brown
					SANDSTONE, fine to coarse grained, pale grey and pale yellow
	R6	100	99		SANDSTONE, fine to coarse grained, pale grey and purple
					SANDSTONE, pale orange-brown
	R7	100	100		SANDSTONE, fine to medium grained, pale grey
					SANDSTONE, fine to medium grained, grey
	R8	100	100		SANDSTONE, fine to coarse grained, pale grey
					SANDSTONE, fine to coarse grained, grey
	R9	100	96		SANDSTONE, fine to coarse grained, pale grey and grey
					SANDSTONE, fine to coarse grained, yellow-brown and red-brown
	R10	100	97	30.0	SANDSTONE, fine to coarse grained, pale grey

Ground Water: 28/09/2017 (approx. 20.2 m depth)

Piezometer construction:

Length	Details
Length 0.0 to 0.1 m	GATIC COVER
Length 0.1 to 11.6 m	CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE
Length 11.6 to 11.8 m	VIBRATING WIRE SENSOR + SLOTTED PVC PIPE
Length 11.8 to 34.0 m	CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B132

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** KW	**Checked by:** PV/RR
Location: Balls Head Drive - Waverton		**Start Date:** 19/06/2017	**End Date:** 6/07/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 332923.5 m	**RL:** 20.56 m
Drill Rig: Comacchio 405	**Inclination:** -59°	**Northing:** 6253603.3 m	**Ver. Datum:** AHD
	Bearing: 340°	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Road surface

Piezometer Details

Construction details: Vibrating Wire Piezometer
Remarks: VWP sensor in slotted Class 18 PVC 50 mm ID
Casing Top RL: -
Casing Top: -
Casing Base: -

Response Zone Top RL: -
Response Zone Base RL: -
Length of Response Zone: -

Instrument Details: VWP1 at -74.2 mAHD, VWP2 at -28.26 mAHD, WWP3 at -8.9 mAHD, VWP4 at 10.40 mAHD
Installation Date: 6/08/2017
Development Date: -

Field Data

Method: HQ3

Core Run	TCR (%)	RQD (%)
R11	100	96
R12	100	98
R13	100	95
R14	100	100
R15	100	100
R16	100	99
R17	100	99
R18	100	100
R19	100	97
R20	100	100
R21	100	88

Depth (m): 32.0, 34.0, 36.0, 38.0, 40.0, 42.0, 44.0, 46.0, 48.0, 50.0, 52.0, 54.0, 56.0, 58.0, 60.0

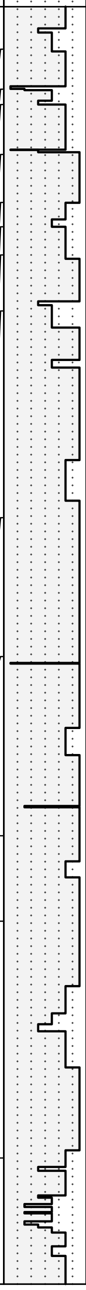
Reduced Level (m): -6.0, -8.0, -10.0, -12.0, -14.0, -16.0, -18.0, -20.0, -22.0, -24.0, -26.0, -28.0, -30.0

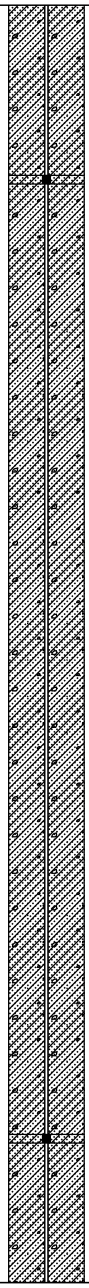
Rock Description

Summary Geology (refer to geological log for full descriptions)

- MUDSTONE
- INTERBEDDED SANDSTONE AND MUDSTONE
- SANDSTONE, fine to coarse grained, pale grey to grey *continued*
- INTERBEDDED SANDSTONE AND MUDSTONE
- SANDSTONE, medium to coarse grained, red-brown and yellow-brown
- SANDSTONE, fine to coarse grained, pale grey
- SANDSTONE, medium to coarse grained, red-brown, orange and pale grey
- SANDSTONE, fine to medium grained, pale grey
- SANDSTONE, fine to medium grained, grey
- SHALE BRECCIA
- SANDSTONE, fine to coarse grained, pale grey
- SANDSTONE, fine to medium grained, grey
- SANDSTONE, fine to coarse grained, pale grey
- SANDSTONE, fine to coarse grained, pale grey
- SANDSTONE, fine to medium grained, pale grey
- SANDSTONE, fine to coarse grained, pale grey to grey

Defect Spacing (mm): 20, 40, 100, 300, 1000





Interval	Construction
Length 11.8 to 34.0 m	CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE
Length 34.0 to 34.2 m	VIBRATING WIRE SENSOR + SLOTTED PVC PIPE
Length 34.2 to 56.5 m	CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE
Length 56.5 to 56.7 m	VIBRATING WIRE SENSOR + SLOTTED PVC PIPE
Length 56.7 to 109.8 m	CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE

Reduced Level RL (m): -6.0, -8.0, -10.0, -12.0, -14.0, -16.0, -18.0, -20.0, -22.0, -24.0, -26.0, -28.0, -30.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log — PIEZOMETER No. B132

Sheet: 3 of 5

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** KW	**Checked by:** PV/RR
Location: Balls Head Drive - Waverton		**Start Date:** 19/06/2017	**End Date:** 6/07/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 332923.5 m	**RL:** 20.56 m
Drill Rig: Comacchio 405	**Inclination:** -59°	**Northing:** 6253603.3 m	**Ver. Datum:** AHD
	Bearing: 340°	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Road surface

Field Data

Method: HQ3

Core Run	TCR (%)	RQD (%)
R22	100	100
R23	100	100
R24	100	100
R25	100	100
R26	100	99
R27	100	100
R28	100	93
R29	100	100
R30	100	98
R31	100	95
R32	100	80
R33	100	99
R34	100	99
R35	100	99

Reduced Level (m): -32.0, -34.0, -36.0, -38.0, -40.0, -42.0, -44.0, -46.0, -48.0, -50.0, -52.0, -54.0, -56.0

Depth (m): 62.0, 64.0, 66.0, 68.0, 70.0, 72.0, 74.0, 76.0, 78.0, 80.0, 82.0, 84.0, 86.0, 88.0, 90.0

Rock Description

Summary Geology (refer to geological log for full descriptions)

Defect Spacing (mm): 20, 40, 100, 300, 1000

- SANDSTONE, fine to coarse grained, pale grey to grey *continued*
- SHALE BRECCIA
- SANDSTONE, fine to medium grained, grey
- SANDSTONE, fine to coarse grained, pale grey to pale brown
- LAMINITE
- SANDSTONE, pale grey to pale brown
- SANDSTONE, fine to coarse grained, pale grey
- SANDSTONE, medium to coarse grained, pale grey
- SANDSTONE, fine to coarse grained, pale grey

Piezometer Details

Construction details: Vibrating Wire Piezometer
Remarks: VWP sensor in slotted Class 18 PVC 50 mm ID
Casing Top RL: -
Casing Top: -
Casing Base: -

Response Zone Top RL: -
Response Zone Base RL: -
Length of Response Zone: -

Instrument Details: VWP1 at -74.2 mAHD, VWP2 at -28.26 mAHD, WWP3 at -8.9 mAHD, VWP4 at 10.40 mAHD
Installation Date: 6/08/2017
Development Date: -

Length 56.7 to 109.8 m

CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE

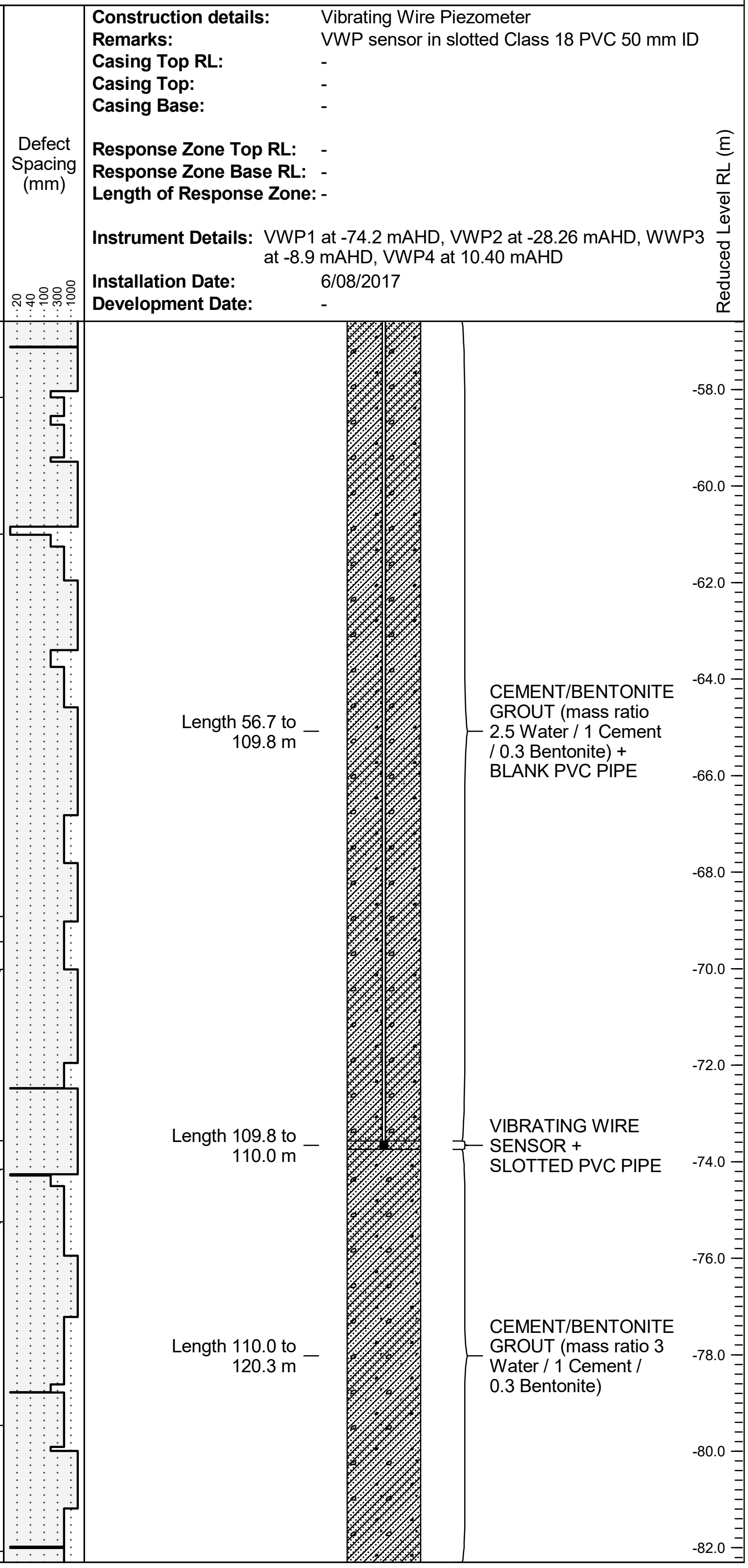
Reduced Level RL (m): -32.0, -34.0, -36.0, -38.0, -40.0, -42.0, -44.0, -46.0, -48.0, -50.0, -52.0, -54.0, -56.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** KW	**Checked by:** PV/RR
Location: Balls Head Drive - Waverton		**Start Date:** 19/06/2017	**End Date:** 6/07/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 332923.5 m	**RL:** 20.56 m
Drill Rig: Comacchio 405	**Inclination:** -59°	**Northing:** 6253603.3 m	**Ver. Datum:** AHD
	Bearing: 340°	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Road surface

Construction details: Vibrating Wire Piezometer
Remarks: VWP sensor in slotted Class 18 PVC 50 mm ID
Casing Top RL: -
Casing Top: -
Casing Base: -
Response Zone Top RL: -
Response Zone Base RL: -
Length of Response Zone: -
Instrument Details: VWP1 at -74.2 mAHD, VWP2 at -28.26 mAHD, WWP3 at -8.9 mAHD, VWP4 at 10.40 mAHD
Installation Date: 6/08/2017
Development Date: -

Method	Core Run	TCR (%)	RQD (%)	Depth (m)	Summary Geology (refer to geological log for full descriptions)
HQ3	R35	100	99	– 92.0	SANDSTONE, fine to coarse grained, pale grey to grey *continued*
	R36	100	100	92.0 –	SANDSTONE, fine to coarse grained, pale grey and pale yellow-brown
	R37	100	100		SANDSTONE, fine to coarse grained, pale grey
	R38	100	100		
	R39	100	100		
	R40	100	100		
	R41	100	100		SHALE BRECCIA
					SANDSTONE, fine to medium grained, dark grey
	R42	100	100		SANDSTONE, fine to coarse grained, pale grey
	R43	100	99		SANDSTONE, fine to medium grained, grey
					SANDSTONE, fine to medium grained, pale grey
	R44	100	100		SANDSTONE, fine to coarse grained, pale grey and grey
	R45	100	100		SANDSTONE, medium to coarse grained, pale grey
	R46	100	98	– 120.0	



GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B132

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** KW	**Checked by:** PV/RR
Location: Balls Head Drive - Waverton		**Start Date:** 19/06/2017	**End Date:** 6/07/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 332923.5 m	**RL:** 20.56 m
Drill Rig: Comacchio 405	**Inclination:** -59°	**Northing:** 6253603.3 m	**Ver. Datum:** AHD
	Bearing: 340°	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Road surface

Field Data	Rock Description	Piezometer Details
Method / Core Run / TCR (%) / RQD (%) / Ground Water / Reduced Level (m) / Depth (m) / Graphic Log	Summary Geology (refer to geological log for full descriptions); Defect Spacing (mm) 20 40 100 300 1000	**Construction details:** Vibrating Wire Piezometer **Remarks:** VWP sensor in slotted Class 18 PVC 50 mm ID **Casing Top RL:** - **Casing Top:** - **Casing Base:** - **Response Zone Top RL:** - **Response Zone Base RL:** - **Length of Response Zone:** - **Instrument Details:** VWP1 at -74.2 mAHD, VWP2 at -28.26 mAHD, WWP3 at -8.9 mAHD, VWP4 at 10.40 mAHD **Installation Date:** 6/08/2017 **Development Date:** -
Depth (m): 122.0, 124.0, 126.0, 128.0, 130.0, 132.0, 134.0, 136.0, 138.0, 140.0, 142.0, 144.0, 146.0, 148.0, 150.0 Reduced Level (m): -84.0, -86.0, -88.0, -90.0, -92.0, -94.0, -96.0, -98.0, -100.0, -102.0, -104.0, -106.0	SANDSTONE, fine to coarse grained, pale grey *continued*	*B132 terminated at 120.27 m.* Reduced Level RL (m): -84.0, -86.0, -88.0, -90.0, -92.0, -94.0, -96.0, -98.0, -100.0, -102.0, -104.0, -106.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

AECOM coffey

Engineering Log

PIEZOMETER No. B133

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** KW	**Checked by:** RR
Location: Harriot Street - Waverton		**Start Date:** 4/07/2017	**End Date:** 14/07/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 333489.1 m	**RL:** 63.41 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:** 6254554.2 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Road surface

Field Data | Rock Description | Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 63.39 m AHD
Casing Top: 0.0 mBGL
Casing Base: 49.7 mBGL

Response Zone Top RL: 17.71 m AHD
Response Zone Base RL: 14.71 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at 33.29 mAHD

Installation Date: 13/07/2017
Development Date: 6/10/2017

Summary Geology (refer to geological log for full descriptions)

Method	Core Run TCR (%)	RQD (%)	Ground Water	Depth (m)	Rock Description
ADT NDD				0.0	ASPHALTIC CONCRETE, black
					Clayey SAND, fine to coarse, brown
HQ3	100	66		2.0	SANDSTONE, red-brown and pale grey
				4.0	SANDSTONE, fine to coarse, red-brown and pale grey
	100	100			SANDSTONE, fine to coarse, pale grey
	100	99		8.0	
	100	96		10.0	
	100	98		14.0	
	100	100		16.0	
	100	97		20.0	
	100	96		22.0	
	100	96		26.0	SANDSTONE, fine to coarse, grey
					SANDSTONE, fine to coarse, pale grey
	100	98	29/09/2017	28.0	

Piezometer: Length 0.0 to 0.0 m — GATIC COVER
Length 0.0 to 41.5 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

Reduced Level RL (m): 62.0, 60.0, 58.0, 56.0, 54.0, 52.0, 50.0, 48.0, 46.0, 44.0, 42.0, 40.0, 38.0, 36.0, 34.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

AECOM coffey

PIEZOMETER No. B133

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	KW	**Checked by:**	RR
Location:	Harriot Street - Waverton	**Start Date:**	4/07/2017	**End Date:**	14/07/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:**	333489.1 m	**RL:**	63.41 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:**	6254554.2 m	**Ver. Datum:**	AHD
	Bearing: N/A	**Hor. Proj/Dat:**	MGA94/GDA94-56	**Surface:**	Road surface

Field Data / Rock Description

Method: HQ3

Core Run	TCR (%)	RQD (%)
1	100	100
2	100	100
3	100	99
4	100	100
5	100	100
6	100	100
7	100	97
8	100	100
9	100	98
10	100	100
11	100	100

Reduced Level (m): 32.0, 30.0, 28.0, 26.0, 24.0, 22.0, 20.0, 18.0, 16.0, 14.0, 12.0, 10.0, 8.0, 6.0, 4.0

Depth (m): 32.0, 34.0, 36.0, 38.0, 40.0, 42.0, 44.0, 46.0, 48.0, 50.0, 52.0, 54.0, 56.0, 58.0, 60.0

Summary Geology (refer to geological log for full descriptions):

- SANDSTONE, fine to coarse, pale grey *continued*
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, fine to coarse, pale brown to pale grey
- SANDSTONE, fine to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, fine to coarse, pale grey
- SANDSTONE, fine to medium, pale grey
- SANDSTONE, fine to coarse, pale grey and grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, fine to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, fine to coarse, dark grey to pale grey
- SANDSTONE, fine to coarse, pale grey and grey

Defect Spacing (mm): 20, 40, 100, 300, 1000

Piezometer Details

Construction details:	Standpipe Piezometer, 3 m slotted screen, sump
Remarks:	Class 18 PVC 50 mm ID
Casing Top RL:	63.39 m AHD
Casing Top:	0.0 mBGL
Casing Base:	49.7 mBGL
Response Zone Top RL:	17.71 m AHD
Response Zone Base RL:	14.71 m AHD
Length of Response Zone:	3.00 m
Instrument Details:	Piezo-resistive piezometer (3G) at 33.29 mAHD
Installation Date:	13/07/2017
Development Date:	6/10/2017

Length	Material
Length 0.0 to 41.5 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)
Length 41.5 to 43.6 m	BENTONITE SEAL (PELLETS)
Length 43.6 to 45.7 m	2mm FILTER SAND
Length 45.7 to 48.7 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 48.7 to 49.7 m	2mm FILTER SAND (SUMP/PVC CAP)
Length 49.7 to 50.7 m	BENTONITE SEAL (PELLETS)
Length 50.7 to 65.2 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

Reduced Level RL (m): 32.0, 30.0, 28.0, 26.0, 24.0, 22.0, 20.0, 18.0, 16.0, 14.0, 12.0, 10.0, 8.0, 6.0, 4.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

AECOM coffey

PIEZOMETER No. B133

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** KW	**Checked by:** RR
Location: Harriot Street - Waverton		**Start Date:** 4/07/2017	**End Date:** 14/07/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 333489.1 m	**RL:** 63.41 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:** 6254554.2 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Road surface

Field Data | **Rock Description** | **Piezometer Details**

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 63.39 m AHD
Casing Top: 0.0 mBGL
Casing Base: 49.7 mBGL

Response Zone Top RL: 17.71 m AHD
Response Zone Base RL: 14.71 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at 33.29 mAHD

Installation Date: 13/07/2017
Development Date: 6/10/2017

Summary Geology (refer to geological log for full descriptions)

Method	Core Run	TCR (%)	RQD (%)	Reduced Level (m)	Depth (m)	Rock Description
HQ3		100	99	2.0	62.0	SANDSTONE, fine to medium, pale grey and pale brown
						SANDSTONE, fine to medium, grey
		100	96	0.0	64.0	MUDSTONE, dark grey
						LAMINITE
				-2.0	66.0	MUDSTONE, dark grey
				-4.0	68.0	
				-6.0	70.0	
				-8.0	72.0	
				-10.0	74.0	
				-12.0	76.0	
				-14.0	78.0	
				-16.0	80.0	
				-18.0	82.0	
				-20.0	84.0	
				-22.0	86.0	
				-24.0	88.0	
				-26.0	90.0	

Defect Spacing (mm): 20, 40, 100, 300, 1000

Length 50.7 to 65.2 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

B133 terminated at 65.22 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B149

Sheet: 1 of 3

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** DK	**Checked by:** DMH
Location: Beattie St - Balmain		**Start Date:** 14/08/2017	**End Date:** 21/08/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 331286.2 m	**RL:** 28.37 m
Drill Rig: Comacchio 305	**Inclination:** -90°	**Northing:** 6251986.9 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Road surface

Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 28.29 m AHD
Casing Top: 0.1 mBGL
Casing Base: 65.0 mBGL

Response Zone Top RL: -32.64 m AHD
Response Zone Base RL: -35.64 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at 3.59 mAHD

Installation Date: 23/08/2017
Development Date: 8/12/2017

Field Data

Method	Core Run	TCR (%)	RQD (%)
NDD			
HQ3	R1	100	92
HQ3	R2	100	87
HQ3	R3	100	100
HQ3	R4	100	100
HQ3	R5	100	100
HQ3	R6	92	87
HQ3	R7	100	100
HQ3	R8	100	93
HQ3	R9	100	97
HQ3	R10	88	88
HQ3	R11	100	89

Ground Water: 20/09/2017

Depth (m): 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 22.0, 24.0, 26.0, 28.0, 30.0

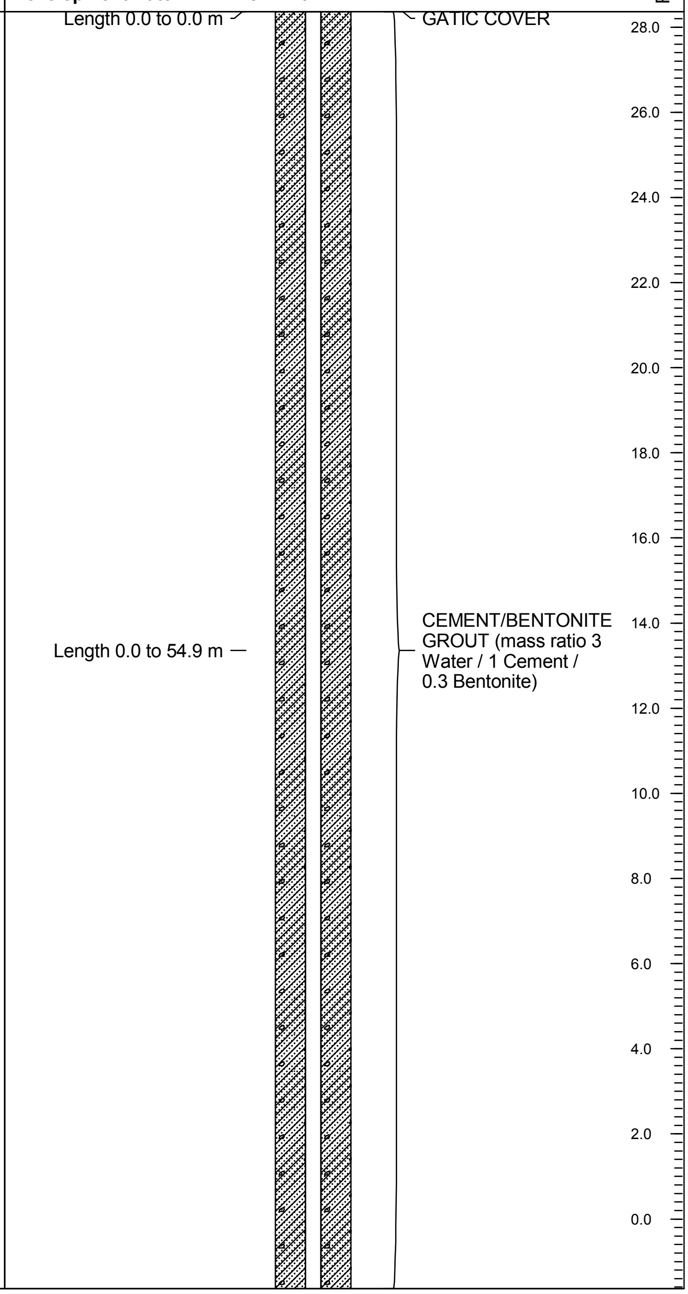
Reduced Level (m): 28.0, 26.0, 24.0, 22.0, 20.0, 18.0, 16.0, 14.0, 12.0, 10.0, 8.0, 6.0, 4.0, 2.0, 0.0

Rock Description

Summary Geology (refer to geological log for full descriptions)

- ASPHALTIC CONCRETE, fine to medium, dark grey
- GRAVEL, fine to coarse, brown and grey
- CLAY, brown-orange
- SANDSTONE, pale grey and orange-brown
- SANDSTONE, medium to coarse, orange-brown
- SANDSTONE, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, fine, pale grey and grey
- SANDSTONE, fine to medium, pale grey and grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, fine to medium, pale grey
- LAMINITE
- NO CORE
- LAMINITE
- SANDSTONE, coarse, pale grey
- SANDSTONE, medium to coarse, pale grey
- NO CORE
- SANDSTONE, fine, grey
- LAMINITE
- SANDSTONE, medium to coarse, pale

Defect Spacing (mm): 20, 40, 100, 300, 1000



GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. **B149**

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** DK	**Checked by:** DMH
Location: Beattie St - Balmain		**Start Date:** 14/08/2017	**End Date:** 21/08/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 331286.2 m	**RL:** 28.37 m
Drill Rig: Comacchio 305	**Inclination:** -90°	**Northing:** 6251986.9 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Road surface

Field Data / Rock Description / Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 28.29 m AHD
Casing Top: 0.1 mBGL
Casing Base: 65.0 mBGL

Response Zone Top RL: -32.64 m AHD
Response Zone Base RL: -35.64 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at 3.59 mAHD

Installation Date: 23/08/2017
Development Date: 8/12/2017

Method: HQ3

Core Run	TCR (%)	RQD (%)
R12	100	100
R13	100	100
R14	100	100
R15	100	100
R16	100	100
R17	100	100
R18	100	96
R19	100	99
R20	100	100
R21	100	100
R22	100	100
R23	100	100

Summary Geology (refer to geological log for full descriptions)

- grey
- SANDSTONE, coarse, pale grey *continued*
- SANDSTONE, medium to coarse, pale grey
- MUDSTONE, fine, dark grey and pale grey
- LAMINITE
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, fine, grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey and pale brown
- SANDSTONE, medium to coarse, pale grey

Defect Spacing (mm): 20, 40, 100, 300, 1000

Depth (m): 32.0, 34.0, 36.0, 38.0, 40.0, 42.0, 44.0, 46.0, 48.0, 50.0, 52.0, 54.0, 56.0, 58.0, 60.0

Reduced Level (m): -2.0, -4.0, -6.0, -8.0, -10.0, -12.0, -14.0, -16.0, -18.0, -20.0, -22.0, -24.0, -26.0, -28.0, -30.0

Length	Material
Length 0.0 to 54.9 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)
Length 54.9 to 59.0 m	BENTONITE SEAL (PELLETS)
Length 59.0 to 61.0 m	2mm FILTER SAND

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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Engineering Log

PIEZOMETER No. B149

Client:	RMS		**Project No:**	60537922	
Project:	Western Harbour Tunnel and Beaches Link		**Logged by:**	DK	**Checked by:** DMH
Location:	Beattie St - Balmain		**Start Date:**	14/08/2017	**End Date:** 21/08/2017
Driller:	Terratest	**Hole Diameter:** 96 mm	**Easting:**	331286.2 m	**RL:** 28.37 m
Drill Rig:	Comacchio 305	**Inclination:** -90°	**Northing:**	6251986.9 m	**Ver. Datum:** AHD
		Bearing: N/A	**Hor. Proj/Dat:**	MGA94/GDA94-56	**Surface:** Road surface

Field Data | Rock Description | Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 28.29 m AHD
Casing Top: 0.1 mBGL
Casing Base: 65.0 mBGL

Response Zone Top RL: -32.64 m AHD
Response Zone Base RL: -35.64 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at 3.59 mAHD

Installation Date: 23/08/2017
Development Date: 8/12/2017

Method: HQ3

Core Run	TCR (%)	RQD (%)
R24	100	100
R25	33	100
R26	100	100
R27	100	95
R28	100	98
R29	100	100
R30	100	72

Summary Geology (refer to geological log for full descriptions)

Depth (m)	Description
61.0 – 66.0	SANDSTONE, medium to coarse, pale grey *continued*
66.0 – 67.0	SANDSTONE, coarse, pale grey
67.0 – 68.5	MUDSTONE, dark grey
68.5 – 71.5	SANDSTONE, fine to medium, pale grey to grey
71.5 – 72.5	SANDSTONE, fine to coarse, pale grey
72.5 – 73.0	MUDSTONE, dark grey
73.0 – 74.2	SANDSTONE, fine to medium, pale grey
74.2 – 77.8	SANDSTONE, medium to coarse, pale grey
77.8 – 79.0	SANDSTONE, fine to medium, pale grey

Defect Spacing (mm): 20, 40, 100, 300, 1000

Interval	Piezometer Details
Length 59.0 to 61.0 m	2mm FILTER SAND
Length 61.0 to 64.0 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 64.0 to 65.0 m	2mm FILTER SAND (SUMP/PVC CAP)
Length 65.0 to 79.0 m	BENTONITE SEAL (PELLETS)

B149 terminated at 79.00 m.

Depth (m) scale: 62.0 – 90.0; Reduced Level (m) scale: -32.0 – -60.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B150

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** LH	**Checked by:** RPW
Location: Elliot Street - North Sydney		**Start Date:** 11/07/2017	**End Date:** 13/07/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 334252.6 m	**RL:** 80.08 m
Drill Rig: Comacchio 305	**Inclination:** -90°	**Northing:** 6254833.6 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H	**Surface:** Road Surface

Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 79.99 m AHD
Casing Top: 0.1 mBGL
Casing Base: 29.0 mBGL

Response Zone Top RL: 56.08 m AHD
Response Zone Base RL: 53.08 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at 63.24 mAHD

Installation Date: 13/07/2017
Development Date: 13/10/2017

Field Data / Rock Description

Summary Geology (refer to geological log for full descriptions)

Method	Core Run	TCR (%)	RQD (%)	Summary Geology
NDD				ASPHALTIC CONCRETE
				Sandy GRAVEL, medium, dark grey
				CLAY, red-brown
HQ3	R1	100	0	Sandy CLAY, pale grey to white
	R2	78	24	SANDSTONE, medium, red to dark purple
				Sandy CLAY, pale grey and white
				NO CORE
	R3	100	98	SANDSTONE, medium, pale grey to dark purple and red
				SANDSTONE, medium, mottled pale grey to purple
	R4	100	100	SANDSTONE, medium, pale grey
				SANDSTONE, medium, mottled pale grey, purple and pink
	R5	100	99	SANDSTONE, medium, pale grey to pale orange-brown and purple
				SANDSTONE, medium, pale grey
	R6	100	92	SANDSTONE, medium to coarse, orange-brown
				LAMINITE
	R7	100	100	SANDSTONE, fine, grey
				SANDSTONE, fine to medium, grey
	R8	100	100	SANDSTONE, medium, pale grey
	R9	100	100	
	R10	100	100	

Ground Water: 29/09/2017 (approx. 12.5 m depth)

Installation

Length	Material
Length 0.0 to 0.1 m	GATIC COVER
Length 0.0 to 20.0 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)
Length 20.0 to 22.0 m	BENTONITE SEAL (PELLETS)
Length 22.0 to 24.0 m	2mm FILTER SAND
Length 24.0 to 27.0 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 27.0 to 29.0 m	2mm FILTER SAND (SUMP/PVC CAP)
Length 29.0 to 43.0 m	BENTONITE SEAL (PELLETS)

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B150

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** LH	**Checked by:** RPW
Location: Elliot Street - North Sydney		**Start Date:** 11/07/2017	**End Date:** 13/07/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 334252.6 m	**RL:** 80.08 m
Drill Rig: Comacchio 305	**Inclination:** -90°	**Northing:** 6254833.6 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H	**Surface:** Road Surface

Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 79.99 m AHD
Casing Top: 0.1 mBGL
Casing Base: 29.0 mBGL

Response Zone Top RL: 56.08 m AHD
Response Zone Base RL: 53.08 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at 63.24 mAHD

Installation Date: 13/07/2017
Development Date: 13/10/2017

Field Data / Rock Description

Summary Geology (refer to geological log for full descriptions)

Method	Core Run	TCR (%)	RQD (%)	Depth (m)	Reduced Level (m)	Summary Geology
HQ3	R11	100	100	30.0–32.0	50.0–48.0	SANDSTONE, medium, pale grey *continued*
HQ3	R12	100	100			
HQ3	R13	100	100	38.0–38.4		SHALE BRECCIA
HQ3	R14	100	100			SANDSTONE, medium to coarse, pale grey
HQ3				42.0–42.6		SANDSTONE, fine, grey
HQ3	R15	100	100	–43.0		SANDSTONE, medium, pale grey

Defect Spacing (mm): 20, 40, 100, 300, 1000

Length 29.0 to 43.0 m — BENTONITE SEAL (PELLETS)

B150 terminated at 43.00 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B150P

Sheet: 1 of 1

Client: RMS		**Project No:** 60537922			
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** MC/AM		**Checked by:** -	
Location: Elliot Street - North Sydney		**Start Date:** 18/12/2017		**End Date:** 19/12/2017	
Driller: Terratest	**Hole Diameter:** 99 mm	**Easting:** 334254.5 m		**RL:** 80.59 m	
Drill Rig: Comacchio 450P	**Inclination:** -90°	**Northing:** 6254846.1 m		**Ver. Datum:** AHD	
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H		**Surface:** Road Surface	

Field Data (Method, Core Run, TCR (%), RQD (%), Ground Water, Reduced Level (m), Depth (m), Graphic Log) — Method: WB

Rock Description

Summary Geology (refer to geological log for full descriptions)

- ASPHALTIC CONCRETE
- Sandy GRAVEL, medium, dark grey
- CLAY, red-brown
- Sandy CLAY, pale grey to white
- SANDSTONE, medium, red to dark purple
- Sandy CLAY, pale grey and white
- NO CORE
- SANDSTONE, medium, pale grey to dark purple and red
- SANDSTONE, medium, mottled pale grey to purple
- SANDSTONE, medium, pale grey
- SANDSTONE, medium, mottled pale grey, purple and pink
- SANDSTONE, medium, pale grey to pale orange-brown and purple
- SANDSTONE, medium, pale grey
- SANDSTONE, medium to coarse, orange-brown
- LAMINITE
- SANDSTONE, fine, grey
- SANDSTONE, fine to medium, grey
- SANDSTONE, medium, pale grey

Defect Spacing (mm): 20, 40, 100, 300, 1000

Piezometer Details

Construction details:	Standpipe Piezometer, 3 m slotted screen, sump
Remarks:	Class 18 PVC 50 mm ID
Casing Top RL:	80.52 m AHD
Casing Top:	0.1 mBGL
Casing Base:	29.3 mBGL
Response Zone Top RL:	56.59 m AHD
Response Zone Base RL:	53.59 m AHD
Length of Response Zone:	3.00 m
Instrument Details:	Piezo-resistive piezometer (3G) at 63.77 mAHD
Installation Date:	19/12/2017
Development Date:	25/01/2018

Interval	Detail
Length 0.0 to 0.0 m	GATIC COVER
Length 0.0 to 0.4 m	CONCRETE ROAD BOX
Length 0.4 to 6.5 m	BENTONITE
Length 6.5 to 20.0 m	BENTONITE
Length 20.0 to 22.0 m	BENTONITE SEAL (PELLETS)
Length 22.0 to 24.0 m	2mm FILTER SAND
Length 24.0 to 27.0 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 27.0 to 29.3 m	2mm FILTER SAND (SUMP/PVC CAP)

Reduced Level RL (m): 80.0, 78.0, 76.0, 74.0, 72.0, 70.0, 68.0, 66.0, 64.0, 62.0, 60.0, 58.0, 56.0, 54.0, 52.0

Depth (m): 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 22.0, 24.0, 26.0, 28.0, 30.0

B150P terminated at 29.30 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B343

Sheet: 1 of 2

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	KW	**Checked by:**	DMH
Location:	Warringah Freeway - North Sydney	**Start Date:**	5/09/2017	**End Date:**	12/09/2017
Driller:	Hagstrom Drilling	**Easting:**	334419.7 m	**RL:**	76.91 m
Drill Rig:	Hydrapower Scout	**Northing:**	6255903.0 m	**Ver. Datum:**	AHD
Hole Diameter:	96 mm	**Hor. Proj/Dat:**	MGA94/GDA94-56	**Surface:**	Road Surface
Inclination:	-90°				
Bearing:	N/A				

Piezometer Details

- **Construction details:** Standpipe Piezometer, 3 m slotted screen, sump
- **Remarks:** Class 18 PVC 50 mm ID
- **Casing Top RL:** 76.85 m AHD
- **Casing Top:** 0.1 mBGL
- **Casing Base:** 43.5 mBGL
- **Response Zone Top RL:** 40.41 m AHD
- **Response Zone Base RL:** 34.41 m AHD
- **Length of Response Zone:** 6.00 m
- **Instrument Details:** Piezo-resistive piezometer (3G) at 56.85 mAHD
- **Installation Date:** 13/09/2017
- **Development Date:** 18/01/2018

Field Data / Rock Description

Summary Geology (refer to geological log for full descriptions)

Method: DT (0–~1.0 m), HQ3 below

Ground Water: 6/09/2017; 20/09/2017

Core Run	TCR (%)	RQD (%)	Rock Description
			CONCRETE
R1	100	44	SANDSTONE, fine to medium, pale grey
R2	100	90	SANDSTONE, medium to coarse
R3	100	100	SANDSTONE, medium to coarse, pale grey
R4	100	94	SANDSTONE, medium to coarse, yellow and brown stained pale brown
			SANDSTONE, medium to coarse, yellow and brown stained pale brown
R5	100	100	SANDSTONE, coarse, pale yellow brown
			SANDSTONE, medium to coarse, yellow and brown
R6	100	98	SANDSTONE, medium to coarse, pale grey
			SANDSTONE, medium to coarse, pale grey
R7	100	93	
R8	100	90	SANDSTONE, medium to coarse, yellow, brown and red brown stained pale grey
			SANDSTONE, medium to coarse, red and brown stained pale grey
R9	100	97	SANDSTONE, medium to coarse, pale grey
			SANDSTONE, medium to coarse, red-brown stained pale grey
R10	100	100	SANDSTONE, medium to coarse, pale grey
			SANDSTONE, medium to coarse, pale grey
R11	100	100	SANDSTONE, medium to coarse, pale grey
			SANDSTONE, medium to coarse, pale grey
R12	100	100	SANDSTONE, medium to coarse, pale grey
			SANDSTONE, medium to coarse, pale grey

Piezometer Construction

Interval	Material
Length 0.0 to 0.0 m	GATIC COVER
Length 0.0 to 28.0 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)
Length 28.0 to 32.8 m	BENTONITE SEAL (PELLETS)

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B343

Sheet: 2 of 2

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** KW	**Checked by:** DMH
Location: Warringah Freeway - North Sydney		**Start Date:** 5/09/2017	**End Date:** 12/09/2017
Driller: Hagstrom Drilling	**Hole Diameter:** 96 mm	**Easting:** 334419.7 m	**RL:** 76.91 m
Drill Rig: Hydrapower Scout	**Inclination:** -90°	**Northing:** 6255903.0 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Road Surface

Field Data | **Rock Description** | **Piezometer Details**

Summary Geology (refer to geological log for full descriptions)

Defect Spacing (mm): 20, 40, 100, 300, 1000

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 76.85 m AHD
Casing Top: 0.1 mBGL
Casing Base: 43.5 mBGL

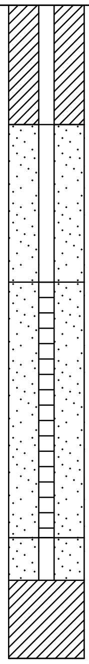
Response Zone Top RL: 40.41 m AHD
Response Zone Base RL: 34.41 m AHD
Length of Response Zone: 6.00 m

Instrument Details: Piezo-resistive piezometer (3G) at 56.85 mAHD

Installation Date: 13/09/2017
Development Date: 18/01/2018

Method	Core Run	TCR (%)	RQD (%)	Depth (m)	Rock Description
HQ3	R13	100	93		SANDSTONE, medium to coarse, pale grey
	R14	100	95	32.0	MUDSTONE, dark grey *continued*
					SANDSTONE, medium to coarse, pale grey
	R15	100	100	34.0	SANDSTONE, medium to coarse, pale grey
				36.0	SANDSTONE, medium to coarse, pale grey
	R16	100	100	38.0	SANDSTONE, medium to coarse, pale grey
					SANDSTONE, medium to coarse, pale grey
	R17	100	100	40.0	SANDSTONE, medium to coarse, pale grey
				42.0	SANDSTONE, medium to coarse, pale grey
	R18	100	100	44.0	SANDSTONE, medium to coarse, pale grey
					SANDSTONE, medium to coarse, pale grey
				46.0	SANDSTONE, fine to coarse, pale grey
				48.0	SANDSTONE, medium to coarse, pale grey
					SANDSTONE, medium to coarse, pale grey
				50.0	SANDSTONE, medium to coarse, pale grey
				52.0	SANDSTONE, fine to medium, grey

Reduced Level (m): 46.0, 44.0, 42.0, 40.0, 38.0, 36.0, 34.0, 32.0, 30.0, 28.0, 26.0, 24.0, 22.0, 20.0, 18.0
Depth (m): 32.0, 34.0, 36.0, 38.0, 40.0, 42.0, 44.0, 46.0, 48.0, 50.0, 52.0, 54.0, 56.0, 58.0, 60.0



Interval	Installation
Length 28.0 to 32.8 m	BENTONITE SEAL (PELLETS)
Length 32.8 to 36.5 m	2mm FILTER SAND
Length 36.5 to 42.5 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 42.5 to 43.5 m	2mm FILTER SAND (SUMP/PVC CAP)
Length 43.5 to 45.3 m	BENTONITE SEAL (PELLETS)

B343 terminated at 45.33 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

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PIEZOMETER No. B390

Sheet: 1 of 2

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** KW	**Checked by:** DMH
Location: Alice Street - Rozelle		**Start Date:** 18/08/2017	**End Date:** 22/08/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 330684.1 m	**RL:** 10.93 m
Drill Rig: Comacchio 450P	**Inclination:** -90°	**Northing:** 6250754.0 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H	**Surface:** Road surface

Field Data

Method: AD/T (0.0–~1.0 m); HQ3

Ground Water: 20/09/2017 / 22/08/2017 (level at ~1.8 m)

Core Run	TCR (%)	RQD (%)
R1	100	91
R2	100	98
R3	100	100
R4	100	97
R5	100	96
R6	100	100
R7	100	98
R8	100	92
R9	100	96
R10	100	100

Rock Description

Summary Geology (refer to geological log for full descriptions)

- ASPHALTIC CONCRETE, black
- Silty SAND, dark grey
- CLAY, yellow-brown
- SANDSTONE, medium to coarse, red-brown, yellow-brown and pale grey
- SANDSTONE, medium to coarse, pale brown, red-brown, yellow-brown
- SANDSTONE, medium to coarse, pale grey and yellow-brown
- SANDSTONE, fine to coarse, yellow-brown and pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, fine to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, fine to medium, pale grey
- SANDSTONE, fine, grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, fine to medium, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey and brown
- SANDSTONE, fine to coarse, pale grey and brown
- SANDSTONE, medium to coarse, pale grey
- LAMINITE
- SANDSTONE, fine to medium, pale grey

Defect Spacing (mm): 20, 40, 100, 300, 1000

Piezometer Details

Construction details:	Standpipe Piezometer, 3 m slotted screen, sump
Remarks:	Class 18 PVC 50 mm ID
Casing Top RL:	10.84 m AHD
Casing Top:	0.1 mBGL
Casing Base:	20.4 mBGL
Response Zone Top RL:	-2.38 m AHD
Response Zone Base RL:	-8.38 m AHD
Length of Response Zone:	6.00 m
Instrument Details:	Piezo-resistive piezometer (3G) at 0.84 mAHD
Installation Date:	22/08/2017
Development Date:	18/07/2018

Length	Installation
Length 0.0 to 0.0 m	GATIC COVER
Length 0.0 to 2.4 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)
Length 2.4 to 11.4 m	BENTONITE SEAL (PELLETS)
Length 11.4 to 13.3 m	2mm FILTER SAND
Length 13.3 to 19.3 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 19.3 to 20.4 m	2mm FILTER SAND (SUMP/PVC CAP)
Length 20.4 to 30.2 m	BENTONITE SEAL (PELLETS)

Reduced Level RL (m): 10.0, 8.0, 6.0, 4.0, 2.0, 0.0, -2.0, -4.0, -6.0, -8.0, -10.0, -12.0, -14.0, -16.0, -18.0

Depth (m): 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 22.0, 24.0, 26.0, 28.0, 30.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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Engineering Log

PIEZOMETER No. B390

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	KW	**Checked by:**	DMH
Location:	Alice Street - Rozelle	**Start Date:**	18/08/2017	**End Date:**	22/08/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:**	330684.1 m	**RL:**	10.93 m
Drill Rig: Comacchio 450P	**Inclination:** -90°	**Northing:**	6250754.0 m	**Ver. Datum:**	AHD
	Bearing: N/A	**Hor. Proj/Dat:**	MGA94/GDA94-56H	**Surface:**	Road surface

Field Data | **Rock Description** | **Piezometer Details**

Method | Core Run | TCR (%) | RQD (%) | Ground Water | Reduced Level (m) | Depth (m) | Graphic Log

Summary Geology (refer to geological log for full descriptions)

Defect Spacing (mm): 20, 40, 100, 300, 1000

Construction details:	Standpipe Piezometer, 3 m slotted screen, sump
Remarks:	Class 18 PVC 50 mm ID
Casing Top RL:	10.84 m AHD
Casing Top:	0.1 mBGL
Casing Base:	20.4 mBGL
Response Zone Top RL:	-2.38 m AHD
Response Zone Base RL:	-8.38 m AHD
Length of Response Zone:	6.00 m
Instrument Details:	Piezo-resistive piezometer (3G) at 0.84 mAHD
Installation Date:	22/08/2017
Development Date:	18/07/2018

Reduced Level RL (m)

Reduced Level (m)	Depth (m)	Summary Geology
		LAMINITE
-20.0	32.0	SANDSTONE, medium to coarse, dark grey
-22.0	34.0	SANDSTONE, medium to coarse, pale grey
-24.0	36.0	SANDSTONE, medium to coarse, pale grey
		SANDSTONE, fine to coarse, pale grey
-26.0	38.0	SANDSTONE, medium to coarse, pale grey
		SANDSTONE, fine to medium, grey
-28.0	40.0	SANDSTONE, medium, pale grey *continued*
-30.0	42.0	
-32.0	44.0	
-34.0	46.0	
-36.0	48.0	
-38.0	50.0	
-40.0	52.0	
-42.0	54.0	
-44.0	56.0	
-46.0	58.0	
-48.0	60.0	

B390 terminated at 30.16 m.

Reduced Level RL (m): -20.0, -22.0, -24.0, -26.0, -28.0, -30.0, -32.0, -34.0, -36.0, -38.0, -40.0, -42.0, -44.0, -46.0, -48.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

PIEZOMETER CONSTRUCTION

HOLE NO : B104A_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Birchgrove - The Terrace

POSITION : E: 331665.8, N: 6252920.8 (56 MGA94) SURFACE ELEVATION : 7.59 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Explora 140 MOUNTING : Truck CONTRACTOR : Ground Test
DATE STARTED : 16/8/17 DATE COMPLETED : 24/8/17 DATE LOGGED : 16/8/17 LOGGED BY : ARM CHECKED BY : GS

MATERIAL

Depth	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.00–0.40m	FILL
0.40–1.60m	CLAYEY SAND
1.60–49.31m	SANDSTONE; - siltstone band (approx. 34.5 m)
49.31–52.00m	SILTSTONE AND SANDSTONE
52.00–58.11m	SANDSTONE

B104A_w TERMINATED AT 58.11 m
Target depth
ATV Imaging Completed
Groundwater Monitoring Well Installed

DRILLING: ADT/NMLC, HW Casing (to ~1.5 m); HQ3 to 58.11 m. WATER: 0% LOSS (to ~45 m), 5% LOSS (to 58.11 m). Ground water levels: 23/05/17, 18/05/17 (approx. 3.0 m).

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe Piezometer		42.70 m -35.11 m AHD	24/08/2017	

Depth	Construction
0.05 m	Gatic cover
0.05–0.30 m	Concrete
0.30–34.63 m	Cement Bentonite Grout
34.63–37.60 m	Bentonite
37.60–44.50 m	<5mm sand/gravel
39.70–42.70 m	PVC slotted screen
43.70 m	End Cap
44.50–58.11 m	Bentonite Pellet Backfill

This report of standpipe installation must be read in conjunction with accompanying notes and abbreviations. The geotechnical log is a summary only and the detailed log should be referred to for strata details and any core loss zones.

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PIEZOMETER CONSTRUCTION

HOLE NO : B105A_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Birchgrove - Deloitte Avenue

POSITION : E: 331813.4, N: 6253140.2 (56 MGA94) SURFACE ELEVATION : 2.24 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Hanjin DB8 MOUNTING : Track CONTRACTOR : Terratest
DATE STARTED : 5/9/17 DATE COMPLETED : 8/9/17 DATE LOGGED : 5/9/17 LOGGED BY : JN CHECKED BY : GS

DRILLING

PROGRESS: DRILLING & CASING / WATER; GROUND WATER LEVELS; DEPTH (m)

- Drilling & casing: HA (0.0–0.5 m approx.); HQ3 (to ~4.0 m); WB (~4.0–6.3 m); HQ3 (6.3–52.0 m)
- Water: 0% LOSS; 100% LOSS; 0% LOSS; 50% LOSS; 80-95% LOSS
- Ground water levels: 07/09/17 08:15

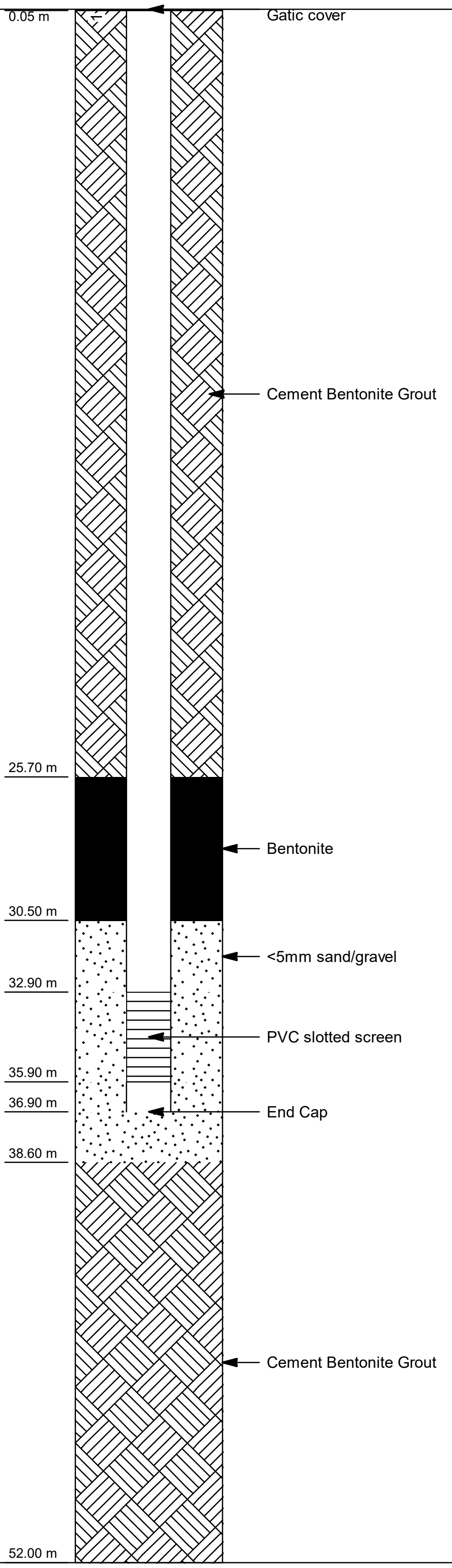
MATERIAL

GRAPHIC LOG | CLASSIFICATION SYMBOL | MATERIAL DESCRIPTION: Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components

Depth	Material Description
0.0	FILL
4.00m	SILTY SAND/SILTY CLAYEY SAND
6.30m	SANDSTONE
8.27m / 8.38m	CORE LOSS 0.11m (8.27-8.38)
	SANDSTONE
18.27m / 18.31m	CORE LOSS 0.04m (18.27-18.31)
	SANDSTONE - siltstone and sandstone band (0.45m) - siltstone and sandstone band (0.57m)
41.19m	SILTSTONE AND SANDSTONE
45.47m	SANDSTONE
46.42m	SILTSTONE AND SANDSTONE
47.22m	SANDSTONE
52.00m	B105A_w TERMINATED AT 52.00 m ATV IMAGING COMPLETED GROUTED

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe Piezometer		36.90 m -34.66 m AHD	11/09/2017	



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RMS LIB 40.3.1.GLB Log RTA PIEZOMETER INSTALLATION LOG 1 B105A_W.GPJ <<DrawingFile>> 14/Sep/2017 14:27 8.30.004 Datgel Tools

PIEZOMETER CONSTRUCTION

HOLE NO : B131A_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Birchgrove - Louisa Road

POSITION : E: 332031.4, N: 6253234.7 (56 MGA94) SURFACE ELEVATION : 3.97 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Comacchio 405 MOUNTING : Track CONTRACTOR : Terratest
DATE STARTED : 30/8/17 DATE COMPLETED : 6/9/17 DATE LOGGED : 30/8/17 LOGGED BY : JN CHECKED BY : GS

DRILLING

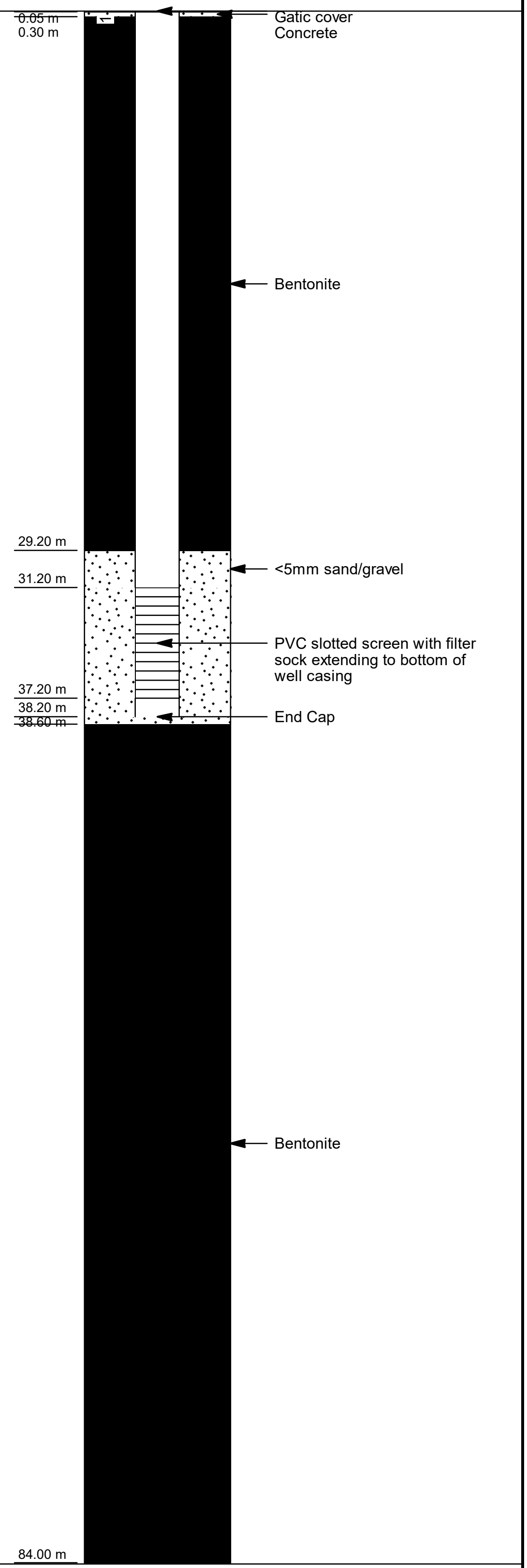
DRILLING & CASING	WATER
AD/T (0.0–3.0)	(GWNE)
HQ3 (3.0–84.06)	0% LOSS (3.0–6.0)
	0% LOSS (6.0–21.0)
	10-20% LOSS (21.0–57.0)
	80-95% LOSS (57.0–67.0)
	90-100% LOSS (67.0–84.06)

MATERIAL

Depth (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.0	FILL
2.60m	SANDSTONE
6.94m – 7.00m	CORE LOSS 0.06m (6.94-7.00)
7.00m	SANDSTONE
16.66m	SILTSTONE
18.45m	SANDSTONE
20.00m – 20.11m	CORE LOSS 0.11m (20.00-20.11)
20.11m	SANDSTONE
40.99m	SILTSTONE AND SANDSTONE
43.40m	SANDSTONE
44.20m	SILTSTONE AND SANDSTONE
44.79m	SANDSTONE
84.06m	B131A_w TERMINATED AT 84.06 m STRESS TESTING ATV IMAGING COMPLETED GROUTED

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe Piezometer		37.20 m -33.23 m AHD	11/09/2017	



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PIEZOMETER CONSTRUCTION

HOLE NO : B181A_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Rozelle - Ellen Street

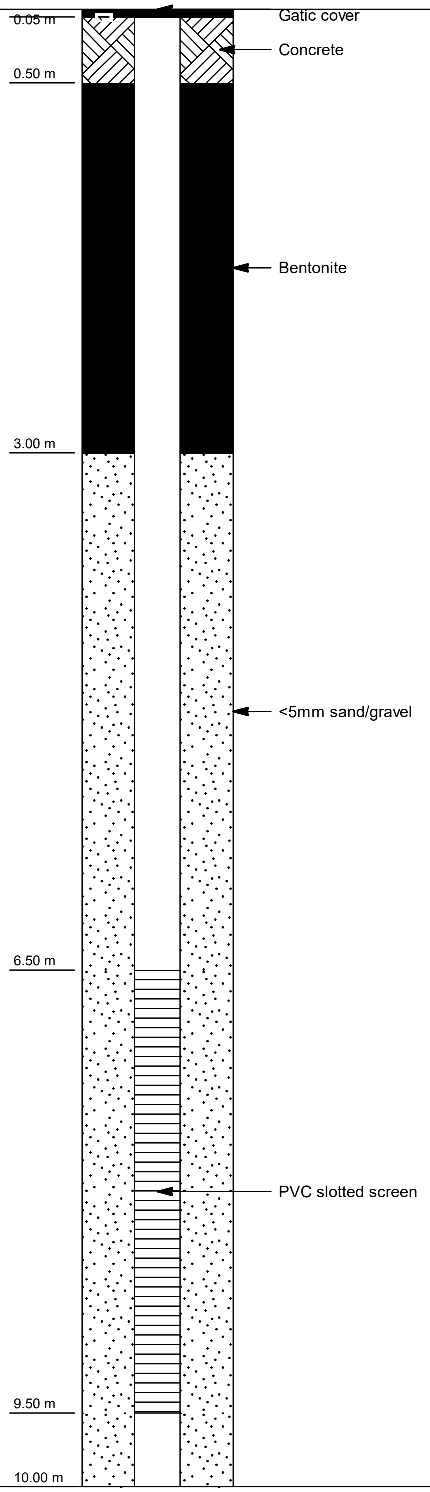
POSITION : E: 330808.1, N: 6251232.3 (56 MGA94) SURFACE ELEVATION : 30.24 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : DT100 MOUNTING : Truck CONTRACTOR : Ground Test
DATE STARTED : 12/10/17 DATE COMPLETED : 12/10/17 DATE LOGGED : 12/10/17 LOGGED BY : LJH CHECKED BY : GS

DRILLING / MATERIAL

DRILLING & CASING	WATER	DEPTH (m)	MATERIAL DESCRIPTION
NDD, HW Casing (0.0–0.7)		0.0	FILL
AD/T (0.0–1.4)	(GWNO) (0.0–1.4)	0.50m	SANDSTONE
WB (1.4–2.0)	0% LOSS (1.4–2.0)		
HQ3 (2.0–10.0)	0% LOSS (2.0–10.0)	10.00m	B181A_w TERMINATED AT 10.00 m Target depth Standpipe Installed

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe Piezometer		9.50 m 20.74 m AHD	12/10/2017	



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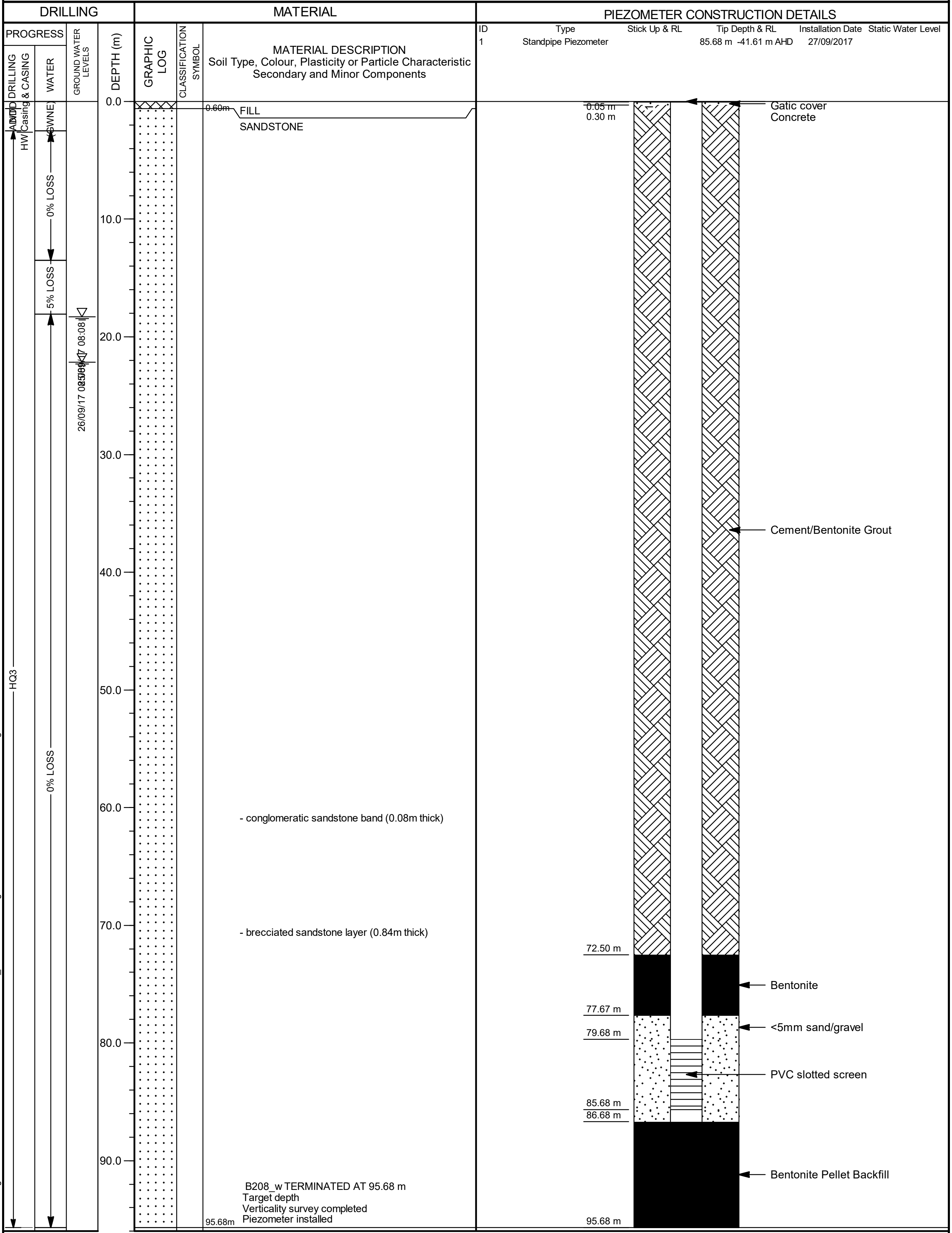
PIEZOMETER CONSTRUCTION

HOLE NO : B208_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Balmain - Little Darling Street

POSITION : E: 331415.4, N: 6252215.9 (56 MGA94) SURFACE ELEVATION : 44.07 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Comacchio 450P MOUNTING : Track CONTRACTOR : Terratest
DATE STARTED : 20/9/17 DATE COMPLETED : 25/9/17 DATE LOGGED : 20/9/17 LOGGED BY : MHA CHECKED BY : GS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe Piezometer		85.68 m -41.61 m AHD	27/09/2017	



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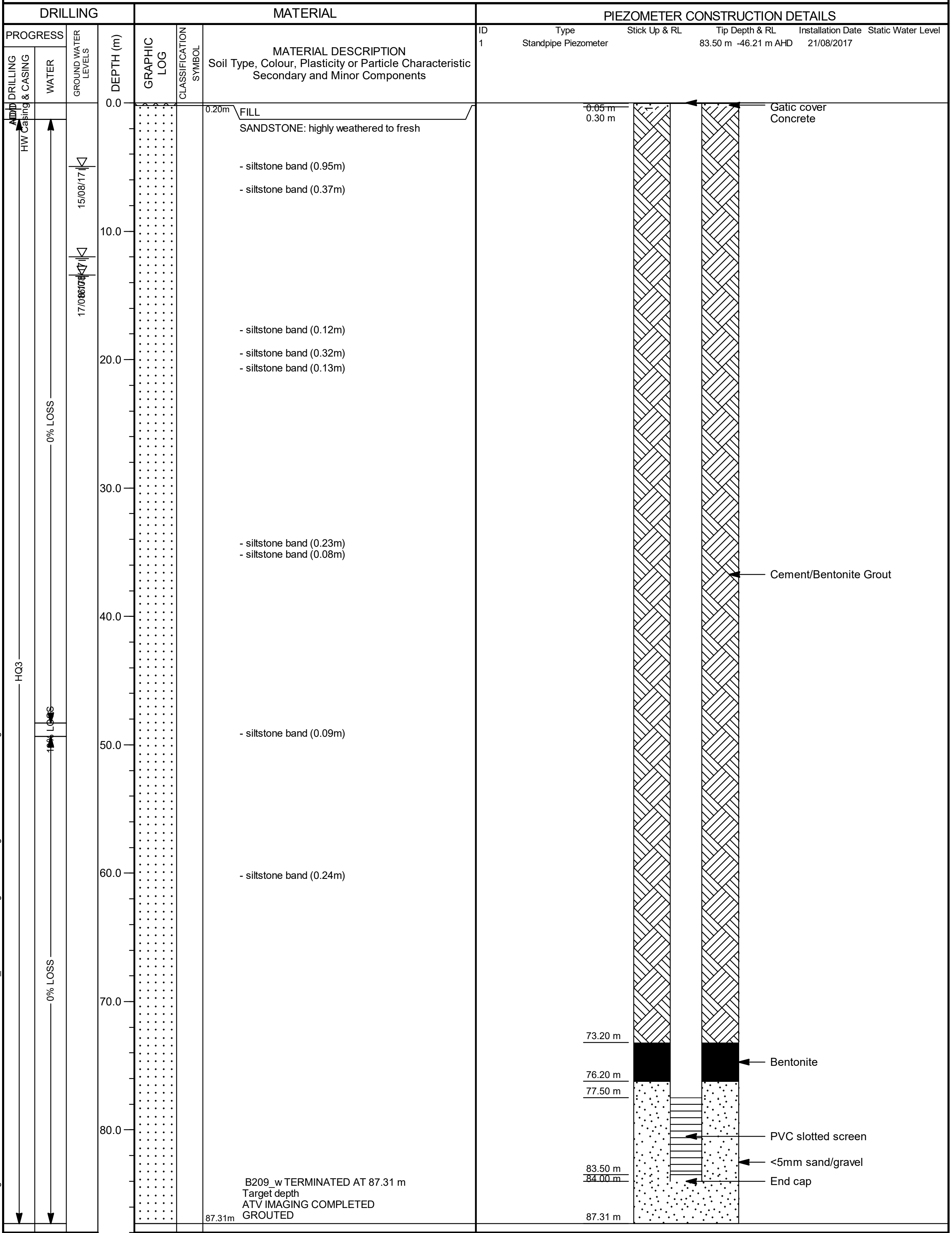
PIEZOMETER CONSTRUCTION

HOLE NO : **B209_w**
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Birchgrove - Thomas Street

POSITION : E: 331520.7, N: 6252619.2 (56 MGA94) SURFACE ELEVATION : 37.29 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Comacchio 405 MOUNTING : Track CONTRACTOR : Terra Test
DATE STARTED : 14/8/17 DATE COMPLETED : 18/7/17 DATE LOGGED : 14/8/17 LOGGED BY : JS/PGH CHECKED BY : GS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe Piezometer		83.50 m -46.21 m AHD	21/08/2017	



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PIEZOMETER CONSTRUCTION

HOLE NO : B106A_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Birchgrove - Yurulbin Park

POSITION : E: 332168.1, N: 6253322.9 (56 MGA94) | SURFACE ELEVATION : 2.68 (AHD) | ANGLE FROM HORIZONTAL : 68° AT 330°

RIG TYPE : Comacchio 305 | MOUNTING : Track | CONTRACTOR : Groundtest

DATE STARTED : 11/10/17 | DATE COMPLETED : 27/10/17 | DATE LOGGED : 27/10/17 | LOGGED BY : MB | CHECKED BY : GS

DRILLING

Depth (m)	Drilling & Casing	Water
0.0 – approx. 2.0	ADH, HW Casing	(OWNO)
approx. 2.0 – 95.80	HQ3	
approx. 2.0 – approx. 25.0		0% LOSS
approx. 25.0 – approx. 26.0		0% LOSS
approx. 26.0 – approx. 31.5		0% LOSS
approx. 31.5 – approx. 45.5		10% LOSS
approx. 45.5 – approx. 46.0		LOSS
approx. 46.0 – 67.00		40% LOSS
67.00 – 95.80		100% LOSS

MATERIAL

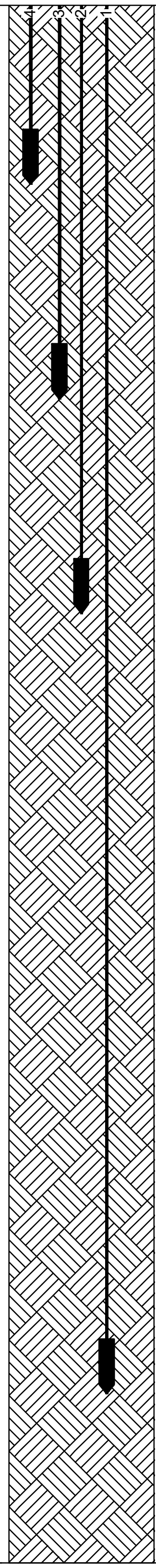
MATERIAL DESCRIPTION
Soil Type, Colour, Plasticity or Particle Characteristic
Secondary and Minor Components

Depth (m)	Material Description
0.00 – 0.80m	FILL
0.80 – 13.69m	SANDSTONE
13.69 – 15.40m	SILTSTONE
15.40 – 39.40m	SANDSTONE
39.40 – 39.45m	CORE LOSS 0.05m (39.40-39.45)
39.45 – 46.08m	SANDSTONE
46.08 – 46.13m	CORE LOSS 0.05m (46.08-46.13)
46.13 – 67.00m	SANDSTONE
67.00 – 67.20m	CORE LOSS 0.20m (67.00-67.20)
67.20 – 84.23m	SANDSTONE
84.23 – 84.38m	CORE LOSS 0.15m (84.23-84.38)
84.38 – 95.80m	SANDSTONE

B106A_w TERMINATED AT 95.80 m
Target depth
Imaging completed (ATV and OTV)
4x VWPs installed

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
4	Vibrating Wire Piezometer		11.00 m -7.52 m AHD	25/10/2017	
3	Vibrating Wire Piezometer		24.20 m -19.76 m AHD	25/10/2017	
2	Vibrating Wire Piezometer		37.40 m -32.00 m AHD	25/10/2017	
1	Vibrating Wire Piezometer		85.40 m -76.50 m AHD	25/10/2017	



VWPs installed in full cement/bentonite grout mix

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PIEZOMETER CONSTRUCTION

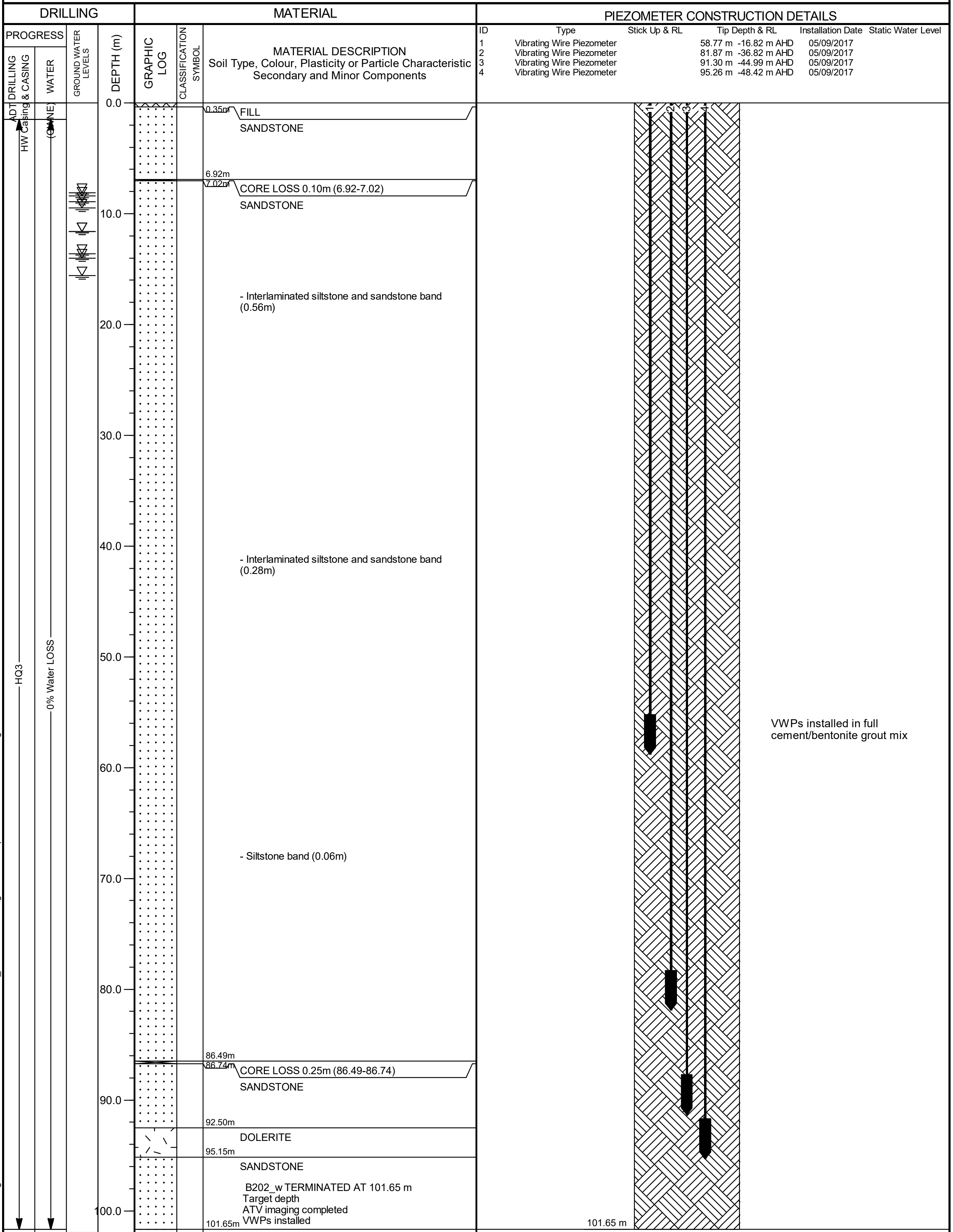
HOLE NO : B202_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Rozelle - Cross Street

POSITION : E: 330942.5, N: 6251497.3 (56 MGA94) SURFACE ELEVATION : 34.08 (AHD) ANGLE FROM HORIZONTAL : 60° AT 200°
RIG TYPE : Comacchio 305 MOUNTING : Track CONTRACTOR : Groundtest
DATE STARTED : 15/8/17 DATE COMPLETED : 29/8/17 DATE LOGGED : 15/8/17 LOGGED BY : MB CHECKED BY : GS

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Vibrating Wire Piezometer		58.77 m -16.82 m AHD	05/09/2017	
2	Vibrating Wire Piezometer		81.87 m -36.82 m AHD	05/09/2017	
3	Vibrating Wire Piezometer		91.30 m -44.99 m AHD	05/09/2017	
4	Vibrating Wire Piezometer		95.26 m -48.42 m AHD	05/09/2017	



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PIEZOMETER CONSTRUCTION

HOLE NO : B211_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Birchgrove - Yurulbin Park

POSITION : E: 332208.5, N: 6253348.4 (56 MGA94) SURFACE ELEVATION : 5.43 (AHD) ANGLE FROM HORIZONTAL : 60° AT 333°
RIG TYPE : Explora 140 MOUNTING : Truck CONTRACTOR : Ground Test
DATE STARTED : 11/10/17 DATE COMPLETED : 20/10/17 DATE LOGGED : 11/10/17 LOGGED BY : MHA CHECKED BY : GS

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
4	Vibrating Wire Piezometer		12.50 m -5.40 m AHD	24/10/2017	
3	Vibrating Wire Piezometer		27.75 m -18.60 m AHD	24/10/2017	
2	Vibrating Wire Piezometer		43.00 m -31.81 m AHD	24/10/2017	
1	Vibrating Wire Piezometer		59.15 m -45.80 m AHD	24/10/2017	

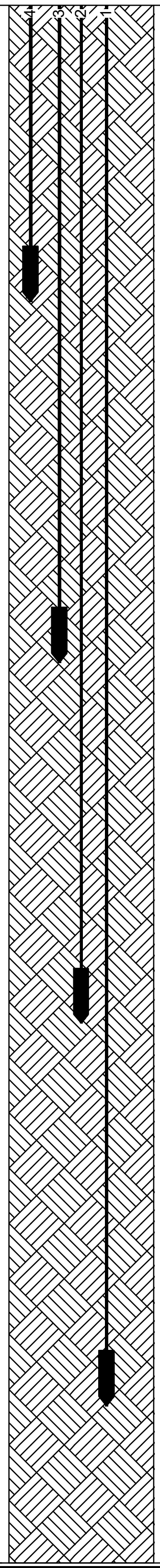
MATERIAL

Depth	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.0	FILL
2.95m	SANDSTONE
12.86m–12.95m	CORE LOSS 0.09m (12.86-12.95)
12.95m	SANDSTONE
17.39m–17.44m	CORE LOSS 0.05m (17.39-17.44)
17.44m	SANDSTONE
18.09m	SILTSTONE/SANDSTONE
20.41m	SANDSTONE
57.08m	SILTSTONE/SANDSTONE
62.30m	SANDSTONE
65.81m	B211_w TERMINATED AT 65.81 m Target depth ATV completed VWP installed

DRILLING

PROGRESS — DRILLING & CASING: AD/T, HW Casing (0–3.5 m approx.); HQ3 (to 65.81 m)

WATER: 100% Water LOSS (GWNE); 3% Water LOSS; 2% Water LOSS; 5% Water LOSS; 10% Water LOSS; 50% Water LOSS (repeated to end of hole)



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Appendix B. Piezometer construction details

Monitoring bore construction details (AEC)

Borehole name	Approximate Location	Easting (MGA56)	Northing (MGA56)	Ground Surface Level (mAHD)	Length of Borehole (m)	End of Borehole Elevation (mAHD)	Diametre (mm)	Drill date (finished)	Monitoring Date (from)	Monitoring Date (to)	Construction Material	Monitored Zone (mAHD)	Screened unit
B112	Waverton Park - Waverton	333240.44	6254091.13	15.99	76.09	-60.10	96	20/06/2017	10/08/2017	24/11/2017	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	-44.51 to -50.51	Sandstone
B112P	Waverton Park - Waverton	333230.4	6254078.3	15.94	70.00	-54.06	99	22/12/2017	22/12/2017	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	-44.56 to -54.06	Sandstone
B128	Balgowlah Cycleway - North Sydney	338487.22	6259591.57	30.79	19.00	11.79	96	3/08/2017	25/08/2017	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	-17.79 to -11.79	Sandstone
B133	Harriot Street - Waverton	333489.12	6254554.22	63.41	65.22	-1.82	96	14/07/2017	1/09/2017	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	19.86 to 13.71	Sandstone
B150	Elliot Street - North Sydney	334252.64	6254833.61	80.08	43.00	37.08	96	13/07/2017	9/08/2017	23/11/2017	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	57.98 to 51.08	Sandstone
B150P	Elliot Street - North Sydney	334254.5	6254846.1	80.59	29.30	51.29	99	19/12/2017	22/12/2017	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	58.59 to 51.29	Sandstone
B343	Warringah Freeway – North Sydney	334419.7	6255903.0	76.91	45.33	31.58	96	12/09/2017	18/01/2018	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	44.11 to 33.41	Sandstone
B390	Alice Street – Rozelle	330684.1	6250754.0	10.93	30.16	-19.23	96	22/08/2017	18/01/2018	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	-0.47 to -9.47	Sandstone

Appendix B. Piezometer construction details

Monitoring bore construction details (GDP)

Borehole name	Approximate Location	Easting (MGA56)	Northing (MGA56)	Ground Surface Level (mAHD)	Length of Borehole (m)	End of Borehole Elevation (mAHD)	Diametre (mm)	Drill date (finished)	Monitoring Date (from)	Monitoring Date (to) (for GW modelling)	Construction Material	Slotted screen interval (mAHD)	Screened unit
B104A	Birchgrove - The Terrace	331665.8	6252920.8	7.59	58.11	-50.52		24/08/2017	04/10/2017	1/11/2017	Standpipe Piezometer	-32.11 to -35.11	Sandstone
B105A	Birchgrove - Deloitte Avenue	331813.4	6253140.2	2.24	52.00	-49.76		08/09/2017	29/09/2017	1/11/2017	Standpipe Piezometer	-30.66 to -33.66	Sandstone
B131A	Birchgrove - Louisa Road	332031.4	6253234.7	3.97	84.06	-80.09		06/09/2017	29/09/2017	01/11/2017	Standpipe Piezometer	-27.23 to -33.23	Sandstone
B181A	Rozelle – Ellen Street	330808.1	6251232.3	30.24	10	20.24		12/10/2017	13/10/2017	01/11/2017	Standpipe Piezometer	23.74 to 20.74	Sandstone
B208	Balmain - Little Darling Street	331415.4	6252215.9	44.07	95.68	51.61		25/09/2017	29/09/2017	07/11/2017	Standpipe Piezometer	-35.61 to -41.61	Sandstone
B209	Birchgrove - Thomas Street	331520.7	6252619.2	37.29	87.31	-50.02		18/07/2017	29/09/2017	01/11/2017	Standpipe Piezometer	-40.21 to -46.21	Sandstone

VWP construction details (AEC)

Borehole name	Approximate Location	Easting (MGA56)	Northing (MGA56)	Ground Surface Level (mAHD)	Length of Borehole (m)	End of Borehole Elevation (mAHD)	Diametre (mm)	Drill date (finished)	Monitoring Date (from)	Monitoring Date (to)	Construction Material	VWP tip depth (mAHD)	Screened unit
B132	Balls Head Drive - Waverton	332923.50	6253603.28	20.56	120.27	-83.05	96	6/07/2017	21/07/2017	15/03/2018	Vibrating Wire Piezometer	VWP1 = -74.20 VWP2 = -28.26 VWP3 = -8.90 VWP4 = 10.40	

Appendix B. Piezometer construction details

VWP construction details (GDP)

Borehole name	Approximate Location	Easting (MGA56)	Northing (MGA56)	Ground Surface Level (mAHD)	Length of Borehole (m)	End of Borehole Elevation (mAHD)	Diametre (mm)	Drill date (finished)	Monitoring Date (from)	Monitoring Date (to)	Construction Material	VWP tip depth (mAHD)	Screened unit
B106A	Birchgrove – Yurulbin Park	332168.1	6253322.9	2.68	95.80	-93.12		27/10/2017	NRD*	NRD*	Vibrating Wire Piezometer	VWP1 = -76.50 VWP2 = -32.00 VWP3 = -19.76 VWP4 = -7.52	
B202	Rozelle – Cross Street	330942.5	6251497.3	34.08	101.65	-67.57		29/08/2017	12/09/2017	22/03/2018	Vibrating Wire Piezometer	VWP1 = -16.82 VWP2 = -36.82 VWP3 = -44.99 VWP4 = -48.42	
B211	Birchgrove – Yurulbin Park	332208.5	6253348.4	5.43	65.81	-60.38		20/10/2017	30/10/2017	1/03/2018	Vibrating Wire Piezometer	VWP1 = -45.80 VWP2 = -31.81 VWP3 = -18.60 VWP4 = -5.40	

*Data was not received

Appendix C. Packer test intervals and interpretation

Borehole	Inclination	Length to Top	Length to Bottom	Test Number	Reading Method	Fixed Volume	Packer Inflation Pressure	Packer Seal Condition	Pressure Gauge Height	Initial Groundwater Length	Initial Groundwater Depth	Depth to Top	Depth to Bottom	Depth to Centre	Section Length	Correction Gauge Pressure
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)
B110	-90.0	16.40	22.40	1	Fixed Time	100.0	1400.0	Good	1.3	5.5	5.48	16.40	22.40	19.40	6.00	66.5
B110	-90.0	16.40	22.40	1	Fixed Time	100.0	1400.0	Good	1.3	5.5	5.48	16.40	22.40	19.40	6.00	66.5
B110	-90.0	16.40	22.40	1	Fixed Time	100.0	1400.0	Good	1.3	5.5	5.48	16.40	22.40	19.40	6.00	66.5
B110	-90.0	16.40	22.40	1	Fixed Time	100.0	1400.0	Good	1.3	5.5	5.48	16.40	22.40	19.40	6.00	66.5
B110	-90.0	16.40	22.40	1	Fixed Time	100.0	1400.0	Good	1.3	5.5	5.48	16.40	22.40	19.40	6.00	66.5
B110	-90.0	21.40	30.40	2	Fixed Time	100.0	1500.0	Good	1.3	5.5	5.48	21.40	30.40	25.90	9.00	66.5
B110	-90.0	21.40	30.40	2	Fixed Time	100.0	1500.0	Good	1.3	5.5	5.48	21.40	30.40	25.90	9.00	66.5
B110	-90.0	21.40	30.40	2	Fixed Time	100.0	1500.0	Good	1.3	5.5	5.48	21.40	30.40	25.90	9.00	66.5
B110	-90.0	21.40	30.40	2	Fixed Time	100.0	1500.0	Good	1.3	5.5	5.48	21.40	30.40	25.90	9.00	66.5
B110	-90.0	29.40	33.40	3	Fixed Time	100.0	1400.0	Good	1.3	11.2	11.22	29.40	33.40	31.40	4.00	122.8
B110	-90.0	29.40	33.40	3	Fixed Time	100.0	1400.0	Good	1.3	11.2	11.22	29.40	33.40	31.40	4.00	122.8
B110	-90.0	29.40	33.40	3	Fixed Time	100.0	1400.0	Good	1.3	11.2	11.22	29.40	33.40	31.40	4.00	122.8
B110	-90.0	29.40	33.40	3	Fixed Time	100.0	1400.0	Good	1.3	11.2	11.22	29.40	33.40	31.40	4.00	122.8
B110	-90.0	29.40	33.40	3	Fixed Time	100.0	1400.0	Good	1.3	11.2	11.22	29.40	33.40	31.40	4.00	122.8
B110	-90.0	33.50	38.47	4	Fixed Time	100.0	1600.0	Good	1.3	11.2	11.22	33.50	38.47	35.99	4.97	122.8
B110	-90.0	33.50	38.47	4	Fixed Time	100.0	1600.0	Good	1.3	11.2	11.22	33.50	38.47	35.99	4.97	122.8
B110	-90.0	33.50	38.47	4	Fixed Time	100.0	1600.0	Good	1.3	11.2	11.22	33.50	38.47	35.99	4.97	122.8
B110	-90.0	33.50	38.47	4	Fixed Time	100.0	1600.0	Good	1.3	11.2	11.22	33.50	38.47	35.99	4.97	122.8
B110	-90.0	33.50	38.47	4	Fixed Time	100.0	1600.0	Good	1.3	11.2	11.22	33.50	38.47	35.99	4.97	122.8
B110	-90.0	37.50	46.50	5	Fixed Time	100.0	2000.0	Good	1.3	11.2	11.22	37.50	46.50	42.00	9.00	122.8
B110	-90.0	37.50	46.50	5	Fixed Time	100.0	2000.0	Good	1.3	11.2	11.22	37.50	46.50	42.00	9.00	122.8
B110	-90.0	37.50	46.50	5	Fixed Time	100.0	2000.0	Good	1.3	11.2	11.22	37.50	46.50	42.00	9.00	122.8
B110	-90.0	37.50	46.50	5	Fixed Time	100.0	2000.0	Good	1.3	11.2	11.22	37.50	46.50	42.00	9.00	122.8
B110	-90.0	37.50	46.50	5	Fixed Time	100.0	2000.0	Good	1.3	11.2	11.22	37.50	46.50	42.00	9.00	122.8
B110	-90.0	45.50	54.44	6	Fixed Time	100.0	2000.0	Good	1.3	15.0	15.00	45.50	54.44	49.97	8.94	159.9
B110	-90.0	45.50	54.44	6	Fixed Time	100.0	2000.0	Good	1.3	15.0	15.00	45.50	54.44	49.97	8.94	159.9
B110	-90.0	45.50	54.44	6	Fixed Time	100.0	2000.0	Good	1.3	15.0	15.00	45.50	54.44	49.97	8.94	159.9
B110	-90.0	45.50	54.44	6	Fixed Time	100.0	2000.0	Good	1.3	15.0	15.00	45.50	54.44	49.97	8.94	159.9
B110	-90.0	45.50	54.44	6	Fixed Time	100.0	2000.0	Good	1.3	15.0	15.00	45.50	54.44	49.97	8.94	159.9
B110	-90.0	51.50	54.44	7	Fixed Time	100.0	2000.0	Good	1.3	15.0	15.00	51.50	54.44	52.97	2.94	159.9
B110	-90.0	51.50	54.44	7	Fixed Time	100.0	2000.0	Good	1.3	15.0	15.00	51.50	54.44	52.97	2.94	159.9
B110	-90.0	51.50	54.44	7	Fixed Time	100.0	2000.0	Good	1.3	15.0	15.00	51.50	54.44	52.97	2.94	159.9
B110	-90.0	51.50	54.44	7	Fixed Time	100.0	2000.0	Good	1.3	15.0	15.00	51.50	54.44	52.97	2.94	159.9
B110	-90.0	51.50	54.44	7	Fixed Time	100.0	2000.0	Good	1.3	15.0	15.00	51.50	54.44	52.97	2.94	159.9
B110	-90.0	53.50	57.00	8	Fixed Time	100.0	2000.0	Good	1.3	14.6	14.60	53.50	57.00	55.25	3.50	156.0
B110	-90.0	53.50	57.00	8	Fixed Time	100.0	2000.0	Good	1.3	14.6	14.60	53.50	57.00	55.25	3.50	156.0
B110	-90.0	53.50	57.00	8	Fixed Time	100.0	2000.0	Good	1.3	14.6	14.60	53.50	57.00	55.25	3.50	156.0
B110	-90.0	53.50	57.00	8	Fixed Time	100.0	2000.0	Good	1.3	14.6	14.60	53.50	57.00	55.25	3.50	156.0
B110	-90.0	53.50	57.00	8	Fixed Time	100.0	2000.0	Good	1.3	14.6	14.60	53.50	57.00	55.25	3.50	156.0
B110	-90.0	21.40	30.40	2	Fixed Time	100.0	1500.0	Good	1.3	5.5	5.48	21.40	30.40	25.90	9.00	66.5
B112	-90.0	18.23	27.23	1	Fixed Time	100.0	1400.0	Good	0.8	9.6	9.60	18.23	27.23	22.73	9.00	101.6
B112	-90.0	18.23	27.23	1	Fixed Time	100.0	1400.0	Good	0.8	9.6	9.60	18.23	27.23	22.73	9.00	101.6
B112	-90.0	18.23	27.23	1	Fixed Time	100.0	1400.0	Good	0.8	9.6	9.60	18.23	27.23	22.73	9.00	101.6
B112	-90.0	18.23	27.23	1	Fixed Time	100.0	1400.0	Good	0.8	9.6	9.60	18.23	27.23	22.73	9.00	101.6
B112	-90.0	18.23	27.23	1	Fixed Time	100.0	1400.0	Good	0.8	9.6	9.60	18.23	27.23	22.73	9.00	101.6
B112	-90.0	26.23	36.23	2	Fixed Time	100.0	1400.0	Good	0.8	9.6	9.60	26.23	36.23	31.23	10.00	101.6
B112	-90.0	26.23	36.23	2	Fixed Time	100.0	1400.0	Good	0.8	9.6	9.60	26.23	36.23	31.23	10.00	101.6
B112	-90.0	26.23	36.23	2	Fixed Time	100.0	1400.0	Good	0.8	9.6	9.60	26.23	36.23	31.23	10.00	101.6
B112	-90.0	26.23	36.23	2	Fixed Time	100.0	1400.0	Good	0.8	9.6	9.60	26.23	36.23	31.23	10.00	101.6
B112	-90.0	26.23	36.23	2	Fixed Time	100.0	1400.0	Good	0.8	9.6	9.60	26.23	36.23	31.23	10.00	101.6
B112	-90.0	35.20	45.27	3	Fixed Time	100.0	1800.0	Good	0.8	10.3	10.30	35.20	45.27	40.24	10.07	108.5
B112	-90.0	35.20	45.27	3	Fixed Time	100.0	1800.0	Good	0.8	10.3	10.30	35.20	45.27	40.24	10.07	108.5
B112	-90.0	35.20	45.27	3	Fixed Time	100.0	1800.0	Good	0.8	10.3	10.30	35.20	45.27	40.24	10.07	108.5
B112	-90.0	35.20	45.27	3	Fixed Time	100.0	1800.0	Good	0.8	10.3	10.30	35.20	45.27	40.24	10.07	108.5
B112	-90.0	35.20	45.27	3	Fixed Time	100.0	1800.0	Good	0.8	10.3	10.30	35.20	45.27	40.24	10.07	108.5
B112	-90.0	44.20	54.26	4	Fixed Time	100.0	1850.0	Good	0.8	10.3	10.30	44.20	54.26	49.23	10.06	108.5
B112	-90.0	44.20	54.26	4	Fixed Time	100.0	1850.0	Good	0.8	10.3	10.30	44.20	54.26	49.23	10.06	108.5
B112	-90.0	44.20	54.26	4	Fixed Time	100.0	1850.0	Good	0.8	10.3	10.30	44.20	54.26	49.23	10.06	108.5
B112	-90.0	44.20	54.26	4	Fixed Time	100.0	1850.0	Good	0.8	10.3	10.30	44.20	54.26	49.23	10.06	108.5
B112	-90.0	44.20	54.26	4	Fixed Time	100.0	1850.0	Good	0.8	10.3	10.30	44.20	54.26	49.23	10.06	108.5
B112	-90.0	53.20	62.27	5	Fixed Time	100.0	1700.0	Good	0.8	11.3	11.30	53.20	62.27	57.74	9.07	118.3
B112	-90.0	53.20	62.27	5	Fixed Time	100.0	1700.0	Good	0.8	11.3	11.30	53.20	62.27	57.74	9.07	118.3
B112	-90.0	53.20	62.27	5	Fixed Time	100.0	1700.0	Good	0.8	11.3	11.30	53.20	62.27	57.74	9.07	118.3
B112	-90.0	53.20	62.27	5	Fixed Time	100.0	1700.0	Good	0.8	11.3	11.30	53.20	62.27	57.74	9.07	118.3
B112	-90.0	53.20	62.27	5	Fixed Time	100.0	1700.0	Good	0.8	11.3	11.30	53.20	62.27	57.74	9.07	118.3
B112	-90.0	61.20	70.24	6	Fixed Time	100.0	1950.0	Good	0.8	11.3	11.30	61.20	70.24	65.72	9.04	118.3
B112	-90.0	61.20	70.24	6	Fixed Time	100.0	1950.0	Good	0.8	11.3	11.30	61.20	70.24	65.72	9.04	118.3
B112	-90.0	61.20	70.24	6	Fixed Time	100.0	1950.0	Good	0.8	11.3	11.30	61.20	70.24	65.72	9.04	118.3
B112	-90.0	61.20	70.24	6	Fixed Time	100.0	1950.0	Good	0.8	11.3	11.30	61.20	70.24	65.72	9.04	118.3
B112	-90.0	61.20	70.24	6	Fixed Time	100.0	1950.0	Good	0.8	11.3	11.30	61.20	70.24	65.72	9.04	118.3
B112	-90.0	69.09	76.09	7	Fixed Time	100.0	1950.0	Good	0.8	11.9	11.90	69.09	76.09	72.59	7.00	124.2
B112	-90.0	69.09	76.09	7	Fixed Time	100.0	1950.0	Good	0.8	11.9	11.90	69.09	76.09	72.59	7.00	124.2
B112	-90.0	69.09	76.09	7	Fixed Time	100.0	1950.0	Good	0.8	11.9	11.90	69.09	76.09	72.59	7.00	124.2
B112	-90.0	69.09	76.09	7	Fixed Time	100.0	1950.0	Good	0.8	11.9	11.90	69.09	76.09	72.59	7.00	124.2
B112	-90.0	69.09	76.09	7	Fixed Time	100.0	1950.0	Good	0.8	11.9	11.90	69.09	76.09	72.59	7.00	124.2
B115	-90.0	69.10	78.00	1	Fixed Time	100.0	1800.0	Good	1.0	37.5	37.50	69.10	78.00	73.55	8.90	377.7
B115	-90.0	69.10	78.00	1	Fixed Time	100.0	1800.0	Good	1.0	37.5	37.50	69.10	78.00	73.55	8.90	377.7
B115	-90.0	69.10	78.00	1	Fixed Time	100.0	1800.0	Good	1.0	37.5	37.50	69.10	78.00	73.55	8.90	377.7
B115	-90.0	69.10	78.00	1	Fixed Time	100.0	1800.0	Good	1.0	37.5	37.50	69.10	78.00	73.55	8.90	377.7
B115	-90.0	69.10	78.00	1	Fixed Time	100.0	1800.0	Good	1.0	37.5	37.50	69.10	78.00	73.55	8.90	377.7
B115	-90.0	77.10	86.00	2	Fixed Time	100.0	2000.0	Good	1.0	37.5	37.50	77.10	86.00	81.55	8.90	377.7
B115	-90.0	77.10	86.00	2	Fixed Time	100.0	2000.0	Good	1.0	37.5	37.50	77.10	86.00	81.55	8.90	377.7
B115	-90.0	77.10	86.00	2	Fixed Time	100.0	2000.0	Good	1.0	37.5	37.50	77.10	86.00	81.55	8.90	377.7
B115	-90.0	77.10	86.00	2	Fixed Time	100.0	2000.0	Good	1.0	37.5	37.50	77.10	86.00	81.55	8.90	377.7
B115	-90.0	77.10	86.00	2	Fixed Time	100.0	2000.0	Good	1.0	37.5	37.50	77.10	86.00	81.55	8.90	377.7
B115	-90.0	85.00	97.00	3	Fixed Time	100.0	2200.0	Good	1.0	37.0	37.00	85.00	97.00	91.00	12.00	372.8
B115	-90.0	85.00	97.00	3	Fixed Time	100.0	2200.0	Good	1.0	37.0	37.00	85.00	97.00	91.00	12.00	372.8
B115	-90.0	85.00	97.00	3	Fixed Time	100.0	2200.0	Good	1.0	37.0	37.00	85.00	97.00	91.00	12.00	372.8
B115	-90.0	85.00	97.00	3	Fixed Time	100.0	2200.0	Good	1.0	37.0	37.00	85.00	97.00	91.00	12.00	372.8
B115	-90.0	85.00	97.00	3	Fixed Time	100.0	2200.0	Good	1.0	37.0	37.00	85.00	97.00	91.00	12.00	372.8
B115	-90.0	96.00	108.00	4	Fixed Time	100.0	2200.0	Good	1.0	37.0	37.00	96.00	108.00	102.00	12.00	372.8
B115	-90.0	96.50	108.00	5	Fixed Time	100.0	2200.0	Good	1.0	37.0	37.00	96.50	108.00	102.25	11.50	372.8
B115	-90.0	96.50	108.00	5	Fixed Time	100.0	2200.0	Good	1.0	37.0	37.00	96.50	108.00	102.25	11.50	372.8
B115	-90.0	96.50	108.00	6	Fixed Time	100.0	2200.0	Good	1.0	43.0	43.00	96.50	108.00	102.25	11.50	431.6
B115	-90.0	96.50	108.00	6	Fixed Time	100.0	2200.0	Good	1.0	43.0	43.00	96.50	108.00	102.25	11.50	431.6
B115	-90.0	96.50	108.00	6	Fixed Time	100.0	2200.0	Good	1.0	43.0	43.00	96.50	108.00	102.25	11.50	431.6
B115	-90.0	96.50	108.00	6	Fixed Time	100.0	2200.0	Good	1.0	43.0	43.00	96.50	108.00	102.25	11.50	431.6
B115	-90.0	96.50	108.00	6	Fixed Time	100.0	2200.0	Good	1.0	43.0	43.00	96.50	108.00	102.25	11.50	431.6
B115	-90.0	102.00	108.00	7	Fixed Time	100.0	2200.0	Good	1.0	43.0	43.00	102.00	108.00	105.00	6.00	431.6
B115	-90.0	102.00	108.00	7	Fixed Time	100.0	2200.0	Good	1.0	43.0	43.00	102.00	108.00	105.00	6.00	431.6
B115	-90.0	102.00	108.00	7	Fixed Time	100.0	2200.0	Good	1.0	43.0	43.00	102.00	108.00	105.00	6.00	431.6
B115	-90.0	102.00	108.00	7	Fixed Time	100.0	2200.0	Good	1.0	43.0	43.00	102.00	108.00	105.00	6.00	431.6
B115	-90.0	102.00	108.00	7	Fixed Time	100.0	2200.0	Good	1.0	43.0	43.00	102.00	108.00	105.00	6.00	431.6
B115	-90.0	107.00	118.00	8	Fixed Time	100.0	2200.0	Good	1.0	39.5	39.50	107.00	118.00	112.50	11.00	397.3
B115	-90.0	107.00	118.00	8	Fixed Time	100.0	2200.0	Good	1.0	39.5	39.50	107.00	118.00	112.50	11.00	397.3
B115	-90.0	107.00	118.00	8	Fixed Time	100.0	2200.0	Good	1.0	39.5	39.50	107.00	118.00	112.50	11.00	397.3
B115	-90.0	107.00	118.00	8	Fixed Time	100.0	2200.0	Good	1.0	39.5	39.50	107.00	118.00	112.50	11.00	397.3
B115	-90.0	107.00	118.00	8	Fixed Time	100.0	2200.0	Good	1.0	39.5	39.50	107.00	118.00	112.50	11.00	397.3
B116	-90.0	82.90	89.09	1	Fixed Time	100.0	2200.0	Good	0.8	10.4	10.41	82.90	89.09	86.00	6.19	109.6
B116	-90.0	82.90	89.09	1	Fixed Time	100.0	2200.0	Good	0.8	10.4	10.41	82.90	89.09	86.00	6.19	109.6
B116	-90.0	82.90	89.09	1	Fixed Time	100.0	2200.0	Good	0.8	10.4	10.41	82.90	89.09	86.00	6.19	109.6
B116	-90.0	82.90	89.09	1	Fixed Time	100.0	2200.0	Good	0.8	10.4	10.41	82.90	89.09	86.00	6.19	109.6
B116	-90.0	82.90	89.09	1	Fixed Time	100.0	2200.0	Good	0.8	10.4	10.41	82.90	89.09	86.00	6.19	109.6

Reading Number	Test Pressure	Flow Meter Reading Start	Flow Meter Reading 5 min	Flow Meter Reading 10 min	Flow Meter Reading 15 min	Volume 0-5 min	Volume 5-10 min	Volume 10-15 min	Elapsed Time 1	Elapsed Time 2	Elapsed Time 3	Effective Head	Volume Loss	Flow Rate	Flow Rate Per Metre	Average Lugeon Value	Flow Type
	(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)	
1	45.0	2350	2350.1	2350.1	2350.1	0.1	0	0				111.5	0.03	0.01	0.00	0.0	other - see comments
2	90.0	3615	3615	3615	3615	0	0	0				156.5	0.00	0.00	0.00	0.0	other - see comments
3	135.0	3624	3624	3624	3624	0	0	0				201.5	0.00	0.00	0.00	0.0	other - see comments
4	90.0	3518	3518	3518	3518	0	0	0				156.5	0.00	0.00	0.00	0.0	other - see comments
5	45.0	3525	3525	3525	3525	0	0	0				111.5	0.00	0.00	0.00	0.0	other - see comments
1	85.0	488.2	488.2	488.2	488.2	0	0	0				151.5	0.00	0.00	0.00	0.0	void filling
2	170.0	492	492.1	492.2	492.2	0.1	0.1	0				236.5	0.07	0.01	0.00	0.0	void filling
3	255.0	496.8	498.8	500.1	501.1	2	1.3	1				321.5	1.43	0.29	0.03	0.1	void filling
4	170.0	500.4	500.55	500.65	500.65	0.15	0.1	0				236.5	0.08	0.02	0.00	0.0	void filling
1	85.0	488.2	488.2	488.2	488.2	0	0	0				207.8	0.00	0.00	0.00	0.0	dilation
2	170.0	492	492.1	492.2	492.2	0.1	0.1	0				292.8	0.07	0.01	0.00	0.0	dilation
3	255.0	496.8	498.8	500.1	501.1	2	1.3	1				377.8	1.43	0.29	0.07	0.2	dilation
4	170.0	500.4	500.55	500.65	500.65	0.15	0.1	0				292.8	0.08	0.02	0.00	0.0	dilation
5	85.0	509.2	509.25	509.25	509.25	0.05	0	0				207.8	0.02	0.00	0.00	0.0	dilation
1	95.0	514	514.1	514.1	514.1	0.1	0	0				217.8	0.03	0.01	0.00	0.0	other - see comments
2	195.0	514.6	514.65	514.65	514.7	0.05	0	0.05				317.8	0.03	0.01	0.00	0.0	other - see comments
3	290.0	517.7	517.7	517.7	517.7	0	0	0				412.8	0.00	0.00	0.00	0.0	other - see comments
4	195.0	517.45	517.45	517.45	517.45	0	0	0				317.8	0.00	0.00	0.00	0.0	other - see comments
5	95.0	517.45	517.45	517.45	517.45	0	0	0				217.8	0.00	0.00	0.00	0.0	other - see comments
1	110.0	589.7	605.9	622	637.9	16.2	16.1	15.9				232.8	16.07	3.21	0.36	1.5	laminar flow
2	215.0	672	696.9	721	746.8	24.9	24.1	25.8				337.8	24.93	4.99	0.55	1.6	laminar flow
3	325.0	769.7	802.7	835.5	868.5	33	32.8	33				447.8	32.93	6.59	0.73	1.6	laminar flow
4	215.0	875.5	901.7	926.3	951.9	26.2	24.6	25.6				337.8	25.47	5.09	0.57	1.7	laminar flow
5	110.0	957	974.7	993	1011.2	17.7	18.3	18.2				232.8	18.07	3.61	0.40	1.7	laminar flow
1	135.0	337.5	388.4	451	505.3	50.9	62.6	54.3				294.9	55.93	11.19	1.25	4.2	void filling
2	265.0	659.1	769.2	868.1	964.3	110.1	98.9	96.2				424.9	101.73	20.35	2.28	5.4	void filling
3	400.0	77	207.1	333.1	454.8	130.1	126	121.7				559.9	125.93	25.19	2.82	5.0	void filling
4	265.0	502	585.6	669.5	745	83.6	83.9	75.5				424.9	81.00	16.20	1.81	4.3	void filling
5	135.0	789	836.1	884.8	933.9	47.1	48.7	49.1				294.9	48.30	9.66	1.08	3.7	void filling
1	135.0	76.8	112.3	147.8	183	35.5	35.5	35.2				294.9	35.40	7.08	2.41	8.2	turbulent flow
2	270.0	351.2	407.7	454.3	500.6	56.5	46.6	46.3				429.9	49.80	9.96	3.39	7.9	turbulent flow
3	400.0	667.7	727.7	787.3	846.4	60	59.6	59.1				559.9	59.57	11.91	4.05	7.2	turbulent flow
4	270.0	851.5	907.6	954.2	1001.8	56.1	46.6	47.6				429.9	50.10	10.02	3.41	7.9	turbulent flow
5	135.0	17	50.5	84	117.4	33.5	33.5	33.4				294.9	33.47	6.69	2.28	7.7	turbulent flow
1	50.0	599.8	599.9	599.9	599.9	0.1	0	0				206.0	0.03	0.01	0.00	0.0	other - see comments
2	105.0	601.7	601.7	601.7	601.7	0	0	0				261.0	0.00	0.00	0.00	0.0	other - see comments
3	155.0	602.9	602.9	602.9	602.9	0	0	0				311.0	0.00	0.00	0.00	0.0	other - see comments
4	105.0	602.9	602.9	602.9	602.9	0	0	0				261.0	0.00	0.00	0.00	0.0	other - see comments
5	50.0	602.9	602.9	602.9	602.9	0	0	0				206.0	0.00	0.00	0.00	0.0	other - see comments
5	85.0	509.2	509.25	509.25	509.25	0.05	0	0				151.5	0.02	0.00	0.00	0.0	void filling
1	50.0	599.8	599.9	599.9	599.9	0.1	0	0				151.6	0.03	0.01	0.00	0.0	other - see comments
2	105.0	601.7	601.7	601.7	601.7	0	0	0				206.6	0.00	0.00	0.00	0.0	other - see comments
3	155.0	602.9	602.9	602.9	602.9	0	0	0				256.6	0.00	0.00	0.00	0.0	other - see comments
4	105.0	602.9	602.9	602.9	602.9	0	0	0				206.6	0.00	0.00	0.00	0.0	other - see comments
5	50.0	602.9	602.9	602.9	602.9	0	0	0				151.6	0.00	0.00	0.00	0.0	other - see comments
1	75.0	606	606	606	606	0	0	0				176.6	0.00	0.00	0.00	0.0	other - see comments
2	150.0	608.6	608.6	608.6	608.6	0	0	0				251.6	0.00	0.00	0.00	0.0	other - see comments
3	225.0	609.1	609.1	609.1	609.1	0	0	0				326.6	0.00	0.00	0.00	0.0	other - see comments
4	150.0	609.1	609.1	609.1	609.1	0	0	0				251.6	0.00	0.00	0.00	0.0	other - see comments
5	75.0	609.1	609.1	609.1	609.1	0	0	0				176.6	0.00	0.00	0.00	0.0	other - see comments
1	105.0	614.7	614.7	614.7	614.7	0	0	0				213.5	0.00	0.00	0.00	0.0	other - see comments
2	205.0	616	616.1	616.1	616.1	0.1	0	0				313.5	0.03	0.01	0.00	0.0	other - see comments
3	310.0	617.2	618.4	619.6	620.7	1.2	1.2	1.1				418.5	1.17	0.23	0.02	0.1	other - see comments
4	205.0	620.8	620.8	620.8	620.8	0	0	0				313.5	0.00	0.00	0.00	0.0	other - see comments
5	105.0	620.8	620.8	620.8	620.8	0	0	0				213.5	0.00	0.00	0.00	0.0	other - see comments
1	135.0	625.5	625.5	625.5	625.5	0	0	0				243.5	0.00	0.00	0.00	0.0	other - see comments
2	270.0	626.1	626.1	626.1	626.1	0	0	0				378.5	0.00	0.00	0.00	0.0	other - see comments
3	400.0	626.4	626.4	626.4	626.4	0	0	0				508.5	0.00	0.00	0.00	0.0	other - see comments
4	270.0	626.4	626.4	626.4	626.4	0	0	0				378.5	0.00	0.00	0.00	0.0	other - see comments
5	135.0	626.4	626.4	626.4	626.4	0	0	0				243.5	0.00	0.00	0.00	0.0	other - see comments
1	135.0	645	645	645	645	0	0	0				253.3	0.00	0.00	0.00	0.0	other - see comments
2	270.0	646.2	646.8	647.3	647.7	0.6	0.5	0.4				388.3	0.50	0.10	0.01	0.0	other - see comments
3	400.0	648.5	650	651.3	652.7	1.5	1.3	1.4				518.3	1.40	0.28	0.03	0.1	other - see comments
4	270.0	652.8	653	653.1	653.2	0.2	0.1	0.1				388.3	0.13	0.03	0.00	0.0	other - see comments
5	135.0	653.2	653.2	653.2	653.2	0	0	0				253.3	0.00	0.00	0.00	0.0	other - see comments
1	135.0	656.9	656.9	656.9	656.9	0	0	0				253.3	0.00	0.00	0.00	0.0	other - see comments
2	270.0	657.7	657.7	657.7	657.7	0	0	0				388.3	0.00	0.00	0.00	0.0	other - see comments
3	400.0	658.1	658.1	658.1	658.1	0	0	0				518.3	0.00	0.00	0.00	0.0	other - see comments
4	270.0	658.1	658.1	658.1	658.1	0	0	0				388.3	0.00	0.00	0.00	0.0	other - see comments
5	135.0	658.1	658.1	658.1	658.1	0	0	0				253.3	0.00	0.00	0.00	0.0	other - see comments
1	135.0	667.5	667.5	667.5	667.5	0	0	0				259.2	0.00	0.00	0.00	0.0	other - see comments
2	270.0	669.5	669.5	669.5	669.5	0	0	0				394.2	0.00	0.00	0.00	0.0	other - see comments
3	400.0	670.4	670.4	670.4	670.4	0	0	0				524.2	0.00	0.00	0.00	0.0	other - see comments
4	270.0	670.4	670.4	670.4	670.4	0	0	0				394.2	0.00	0.00	0.00	0.0	other - see comments
5	135.0	670.4	670.4	670.4	670.4	0	0	0				259.2	0.00	0.00	0.00	0.0	other - see comments
1	135.0	32511	32511	32511	32511	0	0	0				512.7	0.00	0.00	0.00	0.0	other - see comments
2	270.0	32562.9	32562.9	32562.9	32562.9	0	0	0				647.7	0.00	0.00	0.00	0.0	other - see comments
3	400.0	32563	32563	32563.1	32563.2	0	0.1	0.1				777.7	0.07	0.01	0.00	0.0	other - see comments
4	270.0	32563.2	32563.2	32563.2	32563.2	0	0	0				647.7	0.00	0.00	0.00	0.0	other - see comments
5	135.0	32563.2	32563.2	32563.2	32563.2	0	0	0				512.7	0.00	0.00	0.00	0.0	other - see comments
1	135.0	32663.8	32664.1	32664.6	32665.2	0.3	0.5	0.6				512.7	0.47	0.09	0.01	0.0	other - see comments
2	270.0	32695.3	32696.1	32697	32698	0.8	0.9	1				647.7	0.90	0.18	0.02	0.0	other - see comments
3	400.0	32713.4	32719.9	32727.1	32733.9	6.5	7.2	6.8				777.7	6.83	1.37	0.15	0.2	other - see comments
4	270.0	32723.9	32724	32724	32724	0.1	0	0				647.7	0.03	0.01	0.00	0.0	other - see comments
5	135.0	32725.5	32725.5	32725.5	32725.5	0	0	0				512.7	0.00	0.00	0.00	0.0	other - see comments
1	135.0	33880.2	33880.2	33880.2	33880.2	0	0	0				507.8	0.00	0.00	0.00	0.0	other - see comments
2	270.0	33903.9	33904.4	33904.9	33905.4	0.5	0.5	0.5				642.8	0.50	0.10	0.01	0.0	other - see comments
3	400.0	33912.5	33912.5	33912.5	33912.5	0	0	0				772.8	0.00	0.00	0.00	0.0	other - see comments
4	270.0	33912.5	33912.5	33912.5	33912.5	0	0	0				642.8	0.00	0.00	0.00	0.0	other - see comments
5	135.0	33912.5	33912.5	33912.5	33912.5	0	0	0				507.8	0.00	0.00	0.00	0.0	other - see comments
1	135.0	33159.9	33202.8	33227.5	33268.5	42.9	24.7	41				507.8	36.20	7.24	0.60	1.2	other - see comments
1	135.0	33479.5	33505.7	33539.7	33572.6	26.2	34	32.9				507.8	31.03	6.21	0.54	1.1	other - see comments
2	270.0	33703.1	33750.2	33793.2	33842.2	47.1	43	49				642.8	46.37	9.27	0.81	1.3	other - see comments
1	135.0	35485.9	35485.9	35485.9	35485.9	0	0	0				566.6	0.00	0.00	0.00	0.0	dilation
2	270.0	35525.3	35525.3	35525.4	35525.5	0	0.1	0.1				701.6	0.07	0.01	0.00	0.0	dilation
3	400.0	35532.6	35532.6	35532.6	35532.7	0	0	0.1				831.6	0.03	0.01	0.00	0.0	dilation
4	270.0	35532.7	35532.7	35532.7	35532.7	0	0	0				701.6	0.00	0.00	0.00	0.0	dilation
5	135.0	35532.7	35532.7	35532.7	35532.7	0	0	0				566.6	0.00	0.00	0.00	0.0	dilation
1	135.0	35485.9	35485.9	35485.9	35485.9	0	0	0				566.6	0.00	0.00	0.00	0.0	other - see comments
2	270.0	35525.3	35525.3	35525.4	35525.5	0	0.1	0.1				701.6	0.07	0.01	0.00	0.0	other - see comments
3	400.0	35532.6	35532.6	35532.6	35532.7	0	0	0.1				831.6	0.03	0.01	0.00	0.0	other - see comments
4	270.0	35532.7	35532.7	35532.7	35532.7	0	0	0				701.6	0.00	0.00	0.00	0.0	other - see comments
5	135.0	35532.7	35532.7	35532.7	35532.7	0	0	0				566.6	0.00	0.00	0.00	0.0	other - see comments
1	135.0	699.7	699.7	699.7	699.7	0	0	0				532.3	0.00	0.00	0.00	0.0	other - see comments
2	270.0	707.6	708.4	708.1	706	0.8	-0.3	-2.1				667.3	-0.53	-0.11	-0.01	0.0	other - see comments
3	400.0	705.8	706.2	707.7	708.9	0.4	1.5	1.2				797.3	1.03	0.21	0.02	0.0	other - see comments
4	270.0	709.1	705.6	705.1	705.1	-3.5	-0.5	0				667.3	-1.33	-0.27	-0.02	0.0	other - see comments
5	135.0	705.1	705.2	705.3	705.5	0.1	0.1	0.2				532.3	0.13	0.03	0.00	0.0	other - see comments
1	135.0	699.7	700.66	701.38	702.1	0.96	0.72	0.72				244.6	0.80	0.16	0.03	0.1	other - see comments
2	270.0	707.6	708.32	708.8	709.28	0.72	0.48	0.48				379.6	0.56	0.11	0.02	0.0	other - see comments
3	400.0	705.8	706.28	707	707.72	0.48	0.72	0.72				509.6	0.64	0.13	0.02	0.0	other - see comments
4	270.0	709.1	709.82	710.3	710.78	0.72	0.48	0.48				379.6	0.56	0.11	0.02	0.0	other - see comments
5	135.0	705.1	705.58	706.3	707.02	0.48	0.72	0.72				244.6	0.64	0.13	0.02	0.1	other - see comments

Interpreted Lugeon Value (Houlsby) (uL)	Remark
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	None.
<1	None.
<1	None.
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<1	Flow rate too low to define flow type.
1.53	None.
1.64	None.
1.63	None.
1.68	None.
1.72	None.
4.24	None.
5.36	None.
5.03	None.
4.26	None.
3.66	None.
8.17	None.
7.88	None.
7.24	None.
7.93	None.
7.72	None.
<1	Flow rate too low to define flow type.
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<1	None.
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<1	Flow rate too low to define flow type.
1.19	Test terminated early due to high water loss (>40L/5min). Packer re-seated at 96.5 m and test started (see test 5).
1.06	Test terminated early due to high water loss (>45L/5min). Packer test successfully repeated 10/07/2017 at same depth interval.
1.25	Test terminated early due to high water loss (>45L/5min). Packer test successfully repeated 10/07/2017 at same depth interval.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
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Borehole	Inclination	Length to Top	Length to Bottom	Test Number	Reading Method	Fixed Volume	Packer Inflation Pressure	Packer Seal Condition	Pressure Gauge Height	Initial Groundwater Length	Initial Groundwater Depth	Depth to Top	Depth to Bottom	Depth to Centre	Section Length	Correction Gauge Pressure
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)
B116	-90.0	88.08	100.08	2	Fixed Time	100.0	2200.0	Good	0.8	10.4	10.41	88.08	100.08	94.08	12.00	109.6
B116	-90.0	88.08	100.08	2	Fixed Time	100.0	2200.0	Good	0.8	10.4	10.41	88.08	100.08	94.08	12.00	109.6
B116	-90.0	88.08	100.08	2	Fixed Time	100.0	2200.0	Good	0.8	10.4	10.41	88.08	100.08	94.08	12.00	109.6
B116	-90.0	88.08	100.08	2	Fixed Time	100.0	2200.0	Good	0.8	10.4	10.41	88.08	100.08	94.08	12.00	109.6
B116	-90.0	88.08	100.08	2	Fixed Time	100.0	2200.0	Good	0.8	10.4	10.41	88.08	100.08	94.08	12.00	109.6
B116	-90.0	99.11	111.11	3	Fixed Time	100.0	2200.0	Good	0.8	9.2	9.23	99.11	111.11	105.11	12.00	98.0
B116	-90.0	99.11	111.11	3	Fixed Time	100.0	2200.0	Good	0.8	9.2	9.23	99.11	111.11	105.11	12.00	98.0
B116	-90.0	99.11	111.11	3	Fixed Time	100.0	2200.0	Good	0.8	9.2	9.23	99.11	111.11	105.11	12.00	98.0
B116	-90.0	99.11	111.11	3	Fixed Time	100.0	2200.0	Good	0.8	9.2	9.23	99.11	111.11	105.11	12.00	98.0
B116	-90.0	99.11	111.11	3	Fixed Time	100.0	2200.0	Good	0.8	9.2	9.23	99.11	111.11	105.11	12.00	98.0
B116	-90.0	110.00	119.20	4	Fixed Time	100.0	2400.0	Good	0.8	12.1	12.14	110.00	119.20	114.60	9.20	126.9
B116	-90.0	110.00	119.20	4	Fixed Time	100.0	2400.0	Good	0.8	12.1	12.14	110.00	119.20	114.60	9.20	126.9
B116	-90.0	110.00	119.20	4	Fixed Time	100.0	2400.0	Good	0.8	12.1	12.14	110.00	119.20	114.60	9.20	126.9
B116	-90.0	110.00	119.20	4	Fixed Time	100.0	2400.0	Good	0.8	12.1	12.14	110.00	119.20	114.60	9.20	126.9
B116	-90.0	110.00	119.20	4	Fixed Time	100.0	2400.0	Good	0.8	12.1	12.14	110.00	119.20	114.60	9.20	126.9
B116	-90.0	118.09	126.09	5	Fixed Time	100.0	2500.0	Good	0.8	10.3	10.28	118.09	126.09	122.09	8.00	108.3
B116	-90.0	118.09	126.09	5	Fixed Time	100.0	2500.0	Good	0.8	10.3	10.28	118.09	126.09	122.09	8.00	108.3
B116	-90.0	118.09	126.09	5	Fixed Time	100.0	2500.0	Good	0.8	10.3	10.28	118.09	126.09	122.09	8.00	108.3
B116	-90.0	118.09	126.09	5	Fixed Time	100.0	2500.0	Good	0.8	10.3	10.28	118.09	126.09	122.09	8.00	108.3
B116	-90.0	118.09	126.09	5	Fixed Time	100.0	2500.0	Good	0.8	10.3	10.28	118.09	126.09	122.09	8.00	108.3
B116	-90.0	124.70	130.17	6	Fixed Time	100.0	2500.0	Good	0.8	10.3	10.28	124.70	130.17	127.44	5.47	108.3
B116	-90.0	124.70	130.17	6	Fixed Time	100.0	2500.0	Good	0.8	10.3	10.28	124.70	130.17	127.44	5.47	108.3
B116	-90.0	124.70	130.17	6	Fixed Time	100.0	2500.0	Good	0.8	10.3	10.28	124.70	130.17	127.44	5.47	108.3
B116	-90.0	124.70	130.17	6	Fixed Time	100.0	2500.0	Good	0.8	10.3	10.28	124.70	130.17	127.44	5.47	108.3
B116	-90.0	124.70	130.17	6	Fixed Time	100.0	2500.0	Good	0.8	10.3	10.28	124.70	130.17	127.44	5.47	108.3
B116	-90.0	130.00	135.19	7	Fixed Time	100.0	2500.0	Good	0.8	17.1	17.07	130.00	135.19	132.60	5.19	174.9
B116	-90.0	130.00	135.19	7	Fixed Time	100.0	2500.0	Good	0.8	17.1	17.07	130.00	135.19	132.60	5.19	174.9
B116	-90.0	130.00	135.19	7	Fixed Time	100.0	2500.0	Good	0.8	17.1	17.07	130.00	135.19	132.60	5.19	174.9
B116	-90.0	130.00	135.19	7	Fixed Time	100.0	2500.0	Good	0.8	17.1	17.07	130.00	135.19	132.60	5.19	174.9
B116	-90.0	130.00	135.19	7	Fixed Time	100.0	2500.0	Good	0.8	17.1	17.07	130.00	135.19	132.60	5.19	174.9
B123	-59.0	44.20	54.20	1	Fixed Time	100.0	2000.0	Good	0.9	38.7	33.17	37.89	46.46	42.17	8.57	333.8
B123	-59.0	49.20	54.20	2	Fixed Time	100.0	2000.0	Good	0.9	38.8	33.26	42.17	46.46	44.32	4.29	334.6
B123	-59.0	49.20	54.20	2	Fixed Time	100.0	2000.0	Good	0.9	38.8	33.26	42.17	46.46	44.32	4.29	334.6
B123	-59.0	49.20	54.20	2	Fixed Time	100.0	2000.0	Good	0.9	38.8	33.26	42.17	46.46	44.32	4.29	334.6
B123	-59.0	49.20	54.20	2	Fixed Time	100.0	2000.0	Good	0.9	38.8	33.26	42.17	46.46	44.32	4.29	334.6
B123	-59.0	49.20	54.20	2	Fixed Time	100.0	2000.0	Good	0.9	38.8	33.26	42.17	46.46	44.32	4.29	334.6
B123	-59.0	53.20	61.00	3	Fixed Time	100.0	2000.0	Good	0.9	38.7	33.15	45.60	52.29	48.94	6.69	333.5
B123	-59.0	53.20	61.00	3	Fixed Time	100.0	2000.0	Good	0.9	38.7	33.15	45.60	52.29	48.94	6.69	333.5
B123	-59.0	53.20	61.00	3	Fixed Time	100.0	2000.0	Good	0.9	38.7	33.15	45.60	52.29	48.94	6.69	333.5
B123	-59.0	53.20	61.00	3	Fixed Time	100.0	2000.0	Good	0.9	38.7	33.15	45.60	52.29	48.94	6.69	333.5
B123	-59.0	53.20	61.00	3	Fixed Time	100.0	2000.0	Good	0.9	38.7	33.15	45.60	52.29	48.94	6.69	333.5
B123	-59.0	60.00	66.20	4	Fixed Time	100.0	2000.0	Good	0.9	38.7	33.15	51.43	56.74	54.09	5.31	334.0
B123	-59.0	60.00	66.20	4	Fixed Time	100.0	2000.0	Good	0.9	38.7	33.15	51.43	56.74	54.09	5.31	334.0
B123	-59.0	60.00	66.20	4	Fixed Time	100.0	2000.0	Good	0.9	38.7	33.15	51.43	56.74	54.09	5.31	334.0
B123	-59.0	60.00	66.20	4	Fixed Time	100.0	2000.0	Good	0.9	38.7	33.15	51.43	56.74	54.09	5.31	334.0
B123	-59.0	60.00	66.20	4	Fixed Time	100.0	2000.0	Good	0.9	38.7	33.15	51.43	56.74	54.09	5.31	334.0
B123	-59.0	65.20	74.20	5	Fixed Time	100.0	2000.0	Good	0.9	36.7	31.46	55.89	63.60	59.74	7.71	316.9
B123	-59.0	65.20	74.20	5	Fixed Time	100.0	2000.0	Good	0.9	36.7	31.46	55.89	63.60	59.74	7.71	316.9
B123	-59.0	65.20	74.20	5	Fixed Time	100.0	2000.0	Good	0.9	36.7	31.46	55.89	63.60	59.74	7.71	316.9
B123	-59.0	65.20	74.20	5	Fixed Time	100.0	2000.0	Good	0.9	36.7	31.46	55.89	63.60	59.74	7.71	316.9
B123	-59.0	65.20	74.20	5	Fixed Time	100.0	2000.0	Good	0.9	36.7	31.46	55.89	63.60	59.74	7.71	316.9
B123	-59.0	73.20	84.20	6	Fixed Time	100.0	2000.0	Good	0.9	38.5	33.00	62.74	72.17	67.46	9.43	332.1
B123	-59.0	73.20	84.20	6	Fixed Time	100.0	2000.0	Good	0.9	38.5	33.00	62.74	72.17	67.46	9.43	332.1
B123	-59.0	73.20	84.20	6	Fixed Time	100.0	2000.0	Good	0.9	38.5	33.00	62.74	72.17	67.46	9.43	332.1
B123	-59.0	73.20	84.20	6	Fixed Time	100.0	2000.0	Good	0.9	38.5	33.00	62.74	72.17	67.46	9.43	332.1
B123	-59.0	73.20	84.20	6	Fixed Time	100.0	2000.0	Good	0.9	38.5	33.00	62.74	72.17	67.46	9.43	332.1
B123	-59.0	81.20	90.20	7	Fixed Time	100.0	2000.0	Good	0.9	38.5	33.00	69.60	77.32	73.46	7.71	332.1
B123	-59.0	81.20	90.20	7	Fixed Time	100.0	2000.0	Good	0.9	38.5	33.00	69.60	77.32	73.46	7.71	332.1
B123	-59.0	81.20	90.20	7	Fixed Time	100.0	2000.0	Good	0.9	38.5	33.00	69.60	77.32	73.46	7.71	332.1
B123	-59.0	81.20	90.20	7	Fixed Time	100.0	2000.0	Good	0.9	38.5	33.00	69.60	77.32	73.46	7.71	332.1
B123	-59.0	81.20	90.20	7	Fixed Time	100.0	2000.0	Good	0.9	38.5	33.00	69.60	77.32	73.46	7.71	332.1
B123	-59.0	89.20	97.00	8	Fixed Time	100.0	1900.0	Good	0.9	45.7	39.16	76.46	83.15	79.80	6.69	392.5
B123	-59.0	89.20	97.00	8	Fixed Time	100.0	1900.0	Good	0.9	45.7	39.16	76.46	83.15	79.80	6.69	392.5
B123	-59.0	89.20	97.00	8	Fixed Time	100.0	1900.0	Good	0.9	45.7	39.16	76.46	83.15	79.80	6.69	392.5
B123	-59.0	89.20	97.00	8	Fixed Time	100.0	1900.0	Good	0.9	45.7	39.16	76.46	83.15	79.80	6.69	392.5
B123	-59.0	89.20	97.00	8	Fixed Time	100.0	1900.0	Good	0.9	45.7	39.16	76.46	83.15	79.80	6.69	392.5

Reading Number	Test Pressure (kPa)	Flow Meter Reading Start (L)	Flow Meter Reading 5 min (L)	Flow Meter Reading 10 min (L)	Flow Meter Reading 15 min (L)	Volume 0-5 min (L)	Volume 5-10 min (L)	Volume 10-15 min (L)	Elapsed Time 1 (mm:ss)	Elapsed Time 2 (mm:ss)	Elapsed Time 3 (mm:ss)	Effective Head (kPa)	Volume Loss (L)	Flow Rate (L/min)	Flow Rate Per Metre (L/min/m)	Average Lugeon Value (uL)	Flow Type
1	135.0	767.9	767.9	768.38	768.86	0	0.48	0.48				244.6	0.32	0.06	0.01	0.0	other - see comments
2	270.0	767.9	769.1	770.3	771.5	1.2	1.2	1.2				379.6	1.20	0.24	0.02	0.1	other - see comments
3	400.0	767.9	768.86	770.3	771.5	0.96	1.44	1.2				509.6	1.20	0.24	0.02	0.0	other - see comments
4	270.0	767.9	768.38	769.1	769.82	0.48	0.72	0.72				379.6	0.64	0.13	0.01	0.0	other - see comments
5	135.0	767.9	768.14	768.62	769.1	0.24	0.48	0.48				244.6	0.40	0.08	0.01	0.0	other - see comments
1	135.0	760	760.48	761.2	761.92	0.48	0.72	0.72				233.0	0.64	0.13	0.01	0.0	other - see comments
2	270.0	759.8	761	762.44	763.64	1.2	1.44	1.2				368.0	1.28	0.26	0.02	0.1	other - see comments
3	400.0	759.8	760.28	761.48	762.68	0.48	1.2	1.2				498.0	0.96	0.19	0.02	0.0	other - see comments
4	270.0	769.8	769.8	770.04	770.52	0	0.24	0.48				368.0	0.24	0.05	0.00	0.0	other - see comments
5	135.0	769.8	769.8	769.8	769.8	0	0	0				233.0	0.00	0.00	0.00	0.0	other - see comments
1	135.0	770.5	771.46	772.42	773.62	0.96	0.96	1.2				261.9	1.04	0.21	0.02	0.1	other - see comments
2	270.0	770.5	772.42	774.1	775.54	1.92	1.68	1.44				396.9	1.68	0.34	0.04	0.1	other - see comments
3	400.0	770.5	771.94	773.14	774.34	1.44	1.2	1.2				526.9	1.28	0.26	0.03	0.1	other - see comments
4	270.0	770.5	771.7	773.14	774.58	1.2	1.44	1.44				396.9	1.36	0.27	0.03	0.1	other - see comments
5	135.0	770.5	771.7	772.66	773.86	1.2	0.96	1.2				261.9	1.12	0.22	0.02	0.1	other - see comments
1	135.0	803.4	804.12	804.36	804.84	0.72	0.24	0.48				243.3	0.48	0.10	0.01	0.0	other - see comments
2	270.0	804	804.48	805.44	806.4	0.48	0.96	0.96				378.3	0.80	0.16	0.02	0.1	other - see comments
3	400.0	804	804.48	804.96	805.44	0.48	0.48	0.48				508.3	0.48	0.10	0.01	0.0	other - see comments
4	270.0	804	804.48	804.72	804.96	0.48	0.24	0.24				378.3	0.32	0.06	0.01	0.0	other - see comments
5	135.0	804	804	804	804	0	0	0				243.3	0.00	0.00	0.00	0.0	other - see comments
1	135.0	812.7	815.1	818.22	821.58	2.4	3.12	3.36				243.3	2.96	0.59	0.11	0.4	laminar flow
2	270.0	814.1	817.22	820.1	823.22	3.12	2.88	3.12				378.3	3.04	0.61	0.11	0.3	laminar flow
3	400.0	814.5	818.82	822.18	825.78	4.32	3.36	3.6				508.3	3.76	0.75	0.14	0.3	laminar flow
4	270.0	814.5	817.62	820.5	823.38	3.12	2.88	2.88				378.3	2.96	0.59	0.11	0.3	laminar flow
5	135.0	814.5	815.94	818.82	821.46	1.44	2.88	2.64				243.3	2.32	0.46	0.08	0.3	laminar flow
1	135.0	816.6	817.8	818.28	818.76	1.2	0.48	0.48				309.9	0.72	0.14	0.03	0.1	other - see comments
2	270.0	817.1	818.06	819.02	819.98	0.96	0.96	0.96				444.9	0.96	0.19	0.04	0.1	other - see comments
3	400.0	817.1	817.82	819.02	819.98	0.72	1.2	0.96				574.9	0.96	0.19	0.04	0.1	other - see comments
4	270.0	817.1	817.82	818.78	819.74	0.72	0.96	0.96				444.9	0.88	0.18	0.03	0.1	other - see comments
5	135.0	817.1	817.58	818.06	818.54	0.48	0.48	0.48				309.9	0.48	0.10	0.02	0.1	other - see comments
1	130.0	14865	14942	15030	15117	77	88	87				463.8	84.00	16.80	1.96	4.2	other - see comments
1	135.0	58148.7	58151.2	58153.8	58156.6	2.5	2.6	2.8				469.6	2.63	0.53	0.12	0.3	laminar flow
2	270.0	58165.2	58168.9	58172.4	58176.2	3.7	3.5	3.8				604.6	3.67	0.73	0.17	0.3	laminar flow
3	400.0	58187.2	58190	58192.2	58195.2	2.8	2.2	3				734.6	2.67	0.53	0.12	0.2	laminar flow
4	270.0	58198.4	58199.5	58201	58202.3	1.1	1.5	1.3				604.6	1.30	0.26	0.06	0.1	laminar flow
5	135.0	58204	58204.7	58205.4	58206.1	0.7	0.7	0.7				469.6	0.70	0.14	0.03	0.1	laminar flow
1	135.0	454.3	458.8	466.7	474.7	4.5	7.9	8				468.5	6.80	1.36	0.20	0.4	laminar flow
2	270.0	519.1	530.4	540.3	549.4	11.3	9.9	9.1				603.5	10.10	2.02	0.30	0.5	laminar flow
3	400.0	584.1	601.4	617.8	633.6	17.3	16.4	15.8				733.5	16.50	3.30	0.49	0.7	laminar flow
4	270.0	726.6	728.3	737.9	749.5	1.7	9.6	11.6				603.5	7.63	1.53	0.23	0.4	laminar flow
5	135.0	763.7	766.3	774.7	781.5	2.6	8.4	6.8				468.5	5.93	1.19	0.18	0.4	laminar flow
1	135.0	25.7	27.9	28	28	2.2	0.1	0				469.0	0.77	0.15	0.03	0.1	dilation
2	270.0	84.1	89.3	100.2	111.1	5.2	10.9	10.9				604.0	9.00	1.80	0.34	0.6	dilation
3	410.0	158	182	203.4	224.1	24	21.4	20.7				744.0	22.03	4.41	0.83	1.1	dilation
4	220.0	235.9	240.1	247.6	254.8	4.2	7.5	7.2				554.0	6.30	1.26	0.24	0.4	dilation
5	135.0	266.5	268.1	270	272	1.6	1.9	2				469.0	1.83	0.37	0.07	0.1	dilation
1	135.0	365.8	383.3	397.6	412.2	17.5	14.3	14.6				451.9	15.47	3.09	0.40	0.9	laminar flow
2	270.0	453.8	468.6	480.3	491.8	14.8	11.7	11.5				586.9	12.67	2.53	0.33	0.6	laminar flow
3	410.0	507.7	524.5	540.6	556	16.8	16.1	15.4				726.9	16.10	3.22	0.42	0.6	laminar flow
4	270.0	575.6	592.6	608.9	625.5	17	16.3	16.6				586.9	16.63	3.33	0.43	0.7	laminar flow
5	135.0	651.2	667.1	680.3	693.4	15.9	13.2	13.1				451.9	14.07	2.81	0.36	0.8	laminar flow
1	135.0	335	351.4	365.2	378.2	16.4	13.8	13				467.1	14.40	2.88	0.31	0.7	laminar flow
2	270.0	405.8	421.9	438	454	16.1	16.1	16				602.1	16.07	3.21	0.34	0.6	laminar flow
3	400.0	478.8	499	518.9	539.1	20.2	19.9	20.2				732.1	20.10	4.02	0.43	0.6	laminar flow
4	270.0	561.5	578.7	594.3	610	17.2	15.6	15.7				602.1	16.17	3.23	0.34	0.6	laminar flow
5	135.0	618.1	631.7	643.6	656.4	13.6	11.9	12.8				467.1	12.77	2.55	0.27	0.6	laminar flow
1	135.0	740.8	740.8	740.8	740.8	0	0	0				467.1	0.00	0.00	0.00	0.0	other - see comments
2	270.0	766.4	766.4	766.4	766.4	0	0	0				602.1	0.00	0.00	0.00	0.0	other - see comments
3	400.0	772.8	772.8	772.8	772.8	0	0	0				732.1	0.00	0.00	0.00	0.0	other - see comments
4	270.0	772.8	772.8	772.8	772.8	0	0	0				602.1	0.00	0.00	0.00	0.0	other - see comments
5	135.0	772.8	772.8	772.8	772.8	0	0	0				467.1	0.00	0.00	0.00	0.0	other - see comments
1	130.0	57.7	83	108.9	134	25.3	25.9	25.1				522.5	25.43	5.09	0.76	1.5	laminar flow
2	270.0	222.3	255	286.7	318.8	32.7	31.7	32.1				662.5	32.17	6.43	0.96	1.5	laminar flow
3	395.0	369.5	406.6	444	480	37.1	37.4	36				787.5	36.83	7.37	1.10	1.4	laminar flow
4	260.0	521.2	552.9	584.8	616.4	31.7	31.9	31.6				652.5	31.73	6.35	0.95	1.5	laminar flow
5	135.0	654.4	682.6	710.6	738.6	28.2	28	28				527.5	28.07	5.61	0.84	1.6	laminar flow

Interpreted Lugeon Value (Houlsby) (uL)	Remark
<1	Flow rate too low to define flow type. Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
<1	Flow rate too low to define flow type. Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
<1	Flow rate too low to define flow type. Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
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<1	Flow rate too low to define flow type. Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
4.23	Test invalid: Could not hold pressure beyond 130kPa or maintain continuous water inflow due to high water take. Non standard method used. Test invalid due to air bubbles in equipment.
<1	Second attempt at 49.2 to 54.2 m depth interval. Previous attempt on 25/5/17 abandoned due to equipment issues with flow meter and water leaks. Issues resolved and test repeated 26/5/17.
<1	Second attempt at 49.2 to 54.2 m depth interval. Previous attempt on 25/5/17 abandoned due to equipment issues with flow meter and water leaks. Issues resolved and test repeated 26/5/17.
<1	Second attempt at 49.2 to 54.2 m depth interval. Previous attempt on 25/5/17 abandoned due to equipment issues with flow meter and water leaks. Issues resolved and test repeated 26/5/17.
<1	Second attempt at 49.2 to 54.2 m depth interval. Previous attempt on 25/5/17 abandoned due to equipment issues with flow meter and water leaks. Issues resolved and test repeated 26/5/17.
<1	Second attempt at 49.2 to 54.2 m depth interval. Previous attempt on 25/5/17 abandoned due to equipment issues with flow meter and water leaks. Issues resolved and test repeated 26/5/17.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
1.11	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
1.46	None.
1.45	None.
1.40	None.
1.45	None.
1.59	None.

Borehole	Inclination	Length to Top	Length to Bottom	Test Number	Reading Method	Fixed Volume	Packer Inflation Pressure	Packer Seal Condition	Pressure Gauge Height	Initial Groundwater Length	Initial Groundwater Depth	Depth to Top	Depth to Bottom	Depth to Centre	Section Length	Correction Gauge Pressure
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)
B123	-59.0	94.20	97.00	9	Fixed Time	100.0	1900.0	Good	0.9	45.7	39.16	80.75	83.15	81.95	2.40	392.5
B123	-59.0	94.20	97.00	9	Fixed Time	100.0	1900.0	Good	0.9	45.7	39.16	80.75	83.15	81.95	2.40	392.5
B123	-59.0	94.20	97.00	9	Fixed Time	100.0	1900.0	Good	0.9	45.7	39.16	80.75	83.15	81.95	2.40	392.5
B123	-59.0	94.20	97.00	9	Fixed Time	100.0	1900.0	Good	0.9	45.7	39.16	80.75	83.15	81.95	2.40	392.5
B123	-59.0	94.20	97.00	9	Fixed Time	100.0	1900.0	Good	0.9	45.7	39.16	80.75	83.15	81.95	2.40	392.5
B124	-55.0	64.70	73.70	1	Fixed Time	100.0	1700.0	Good	1.0	13.3	10.89	53.00	60.37	56.69	7.37	116.7
B124	-55.0	64.70	73.70	1	Fixed Time	100.0	1700.0	Good	1.0	13.3	10.89	53.00	60.37	56.69	7.37	116.7
B124	-55.0	64.70	73.70	1	Fixed Time	100.0	1700.0	Good	1.0	13.3	10.89	53.00	60.37	56.69	7.37	116.7
B124	-55.0	64.70	73.70	1	Fixed Time	100.0	1700.0	Good	1.0	13.3	10.89	53.00	60.37	56.69	7.37	116.7
B124	-55.0	64.70	73.70	1	Fixed Time	100.0	1700.0	Good	1.0	13.3	10.89	53.00	60.37	56.69	7.37	116.7
B124	-55.0	72.50	81.50	2	Fixed Time	100.0	1600.0	Good	1.0	13.1	10.73	59.39	66.76	63.07	7.37	115.1
B124	-55.0	72.50	81.50	2	Fixed Time	100.0	1600.0	Good	1.0	13.1	10.73	59.39	66.76	63.07	7.37	115.1
B124	-55.0	72.50	81.50	2	Fixed Time	100.0	1600.0	Good	1.0	13.1	10.73	59.39	66.76	63.07	7.37	115.1
B124	-55.0	72.50	81.50	2	Fixed Time	100.0	1600.0	Good	1.0	13.1	10.73	59.39	66.76	63.07	7.37	115.1
B124	-55.0	72.50	81.50	2	Fixed Time	100.0	1600.0	Good	1.0	13.1	10.73	59.39	66.76	63.07	7.37	115.1
B124	-55.0	80.50	89.50	3	Fixed Time	100.0	1600.0	Good	1.0	13.1	10.73	65.94	73.31	69.63	7.37	115.1
B124	-55.0	80.50	89.50	3	Fixed Time	100.0	1600.0	Good	1.0	13.1	10.73	65.94	73.31	69.63	7.37	115.1
B124	-55.0	80.50	89.50	3	Fixed Time	100.0	1600.0	Good	1.0	13.1	10.73	65.94	73.31	69.63	7.37	115.1
B124	-55.0	80.50	89.50	3	Fixed Time	100.0	1600.0	Good	1.0	13.1	10.73	65.94	73.31	69.63	7.37	115.1
B124	-55.0	80.50	89.50	3	Fixed Time	100.0	1600.0	Good	1.0	13.1	10.73	65.94	73.31	69.63	7.37	115.1
B124	-55.0	88.50	97.50	5	Fixed Time	100.0	1600.0	Good	1.0	16.8	13.76	72.49	79.87	76.18	7.37	144.8
B124	-55.0	88.50	97.50	5	Fixed Time	100.0	1600.0	Good	1.0	16.8	13.76	72.49	79.87	76.18	7.37	144.8
B124	-55.0	88.50	97.50	5	Fixed Time	100.0	1600.0	Good	1.0	16.8	13.76	72.49	79.87	76.18	7.37	144.8
B124	-55.0	88.50	97.50	5	Fixed Time	100.0	1600.0	Good	1.0	16.8	13.76	72.49	79.87	76.18	7.37	144.8
B124	-55.0	88.50	97.50	5	Fixed Time	100.0	1600.0	Good	1.0	16.8	13.76	72.49	79.87	76.18	7.37	144.8
B124	-55.0	96.50	99.50	4	Fixed Time	100.0	1600.0	Good	1.0	15.1	12.37	79.05	81.51	80.28	2.46	131.2
B124	-55.0	96.50	99.50	4	Fixed Time	100.0	1600.0	Good	1.0	15.1	12.37	79.05	81.51	80.28	2.46	131.2
B124	-55.0	96.50	99.50	4	Fixed Time	100.0	1600.0	Good	1.0	15.1	12.37	79.05	81.51	80.28	2.46	131.2
B124	-55.0	96.50	99.50	4	Fixed Time	100.0	1600.0	Good	1.0	15.1	12.37	79.05	81.51	80.28	2.46	131.2
B124	-55.0	96.50	99.50	4	Fixed Time	100.0	1600.0	Good	1.0	15.1	12.37	79.05	81.51	80.28	2.46	131.2
B124	-55.0	98.50	104.50	6	Fixed Time	100.0	1600.0	Good	1.0	50.7	41.53	80.69	85.60	83.14	4.91	417.2
B124	-55.0	98.50	104.50	6	Fixed Time	100.0	1600.0	Good	1.0	50.7	41.53	80.69	85.60	83.14	4.91	417.2
B124	-55.0	98.50	104.50	6	Fixed Time	100.0	1600.0	Good	1.0	50.7	41.53	80.69	85.60	83.14	4.91	417.2
B124	-55.0	98.50	104.50	6	Fixed Time	100.0	1600.0	Good	1.0	50.7	41.53	80.69	85.60	83.14	4.91	417.2
B124	-55.0	98.50	104.50	6	Fixed Time	100.0	1600.0	Good	1.0	50.7	41.53	80.69	85.60	83.14	4.91	417.2
B124	-55.0	103.50	112.50	7	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	84.78	92.15	88.47	7.37	418.0
B124	-55.0	103.50	112.50	7	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	84.78	92.15	88.47	7.37	418.0
B124	-55.0	103.50	112.50	7	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	84.78	92.15	88.47	7.37	418.0
B124	-55.0	103.50	112.50	7	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	84.78	92.15	88.47	7.37	418.0
B124	-55.0	103.50	112.50	7	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	84.78	92.15	88.47	7.37	418.0
B124	-55.0	111.50	120.50	8	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	91.34	98.71	95.02	7.37	418.0
B124	-55.0	111.50	120.50	8	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	91.34	98.71	95.02	7.37	418.0
B124	-55.0	111.50	120.50	8	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	91.34	98.71	95.02	7.37	418.0
B124	-55.0	111.50	120.50	8	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	91.34	98.71	95.02	7.37	418.0
B124	-55.0	111.50	120.50	8	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	91.34	98.71	95.02	7.37	418.0
B124	-55.0	119.50	128.50	9	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	97.89	105.26	101.57	7.37	418.0
B124	-55.0	119.50	128.50	9	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	97.89	105.26	101.57	7.37	418.0
B124	-55.0	119.50	128.50	9	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	97.89	105.26	101.57	7.37	418.0
B124	-55.0	119.50	128.50	9	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	97.89	105.26	101.57	7.37	418.0
B124	-55.0	119.50	128.50	9	Fixed Time	100.0	1600.0	Good	1.0	50.8	41.61	97.89	105.26	101.57	7.37	418.0
B124	-55.0	127.50	135.50	10	Fixed Time	100.0	1800.0	Good	1.0	51.2	41.94	104.44	111.00	107.72	6.55	421.2
B124	-55.0	127.50	135.50	10	Fixed Time	100.0	1800.0	Good	1.0	51.2	41.94	104.44	111.00	107.72	6.55	421.2
B124	-55.0	127.50	135.50	10	Fixed Time	100.0	1800.0	Good	1.0	51.2	41.94	104.44	111.00	107.72	6.55	421.2
B124	-55.0	127.50	135.50	10	Fixed Time	100.0	1800.0	Good	1.0	51.2	41.94	104.44	111.00	107.72	6.55	421.2
B124	-55.0	127.50	135.50	10	Fixed Time	100.0	1800.0	Good	1.0	51.2	41.94	104.44	111.00	107.72	6.55	421.2
B124	-55.0	134.50	140.00	11	Fixed Time	100.0	1800.0	Good	1.0	51.2	41.94	110.18	114.68	112.43	4.51	421.2
B124	-55.0	134.50	140.00	11	Fixed Time	100.0	1800.0	Good	1.0	51.2	41.94	110.18	114.68	112.43	4.51	421.2
B124	-55.0	134.50	140.00	11	Fixed Time	100.0	1800.0	Good	1.0	51.2	41.94	110.18	114.68	112.43	4.51	421.2
B124	-55.0	134.50	140.00	11	Fixed Time	100.0	1800.0	Good	1.0	51.2	41.94	110.18	114.68	112.43	4.51	421.2
B124	-55.0	134.50	140.00	11	Fixed Time	100.0	1800.0	Good	1.0	51.2	41.94	110.18	114.68	112.43	4.51	421.2
B128	-90.0	5.00	11.00	1	Fixed Time	100.0	1800.0	Good	0.8	11.0	11.00	5.00	11.00	8.00	6.00	115.3
B128	-90.0	5.00	11.00	1	Fixed Time	100.0	1800.0	Good	0.8	11.0	11.00	5.00	11.00	8.00	6.00	115.3
B128	-90.0	5.00	11.00	1	Fixed Time	100.0	1800.0	Good	0.8	11.0	11.00	5.00	11.00	8.00	6.00	115.3
B128	-90.0	5.00	11.00	1	Fixed Time	100.0	1800.0	Good	0.8	11.0	11.00	5.00	11.00	8.00	6.00	115.3
B128	-90.0	5.00	11.00	1	Fixed Time	100.0	1800.0	Good	0.8	11.0	11.00	5.00	11.00	8.00	6.00	115.3
B128	-90.0	10.00	16.00	2	Fixed Time	100.0	1800.0	Good	0.8	16.0	16.00	10.00	16.00	13.00	6.00	164.3
B128	-90.0	10.00	16.00	2	Fixed Time	100.0	1800.0	Good	0.8	16.0	16.00	10.00	16.00	13.00	6.00	164.3
B128	-90.0	10.00	16.00	2	Fixed Time	100.0	1800.0	Good	0.8	16.0	16.00	10.00	16.00	13.00	6.00	164.3
B128	-90.0	10.00	16.00	2	Fixed Time	100.0	1800.0	Good	0.8	16.0	16.00	10.00	16.00	13.00	6.00	164.3
B128	-90.0	10.00	16.00	2	Fixed Time	100.0	1800.0	Good	0.8	16.0	16.00	10.00	16.00	13.00	6.00	164.3
B128	-90.0	15.00	19.00	3	Fixed Time	100.0	1100.0	Good	0.8	1.6	1.61	15.00	19.00	17.00	4.00	23.2
B128	-90.0	15.00	19.00	3	Fixed Time	100.0	1100.0	Good	0.8	1.6	1.61	15.00	19.00	17.00	4.00	23.2
B128	-90.0	15.00	19.00	3	Fixed Time	100.0	1100.0	Good	0.8	1.6	1.61	15.00	19.00	17.00	4.00	23.2
B128	-90.0	15.00	19.00	3	Fixed Time	100.0	1100.0	Good	0.8	1.6	1.61	15.00	19.00	17.00	4.00	23.2
B128	-90.0	15.00	19.00	3	Fixed Time	100.0	1100.0	Good	0.8	1.6	1.61	15.00	19.00	17.00	4.00	23.2
B132	-59.0	27.20	33.33	1	Fixed Time	100.0	1400.0	Good	0.8	12.3	10.54	23.31	28.57	25.94	5.25	111.3
B132	-59.0	27.20	33.33	1	Fixed Time	100.0	1400.0	Good	0.8	12.3	10.54	23.31	28.57	25.94	5.25	111.3
B132	-59.0	27.20	33.33	1	Fixed Time	100.0	1400.0	Good	0.8	12.3	10.54	23.31	28.57	25.94	5.25	111.3
B132	-59.0	27.20	33.33	1	Fixed Time	100.0	1400.0	Good	0.8	12.3	10.54	23.31	28.57	25.94	5.25	111.3
B132	-59.0	27.20	33.33	1	Fixed Time	100.0	1400.0	Good	0.8	12.3	10.54	23.31	28.57	25.94	5.25	111.3
B132	-59.0	32.30	38.30	2	Fixed Time	100.0	1400.0	Good	0.8	17.3	14.83	27.69	32.83	30.26	5.14	153.3
B132	-59.0	32.30	38.30	2	Fixed Time	100.0	1400.0	Good	0.8	17.3	14.83	27.69	32.83	30.26	5.14	153.3
B132	-59.0	32.30	38.30	2	Fixed Time	100.0	1400.0	Good	0.8	17.3	14.83	27.69	32.83	30.26	5.14	153.3
B132	-59.0	32.30	38.30	2	Fixed Time	100.0	1400.0	Good	0.8	17.3	14.83	27.69	32.83	30.26	5.14	153.3
B132	-59.0	32.30	38.30	2	Fixed Time	100.0	1400.0	Good	0.8	17.3	14.83	27.69	32.83	30.26	5.14	153.3
B132	-59.0	37.30	49.39	3	Fixed Time	100.0	1400.0	Good	0.8	17.3	14.83	31.97	42.34	37.15	10.36	153.3
B132	-59.0	37.30	49.39	3	Fixed Time	100.0	1400.0	Good	0.8	17.3	14.83	31.97	42.34	37.15	10.36	153.3
B132	-59.0	37.30	49.39	3	Fixed Time	100.0	1400.0	Good	0.8	17.3	14.83	31.97	42.34	37.15	10.36	153.3
B132	-59.0	37.30	49.39	3	Fixed Time	100.0	1400.0	Good	0.8	17.3	14.83	31.97	42.34	37.15	10.36	153.3
B132	-59.0	37.30	49.39	3	Fixed Time	100.0	1400.0	Good	0.8	17.3	14.83	31.97	42.34	37.15	10.36	153.3
B132	-59.0	59.27	65.30	6	Fixed Time	100.0	1600.0	Good	0.8	20.7	17.74	50.80	55.97	53.39	5.17	181.9
B132	-59.0	59.27	65.30	6	Fixed Time	100.0	1600.0	Good	0.8	20.7	17.74	50.80	55.97	53.39	5.17	181.9
B132	-59.0	59.27	65.30	6	Fixed Time	100.0	1600.0	Good	0.8	20.7	17.74	50.80	55.97	53.39	5.17	181.9
B132	-59.0	59.27	65.30	6	Fixed Time	100.0	1600.0	Good	0.8	20.7	17.74	50.80	55.97	53.39	5.17	181.9
B132	-59.0	59.27	65.30	6	Fixed Time	100.0	1600.0	Good	0.8	20.7	17.74	50.80	55.97	53.39	5.17	181.9
B132	-59.0	64.30	70.28	7	Fixed Time	100.0	1600.0	Good	0.8	22.4	19.20	55.12	60.24	57.68	5.13	196.2
B132	-59.0	64.30	70.28	7	Fixed Time	100.0	1600.0	Good	0.8	22.4	19.20	55.12	60.24	57.68	5.13	196.2
B132	-59.0	64.30	70.28	7	Fixed Time	100.0	1600.0	Good	0.8	22.4	19.20	55.12	60.24	57.68	5.13	196.2
B132	-59.0	64.30	70.28	7	Fixed Time	100.0	1600.0	Good	0.8	22.4	19.20	55.12	60.24	57.68	5.13	196.2
B132	-59.0	64.30	70.28	7	Fixed Time	100.0	1600.0	Good	0.8	22.4	19.20	55.12	60.24	57.68	5.13	196.2
B132	-59.0	69.28	75.32	8	Fixed Time	100.0	1800.0	Good	0.8	23.0	19.67	59.38	64.56	61.97	5.18	200.8
B132	-59.0	69.28	75.32	8	Fixed Time	100.0	1800.0	Good	0.8	23.0	19.67	59.38	64.56	61.97	5.18	200.8
B132	-59.0	69.28	75.32	8	Fixed Time	100.0	1800.0	Good	0.8	23.0	19.67	59.38	64.56	61.97	5.18	200.8
B132	-59.0	69.28	75.32	8	Fixed Time	100.0	1800.0	Good	0.8	23.0	19.67	59.38	64.56	61.97	5.18	200.8
B132	-59.0	69.28	75.32	8	Fixed Time	100.0	1800.0	Good	0.8	23.0	19.67	59.38	64.56	61.97	5.18	200.8
B132	-59.0	75.32	81.37	9	Fixed Time	100.0	1800.0	Good	0.8	23.0	19.67	64.56	69.75	67.15	5.19	200.8
B132	-59.0	75.32	81.37	9	Fixed Time	100.0	1800.0	Good	0.8	23.0	19.67	64.56	69.75	67.15	5.19	200.8
B132	-59.0	75.32	81.37	9	Fixed Time	100.0	1800.0	Good	0.8	23.0	19.67	64.56	69.75	67.15	5.19	200.8
B132	-59.0	75.32	81.37	9	Fixed Time	100.0	1800.0	Good	0.8	23.0	19.67	64.56	69.75	67.15	5.19	200.8
B132	-59.0	75.32	81.37	9	Fixed Time	100.0	1800.0	Good	0.8	23.0	19.67	64.56	69.75	67.15	5.19	200.8
B132	-59.0	83.01	88.99	11	Fixed Time	100.0	2100.0	Good	0.8	22.5	19.32	71.15	76.28	73.72	5.13	197.4
B132	-59.0	83.01	88.99	11	Fixed Time	100.0	2100.0	Good	0.8	22.5	19.32	71.15	76.28	73.72	5.13	197.4
B132	-59.0	83.01	88.99	11	Fixed Time	100.0	2100.0	Good	0.8	22.5	19.32	71.15	76.28	73.72	5.13	197.4
B132	-59.0	83.01	88.99	11	Fixed Time	100.0	2100.0	Good	0.8	22.5	19.32	71.15	76.28	73.72	5.13	197.4
B132	-59.0	83.01	88.99	11	Fixed Time	100.0	2100.0	Good	0.8	22.5	19.32	71.15	76.28	73.72	5.13	197.4
B132	-59.0	93.30	102.30	12	Fixed Time	100.0	2100.0	Good	0.8	22.4	19.19	79.97	87.69	83.83	7.71	196.1
B132	-59.0	93.30	102.30	12	Fixed Time	100.0	2100.0	Good	0.8	22.4	19.19	79.97	87.69	83.83	7.71	196.1
B132	-59.0	93.30	102.30	12	Fixed Time	100.0	2100.0	Good	0.8	22.4	19.19	79.97	87.69	83.83	7.71	196.1
B132	-59.0	93.30	102.30	12	Fixed Time	100.0	2100.0	Good	0.8	22.4	19.19	79.97	87.69	83.83	7.71	196.1
B132	-59.0	93.30	102.30	12	Fixed Time	100.0	2100.0	Good	0.8	22.4	19.19	79.97	87.69	83.83	7.71	196.1
B132	-59.0	101.30	112.33	13	Fixed Time	100.0	2100.0	Good	0.8	22.4	19.19	86.83	96.29	91.56	9.45	196.1
B132	-59.0	101.30	112.33	13	Fixed Time	100.0	2100.0	Good	0.8	22.4	19.19	86.83	96.29	91.56	9.45	196.1
B132	-59.0	101.30	112.33	13	Fixed Time	100.0	2100.0	Good	0.8	22.4	19.19	86.83	96.29	91.56	9.45	196.1
B132	-59.0	101.30	112.33	13	Fixed Time	100.0	2100.0	Good	0.8	22.4	19.19	86.83	96.29	91.56	9.45	196.1
B132	-59.0	101.30	112.33	13	Fixed Time	100.0	2100.0	Good	0.8	22.4	19.19	86.83	96.29	91.56	9.45	196.1
B132	-59.0	111.27	120.27	14	Fixed Time	100.0	2100.0	Good	0.8	22.1	18.91	95.38	103.09	99.23	7.71	193.3
B132	-59.0	111.27	120.27	14	Fixed Time	100.0	2100.0	Good	0.8	22.1	18.91	95.38	103.09	99.23	7.71	193.3
B132	-59.0	111.27	120.27	14	Fixed Time	100.0	2100.0	Good	0.8	22.1	18.91	95.38	103.09	99.23	7.71	193.3
B132	-59.0	111.27	120.27	14	Fixed Time	100.0	2100.0	Good	0.8	22.1	18.91	95.38	103.09	99.23	7.71	193.3
B132	-59.0	111.27	120.27	14	Fixed Time	100.0	2100.0	Good	0.8	22.1	18.91	95.38	103.09	99.23	7.71	193.3

Reading Number	Test Pressure	Flow Meter Reading Start	Flow Meter Reading 5 min	Flow Meter Reading 10 min	Flow Meter Reading 15 min	Volume 0-5 min	Volume 5-10 min	Volume 10-15 min	Elapsed Time 1	Elapsed Time 2	Elapsed Time 3	Effective Head	Volume Loss	Flow Rate	Flow Rate Per Metre	Average Lugeon Value	Flow Type
	(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)	
1	130.0	897.4	907.6	918.3	928.3	10.2	10.7	10				522.5	10.30	2.06	0.86	1.6	laminar flow
2	260.0	4.9	16.6	31.9	46.2	11.7	15.3	14.3				652.5	13.77	2.75	1.15	1.8	laminar flow
3	400.0	83.1	99.2	114.8	131	16.1	15.6	16.2				792.5	15.97	3.19	1.33	1.7	laminar flow
4	260.0	134	143.8	156.4	169.6	9.8	12.6	13.2				652.5	11.87	2.37	0.99	1.5	laminar flow
5	135.0	184.3	191.5	204.8	218.1	7.2	13.3	13.3				527.5	11.27	2.25	0.94	1.8	laminar flow
1	135.0	4.6	4.6	4.6	4.6	0	0	0				251.7	0.00	0.00	0.00	0.0	other - see comments
2	270.0	4.8	4.8	4.8	4.8	0	0	0				386.7	0.00	0.00	0.00	0.0	other - see comments
3	400.0	5.1	6.5	7.8	9.4	1.4	1.3	1.6				516.7	1.43	0.29	0.04	0.1	other - see comments
4	270.0	9.5	9.7	9.9	10.2	0.2	0.2	0.3				386.7	0.23	0.05	0.01	0.0	other - see comments
5	135.0	10.2	10.2	10.3	10.4	0	0.1	0.1				251.7	0.07	0.01	0.00	0.0	other - see comments
1	135.0	258.8	259.6	260.5	261.4	0.8	0.9	0.9				250.1	0.87	0.17	0.02	0.1	other - see comments
2	270.0	268.5	272.9	279	285.9	4.4	6.1	6.9				385.1	5.80	1.16	0.16	0.4	other - see comments
3	400.0	290.4	299.9	320.2	329.1	9.5	20.3	8.9				515.1	12.90	2.58	0.35	0.7	other - see comments
4	270.0	329.8	331.4	332.6	335.6	1.6	1.2	3				385.1	1.93	0.39	0.05	0.1	other - see comments
5	135.0	336.1	339.9	343.3	347.3	3.8	3.4	4				250.1	3.73	0.75	0.10	0.4	other - see comments
1	135.0	199.2	200.3	200.8	201.4	1.1	0.5	0.6				250.1	0.73	0.15	0.02	0.1	other - see comments
2	270.0	207.4	209	211.4	213.5	1.6	2.4	2.1				385.1	2.03	0.41	0.06	0.1	other - see comments
3	400.0	216.6	222.2	206.5	231.3	5.6	-15.7	24.8				515.1	4.90	0.98	0.13	0.3	other - see comments
4	270.0	233.9	235.1	236.5	238.7	1.2	1.4	2.2				385.1	1.60	0.32	0.04	0.1	other - see comments
5	135.0	238.9	238.9	239.2	239.5	0	0.3	0.3				250.1	0.20	0.04	0.01	0.0	other - see comments
1	135.0	258.8	259.6	260.5	261.4	0.8	0.9	0.9				279.8	0.87	0.17	0.02	0.1	other - see comments
2	270.0	268.5	272.9	279	285.9	4.4	6.1	6.9				414.8	5.80	1.16	0.16	0.4	other - see comments
3	400.0	290.4	299.9	320.2	329.1	9.5	20.3	8.9				544.8	12.90	2.58	0.35	0.6	other - see comments
4	270.0	329.8	331.4	332.6	335.6	1.6	1.2	3				414.8	1.93	0.39	0.05	0.1	other - see comments
5	135.0	336.1	339.9	343.3	347.3	3.8	3.4	4				279.8	3.73	0.75	0.10	0.4	other - see comments
1	135.0	258.8	259.6	260.5	261.4	0.8	0.9	0.9				266.2	0.87	0.17	0.07	0.3	other - see comments
2	270.0	268.5	272.9	279	285.9	4.4	6.1	6.9				401.2	5.80	1.16	0.47	1.2	other - see comments
3	400.0	290.4	299.9	320.2	329.1	9.5	20.3	8.9				531.2	12.90	2.58	1.05	2.0	other - see comments
4	270.0	329.8	331.4	332.6	335.6	1.6	1.2	3				401.2	1.93	0.39	0.16	0.4	other - see comments
5	135.0	336.1	339.9	343.3	347.3	3.8	3.4	4				266.2	3.73	0.75	0.30	1.1	other - see comments
1	135.0	531	570.9	588.8	600.8	39.9	17.9	12				552.2	23.27	4.65	0.95	1.7	laminar flow
2	270.0	718.6	740.9	767.8	789.8	22.3	26.9	22				687.2	23.73	4.75	0.97	1.4	laminar flow
3	400.0	938.3	979.7	1022	1048.2	41.4	42.3	26.2				817.2	36.63	7.33	1.49	1.8	laminar flow
4	270.0	1125.3	1141.8	1156.3	1172.4	16.5	14.5	16.1				687.2	15.70	3.14	0.64	0.9	laminar flow
5	135.0	1174.5	1174.5	1174.5	1174.5	0	0	0				552.2	0.00	0.00	0.00	0.0	laminar flow
1	135.0	232	234.5	234.5	234.9	2.5	0	0.4				553.0	0.97	0.19	0.03	0.0	other - see comments
2	270.0	253.4	253.4	253.4	253.4	0	0	0				688.0	0.00	0.00	0.00	0.0	other - see comments
3	400.0	263	264.8	265.3	265.3	1.8	0.5	0				818.0	0.77	0.15	0.02	0.0	other - see comments
4	270.0	265.3	265.3	265.3	265.3	0	0	0				688.0	0.00	0.00	0.00	0.0	other - see comments
5	135.0	265.3	265.3	265.3	265.3	0	0	0				553.0	0.00	0.00	0.00	0.0	other - see comments
1	135.0	205	206.5	208.9	210.6	1.5	2.4	1.7				553.0	1.87	0.37	0.05	0.1	other - see comments
2	270.0	219.6	220.4	222.2	222.2	0.8	1.8	0				688.0	0.87	0.17	0.02	0.0	other - see comments
3	400.0	226.7	227.3	229.7	232.1	0.6	2.4	2.4				818.0	1.80	0.36	0.05	0.1	other - see comments
4	270.0	240.1	241.2	242.2	242.4	1.1	1	0.2				688.0	0.77	0.15	0.02	0.0	other - see comments
5	135.0	242.4	242.4	242.4	242.4	0	0	0				553.0	0.00	0.00	0.00	0.0	other - see comments
1	135.0	376	376.1	378.2	380.1	0.1	2.1	1.9				553.0	1.37	0.27	0.04	0.1	other - see comments
2	270.0	391.2	392.2	395.1	400.9	1	2.9	5.8				688.0	3.23	0.65	0.09	0.1	other - see comments
3	400.0	403.9	408.4	412.1	415.5	4.5	3.7	3.4				818.0	3.87	0.77	0.10	0.1	other - see comments
4	270.0	415.5	416	416.9	418.3	0.5	0.9	1.4				688.0	0.93	0.19	0.03	0.0	other - see comments
5	135.0	422.9	423	423.7	423.7	0.1	0.7	0				553.0	0.27	0.05	0.01	0.0	other - see comments
1	270.0	28	39.9	53.3	66.9	11.9	13.4	13.6				691.2	12.97	2.59	0.40	0.6	other - see comments
2	135.0	70.2	81.8	93.3	104.6	11.6	11.5	11.3				556.2	11.47	2.29	0.35	0.6	other - see comments
3	400.0	533.5	536.7	541.1	546.1	3.2	4.4	5				821.2	4.20	0.84	0.13	0.2	other - see comments
4	270.0	547.8	549.4	551.7	553.8	1.6	2.3	2.1				691.2	2.00	0.40	0.06	0.1	other - see comments
5	135.0	553.9	553.901	553.902	553.903	0.001	0.001	0.001				556.2	0.00	0.00	0.00	0.0	other - see comments
1	135.0	582.7	583.33	584.9	585.2	0.63	1.57	0.3				556.2	0.83	0.17	0.04	0.1	other - see comments
2	270.0	595	601.1	607.8	612.4	6.1	6.7	4.6				691.2	5.80	1.16	0.26	0.4	other - see comments
3	400.0	612.9	616.2	618.4	620.5	3.3	2.2	2.1				821.2	2.53	0.51	0.11	0.1	other - see comments
4	270.0	620.9	622.4	623.2	624.3	1.5	0.8	1.1				691.2	1.13	0.23	0.05	0.1	other - see comments
5	135.0	624.3	624.4	624.6	624.7	0.1	0.2	0.1				556.2	0.13	0.03	0.01	0.0	other - see comments
1	45.0	799.9	809.6	819.8	829.8	9.7	10.2	10				130.8	9.97	1.99	0.33	2.5	laminar flow
2	85.0	839.2	854.3	869.5	884.8	15.1	15.2	15.3				170.8	15.20	3.04	0.51	3.0	laminar flow
3	130.0	901.5	921.1	939.8	958.6	19.6	18.7	18.8				215.8	19.03	3.81	0.63	2.9	laminar flow
4	85.0	979.8	990.7	1003.4	1016.6	10.9	12.7	13.2				170.8	12.27	2.45	0.41	2.4	laminar flow
5	45.0	1026.9	1032	1042.1	1049.5	5.1	10.1	7.4				130.8	7.53	1.51	0.25	1.9	laminar flow
1	30.0	743.6	745.1	746.1	747	1.5	1	0.9				164.9	1.13	0.23	0.04	0.2	laminar flow
2	55.0	747.3	748.9	750.2	751.6	1.6	1.3	1.4				189.9	1.43	0.29	0.05	0.3	laminar flow
3	85.0	752.2	754.1	756	757.9	1.9	1.9	1.9				219.9	1.90	0.38	0.06	0.3	laminar flow
4	50.0	758.3	759.4	760.6	761.8	1.1	1.2	1.2				184.9	1.17	0.23	0.04	0.2	laminar flow
5	30.0	762.6	763.2	763.7	764.3	0.6	0.5	0.6				164.9	0.57	0.11	0.02	0.1	laminar flow
1	45.0	799.9	809.6	819.8	829.8	9.7	10.2	10				68.2	9.97	1.99	0.50	7.3	void filling
2	85.0	839.2	854.3	869.5	884.8	15.1	15.2	15.3				108.2	15.20	3.04	0.76	7.0	void filling
3	130.0	901.5	921.1	939.8	958.6	19.6	18.7	18.8				153.2	19.03	3.81	0.95	6.2	void filling
4	85.0	979.8	990.7	1003.4	1016.6	10.9	12.7	13.2				108.2	12.27	2.45	0.61	5.7	void filling
5	45.0	1026.9	1032	1042.1	1049.5	5.1	10.1	7.4				68.2	7.53	1.51	0.38	5.5	void filling
1	65.0	867.8	867.8	867.8	867.8	0	0	0				176.3	0.00	0.00	0.00	0.0	other - see comments
2	135.0	867.8	867.8	867.8	867.8	0	0	0				246.3	0.00	0.00	0.00	0.0	other - see comments
3	200.0	867.8	867.8	867.8	867.8	0	0	0				311.3	0.00	0.00	0.00	0.0	other - see comments
4	135.0	867.8	867.8	867.8	867.8	0	0	0				246.3	0.00	0.00	0.00	0.0	other - see comments
5	65.0	867.8	867.8	867.8	867.8	0	0	0				176.3	0.00	0.00	0.00	0.0	other - see comments
1	80.0	999.7	999.7	999.7	999.7	0	0	0				233.3	0.00	0.00	0.00	0.0	other - see comments
2	165.0	999.8	999.8	999.8	999.8	0	0	0				318.3	0.00	0.00	0.00	0.0	other - see comments
3	245.0	1001.9	1001.9	1001.9	1001.9	0	0	0				398.3	0.00	0.00	0.00	0.0	other - see comments
4	165.0	1001.9	1001.9	1001.9	1001.9	0	0	0				318.3	0.00	0.00	0.00	0.0	other - see comments
5	80.0	1001.9	1001.9	1001.9	1001.9	0	0	0				233.3	0.00	0.00	0.00	0.0	other - see comments
1	95.0	914.7	917.5	918.7	919.9	2.8	1.2	1.2				248.3	1.73	0.35	0.03	0.1	other - see comments
2	185.0	923.9	926.2	927.3	928.4	2.3	1.1	1.1				338.3	1.50	0.30	0.03	0.1	other - see comments
3	280.0	930.8	934.2	937.5	940.8	3.4	3.3	3.3				433.3	3.33	0.67	0.06	0.1	other - see comments
4	185.0	941.6	943.8	944.2	944.4	2.2	0.4	0.2				338.3	0.93	0.19	0.02	0.1	other - see comments
5	95.0	944.5	944.7	945	945.3	0.2	0.3	0.3				248.3	0.27	0.05	0.01	0.0	other - see comments
1	135.0	790.4	800.4	807.4	816.7	10	7	9.3				316.9	8.77	1.75	0.34	1.1	void filling
2	270.0	853	866.3	878.5	890.4	13.3	12.2	11.9				451.9	12.47	2.49	0.48	1.1	void filling
3	400.0	901.7	917.8	934.5	950.9	16.1	16.7	16.4				581.9	16.40	3.28	0.63	1.1	void filling
4	270.0	956.4	963.4	970.6	977.5	7	7.2	6.9				451.9	7.03	1.41	0.27	0.6	void filling
5	135.0	977.5	977.5	978.7	979.3	0	1.2	0.6				316.9	0.60	0.12	0.02	0.1	void filling
1	135.0	68.6	68.6	68.6	68.6	0	0	0				331.2	0.00	0.00	0.00	0.0	other - see comments
2	270.0	86.5	86.5	86.5	86.5	0	0	0				466.2	0.00	0.00	0.00	0.0	other - see comments
3	400.0	96.1	96.1	96.1	96.1	0	0	0				596.2	0.00	0.00	0.00	0.0	other - see comments
4	270.0	96.1	96.1	96.1	96.1	0	0	0				466.2	0.00	0.00	0.00	0.0	other - see comments
5	135.0	96.1	96.1	96.1	96.1	0	0	0				331.2	0.00	0.00	0.00	0.0	other - see comments
1	135.0	180.8	210.6	219.6	219.6	29.8	9	0				335.8	12.93	2.59	0.50	1.5	other - see comments
2	270.0	219.6	219.7	219.7	219.7	0.1	0	0				470.8	0.03	0.01	0.00	0.0	other - see comments
3	400.0	219.7	219.7	219.7	219.7	0	0	0				600.8	0.00	0.00	0.00	0.0	other - see comments
4	270.0	219.7	219.7	219.7	219.7	0	0	0				470.8	0.00	0.00	0.00	0.0	other - see comments
5	135.0	219.7	219.7	219.7	219.7	0	0	0				335.8	0.00	0.00	0.00	0.0	other - see comments
1	135.0	334.7	361.1	388.4	418.1	26.4	27.3	29.7				335.8	27.80	5.56	1.07	3.2	dilation
2	270.0	478.7	527.2	571.3	613.5	48.5	44.1	42.2				470.8	44.93	8.99	1.73	3.7	dilation
3	400.0	653	723	788.5	855.1	70	65.5	66.6				600.8	67.37	13.47	2.60	4.3	dilation
4	270.0	865	907.1	951.9	996.8	42.1	44.8	44.9				470.8	43.93	8.79	1.69	3.6	dilation
5	135.0	999.7	1012	1034.9	1061.1	12.3	22.9	26.2				335.8	20.47	4.09	0.79	2.4	dilation
1	135.0	542.7	543	543.7	544.9	0.3	0.7	1.2				332.4	0.73	0.15	0.03	0.1	other - see comments
2	270.0	558.1	558.9	560.2	561.5	0.8	1.3	1.3				467.4	1.13	0.23	0.04	0.1	other - see comments
3	400.0	566.5	566.9	567.4	568	0.4	0.5	0.6				597.4	0.50	0.10	0.02	0.0	other - see comments
4	270.0	568.9	568.9	568.9	568.9	0	0	0				467.4	0.00	0.00	0.00	0.0	other - see comments
5	135.0	568.2	568.2	568.2	568.2	0	0	0				332.4	0.00	0.00	0.00	0.0	other - see comments
1	135.0	656.4	659.9	666.9	673.5	3.5	7	6.6				331.1	5.70	1.14	0.15	0.4	other - see comments
2	270.0	684.2	685.8	686.5	687.2	1.6	0.7	0.7				466.1	1.00	0.20	0.03	0.1	other - see comments
3	400.0	696.4	698.4	700.4	702.3	2	2	1.9				596.1	1.97	0.39	0.05	0.1	other - see comments
4	270.0	700.7	701.7	702.6	703.6	1	0.9	1				466.1	0.97	0.19	0.03	0.1	other - see comments
5	135.0	703.6	704.3	705.2	706.1	0.7	0.9	0.9				331.1	0.83	0.17	0.02	0.1	other - see comments
1	135.0	840	851.2	861.2	871.9	11.2	10	10.7				331.1	10.63	2.13	0.22	0.7	turbulent flow
2	270.0	883	904.7	926.1	946.8	21.7	21.4	20.7				466.1	21.27	4.25	0.45	1.0	turbulent flow
3	400.0	970	986	1002.4	1019.4	16	16.4	17				596.1	16.47	3.29	0.35	0.6	turbulent flow
4	270.0	28	39.9	53.3	66.9	11.9	13.4	13.6				466.1	12.97	2.59	0.27	0.6	turbulent flow
5	135.0	70.2	81.8	93.3	104.6	11.6	11.5	11.3				331.1	11.47	2.29	0.24	0.7	turbulent flow
1	135.0	218	220.6	222.4	222.9	2.6	1.8	0.5				328.3	1.63	0.33	0.04	0.1	dilation
2	270.0	225	227.4	229.8	232.6	2.4	2.4	2.8				463.3	2.53	0.51	0.07	0.1	dilation
3	400.0	250	260.9	271.8	283.3	10.9	10.9	11.5				593.3	11.10	2.22	0.29	0.5	dilation
4	270.0	290.2	293.6	295.9	298.1	3.4	2.3	2.2				463.3	2.63	0.53	0.07	0.1	dilation
5	135.0	298.4	298.5	298.9	298.9	0.1	0.4	0				328.3	0.17	0.03	0.00	0.0	dilation

Interpreted Lugeon Value (Houlsby) (uL)	Remark
1.64	None.
1.76	None.
1.68	None.
1.52	None.
1.78	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
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<1	Flow rate too low to define flow type.
1.18	Flow rate too low to define flow type.
1.98	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
1.14	Flow rate too low to define flow type.
1.71	Pump pressure fluctuating during final stage of test, disregard stage 5 result.
1.41	Pump pressure fluctuating during final stage of test, disregard stage 5 result.
1.82	Pump pressure fluctuating during final stage of test, disregard stage 5 result.
<1	Pump pressure fluctuating during final stage of test, disregard stage 5 result.
<1	Pump pressure fluctuating during final stage of test, disregard stage 5 result.
<1	Changed pump valve after previous test, pressure is stable.
<1	Changed pump valve after previous test, pressure is stable.
<1	Changed pump valve after previous test, pressure is stable.
<1	Changed pump valve after previous test, pressure is stable.
<1	Changed pump valve after previous test, pressure is stable.
<1	Flow rate too low to define flow type.
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<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
2.54	None.
2.97	None.
2.94	None.
2.39	None.
1.92	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
7.31	None.
7.03	None.
6.21	None.
5.67	None.
5.53	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
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<1	Flow rate too low to define flow type.
1.07	None.
1.07	None.
1.09	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
1.49	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
3.19	None.
3.68	None.
4.32	None.
3.60	None.
2.35	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
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<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.

Borehole	Inclination	Length to Top	Length to Bottom	Test Number	Reading Method	Fixed Volume	Packer Inflation Pressure	Packer Seal Condition	Pressure Gauge Height	Initial Groundwater Length	Initial Groundwater Depth	Depth to Top	Depth to Bottom	Depth to Centre	Section Length	Correction Gauge Pressure
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)
B132	-59.0	48.20	60.27	4	Fixed Volume	20.0	1600.0	Good	0.8	20.7	17.74	41.32	51.66	46.49	10.35	181.9
B132	-59.0	57.00	60.27	5	Fixed Volume	300.0	1600.0	Good	0.8	20.7	17.74	48.86	51.66	50.26	2.80	181.9
B132	-59.0	57.00	60.27	5	Fixed Volume	300.0	1600.0	Good	0.8	20.7	17.74	48.86	51.66	50.26	2.80	181.9
B132	-59.0	78.90	84.01	10	Fixed Volume	250.0	1900.0	Good	0.8	22.4	19.19	67.63	72.01	69.82	4.38	196.1
B132	-59.0	78.90	84.01	10	Fixed Volume	250.0	1900.0	Good	0.8	22.4	19.19	67.63	72.01	69.82	4.38	196.1
B133	-90.0	24.50	29.98	1	Fixed Time	100.0	1900.0	Good	0.8	13.4	13.38	24.50	29.98	27.24	5.48	139.3
B133	-90.0	24.50	29.98	1	Fixed Time	100.0	1900.0	Good	0.8	13.4	13.38	24.50	29.98	27.24	5.48	139.3
B133	-90.0	24.50	29.98	1	Fixed Time	100.0	1900.0	Good	0.8	13.4	13.38	24.50	29.98	27.24	5.48	139.3
B133	-90.0	24.50	29.98	1	Fixed Time	100.0	1900.0	Good	0.8	13.4	13.38	24.50	29.98	27.24	5.48	139.3
B133	-90.0	24.50	29.98	1	Fixed Time	100.0	1900.0	Good	0.8	13.4	13.38	24.50	29.98	27.24	5.48	139.3
B133	-90.0	29.00	37.97	2	Fixed Time	100.0	1600.0	Good	0.8	13.4	13.38	29.00	37.97	33.49	8.97	139.3
B133	-90.0	29.00	37.97	2	Fixed Time	100.0	1600.0	Good	0.8	13.4	13.38	29.00	37.97	33.49	8.97	139.3
B133	-90.0	29.00	37.97	2	Fixed Time	100.0	1600.0	Good	0.8	13.4	13.38	29.00	37.97	33.49	8.97	139.3
B133	-90.0	29.00	37.97	2	Fixed Time	100.0	1600.0	Good	0.8	13.4	13.38	29.00	37.97	33.49	8.97	139.3
B133	-90.0	29.00	37.97	2	Fixed Time	100.0	1600.0	Good	0.8	13.4	13.38	29.00	37.97	33.49	8.97	139.3
B133	-90.0	37.00	48.95	3	Fixed Time	100.0	1900.0	Good	0.8	16.4	16.35	37.00	48.95	42.98	11.95	168.4
B133	-90.0	37.00	48.95	3	Fixed Time	100.0	1900.0	Good	0.8	16.4	16.35	37.00	48.95	42.98	11.95	168.4
B133	-90.0	37.00	48.95	3	Fixed Time	100.0	1900.0	Good	0.8	16.4	16.35	37.00	48.95	42.98	11.95	168.4
B133	-90.0	37.00	48.95	3	Fixed Time	100.0	1900.0	Good	0.8	16.4	16.35	37.00	48.95	42.98	11.95	168.4
B133	-90.0	37.00	48.95	3	Fixed Time	100.0	1900.0	Good	0.8	16.4	16.35	37.00	48.95	42.98	11.95	168.4
B133	-90.0	48.00	54.00	4	Fixed Time	100.0	2200.0	Good	0.8	14.7	14.67	48.00	54.00	51.00	6.00	152.0
B133	-90.0	48.00	54.00	4	Fixed Time	100.0	2200.0	Good	0.8	14.7	14.67	48.00	54.00	51.00	6.00	152.0
B133	-90.0	48.00	54.00	4	Fixed Time	100.0	2200.0	Good	0.8	14.7	14.67	48.00	54.00	51.00	6.00	152.0
B133	-90.0	48.00	54.00	4	Fixed Time	100.0	2200.0	Good	0.8	14.7	14.67	48.00	54.00	51.00	6.00	152.0
B133	-90.0	48.00	54.00	4	Fixed Time	100.0	2200.0	Good	0.8	14.7	14.67	48.00	54.00	51.00	6.00	152.0
B133	-90.0	53.00	65.22	5	Fixed Time	100.0	1900.0	Good	0.8	13.4	13.40	53.00	65.22	59.11	12.22	139.5
B133	-90.0	53.00	65.22	5	Fixed Time	100.0	1900.0	Good	0.8	13.4	13.40	53.00	65.22	59.11	12.22	139.5
B133	-90.0	53.00	65.22	5	Fixed Time	100.0	1900.0	Good	0.8	13.4	13.40	53.00	65.22	59.11	12.22	139.5
B133	-90.0	53.00	65.22	5	Fixed Time	100.0	1900.0	Good	0.8	13.4	13.40	53.00	65.22	59.11	12.22	139.5
B133	-90.0	53.00	65.22	5	Fixed Time	100.0	1900.0	Good	0.8	13.4	13.40	53.00	65.22	59.11	12.22	139.5
B135	-58.0	60.50	69.55	1	Fixed Time	100.0	1600.0	Good	1.0	6.5	5.51	51.31	58.98	55.14	7.67	63.9
B135	-58.0	60.50	69.55	1	Fixed Time	100.0	1600.0	Good	1.0	6.5	5.51	51.31	58.98	55.14	7.67	63.9
B135	-58.0	60.50	69.55	1	Fixed Time	100.0	1600.0	Good	1.0	6.5	5.51	51.31	58.98	55.14	7.67	63.9
B135	-58.0	60.50	69.55	1	Fixed Time	100.0	1600.0	Good	1.0	6.5	5.51	51.31	58.98	55.14	7.67	63.9
B135	-58.0	60.50	69.55	1	Fixed Time	100.0	1600.0	Good	1.0	6.5	5.51	51.31	58.98	55.14	7.67	63.9
B135	-58.0	68.50	77.51	2	Fixed Time	100.0	1600.0	Good	1.0	8.5	7.21	58.09	65.73	61.91	7.64	80.5
B135	-58.0	68.50	77.51	2	Fixed Time	100.0	1600.0	Good	1.0	8.5	7.21	58.09	65.73	61.91	7.64	80.5
B135	-58.0	68.50	77.51	2	Fixed Time	100.0	1600.0	Good	1.0	8.5	7.21	58.09	65.73	61.91	7.64	80.5
B135	-58.0	68.50	77.51	2	Fixed Time	100.0	1600.0	Good	1.0	8.5	7.21	58.09	65.73	61.91	7.64	80.5
B135	-58.0	68.50	77.51	2	Fixed Time	100.0	1600.0	Good	1.0	8.5	7.21	58.09	65.73	61.91	7.64	80.5
B135	-58.0	76.50	85.55	3	Fixed Time	100.0	1600.0	Good	1.0	15.0	12.72	64.88	72.55	68.71	7.67	134.6
B135	-58.0	76.50	85.55	3	Fixed Time	100.0	1600.0	Good	1.0	15.0	12.72	64.88	72.55	68.71	7.67	134.6
B135	-58.0	76.50	85.55	3	Fixed Time	100.0	1600.0	Good	1.0	15.0	12.72	64.88	72.55	68.71	7.67	134.6
B135	-58.0	76.50	85.55	3	Fixed Time	100.0	1600.0	Good	1.0	15.0	12.72	64.88	72.55	68.71	7.67	134.6
B135	-58.0	76.50	85.55	3	Fixed Time	100.0	1600.0	Good	1.0	15.0	12.72	64.88	72.55	68.71	7.67	134.6
B135	-58.0	84.50	93.52	4	Fixed Time	100.0	1600.0	Good	1.0	15.0	12.72	71.66	79.31	75.48	7.65	134.6
B135	-58.0	84.50	93.52	4	Fixed Time	100.0	1600.0	Good	1.0	15.0	12.72	71.66	79.31	75.48	7.65	134.6
B135	-58.0	84.50	93.52	4	Fixed Time	100.0	1600.0	Good	1.0	15.0	12.72	71.66	79.31	75.48	7.65	134.6
B135	-58.0	84.50	93.52	4	Fixed Time	100.0	1600.0	Good	1.0	15.0	12.72	71.66	79.31	75.48	7.65	134.6
B135	-58.0	84.50	93.52	4	Fixed Time	100.0	1600.0	Good	1.0	15.0	12.72	71.66	79.31	75.48	7.65	134.6
B135	-58.0	92.50	101.55	5	Fixed Time	100.0	1600.0	Good	1.0	23.5	19.93	78.44	86.12	82.28	7.67	205.3
B135	-58.0	92.50	101.55	5	Fixed Time	100.0	1600.0	Good	1.0	23.5	19.93	78.44	86.12	82.28	7.67	205.3
B135	-58.0	92.50	101.55	5	Fixed Time	100.0	1600.0	Good	1.0	23.5	19.93	78.44	86.12	82.28	7.67	205.3
B135	-58.0	92.50	101.55	5	Fixed Time	100.0	1600.0	Good	1.0	23.5	19.93	78.44	86.12	82.28	7.67	205.3
B135	-58.0	92.50	101.55	5	Fixed Time	100.0	1600.0	Good	1.0	23.5	19.93	78.44	86.12	82.28	7.67	205.3
B135	-58.0	100.50	112.45	6	Fixed Time	100.0	1600.0	Good	1.0	30.5	25.87	85.23	95.36	90.30	10.13	263.6
B135	-58.0	100.50	112.45	6	Fixed Time	100.0	1600.0	Good	1.0	30.5	25.87	85.23	95.36	90.30	10.13	263.6
B135	-58.0	100.50	112.45	6	Fixed Time	100.0	1600.0	Good	1.0	30.5	25.87	85.23	95.36	90.30	10.13	263.6
B135	-58.0	100.50	112.45	6	Fixed Time	100.0	1600.0	Good	1.0	30.5	25.87	85.23	95.36	90.30	10.13	263.6
B135	-58.0	100.50	112.45	6	Fixed Time	100.0	1600.0	Good	1.0	30.5	25.87	85.23	95.36	90.30	10.13	263.6
B135	-58.0	111.50	123.43	7	Fixed Time	100.0	1600.0	Good	1.0	30.5	25.87	94.56	104.67	99.62	10.12	263.6
B135	-58.0	111.50	123.43	7	Fixed Time	100.0	1600.0	Good	1.0	30.5	25.87	94.56	104.67	99.62	10.12	263.6
B135	-58.0	111.50	123.43	7	Fixed Time	100.0	1600.0	Good	1.0	30.5	25.87	94.56	104.67	99.62	10.12	263.6
B135	-58.0	111.50	123.43	7	Fixed Time	100.0	1600.0	Good	1.0	30.5	25.87	94.56	104.67	99.62	10.12	263.6
B135	-58.0	111.50	123.43	7	Fixed Time	100.0	1600.0	Good	1.0	30.5	25.87	94.56	104.67	99.62	10.12	263.6
B135	-58.0	122.50	134.49	8	Fixed Time	100.0	1600.0	Good	1.0	38.5	32.65	103.89	114.05	108.97	10.17	330.1
B135	-58.0	122.50	134.49	8	Fixed Time	100.0	1600.0	Good	1.0	38.5	32.65	103.89	114.05	108.97	10.17	330.1
B135	-58.0	122.50	134.49	8	Fixed Time	100.0	1600.0	Good	1.0	38.5	32.65	103.89	114.05	108.97	10.17	330.1
B135	-58.0	122.50	134.49	8	Fixed Time	100.0	1600.0	Good	1.0	38.5	32.65	103.89	114.05	108.97	10.17	330.1
B135	-58.0	122.50	134.49	8	Fixed Time	100.0	1600.0	Good	1.0	38.5	32.65	103.89	114.05	108.97	10.17	330.1
B135	-58.0	133.50	145.45	9	Fixed Time	100.0	1800.0	Good	1.0	42.1	35.70	113.21	123.35	118.28	10.13	360.1
B135	-58.0	133.50	145.45	9	Fixed Time	100.0	1800.0	Good	1.0	42.1	35.70	113.21	123.35	118.28	10.13	360.1
B135	-58.0	133.50	145.45	9	Fixed Time	100.0	1800.0	Good	1.0	42.1	35.70	113.21	123.35	118.28	10.13	360.1
B135	-58.0	133.50	145.45	9	Fixed Time	100.0	1800.0	Good	1.0	42.1	35.70	113.21	123.35	118.28	10.13	360.1
B135	-58.0	133.50	145.45	9	Fixed Time	100.0	1800.0	Good	1.0	42.1	35.70	113.21	123.35	118.28	10.13	360.1
B135	-58.0	141.50	147.45	10	Fixed Time	100.0	1800.0	Good	1.0	42.0	35.62	120.00	125.04	122.52	5.05	359.2
B135	-58.0	141.50	147.45	10	Fixed Time	100.0	1800.0	Good	1.0	42.0	35.62	120.00	125.04	122.52	5.05	359.2
B135	-58.0	141.50	147.45	10	Fixed Time	100.0	1800.0	Good	1.0	42.0	35.62	120.00	125.04	122.52	5.05	359.2
B135	-58.0	141.50	147.45	10	Fixed Time	100.0	1800.0	Good	1.0	42.0	35.62	120.00	125.04	122.52	5.05	359.2
B135	-58.0	141.50	147.45	10	Fixed Time	100.0	1800.0	Good	1.0	42.0	35.62	120.00	125.04	122.52	5.05	359.2
B135	-58.0	146.50	153.45	11	Fixed Time	100.0	1800.0	Good	1.0	42.0	35.62	124.24	130.13	127.19	5.89	359.2
B135	-58.0	146.50	153.45	11	Fixed Time	100.0	1800.0	Good	1.0	42.0	35.62	124.24	130.13	127.19	5.89	359.2
B135	-58.0	146.50	153.45	11	Fixed Time	100.0	1800.0	Good	1.0	42.0	35.62	124.24	130.13	127.19	5.89	359.2
B135	-58.0	146.50	153.45	11	Fixed Time	100.0	1800.0	Good	1.0	42.0	35.62	124.24	130.13	127.19	5.89	359.2
B135	-58.0	146.50	153.45	11	Fixed Time	100.0	1800.0	Good	1.0	42.0	35.62	124.24	130.13	127.19	5.89	359.2
B135	-58.0	153.50	160.00	12	Fixed Time	100.0	1800.0	Good	1.0	49.0	41.55	130.18	135.69	132.93	5.51	417.5
B135	-58.0	153.50	160.00	12	Fixed Time	100.0	1800.0	Good	1.0	49.0	41.55	130.18	135.69	132.93	5.51	417.5
B135	-58.0	153.50	160.00	12	Fixed Time	100.0	1800.0	Good	1.0	49.0	41.55	130.18	135.69	132.93	5.51	417.5
B135	-58.0	153.50	160.00	12	Fixed Time	100.0	1800.0	Good	1.0	49.0	41.55	130.18	135.69	132.93	5.51	417.5
B135	-58.0	153.50	160.00	12	Fixed Time	100.0	1800.0	Good	1.0	49.0	41.55	130.18	135.69	132.93	5.51	417.5
B138	-90.0	51.00	60.00	1	Fixed Time	100.0	1000.0	Good	1.2	53.0	53.00	51.00	60.00	55.50	9.00	531.7
B138	-90.0	51.00	60.00	1	Fixed Time	100.0	1000.0	Good	1.2	53.0	53.00	51.00	60.00	55.50	9.00	531.7
B138	-90.0	51.00	60.00	1	Fixed Time	100.0	1000.0	Good	1.2	53.0	53.00	51.00	60.00	55.50	9.00	531.7
B138	-90.0	51.00	60.00	1	Fixed Time	100.0	1000.0	Good	1.2	53.0	53.00	51.00	60.00	55.50	9.00	531.7
B138	-90.0	51.00	60.00	1	Fixed Time	100.0	1000.0	Good	1.2	53.0	53.00	51.00	60.00	55.50	9.00	531.7
B138	-90.0	59.00	68.00	2	Fixed Time	100.0	1200.0	Good	1.2	53.0	53.00	59.00	68.00	63.50	9.00	531.7
B138	-90.0	59.00	68.00	2	Fixed Time	100.0	1200.0	Good	1.2	53.0	53.00	59.00	68.00	63.50	9.00	531.7
B138	-90.0	59.00	68.00	2	Fixed Time	100.0	1200.0	Good	1.2	53.0	53.00	59.00	68.00	63.50	9.00	531.7
B138	-90.0	59.00	68.00	2	Fixed Time	100.0	1200.0	Good	1.2	53.0	53.00	59.00	68.00	63.50	9.00	531.7
B138	-90.0	59.00	68.00	2	Fixed Time	100.0	1200.0	Good	1.2	53.0	53.00	59.00	68.00	63.50	9.00	531.7
B138	-90.0	66.00	69.00	3	Fixed Time	100.0	1200.0	Good	1.2	53.5	53.50	66.00	69.00	67.50	3.00	536.6
B138	-90.0	66.00	69.00	3	Fixed Time	100.0	1200.0	Good	1.2	53.5	53.50	66.00	69.00	67.50	3.00	536.6
B138	-90.0	68.00	74.00	4	Fixed Time	100.0	1200.0	Good	1.2	53.5	53.50	68.00	74.00	71.00	6.00	536.6
B138	-90.0	68.00	74.00	4	Fixed Time	100.0	1200.0	Good	1.2	53.5	53.50	68.00	74.00	71.00	6.00	536.6
B138	-90.0	68.00	74.00	4	Fixed Time	100.0	1200.0	Good	1.2	53.5	53.50	68.00	74.00	71.00	6.00	536.6
B138	-90.0	68.00	74.00	4	Fixed Time	100.0	1200.0	Good	1.2	53.5	53.50	68.00	74.00	71.00	6.00	536.6
B138	-90.0	68.00	74.00	4	Fixed Time	100.0	1200.0	Good	1.2	53.5	53.50	68.00	74.00	71.00	6.00	536.6
B138	-90.0	72.00	75.00	5	Fixed Time	100.0	1200.0	Good	1.0	53.5	53.50	72.00	75.00	73.50	3.00	534.6
B138	-90.0	72.00	75.00	5	Fixed Time	100.0	1200.0	Good	1.0	53.5	53.50	72.00	75.00	73.50	3.00	534.6
B138	-90.0	72.00	75.00	5	Fixed Time	100.0	1200.0	Good	1.0	53.5	53.50	72.00	75.00	73.50	3.00	534.6
B138	-90.0	72.00	75.00	5	Fixed Time	100.0	1200.0	Good	1.0	53.5	53.50	72.00	75.00	73.50	3.00	534.6
B138	-90.0	72.00	75.00	5	Fixed Time	100.0	1200.0	Good	1.0	53.5	53.50	72.00	75.00	73.50	3.00	534.6
B138	-90.0	74.00	83.00	6	Fixed Time	100.0	1200.0	Good	1.2	53.5	53.50	74.00	83.00	78.50	9.00	536.6
B138	-90.0	74.00	83.00	6	Fixed Time	100.0	1200.0	Good	1.2	53.5	53.50	74.00	83.00	78.50	9.00	536.6
B138	-90.0	74.00	83.00	6	Fixed Time	100.0	1200.0	Good	1.2	53.5	53.50	74.00	83.00	78.50	9.00	536.6
B138	-90.0	74.00	83.00	6	Fixed Time	100.0	1200.0	Good	1.2	53.5	53.50	74.00	83.00	78.50	9.00	536.6
B138	-90.0	74.00	83.00	6	Fixed Time	100.0	1200.0	Good	1.2	53.5	53.50	74.00	83.00	78.50	9.00	536.6
B138	-90.0	93.00	96.00	11	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	93.00	96.00	94.50	3.00	580.8
B138	-90.0	93.00	96.00	11	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	93.00	96.00	94.50	3.00	580.8
B138	-90.0	95.00	98.00	13	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	95.00	98.00	96.50	3.00	580.8
B138	-90.0	95.00	98.00	13	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	95.00	98.00	96.50	3.00	580.8
B138	-90.0	95.00	98.00	13	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	95.00	98.00	96.50	3.00	580.8
B138	-90.0	95.00	98.00	13	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	95.00	98.00	96.50	3.00	580.8
B138	-90.0	95.00	98.00	13	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	95.00	98.00	96.50	3.00	580.8

Reading Number	Test Pressure (kPa)	Flow Meter Reading Start (L)	Flow Meter Reading 5 min (L)	Flow Meter Reading 10 min (L)	Flow Meter Reading 15 min (L)	Volume 0-5 min (L)	Volume 5-10 min (L)	Volume 10-15 min (L)	Elapsed Time 1 (mm:ss)	Elapsed Time 2 (mm:ss)	Elapsed Time 3 (mm:ss)	Effective Head (kPa)	Volume Loss (L)	Flow Rate (L/min)	Flow Rate Per Metre (L/min/m)	Average Lugeon Value (uL)	Flow Type
1	20.0								1:00	1:00	1:00	201.9	60.0	20.00	1.93	9.6	other - see comments
2	30.0								3:30	3:29	3:28	211.9	100.0	31.58	11.27	53.2	other - see comments
1	20.0								4:04	4:04	4:04	201.9	200.0	55.05	19.64	97.3	other - see comments
2	150.0								4:08	5:24	6:19	346.1	300.0	22.12	5.05	14.6	other - see comments
1	150.0								4:27	5:23	5:26	346.1	250.0	53.57	12.23	35.3	other - see comments
1	70.0	726.5	726.5	726.5	726.5	0	0	0				209.3	0.00	0.00	0.00	0.0	other - see comments
2	140.0	736.7	736.8	736.9	737	0.1	0.1	0.1				279.3	0.10	0.02	0.00	0.0	other - see comments
3	210.0	735.9	736.1	736.4	736.7	0.2	0.3	0.3				349.3	0.27	0.05	0.01	0.0	other - see comments
4	140.0	737.8	737.8	737.8	737.8	0	0	0				279.3	0.00	0.00	0.00	0.0	other - see comments
5	70.0	737.8	737.8	737.8	737.8	0	0	0				209.3	0.00	0.00	0.00	0.0	other - see comments
1	85.0	804.6	805.7	806.8	807.8	1.1	1.1	1				224.3	1.07	0.21	0.02	0.1	other - see comments
2	170.0	808.8	810.1	811.2	812.1	1.3	1.1	0.9				309.3	1.10	0.22	0.02	0.1	other - see comments
3	255.0	813	814.9	816.6	818.2	1.9	1.7	1.6				394.3	1.73	0.35	0.04	0.1	other - see comments
4	170.0	818.3	818.9	819.4	819.9	0.6	0.5	0.5				309.3	0.53	0.11	0.01	0.0	other - see comments
5	85.0	820.9	821	821.1	821.2	0.1	0.1	0.1				224.3	0.10	0.02	0.00	0.0	other - see comments
1	110.0	810.8	810.8	810.8	810.8	0	0	0				278.4	0.00	0.00	0.00	0.0	other - see comments
2	210.0	810.8	810.8	810.8	810.8	0	0	0				378.4	0.00	0.00	0.00	0.0	other - see comments
3	325.0	810.9	810.9	810.9	810.9	0	0	0				493.4	0.00	0.00	0.00	0.0	other - see comments
4	215.0	810.9	810.9	810.9	810.9	0	0	0				383.4	0.00	0.00	0.00	0.0	other - see comments
5	110.0	810.9	810.9	810.9	810.9	0	0	0				278.4	0.00	0.00	0.00	0.0	other - see comments
1	135.0	833	839.9	846.8	853.9	6.9	6.9	7.1				287.0	6.97	1.39	0.23	0.8	other - see comments
2	270.0	856.6	857.5	858.4	859.2	0.9	0.9	0.8				422.0	0.87	0.17	0.03	0.1	other - see comments
3	400.0	859.5	859.7	859.7	859.8	0.2	0	0.1				552.0	0.10	0.02	0.00	0.0	other - see comments
4	270.0	860	860.8	861.7	861.6	0.8	0.9	-0.1				422.0	0.53	0.11	0.02	0.0	other - see comments
5	135.0	864	866.9	869.7	872.2	2.9	2.8	2.5				287.0	2.73	0.55	0.09	0.3	other - see comments
1	135.0	884.4	884.4	884.4	884.4	0	0	0				274.5	0.00	0.00	0.00	0.0	other - see comments
2	270.0	884.5	884.5	884.5	884.5	0	0	0				409.5	0.00	0.00	0.00	0.0	other - see comments
3	400.0	884.5	884.5	884.5	884.5	0	0	0				539.5	0.00	0.00	0.00	0.0	other - see comments
4	270.0	884.5	884.5	884.5	884.5	0	0	0				409.5	0.00	0.00	0.00	0.0	other - see comments
5	135.0	884.5	884.5	884.5	884.5	0	0	0				274.5	0.00	0.00	0.00	0.0	other - see comments
1	135.0	867.5	867.5	867.5	867.5	0	0	0				198.9	0.00	0.00	0.00	0.0	other - see comments
2	270.0	870.5	870.5	870.5	870.5	0	0	0				333.9	0.00	0.00	0.00	0.0	other - see comments
3	400.0	871.5	871.5	871.7	871.9	0	0.2	0.2				463.9	0.13	0.03	0.00	0.0	other - see comments
4	270.0	872	872	872	872	0	0	0				333.9	0.00	0.00	0.00	0.0	other - see comments
5	135.0	872	872	872	872	0	0	0				198.9	0.00	0.00	0.00	0.0	other - see comments
1	135.0	889.9	889.9	889.9	889.9	0	0	0				215.5	0.00	0.00	0.00	0.0	other - see comments
2	270.0	894.7	894.7	894.7	894.7	0	0	0				350.5	0.00	0.00	0.00	0.0	other - see comments
3	400.0	895	895	895	895	0	0	0				480.5	0.00	0.00	0.00	0.0	other - see comments
4	270.0	895	895	895	895	0	0	0				350.5	0.00	0.00	0.00	0.0	other - see comments
5	135.0	895	895	895	895	0	0	0				215.5	0.00	0.00	0.00	0.0	other - see comments
1	135.0	909.4	909.4	909.4	909.4	0	0	0				269.6	0.00	0.00	0.00	0.0	other - see comments
2	270.0	906.8	907.8	908.4	909	1	0.6	0.6				404.6	0.73	0.15	0.02	0.0	other - see comments
3	400.0	911.6	912.5	913.6	914.8	0.9	1.1	1.2				534.6	1.07	0.21	0.03	0.1	other - see comments
4	270.0	914.8	914.8	914.9	915.2	0	0.1	0.3				404.6	0.13	0.03	0.00	0.0	other - see comments
5	135.0	915.3	915.3	915.3	915.3	0	0	0				269.6	0.00	0.00	0.00	0.0	other - see comments
1	135.0	929.9	929.9	929.9	929.9	0	0	0				269.6	0.00	0.00	0.00	0.0	other - see comments
2	270.0	931.7	931.7	931.7	931.7	0	0	0				404.6	0.00	0.00	0.00	0.0	other - see comments
3	400.0	932.4	932.4	932.4	932.4	0	0	0				534.6	0.00	0.00	0.00	0.0	other - see comments
4	270.0	932.4	932.4	932.4	932.4	0	0	0				404.6	0.00	0.00	0.00	0.0	other - see comments
5	135.0	932.4	932.4	932.4	932.4	0	0	0				269.6	0.00	0.00	0.00	0.0	other - see comments
1	135.0	941.7	941.7	941.7	941.7	0	0	0				340.3	0.00	0.00	0.00	0.0	other - see comments
2	270.0	948.4	948.8	949.1	949.3	0.4	0.3	0.2				475.3	0.30	0.06	0.01	0.0	other - see comments
3	400.0	952.3	954.3	956.5	958.2	2	2.2	1.7				605.3	1.97	0.39	0.05	0.1	other - see comments
4	270.0	958.2	958.2	958.2	958.2	0	0	0				475.3	0.00	0.00	0.00	0.0	other - see comments
5	135.0	958.2	958.2	958.2	958.2	0	0	0				340.3	0.00	0.00	0.00	0.0	other - see comments
1	135.0	913.6	914.4	914.7	915.8	0.8	0.3	1.1				398.6	0.73	0.15	0.01	0.0	other - see comments
2	270.0	929.2	930.4	931.2	933.5	1.2	0.8	2.3				533.6	1.43	0.29	0.03	0.1	other - see comments
3	400.0	937.4	942.8	948.1	953.2	5.4	5.3	5.1				663.6	5.27	1.05	0.10	0.2	other - see comments
4	270.0	958.2	958.6	958.9	959.3	0.4	0.3	0.4				533.6	0.37	0.07	0.01	0.0	other - see comments
5	135.0	959.3	959.3	959.3	959.3	0	0	0				398.6	0.00	0.00	0.00	0.0	other - see comments
1	135.0	67.9	67.9	67.9	67.9	0	0	0				398.6	0.00	0.00	0.00	0.0	other - see comments
2	270.0	69.7	71.7	71.7	71.7	2	0	0				533.6	0.67	0.13	0.01	0.0	other - see comments
3	400.0	71.8	71.8	72	72.2	0	0.2	0.2				663.6	0.13	0.03	0.00	0.0	other - see comments
4	270.0	72.2	72.2	72.2	72.2	0	0	0				533.6	0.00	0.00	0.00	0.0	other - see comments
5	135.0	72.2	72.2	72.2	72.2	0	0	0				398.6	0.00	0.00	0.00	0.0	other - see comments
1	135.0	82.2	82.3	82.3	82.3	0.1	0	0				465.1	0.03	0.01	0.00	0.0	other - see comments
2	270.0	84.7	85.5	85.6	85.6	0.8	0.1	0				600.1	0.30	0.06	0.01	0.0	other - see comments
3	400.0	95.6	99	101.3	104.4	3.4	2.3	3.1				730.1	2.93	0.59	0.06	0.1	other - see comments
4	270.0	102.6	102.9	103.1	103.1	0.3	0.2	0				600.1	0.17	0.03	0.00	0.0	other - see comments
5	135.0	103.1	103.1	103.1	103.1	0	0	0				465.1	0.00	0.00	0.00	0.0	other - see comments
1	135.0	137.7	138.1	138.3	138.4	0.4	0.2	0.1				495.1	0.23	0.05	0.00	0.0	other - see comments
2	270.0	140.2	142.3	147.1	152.8	2.1	4.8	5.7				630.1	4.20	0.84	0.08	0.1	other - see comments
3	400.0	162.9	167.7	170.4	174.9	4.8	2.7	4.5				760.1	4.00	0.80	0.08	0.1	other - see comments
4	270.0	176.2	179	182.7	185.7	2.8	3.7	3				630.1	3.17	0.63	0.06	0.1	other - see comments
5	135.0	185.9	186.2	186.5	186.7	0.3	0.3	0.2				495.1	0.27	0.05	0.01	0.0	other - see comments
1	135.0	109.9	123.1	117.2	119.3	13.2	-5.9	2.1				494.2	3.13	0.63	0.12	0.3	other - see comments
2	270.0	221.1	221.9	222.6	223.9	0.8	0.7	1.3				629.2	0.93	0.19	0.04	0.1	other - see comments
3	400.0	224	225.8	228.1	230.6	1.8	2.3	2.5				759.2	2.20	0.44	0.09	0.1	other - see comments
4	270.0	230.7	231.1	231.5	232	0.4	0.4	0.5				629.2	0.43	0.09	0.02	0.0	other - see comments
5	135.0	232	232	232.1	232.1	0	0.1	0				494.2	0.03	0.01	0.00	0.0	other - see comments
1	135.0	239.7	239.7	239.7	239.7	0	0	0				494.2	0.00	0.00	0.00	0.0	other - see comments
2	270.0	242	243.3	244.7	245.5	1.3	1.4	0.8				629.2	1.17	0.23	0.04	0.1	other - see comments
3	400.0	246.8	253	261.4	269.6	6.2	8.4	8.2				759.2	7.60	1.52	0.26	0.3	other - see comments
4	270.0	260.7	261.1	261.7	262.8	0.4	0.6	1.1				629.2	0.70	0.14	0.02	0.0	other - see comments
5	135.0	262.8	262.8	262.9	263	0	0.1	0.1				494.2	0.07	0.01	0.00	0.0	other - see comments
1	135.0	270.4	270.4	270.4	270.4	0	0	0				552.5	0.00	0.00	0.00	0.0	other - see comments
2	270.0	273.6	276.8	279.1	281.1	3.2	2.3	2				687.5	2.50	0.50	0.09	0.1	other - see comments
3	400.0	404.6	406.1	407.9	409.6	1.5	1.8	1.7				817.5	1.67	0.33	0.06	0.1	other - see comments
4	270.0	409.6	410.9	411.8	412.8	1.3	0.9	1				687.5	1.07	0.21	0.04	0.1	other - see comments
5	135.0	412.8	413	413.2	413.3	0.2	0.2	0.1				552.5	0.17	0.03	0.01	0.0	other - see comments
1	135.0	73.5	74	74.4	74.7	0.5	0.4	0.3				666.7	0.40	0.08	0.01	0.0	other - see comments
2	270.0	77	78.9	80.5	81.8	1.9	1.6	1.3				801.7	1.60	0.32	0.04	0.0	other - see comments
3	400.0	81.9	87	92.5	97.8	5.1	5.5	5.3				931.7	5.30	1.06	0.12	0.1	other - see comments
4	270.0	99.1	101.7	104.4	107	2.6	2.7	2.6				801.7	2.63	0.53	0.06	0.1	other - see comments
5	135.0	107.8	108.9	109.9	111.1	1.1	1	1.2				666.7	1.10	0.22	0.02	0.0	other - see comments
1	135.0	385	440	493	546	55	53	53				666.7	53.67	10.73	1.19	1.8	wash-out
2	270.0	637	709	782	856	72	73	74				801.7	73.00	14.60	1.62	2.0	wash-out
3	400.0	924	1037	1156	1270	113	119	114				931.7	115.33	23.07	2.56	2.8	wash-out
4	270.0	1290	1393	1493	1593	103	100	100				801.7	101.00	20.20	2.24	2.8	wash-out
5	135.0	1610	1695	1783	1869	85	88	86				666.7	86.33	17.27	1.92	2.9	wash-out
1	135.0	65	127.9	198.2	268.3	62.9	70.3	70.1				671.6	67.77	13.55	4.52	6.7	other - see comments
2	270.0	398	493.3	590	684	95.3	96.7	94				806.6	95.33	19.07	6.36	7.9	other - see comments
1	135.0	203.2	226.6	249	272.3	23.4	22.4	23.3				671.6	23.03	4.61	0.77	1.1	dilation
2	270.0	298.2	309.2	321	332.7	11	11.8	11.7				806.6	11.50	2.30	0.38	0.5	dilation
3	400.0	356	421	487.5	559	65	66.5	71.5				936.6	67.67	13.53	2.26	2.4	dilation
4	270.0	568.3	580.5	594	607.3	12.2	13.5	13.3				806.6	13.00	2.60	0.43	0.5	dilation
5	135.0	625.8	629.7	633.4	637.4	3.9	3.7	4				671.6	3.87	0.77	0.13	0.2	dilation
1	135.0	792.4	792.8	793.6	794.9	0.4	0.8	1.3				669.6	0.83	0.17	0.06	0.1	dilation
2	270.0	839.7	841.8	845	848.3	2.1	3.2	3.3				804.6	2.87	0.57	0.19	0.2	dilation
3	400.0	871	891.5	912	933	20.5	20.5	21				934.6	20.67	4.13	1.38	1.5	dilation
4	270.0	917.2	919.6	922.2	925	2.4	2.6	2.8				804.6	2.60	0.52	0.17	0.2	dilation
5	135.0	925.2	926.9	928.5	930.1	1.7	1.6	1.6				669.6	1.63	0.33	0.11	0.2	dilation
1	135.0	96.4	97.6	99	100.4	1.2	1.4	1.4				671.6	1.33	0.27	0.03	0.0	dilation
2	270.0	101.8	105.2	108.8	112.5	3.4	3.6	3.7				806.6	3.57	0.71	0.08	0.1	dilation
3	400.0	184	261	337.5	411.7	77	76.5	74.2				936.6	75.90	15.18	1.69	1.8	dilation
4	270.0	394.2	397.6	401.2	404.5	3.4	3.6	3.3				806.6	3.43	0.69	0.08	0.1	dilation
5	135.0	304.5	306.5	309.1	311.4	2	2.6	2.3				671.6	2.30	0.46	0.05	0.1	dilation
1	135.0	537	615	694	769.1	78	79	75.1				715.8	77.37	15.47	5.16	7.2	other - see comments
2	270.0	1036	1136.3	1233	1335.1	100.3	96.7	102.1				850.8	99.70	19.94	6.65	7.8	other - see comments
1	135.0	855.4	859.8	864.3	868.3	4.4	4.5	4				715.8	4.30	0.86	0.29	0.4	other - see comments
2	270.0	871.8	877.8	883.4	889.4	6	5.6	6				850.8	5.87	1.17	0.39	0.5	other - see comments
3	400.0	887.4	894.4	901.6	908.9	7	7.2	7.3				980.8	7.17	1.43	0.48	0.5	other - see comments
4	270.0	903.9	908.4	913.1	917.7	4.5	4.7	4.6				850.8	4.60	0.92	0.31	0.4	other - see comments
5	135.0	942.2	945.3	948.1	951.3	3.1	2.8	3.2				715.8	3.03	0.61	0.20	0.3	other - see comments

Interpreted Lugeon Value (Houlsby) (uL)	Remark
N/A	Could not hold pressure beyond 20 kPa due to high water loss, non standard method used.
N/A	Could not hold pressure beyond 40 kPa due to high water loss, non standard method used.
N/A	Could not hold pressure beyond 40 kPa due to high water loss, non standard method used.
N/A	Could not hold pressure beyond 150 kPa due to high water loss, non standard method used.
N/A	Could not hold pressure beyond 150 kPa due to high water loss, non standard method used.
<1	Flow rate too low to define flow type.
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1.79	None.
2.02	None.
2.75	None.
2.80	None.
2.88	None.
6.73	Test making water at highest pressure stage, unable to seal out water leakage so test terminated early. Seal held at stages 1 and 2.
7.88	Test making water at highest pressure stage, unable to seal out water leakage so test terminated early. Seal held at stages 1 and 2.
1.14	None.
<1	None.
2.41	None.
<1	None.
<1	None.
<1	None.
<1	None.
1.47	None.
<1	None.
<1	None.
<1	None.
<1	None.
1.80	None.
<1	None.
<1	None.
7.21	Could not hold pressure due to high water take, non standard method used.
7.81	Could not hold pressure due to high water take, non standard method used.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
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<1	Flow rate too low to define flow type.

Borehole	Inclination	Length to Top	Length to Bottom	Test Number	Reading Method	Fixed Volume	Packer Inflation Pressure	Packer Seal Condition	Pressure Gauge Height	Initial Groundwater Length	Initial Groundwater Depth	Depth to Top	Depth to Bottom	Depth to Centre	Section Length	Correction Gauge Pressure
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)
B138	-90.0	97.00	109.00	14	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	97.00	109.00	103.00	12.00	580.8
B138	-90.0	97.00	109.00	14	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	97.00	109.00	103.00	12.00	580.8
B138	-90.0	97.00	109.00	14	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	97.00	109.00	103.00	12.00	580.8
B138	-90.0	97.00	109.00	14	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	97.00	109.00	103.00	12.00	580.8
B138	-90.0	97.00	109.00	14	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	97.00	109.00	103.00	12.00	580.8
B138	-90.0	108.00	117.00	15	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	108.00	117.00	112.50	9.00	580.8
B138	-90.0	108.00	117.00	15	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	108.00	117.00	112.50	9.00	580.8
B138	-90.0	108.00	117.00	15	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	108.00	117.00	112.50	9.00	580.8
B138	-90.0	108.00	117.00	15	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	108.00	117.00	112.50	9.00	580.8
B138	-90.0	108.00	117.00	15	Fixed Time	100.0	1200.0	Good	1.2	58.0	58.00	108.00	117.00	112.50	9.00	580.8
B138	-90.0	116.00	125.00	16	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	116.00	125.00	120.50	9.00	585.7
B138	-90.0	116.00	125.00	16	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	116.00	125.00	120.50	9.00	585.7
B138	-90.0	116.00	125.00	16	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	116.00	125.00	120.50	9.00	585.7
B138	-90.0	116.00	125.00	16	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	116.00	125.00	120.50	9.00	585.7
B138	-90.0	116.00	125.00	16	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	116.00	125.00	120.50	9.00	585.7
B138	-90.0	124.00	133.00	17	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	124.00	133.00	128.50	9.00	585.7
B138	-90.0	124.00	133.00	17	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	124.00	133.00	128.50	9.00	585.7
B138	-90.0	124.00	133.00	17	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	124.00	133.00	128.50	9.00	585.7
B138	-90.0	124.00	133.00	17	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	124.00	133.00	128.50	9.00	585.7
B138	-90.0	124.00	133.00	17	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	124.00	133.00	128.50	9.00	585.7
B138	-90.0	132.00	137.00	18	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	132.00	137.00	134.50	5.00	585.7
B138	-90.0	132.00	137.00	18	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	132.00	137.00	134.50	5.00	585.7
B138	-90.0	132.00	137.00	18	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	132.00	137.00	134.50	5.00	585.7
B138	-90.0	132.00	137.00	18	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	132.00	137.00	134.50	5.00	585.7
B138	-90.0	132.00	137.00	18	Fixed Time	100.0	1800.0	Good	1.2	58.5	58.50	132.00	137.00	134.50	5.00	585.7
B138	-90.0	82.00	88.00	7	Fixed Volume	100.0	1200.0	Good	1.2	53.0	53.00	82.00	88.00	85.00	6.00	531.7
B138	-90.0	85.00	88.00	8	Fixed Volume	100.0	1200.0	Good	1.2	53.0	53.00	85.00	88.00	86.50	3.00	531.7
B138	-90.0	85.00	91.00	9	Fixed Volume	100.0	1200.0	Good	1.2	58.0	58.00	85.00	91.00	88.00	6.00	580.8
B138	-90.0	90.00	96.00	10	Fixed Volume	100.0	1200.0	Good	1.2	58.0	58.00	90.00	96.00	93.00	6.00	580.8
B138	-90.0	85.00	88.00	8	Fixed Volume	100.0	1200.0	Good	1.2	53.0	53.00	85.00	88.00	86.50	3.00	531.7
B138	-90.0	85.00	91.00	9	Fixed Volume	100.0	1200.0	Good	1.2	58.0	58.00	85.00	91.00	88.00	6.00	580.8
B138	-90.0	93.00	96.00	12	Fixed Volume	100.0	1200.0	Good	1.2	58.0	58.00	93.00	96.00	94.50	3.00	580.8
B140	-90.0	45.90	51.90	1	Fixed Time	100.0	1400.0	Good	0.8	7.4	7.40	45.90	51.90	48.90	6.00	80.0
B140	-90.0	45.90	51.90	1	Fixed Time	100.0	1400.0	Good	0.8	7.4	7.40	45.90	51.90	48.90	6.00	80.0
B140	-90.0	45.90	51.90	1	Fixed Time	100.0	1400.0	Good	0.8	7.4	7.40	45.90	51.90	48.90	6.00	80.0
B140	-90.0	45.90	51.90	1	Fixed Time	100.0	1400.0	Good	0.8	7.4	7.40	45.90	51.90	48.90	6.00	80.0
B140	-90.0	45.90	51.90	1	Fixed Time	100.0	1400.0	Good	0.8	7.4	7.40	45.90	51.90	48.90	6.00	80.0
B140	-90.0	50.80	59.77	2	Fixed Time	100.0	1400.0	Good	0.8	8.4	8.40	50.80	59.77	55.29	8.97	89.9
B140	-90.0	50.80	59.77	2	Fixed Time	100.0	1400.0	Good	0.8	8.4	8.40	50.80	59.77	55.29	8.97	89.9
B140	-90.0	50.80	59.77	2	Fixed Time	100.0	1400.0	Good	0.8	8.4	8.40	50.80	59.77	55.29	8.97	89.9
B140	-90.0	50.80	59.77	2	Fixed Time	100.0	1400.0	Good	0.8	8.4	8.40	50.80	59.77	55.29	8.97	89.9
B140	-90.0	50.80	59.77	2	Fixed Time	100.0	1400.0	Good	0.8	8.4	8.40	50.80	59.77	55.29	8.97	89.9
B140	-90.0	58.80	67.85	3	Fixed Time	100.0	1400.0	Good	0.8	8.4	8.40	58.80	67.85	63.33	9.05	89.9
B140	-90.0	58.80	67.85	3	Fixed Time	100.0	1400.0	Good	0.8	8.4	8.40	58.80	67.85	63.33	9.05	89.9
B140	-90.0	58.80	67.85	3	Fixed Time	100.0	1400.0	Good	0.8	8.4	8.40	58.80	67.85	63.33	9.05	89.9
B140	-90.0	58.80	67.85	3	Fixed Time	100.0	1400.0	Good	0.8	8.4	8.40	58.80	67.85	63.33	9.05	89.9
B140	-90.0	58.80	67.85	3	Fixed Time	100.0	1400.0	Good	0.8	8.4	8.40	58.80	67.85	63.33	9.05	89.9
B140	-90.0	66.39	75.39	4	Fixed Time	100.0	1400.0	Good	0.8	22.5	22.45	66.39	75.39	70.89	9.00	227.7
B140	-90.0	66.39	75.39	4	Fixed Time	100.0	1400.0	Good	0.8	22.5	22.45	66.39	75.39	70.89	9.00	227.7
B140	-90.0	66.39	75.39	4	Fixed Time	100.0	1400.0	Good	0.8	22.5	22.45	66.39	75.39	70.89	9.00	227.7
B140	-90.0	66.39	75.39	4	Fixed Time	100.0	1400.0	Good	0.8	22.5	22.45	66.39	75.39	70.89	9.00	227.7
B140	-90.0	66.39	75.39	4	Fixed Time	100.0	1400.0	Good	0.8	22.5	22.45	66.39	75.39	70.89	9.00	227.7
B140	-90.0	74.38	77.38	5	Fixed Time	100.0	1400.0	Good	0.8	22.5	22.45	74.38	77.38	75.88	3.00	227.7
B140	-90.0	74.38	77.38	5	Fixed Time	100.0	1400.0	Good	0.8	22.5	22.45	74.38	77.38	75.88	3.00	227.7
B140	-90.0	74.38	77.38	5	Fixed Time	100.0	1400.0	Good	0.8	22.5	22.45	74.38	77.38	75.88	3.00	227.7
B140	-90.0	74.38	77.38	5	Fixed Time	100.0	1400.0	Good	0.8	22.5	22.45	74.38	77.38	75.88	3.00	227.7
B140	-90.0	74.38	77.38	5	Fixed Time	100.0	1400.0	Good	0.8	22.5	22.45	74.38	77.38	75.88	3.00	227.7
B140	-90.0	76.43	79.43	6	Fixed Time	100.0	1400.0	Good	0.8	46.0	46.00	76.43	79.43	77.93	3.00	458.7
B140	-90.0	76.43	79.43	6	Fixed Time	100.0	1400.0	Good	0.8	46.0	46.00	76.43	79.43	77.93	3.00	458.7
B140	-90.0	76.43	79.43	6	Fixed Time	100.0	1400.0	Good	0.8	46.0	46.00	76.43	79.43	77.93	3.00	458.7
B140	-90.0	76.43	79.43	6	Fixed Time	100.0	1400.0	Good	0.8	46.0	46.00	76.43	79.43	77.93	3.00	458.7
B140	-90.0	76.43	79.43	6	Fixed Time	100.0	1400.0	Good	0.8	46.0	46.00	76.43	79.43	77.93	3.00	458.7
B140	-90.0	78.38	84.38	7	Fixed Time	100.0	1400.0	Good	0.8	46.0	46.00	78.38	84.38	81.38	6.00	458.7
B140	-90.0	78.38	84.38	7	Fixed Time	100.0	1400.0	Good	0.8	46.0	46.00	78.38	84.38	81.38	6.00	458.7
B140	-90.0	78.38	84.38	7	Fixed Time	100.0	1400.0	Good	0.8	46.0	46.00	78.38	84.38	81.38	6.00	458.7
B140	-90.0	78.38	84.38	7	Fixed Time	100.0	1400.0	Good	0.8	46.0	46.00	78.38	84.38	81.38	6.00	458.7
B140	-90.0	78.38	84.38	7	Fixed Time	100.0	1400.0	Good	0.8	46.0	46.00	78.38	84.38	81.38	6.00	458.7
B140	-90.0	83.37	89.37	8	Fixed Time	100.0	1400.0	Good	0.8	44.0	44.00	83.37	89.37	86.37	6.00	439.1
B140	-90.0	83.37	89.37	8	Fixed Time	100.0	1400.0	Good	0.8	44.0	44.00	83.37	89.37	86.37	6.00	439.1
B140	-90.0	83.37	89.37	8	Fixed Time	100.0	1400.0	Good	0.8	44.0	44.00	83.37	89.37	86.37	6.00	439.1
B140	-90.0	83.37	89.37	8	Fixed Time	100.0	1400.0	Good	0.8	44.0	44.00	83.37	89.37	86.37	6.00	439.1
B140	-90.0	83.37	89.37	8	Fixed Time	100.0	1400.0	Good	0.8	44.0	44.00	83.37	89.37	86.37	6.00	439.1
B140	-90.0	92.70	97.20	11	Fixed Time	100.0	1400.0	Good	0.8	58.3	58.30	92.70	97.20	94.95	4.50	579.4
B140	-90.0	92.70	97.20	11	Fixed Time	100.0	1400.0	Good	0.8	58.3	58.30	92.70	97.20	94.95	4.50	579.4
B140	-90.0	92.70	97.20	11	Fixed Time	100.0	1400.0	Good	0.8	58.3	58.30	92.70	97.20	94.95	4.50	579.4
B140	-90.0	92.70	97.20	11	Fixed Time	100.0	1400.0	Good	0.8	58.3	58.30	92.70	97.20	94.95	4.50	579.4
B140	-90.0	92.70	97.20	11	Fixed Time	100.0	1400.0	Good	0.8	58.3	58.30	92.70	97.20	94.95	4.50	579.4
B140	-90.0	97.00	102.30	12	Fixed Time	100.0	1400.0	Good	0.8	57.2	57.20	97.00	102.30	99.65	5.30	568.6
B140	-90.0	97.00	102.30	12	Fixed Time	100.0	1400.0	Good	0.8	57.2	57.20	97.00	102.30	99.65	5.30	568.6
B140	-90.0	97.00	102.30	12	Fixed Time	100.0	1400.0	Good	0.8	57.2	57.20	97.00	102.30	99.65	5.30	568.6
B140	-90.0	97.00	102.30	12	Fixed Time	100.0	1400.0	Good	0.8	57.2	57.20	97.00	102.30	99.65	5.30	568.6
B140	-90.0	97.00	102.30	12	Fixed Time	100.0	1400.0	Good	0.8	57.2	57.20	97.00	102.30	99.65	5.30	568.6
B140	-90.0	101.30	106.80	13	Fixed Time	100.0	1900.0	Good	0.8	57.3	57.30	101.30	106.80	104.05	5.50	569.6
B140	-90.0	101.30	106.80	13	Fixed Time	100.0	1900.0	Good	0.8	57.3	57.30	101.30	106.80	104.05	5.50	569.6
B140	-90.0	101.30	106.80	13	Fixed Time	100.0	1900.0	Good	0.8	57.3	57.30	101.30	106.80	104.05	5.50	569.6
B140	-90.0	101.30	106.80	13	Fixed Time	100.0	1900.0	Good	0.8	57.3	57.30	101.30	106.80	104.05	5.50	569.6
B140	-90.0	101.30	106.80	13	Fixed Time	100.0	1900.0	Good	0.8	57.3	57.30	101.30	106.80	104.05	5.50	569.6
B140	-90.0	107.30	113.39	14	Fixed Time	100.0	1800.0	Good	0.8	59.0	59.00	107.30	113.39	110.35	6.09	586.2
B140	-90.0	107.30	113.39	14	Fixed Time	100.0	1800.0	Good	0.8	59.0	59.00	107.30	113.39	110.35	6.09	586.2
B140	-90.0	107.30	113.39	14	Fixed Time	100.0	1800.0	Good	0.8	59.0	59.00	107.30	113.39	110.35	6.09	586.2
B140	-90.0	107.30	113.39	14	Fixed Time	100.0	1800.0	Good	0.8	59.0	59.00	107.30	113.39	110.35	6.09	586.2
B140	-90.0	107.30	113.39	14	Fixed Time	100.0	1800.0	Good	0.8	59.0	59.00	107.30	113.39	110.35	6.09	586.2
B140	-90.0	87.20	93.20	9	Fixed Volume	250.0	1400.0	Good	0.8	58.3	58.30	87.20	93.20	90.20	6.00	579.4
B140	-90.0	87.20	93.20	9	Fixed Volume	250.0	1400.0	Good	0.8	58.3	58.30	87.20	93.20	90.20	6.00	579.4
B140	-90.0	92.20	95.20	10	Fixed Volume	250.0	1400.0	Good	0.8	58.3	58.30	92.20	95.20	93.70	3.00	579.4
B141	-90.0	33.40	39.40	1	Fixed Time	100.0	1400.0	Good	0.8	10.2	10.20	33.40	39.40	36.40	6.00	107.5
B141	-90.0	33.40	39.40	1	Fixed Time	100.0	1400.0	Good	0.8	10.2	10.20	33.40	39.40	36.40	6.00	107.5
B141	-90.0	33.40	39.40	1	Fixed Time	100.0	1400.0	Good	0.8	10.2	10.20	33.40	39.40	36.40	6.00	107.5
B141	-90.0	33.40	39.40	1	Fixed Time	100.0	1400.0	Good	0.8	10.2	10.20	33.40	39.40	36.40	6.00	107.5
B141	-90.0	33.40	39.40	1	Fixed Time	100.0	1400.0	Good	0.8	10.2	10.20	33.40	39.40	36.40	6.00	107.5
B141	-90.0	38.39	44.39	2	Fixed Time	100.0	1400.0	Good	0.8	10.2	10.20	38.39	44.39	41.39	6.00	107.5
B141	-90.0	38.39	44.39	2	Fixed Time	100.0	1400.0	Good	0.8	10.2	10.20	38.39	44.39	41.39	6.00	107.5
B141	-90.0	38.39	44.39	2	Fixed Time	100.0	1400.0	Good	0.8	10.2	10.20	38.39	44.39	41.39	6.00	107.5
B141	-90.0	38.39	44.39	2	Fixed Time	100.0	1400.0	Good	0.8	10.2	10.20	38.39	44.39	41.39	6.00	107.5
B141	-90.0	38.39	44.39	2	Fixed Time	100.0	1400.0	Good	0.8	10.2	10.20	38.39	44.39	41.39	6.00	107.5
B141	-90.0	43.38	52.38	3	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	43.38	52.38	47.88	9.00	163.4
B141	-90.0	43.38	52.38	3	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	43.38	52.38	47.88	9.00	163.4
B141	-90.0	43.38	52.38	3	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	43.38	52.38	47.88	9.00	163.4
B141	-90.0	43.38	52.38	3	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	43.38	52.38	47.88	9.00	163.4
B141	-90.0	43.38	52.38	3	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	43.38	52.38	47.88	9.00	163.4
B141	-90.0	51.44	58.96	4	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	51.44	58.96	55.20	7.52	163.4
B141	-90.0	51.44	58.96	4	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	51.44	58.96	55.20	7.52	163.4
B141	-90.0	51.44	58.96	4	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	51.44	58.96	55.20	7.52	163.4
B141	-90.0	51.44	58.96	4	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	51.44	58.96	55.20	7.52	163.4

Reading Number	Test Pressure	Flow Meter Reading Start	Flow Meter Reading 5 min	Flow Meter Reading 10 min	Flow Meter Reading 15 min	Volume 0-5 min	Volume 5 10 min	Volume 10 15 min	Elapsed Time 1	Elapsed Time 2	Elapsed Time 3	Effective Head	Volume Loss	Flow Rate	Flow Rate Per Metre	Average Lugeon Value	Flow Type
	(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)	
1	135.0	990.5	996.7	1002.3	1007.5	6.2	5.6	5.2				715.8	5.67	1.13	0.09	0.1	dilation
2	270.0	1016	1022.7	1029.2	1035.5	6.7	6.5	6.3				850.8	6.50	1.30	0.11	0.1	dilation
3	400.0	1040.4	1048.2	1055.5	1062.5	7.8	7.3	7				980.8	7.37	1.47	0.12	0.1	dilation
4	270.0	1063.2	1068	1072.8	1077	4.8	4.8	4.2				850.8	4.60	0.92	0.08	0.1	dilation
5	135.0	1077.6	1079.9	1082.5	1084.3	2.3	2.6	1.8				715.8	2.23	0.45	0.04	0.1	dilation
1	135.0	116.6	118.6	120.3	122	2	1.7	1.7				715.8	1.80	0.36	0.04	0.1	other - see comments
2	270.0	123.8	127.5	131.1	134.7	3.7	3.6	3.6				850.8	3.63	0.73	0.08	0.1	other - see comments
3	400.0	156.5	216	278	342	59.5	62	64				980.8	61.83	12.37	1.37	1.4	other - see comments
4	270.0	346.5	350.3	354.4	358.6	3.8	4.1	4.2				850.8	4.03	0.81	0.09	0.1	other - see comments
5	135.0	359.6	360	360.5	360.9	0.4	0.5	0.4				715.8	0.43	0.09	0.01	0.0	other - see comments
1	135.0	393	397.5	401.7	405.5	4.5	4.2	3.8				720.7	4.17	0.83	0.09	0.1	dilation
2	270.0	408.3	413.2	418.5	423.5	4.9	5.3	5				855.7	5.07	1.01	0.11	0.1	dilation
3	400.0	427.4	439.3	451.5	564.5	11.9	12.2	113				985.7	45.70	9.14	1.02	1.0	dilation
4	270.0	465.8	469.5	473.6	477.5	3.7	4.1	3.9				855.7	3.90	0.78	0.09	0.1	dilation
5	135.0	476.1	478.4	482.9	486.3	2.3	4.5	3.4				720.7	3.40	0.68	0.08	0.1	dilation
1	135.0	616.4	617.8	619.2	620.5	1.4	1.4	1.3				720.7	1.37	0.27	0.03	0.0	other - see comments
2	270.0	693	693.5	693.8	694.2	0.5	0.3	0.4				855.7	0.40	0.08	0.01	0.0	other - see comments
3	400.0	694.4	699.4	704	708.5	5	4.6	4.5				985.7	4.70	0.94	0.10	0.1	other - see comments
4	270.0	708.3	708.301	708.302	708.303	0.001	0.001	0.001				855.7	0.00	0.00	0.00	0.0	other - see comments
5	135.0	708.3	708.301	708.302	708.303	0.001	0.001	0.001				720.7	0.00	0.00	0.00	0.0	other - see comments
1	135.0	543.7	543.701	543.702	543.703	0.001	0.001	0.001				720.7	0.00	0.00	0.00	0.0	dilation
2	270.0	569.7	571.9	574.4	576.7	2.2	2.5	2.3				855.7	2.33	0.47	0.09	0.1	dilation
3	400.0	624	682	743.1	782.7	58	61.1	39.6				985.7	52.90	10.58	2.12	2.1	dilation
4	270.0	797.3	799.8	802.6	805.4	2.5	2.8	2.8				855.7	2.70	0.54	0.11	0.1	dilation
5	135.0	804.7	804.701	804.702	804.703	0.001	0.001	0.001				720.7	0.00	0.00	0.00	0.0	dilation
1	50.0								1:42	1:40	1:42	581.7	750.0	49.54	8.26	14.2	other - see comments
1	50.0								1:50	1:52	1:44	581.7	750.0	48.79	16.26	28.0	other - see comments
1	50.0								1:50	1:52	1:44	630.8	300.0	59.22	9.87	15.6	other - see comments
1	270.0								1:50	1:48		850.8	300.0	55.27	9.21	10.8	other - see comments
2	25.0								3:10			556.7	100.0	31.58	10.53	18.9	other - see comments
2	25.0								3:10			605.8	300.0	55.27	9.21	15.2	other - see comments
1	400.0								4:30	4:35	4:29	980.8	250.0	48.39	16.13	16.5	other - see comments
1	135.0	344	344	344	344	0	0	0				215.0	0.00	0.00	0.00	0.0	other - see comments
2	270.0	345	346	346	346	1	0	0				350.0	0.33	0.07	0.01	0.0	other - see comments
3	400.0	348	349	350	350	1	1	0				480.0	0.67	0.13	0.02	0.0	other - see comments
4	270.0	350	350	350	350	0	0	0				350.0	0.00	0.00	0.00	0.0	other - see comments
5	135.0	350	350	350	350	0	0	0				215.0	0.00	0.00	0.00	0.0	other - see comments
1	135.0	409.7	411	411	411	1.3	0	0				224.9	0.43	0.09	0.01	0.0	other - see comments
2	270.0	414.9	414.9	414.9	414.9	0	0	0				359.9	0.00	0.00	0.00	0.0	other - see comments
3	400.0	416.5	416.8	416.8	416.8	0.3	0	0				489.9	0.10	0.02	0.00	0.0	other - see comments
4	270.0	416.8	416.8	416.8	416.8	0	0	0				359.9	0.00	0.00	0.00	0.0	other - see comments
5	135.0	416.8	416.8	416.8	416.8	0	0	0				224.9	0.00	0.00	0.00	0.0	other - see comments
1	135.0	409.7	411	411	411	1.3	0	0				224.9	0.43	0.09	0.01	0.0	laminar flow
2	270.0	414.9	414.9	414.9	414.9	0	0	0				359.9	0.00	0.00	0.00	0.0	laminar flow
3	400.0	416.5	416.8	416.8	416.8	0.3	0	0				489.9	0.10	0.02	0.00	0.0	laminar flow
4	270.0	416.8	416.8	416.8	416.8	0	0	0				359.9	0.00	0.00	0.00	0.0	laminar flow
5	135.0	416.8	416.8	416.8	416.8	0	0	0				224.9	0.00	0.00	0.00	0.0	laminar flow
1	135.0	865	944	1023	1104	79	79	81				362.7	79.67	15.93	1.77	4.9	turbulent flow
2	270.0	1320	1415	1501	1588	95	86	87				497.7	89.33	17.87	1.99	4.0	turbulent flow
3	400.0	1668	1763	1858	1953	95	95	95				627.7	95.00	19.00	2.11	3.4	turbulent flow
4	270.0	1989	2076	2160	2241	87	84	81				497.7	84.00	16.80	1.87	3.8	turbulent flow
5	135.0	2280	2351	2423	2495	71	72	72				362.7	71.67	14.33	1.59	4.4	turbulent flow
1	135.0	663	711	760	805	48	49	45				362.7	47.33	9.47	3.16	8.7	wash-out
2	270.0	913	963	1022	1077	50	59	55				497.7	54.67	10.93	3.64	7.3	wash-out
3	400.0	169	245	315	376	76	70	61				627.7	69.00	13.80	4.60	7.3	wash-out
4	270.0	463	520	579	638	57	59	59				497.7	58.33	11.67	3.89	7.8	wash-out
5	135.0	655	704	755	806	49	51	51				362.7	50.33	10.07	3.36	9.3	wash-out
1	135.0	818.1	818.1	818.1	818.1	0	0	0				593.7	0.00	0.00	0.00	0.0	other - see comments
2	270.0	818.4	818.4	818.4	818.4	0	0	0				728.7	0.00	0.00	0.00	0.0	other - see comments
3	400.0	818.9	818.9	818.9	818.9	0	0	0				858.7	0.00	0.00	0.00	0.0	other - see comments
4	270.0	818.9	818.9	818.9	818.9	0	0	0				728.7	0.00	0.00	0.00	0.0	other - see comments
5	135.0	818.9	818.9	818.9	818.9	0	0	0				593.7	0.00	0.00	0.00	0.0	other - see comments
1	135.0	838.5	838.6	838.7	838.8	0.1	0.1	0.1				593.7	0.10	0.02	0.00	0.0	other - see comments
2	270.0	840.1	842	844.7	847.1	1.9	2.7	2.4				728.7	2.33	0.47	0.08	0.1	other - see comments
3	400.0	848.5	853.4	858.3	863.1	4.9	4.9	4.8				858.7	4.87	0.97	0.16	0.2	other - see comments
4	270.0	869.6	871.7	873.8	875.8	2.1	2.1	2				728.7	2.07	0.41	0.07	0.1	other - see comments
5	135.0	875.9	876	876	876.2	0.1	0	0.2				593.7	0.10	0.02	0.00	0.0	other - see comments
1	135.0	218	218	218	218	0	0	0				574.1	0.00	0.00	0.00	0.0	other - see comments
2	270.0	220.7	222.8	223.2	223.7	2.1	0.4	0.5				709.1	1.00	0.20	0.03	0.0	other - see comments
3	400.0	226.4	228.9	231	233	2.5	2.1	2				839.1	2.20	0.44	0.07	0.1	other - see comments
4	270.0	233.1	233.3	233.3	233.3	0.2	0	0				709.1	0.07	0.01	0.00	0.0	other - see comments
5	135.0	233.3	233.3	233.3	233.3	0	0	0				574.1	0.00	0.00	0.00	0.0	other - see comments
1	135.0	134.5	183	232	283	48.5	49	51				714.4	49.50	9.90	2.20	3.1	dilation
2	270.0	391	459	528	592	68	69	64				849.4	67.00	13.40	2.98	3.5	dilation
3	400.0	628	717	799	882	89	82	83				979.4	84.67	16.93	3.76	3.8	dilation
4	270.0	940	1017	1092	1162	77	75	70				849.4	74.00	14.80	3.29	3.9	dilation
5	135.0	1173	1227	1277	1331	54	50	54				714.4	52.67	10.53	2.34	3.3	dilation
1	135.0	95.4	98.1	100.4	102.7	2.7	2.3	2.3				703.6	2.43	0.49	0.09	0.1	dilation
2	270.0	105.7	109.2	112.7	116.2	3.5	3.5	3.5				838.6	3.50	0.70	0.13	0.2	dilation
3	400.0	131	205	287	374	74	82	87				968.6	81.00	16.20	3.06	3.2	dilation
4	270.0	401.1	410.6	418.5	426.5	9.5	7.9	8				838.6	8.47	1.69	0.32	0.4	dilation
5	135.0	427.2	429.9	431.9	433.9	2.7	2	2				703.6	2.23	0.45	0.08	0.1	dilation
1	135.0	538	627	723	822	89	96	99				704.6	94.67	18.93	3.44	4.9	wash-out
2	200.0	1050	1220	1370	1544	170	150	174				769.6	164.67	32.93	5.99	7.8	wash-out
3	300.0	390	610	839	1061	220	229	222				869.6	223.67	44.73	8.13	9.4	wash-out
4	200.0	1230	1445	1655	1868	215	210	213				769.6	212.67	42.53	7.73	10.0	wash-out
5	135.0	1910	2083	2282	2480	173	199	198				704.6	190.00	38.00	6.91	9.8	wash-out
1	135.0	719	739.7	759.8	779.5	20.7	20.1	19.7				721.2	20.17	4.03	0.66	0.9	laminar flow
2	270.0	800	824.3	847.5	870.7	24.3	23.2	23.2				856.2	23.57	4.71	0.77	0.9	laminar flow
3	400.0	884.5	911	936.8	962.7	26.5	25.8	25.9				986.2	26.07	5.21	0.86	0.9	laminar flow
4	270.0	973	994.5	1015.6	1036.7	21.5	21.1	21.1				856.2	21.23	4.25	0.70	0.8	laminar flow
5	135.0	1042.1	1059.2	1076.7	1094.1	17.1	17.5	17.4				721.2	17.33	3.47	0.57	0.8	laminar flow
1	135.0								4:40			714.4	500.0	29.59	4.93	6.9	other - see comments
2	200.0								5:10			779.4	300.0	65.22	10.87	13.9	other - see comments
1	400.0								8:10	8:45		979.4	300.0	75.32	25.11	25.6	other - see comments
1	95.0	127.5	138.2	148.6	159.2	10.7	10.4	10.6				202.5	10.57	2.11	0.35	1.7	laminar flow
2	195.0	168.8	183	197.9	213.2	14.2	14.9	15.3				302.5	14.80	2.96	0.49	1.6	laminar flow
3	290.0	225.1	243.8	262.4	280	18.7	18.6	17.6				397.5	18.30	3.66	0.61	1.5	laminar flow
4	195.0	287.1	301	315.5	332.1	13.9	14.5	16.6				302.5	15.00	3.00	0.50	1.7	laminar flow
5	95.0	335	346.7	358.2	369.7	11.7	11.5	11.5				202.5	11.57	2.31	0.39	1.9	laminar flow
1	110.0	368.3	368.3	368.3	368.3	0	0	0				217.5	0.00	0.00	0.00	0.0	dilation
2	225.0	369.1	369.8	370.5	371.2	0.7	0.7	0.7				332.5	0.70	0.14	0.02	0.1	dilation
3	335.0	374.7	380.3	386.3	392.2	5.6	6	5.9				442.5	5.83	1.17	0.19	0.4	dilation
4	225.0	395.2	396.2	397.2	398.1	1	1	0.9				332.5	0.97	0.19	0.03	0.1	dilation
5	110.0	398.2	398.2	398.2	398.2	0	0	0				217.5	0.00	0.00	0.00	0.0	dilation
1	125.0	643.2	643.2	643.2	643.2	0	0	0				288.4	0.00	0.00	0.00	0.0	laminar flow
2	255.0	655	656.7	657.7	658.7	1.7	1	1				418.4	1.23	0.25	0.03	0.1	laminar flow
3	380.0	658.3	662.5	665.3	668	4.2	2.8	2.7				543.4	3.23	0.65	0.07	0.1	laminar flow
4	255.0	669.2	670.7	672.6	674.7	1.5	1.9	2.1				418.4	1.83	0.37	0.04	0.1	laminar flow
5	125.0	674.9	674.9	674.9	674.9	0	0	0				288.4	0.00	0.00	0.00	0.0	laminar flow
1	135.0	698.6	698.9	699	699	0.3	0.1	0				298.4	0.13	0.03	0.00	0.0	other - see comments
2	270.0	700	703.9	709.3	715.2	3.9	5.4	5.9				433.4	5.07	1.01	0.13	0.3	other - see comments
3	400.0	730	737	742.5	747.9	7	5.5	5.4				563.4	5.97	1.19	0.16	0.3	other - see comments
4	270.0	748.5	751.2	753.9	756.4	2.7	2.7	2.5				433.4	2.63	0.53	0.07	0.2	other - see comments

Interpreted Lugeon Value (Houlsby) (uL)	Remark
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
1.40	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	None.
<1	None.
1.03	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	None.
<1	None.
2.15	None.
<1	None.
<1	None.
N/A	Could not hold pressure beyond 50 kPa due to very high water take, non standard method used.
N/A	Could not hold pressure beyond 45 kPa due to very high water take, non standard method used.
N/A	Could not hold pressure beyond 50 kPa due to very high water take, non standard method used.
N/A	Could not build pressure beyond 270 kPa - reverted to fixed volume method.
N/A	Could not hold pressure beyond 45 kPa due to very high water take, non standard method used.
N/A	Could not hold pressure beyond 50 kPa due to very high water take, non standard method used.
N/A	Could not hold pressure due to high water take, non standard method used.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
4.88	None.
3.99	None.
3.36	None.
3.75	None.
4.39	None.
8.70	None.
7.32	None.
7.33	None.
7.81	None.
9.25	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
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<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
3.08	None.
3.51	None.
3.84	None.
3.87	None.
3.28	None.
<1	None.
<1	None.
3.16	None.
<1	None.
<1	None.
4.89	Test making water at highest pressure stage. Packer inflation increased from 1400 kPa to 1900 kPa and test resumed at 300 kPa.
7.78	Test making water at highest pressure stage. Packer inflation increased from 1400 kPa to 1900 kPa and test resumed at 300 kPa.
9.35	Test making water at highest pressure stage. Packer inflation increased from 1400 kPa to 1900 kPa and test resumed at 300 kPa.
10.05	Test making water at highest pressure stage. Packer inflation increased from 1400 kPa to 1900 kPa and test resumed at 300 kPa.
9.81	Test making water at highest pressure stage. Packer inflation increased from 1400 kPa to 1900 kPa and test resumed at 300 kPa.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
N/A	Could not hold pressure beyond 200 kPa due to very high water take, non-standard method used.
N/A	Could not hold pressure beyond 200 kPa due to very high water take, non-standard method used.
N/A	Could not hold pressure beyond 200 kPa due to very high water take, non-standard method used.
1.74	None.
1.63	None.
1.53	None.
1.65	None.
1.90	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type. Observed minor leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
<1	Flow rate too low to define flow type. Observed minor leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
<1	Flow rate too low to define flow type. Observed minor leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
<1	Flow rate too low to define flow type. Observed minor leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).

Borehole	Inclination	Length to Top	Length to Bottom	Test Number	Reading Method	Fixed Volume	Packer Inflation Pressure	Packer Seal Condition	Pressure Gauge Height	Initial Groundwater Length	Initial Groundwater Depth	Depth to Top	Depth to Bottom	Depth to Centre	Section Length	Correction Gauge Pressure
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)
B141	-90.0	51.44	58.96	4	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	51.44	58.96	55.20	7.52	163.4
B141	-90.0	58.00	66.00	5	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	58.00	66.00	62.00	8.00	163.4
B141	-90.0	58.00	66.00	5	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	58.00	66.00	62.00	8.00	163.4
B141	-90.0	58.00	66.00	5	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	58.00	66.00	62.00	8.00	163.4
B141	-90.0	58.00	66.00	5	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	58.00	66.00	62.00	8.00	163.4
B141	-90.0	58.00	66.00	5	Fixed Time	100.0	1900.0	Good	0.8	15.9	15.90	58.00	66.00	62.00	8.00	163.4
B141	-90.0	65.42	74.42	6	Fixed Time	100.0	1850.0	Good	0.8	16.5	16.50	65.42	74.42	69.92	9.00	169.3
B141	-90.0	65.42	74.42	6	Fixed Time	100.0	1850.0	Good	0.8	16.5	16.50	65.42	74.42	69.92	9.00	169.3
B141	-90.0	65.42	74.42	6	Fixed Time	100.0	1850.0	Good	0.8	16.5	16.50	65.42	74.42	69.92	9.00	169.3
B141	-90.0	65.42	74.42	6	Fixed Time	100.0	1850.0	Good	0.8	16.5	16.50	65.42	74.42	69.92	9.00	169.3
B141	-90.0	65.42	74.42	6	Fixed Time	100.0	1850.0	Good	0.8	16.5	16.50	65.42	74.42	69.92	9.00	169.3
B141	-90.0	73.40	81.41	7	Fixed Time	100.0	1850.0	Good	0.8	16.5	16.50	73.40	81.41	77.41	8.01	169.3
B141	-90.0	73.40	81.41	7	Fixed Time	100.0	1850.0	Good	0.8	16.5	16.50	73.40	81.41	77.41	8.01	169.3
B141	-90.0	73.40	81.41	7	Fixed Time	100.0	1850.0	Good	0.8	16.5	16.50	73.40	81.41	77.41	8.01	169.3
B141	-90.0	73.40	81.41	7	Fixed Time	100.0	1850.0	Good	0.8	16.5	16.50	73.40	81.41	77.41	8.01	169.3
B141	-90.0	73.40	81.41	7	Fixed Time	100.0	1850.0	Good	0.8	16.5	16.50	73.40	81.41	77.41	8.01	169.3
B141	-90.0	80.42	86.42	8	Fixed Time	100.0	1850.0	Good	0.8	12.2	12.20	80.42	86.42	83.42	6.00	127.1
B141	-90.0	80.42	86.42	8	Fixed Time	100.0	1850.0	Good	0.8	12.2	12.20	80.42	86.42	83.42	6.00	127.1
B141	-90.0	80.42	86.42	8	Fixed Time	100.0	1850.0	Good	0.8	12.2	12.20	80.42	86.42	83.42	6.00	127.1
B141	-90.0	80.42	86.42	8	Fixed Time	100.0	1850.0	Good	0.8	12.2	12.20	80.42	86.42	83.42	6.00	127.1
B141	-90.0	80.42	86.42	8	Fixed Time	100.0	1850.0	Good	0.8	12.2	12.20	80.42	86.42	83.42	6.00	127.1
B141	-90.0	85.44	91.44	9	Fixed Time	100.0	1850.0	Good	0.8	12.2	12.20	85.44	91.44	88.44	6.00	127.1
B141	-90.0	85.44	91.44	9	Fixed Time	100.0	1850.0	Good	0.8	12.2	12.20	85.44	91.44	88.44	6.00	127.1
B141	-90.0	85.44	91.44	9	Fixed Time	100.0	1850.0	Good	0.8	12.2	12.20	85.44	91.44	88.44	6.00	127.1
B141	-90.0	85.44	91.44	9	Fixed Time	100.0	1850.0	Good	0.8	12.2	12.20	85.44	91.44	88.44	6.00	127.1
B141	-90.0	85.44	91.44	9	Fixed Time	100.0	1850.0	Good	0.8	12.2	12.20	85.44	91.44	88.44	6.00	127.1
B141	-90.0	91.10	100.16	10	Fixed Time	100.0	1900.0	Good	0.8	21.0	21.00	91.10	100.16	95.63	9.06	213.5
B141	-90.0	91.10	100.16	10	Fixed Time	100.0	1900.0	Good	0.8	21.0	21.00	91.10	100.16	95.63	9.06	213.5
B141	-90.0	91.10	100.16	10	Fixed Time	100.0	1900.0	Good	0.8	21.0	21.00	91.10	100.16	95.63	9.06	213.5
B141	-90.0	91.10	100.16	10	Fixed Time	100.0	1900.0	Good	0.8	21.0	21.00	91.10	100.16	95.63	9.06	213.5
B141	-90.0	91.10	100.16	10	Fixed Time	100.0	1900.0	Good	0.8	21.0	21.00	91.10	100.16	95.63	9.06	213.5
B154	-90.0	21.00	28.00	1	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	21.00	28.00	24.50	7.00	63.8
B154	-90.0	21.00	28.00	1	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	21.00	28.00	24.50	7.00	63.8
B154	-90.0	21.00	28.00	1	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	21.00	28.00	24.50	7.00	63.8
B154	-90.0	21.00	28.00	1	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	21.00	28.00	24.50	7.00	63.8
B154	-90.0	21.00	28.00	1	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	21.00	28.00	24.50	7.00	63.8
B154	-90.0	26.00	29.00	2	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	26.00	29.00	27.50	3.00	63.8
B154	-90.0	26.00	29.00	2	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	26.00	29.00	27.50	3.00	63.8
B154	-90.0	26.00	29.00	2	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	26.00	29.00	27.50	3.00	63.8
B154	-90.0	26.00	29.00	2	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	26.00	29.00	27.50	3.00	63.8
B154	-90.0	26.00	29.00	2	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	26.00	29.00	27.50	3.00	63.8
B154	-90.0	28.00	37.00	3	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	28.00	37.00	32.50	9.00	63.8
B154	-90.0	28.00	37.00	3	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	28.00	37.00	32.50	9.00	63.8
B154	-90.0	28.00	37.00	3	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	28.00	37.00	32.50	9.00	63.8
B154	-90.0	28.00	37.00	3	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	28.00	37.00	32.50	9.00	63.8
B154	-90.0	28.00	37.00	3	Fixed Time	100.0	1800.0	Good	1.2	5.3	5.30	28.00	37.00	32.50	9.00	63.8
B154	-90.0	33.00	39.00	4	Fixed Time	100.0	1800.0	Good	1.2	5.7	5.70	33.00	39.00	36.00	6.00	67.7
B154	-90.0	33.00	39.00	4	Fixed Time	100.0	1800.0	Good	1.2	5.7	5.70	33.00	39.00	36.00	6.00	67.7
B154	-90.0	33.00	39.00	4	Fixed Time	100.0	1800.0	Good	1.2	5.7	5.70	33.00	39.00	36.00	6.00	67.7
B154	-90.0	33.00	39.00	4	Fixed Time	100.0	1800.0	Good	1.2	5.7	5.70	33.00	39.00	36.00	6.00	67.7
B154	-90.0	33.00	39.00	4	Fixed Time	100.0	1800.0	Good	1.2	5.7	5.70	33.00	39.00	36.00	6.00	67.7
B154	-90.0	37.00	49.00	7	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	37.00	49.00	43.00	12.00	81.4
B154	-90.0	37.00	49.00	7	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	37.00	49.00	43.00	12.00	81.4
B154	-90.0	37.00	49.00	7	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	37.00	49.00	43.00	12.00	81.4
B154	-90.0	37.00	49.00	7	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	37.00	49.00	43.00	12.00	81.4
B154	-90.0	37.00	49.00	7	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	37.00	49.00	43.00	12.00	81.4
B154	-90.0	38.00	44.00	5	Fixed Time	100.0	1800.0	Good	1.2	5.7	5.70	38.00	44.00	41.00	6.00	67.7
B154	-90.0	38.00	44.00	5	Fixed Time	100.0	1800.0	Good	1.2	5.7	5.70	38.00	44.00	41.00	6.00	67.7
B154	-90.0	38.00	44.00	5	Fixed Time	100.0	1800.0	Good	1.2	5.7	5.70	38.00	44.00	41.00	6.00	67.7
B154	-90.0	38.00	44.00	5	Fixed Time	100.0	1800.0	Good	1.2	5.7	5.70	38.00	44.00	41.00	6.00	67.7
B154	-90.0	38.00	44.00	5	Fixed Time	100.0	1800.0	Good	1.2	5.7	5.70	38.00	44.00	41.00	6.00	67.7
B154	-90.0	43.00	49.00	6	Fixed Time	100.0	1800.0	Good	1.2	5.7	5.70	43.00	49.00	46.00	6.00	67.7
B154	-90.0	46.00	49.00	8	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	46.00	49.00	47.50	3.00	81.4
B154	-90.0	46.00	49.00	8	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	46.00	49.00	47.50	3.00	81.4
B154	-90.0	46.00	49.00	8	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	46.00	49.00	47.50	3.00	81.4
B154	-90.0	46.00	49.00	8	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	46.00	49.00	47.50	3.00	81.4
B154	-90.0	46.00	49.00	8	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	46.00	49.00	47.50	3.00	81.4
B154	-90.0	48.00	54.00	9	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	48.00	54.00	51.00	6.00	81.4
B154	-90.0	48.00	54.00	9	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	48.00	54.00	51.00	6.00	81.4
B154	-90.0	48.00	54.00	9	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	48.00	54.00	51.00	6.00	81.4
B154	-90.0	48.00	54.00	9	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	48.00	54.00	51.00	6.00	81.4
B154	-90.0	48.00	54.00	9	Fixed Time	100.0	1800.0	Good	1.2	7.1	7.10	48.00	54.00	51.00	6.00	81.4
B154	-90.0	52.00	55.00	10	Fixed Time	100.0	1600.0	Good	1.2	8.0	8.00	52.00	55.00	53.50	3.00	90.3
B154	-90.0	52.00	55.00	10	Fixed Time	100.0	1600.0	Good	1.2	8.0	8.00	52.00	55.00	53.50	3.00	90.3
B154	-90.0	52.00	55.00	10	Fixed Time	100.0	1600.0	Good	1.2	8.0	8.00	52.00	55.00	53.50	3.00	90.3
B154	-90.0	52.00	55.00	10	Fixed Time	100.0	1600.0	Good	1.2	8.0	8.00	52.00	55.00	53.50	3.00	90.3
B154	-90.0	52.00	55.00	10	Fixed Time	100.0	1600.0	Good	1.2	8.0	8.00	52.00	55.00	53.50	3.00	90.3
B154	-90.0	54.00	57.00	11	Fixed Time	100.0	1600.0	Good	1.2	8.0	8.00	54.00	57.00	55.50	3.00	90.3
B154	-90.0	54.00	57.00	11	Fixed Time	100.0	1600.0	Good	1.2	8.0	8.00	54.00	57.00	55.50	3.00	90.3
B154	-90.0	54.00	57.00	11	Fixed Time	100.0	1600.0	Good	1.2	8.0	8.00	54.00	57.00	55.50	3.00	90.3
B154	-90.0	54.00	57.00	11	Fixed Time	100.0	1600.0	Good	1.2	8.0	8.00	54.00	57.00	55.50	3.00	90.3
B154	-90.0	54.00	57.00	11	Fixed Time	100.0	1600.0	Good	1.2	8.0	8.00	54.00	57.00	55.50	3.00	90.3
B154	-90.0	56.00	62.00	12	Fixed Time	100.0	1800.0	Good	1.2	8.2	8.20	56.00	62.00	59.00	6.00	92.2
B154	-90.0	56.00	62.00	12	Fixed Time	100.0	1800.0	Good	1.2	8.2	8.20	56.00	62.00	59.00	6.00	92.2
B154	-90.0	56.00	62.00	12	Fixed Time	100.0	1800.0	Good	1.2	8.2	8.20	56.00	62.00	59.00	6.00	92.2
B154	-90.0	56.00	62.00	12	Fixed Time	100.0	1800.0	Good	1.2	8.2	8.20	56.00	62.00	59.00	6.00	92.2
B154	-90.0	56.00	62.00	12	Fixed Time	100.0	1800.0	Good	1.2	8.2	8.20	56.00	62.00	59.00	6.00	92.2
B154	-90.0	61.00	68.00	13	Fixed Time	100.0	1800.0	Good	1.2	8.2	8.20	61.00	68.00	64.50	7.00	92.2
B154	-90.0	61.00	68.00	13	Fixed Time	100.0	1800.0	Good	1.2	8.2	8.20	61.00	68.00	64.50	7.00	92.2
B154	-90.0	61.00	68.00	13	Fixed Time	100.0	1800.0	Good	1.2	8.2	8.20	61.00	68.00	64.50	7.00	92.2
B154	-90.0	61.00	68.00	13	Fixed Time	100.0	1800.0	Good	1.2	8.2	8.20	61.00	68.00	64.50	7.00	92.2
B154	-90.0	61.00	68.00	13	Fixed Time	100.0	1800.0	Good	1.2	8.2	8.20	61.00	68.00	64.50	7.00	92.2
B155	-90.0	75.00	84.00	1	Fixed Time	100.0	1800.0	Good	1.2	15.2	15.20	75.00	84.00	79.50	9.00	160.9
B155	-90.0	75.00	84.00	1	Fixed Time	100.0	1800.0	Good	1.2	15.2	15.20	75.00	84.00	79.50	9.00	160.9
B155	-90.0	75.00	84.00	1	Fixed Time	100.0	1800.0	Good	1.2	15.2	15.20	75.00	84.00	79.50	9.00	160.9
B155	-90.0	75.00	84.00	1	Fixed Time	100.0	1800.0	Good	1.2	15.2	15.20	75.00	84.00	79.50	9.00	160.9
B155	-90.0	75.00	84.00	1	Fixed Time	100.0	1800.0	Good	1.2	15.2	15.20	75.00	84.00	79.50	9.00	160.9
B155	-90.0	83.00	95.00	2	Fixed Time	100.0	1800.0	Good	1.2	22.5	22.50	83.00	95.00	89.00	12.00	232.5
B155	-90.0	83.00	95.00	2	Fixed Time	100.0	1800.0	Good	1.2	22.5	22.50	83.00	95.00	89.00	12.00	232.5
B155	-90.0	83.00	95.00	2	Fixed Time	100.0	1800.0	Good	1.2	22.5	22.50	83.00	95.00	89.00	12.00	232.5
B155	-90.0	83.00	95.00	2	Fixed Time	100.0	1800.0	Good	1.2	22.5	22.50	83.00	95.00	89.00	12.00	232.5
B155	-90.0	83.00	95.00	2	Fixed Time	100.0	1800.0	Good	1.2	22.5	22.50	83.00	95.00	89.00	12.00	232.5
B155	-90.0	94.00	103.00	3	Fixed Time	100.0	1800.0	Good	1.2	22.5	22.50	94.00	103.00	98.50	9.00	232.5
B155	-90.0	94.00	103.00	3	Fixed Time	100.0	1800.0	Good	1.2	22.5	22.50	94.00	103.00	98.50	9.00	232.5
B155	-90.0	94.00	103.00	3	Fixed Time	100.0	1800.0	Good	1.2	22.5	22.50	94.00	103.00	98.50	9.00	232.5
B155	-90.0	94.00	103.00	3	Fixed Time	100.0	1800.0	Good	1.2	22.5	22.50	94.00	103.00	98.50	9.00	232.5
B155	-90.0	94.00	103.00	3	Fixed Time	100.0	1800.0	Good	1.2	22.5	22.50	94.00	103.00	98.50	9.00	232.5
B155	-90.0	102.00	111.00	4	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	102.00	111.00	106.50	9.00	238.4
B155	-90.0	102.00	111.00	4	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	102.00	111.00	106.50	9.00	238.4
B155	-90.0	102.00	111.00	4	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	102.00	111.00	106.50	9.00	238.4
B155	-90.0	102.00	111.00	4	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	102.00	111.00	106.50	9.00	238.4
B155	-90.0	102.00	111.00	4	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	102.00	111.00	106.50	9.00	238.4
B155	-90.0	110.00	119.00	5	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	110.00	119.00	114.50	9.00	238.4
B155	-90.0	110.00	119.00	5	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	110.00	119.00	114.50	9.00	238.4

Reading Number	Test Pressure	Flow Meter Reading Start	Flow Meter Reading 5 min	Flow Meter Reading 10 min	Flow Meter Reading 15 min	Volume 0-5 min	Volume 5-10 min	Volume 10-15 min	Elapsed Time 1	Elapsed Time 2	Elapsed Time 3	Effective Head	Volume Loss	Flow Rate	Flow Rate Per Metre	Average Lugeon Value	Flow Type
	(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)	
5	135.0	756.6	757.1	757.9	758.5	0.5	0.8	0.6				298.4	0.63	0.13	0.02	0.1	other - see comments
1	135.0	803.6	807.3	807.3	807.3	3.7	0	0				298.4	1.23	0.25	0.03	0.1	other - see comments
2	270.0	813.4	817.5	819.2	820.7	4.1	1.7	1.5				433.4	2.43	0.49	0.06	0.1	other - see comments
3	400.0	827.6	830	831.8	833.4	2.4	1.8	1.6				563.4	1.93	0.39	0.05	0.1	other - see comments
4	270.0	833.4	834.2	835	835.7	0.8	0.8	0.7				433.4	0.77	0.15	0.02	0.0	other - see comments
5	135.0	835.7	835.7	835.7	835.7	0	0	0				298.4	0.00	0.00	0.00	0.0	other - see comments
1	135.0	425.7	425.7	425.7	425.7	0	0	0				304.3	0.00	0.00	0.00	0.0	other - see comments
2	270.0	426	426	426	426	0	0	0				439.3	0.00	0.00	0.00	0.0	other - see comments
3	400.0	426.3	426.3	426.3	426.3	0	0	0				569.3	0.00	0.00	0.00	0.0	other - see comments
4	270.0	426.3	426.4	426.4	426.4	0.1	0	0				439.3	0.03	0.01	0.00	0.0	other - see comments
5	135.0	426.4	426.4	426.4	426.4	0	0	0				304.3	0.00	0.00	0.00	0.0	other - see comments
1	135.0	446	446	446	446	0	0	0				304.3	0.00	0.00	0.00	0.0	other - see comments
2	270.0	446.8	446.8	446.8	446.8	0	0	0				439.3	0.00	0.00	0.00	0.0	other - see comments
3	400.0	447.3	448	448.6	449.3	0.7	0.6	0.7				569.3	0.67	0.13	0.02	0.0	other - see comments
4	270.0	449.5	449.5	449.5	449.5	0	0	0				439.3	0.00	0.00	0.00	0.0	other - see comments
5	135.0	449.5	449.5	449.5	449.5	0	0	0				304.3	0.00	0.00	0.00	0.0	other - see comments
1	135.0	467.7	468.8	468.8	468.8	1.1	0	0				262.1	0.37	0.07	0.01	0.0	other - see comments
2	270.0	468.4	468.4	468.4	468.4	0	0	0				397.1	0.00	0.00	0.00	0.0	other - see comments
3	400.0	470.2	471	471.9	472.8	0.8	0.9	0.9				527.1	0.87	0.17	0.03	0.1	other - see comments
4	270.0	473	473.5	473.5	473.6	0.5	0	0.1				397.1	0.20	0.04	0.01	0.0	other - see comments
5	135.0	473.6	473.6	473.6	473.6	0	0	0				262.1	0.00	0.00	0.00	0.0	other - see comments
1	135.0	498.4	500.2	502	504	1.8	1.8	2				262.1	1.87	0.37	0.06	0.2	laminar flow
2	270.0	505.6	508.6	511.6	514.6	3	3	3				397.1	3.00	0.60	0.10	0.3	laminar flow
3	400.0	516.4	519.9	523.8	527.5	3.5	3.9	3.7				527.1	3.70	0.74	0.12	0.2	laminar flow
4	270.0	528.5	531.3	534.2	537.1	2.8	2.9	2.9				397.1	2.87	0.57	0.10	0.2	laminar flow
5	135.0	537.4	538.7	540.5	542.1	1.3	1.8	1.6				262.1	1.57	0.31	0.05	0.2	laminar flow
1	135.0	564.6	564.7	564.7	564.7	0.1	0	0				348.5	0.03	0.01	0.00	0.0	other - see comments
2	270.0	566	567	567.8	568.5	1	0.8	0.7				483.5	0.83	0.17	0.02	0.0	other - see comments
3	400.0	569.3	570.7	571.9	573	1.4	1.2	1.1				613.5	1.23	0.25	0.03	0.0	other - see comments
4	270.0	573	573	573.1	573.1	0	0.1	0				483.5	0.03	0.01	0.00	0.0	other - see comments
5	135.0	573.1	573.1	573.1	573.1	0	0	0				348.5	0.00	0.00	0.00	0.0	other - see comments
1	60.0	956.8	961.8	966.7	971.6	5	4.9	4.9				123.8	4.93	0.99	0.14	1.1	turbulent flow
2	120.0	986.1	997.1	1007.8	1017.9	11	10.7	10.1				183.8	10.60	2.12	0.30	1.6	turbulent flow
3	180.0	1034	1049	1063.9	1069	15	14.9	5.1				243.8	11.67	2.33	0.33	1.4	turbulent flow
4	120.0	1077	1086.2	1096.1	1106.2	9.2	9.9	10.1				183.8	9.73	1.95	0.28	1.5	turbulent flow
5	60.0	1106.4	1110.5	1114.6	1118.6	4.1	4.1	4				123.8	4.07	0.81	0.12	0.9	turbulent flow
1	80.0	131	133.5	135.6	138	2.5	2.1	2.4				143.8	2.33	0.47	0.16	1.1	turbulent flow
2	155.0	141.8	142.6	143.4	144.2	0.8	0.8	0.8				218.8	0.80	0.16	0.05	0.2	turbulent flow
3	235.0	146.2	147.7	149.2	150.6	1.5	1.5	1.4				298.8	1.47	0.29	0.10	0.3	turbulent flow
4	155.0	150	150.3	150.7	151.1	0.3	0.4	0.4				218.8	0.37	0.07	0.02	0.1	turbulent flow
5	80.0	151.4	153.1	154.6	156	1.7	1.5	1.4				143.8	1.53	0.31	0.10	0.7	turbulent flow
1	80.0	173.2	174.6	176	177.5	1.4	1.4	1.5				143.8	1.43	0.29	0.03	0.2	other - see comments
2	165.0	185.1	186.9	188.6	190.2	1.8	1.7	1.6				228.8	1.70	0.34	0.04	0.2	other - see comments
3	245.0	194.4	197.6	200.7	203.5	3.2	3.1	2.8				308.8	3.03	0.61	0.07	0.2	other - see comments
4	165.0	203.1	203.1	203.3	203.6	0	0.2	0.3				228.8	0.17	0.03	0.00	0.0	other - see comments
5	80.0	204.1	204.9	205.8	206.6	0.8	0.9	0.8				143.8	0.83	0.17	0.02	0.1	other - see comments
1	95.0	222.8	226.4	229.6	232.7	3.6	3.2	3.1				162.7	3.30	0.66	0.11	0.7	other - see comments
2	195.0	241.9	243.6	245.2	246.7	1.7	1.6	1.5				262.7	1.60	0.32	0.05	0.2	other - see comments
3	290.0	251.1	253.4	255.6	257.8	2.3	2.2	2.2				357.7	2.23	0.45	0.07	0.2	other - see comments
4	195.0	256.7	257.8	258.8	259.9	1.1	1	1.1				262.7	1.07	0.21	0.04	0.1	other - see comments
5	95.0	259.5	259.5	259.5	259.5	0	0	0				162.7	0.00	0.00	0.00	0.0	other - see comments
1	110.0	679	685	690.6	696	6	5.6	5.4				191.4	5.67	1.13	0.09	0.5	void filling
2	215.0	708.3	716.4	724.1	731.6	8.1	7.7	7.5				296.4	7.77	1.55	0.13	0.4	void filling
3	325.0	744.5	755.8	766.5	777	11.3	10.7	10.5				406.4	10.83	2.17	0.18	0.4	void filling
4	215.0	777	780.8	785	789.8	3.8	4.2	4.8				296.4	4.27	0.85	0.07	0.2	void filling
5	110.0	790.6	792	793.3	794.3	1.4	1.3	1				191.4	1.23	0.25	0.02	0.1	void filling
1	110.0	335.2	336.4	337.6	338.9	1.2	1.2	1.3				177.7	1.23	0.25	0.04	0.2	other - see comments
2	225.0	339.3	339.4	339.4	339.4	0.1	0	0				292.7	0.03	0.01	0.00	0.0	other - see comments
3	335.0	340.1	341.2	342.3	343.3	1.1	1.1	1				402.7	1.07	0.21	0.04	0.1	other - see comments
4	225.0	343.4	343.7	344.1	344.5	0.3	0.4	0.4				292.7	0.37	0.07	0.01	0.0	other - see comments
5	110.0	344.3	344.8	345.5	346.2	0.5	0.7	0.7				177.7	0.63	0.13	0.02	0.1	other - see comments
1	125.0	416	443.4	470	494	27.4	26.6	24				192.7	26.00	5.20	0.87	4.5	other - see comments
1	135.0	831.8	841.1	849.3	857.1	9.3	8.2	7.8				216.4	8.43	1.69	0.56	2.6	void filling
2	270.0	869	881.1	892.4	903.5	12.1	11.3	11.1				351.4	11.50	2.30	0.77	2.2	void filling
3	400.0	912.9	925	936.6	947.7	12.1	11.6	11.1				481.4	11.60	2.32	0.77	1.6	void filling
4	270.0	948.7	954.4	960.7	967.1	5.7	6.3	6.4				351.4	6.13	1.23	0.41	1.2	void filling
5	135.0	964	964.3	964.8	965.3	0.3	0.5	0.5				216.4	0.43	0.09	0.03	0.1	void filling
1	135.0	831.8	841.1	849.3	857.1	9.3	8.2	7.8				216.4	8.43	1.69	0.28	1.3	void filling
2	270.0	869	881.1	892.4	903.5	12.1	11.3	11.1				351.4	11.50	2.30	0.38	1.1	void filling
3	400.0	912.9	925	936.6	947.7	12.1	11.6	11.1				481.4	11.60	2.32	0.39	0.8	void filling
4	270.0	948.7	954.4	960.7	967.1	5.7	6.3	6.4				351.4	6.13	1.23	0.20	0.6	void filling
5	135.0	964	964.3	964.8	965.3	0.3	0.5	0.5				216.4	0.43	0.09	0.01	0.1	void filling
1	135.0	182.2	185.9	189.2	191.9	3.7	3.3	2.7				225.3	3.23	0.65	0.22	1.0	dilation
2	270.0	196	197.1	198.5	200.9	1.1	1.4	2.4				360.3	1.63	0.33	0.11	0.3	dilation
3	400.0	204.6	209.7	212.7	217.5	5.1	3	4.8				490.3	4.30	0.86	0.29	0.6	dilation
4	270.0	225.2	226.7	228.3	230.4	1.5	1.6	2.1				360.3	1.73	0.35	0.12	0.3	dilation
5	135.0	230.6	232.1	234.2	236.5	1.5	2.1	2.3				225.3	1.97	0.39	0.13	0.6	dilation
1	135.0	441.2	442.9	444.4	445.9	1.7	1.5	1.5				225.3	1.57	0.31	0.10	0.5	dilation
2	270.0	447.4	450.3	453.9	457	2.9	3.6	3.1				360.3	3.20	0.64	0.21	0.6	dilation
3	400.0	459.8	467.1	472.8	479.4	7.3	5.7	6.6				490.3	6.53	1.31	0.44	0.9	dilation
4	270.0	479.4	480.7	482.1	483.9	1.3	1.4	1.8				360.3	1.50	0.30	0.10	0.3	dilation
5	135.0	483.9	484	484.3	484.7	0.1	0.3	0.4				225.3	0.27	0.05	0.02	0.1	dilation
1	135.0	572.7	575.1	577.5	579.7	2.4	2.4	2.2				227.2	2.33	0.47	0.08	0.3	laminar flow
2	270.0	582	584.4	586.6	589	2.4	2.2	2.4				362.2	2.33	0.47	0.08	0.2	laminar flow
3	400.0	591.3	595.1	598.5	601.7	3.8	3.4	3.2				492.2	3.47	0.69	0.12	0.2	laminar flow
4	270.0	602	603.9	605.9	608	1.9	2	2.1				362.2	2.00	0.40	0.07	0.2	laminar flow
5	135.0	607.8	609	610.5	612	1.2	1.5	1.5				227.2	1.40	0.28	0.05	0.2	laminar flow
1	135.0	629.3	630.5	631.7	632.8	1.2	1.2	1.1				227.2	1.17	0.23	0.03	0.1	laminar flow
2	270.0	635.1	637.5	639.8	642.3	2.4	2.3	2.5				362.2	2.40	0.48	0.07	0.2	laminar flow
3	400.0	646	649.3	652.6	655.9	3.3	3.3	3.3				492.2	3.30	0.66	0.09	0.2	laminar flow
4	270.0	657.2	659.7	662	664.5	2.5	2.3	2.5				362.2	2.43	0.49	0.07	0.2	laminar flow
5	135.0	665.5	667.1	669	671.1	1.6	1.9	2.1				227.2	1.87	0.37	0.05	0.2	laminar flow
1	135.0	747.7	747.7	747.8	747.8	0	0.1	0				295.9	0.03	0.01	0.00	0.0	other - see comments
2	270.0	748.2	748.8	749.5	750.2	0.6	0.7	0.7				430.9	0.67	0.13	0.01	0.0	other - see comments
3	400.0	750.6	752	753.5	755	1.4	1.5	1.5				560.9	1.47	0.29	0.03	0.1	other - see comments
4	270.0	755.3	755.6	755.9	756.1	0.3	0.3	0.2				430.9	0.27	0.05	0.01	0.0	other - see comments
5	135.0	756.8	756.8	756.8	756.8	0	0	0				295.9	0.00	0.00	0.00	0.0	other - see comments
1	135.0	765.3	765.4	765.5	765.5	0.1	0.1	0				367.5	0.07	0.01	0.00	0.0	other - see comments
2	270.0	765.9	766	766	766.1	0.1	0	0.1				502.5	0.07	0.01	0.00	0.0	other - see comments
3	400.0	766.3	766.5	766.5	766.6	0.2	0	0.1				632.5	0.10	0.02	0.00	0.0	other - see comments
4	270.0	766.4	766.4	766.5	766.5	0	0.1	0				502.5	0.03	0.01	0.00	0.0	other - see comments
5	135.0	766.3	766.3	766.3	766.3	0	0	0				367.5	0.00	0.00	0.00	0.0	other - see comments
1	135.0	790.2	790.3	790.3	790.4	0.1	0	0.1				367.5	0.07	0.01	0.00	0.0	other - see comments
2	270.0	790.9	791	791.2	791.4	0.1	0.2	0.2				502.5	0.17	0.03	0.00	0.0	other - see comments
3	400.0	792	793.9	795.7	797.5	1.9	1.8	1.8				632.5	1.83	0.37	0.04	0.1	other - see comments
4	270.0	797	797.2	797.4	797.6	0.2	0.2	0.2				502.5	0.20	0.04	0.00	0.0	other - see comments
5	135.0	797.6	797.6	797.6	797.6	0	0	0				367.5	0.00	0.00	0.00	0.0	other - see comments
1	135.0	802.5	802.8	803.1	803.4	0.3	0.3	0.3				373.4	0.30	0.06	0.01	0.0	other - see comments
2	270.0	804.3	804.4	804.5	804.6	0.1	0.1	0.1				508.4	0.10	0.02	0.00	0.0	other - see comments
3	400.0	805	805.01	805.02	805.03	0.01	0.01	0.01				638.4	0.01	0.00	0.00	0.0	other - see comments
4	270.0	804.7	804.71	804.72	804.73	0.01	0.01	0.01				508.4	0.01	0.00	0.00	0.0	other - see comments
5	135.0	804.2	804.21	804.22	804.3	0.01	0.01	0.08				373.4	0.03	0.01	0.00	0.0	other - see comments
1	135.0	812.4	812.7	813	813.2	0.3	0.3	0.2				373.4	0.27	0.05	0.01	0.0	other - see comments
2	270.0	813.9	815	815.9	816.9	1.1	0.9	1				508.4	1.00	0.20	0.02	0.0	other - see comments

Interpreted Lugeon Value (Houlsby) (uL)	Remark
<1	Flow rate too low to define flow type. Observed minor leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
<1	Flow rate too low to define flow type. Observed leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
<1	Flow rate too low to define flow type. Observed leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
<1	Flow rate too low to define flow type. Observed leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
<1	Flow rate too low to define flow type. Observed leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
<1	Flow rate too low to define flow type. Observed leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
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<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
1.14	None.
1.65	None.
1.37	None.
1.51	None.
<1	None.
1.08	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
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<1	Flow rate too low to define flow type.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
4.50	Test terminated due to high water loss across area of sub-vertical joint sets, which prevented packer being able to be re-seated in this zone. Packer was re-seated at higher elevation and test interval increased to 12.00m in order to test this interval (see Test 7).
2.60	None.
2.18	None.
1.61	None.
1.16	None.
<1	None.
1.30	None.
1.09	None.
<1	None.
<1	None.
<1	None.
<1	Mixture of dilation and turbulent flow types.
<1	Mixture of dilation and turbulent flow types.
<1	Mixture of dilation and turbulent flow types.
<1	Mixture of dilation and turbulent flow types.
<1	Mixture of dilation and turbulent flow types.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type.
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<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.

Borehole	Inclination	Length to Top	Length to Bottom	Test Number	Reading Method	Fixed Volume	Packer Inflation Pressure	Packer Seal Condition	Pressure Gauge Height	Initial Groundwater Length	Initial Groundwater Depth	Depth to Top	Depth to Bottom	Depth to Centre	Section Length	Correction Gauge Pressure
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)
B155	-90.0	110.00	119.00	5	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	110.00	119.00	114.50	9.00	238.4
B155	-90.0	110.00	119.00	5	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	110.00	119.00	114.50	9.00	238.4
B155	-90.0	110.00	119.00	5	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	110.00	119.00	114.50	9.00	238.4
B155	-90.0	118.00	127.00	6	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	118.00	127.00	122.50	9.00	238.4
B155	-90.0	118.00	127.00	6	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	118.00	127.00	122.50	9.00	238.4
B155	-90.0	118.00	127.00	6	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	118.00	127.00	122.50	9.00	238.4
B155	-90.0	118.00	127.00	6	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	118.00	127.00	122.50	9.00	238.4
B155	-90.0	118.00	127.00	6	Fixed Time	100.0	1800.0	Good	1.2	23.1	23.10	118.00	127.00	122.50	9.00	238.4
B155	-90.0	126.00	135.00	7	Fixed Time	100.0	1800.0	Good	1.2	22.4	22.40	126.00	135.00	130.50	9.00	231.5
B155	-90.0	126.00	135.00	7	Fixed Time	100.0	1800.0	Good	1.2	22.4	22.40	126.00	135.00	130.50	9.00	231.5
B155	-90.0	126.00	135.00	7	Fixed Time	100.0	1800.0	Good	1.2	22.4	22.40	126.00	135.00	130.50	9.00	231.5
B155	-90.0	126.00	135.00	7	Fixed Time	100.0	1800.0	Good	1.2	22.4	22.40	126.00	135.00	130.50	9.00	231.5
B155	-90.0	126.00	135.00	7	Fixed Time	100.0	1800.0	Good	1.2	22.4	22.40	126.00	135.00	130.50	9.00	231.5
B155	-90.0	134.00	143.00	8	Fixed Time	100.0	1800.0	Good	1.2	24.2	24.20	134.00	143.00	138.50	9.00	249.2
B155	-90.0	134.00	143.00	8	Fixed Time	100.0	1800.0	Good	1.2	24.2	24.20	134.00	143.00	138.50	9.00	249.2
B155	-90.0	134.00	143.00	8	Fixed Time	100.0	1800.0	Good	1.2	24.2	24.20	134.00	143.00	138.50	9.00	249.2
B155	-90.0	134.00	143.00	8	Fixed Time	100.0	1800.0	Good	1.2	24.2	24.20	134.00	143.00	138.50	9.00	249.2
B155	-90.0	134.00	143.00	8	Fixed Time	100.0	1800.0	Good	1.2	24.2	24.20	134.00	143.00	138.50	9.00	249.2
B155	-90.0	142.00	149.00	9	Fixed Time	100.0	1800.0	Good	1.2	24.2	24.20	142.00	149.00	145.50	7.00	249.2
B155	-90.0	142.00	149.00	9	Fixed Time	100.0	1800.0	Good	1.2	24.2	24.20	142.00	149.00	145.50	7.00	249.2
B155	-90.0	142.00	149.00	9	Fixed Time	100.0	1800.0	Good	1.2	24.2	24.20	142.00	149.00	145.50	7.00	249.2
B155	-90.0	142.00	149.00	9	Fixed Time	100.0	1800.0	Good	1.2	24.2	24.20	142.00	149.00	145.50	7.00	249.2
B155	-90.0	142.00	149.00	9	Fixed Time	100.0	1800.0	Good	1.2	24.2	24.20	142.00	149.00	145.50	7.00	249.2
B156	-60.0	5.80	11.27	1	Fixed Time	100.0	1900.0	Good	0.8	1.1	0.95	5.02	9.76	7.39	4.74	17.2
B156	-60.0	5.80	11.27	1	Fixed Time	100.0	1900.0	Good	0.8	1.1	0.95	5.02	9.76	7.39	4.74	17.2
B156	-60.0	5.80	11.27	1	Fixed Time	100.0	1900.0	Good	0.8	1.1	0.95	5.02	9.76	7.39	4.74	17.2
B156	-60.0	5.80	11.27	1	Fixed Time	100.0	1900.0	Good	0.8	1.1	0.95	5.02	9.76	7.39	4.74	17.2
B156	-60.0	10.30	16.30	2	Fixed Time	100.0	1900.0	Good	0.8	1.1	0.95	8.92	14.12	11.52	5.20	17.2
B156	-60.0	10.30	16.30	2	Fixed Time	100.0	1900.0	Good	0.8	1.1	0.95	8.92	14.12	11.52	5.20	17.2
B156	-60.0	10.30	16.30	2	Fixed Time	100.0	1900.0	Good	0.8	1.1	0.95	8.92	14.12	11.52	5.20	17.2
B156	-60.0	10.30	16.30	2	Fixed Time	100.0	1900.0	Good	0.8	1.1	0.95	8.92	14.12	11.52	5.20	17.2
B156	-60.0	10.30	16.30	2	Fixed Time	100.0	1900.0	Good	0.8	1.1	0.95	8.92	14.12	11.52	5.20	17.2
B156	-60.0	15.30	21.32	3	Fixed Time	100.0	1400.0	Good	0.8	1.5	1.28	13.25	18.46	15.86	5.21	20.4
B156	-60.0	15.30	21.32	3	Fixed Time	100.0	1400.0	Good	0.8	1.5	1.28	13.25	18.46	15.86	5.21	20.4
B156	-60.0	15.30	21.32	3	Fixed Time	100.0	1400.0	Good	0.8	1.5	1.28	13.25	18.46	15.86	5.21	20.4
B156	-60.0	15.30	21.32	3	Fixed Time	100.0	1400.0	Good	0.8	1.5	1.28	13.25	18.46	15.86	5.21	20.4
B156	-60.0	15.30	21.32	3	Fixed Time	100.0	1400.0	Good	0.8	1.5	1.28	13.25	18.46	15.86	5.21	20.4
B156	-60.0	20.19	26.19	4	Fixed Time	100.0	1400.0	Good	0.8	1.5	1.28	17.49	22.68	20.08	5.20	20.4
B156	-60.0	20.19	26.19	4	Fixed Time	100.0	1400.0	Good	0.8	1.5	1.28	17.49	22.68	20.08	5.20	20.4
B156	-60.0	20.19	26.19	4	Fixed Time	100.0	1400.0	Good	0.8	1.5	1.28	17.49	22.68	20.08	5.20	20.4
B156	-60.0	20.19	26.19	4	Fixed Time	100.0	1400.0	Good	0.8	1.5	1.28	17.49	22.68	20.08	5.20	20.4
B156	-60.0	20.19	26.19	4	Fixed Time	100.0	1400.0	Good	0.8	1.5	1.28	17.49	22.68	20.08	5.20	20.4
B156	-60.0	25.10	31.07	5	Fixed Time	100.0	1400.0	Good	0.8	1.1	0.95	21.74	26.91	24.32	5.17	17.2
B156	-60.0	25.10	31.07	5	Fixed Time	100.0	1400.0	Good	0.8	1.1	0.95	21.74	26.91	24.32	5.17	17.2
B156	-60.0	25.10	31.07	5	Fixed Time	100.0	1400.0	Good	0.8	1.1	0.95	21.74	26.91	24.32	5.17	17.2
B156	-60.0	25.10	31.07	5	Fixed Time	100.0	1400.0	Good	0.8	1.1	0.95	21.74	26.91	24.32	5.17	17.2
B156	-60.0	25.10	31.07	5	Fixed Time	100.0	1400.0	Good	0.8	1.1	0.95	21.74	26.91	24.32	5.17	17.2
B156	-60.0	30.10	36.40	6	Fixed Time	100.0	1400.0	Good	0.8	1.1	0.95	26.07	31.52	28.80	5.46	17.2
B156	-60.0	30.10	36.40	6	Fixed Time	100.0	1400.0	Good	0.8	1.1	0.95	26.07	31.52	28.80	5.46	17.2
B156	-60.0	30.10	36.40	6	Fixed Time	100.0	1400.0	Good	0.8	1.1	0.95	26.07	31.52	28.80	5.46	17.2
B156	-60.0	30.10	36.40	6	Fixed Time	100.0	1400.0	Good	0.8	1.1	0.95	26.07	31.52	28.80	5.46	17.2
B156	-60.0	30.10	36.40	6	Fixed Time	100.0	1400.0	Good	0.8	1.1	0.95	26.07	31.52	28.80	5.46	17.2
B156	-60.0	41.40	47.45	9	Fixed Time	100.0	1600.0	Good	0.8	35.7	30.92	35.85	41.09	38.47	5.24	311.1
B156	-60.0	41.40	47.45	9	Fixed Time	100.0	1600.0	Good	0.8	35.7	30.92	35.85	41.09	38.47	5.24	311.1
B156	-60.0	41.40	47.45	9	Fixed Time	100.0	1600.0	Good	0.8	35.7	30.92	35.85	41.09	38.47	5.24	311.1
B156	-60.0	41.40	47.45	9	Fixed Time	100.0	1600.0	Good	0.8	35.7	30.92	35.85	41.09	38.47	5.24	311.1
B156	-60.0	41.40	47.45	9	Fixed Time	100.0	1600.0	Good	0.8	35.7	30.92	35.85	41.09	38.47	5.24	311.1
B156	-60.0	46.30	52.35	10	Fixed Time	100.0	1600.0	Good	0.8	35.7	30.92	40.10	45.34	42.72	5.24	311.1
B156	-60.0	46.30	52.35	10	Fixed Time	100.0	1600.0	Good	0.8	35.7	30.92	40.10	45.34	42.72	5.24	311.1
B156	-60.0	46.30	52.35	10	Fixed Time	100.0	1600.0	Good	0.8	35.7	30.92	40.10	45.34	42.72	5.24	311.1
B156	-60.0	46.30	52.35	10	Fixed Time	100.0	1600.0	Good	0.8	35.7	30.92	40.10	45.34	42.72	5.24	311.1
B156	-60.0	46.30	52.35	10	Fixed Time	100.0	1600.0	Good	0.8	35.7	30.92	40.10	45.34	42.72	5.24	311.1
B156	-60.0	51.30	60.51	11	Fixed Time	100.0	1600.0	Good	0.8	37.2	32.22	44.43	52.40	48.42	7.98	323.9
B156	-60.0	51.30	60.51	11	Fixed Time	100.0	1600.0	Good	0.8	37.2	32.22	44.43	52.40	48.42	7.98	323.9
B156	-60.0	51.30	60.51	11	Fixed Time	100.0	1600.0	Good	0.8	37.2	32.22	44.43	52.40	48.42	7.98	323.9
B156	-60.0	51.30	60.51	11	Fixed Time	100.0	1600.0	Good	0.8	37.2	32.22	44.43	52.40	48.42	7.98	323.9
B156	-60.0	51.30	60.51	11	Fixed Time	100.0	1600.0	Good	0.8	37.2	32.22	44.43	52.40	48.42	7.98	323.9
B156	-60.0	38.40	42.40	8	Fixed Volume	100.0	1400.0	Good	0.8	1.1	0.95	33.26	36.72	34.99	3.46	17.2
B156	-60.0	35.40	42.40	7	Fixed Volume	100.0	1400.0	Good	0.8	1.1	0.95	30.66	36.72	33.69	6.06	17.2
B177	-58.0	36.00	45.00	1	Fixed Time	100.0	2000.0	Good	1.2	7.5	6.36	30.53	38.16	34.35	7.63	74.2
B177	-58.0	36.00	45.00	1	Fixed Time	100.0	2000.0	Good	1.2	7.5	6.36	30.53	38.16	34.35	7.63	74.2
B177	-58.0	36.00	45.00	1	Fixed Time	100.0	2000.0	Good	1.2	7.5	6.36	30.53	38.16	34.35	7.63	74.2
B177	-58.0	36.00	45.00	1	Fixed Time	100.0	2000.0	Good	1.2	7.5	6.36	30.53	38.16	34.35	7.63	74.2
B177	-58.0	36.00	45.00	1	Fixed Time	100.0	2000.0	Good	1.2	7.5	6.36	30.53	38.16	34.35	7.63	74.2
B177	-58.0	39.00	45.00	2	Fixed Time	100.0	2000.0	Good	1.2	7.5	6.36	33.07	38.16	35.62	5.09	74.2
B177	-58.0	39.00	45.00	2	Fixed Time	100.0	2000.0	Good	1.2	7.5	6.36	33.07	38.16	35.62	5.09	74.2
B177	-58.0	39.00	45.00	2	Fixed Time	100.0	2000.0	Good	1.2	7.5	6.36	33.07	38.16	35.62	5.09	74.2
B177	-58.0	39.00	45.00	2	Fixed Time	100.0	2000.0	Good	1.2	7.5	6.36	33.07	38.16	35.62	5.09	74.2
B177	-58.0	39.00	45.00	2	Fixed Time	100.0	2000.0	Good	1.2	7.5	6.36	33.07	38.16	35.62	5.09	74.2
B177	-58.0	44.00	50.00	3	Fixed Time	100.0	2000.0	Good	1.2	7.5	6.36	37.31	42.40	39.86	5.09	74.2
B177	-58.0	47.00	50.00	4	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	39.86	42.40	41.13	2.54	259.7
B177	-58.0	47.00	50.00	4	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	39.86	42.40	41.13	2.54	259.7
B177	-58.0	47.00	50.00	4	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	39.86	42.40	41.13	2.54	259.7
B177	-58.0	47.00	50.00	4	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	39.86	42.40	41.13	2.54	259.7
B177	-58.0	47.00	50.00	4	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	39.86	42.40	41.13	2.54	259.7
B177	-58.0	49.00	55.00	5	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	41.55	46.64	44.10	5.09	259.7
B177	-58.0	49.00	55.00	5	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	41.55	46.64	44.10	5.09	259.7
B177	-58.0	49.00	55.00	5	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	41.55	46.64	44.10	5.09	259.7
B177	-58.0	49.00	55.00	5	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	41.55	46.64	44.10	5.09	259.7
B177	-58.0	49.00	55.00	5	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	41.55	46.64	44.10	5.09	259.7
B177	-58.0	54.00	60.00	6	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	45.79	50.88	48.34	5.09	259.7
B177	-58.0	54.00	60.00	6	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	45.79	50.88	48.34	5.09	259.7
B177	-58.0	54.00	60.00	6	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	45.79	50.88	48.34	5.09	259.7
B177	-58.0	54.00	60.00	6	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	45.79	50.88	48.34	5.09	259.7
B177	-58.0	54.00	60.00	6	Fixed Time	100.0	2000.0	Good	1.2	29.8	25.27	45.79	50.88	48.34	5.09	259.7
B177	-58.0	57.00	60.00	7	Fixed Time	100.0	2000.0	Good	1.2	29.5	25.02	48.34	50.88	49.61	2.54	257.2
B177	-58.0	57.00	60.00	7	Fixed Time	100.0	2000.0	Good	1.2	29.5	25.02	48.34	50.88	49.61	2.54	257.2
B177	-58.0	57.00	60.00	7	Fixed Time	100.0	2000.0	Good	1.2	29.5	25.02	48.34	50.88	49.61	2.54	257.2
B177	-58.0	57.00	60.00	7	Fixed Time	100.0	2000.0	Good	1.2	29.5	25.02	48.34	50.88	49.61	2.54	257.2
B177	-58.0	57.00	60.00	7	Fixed Time	100.0	2000.0	Good	1.2	29.5	25.02	48.34	50.88	49.61	2.54	257.2
B177	-58.0	59.00	68.00	8	Fixed Time	100.0	2000.0	Good	1.2	29.5	25.02	50.03	57.67	53.85	7.63	257.2
B177	-58.0	59.00	68.00	8	Fixed Time	100.0	2000.0	Good	1.2	29.5	25.02	50.03	57.67	53.85	7.63	257.2
B177	-58.0	59.00	68.00	8	Fixed Time	100.0	2000.0	Good	1.2	29.5	25.02	50.03	57.67	53.85	7.63	257.2
B177	-58.0	59.00	68.00	8	Fixed Time	100.0	2000.0	Good	1.2	29.5	25.02	50.03	57.67	53.85	7.63	257.2
B177	-58.0	59.00	68.00	8	Fixed Time	100.0	2000.0	Good	1.2	29.5	25.02	50.03	57.67	53.85	7.63	257.2
B177	-58.0	67.00	74.00	9	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	56.82	62.76	59.79	5.94	267.2
B177	-58.0	67.00	74.00	9	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	56.82	62.76	59.79	5.94	267.2
B177	-58.0	67.00	74.00	9	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	56.82	62.76	59.79	5.94	267.2
B177	-58.0	67.00	74.00	9	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	56.82	62.76	59.79	5.94	267.2
B177	-58.0	67.00	74.00	9	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	56.82	62.76	59.79	5.94	267.2
B177	-58.0	73.00	82.00	10	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	61.91	69.54	65.72	7.63	267.2
B177	-58.0	73.00	82.00	10	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	61.91	69.54	65.72	7.63	267.2
B177	-58.0	73.00	82.00	10	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	61.91	69.54	65.72	7.63	267.2
B177	-58.0	73.00	82.00	10	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	61.91	69.54	65.72	7.63	267.2
B177	-58.0	73.00	82.00	10	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	61.91	69.54	65.72	7.63	267.2
B177	-58.0	81.00	93.00	11	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	68.69	78.87	73.78	10.18	267.2
B177	-58.0	81.00	93.00	11	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	68.69	78.87	73.78	10.18	267.2
B177	-58.0	81.00	93.00	11	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	68.69	78.87	73.78	10.18	267.2
B177	-58.0	81.00	93.00	11	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	68.69	78.87	73.78	10.18	267.2
B177	-58.0	81.00	93.00	11	Fixed Time	100.0	2100.0	Good	1.2	30.7	26.04	68.69	78.87	73.78	10.18	267.2
B365	-90.0	20.50	26.52	1	Fixed Time	100.0	2000.0	Good	0.7	10.0	10.00	20.50	26.52	23.51	6.02	105.3
B365	-90.0	20.50	26.52	1	Fixed Time	100.0	2000.0	Good	0.7	10.0	10.00	20.50	26.52	23.51	6.02	105.3
B365	-90.0	20.50	26.52	1	Fixed Time	100.0	2000.0	Good	0.7	10.0	10.00	20.50	26.52	23.51	6.02	105.3
B365	-90.0	20.50	26.52	1	Fixed Time	100.0	2000.0	Good	0.7	10.0	10.00	20.50	26.52	23.51	6.02	105.3
B365	-90.0	20.50	26.52	1	Fixed Time	100.0	2000.0	Good	0.7	10.0	10.00	20.50	26.52	23.51	6.02	105.3
B365	-90.0	25.50	34.50	2	Fixed Time	100.0	1700.0	Good	0.7	10.0	10.00	25.50	34.50	30.00	9.00	105.0
B365	-90.0	25.50	34.50	2	Fixed Time	100.0	1700.0	Good	0.7	10.0	10.00	25.50	34.50	30.00	9.00	105.0
B365	-90.0	25.50	34.50	2	Fixed Time	100.0	1700.0	Good	0.7	10.0	10.00	25.50	34.50	30.00	9.00	105.0
B365	-90.0	25.50	34.50	2	Fixed Time	100.0	1700.0	Good	0.7	10.0	10.00	25.50	34.50	30.00	9.00	105.0

Reading Number	Test Pressure	Flow Meter Reading Start	Flow Meter Reading 5 min	Flow Meter Reading 10 min	Flow Meter Reading 15 min	Volume 0-5 min	Volume 5-10 min	Volume 10-15 min	Elapsed Time 1	Elapsed Time 2	Elapsed Time 3	Effective Head	Volume Loss	Flow Rate	Flow Rate Per Metre	Average Lugeon Value	Flow Type
	(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)	
3	400.0	817.5	819.7	821.8	823.8	2.2	2.1	2				638.4	2.10	0.42	0.05	0.1	other - see comments
4	270.0	824	824.9	825.9	826.7	0.9	1	0.8				508.4	0.90	0.18	0.02	0.0	other - see comments
5	135.0	826.4	826.5	826.6	826.7	0.1	0.1	0.1				373.4	0.10	0.02	0.00	0.0	other - see comments
1	135.0	833.1	833.5	834	834.4	0.4	0.5	0.4				373.4	0.43	0.09	0.01	0.0	other - see comments
2	270.0	834.9	835.9	836.9	837.9	1	1	1				508.4	1.00	0.20	0.02	0.0	other - see comments
3	400.0	837.6	841.2	844.8	848.4	3.6	3.6	3.6				638.4	3.60	0.72	0.08	0.1	other - see comments
4	270.0	844.3	845.3	846.1	847	1	0.8	0.9				508.4	0.90	0.18	0.02	0.0	other - see comments
5	135.0	845.7	846	846.3	846.7	0.3	0.3	0.4				373.4	0.33	0.07	0.01	0.0	other - see comments
1	135.0	864.4	864.5	864.51	864.52	0.1	0.01	0.01				366.5	0.04	0.01	0.00	0.0	other - see comments
2	270.0	939.1	940.2	941.3	942.3	1.1	1.1	1				501.5	1.07	0.21	0.02	0.0	other - see comments
3	400.0	943	944.8	946.5	948.2	1.8	1.7	1.7				631.5	1.73	0.35	0.04	0.1	other - see comments
4	270.0	949.2	949.8	950.2	950.6	0.6	0.4	0.4				501.5	0.47	0.09	0.01	0.0	other - see comments
5	135.0	950.3	950.31	950.32	950.33	0.01	0.01	0.01				366.5	0.01	0.00	0.00	0.0	other - see comments
1	135.0	959.8	961.9	963.8	965.6	2.1	1.9	1.8				384.2	1.93	0.39	0.04	0.1	other - see comments
2	270.0	967.2	970.6	973.7	977.5	3.4	3.1	3.8				519.2	3.43	0.69	0.08	0.1	other - see comments
3	400.0	212.1	217.8	223.5	228.7	5.7	5.7	5.2				649.2	5.53	1.11	0.12	0.2	other - see comments
4	270.0	228.5	229.9	231.5	233.3	1.4	1.6	1.8				519.2	1.60	0.32	0.04	0.1	other - see comments
5	135.0	232.9	234.1	235.3	236.4	1.2	1.2	1.1				384.2	1.17	0.23	0.03	0.1	other - see comments
1	135.0	240.9	241.7	241.8	242.2	0.8	0.1	0.4				384.2	0.43	0.09	0.01	0.0	other - see comments
2	270.0	242.9	244.8	246.4	248.2	1.9	1.6	1.8				519.2	1.77	0.35	0.05	0.1	other - see comments
3	400.0	248.6	252.8	257	261.4	4.2	4.2	4.4				649.2	4.27	0.85	0.12	0.2	other - see comments
4	270.0	261.2	262.4	263.6	264.8	1.2	1.2	1.2				519.2	1.20	0.24	0.03	0.1	other - see comments
5	135.0	264.7	265.3	265.8	266.3	0.6	0.5	0.5				384.2	0.53	0.11	0.02	0.0	other - see comments
1	20.0	226.7	226.7	226.7	226.7	0	0	0				37.2	0.00	0.00	0.00	0.0	other - see comments
2	25.0	226.7	226.7	226.7	226.7	0	0	0				42.2	0.00	0.00	0.00	0.0	other - see comments
3	40.0	227.1	227.1	227.1	227.1	0	0	0				57.2	0.00	0.00	0.00	0.0	other - see comments
4	25.0	227.2	227.2	227.2	227.2	0	0	0				42.2	0.00	0.00	0.00	0.0	other - see comments
1	25.0	235.4	235.4	235.4	235.4	0	0	0				42.2	0.00	0.00	0.00	0.0	other - see comments
2	50.0	238.1	239.1	239.6	239.9	1	0.5	0.3				67.2	0.60	0.12	0.02	0.3	other - see comments
3	80.0	239.6	240.2	240.2	240.2	0.6	0	0				97.2	0.20	0.04	0.01	0.1	other - see comments
4	50.0	240.2	240.2	240.2	240.2	0	0	0				67.2	0.00	0.00	0.00	0.0	other - see comments
5	25.0	240.2	240.2	240.2	240.2	0	0	0				42.2	0.00	0.00	0.00	0.0	other - see comments
1	35.0	248.4	248.4	248.4	248.4	0	0	0				55.4	0.00	0.00	0.00	0.0	other - see comments
2	75.0	248.4	248.4	248.4	248.4	0	0	0				95.4	0.00	0.00	0.00	0.0	other - see comments
3	110.0	248.5	248.5	248.5	248.5	0	0	0				130.4	0.00	0.00	0.00	0.0	other - see comments
4	75.0	248.5	248.5	248.5	248.5	0	0	0				95.4	0.00	0.00	0.00	0.0	other - see comments
5	35.0	248.5	248.5	248.5	248.5	0	0	0				55.4	0.00	0.00	0.00	0.0	other - see comments
1	50.0	303.9	304.1	304.8	304.8	0.2	0.7	0				70.4	0.30	0.06	0.01	0.2	dilation
2	95.0	369.8	371.9	375.5	378.8	2.1	3.6	3.3				115.4	3.00	0.60	0.12	1.0	dilation
3	145.0	445	470.4	490.8	509.9	25.4	20.4	19.1				165.4	21.63	4.33	0.83	5.0	dilation
4	95.0	534.8	534.8	534.85	534.95	0	0.05	0.1				115.4	0.05	0.01	0.00	0.0	dilation
5	50.0	535.1	535.1	535.1	535.1	0	0	0				70.4	0.00	0.00	0.00	0.0	dilation
1	65.0	536.6	536.6	536.6	536.6	0	0	0				82.2	0.00	0.00	0.00	0.0	
2	125.0	536.75	536.8	536.8	536.8	0.05	0	0				142.2	0.02	0.00	0.00	0.0	
3	190.0	536.8	536.8	536.8	536.8	0	0	0				207.2	0.00	0.00	0.00	0.0	
4	125.0	539.8	539.8	539.8	539.8	0	0	0				142.2	0.00	0.00	0.00	0.0	
5	65.0	539.8	539.8	539.8	539.8	0	0	0				82.2	0.00	0.00	0.00	0.0	
1	65.0	536.6	536.6	536.6	536.6	0	0	0				82.2	0.00	0.00	0.00	0.0	other - see comments
2	125.0	536.75	536.8	536.8	536.8	0.05	0	0				142.2	0.02	0.00	0.00	0.0	other - see comments
3	190.0	536.8	536.8	536.8	536.8	0	0	0				207.2	0.00	0.00	0.00	0.0	other - see comments
4	125.0	539.8	539.8	539.8	539.8	0	0	0				142.2	0.00	0.00	0.00	0.0	other - see comments
5	65.0	539.8	539.8	539.8	539.8	0	0	0				82.2	0.00	0.00	0.00	0.0	other - see comments
1	105.0	446.1	446.1	446.1	446.1	0	0	0				416.1	0.00	0.00	0.00	0.0	other - see comments
2	210.0	447	449.1	449.1	449.1	2.1	0	0				521.1	0.70	0.14	0.03	0.1	other - see comments
3	315.0	467.7	467.85	467.9	467.95	0.15	0.05	0.05				626.1	0.08	0.02	0.00	0.0	other - see comments
4	210.0	467.95	467.95	467.95	467.95	0	0	0				521.1	0.00	0.00	0.00	0.0	other - see comments
5	105.0	467.95	467.95	467.95	467.95	0	0	0				416.1	0.00	0.00	0.00	0.0	other - see comments
1	120.0	566.8	570.2	570.2	570.2	3.4	0	0				431.1	1.13	0.23	0.04	0.1	other - see comments
2	235.0	598.75	598.75	598.75	598.75	0	0	0				546.1	0.00	0.00	0.00	0.0	other - see comments
3	355.0	616.6	617.55	617.55	617.55	0.95	0	0				666.1	0.32	0.06	0.01	0.0	other - see comments
4	235.0	617.55	617.55	617.55	617.55	0	0	0				546.1	0.00	0.00	0.00	0.0	other - see comments
5	355.0	617.6	617.6	617.6	617.6	0	0	0				666.1	0.00	0.00	0.00	0.0	other - see comments
1	130.0	725.1	725.1	725.1	725.1	0	0	0				453.9	0.00	0.00	0.00	0.0	other - see comments
2	280.0	761	767	769.1	771.3	6	2.1	2.2				603.9	3.43	0.69	0.09	0.1	other - see comments
3	390.0	785.3	787.1	787.6	787.6	1.8	0.5	0				713.9	0.77	0.15	0.02	0.0	other - see comments
4	260.0	787.6	787.6	787.6	787.6	0	0	0				583.9	0.00	0.00	0.00	0.0	other - see comments
5	130.0	787.6	787.6	787.6	787.6	0	0	0				453.9	0.00	0.00	0.00	0.0	other - see comments
1	110.0								1:19	1:20	1:20	127.2	900.0	73.77	21.30	167.4	other - see comments
1	180.0								1:32	1:32	1:32	197.2	900.0	86.13	14.21	72.0	other - see comments
1	105.0	43	76.1	108.6	140.7	33.1	32.5	32.1				179.2	32.57	6.51	0.85	4.8	wash-out
2	210.0	174.6	224.6	275.1	325.5	50	50.5	50.4				284.2	50.30	10.06	1.32	4.6	wash-out
3	315.0	383	469.4	554.5	639.4	86.4	85.1	84.9				389.2	85.47	17.09	2.24	5.8	wash-out
4	210.0	664	737.3	810.2	882.4	73.3	72.9	72.2				284.2	72.80	14.56	1.91	6.7	wash-out
5	105.0	893	952.7	1012.4	1071.8	59.7	59.7	59.4				179.2	59.60	11.92	1.56	8.7	wash-out
1	115.0	267	321.4	375.9	430.1	54.4	54.5	54.2				189.2	54.37	10.87	2.14	11.3	turbulent flow
2	230.0	468	538.3	608.6	679	70.3	70.3	70.4				304.2	70.33	14.07	2.76	9.1	turbulent flow
3	335.0	752	838	923.1	1007.5	86	85.1	84.4				409.2	85.17	17.03	3.35	8.2	turbulent flow
4	230.0	1022	1097.5	1172.5	1247.5	75.5	75	75				304.2	75.17	15.03	2.95	9.7	turbulent flow
5	115.0	1258	1316	1373.4	1431.4	58	57.4	58				189.2	57.80	11.56	2.27	12.0	turbulent flow
1	80.0	862	902			40						154.2	40.00	8.00	1.57	10.2	other - see comments
1	130.0	555.3	705.7	860.4	1013.8	150.4	154.7	153.4				389.7	152.83	30.57	12.01	30.8	wash-out
2	240.0	1175.9	1383.3	1592.2	1803.8	207.4	208.9	211.6				499.7	209.30	41.86	16.45	32.9	wash-out
3	360.0	2191.2	2479.2	2770.1	3058.9	288	290.9	288.8				619.7	289.23	57.85	22.74	36.7	wash-out
4	240.0	3162.2	3414.3	3661.4	3910.6	252.1	247.1	249.2				499.7	249.47	49.89	19.61	39.2	wash-out
5	130.0	4276.3	4476.2	4675.3	4875.3	199.9	199.1	200				389.7	199.67	39.93	15.70	40.3	wash-out
1	135.0	66031.5	66040.6	66049.1	66057.2	9.1	8.5	8.1				394.7	8.57	1.71	0.34	0.9	laminar flow
2	270.0	66059.7	66072.4	66084.5	66096.7	12.7	12.1	12.2				529.7	12.33	2.47	0.48	0.9	laminar flow
3	400.0	66100.5	66117.3	66134.1	66150.5	16.8	16.8	16.4				659.7	16.67	3.33	0.66	1.0	laminar flow
4	270.0	66152.9	66165.5	66176.9	66188.5	12.6	11.4	11.6				529.7	11.87	2.37	0.47	0.9	laminar flow
5	135.0	66189.9	66198.2	66206.8	66215	8.3	8.6	8.2				394.7	8.37	1.67	0.33	0.8	laminar flow
1	135.0	66360.2	66373.5	66385.9	66398.6	13.3	12.4	12.7				394.7	12.80	2.56	0.50	1.3	laminar flow
2	270.0	66401.1	66423.8	66445.7	66466.8	22.7	21.9	21.1				529.7	21.90	4.38	0.86	1.6	laminar flow
3	400.0	66467.8	66496.8	66525	66552	29	28.2	27				659.7	28.07	5.61	1.10	1.7	laminar flow
4	270.0	66559.5	66578.6	66597.2	66615.9	19.1	18.6	18.7				529.7	18.80	3.76	0.74	1.4	laminar flow
5	135.0	66617.4	66629.8	66641.5	66653.1	12.4	11.7	11.6				394.7	11.90	2.38	0.47	1.2	laminar flow
1	135.0	67811.6	67814.4	67817.2	67819.9	2.8	2.8	2.7				392.2	2.77	0.55	0.22	0.6	dilation
2	270.0	67822.1	67827.2	67832.4	67837.5	5.1	5.2	5.1				527.2	5.13	1.03	0.40	0.8	dilation
3	400.0	67839	67847.2	67855.5	67863.8	8.2	8.3	8.3				657.2	8.27	1.65	0.65	1.0	dilation
4	270.0	67864.3	67869.8	67875.2	67880.5	5.5	5.4	5.3				527.2	5.40	1.08	0.42	0.8	dilation
5	135.0	67880.5	67881.5	67882.7	67884.2	1	1.2	1.5				392.2	1.23	0.25	0.10	0.2	dilation
1	135.0	67901.4	67904.5	67907.4	67910.2	3.1	2.9	2.8				392.2	2.93	0.59	0.08	0.2	laminar flow
2	270.0	67911.5	67920.6	67929.5	67938.5	9.1	8.9	9				527.2	9.00	1.80	0.24	0.4	laminar flow
3	400.0	67945	67954	67963	67972	9	9	9				657.2	9.00	1.80	0.24	0.4	laminar flow
4	270.0	67976.7	67986.2	67995.9	68005.3	9.5	9.7	9.4				527.2	9.53	1.91	0.25	0.5	laminar flow
5	135.0	68006.4	68011.3	68016.2	68021.1	4.9	4.9	4.9				392.2	4.90	0.98	0.13	0.3	laminar flow
1	135.0	67169.2	67169.2	67169.2	67169.2	0	0	0				402.2	0.00	0.00	0.00	0.0	other - see comments
2	270.0	67169.5	67169.7	67169.7	67169.7	0.2	0	0				537.2	0.07	0.01	0.00	0.0	other - see comments
3	400.0	67170.2	67172.4	67174.6	67176.6	2.2	2.2	2				667.2	2.13	0.43	0.07	0.1	other - see comments
4	270.0	67176.4	67176.4	67176.4	67176.4	0	0	0				537.2	0.00	0.00	0.00	0.0	other - see comments
5	135.0	67176.1	67176.1	67176.1	67176.1	0	0	0				402.2	0.00	0.00	0.00	0.0	other - see comments
1	135.0	67324.9	67324.9	67324.9	67324.9	0	0	0				402.2	0.00	0.00	0.00	0.0	other - see comments
2	270.0	67325.6	67325.7	67325.7	67325.7	0.1	0	0				537.2	0.03	0.01	0.00	0.0	other - see comments
3	400.0	67326.9	67328.3	67329.5	67330.6	1.4	1.2	1.1				667.2	1.23	0.25	0.03	0.0	other - see comments
4	270.0	67330.4	67330.4	67330.4	67330.4	0	0	0				537.2	0.00	0.00	0.00	0.0	other - see comments
5	135.0	67330.1	67330.1	67330.1	67330.1	0	0	0				402.2	0.00	0.00	0.00	0.0	other - see comments
1	135.0	67473.2	67476.7	67479.9	67483	3.5	3.2	3.1				402.2	3.27	0.65	0.06	0.2	laminar flow
2	270.0	67488.7	67494.2	67499.3	67504.1	5.5	5.1	4.8				537.2	5.13	1.03	0.10	0.2	laminar flow
3	400.0	67512	67518.9	67525.4	67531.8	6.9	6.5	6.4				667.2	6.60	1.32	0.13	0.2	laminar flow
4	270.0	67529.5	67533.3	67537.3	67541.3	3.8	4	4				537.2	3.93	0.79	0.08	0.1	laminar flow
5	135.0	67536.5	67539.1	67541.8	67544.2	2.6	2.7	2.4				402.2	2.57	0.51	0.05	0.1	laminar flow
1	60.0	505.7	514.5	527	539.5	8.8	12.5	12.5				165.3	11.27	2.25	0.37	2.3	dilation
2	115.0	699	733.2	778.9	813.6	34.2	45.7	34.7				220.3	38.20	7.64	1.27	5.8	dilation
3	175.0	894	996.9	1054.2	1111.8	102.9	57.3	57.6				280.3	72.60	14.52	2.41	8.6	dilation
4	115.0	1113.6	1129	1167.1	1202.2	15.4	38.1	35.1				220.3	29.53	5.91	0.98	4.5	dilation
5	60.0	1214.3	1229.9	1247.2	1280.4	15.6	17.3	33.2				165.3	22.03	4.41	0.73	4.4	dilation
1	75.0	308.8	308.8	308.8	308.8	0	0	0				180.0	0.00	0.00	0.00	0.0	other - see comments
2	145.0	309.3	311	313	316	1.7	2	3				250.0	2.23	0.45	0.05	0.2	other - see comments
3	220.0	316.6	318	318	319	1.4	0	1				325.0	0.80	0.16	0.02	0.1	other - see comments
4	145.0	310	310	311	311	0	1	0				250.0	0.33	0.07	0.01	0.0	other - see comments

Interpreted Lugeon Value (Houlsby) (uL)	Remark
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
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<1	Flow rate too low to define flow type.
<1	None.
1.00	None.
5.03	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type.
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<1	Flow rate too low to define flow type.
N/A	Test changed to non-standard method as could not hold pressure beyond 110 kPa - due to very high water take.
N/A	Test changed to non-standard method as could not hold pressure beyond 180 kPa - due to very high water take.
4.76	None.
4.64	None.
5.75	None.
6.71	None.
8.72	None.
11.30	None.
9.09	None.
8.18	None.
9.71	None.
12.01	None.
10.20	Test terminated due to high loss of water (>100L/min at 170 kPa).
30.83	None.
32.93	None.
36.69	None.
39.25	None.
40.28	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
1.27	None.
1.63	None.
1.67	None.
1.40	None.
1.19	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
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<1	Flow rate too low to define flow type.
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<1	Flow rate too low to define flow type.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
2.26	None.
5.76	None.
8.61	None.
4.45	None.
4.43	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.

Borehole	Inclination	Length to Top	Length to Bottom	Test Number	Reading Method	Fixed Volume	Packer Inflation Pressure	Packer Seal Condition	Pressure Gauge Height	Initial Groundwater Length	Initial Groundwater Depth	Depth to Top	Depth to Bottom	Depth to Centre	Section Length	Correction Gauge Pressure
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)
B365	-90.0	25.50	34.50	2	Fixed Time	100.0	1700.0	Good	0.7	10.0	10.00	25.50	34.50	30.00	9.00	105.0
B365	-90.0	33.60	42.60	3	Fixed Time	100.0	1800.0	Good	0.7	10.5	10.48	33.60	42.60	38.10	9.00	110.0
B365	-90.0	33.60	42.60	3	Fixed Time	100.0	1800.0	Good	0.7	10.5	10.48	33.60	42.60	38.10	9.00	110.0
B365	-90.0	33.60	42.60	3	Fixed Time	100.0	1800.0	Good	0.7	10.5	10.48	33.60	42.60	38.10	9.00	110.0
B365	-90.0	33.60	42.60	3	Fixed Time	100.0	1800.0	Good	0.7	10.5	10.48	33.60	42.60	38.10	9.00	110.0
B365	-90.0	33.60	42.60	3	Fixed Time	100.0	1800.0	Good	0.7	10.5	10.48	33.60	42.60	38.10	9.00	110.0
B365	-90.0	41.56	48.16	4	Fixed Time	100.0	2000.0	Good	0.7	10.5	10.48	41.56	48.16	44.86	6.60	110.0
B365	-90.0	41.56	48.16	4	Fixed Time	100.0	2000.0	Good	0.7	10.5	10.48	41.56	48.16	44.86	6.60	110.0
B365	-90.0	41.56	48.16	4	Fixed Time	100.0	2000.0	Good	0.7	10.5	10.48	41.56	48.16	44.86	6.60	110.0
B365	-90.0	41.56	48.16	4	Fixed Time	100.0	2000.0	Good	0.7	10.5	10.48	41.56	48.16	44.86	6.60	110.0
B365	-90.0	41.56	48.16	4	Fixed Time	100.0	2000.0	Good	0.7	10.5	10.48	41.56	48.16	44.86	6.60	110.0
B365	-90.0	47.16	52.91	5	Fixed Time	100.0	2000.0	Good	0.7	10.4	10.35	47.16	52.91	50.04	5.75	108.7
B365	-90.0	47.16	52.91	5	Fixed Time	100.0	2000.0	Good	0.7	10.4	10.35	47.16	52.91	50.04	5.75	108.7
B365	-90.0	47.16	52.91	5	Fixed Time	100.0	2000.0	Good	0.7	10.4	10.35	47.16	52.91	50.04	5.75	108.7
B365	-90.0	47.16	52.91	5	Fixed Time	100.0	2000.0	Good	0.7	10.4	10.35	47.16	52.91	50.04	5.75	108.7
B365	-90.0	47.16	52.91	5	Fixed Time	100.0	2000.0	Good	0.7	10.4	10.35	47.16	52.91	50.04	5.75	108.7
B365	-90.0	52.33	56.33	6	Fixed Time	100.0	2000.0	Good	0.7	10.4	10.35	52.33	56.33	54.33	4.00	108.7
B365	-90.0	52.33	56.33	6	Fixed Time	100.0	2000.0	Good	0.7	10.4	10.35	52.33	56.33	54.33	4.00	108.7
B365	-90.0	52.33	56.33	6	Fixed Time	100.0	2000.0	Good	0.7	10.4	10.35	52.33	56.33	54.33	4.00	108.7
B365	-90.0	52.33	56.33	6	Fixed Time	100.0	2000.0	Good	0.7	10.4	10.35	52.33	56.33	54.33	4.00	108.7
B365	-90.0	52.33	56.33	6	Fixed Time	100.0	2000.0	Good	0.7	10.4	10.35	52.33	56.33	54.33	4.00	108.7
B126	-61.0	8.20	14.11	1	Fixed Time	100.0	1500.0	Good	0.8	3.2	2.82	7.17	12.34	9.76	5.17	35.5
B126	-61.0	8.20	14.11	1	Fixed Time	100.0	1500.0	Good	0.8	3.2	2.82	7.17	12.34	9.76	5.17	35.5
B126	-61.0	8.20	14.11	1	Fixed Time	100.0	1500.0	Good	0.8	3.2	2.82	7.17	12.34	9.76	5.17	35.5
B126	-61.0	8.20	14.11	1	Fixed Time	100.0	1500.0	Good	0.8	3.2	2.82	7.17	12.34	9.76	5.17	35.5
B126	-61.0	8.20	14.11	1	Fixed Time	100.0	1500.0	Good	0.8	3.2	2.82	7.17	12.34	9.76	5.17	35.5
B126	-61.0	13.20	22.06	2	Fixed Time	100.0	1500.0	Good	0.8	3.2	2.82	11.54	19.29	15.42	7.75	35.5
B126	-61.0	13.20	22.06	2	Fixed Time	100.0	1500.0	Good	0.8	3.2	2.82	11.54	19.29	15.42	7.75	35.5
B126	-61.0	13.20	22.06	2	Fixed Time	100.0	1500.0	Good	0.8	3.2	2.82	11.54	19.29	15.42	7.75	35.5
B126	-61.0	13.20	22.06	2	Fixed Time	100.0	1500.0	Good	0.8	3.2	2.82	11.54	19.29	15.42	7.75	35.5
B126	-61.0	13.20	22.06	2	Fixed Time	100.0	1500.0	Good	0.8	3.2	2.82	11.54	19.29	15.42	7.75	35.5
B126	-61.0	21.20	27.14	3	Fixed Time	100.0	1500.0	Good	0.8	5.1	4.46	18.54	23.74	21.14	5.20	51.6
B126	-61.0	21.20	27.14	3	Fixed Time	100.0	1500.0	Good	0.8	5.1	4.46	18.54	23.74	21.14	5.20	51.6
B126	-61.0	21.20	27.14	3	Fixed Time	100.0	1500.0	Good	0.8	5.1	4.46	18.54	23.74	21.14	5.20	51.6
B126	-61.0	21.20	27.14	3	Fixed Time	100.0	1500.0	Good	0.8	5.1	4.46	18.54	23.74	21.14	5.20	51.6
B126	-61.0	21.20	27.14	3	Fixed Time	100.0	1500.0	Good	0.8	5.1	4.46	18.54	23.74	21.14	5.20	51.6
B126	-61.0	26.20	38.11	4	Fixed Time	100.0	1500.0	Good	0.8	5.1	4.46	22.92	33.33	28.12	10.42	51.6
B126	-61.0	26.20	38.11	4	Fixed Time	100.0	1500.0	Good	0.8	5.1	4.46	22.92	33.33	28.12	10.42	51.6
B126	-61.0	26.20	38.11	4	Fixed Time	100.0	1500.0	Good	0.8	5.1	4.46	22.92	33.33	28.12	10.42	51.6
B126	-61.0	26.20	38.11	4	Fixed Time	100.0	1500.0	Good	0.8	5.1	4.46	22.92	33.33	28.12	10.42	51.6
B126	-61.0	26.20	38.11	4	Fixed Time	100.0	1500.0	Good	0.8	5.1	4.46	22.92	33.33	28.12	10.42	51.6
B126	-61.0	37.20	49.12	5	Fixed Time	100.0	1500.0	Good	0.8	12.0	10.45	32.54	42.96	37.75	10.43	110.4
B126	-61.0	37.20	49.12	5	Fixed Time	100.0	1500.0	Good	0.8	12.0	10.45	32.54	42.96	37.75	10.43	110.4
B126	-61.0	37.20	49.12	5	Fixed Time	100.0	1500.0	Good	0.8	12.0	10.45	32.54	42.96	37.75	10.43	110.4
B126	-61.0	37.20	49.12	5	Fixed Time	100.0	1500.0	Good	0.8	12.0	10.45	32.54	42.96	37.75	10.43	110.4
B126	-61.0	37.20	49.12	5	Fixed Time	100.0	1500.0	Good	0.8	12.0	10.45	32.54	42.96	37.75	10.43	110.4
B126	-61.0	48.15	60.12	6	Fixed Time	100.0	1500.0	Good	0.8	13.1	11.41	42.11	52.58	47.35	10.47	119.8
B126	-61.0	48.15	60.12	6	Fixed Time	100.0	1500.0	Good	0.8	13.1	11.41	42.11	52.58	47.35	10.47	119.8
B126	-61.0	48.15	60.12	6	Fixed Time	100.0	1500.0	Good	0.8	13.1	11.41	42.11	52.58	47.35	10.47	119.8
B126	-61.0	48.15	60.12	6	Fixed Time	100.0	1500.0	Good	0.8	13.1	11.41	42.11	52.58	47.35	10.47	119.8
B126	-61.0	48.15	60.12	6	Fixed Time	100.0	1500.0	Good	0.8	13.1	11.41	42.11	52.58	47.35	10.47	119.8
B126	-61.0	59.20	65.10	7	Fixed Time	100.0	1500.0	Good	0.8	17.7	15.50	51.78	56.94	54.36	5.16	159.9
B126	-61.0	59.20	65.10	7	Fixed Time	100.0	1500.0	Good	0.8	17.7	15.50	51.78	56.94	54.36	5.16	159.9
B126	-61.0	59.20	65.10	7	Fixed Time	100.0	1500.0	Good	0.8	17.7	15.50	51.78	56.94	54.36	5.16	159.9
B126	-61.0	59.20	65.10	7	Fixed Time	100.0	1500.0	Good	0.8	17.7	15.50	51.78	56.94	54.36	5.16	159.9
B126	-61.0	59.20	65.10	7	Fixed Time	100.0	1500.0	Good	0.8	17.7	15.50	51.78	56.94	54.36	5.16	159.9
B126	-61.0	64.15	73.16	8	Fixed Time	100.0	1500.0	Good	0.8	17.7	15.50	56.11	63.99	60.05	7.88	159.9
B126	-61.0	64.15	73.16	8	Fixed Time	100.0	1500.0	Good	0.8	17.7	15.50	56.11	63.99	60.05	7.88	159.9
B126	-61.0	64.15	73.16	8	Fixed Time	100.0	1500.0	Good	0.8	17.7	15.50	56.11	63.99	60.05	7.88	159.9
B126	-61.0	64.15	73.16	8	Fixed Time	100.0	1500.0	Good	0.8	17.7	15.50	56.11	63.99	60.05	7.88	159.9
B126	-61.0	64.15	73.16	8	Fixed Time	100.0	1500.0	Good	0.8	17.7	15.50	56.11	63.99	60.05	7.88	159.9
B126	-61.0	71.80	79.97	9	Fixed Time	100.0	1500.0	Good	8	17.5	15.28	62.80	69.94	66.37	7.15	228.4
B126	-61.0	71.80	79.97	9	Fixed Time	100.0	1500.0	Good	8	17.5	15.28	62.80	69.94	66.37	7.15	228.4
B126	-61.0	71.80	79.97	9	Fixed Time	100.0	1500.0	Good	8	17.5	15.28	62.80	69.94	66.37	7.15	228.4
B126	-61.0	71.80	79.97	9	Fixed Time	100.0	1500.0	Good	8	17.5	15.28	62.80	69.94	66.37	7.15	228.4
B126	-61.0	71.80	79.97	9	Fixed Time	100.0	1500.0	Good	8	17.5	15.28	62.80	69.94	66.37	7.15	228.4
B149	-90.0	39.00	45.00	1	Fixed Time	100.0	2200.0	Good	0.9	3.5	3.46	39.00	45.00	42.00	6.00	42.8
B149	-90.0	39.00	45.00	1	Fixed Time	100.0	2200.0	Good	0.9	3.5	3.46	39.00	45.00	42.00	6.00	42.8
B149	-90.0	39.00	45.00	1	Fixed Time	100.0	2200.0	Good	0.9	3.5	3.46	39.00	45.00	42.00	6.00	42.8
B149	-90.0	39.00	45.00	1	Fixed Time	100.0	2200.0	Good	0.9	3.5	3.46	39.00	45.00	42.00	6.00	42.8
B149	-90.0	39.00	45.00	1	Fixed Time	100.0	2200.0	Good	0.9	3.5	3.46	39.00	45.00	42.00	6.00	42.8
B149	-90.0	44.00	50.00	2	Fixed Time	100.0	2200.0	Good	0.9	9.3	9.30	44.00	50.00	47.00	6.00	100.5
B149	-90.0	44.00	50.00	2	Fixed Time	100.0	2200.0	Good	0.9	9.3	9.30	44.00	50.00	47.00	6.00	100.5
B149	-90.0	44.00	50.00	2	Fixed Time	100.0	2200.0	Good	0.9	9.3	9.30	44.00	50.00	47.00	6.00	100.5
B149	-90.0	44.00	50.00	2	Fixed Time	100.0	2200.0	Good	0.9	9.3	9.30	44.00	50.00	47.00	6.00	100.5
B149	-90.0	44.00	50.00	2	Fixed Time	100.0	2200.0	Good	0.9	9.3	9.30	44.00	50.00	47.00	6.00	100.5
B149	-90.0	49.00	58.00	3	Fixed Time	100.0	2200.0	Good	0.9	9.3	9.30	49.00	58.00	53.50	9.00	100.1
B149	-90.0	49.00	58.00	3	Fixed Time	100.0	2200.0	Good	0.9	9.3	9.30	49.00	58.00	53.50	9.00	100.1
B149	-90.0	49.00	58.00	3	Fixed Time	100.0	2200.0	Good	0.9	9.3	9.30	49.00	58.00	53.50	9.00	100.1
B149	-90.0	49.00	58.00	3	Fixed Time	100.0	2200.0	Good	0.9	9.3	9.30	49.00	58.00	53.50	9.00	100.1
B149	-90.0	49.00	58.00	3	Fixed Time	100.0	2200.0	Good	0.9	9.3	9.30	49.00	58.00	53.50	9.00	100.1
B149	-90.0	57.00	66.00	4	Fixed Time	100.0	2200.0	Good	0.9	10.3	10.26	57.00	66.00	61.50	9.00	109.5
B149	-90.0	57.00	66.00	4	Fixed Time	100.0	2200.0	Good	0.9	10.3	10.26	57.00	66.00	61.50	9.00	109.5
B149	-90.0	57.00	66.00	4	Fixed Time	100.0	2200.0	Good	0.9	10.3	10.26	57.00	66.00	61.50	9.00	109.5
B149	-90.0	57.00	66.00	4	Fixed Time	100.0	2200.0	Good	0.9	10.3	10.26	57.00	66.00	61.50	9.00	109.5
B149	-90.0	57.00	66.00	4	Fixed Time	100.0	2200.0	Good	0.9	10.3	10.26	57.00	66.00	61.50	9.00	109.5
B149	-90.0	65.00	74.00	5	Fixed Time	100.0	2200.0	Good	0.9	10.3	10.26	65.00	74.00	69.50	9.00	109.5
B149	-90.0	65.00	74.00	5	Fixed Time	100.0	2200.0	Good	0.9	10.3	10.26	65.00	74.00	69.50	9.00	109.5
B149	-90.0	65.00	74.00	5	Fixed Time	100.0	2200.0	Good	0.9	10.3	10.26	65.00	74.00	69.50	9.00	109.5
B149	-90.0	65.00	74.00	5	Fixed Time	100.0	2200.0	Good	0.9	10.3	10.26	65.00	74.00	69.50	9.00	109.5
B149	-90.0	65.00	74.00	5	Fixed Time	100.0	2200.0	Good	0.9	10.3	10.26	65.00	74.00	69.50	9.00	109.5
B149	-90.0	73.00	79.00	6	Fixed Time	100.0	2200.0	Good	0.9	20.8	20.83	73.00	79.00	76.00	6.00	213.2
B149	-90.0	73.00	79.00	6	Fixed Time	100.0	2200.0	Good	0.9	20.8	20.83	73.00	79.00	76.00	6.00	213.2
B149	-90.0	73.00	79.00	6	Fixed Time	100.0	2200.0	Good	0.9	20.8	20.83	73.00	79.00	76.00	6.00	213.2
B149	-90.0	73.00	79.00	6	Fixed Time	100.0	2200.0	Good	0.9	20.8	20.83	73.00	79.00	76.00	6.00	213.2
B149	-90.0	73.00	79.00	6	Fixed Time	100.0	2200.0	Good	0.9	20.8	20.83	73.00	79.00	76.00	6.00	213.2

Reading Number	Test Pressure	Flow Meter Reading Start	Flow Meter Reading 5 min	Flow Meter Reading 10 min	Flow Meter Reading 15 min	Volume 0-5 min	Volume 5-10 min	Volume 10-15 min	Elapsed Time 1	Elapsed Time 2	Elapsed Time 3	Effective Head	Volume Loss	Flow Rate	Flow Rate Per Metre	Average Lugeon Value	Flow Type
	(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)	
5	75.0	321	321	321	321	0	0	0				180.0	0.00	0.00	0.00	0.0	other - see comments
1	95.0	347.1	347.5	347.8	347.8	0.4	0.3	0				205.0	0.23	0.05	0.01	0.0	other - see comments
2	195.0	348.2	348.9	348.9	348.9	0.7	0	0				305.0	0.23	0.05	0.01	0.0	other - see comments
3	290.0	348.9	349	349	349	0.1	0	0				400.0	0.03	0.01	0.00	0.0	other - see comments
4	195.0	349	349	349	349	0	0	0				305.0	0.00	0.00	0.00	0.0	other - see comments
5	95.0	349	349	349	349.1	0	0	0.1				205.0	0.03	0.01	0.00	0.0	other - see comments
1	120.0	360.9	361.3	362.1	362.4	0.4	0.8	0.3				230.0	0.50	0.10	0.02	0.1	other - see comments
2	240.0	363.3	364.9	367.3	369.6	1.6	2.4	2.3				350.0	2.10	0.42	0.06	0.2	other - see comments
3	360.0	374.3	377.2	378.1	378.3	2.9	0.9	0.2				470.0	1.33	0.27	0.04	0.1	other - see comments
4	240.0	378.3	378.4	378.4	378.4	0.1	0	0				350.0	0.03	0.01	0.00	0.0	other - see comments
5	120.0	378.4	378.4	378.4	378.4	0	0	0				230.0	0.00	0.00	0.00	0.0	other - see comments
1	135.0	400.4	400.5	400.5	400.5	0.1	0	0				243.7	0.03	0.01	0.00	0.0	other - see comments
2	270.0	400.8	400.9	400.9	400.9	0.1	0	0				378.7	0.03	0.01	0.00	0.0	other - see comments
3	400.0	401	401.1	401.1	401.1	0.1	0	0				508.7	0.03	0.01	0.00	0.0	other - see comments
4	270.0	401.1	401.1	401.1	401.1	0	0	0				378.7	0.00	0.00	0.00	0.0	other - see comments
5	135.0	401.1	401.1	401.1	401.1	0	0	0				243.7	0.00	0.00	0.00	0.0	other - see comments
1	135.0	437.4	437.4	437.4	437.4	0	0	0				243.7	0.00	0.00	0.00	0.0	other - see comments
2	270.0	437.5	437.5	437.5	437.5	0	0	0				378.7	0.00	0.00	0.00	0.0	other - see comments
3	400.0	437.5	437.5	437.5	437.5	0	0	0				508.7	0.00	0.00	0.00	0.0	other - see comments
4	270.0	437.5	437.5	437.5	437.5	0	0	0				378.7	0.00	0.00	0.00	0.0	other - see comments
5	135.0	437.5	437.5	437.5	437.5	0	0	0				243.7	0.00	0.00	0.00	0.0	other - see comments
1	20.0	473.8	473.8	473.8	473.8	0	0	0				55.5	0.00	0.00	0.00	0.0	other - see comments
2	40.0	474.1	474.1	474.1	474.1	0	0	0				75.5	0.00	0.00	0.00	0.0	other - see comments
3	60.0	474.1	474.1	474.1	474.1	0	0	0				95.5	0.00	0.00	0.00	0.0	other - see comments
4	40.0	474.1	474.1	474.1	474.1	0	0	0				75.5	0.00	0.00	0.00	0.0	other - see comments
5	20.0	474.1	474.1	474.1	474.1	0	0	0				55.5	0.00	0.00	0.00	0.0	other - see comments
1	30.0	475.9	476	476.2	476.4	0.1	0.2	0.2				65.5	0.17	0.03	0.00	0.1	other - see comments
2	60.0	477.3	477.5	477.6	477.7	0.2	0.1	0.1				95.5	0.13	0.03	0.00	0.0	other - see comments
3	90.0	478.3	478.3	478.3	478.4	0	0	0.1				125.5	0.03	0.01	0.00	0.0	other - see comments
4	60.0	478.4	478.4	478.5	478.5	0	0.1	0				95.5	0.03	0.01	0.00	0.0	other - see comments
5	30.0	478.5	478.6	478.7	478.7	0.1	0.1	0				65.5	0.07	0.01	0.00	0.0	other - see comments
1	50.0	486	486.9	487.5	487.9	0.9	0.6	0.4				101.6	0.63	0.13	0.02	0.2	other - see comments
2	105.0	488.5	488.5	488.6	488.6	0	0.1	0				156.6	0.03	0.01	0.00	0.0	other - see comments
3	155.0	488.7	488.7	488.7	488.7	0	0	0				206.6	0.00	0.00	0.00	0.0	other - see comments
4	105.0	488.8	488.8	488.8	488.8	0	0	0				156.6	0.00	0.00	0.00	0.0	other - see comments
5	50.0	488.8	488.9	489	489.1	0.1	0.1	0.1				101.6	0.10	0.02	0.00	0.0	other - see comments
1	65.0	604.5	605.5	606.5	607.7	1	1	1.2				116.6	1.07	0.21	0.02	0.2	dilation
2	130.0	618	621.5	625.5	628	3.5	4	2.5				181.6	3.33	0.67	0.06	0.4	dilation
3	195.0	634	643.5	651.9	661.7	9.5	8.4	9.8				246.6	9.23	1.85	0.18	0.7	dilation
4	130.0	665.8	671.1	677	682.9	5.3	5.9	5.9				181.6	5.70	1.14	0.11	0.6	dilation
5	65.0	683.2	684.3	686.6	688.8	1.1	2.3	2.2				116.6	1.87	0.37	0.04	0.3	dilation
1	95.0	718.7	718.7	718.8	718.8	0	0.1	0				205.4	0.03	0.01	0.00	0.0	other - see comments
2	185.0	718.8	718.8	718.8	718.8	0	0	0				295.4	0.00	0.00	0.00	0.0	other - see comments
3	280.0	718.9	718.9	718.9	718.9	0	0	0				390.4	0.00	0.00	0.00	0.0	other - see comments
4	185.0	718.9	718.9	718.9	718.9	0	0	0				295.4	0.00	0.00	0.00	0.0	other - see comments
5	95.0	718.9	718.9	718.9	718.9	0	0	0				205.4	0.00	0.00	0.00	0.0	other - see comments
1	125.0	852	866.9	879.5	891.4	14.9	12.6	11.9				244.8	13.13	2.63	0.25	1.0	turbulent flow
2	245.0	965	989.2	1013.4	1035.1	24.2	24.2	21.7				364.8	23.37	4.67	0.45	1.2	turbulent flow
3	370.0	110	149.9	178	206.3	39.9	28.1	28.3				489.8	32.10	6.42	0.61	1.3	turbulent flow
4	245.0	272	291.1	305.7	321.5	19.1	14.6	15.8				364.8	16.50	3.30	0.32	0.9	turbulent flow
5	125.0	378	395.4	412.1	428.6	17.4	16.7	16.5				244.8	16.87	3.37	0.32	1.3	turbulent flow
1	135.0	506	510.1	517.3	524.9	4.1	7.2	7.6				294.9	6.30	1.26	0.24	0.8	other - see comments
2	270.0	525.4	525.5	525.6	525.7	0.1	0.1	0.1				429.9	0.10	0.02	0.00	0.0	other - see comments
3	400.0	526.9	527.2	527.7	528.3	0.3	0.5	0.6				559.9	0.47	0.09	0.02	0.0	other - see comments
4	220.0	528.4	528.6	528.6	528.7	0.2	0	0.1				379.9	0.10	0.02	0.00	0.0	other - see comments
5	135.0	528.7	528.7	528.7	528.7	0	0	0				294.9	0.00	0.00	0.00	0.0	other - see comments
1	135.0	548.9	550.6	552.2	553.8	1.7	1.6	1.6				294.9	1.63	0.33	0.04	0.1	dilation
2	270.0	566.6	572.4	579.8	586.9	5.8	7.4	7.1				429.9	6.77	1.35	0.17	0.4	dilation
3	400.0	614	639.7	666.3	692.5	25.7	26.6	26.2				559.9	26.17	5.23	0.66	1.2	dilation
4	270.0	706	722.3	737.9	753.6	16.3	15.6	15.7				429.9	15.87	3.17	0.40	0.9	dilation
5	135.0	755	758.9	764.5	770	3.9	5.6	5.5				294.9	5.00	1.00	0.13	0.4	dilation
1	135.0	859.7	859.7	859.7	859.7	0	0	0				363.4	0.00	0.00	0.00	0.0	other - see comments
2	270.0	861.9	861.9	861.9	861.9	0	0	0				498.4	0.00	0.00	0.00	0.0	other - see comments
3	400.0	864.9	864.9	864.9	864.9	0	0	0				628.4	0.00	0.00	0.00	0.0	other - see comments
4	270.0	864.9	864.9	865.6	865.6	0	0.7	0				498.4	0.23	0.05	0.01	0.0	other - see comments
5	135.0	865.6	865.6	865.6	865.6	0	0	0				363.4	0.00	0.00	0.00	0.0	other - see comments
1	115.0	219.6	220.3	221.1	222	0.7	0.8	0.9				157.8	0.80	0.16	0.03	0.2	void filling
2	230.0	223.1	225.1	227.1	229.1	2	2	2				272.8	2.00	0.40	0.07	0.2	void filling
3	345.0	230.6	234.4	238.6	242.9	3.8	4.2	4.3				387.8	4.10	0.82	0.14	0.4	void filling
4	230.0	243.6	245	246.5	248.1	1.4	1.5	1.6				272.8	1.50	0.30	0.05	0.2	void filling
5	115.0	247.8	247.9	248	248.2	0.1	0.1	0.2				157.8	0.13	0.03	0.00	0.0	void filling
1	115.0	310.4	311.4	312.2	313.1	1	0.8	0.9				215.5	0.90	0.18	0.03	0.1	void filling
2	230.0	314.05	316	317.9	319.75	1.95	1.9	1.85				330.5	1.90	0.38	0.06	0.2	void filling
3	345.0	330	333.8	337.6	341.6	3.8	3.8	4				445.5	3.87	0.77	0.13	0.3	void filling
4	230.0	344.85	345.5	346.6	347.8	0.65	1.1	1.2				330.5	0.98	0.20	0.03	0.1	void filling
5	115.0	348.25	348.3	348.3	348.3	0.05	0	0				215.5	0.02	0.00	0.00	0.0	void filling
1	135.0	413	414.8	416.6	418.4	1.8	1.8	1.8				235.1	1.80	0.36	0.04	0.2	turbulent flow
2	270.0	423.7	427.9	431.5	435.2	4.2	3.6	3.7				370.1	3.83	0.77	0.09	0.2	turbulent flow
3	400.0	437.6	440.2	443.3	446.7	2.6	3.1	3.4				500.1	3.03	0.61	0.07	0.1	turbulent flow
4	270.0	449.6	452.6	455.6	458.6	3	3	3				370.1	3.00	0.60	0.07	0.2	turbulent flow
5	135.0	459.9	462.5	465.4	468.3	2.6	2.9	2.9				235.1	2.80	0.56	0.06	0.3	turbulent flow
1	135.0	643.8	645.6	646.88	648.2	1.8	1.28	1.32				244.5	1.47	0.29	0.03	0.1	void filling
2	270.0	653.7	655.9	657.44	658.98	2.2	1.54	1.54				379.5	1.76	0.35	0.04	0.1	void filling
3	400.0	672.3	674.9	676.04	678.02	2.6	1.14	1.98				509.5	1.91	0.38	0.04	0.1	void filling
4	270.0	704.9	706.4	707.98	709.3	1.5	1.58	1.32				379.5	1.47	0.29	0.03	0.1	void filling
5	135.0	719.3	719.7	720.62	721.28	0.4	0.92	0.66				244.5	0.66	0.13	0.01	0.1	void filling
1	135.0	757.3	760.4	761.92	763.24	3.1	1.52	1.32				244.5	1.98	0.40	0.04	0.2	laminar flow
2	270.0	774.6	777.5	779.22	781.42	2.9	1.72	2.2				379.5	2.27	0.45	0.05	0.1	laminar flow
3	400.0	808.4	811.3	813.9	816.1	2.9	2.6	2.2				509.5	2.57	0.51	0.06	0.1	laminar flow
4	270.0	843.9	846.5	847.86	850.06	2.6	1.36	2.2				379.5	2.05	0.41	0.05	0.1	laminar flow
5	135.0	872.7	873.8	875.34	877.32	1.1	1.54	1.98				244.5	1.54	0.31	0.03	0.1	laminar flow
1	135.0	105.5	172.8	226.2	274.4	67.3	53.4	48.2				348.2	56.30	11.26	1.88	5.4	wash-out
2	270.0	522.3	588.8	655.5	721.3	66.5	66.7	65.8				483.2	66.33	13.27	2.21	4.6	wash-out
3	400.0	762.5	875	990	1107.3	112.5	115	117.3				613.2	114.93	22.99	3.83	6.2	wash-out
4	270.0	170.3	261.6	354.4	449.6	91.3	92.8	95.2				483.2	93.10	18.62	3.10	6.4	wash-out
5	135.0	478.1	545	613	681	66.9	68	68				348.2	67.63	13.53	2.25	6.5	wash-out

Interpreted Lugeon Value (Houlsby) (uL)	Remark
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
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<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
1.02	Small leak observed after 3rd stage, was able to maintain pressure and continue test.
1.22	Small leak observed after 3rd stage, was able to maintain pressure and continue test.
1.25	Small leak observed after 3rd stage, was able to maintain pressure and continue test.
<1	Small leak observed after 3rd stage, was able to maintain pressure and continue test.
1.32	Small leak observed after 3rd stage, was able to maintain pressure and continue test.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	None.
<1	None.
1.19	None.
<1	None.
<1	None.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Flow rate too low to define flow type.
<1	Second attempt at test due to equipment issues during first attempt(resolved). GWL unable to be measured on 17/08/2017 due to rig/equipment issues. GWL used for test interpretation is preceeding measurement of 3.46mbgl taken on 15/08/2017.
<1	Second attempt at test due to equipment issues during first attempt(resolved). GWL unable to be measured on 17/08/2017 due to rig/equipment issues. GWL used for test interpretation is preceeding measurement of 3.46mbgl taken on 15/08/2017.
<1	Second attempt at test due to equipment issues during first attempt(resolved). GWL unable to be measured on 17/08/2017 due to rig/equipment issues. GWL used for test interpretation is preceeding measurement of 3.46mbgl taken on 15/08/2017.
<1	Second attempt at test due to equipment issues during first attempt(resolved). GWL unable to be measured on 17/08/2017 due to rig/equipment issues. GWL used for test interpretation is preceeding measurement of 3.46mbgl taken on 15/08/2017.
<1	Second attempt at test due to equipment issues during first attempt(resolved). GWL unable to be measured on 17/08/2017 due to rig/equipment issues. GWL used for test interpretation is preceeding measurement of 3.46mbgl taken on 15/08/2017.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	None.
<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
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<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
5.39	None.
4.58	None.
6.25	None.
6.42	None.
6.48	None.

Appendix D. Groundwater quality results

Water Quality - Western Harbour

Chem_Group	ChemName	output unit	EQL	ANZECC 2000 FW 95%	ANZECC 2000 MW 95%	ADWG 2015 Health	NHMRC 2008 Recreational Water Quality/ Aesthetics	B104A	B104A	B104A	B104A	B104A	B105A	B105A	B105A	B105A	B105A	B112P	B131A	B131A	B131A	B131A	B131A	B150P	B181A	B181A	B181A
							Monitoring_Zone	Yurulbin Park	Yurulbin Park	Yurulbin Park	Yurulbin Park	Yurulbin Park	Yurulbin Park	Yurulbin Park	Yurulbin Park	Yurulbin Park	Yurulbin Park	Berrys Bay	Yurulbin Park	Yurulbin Park	Yurulbin Park	Yurulbin Park	Yurulbin Park	Berrys Bay	Rozelle Rail Yards	Rozelle Rail Yards	Rozelle Rail Yards
							Sampled_Date_Time	2/11/2017	7/12/2017	10/01/2018	6/02/2018	7/03/2018	15/11/2017	6/12/2017	10/01/2018	6/02/2018	7/03/2018	15/03/2018	15/11/2017	6/12/2017	10/01/2018	6/02/2018	7/03/2018	6/04/2018	2/11/2017	15/11/2017	6/12/2017
EPA 621 Classification of Wastes	PAHs (EPA VIC Total)	µg/L	0.5					-	-	-	-	-	-	-	-	-	-	<0.5	-	-	-	-	-	-	-	-	-
Resistivity (Saturated Paste)	Resistivity at 25°C	ohm cm	1					-	-	-	-	-	-	-	-	-	-	505	-	-	-	-	-	-	-	-	-
Metals	Arsenic (Filtered)	µg/L	1			10	100	2	1	1	<1	1	2	4	8	8	7	4	<1	1	2	1	2	<1	1	<1	<1
	Barium (Filtered)	µg/L	1			2000	20000	624	445	493	486	363	175	182	182	189	186	177	130	119	81	97	92	118	71	37	66
	Boron (Filtered)	µg/L	50	370		4000	40000	<50	70	<50	<50	<50	140	130	120	120	120	<50	930	1050	950	890	730	160	110	140	130
	Cadmium (Filtered)	µg/L	0.1	0.2	5.5	2	20	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	0.2	0.2
	Chromium (III+VI) (Filtered)	µg/L	1					9	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Cobalt (Filtered)	µg/L	1		1			<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	14	15	3	1	3	2	9	2	1	1
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	3	2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	16	9	7
	Iron (Filtered)	mg/L	0.05					<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.23	0.26	417	479	432	506	349	4.49	<0.05	<0.05	<0.05
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	<1	4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	2	3
	Magnesium (Filtered)	mg/L	1					<1	<1	<1	<1	<1	55	51	55	53	54	44	939	905	952	940	752	4	6	7	7
	Manganese (Filtered)	µg/L	1	1900		500	5000	<1	<1	<1	<1	<1	378	422	439	422	450	287	12,600	11,700	12,300	12,300	10,200	457	45	35	35
	Mercury (Filtered)	µg/L	0.1	0.6	0.4	1	10	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Nickel (Filtered)	µg/L	1	11	70	20	200	10	9	9	8	7	<1	<1	<1	<1	<1	13	2	<1	<1	<1	2	24	4	1	2
	Zinc (Filtered)	µg/L	5	8	15			11	9	<5	<5	<5	<5	<5	<5	<5	<5	14	14	<5	<5	34	7	16	264	253	293
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					74	148	109	89	71	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					1050	412	516	606	658	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Alkalinity (total) as CaCO3	mg/L	1					1130	561	626	695	729	179	160	195	206	260	417	96	144	25	54	76	44	2	<1	<1
	Ammonia	mg/L	0.01	0.9	0.91		0.5	1.11	1.09	1.32	1.34	1.23	0.6	0.51	0.49	0.54	0.44	0.03	1.55	<0.5	0.52	<0.5	1.5	0.04	0.01	0.02	<0.01
	Anions Total	meq/L	0.01					32.4	17.9	19.8	21.6	21.1	31.4	29.9	31.3	31.1	30.2	22.6	357	379	379	363	364	3.09	3.62	3.27	3.23
	Bicarbonate Alkalinity as CaCO3	mg/L	1					<1	<1	<1	<1	<1	179	160	195	206	260	417	96	144	25	54	76	44	2	<1	<1
	Calcium (Filtered)	mg/L	1					154	152	174	183	174	110	107	120	122	136	122	1010	957	970	970	813	6	16	18	22
	Cations Total	meq/L	0.01					30	20.2	22.3	21.8	19.2	30.4	27.8	28.5	28.1	27.1	20.5	380	363	375	367	333	3.42	3.38	3.47	3.63
	Chloride	mg/L	1					81	62	73	76	72	825	803	812	796	693	447	11,500	12,300	12,300	11,700	11,700	48	59	54	54
	pH (lab)	pH Units	0.01	7.0 - 8.5[#5]	8.0 - 8.4[#5]			12	11.7	11.9	11.9	12	7.91	8.01	8.03	7.96	7.81	7.4	6.33	6.41	5.74	5.75	5.82	6.9	5.82	4.15	4.42
	Electrical conductivity (lab)	uS/cm	1					5230	2520	3450	3050	3650	3340	3080	3210	3140	2970	1980	36,900	36,200	37,100	35,200	36,800	392	487	458	473
	Fluoride	mg/L	0.1			1.5	15	0.6	0.4	0.5	0.6	0.4	0.3	0.3	0.3	0.4	0.2	0.4	0.2	0.3	0.2	0.2	0.1	-	0.2	<0.1	<0.1
	Ionic Balance	%	0.01					3.83	6.12	5.9	0.35	4.77	1.6	3.62	4.6	5.15	5.42	4.87	3.11	2.15	0.51	0.6	4.49	5.12	3.46	2.97	5.8
	Kjeldahl Nitrogen Total	mg/L	0.1					2.4	1.1	1.9	1.6	1.3	1	0.8	1.1	0.6	0.4	<0.1	4.2	1	1.2	1.8	2.1	<0.1	1.7	1	0.7
	Nitrate & Nitrite (as N)	mg/L	0.01					-	-	-	-	-	-	-	-	-	-	<0.01	-	-	-	-	-	0.02	-	-	-
	Nitrate (as N)	mg/L	0.01	0.1581[#2]		11.29[#1]		<0.01	0.01	0.06	0.04	0.02	0.02	0.13	<0.01	0.03	0.02	<0.01	<0.1	<0.1	0.14	<0.05	<0.25	0.02	6.64	6.28	5.87
	Nitrite (as N)	µg/L	10			910[#3]		120	70	<10	<10	10	<10	<10	<10	<10	<10	10	<100	<100	<10	<50	<250	<10	<10	<10	<10
	Nitrogen (Total Oxidised)	mg/L	0.01					0.04	0.08	0.06	0.04	0.03	0.02	0.13	<0.01	0.03	0.02	<0.01	<0.1	<0.1	0.14	<0.05	<0.25	0.02	6.64	6.28	5.87
	Nitrogen (Total)	mg/L	0.1					2.4	1.2	2	1.6	1.3	1	0.9	1.1	0.6	0.4	<0.1	4.2	1	1.3	1.8	2.1	<0.1	8.3	7.3	6.6
	Phosphorus	mg/L	0.01					0.03	0.08	0.03	<0.01	0.01	0.11	0.09	0.12	0.06	0.05	<0.01	1.22	<0.1	0.12	<0.1	0.15	0.02	0.34	0.09	0.14
	Potassium (Filtered)	mg/L	1					67	35	35	32	25	39	32	29	27	18	7	97	77	82	75	63	2	5	5	5
	Reactive Phosphorus as P	mg/L	0.01		0.01[#4]			<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.05	<0.1	<0.01	<0.05	<0.01	0.02	<0.01	<0.01	<0.01
	Sodium (Filtered)	mg/L	1					473	270	293	272	226	447	401	397	389	355	245	5740	5490	5670	5510	4830	63	45	43	42
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					360	237	253	269	215	221	194	215	218	264	82	1470	1400	1530	1530	1570	41	92	84	82
	Total Dissolved Solids	mg/L	10					-	1280	1250	1570	991	2100	2050	1750	1760	1790	1240	29,500	31,800	26,900	29,600	25,600	200	-	318	296
	Total Dissolved Solids (Filtered)	mg/L	10					1640	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	361	-	-
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					<20	20	30	30	<20	<20	<20	30	<20	<20	<20	550	580	330	30	20	<20	<20	<20	20
	TRH >C10 - C16	µg/L	100					<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	110	160	130	<100	<100	<100	<100	<100	<100
	TRH >C16 - C34	µg/L	100					<100	580	130	<100	<100	<100	<100	<100	<100	<100	<100	130	170	150	<100	<100	<100	160	<100	<100
	TRH >C34 - C40	µg/L	100					<100	180	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
	TRH >C10 - C40 (Sum of total)	µg/L	100					<100	760	130	<100	<100	<100	<100	<100	<100	<100	<100	240	330	280	<100	<100	<100	160	<100	<100
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					<0.02	0.02	0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.12	0.19	0.11	<0.02	<0.02	<0.02	<0.02	<0.02	0.02
	TRH >C10 - C16 less Naphthalene (F2)	mg/L	0.1					<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.11	0.16	0.13	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					<20	30	50	30	<20	<20	<20	40	<20	<20	<20	540	580	350	30	20	<20	<20	<20	20
	TPH C10 - C14	µg/L	50					<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	100	150	100	90	<50	<50	<50	<50	<50
	TPH C15 - C28	µg/L	100					<100	440	130	<100	<100	<100	<100	<100	<100	<100	<100	150	150	160	<100	<100	<100	130	<100	<100
	TPH C29-C36	µg/L	50					<50	240	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
	TPH C10 - C36 (Sum of total)	µg/L	50					<50	680	130	<50	<50	<50	<50	<50	<50	<50	<50	250	300	260	90	<50	<50	130	<50	<50
BTEXN	Benzene	µg/L	1	950	700	1	10	<1	<1	<1	<1	<1	<1	2	2	2	2	<1	10	28	29	24	19	<1	<1	<1	<1
	Ethylbenzene	µg/L	2			300	3000	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<5	<2	<2	<2	<2	<2	<2	<2
	Toluene	µg/L	2			800	8000	<2	<2	10	9	6	<2	<2	22	<2	<2	<2	422	365	194	<2	<2	<2	<2	<2	<2
	Total BTEX	mg/L	0.001					<0.001	<0.001	0.01	0.009	0.006	<0.001	0.002	0.024	0.002	0.002	<0.001	0.432	0.393	0.223	0.024	0.019	<0.001	<0.001	<0.001	<0.001
	Xylene (m & p)	µg/L	2					<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<5	<2	<2	<2	<2	<2	<2	<2
	Xylene (o)	µg/L	2	350				<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<5	<2	<2	<2	<2	<2	<2	<2
	Xylene Total	µg/L	2			600	6000	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<5	<2	<2	<2	<2	<2	<2	<2
PAHs	Benzo[b+j]fluoranthene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Acenaphthene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Acenaphthylene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Anthracene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Benz(a)anthracene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Benzo(a) pyrene	µg/L	0.5			0.01		<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Benzo(a)pyrene TEQ (zero)	µg/L	0.5					<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Benzo(a)pyrene TEQ (lower bound)*	µg/L	0.5					-	-	-	-	-	-	-	-	-	-	<0.5	-	-	-	-	-	<0.5	-	-	-
	Benzo(g,h,i)perylene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Benzo(k)fluoranthene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Chrysene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Dibenz(a,h)anthracene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Fluoranthene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Fluorene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Indeno(1,2,3-c,d)pyrene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Naphthalene	µg/L	1	16	70			<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Phenanthrene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Pyrene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	PAHs (Sum of total)	µg/L	0.5			0.01	0.1	<0.5	-	-	-	-	<0.5	-	-	-	-	<0.5	<0.5	-	-	-	-	<0.5	<0.5	<0.5	-
Halogenated Benzenes	Hexachlorobenzene	µg/L	0.5					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EPA 448 Classification of Wastes	Polycylic aromatic hydrocarbons EPA448	µg/L	0.5					-	<0.5	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5	<0.5	-	-	<0.5	<0.5	<0.5	<0.5	-	-	-	<0.5

Env Stds Comments
#1:Converted from Nitrate as NO3 (50 mg/L)
#2:Converted from Nitrate as NO3 (700ug/L)
#3:Converted from Nitrite as NO2 (3 mg/L)
#4: Table 8.2.5 - ANZECC 2000 - Filterable Reactive Phosphorus for NSW, marine ecosystem
#5: Table 8.2.8 - ANZECC 2000 - pH values for NSW estuarine ecosytems

Water Quality - Western Harbour

							Field_ID	B181A	B181A	B181A	B208	B208	B208	B208A	B208A	B390	B390
							Monitoring_Zone	Rozelle Rail Yards	Rozelle Rail Yards	Rozelle Rail Yards	Victoria Road	Victoria Road	Victoria Road	Victoria Road	Victoria Road	Rozelle Rail Yards	Rozelle Rail Yards
							Sampled_Date_Time	10/01/2018	6/02/2018	7/03/2018	10/01/2018	6/02/2018	7/03/2018	15/11/2017	6/12/2017	9/02/2018	15/03/2018
Chem_Group	ChemName	output unit	EQL	ANZECC 2000 FW 95%	ANZECC 2000 MW 95%	ADWG 2015 Health	NHMRC 2008 Recreational Water Quality/ Aesthetics										
EPA 621 Classification of Wastes	PAHs (EPA VIC Total)	µg/L	0.5					-	-	-	-	-	-	-	-	-	<0.5
Resistivity (Saturated Paste)	Resistivity at 25°C	ohm cm	1					-	-	-	-	-	-	-	-	1560	1680
Metals	Arsenic (Filtered)	µg/L	1			10	100	<1	<1	<1	1	<1	<1	<1	<1	<1	<1
	Barium (Filtered)	µg/L	1			2000	20000	66	73	54	92	78	69	185	129	134	132
	Boron (Filtered)	µg/L	50	370		4000	40000	130	120	130	<50	<50	<50	<50	<50	250	200
	Cadmium (Filtered)	µg/L	0.1	0.2	5.5	2	20	0.1	0.2	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Chromium (III+VI) (Filtered)	µg/L	1					<1	<1	2	6	<1	<1	70	32	<1	<1
	Cobalt (Filtered)	µg/L	1		1			1	1	1	<1	<1	<1	<1	<1	13	13
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	5	4	3	<1	<1	<1	2	1	<1	<1
	Iron (Filtered)	mg/L	0.05					<0.05	<0.05	0.18	<0.05	<0.05	<0.05	<0.05	<0.05	15.6	24.4
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	3	2	<1	<1	<1	<1	<1	<1	<1	<1
	Magnesium (Filtered)	mg/L	1					8	7	5	<1	<1	<1	<1	<1	13	11
	Manganese (Filtered)	µg/L	1	1900		500	5000	33	31	19	<1	<1	<1	<1	<1	832	794
	Mercury (Filtered)	µg/L	0.1	0.6	0.4	1	10	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Nickel (Filtered)	µg/L	1	11	70	20	200	2	2	<1	<1	2	2	<1	<1	19	14
	Zinc (Filtered)	µg/L	5	8	15			242	241	171	<5	6	6	7	6	65	<5
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					<1	<1	<1	57	47	46	59	42	<1	<1
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					<1	<1	<1	147	130	87	643	294	<1	<1
	Alkalinity (total) as CaCO3	mg/L	1					<1	<1	7	204	176	133	702	336	54	75
	Ammonia	mg/L	0.01	0.9	0.91		0.5	<0.01	0.01	<0.01	0.47	0.51	0.47	0.51	0.38	<0.01	<0.01
	Anions Total	meq/L	0.01					3.44	3.56	3.09	6.01	5.84	4.98	15.9	8.77	5.84	6.39
	Bicarbonate Alkalinity as CaCO3	mg/L	1					<1	<1	7	<1	<1	<1	<1	<1	-	75
	Calcium (Filtered)	mg/L	1					26	24	26	58	34	26	192	84	6	4
	Cations Total	meq/L	0.01					3.94	3.62	3.15	6.71	5.91	4.89	13.8	8.82	6.02	5.89
	Chloride	mg/L	1					54	50	41	59	64	64	60	64	143	147
	pH (lab)	pH Units	0.01	7.0 - 8.5[#5]	8.0 - 8.4[#5]			4.18	4.59	6.14	11.4	11	11	11.9	11.8	6.05	6.2
	Electrical conductivity (lab)	uS/cm	1					504	433	409	1140	676	622	2660	1760	642	597
	Fluoride	mg/L	0.1			1.5	15	<0.1	<0.1	0.1	0.6	0.9	0.5	0.4	0.5	0.1	0.2
	Ionic Balance	%	0.01					6.74	0.84	0.96	5.47	0.58	0.92	7.14	0.28	1.52	4.07
	Kjeldahl Nitrogen Total	mg/L	0.1					1.2	0.5	0.5	0.8	0.6	0.5	0.7	0.6	0.1	5
	Nitrate & Nitrite (as N)	mg/L	0.01					-	-	-	-	-	-	-	-	-	<0.01
	Nitrate (as N)	mg/L	0.01	0.1581[#2]		11.29[#1]		5.43	5.83	4.48	0.07	0.02	0.02	<0.01	0.07	0.03	<0.01
	Nitrite (as N)	µg/L	10			910[#3]		<10	<10	<10	<10	<10	<10	10	<10	<10	20
	Nitrogen (Total Oxidised)	mg/L	0.01					5.43	5.83	4.48	0.07	0.02	0.02	0.01	0.07	0.03	<0.01
	Nitrogen (Total)	mg/L	0.1					6.6	6.3	5	0.9	0.6	0.5	0.7	0.7	0.1	5
	Phosphorus	mg/L	0.01					0.37	0.06	0.06	0.04	0.01	0.01	0.02	<0.01	<0.01	1
	Potassium (Filtered)	mg/L	1					6	6	7	30	44	30	40	55	1	4
	Reactive Phosphorus as P	mg/L	0.01		0.01[#4]			<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Sodium (Filtered)	mg/L	1					42	39	29	70	71	65	74	74	87	78
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					92	83	71	13	25	25	11	12	35	36
	Total Dissolved Solids	mg/L	10					280	316	256	494	455	328	654	614	322	340
	Total Dissolved Solids (Filtered)	mg/L	10					-	-	-	-	-	-	-	-	-	-
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					20	<20	<20	30	40	40	<20	30	<20	<20
	TRH >C10 - C16	µg/L	100					<100	<100	<100	<100	<100	<100	<100	<100	<100	150
	TRH >C16 - C34	µg/L	100					<100	<100	<100	220	260	<100	270	150	610	630
	TRH >C34 - C40	µg/L	100					<100	<100	<100	<100	<100	<100	150	<100	<100	<100
	TRH >C10 - C40 (Sum of total)	µg/L	100					<100	<100	<100	220	260	<100	420	150	610	780
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					0.02	<0.02	<0.02	0.02	0.02	0.03	<0.02	0.03	<0.02	<0.02
	TRH >C10 - C16 less Naphthalene (F2)	mg/L	0.1					<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.15
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					20	<20	<20	40	40	30	<20	30	<20	<20
	TPH C10 - C14	µg/L	50					<50	<50	<50	<50	<50	<50	<50	60	<50	120
	TPH C15 - C28	µg/L	100					<100	<100	<100	200	220	<100	190	130	520	640
	TPH C29-C36	µg/L	50					<50	<50	<50	<50	<50	<50	140	<50	<50	<50
	TPH C10 - C36 (Sum of total)	µg/L	50					<50	<50	<50	200	220	<50	330	190	520	760
BTEXN	Benzene	µg/L	1	950	700	1	10	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Ethylbenzene	µg/L	2			300	3000	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Toluene	µg/L	2			800	8000	<2	<2	<2	10	15	12	<2	<2	<2	<2
	Total BTEX	mg/L	0.001					<0.001	<0.001	<0.001	0.01	0.015	0.012	0.002	<0.001	<0.001	<0.001
	Xylene (m & p)	µg/L	2					<2	<2	<2	<2	<2	<2	2	<2	<2	<2
	Xylene (o)	µg/L	2	350				<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Xylene Total	µg/L	2			600	6000	<2	<2	<2	<2	<2	<2	2	<2	<2	<2
PAHs	Benzo[b+j]fluoranthene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Acenaphthene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Acenaphthylene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Anthracene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Benz(a)anthracene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Benzo(a) pyrene	µg/L	0.5			0.01		<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Benzo(a)pyrene TEQ (zero)	µg/L	0.5					<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5
	Benzo(a)pyrene TEQ (lower bound)*	µg/L	0.5					-	-	-	-	-	-	-	-	<0.5	<0.5
	Benzo(g,h,i)perylene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Benzo(k)fluoranthene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Chrysene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Dibenz(a,h)anthracene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Fluoranthene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Fluorene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Indeno(1,2,3-c,d)pyrene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Naphthalene	µg/L	1	16	70			<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Phenanthrene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Pyrene	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	PAHs (Sum of total)	µg/L	0.5			0.01	0.1	-	-	-	-	-	-	<0.5	-	<0.5	<0.5
Halogenated Benzenes	Hexachlorobenzene	µg/L	0.5					-	-	-	<0.5	<0.5	<0.5	-	<0.5	-	-
EPA 448 Classification of Wastes	Polycylic aromatic hydrocarbons EPA448	µg/L	0.5					<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	-

Env Stds Comments
#1:Converted from Nitrate as NO3 (50 mg/L)
#2:Converted from Nitrate as NO3 (700ug/L)
#3:Converted from Nitrite as NO2 (3 mg/L)
#4: Table 8.2.5 - ANZECC 2000 - Filterable Reactive Phosphorus for NSW, marine ecosystem
#5: Table 8.2.8 - ANZECC 2000 - pH values for NSW estuarine ecosytems

Water Quality - Western Harbour Berrys Bay Treatment Facility

				ANZECC 2000 FW 95%	ANZECC 2000 MW 95%	ADWG 2015 Health	NHMRC 2008 Recreational Water Quality/ Aesthetics	Statistical Summary			
Chem_Group	ChemName	output unit	EQL					Number of Results	Maximum Concentration	Median Concentration	Number of Guideline Exceedances
EPA 621 Classification of Wastes	PAHs (EPA VIC Total)	µg/L	0.5					1	<0.5	0.25	0
Resistivity (Saturated Paste)	Resistivity at 25°C	ohm cm	1					1	505	505	0
Metals	Arsenic (Filtered)	µg/L	1			10	100	2	4	2.25	0
	Barium (Filtered)	µg/L	1			2000	20000	2	177	147.5	0
	Boron (Filtered)	µg/L	50	370		4000	40000	2	160	92.5	0
	Cadmium (Filtered)	µg/L	0.1	0.2	5.5	2	20	2	<0.1	0.05	0
	Chromium (III+VI) (Filtered)	µg/L	1					2	<1	0.5	0
	Cobalt (Filtered)	µg/L	1		1			2	14	11.5	2
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	2	<1	0.5	0
	Iron (Filtered)	mg/L	0.05					2	4.49	2.375	2
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	2	<1	0.5	0
	Magnesium (Filtered)	mg/L	1					2	44	24	0
	Manganese (Filtered)	µg/L	1	1900		500	5000	2	457	372	0
	Mercury (Filtered)	µg/L	0.1	0.6	0.4	1	10	2	<0.1	0.05	0
	Nickel (Filtered)	µg/L	1	11	70	20	200	2	24	18.5	2
	Zinc (Filtered)	µg/L	5	8	15			2	16	15	2
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					2	<1	0.5	0
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					2	<1	0.5	0
	Alkalinity (total) as CaCO3	mg/L	1					2	417	230.5	0
	Ammonia	mg/L	0.01	0.9	0.91		0.5	2	0.04	0.035	0
	Anions Total	meq/L	0.01					2	22.6	12.845	0
	Bicarbonate Alkalinity as CaCO3	mg/L	1					2	417	230.5	0
	Calcium (Filtered)	mg/L	1					2	122	64	0
	Cations Total	meq/L	0.01					2	20.5	11.96	0
	Chloride	mg/L	1					2	447	247.5	2
	pH (lab)	pH Units	0.01	7.0 - 8.5[#5]	8.0 - 8.4[#5]			2	7.4	7.15	2
	Electrical conductivity (lab)	uS/cm	1					2	1980	1186	0
	Fluoride	mg/L	0.1			1.5	15	1	0.4	0.4	0
	Ionic Balance	%	0.01					2	5.12	4.995	0
	Kjeldahl Nitrogen Total	mg/L	0.1					2	<0.1	0.05	0
	Nitrate & Nitrite (as N)	mg/L	0.01					2	0.02	0.0125	0
	Nitrate (as N)	mg/L	0.01	0.1581[#2]		11.29[#1]		2	0.02	0.0125	0
	Nitrite (as N)	µg/L	10			910[#3]		2	10	7.5	0
	Nitrogen (Total Oxidised)	mg/L	0.01					2	0.02	0.0125	0
	Nitrogen (Total)	mg/L	0.1					2	<0.1	0.05	0
	Phosphorus	mg/L	0.01					2	0.02	0.0125	0
	Potassium (Filtered)	mg/L	1					2	7	4.5	0
	Reactive Phosphorus as P	mg/L	0.01		0.01[#4]			2	0.02	0.0125	1
	Sodium (Filtered)	mg/L	1					2	245	154	2
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					2	82	61.5	0
	Total Dissolved Solids	mg/L	10					2	1240	720	2
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					2	<20	10	0
	TRH >C10 - C16	µg/L	100					2	<100	50	0
	TRH >C16 - C34	µg/L	100					2	<100	50	0
	TRH >C34 - C40	µg/L	100					2	<100	50	0
	TRH >C10 - C40 (Sum of total)	µg/L	100					2	<100	50	0
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					2	<0.02	0.01	0
	TRH >C10 - C16 less Naphthalene (F2)	mg/L	0.1					2	<0.1	0.05	0
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					2	<20	10	0
	TPH C10 - C14	µg/L	50					2	<50	25	0
	TPH C15 - C28	µg/L	100					2	<100	50	0
	TPH C29-C36	µg/L	50					2	<50	25	0
	TPH C10 - C36 (Sum of total)	µg/L	50					2	<50	25	0
BTEXN	Benzene	µg/L	1	950	700	1	10	2	<1	0.5	0
	Ethylbenzene	µg/L	2			300	3000	2	<2	1	0
	Toluene	µg/L	2			800	8000	2	<2	1	0
	Total BTEX	mg/L	0.001					2	<0.001	0.0005	0
	Xylene (m & p)	µg/L	2					2	<2	1	0
	Xylene (o)	µg/L	2	350				2	<2	1	0
	Xylene Total	µg/L	2			600	6000	2	<2	1	0
PAHs	Benzo[b+j]fluoranthene	µg/L	1					2	<1	0.5	0
	Acenaphthene	µg/L	1					2	<1	0.5	0
	Acenaphthylene	µg/L	1					2	<1	0.5	0
	Anthracene	µg/L	1					2	<1	0.5	0
	Benz(a)anthracene	µg/L	1					2	<1	0.5	0
	Benzo(a) pyrene	µg/L	0.5			0.01		2	<0.5	0.25	2
	Benzo(a)pyrene TEQ (zero)	µg/L	0.5					2	<0.5	0.25	0
	Benzo(a)pyrene TEQ (lower bound)*	µg/L	0.5					2	<0.5	0.25	0
	Benzo(g,h,i)perylene	µg/L	1					2	<1	0.5	0
	Benzo(k)fluoranthene	µg/L	1					2	<1	0.5	0
	Chrysene	µg/L	1					2	<1	0.5	0
	Dibenz(a,h)anthracene	µg/L	1					2	<1	0.5	0
	Fluoranthene	µg/L	1					2	<1	0.5	0
	Fluorene	µg/L	1					2	<1	0.5	0
	Indeno(1,2,3-c,d)pyrene	µg/L	1					2	<1	0.5	0
	Naphthalene	µg/L	1	16	70			2	<1	0.5	0
	Phenanthrene	µg/L	1					2	<1	0.5	0
	Pyrene	µg/L	1					2	<1	0.5	0
	PAHs (Sum of total)	µg/L	0.5			0.01	0.1	2	<0.5	0.25	2

Env Stds Comments
#1:Converted from Nitrate as NO3 (50 mg/L)
#2:Converted from Nitrate as NO3 (700ug/L)
#3:Converted from Nitrite as NO2 (3 mg/L)
#4: Table 8.2.5 - ANZECC 2000 - Filterable Reactive Phosphorus for NSW, marine ecosystem
#5: Table 8.2.8 - ANZECC 2000 - pH values for NSW estuarine ecosytems

Water Quality - Western Harbour Rozelle Treatment Facility

				ANZECC 2000 FW 95%	ANZECC 2000 MW 95%	ADWG 2015 Health	NHMRC 2008 Recreational Water Quality/ Aesthetics	Statistical Summary			
Chem_Group	ChemName	output unit	EQL					Number of Results	Maximum Concentration	Median Concentration	Number of Guideline Exceedances
EPA 621 Classification of Wastes	PAHs (EPA VIC Total)	µg/L	0.5					1	<0.5	0.25	0
Resistivity (Saturated Paste)	Resistivity at 25°C	ohm cm	1					2	1680	1620	0
Metals	Arsenic (Filtered)	µg/L	1			10	100	8	1	0.5	0
	Barium (Filtered)	µg/L	1			2000	20000	8	134	68.5	0
	Boron (Filtered)	µg/L	50	370		4000	40000	8	250	130	0
	Cadmium (Filtered)	µg/L	0.1	0.2	5.5	2	20	8	0.2	0.15	4
	Chromium (III+VI) (Filtered)	µg/L	1					8	2	0.5	0
	Cobalt (Filtered)	µg/L	1		1			8	13	1	8
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	8	16	4.5	6
	Iron (Filtered)	mg/L	0.05					8	24.4	0.025	8
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	8	3	2	0
	Magnesium (Filtered)	mg/L	1					8	13	7	0
	Manganese (Filtered)	µg/L	1	1900		500	5000	8	832	35	2
	Mercury (Filtered)	µg/L	0.1	0.6	0.4	1	10	8	<0.1	0.05	0
	Nickel (Filtered)	µg/L	1	11	70	20	200	8	19	2	2
	Zinc (Filtered)	µg/L	5	8	15			8	293	241.5	7
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					8	<1	0.5	0
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					8	<1	0.5	0
	Alkalinity (total) as CaCO3	mg/L	1					8	75	1.25	0
	Ammonia	mg/L	0.01	0.9	0.91		0.5	8	0.02	0.005	0
	Anions Total	meq/L	0.01					8	6.39	3.5	0
	Bicarbonate Alkalinity as CaCO3	mg/L	1					7	75	0.5	0
	Calcium (Filtered)	mg/L	1					8	26	20	0
	Cations Total	meq/L	0.01					8	6.02	3.625	0
	Chloride	mg/L	1					8	147	54	8
	pH (lab)	pH Units	0.01	7.0 - 8.5[#5]	8.0 - 8.4[#5]			8	6.2	5.205	8
	Electrical conductivity (lab)	uS/cm	1					8	642	480	0
	Fluoride	mg/L	0.1			1.5	15	8	0.2	0.075	0
	Ionic Balance	%	0.01					8	6.74	3.215	0
	Kjeldahl Nitrogen Total	mg/L	0.1					8	5	0.85	0
	Nitrate & Nitrite (as N)	mg/L	0.01					1	<0.01	0.005	0
	Nitrate (as N)	mg/L	0.01	0.1581[#2]		11.29[#1]		8	6.64	5.63	6
	Nitrite (as N)	µg/L	10			910[#3]		8	20	5	0
	Nitrogen (Total Oxidised)	mg/L	0.01					8	6.64	5.63	0
	Nitrogen (Total)	mg/L	0.1					8	8.3	6.45	0
	Phosphorus	mg/L	0.01					8	1	0.115	0
	Potassium (Filtered)	mg/L	1					8	7	5	0
	Reactive Phosphorus as P	mg/L	0.01		0.01[#4]			8	<0.01	0.005	0
	Sodium (Filtered)	mg/L	1					8	87	42.5	8
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					8	92	82.5	0
	Total Dissolved Solids	mg/L	10					7	340	316	7
	Total Dissolved Solids (Filtered)	mg/L	10					1	361	361	1
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					8	20	10	0
	TRH >C10 - C16	µg/L	100					8	150	50	0
	TRH >C16 - C34	µg/L	100					8	630	50	0
	TRH >C34 - C40	µg/L	100					8	<100	50	0
	TRH >C10 - C40 (Sum of total)	µg/L	100					8	780	50	0
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					8	0.02	0.01	0
	TRH >C10 - C16 less Naphthalene (F2)	mg/L	0.1					8	0.15	0.05	0
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					8	20	10	0
	TPH C10 - C14	µg/L	50					8	120	25	0
	TPH C15 - C28	µg/L	100					8	640	50	0
	TPH C29-C36	µg/L	50					8	<50	25	0
	TPH C10 - C36 (Sum of total)	µg/L	50					8	760	25	0
BTEXN	Benzene	µg/L	1	950	700	1	10	8	<1	0.5	0
	Ethylbenzene	µg/L	2			300	3000	8	<2	1	0
	Toluene	µg/L	2			800	8000	8	<2	1	0
	Total BTEX	mg/L	0.001					8	<0.001	0.0005	0
	Xylene (m & p)	µg/L	2					8	<2	1	0
	Xylene (o)	µg/L	2	350				8	<2	1	0
	Xylene Total	µg/L	2			600	6000	8	<2	1	0
PAHs	Benzo[b+j]fluoranthene	µg/L	1					8	<1	0.5	0
	Acenaphthene	µg/L	1					8	<1	0.5	0
	Acenaphthylene	µg/L	1					8	<1	0.5	0
	Anthracene	µg/L	1					8	<1	0.5	0
	Benz(a)anthracene	µg/L	1					8	<1	0.5	0
	Benzo(a) pyrene	µg/L	0.5			0.01		8	<0.5	0.25	8
	Benzo(a)pyrene TEQ (zero)	µg/L	0.5					7	<0.5	0.25	0
	Benzo(a)pyrene TEQ (lower bound)*	µg/L	0.5					2	<0.5	0.25	0
	Benzo(g,h,i)perylene	µg/L	1					8	<1	0.5	0
	Benzo(k)fluoranthene	µg/L	1					8	<1	0.5	0
	Chrysene	µg/L	1					8	<1	0.5	0
	Dibenz(a,h)anthracene	µg/L	1					8	<1	0.5	0
	Fluoranthene	µg/L	1					8	<1	0.5	0
	Fluorene	µg/L	1					8	<1	0.5	0
	Indeno(1,2,3-c,d)pyrene	µg/L	1					8	<1	0.5	0
	Naphthalene	µg/L	1	16	70			8	<1	0.5	0
	Phenanthrene	µg/L	1					8	<1	0.5	0
	Pyrene	µg/L	1					8	<1	0.5	0
	PAHs (Sum of total)	µg/L	0.5			0.01	0.1	4	<0.5	0.25	4
EPA 448 Classification of Wastes	Polycylic aromatic hydrocarbons EPA448	µg/L	0.5					4	<0.5	0.25	0

Env Stds Comments
#1:Converted from Nitrate as NO3 (50 mg/L)
#2:Converted from Nitrate as NO3 (700ug/L)
#3:Converted from Nitrite as NO2 (3 mg/L)
#4: Table 8.2.5 - ANZECC 2000 - Filterable Reactive Phosphorus for NSW, marine ecosystem
#5: Table 8.2.8 - ANZECC 2000 - pH values for NSW estuarine ecosytems

Water Quality - Western Harbour Victoria Rd Treatment Facility

Chem_Group	ChemName	output unit	EQL	ANZECC 2000 FW 95%	ANZECC 2000 MW 95%	ADWG 2015 Health	NHMRC 2008 Recreational Water Quality/ Aesthetics	Statistical Summary Number of Results	Maximum Concentration	Median Concentration	Number of Guideline Exceedances
Metals	Arsenic (Filtered)	µg/L	1			10	100	5	1	0.5	0
	Barium (Filtered)	µg/L	1			2000	20000	5	185	92	0
	Boron (Filtered)	µg/L	50	370		4000	40000	5	<50	25	0
	Cadmium (Filtered)	µg/L	0.1	0.2	5.5	2	20	5	<0.1	0.05	0
	Chromium (III+VI) (Filtered)	µg/L	1					5	70	6	0
	Cobalt (Filtered)	µg/L	1		1			5	<1	0.5	0
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	5	2	0.5	1
	Iron (Filtered)	mg/L	0.05					5	<0.05	0.025	5
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	5	<1	0.5	0
	Magnesium (Filtered)	mg/L	1					5	<1	0.5	0
	Manganese (Filtered)	µg/L	1	1900		500	5000	5	<1	0.5	0
	Mercury (Filtered)	µg/L	0.1	0.6	0.4	1	10	5	<0.1	0.05	0
	Nickel (Filtered)	µg/L	1	11	70	20	200	5	2	0.5	0
	Zinc (Filtered)	µg/L	5	8	15			5	7	6	0
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					5	59	47	0
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					5	643	147	0
	Alkalinity (total) as CaCO3	mg/L	1					5	702	204	0
	Ammonia	mg/L	0.01	0.9	0.91		0.5	5	0.51	0.47	2
	Anions Total	meq/L	0.01					5	15.9	6.01	0
	Bicarbonate Alkalinity as CaCO3	mg/L	1					5	<1	0.5	0
	Calcium (Filtered)	mg/L	1					5	192	58	0
	Cations Total	meq/L	0.01					5	13.8	6.71	0
	Chloride	mg/L	1					5	64	64	5
	pH (lab)	pH Units	0.01	7.0 - 8.5#5	8.0 - 8.4#5			5	11.9	11.4	5
	Electrical conductivity (lab)	uS/cm	1					5	2660	1140	0
	Fluoride	mg/L	0.1			1.5	15	5	0.9	0.5	0
	Ionic Balance	%	0.01					5	7.14	0.92	0
	Kjeldahl Nitrogen Total	mg/L	0.1					5	0.8	0.6	0
	Nitrate (as N)	mg/L	0.01	0.1581#2		11.29#1		5	0.07	0.02	0
	Nitrite (as N)	µg/L	10			910#3		5	10	5	0
	Nitrogen (Total Oxidised)	mg/L	0.01					5	0.07	0.02	0
	Nitrogen (Total)	mg/L	0.1					5	0.9	0.7	0
	Phosphorus	mg/L	0.01					5	0.04	0.01	0
	Potassium (Filtered)	mg/L	1					5	55	40	0
	Reactive Phosphorus as P	mg/L	0.01		0.01#4			5	0.04	0.005	1
	Sodium (Filtered)	mg/L	1					5	74	71	5
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					5	25	13	0
	Total Dissolved Solids	mg/L	10					5	654	494	5
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					5	40	30	0
	TRH >C10 - C16	µg/L	100					5	<100	50	0
	TRH >C16 - C34	µg/L	100					5	270	220	0
	TRH >C34 - C40	µg/L	100					5	150	50	0
	TRH >C10 - C40 (Sum of total)	µg/L	100					5	420	220	0
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					5	0.03	0.02	0
	TRH >C10 - C16 less Naphthalene (F2)	mg/L	0.1					5	<0.1	0.05	0
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					5	40	30	0
	TPH C10 - C14	µg/L	50					5	60	25	0
	TPH C15 - C28	µg/L	100					5	220	190	0
	TPH C29-C36	µg/L	50					5	140	25	0
	TPH C10 - C36 (Sum of total)	µg/L	50					5	330	200	0
BTEXN	Benzene	µg/L	1	950	700	1	10	5	<1	0.5	0
	Ethylbenzene	µg/L	2			300	3000	5	<2	1	0
	Toluene	µg/L	2			800	8000	5	15	10	0
	Total BTEX	mg/L	0.001					5	0.015	0.01	0
	Xylene (m & p)	µg/L	2					5	2	1	0
	Xylene (o)	µg/L	2	350				5	<2	1	0
	Xylene Total	µg/L	2			600	6000	5	2	1	0
PAHs	Benzo[b+j]fluoranthene	µg/L	1					5	<1	0.5	0
	Acenaphthene	µg/L	1					5	<1	0.5	0
	Acenaphthylene	µg/L	1					5	<1	0.5	0
	Anthracene	µg/L	1					5	<1	0.5	0
	Benz(a)anthracene	µg/L	1					5	<1	0.5	0
	Benzo(a) pyrene	µg/L	0.5			0.01		5	<0.5	0.25	5
	Benzo(a)pyrene TEQ (zero)	µg/L	0.5					5	<0.5	0.25	0
	Benzo(g,h,i)perylene	µg/L	1					5	<1	0.5	0
	Benzo(k)fluoranthene	µg/L	1					5	<1	0.5	0
	Chrysene	µg/L	1					5	<1	0.5	0
	Dibenz(a,h)anthracene	µg/L	1					5	<1	0.5	0
	Fluoranthene	µg/L	1					5	<1	0.5	0
	Fluorene	µg/L	1					5	<1	0.5	0
	Indeno(1,2,3-c,d)pyrene	µg/L	1					5	<1	0.5	0
	Naphthalene	µg/L	1	16	70			5	<1	0.5	0
	Phenanthrene	µg/L	1					5	<1	0.5	0
	Pyrene	µg/L	1					5	<1	0.5	0
	PAHs (Sum of total)	µg/L	0.5			0.01	0.1	1	<0.5	0.25	1
Organochlorine Pesticides	4,4-DDE	µg/L	0.5					4	<0.5	0.25	0
	a-BHC	µg/L	0.5					4	<0.5	0.25	0
	Aldrin	µg/L	0.5					4	<0.5	0.25	0
	Aldrin + Dieldrin	µg/L	0.5			0.3	3	4	<0.5	0.25	4
	b-BHC	µg/L	0.5					4	<0.5	0.25	0
	Chlordane	µg/L	0.5	0.08		2		4	<0.5	0.25	4
	Chlordane (cis)	µg/L	0.5					4	<0.5	0.25	0
	Chlordane (trans)	µg/L	0.5					4	<0.5	0.25	0
	d-BHC	µg/L	0.5					4	<0.5	0.25	0
	DDD	µg/L	0.5					4	<0.5	0.25	0
	DDT	µg/L	2	0.01		9	90	4	<2	1	4
	DDT+DDE+DDD	µg/L	0.5					4	<0.5	0.25	0
	Dieldrin	µg/L	0.5					4	<0.5	0.25	0
	Endosulfan I	µg/L	0.5					4	<0.5	0.25	0
	Endosulfan II	µg/L	0.5					4	<0.5	0.25	0
	Endosulfan sulphate	µg/L	0.5					4	<0.5	0.25	0
	Endrin	µg/L	0.5	0.02	0.008			4	<0.5	0.25	4
	Endrin aldehyde	µg/L	0.5					4	<0.5	0.25	0
	Endrin ketone	µg/L	0.5					4	<0.5	0.25	0
	g-BHC (Lindane)	µg/L	0.5	0.2		10	100	4	<0.5	0.25	4
	Heptachlor	µg/L	0.5	0.09		0.3	3	4	<0.5	0.25	4
	Heptachlor epoxide	µg/L	0.5					4	<0.5	0.25	0
	Methoxychlor	µg/L	2				3000	4	<2	1	0
Organophosphorous Pesticides	Azinophos methyl	µg/L	0.5	0.02		30	300	4	<0.5	0.25	4
	Bromophos-ethyl	µg/L	0.5			10	100	4	<0.5	0.25	0
	Carbophenothion	µg/L	0.5			0.5		4	<0.5	0.25	0
	Chlorfenvinphos	µg/L	0.5			2		4	<0.5	0.25	0
	Chlorpyrifos	µg/L	0.5	0.01	0.009	10	100	4	<0.5	0.25	4
	Chlorpyrifos-methyl	µg/L	0.5					4	<0.5	0.25	0
	Demeton-S-methyl	µg/L	0.5					4	<0.5	0.25	0
	Diazinon	µg/L	0.5	0.01		4	40	4	<0.5	0.25	4
	Dichlorvos	µg/L	0.5			5	50	4	<0.5	0.25	0
	Dimethoate	µg/L	0.5	0.15		7	70	4	<0.5	0.25	4
	Ethion	µg/L	0.5			4	40	4	<0.5	0.25	0
	Fenamiphos	µg/L	0.5			0.5	5	4	<0.5	0.25	0
	Fenthion	µg/L	0.5			7	70	4	<0.5	0.25	0
	Malathion	µg/L	0.5	0.05		70	700	4	<0.5	0.25	4
	Methyl parathion	µg/L	2			0.7	7	4	<2	1	4
	Monocrotophos	µg/L	2			2	20	4	<2	1	0
	Parathion	µg/L	2	0.004		20	200	4	<2	1	4
	Pirimphos-ethyl	µg/L	0.5			0.5	5	4	<0.5	0.25	0
	Prothiofos	µg/L	0.5					4	<0.5	0.25	0
Halogenated Benzenes	Hexachlorobenzene	µg/L	0.5					4	<0.5	0.25	0
EPA 448 Classification of Wastes	Polycylic aromatic hydrocarbons EPA448	µg/L	0.5					4	<0.5	0.25	0

Env Stds Comments
#1:Converted from Nitrate as NO3 (50 mg/L)
#2:Converted from Nitrate as NO3 (700ug/L)
#3:Converted from Nitrite as NO2 (3 mg/L
#4: Table 8.2.5 - ANZECC 2000 - Filterable Reactive Phosphorus for NSW, marine ecosystem
#5: Table 8.2.8 - ANZECC 2000 - pH values for NSW estuarine ecosytems

Water Quality - Western Harbour Yurulbin Treatment Facility

Chem_Group	ChemName	output unit	EQL	ANZECC 2000 FW 95%	ANZECC 2000 MW 95%	ADWG 2015 Health	NHMRC 2008 Recreational Water Quality/ Aesthetics	Statistical Summary			
								Number of Results	Maximum Concentration	Median Concentration	Number of Guideline Exceedances
Metals	Arsenic (Filtered)	µg/L	1			10	100	15	8	2	0
	Barium (Filtered)	µg/L	1			2000	20000	15	624	182	0
	Boron (Filtered)	µg/L	50	370		4000	40000	15	1050	120	5
	Cadmium (Filtered)	µg/L	0.1	0.2	5.5	2	20	15	<0.1	0.05	0
	Chromium (III+VI) (Filtered)	µg/L	1					15	9	0.5	0
	Cobalt (Filtered)	µg/L	1		1			15	15	0.5	5
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	15	3	0.5	2
	Iron (Filtered)	mg/L	0.05					15	506	0.025	15
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	15	4	0.5	1
	Magnesium (Filtered)	mg/L	1					15	952	54	0
	Manganese (Filtered)	µg/L	1	1900		500	5000	15	12600	422	5
	Mercury (Filtered)	µg/L	0.1	0.6	0.4	1	10	15	<0.1	0.05	0
	Nickel (Filtered)	µg/L	1	11	70	20	200	15	10	0.5	0
	Zinc (Filtered)	µg/L	5	8	15			15	34	2.5	4
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					15	148	0.5	0
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					15	1050	0.5	0
	Alkalinity (total) as CaCO3	mg/L	1					15	1130	195	0
	Ammonia	mg/L	0.01	0.9	0.91		0.5	15	1.55	0.6	11
	Anions Total	meq/L	0.01					15	379	31.3	0
	Bicarbonate Alkalinity as CaCO3	mg/L	1					15	260	76	0
	Calcium (Filtered)	mg/L	1					15	1010	174	0
	Cations Total	meq/L	0.01					15	380	28.5	0
	Chloride	mg/L	1					15	12300	803	15
	pH (lab)	pH Units	0.01	7.0 - 8.5[#5]	8.0 - 8.4[#5]			15	12	7.96	13
	Electrical conductivity (lab)	uS/cm	1					15	37100	3450	0
	Fluoride	mg/L	0.1			1.5	15	15	0.6	0.3	0
	Ionic Balance	%	0.01					15	6.12	3.83	0
	Kjeldahl Nitrogen Total	mg/L	0.1					15	4.2	1.2	0
	Nitrate (as N)	mg/L	0.01	0.1581[#2]		11.29[#1]		15	<0.25	0.03	1
	Nitrite (as N)	µg/L	10			910[#3]		15	<250	5	0
	Nitrogen (Total Oxidised)	mg/L	0.01					15	<0.25	0.04	0
	Nitrogen (Total)	mg/L	0.1					15	4.2	1.3	0
	Phosphorus	mg/L	0.01					15	1.22	0.06	0
	Potassium (Filtered)	mg/L	1					15	97	35	0
	Reactive Phosphorus as P	mg/L	0.01		0.01[#4]			15	<0.1	0.005	5
	Sodium (Filtered)	mg/L	1					15	5740	401	15
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					15	1570	264	0
	Total Dissolved Solids	mg/L	10					14	31800	1920	14
	Total Dissolved Solids (Filtered)	mg/L	10					1	1640	1640	1
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					15	580	20	0
	TRH >C10 - C16	µg/L	100					15	160	50	0
	TRH >C16 - C34	µg/L	100					15	580	50	0
	TRH >C34 - C40	µg/L	100					15	180	50	0
	TRH >C10 - C40 (Sum of total)	µg/L	100					15	760	50	0
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					15	0.19	0.01	0
	TRH >C10 - C16 less Naphthalene (F2)	mg/L	0.1					15	0.16	0.05	0
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					15	580	30	0
	TPH C10 - C14	µg/L	50					15	150	25	0
	TPH C15 - C28	µg/L	100					15	440	50	0
	TPH C29-C36	µg/L	50					15	240	25	0
	TPH C10 - C36 (Sum of total)	µg/L	50					15	680	25	0
BTEXN	Benzene	µg/L	1	950	700	1	10	15	29	2	9
	Ethylbenzene	µg/L	2			300	3000	15	<5	1	0
	Toluene	µg/L	2			800	8000	15	422	1	0
	Total BTEX	mg/L	0.001					15	0.432	0.009	0
	Xylene (m & p)	µg/L	2					15	<5	1	0
	Xylene (o)	µg/L	2	350				15	<5	1	0
	Xylene Total	µg/L	2			600	6000	15	<5	1	0
PAHs	Benzo[b+j]fluoranthene	µg/L	1					15	<1	0.5	0
	Acenaphthene	µg/L	1					15	<1	0.5	0
	Acenaphthylene	µg/L	1					15	<1	0.5	0
	Anthracene	µg/L	1					15	<1	0.5	0
	Benz(a)anthracene	µg/L	1					15	<1	0.5	0
	Benzo(a) pyrene	µg/L	0.5			0.01		15	<0.5	0.25	15
	Benzo(a)pyrene TEQ (zero)	µg/L	0.5					15	<0.5	0.25	0
	Benzo(g,h,i)perylene	µg/L	1					15	<1	0.5	0
	Benzo(k)fluoranthene	µg/L	1					15	<1	0.5	0
	Chrysene	µg/L	1					15	<1	0.5	0
	Dibenz(a,h)anthracene	µg/L	1					15	<1	0.5	0
	Fluoranthene	µg/L	1					15	<1	0.5	0
	Fluorene	µg/L	1					15	<1	0.5	0
	Indeno(1,2,3-c,d)pyrene	µg/L	1					15	<1	0.5	0
	Naphthalene	µg/L	1	16	70			15	<1	0.5	0
	Phenanthrene	µg/L	1					15	<1	0.5	0
	Pyrene	µg/L	1					15	<1	0.5	0
	PAHs (Sum of total)	µg/L	0.5			0.01	0.1	3	<0.5	0.25	3
EPA 448 Classification of Wastes	Polycylic aromatic hydrocarbons EPA448	µg/L	0.5					12	<0.5	0.25	0

Env Stds Comments
#1:Converted from Nitrate as NO3 (50 mg/L)
#2:Converted from Nitrate as NO3 (700ug/L)
#3:Converted from Nitrite as NO2 (3 mg/L)
#4: Table 8.2.5 - ANZECC 2000 - Filterable Reactive Phosphorus for NSW, marine ecosystem
#5: Table 8.2.8 - ANZECC 2000 - pH values for NSW estuarine ecosytems

Appendix E. Modelled inflows to tunnel components

Table-1 South Model Tunnel Inflows – Rozelle to Sydney Harbour Section of WHT Project

Tunnel Sub-section [1]	Length	Tunnel Inflow (L/s)					
		2021	2022	2023	2024	2025	2126
NB - Entry Ramp - Rozelle Portal to Cavern	1047	0.101	0.058	0.050	0.039	0.035	0.024
NB Main Line Cavern	143	0.000	0.235	0.215	0.191	0.178	0.142
NB Main Line - Cavern towards Tunnel Stub	390	0.000	0.428	0.394	0.356	0.339	0.294
NB Main Line - Victoria Rd Site towards Yurulbin Park	1089	2.676	1.836	1.709	1.535	1.438	1.12
NB Main Line - Yurulbin Park to Sydney Harbour Transition Structure	130	0.000	0.000	0.000	0.000	0.000	0.000
NB Main Line - Yurulbin Park towards Rozelle	1021	1.212	1.714	1.692	1.651	1.633	1.593
SB Main Line - Access Point to Cavern	94	0.000	0.159	0.147	0.131	0.122	0.095
SB Main Line Cavern	137	0.000	0.199	0.182	0.162	0.152	0.121
SB Main Line - Cavern to Tunnel Stub	292	0.000	0.285	0.263	0.240	0.229	0.197
SB Main Line - Victoria Rd Site towards Yurulbin Park	1059	1.505	1.852	1.727	1.555	1.457	1.128
SB Main Line - Yurulbin Park to Sydney Harbour Transition Structure	130	0.212	0.212	0.000	0.000	0.000	0.000
SB Main Line - Yurulbin Park towards Rozelle	1051	1.260	1.714	1.694	1.645	1.621	1.565
SB Exit Ramp - Rozelle Portal to Cavern (SB Ramp Cavern)	131	0.021	0.006	0.004	0.002	0.001	0.000
SB Exit Ramp - Rozelle Portal to Cavern (SB Exit Ramp - Eastern)	240	0.011	0.004	0.004	0.003	0.002	0.002
SB Exit Ramp - Rozelle Portal to Cavern (SB Exit Ramp - Western)	260	0.011	0.006	0.005	0.004	0.004	0.003
SB Exit Ramp - Rozelle Portal to Cavern (SB Exit Ramp - Main)	493	0.319	0.550	0.443	0.322	0.27	0.146
TOTAL INFLOW (L/s)		**7.328**	**9.258**	**8.529**	**7.836**	**7.481**	**6.43**
		Tunnel Inflow (L/s/km)					
		2021	**2022**	**2023**	**2024**	**2025**	**2126**
AVERAGE INFLOW (L/s/km)		**0.951**	**1.201**	**1.107**	**1.017**	**0.971**	**0.834**

Notes. [1] NB = North Bound, SB = South Bound, EB = East Bound & WB = West Bound.

Table-1 North Model Tunnel Inflows – Sydney Harbour to Warringah Freeway Section of WHT Project

Tunnel Sub-section [1]	Length	Tunnel Inflow (L/s)					
		2021	2022	2023	2024	2025	2126
NB Main Line - Berrys Bay towards Sydney Harbour (Undrained)	140	0.153	0.000	0.000	0.000	0.000	0.000
NB Main Line - Berrys Bay towards North Sydney	1348	0.048	0.495	0.418	0.348	0.328	0.288
NB Main Line - Cammeray Golf Course Access Point to NB North Sydney Cavern	937	0.345	0.097	0.109	0.104	0.110	0.151
NB North Sydney Cavern	159	0.223	0.091	0.082	0.072	0.071	0.067
NB Ramp - From NB North Sydney Cavern to Falcon Street Exit Portal	402	0.000	0.104	0.098	0.033	0.090	0.096
NB Main Line - NB North Sydney Cavern towards Sydney Harbour	204	0.173	0.194	0.170	0.142	0.134	0.122
SB Main Line - Berry Bay towards Sydney Harbour (Undrained)	90	0.823	0.000	0.000	0.000	0.000	0.000
SB Main Line - Berrys Bay towards North Sydney	1565	0.916	1.736	1.445	1.221	1.153	1.005
SB Main Line - Cammeray Golf Course Access Point to SB North Sydney Cavern	774	0.088	0.120	0.157	0.142	0.147	0.189
SB North Sydney Cavern	180	0.181	0.059	0.059	0.048	0.048	0.042
SB Ramp - SB North Sydney Cavern towards Berry St Entry Portal	210	0.000	0.101	0.076	0.059	0.057	0.049
SB Main Line - SB North Sydney Cavern towards Sydney Harbour	194	0.000	0.107	0.086	0.070	0.067	0.055
TOTAL TUNNEL INFLOW (L/s)		**2.951**	**3.106**	**2.700**	**2.296**	**2.205**	**2.063**
		Average Inflow (L/s/km)					
		2021	**2022**	**2023**	**2024**	**2025**	**2126**
AVERAGE INFLOW (L/s/km)		**0.476**	**0.501**	**0.435**	**0.370**	**0.355**	**0.333**

Notes. [1] NB = North Bound, SB = South Bound, EB = East Bound & WB = West Bound.

Table-3 Summary of Modelled Tunnel Inflows

Year	Project Inflows				
	Western Harbour		Beaches Link		Cumulative [1]
	L/s/km	ML/day	L/s/km	ML/day	ML/day
2021	0.739	0.888	0.000	0.000	1.740
2022	0.888	1.068	0.419	0.733	2.540
2023	0.807	0.970	0.778	1.361	3.030
2024	0.728	0.875	1.192	2.086	3.590
2025	0.696	0.837	0.950	1.663	3.090
2126	0.611	0.734	0.740	1.294	2.510

Notes: [1] Includes modelled inflows to components of the Chatswood to Sydenham Sydney Metro Project and the proposed Rozelle interchange portion of the M4-M5 Link Project.

Appendix F. Groundwater Modelling Report

Roads and Maritime Services

Western Harbour Tunnel and Warringah Freeway Upgrade

Groundwater Modelling Report

January 2020

Prepared for

Roads and Maritime

Prepared by

Jacobs Group (Australia) Pty. Ltd.

Contents

List of Figures

List of Tables

Executive Summary

The Western Harbour Tunnel and Beaches Link program of works includes a new motorway tunnel across Sydney Harbour (The Western Harbour Tunnel and Warringah Freeway Upgrade project) and a new tolled motorway tunnel connection across Middle Harbour from the Warringah Freeway and Gore Hill Freeway to Balgowlah and Killarney Heights (The Beaches Link and Gore Hill Freeway Connection project).

The proposed tunnels have the potential to cause groundwater-related impacts. Groundwater modelling was undertaken in support of the environmental impact assessment of the potential groundwater-related impacts.

Available hydrogeological, geological, water level and hydraulic testing data were used to develop a conceptual groundwater model and develop a three-dimensional numerical groundwater model. The numerical groundwater model was used to estimate groundwater inflows, groundwater level drawdown, and changes in groundwater discharge to watercourses. Two-dimensional numerical groundwater models were developed to assess the rate of inland movement of saline water from saltwater bodies adjacent to the tunnels.

Two three-dimensional groundwater models were developed to cover the whole proposed tunnel alignment for the program of works. More accurate and efficient modelling was undertaken by splitting the model area into these two models, separated along Sydney Harbour. The developed models meet the Class 2 requirements of the Australian Groundwater Modelling Guidelines. Both models were calibrated for steady state conditions against measured groundwater levels and steam flows, and for transient conditions against measured groundwater levels.

Predictive model scenarios considered the Western Harbour Tunnel project only, the Beaches Link project only, and both projects (the cumulative case). A cumulative scenario considered the presence of the M4-M5 Link project also. The predictive modelling considered a construction phase from January 2015 to December 2035, followed by an operational phase to December 2126.

Project-wide tunnel groundwater inflows were predicted during the construction period and at 100 years of operation. Predicted inflows ranged between 0.04 ML/day and 0.75 ML/day for the Western Harbour Tunnel Project and 0.11 ML/day and 2.77 ML/day for the Beaches Link Tunnel Project during construction and were predicted to be 0.49 ML/day for the Western Harbour Tunnel Project and 1.94 ML/day for the Beaches Link Tunnel Project after approximately 100 years of operation.

Predicted groundwater level drawdown results from the two groundwater models were combined to provide predicted drawdown contours for the Western Harbour Tunnel Project only, the Beaches Link Project only; and the cumulative scenario. Groundwater level drawdown results are provided in the Groundwater Technical Paper at the end of construction and at approximately 100 years of operation.

The potential change in groundwater baseflow contribution to surface waters was simulated. For the cumulative scenario, baseflow reduction was predicted at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek. The baseflow reduction at these three creeks is almost entirely due to the Beaches Link Project, as the impacts due to the Western Harbour Tunnel projects are assessed to be negligible.

Uncertainty analysis was undertaken to investigate the sensitivity of model predictions to the parameter values assigned to the model. Variations in aquifer storage, rainfall recharge, hydraulic conductivity and vertical hydraulic conductivity anisotropy, and model-drain conductance parameters were assessed. The modelled tunnel inflows are most sensitive to changes in hydraulic conductivity and the ratio between vertical and horizontal hydraulic conductivity, and less sensitive to changes in storage parameters, rainfall recharge and drain conductance.

The groundwater level drawdown results from the uncertainty analysis were used to assess modelled conditions that could result in impacts beyond the Level 1 Minimal Impact Considerations nominated in the NSW Aquifer Interference Policy for groundwater supply bores. Modelled uncertainty scenarios generally had similar predicted drawdown impacts at existing bores to the base case models.

Some tunnel sections lie in close proximity to saltwater bodies, and there is potential for saline water intrusion into the groundwater system. Potential saline water intrusion was modelled at each of the deepest sections of the proposed Western Harbour Tunnel project tunnel alignments. Negligible to minor saline water intrusion impacts were predicted.

1. Introduction

1.1 Overview

The Greater Sydney Commission's *Greater Sydney Region Plan – A Metropolis of Three Cities* (Greater Sydney Commission, 2018) proposes a vision of three cities where most residents have convenient and easy access to jobs, education and health facilities and services. In addition to this plan, and to accommodate for Sydney's future growth the NSW Government is implementing the *Future Transport Strategy 2056* (Transport for NSW, 2018), a plan that sets the 40-year vision, directions and outcomes framework for customer mobility in NSW. The Western Harbour Tunnel and Beaches Link program of works is proposed to provide additional road network capacity across Sydney Harbour and to improve transport connectivity with Sydney's northern beaches. The Western Harbour Tunnel and Beaches Link program of works include:

- The Western Harbour Tunnel and Warringah Freeway Upgrade project which comprises a new tolled motorway tunnel connection across Sydney Harbour, and an upgrade of the Warringah Freeway to integrate the new motorway infrastructure with the existing road network and to connect to the Beaches Link and Gore Hill Freeway Connection project
- The Beaches Link and Gore Hill Freeway Connection project which comprises a new tolled motorway tunnel connection across Middle Harbour from the Warringah Freeway and Gore Hill Freeway to Balgowlah and Killarney Heights and including the surface upgrade of Wakehurst Parkway from Seaforth to Frenchs Forest and upgrade and integration works to connect to the Gore Hill Freeway at Artarmon.

A combined delivery of the Western Harbour Tunnel and Beaches Link program of works would unlock a range of benefits for freight, public transport and private vehicle users. It would support faster travel times for journeys between the Northern Beaches and south, west and north-west of Sydney Harbour. Delivering the program of works would also improve the resilience of the motorway network, given that each project provides an alternative to heavily congested harbour crossings.

1.2 The Western Harbour Tunnel and Warringah Freeway Upgrade Project

1.2.1 Project Summary

Roads and Maritime Services (Roads and Maritime) is seeking approval under Division 5.2, Part 5 of the Environmental Planning and Assessment Act 1979 to construct and operate the Western Harbour Tunnel and Warringah Freeway Upgrade, which would comprise two main components:

- A new crossing of Sydney Harbour involving twin tolled motorway tunnels connecting the M4-M5 Link at Rozelle and the existing Warringah Freeway at North Sydney (the Western Harbour Tunnel)
- Upgrade and integration works along the existing Warringah Freeway, including infrastructure required for connections to the Beaches Link and Gore Hill Freeway Connection project (the Warringah Freeway Upgrade).

Key features of the Western Harbour Tunnel component of the project are shown in Figure A1-1 in Annexure 1 and would include:

- Twin mainline tunnels about 6.5 kilometres long and each accommodating three lanes of traffic in each direction, connecting the stub tunnels from the M4-M5 Link at Rozelle to the Warringah Freeway and to the Beaches Link mainline tunnels at Cammeray. The crossing of Sydney Harbour between Birchgrove and Waverton would involve a dual, three lane, immersed tube tunnel
- Connections to the stub tunnels at the M4-M5 Link project in Rozelle and to the mainline tunnels at Cammeray (for a future connection to the Beaches Link and Gore Hill Freeway Connection project)
- Surface connections at Rozelle, North Sydney and Cammeray, including direct connections to and from the Warringah Freeway (including integration with the Warringah Freeway Upgrade), an off ramp to Falcon Street and an on ramp from Berry Street at North Sydney

- A ventilation outlet and motorway facilities (fitout and commissioning only) at the Rozelle Interchange
- A ventilation outlet and motorway facilities at the Warringah Freeway in Cammeray
- Operational facilities including a motorway control centre at Waltham Street, within the Artarmon industrial area and tunnel support facilities at the Warringah Freeway in Cammeray
- Other operational infrastructure including groundwater and tunnel drainage management and treatment systems, signage, tolling infrastructure, fire and life safety systems, lighting, emergency evacuation and emergency smoke extraction infrastructure, CCTV and other traffic management systems.

Key features of the Warringah Freeway Upgrade component of the project are shown in A1-2 and would include:

- Upgrade and reconfiguration of the Warringah Freeway from immediately north of the Sydney Harbour Bridge through to Willoughby Road at Naremburn
- Upgrades to interchanges at Falcon Street in Cammeray and High Street in North Sydney
- New and upgraded pedestrian and cyclist infrastructure
- New, modified and relocated road and shared user bridges across the Warringah Freeway
- Connection of the Warringah Freeway to the portals for the Western Harbour Tunnel mainline tunnels and the Beaches Link tunnels via on and off ramps, which would consist of a combination of trough and cut and cover structures
- Upgrades to existing roads around the Warringah Freeway to integrate the project with the surrounding road network
- Upgrades and modifications to bus infrastructure, including relocation of the existing bus layover along the Warringah Freeway
- Other operational infrastructure, including surface drainage and utility infrastructure, signage, tolling, lighting, CCTV and other traffic management systems.

A detailed description of the project is provided in Chapter 5 (Project description) and construction of the project is described in Chapter 6 (Construction work) of the environmental impact statement. The project alignment at the Rozelle Interchange shown in Figure A1-1 and Figure A1-3 reflects the arrangement presented in the environmental impact statement for the M4-M5 Link, and as amended by the proposed modifications. The project would be constructed in accordance with the now finalised M4-M5 Link detailed design (refer to Section 2.1.1 of Chapter 2 (Assessment process) of the environmental impact statement for further details).

The project does not include ongoing motorway maintenance activities during operation or future use of residual land occupied or affected by project construction activities, but not required for operational infrastructure. These would be subject to separate planning and approval processes at the relevant times.

Subject to the project obtaining planning approval, construction is anticipated to commence in 2020 and is expected to take around six years to complete.

The Western Harbour Tunnel and Warringah Freeway Upgrade Project is referred to in this report as the ‘Western Harbour Tunnel Project’. The Beaches Link and Gore Hill Freeway Connection Project is referred to in this report as the ‘Beaches Link Project’.

1.2.2 Key Construction Activities – Western Harbour Tunnel Project

The area required to construct the project is referred to as the construction footprint. Most of the construction footprint would be located underground within the mainline tunnels. However, surface areas would be required to support tunnelling activities and to construct the tunnel connections, tunnel portals and operational ancillary facilities.

Key construction activities would include:

- Early works and site establishment, with typical activities being property acquisition and condition surveys, utilities installation, protection, adjustments and relocations, installation of site fencing, environmental controls (including noise attenuation and erosion and sediment control) and traffic management controls, vegetation clearing, earthworks and demolition of structures, establishment of construction support sites including acoustic sheds and associated access decline acoustic enclosures (where required), construction of minor access roads and the provision of property access, temporary relocation of pedestrian and cycle paths and bus stops, temporary relocation of swing moorings within Berrys Bay and relocation of the historic vessels

- Construction of Western Harbour Tunnel, with typical activities being excavation of tunnel construction accesses, construction of driven tunnels, cut and cover and trough structures and construction of cofferdams, dredging activities in preparation for the installation of immersed tube tunnels, casting and installation of immersed tube tunnels and civil finishing and tunnel fitout
- Construction of operational facilities comprising of a motorway control centre at Waltham Street in Artarmon, motorway and tunnel support facilities and ventilation outlets at the Warringah Freeway in Cammeray, construction and fitout of the project operational facilities that form part of the M4-M5 Link Rozelle East Motorway Operations Complex, a wastewater treatment plant at Rozelle and the installation of motorway tolling infrastructure
- Construction of the Warringah Freeway Upgrade, with typical activities being earthworks, bridgeworks, construction of retaining walls, stormwater drainage, pavement works and linemarking and the installation of road furniture, lighting, signage and noise barriers
- Testing of plant and equipment, and commissioning of the project, backfill of access declines, removal of construction support sites, landscaping and rehabilitation of disturbed areas and removal of environmental and traffic controls.

Temporary construction support sites would be required as part of the Western Harbour Tunnel Project (refer to Figure A1-3), and would include tunnelling and tunnel support sites, civil surface sites, cofferdams, mooring sites, wharf and berthing facilities, laydown areas, parking and workforce amenities. Construction support sites for Western Harbour Tunnel would include:

- Rozelle Rail Yards (WHT1)
- Victoria Road (WHT2)
- White Bay (WHT3)
- Yurulbin Point (WHT4)
- Sydney Harbour south cofferdam (WHT5)
- Sydney Harbour north cofferdam (WHT6)
- Berrys Bay (WHT7)
- Berry Street north (WHT8).
- Ridge Street north (WHT9)
- Cammeray Golf Course (WHT10)
- Waltham Street (WHT11).

During the construction of the Warringah Freeway Upgrade, smaller construction support sites would be required to support the construction works (as shown in Figure A1-3). These include:

- Blue Street (WFU1)
- High Street south (WFU2)
- High Street north (WFU3)
- Arthur Street east (WFU4)
- Berry Street east (WFU5)
- Ridge Street east (WFU6)
- Merlin Street (WFU7)

- Cammeray Golf Course (WFU8)
- Rosalind Street east (WFU9).

A detailed description of construction works for the project is provided in Chapter 6 (Construction work) of the environmental impact statement.

1.2.3 Project Location – Western Harbour Tunnel Project

The project would be located within the Inner West, North Sydney and Willoughby local government areas, connecting Rozelle in the south with Naremburn in the north.

Commencing at the Rozelle Interchange, the mainline tunnels would pass under Balmain and Birchgrove, then cross Sydney Harbour between Birchgrove and Balls Head. The tunnels would then continue under Waverton and North Sydney, linking directly to the Warringah Freeway to the north of the existing Ernest Street bridge.

The motorway control centre would be located at Waltham Street, Artarmon, with a trenched communications cable connecting the motorway control centre to the Western Harbour tunnel along the Gore Hill Freeway and Warringah Freeway road reserves.

The Warringah Freeway Upgrade would be carried out on the Warringah Freeway from around Fitzroy Street at Milsons Point to around Willoughby Road at Naremburn. Upgrade works would include improvements to bridges across the Warringah Freeway, and upgrades to surrounding roads.

1.3 Construction Methodology and Interaction with Groundwater

The tunnelling strategy considered for the mined land tunnels is the use of a road header. The tunnelling strategy considered for the Western Harbour crossing is the immersed tube tunnel design. The following section describes aspects of the construction methodology that are relevant to the groundwater impact assessment.

1.3.1 Mined Tunnel and Lining Methods

The mined tunnel would be supported by permanent rock bolts, shotcrete and a cast-in-situ concrete lining system depending on the geotechnical and hydrogeological conditions.

The tunnel lining system would comprise the following three methods:

- Typical drained tunnel lining: About 93 per cent of the tunnel would be drained via a typical drained tunnel lining. This method is proposed where groundwater inflows are considered to be low (less than one litre per second per kilometre). The lining would comprise 125-millimetre permanent shotcrete
- Drained tunnel with umbrella: About three per cent of the tunnel is expected to utilise a water proof umbrella system where there is risk of elevated groundwater inflows due to geological features and defects or in the vicinity of water courses and portals. The waterproof umbrella would comprise 50-millimetre permanent shotcrete, 20-millimetre waterproof membrane over concrete drains that direct seepage to the floor drains. The crown of three and two lane tunnels would be finished with a 200 millimetre and 150 millimetre inner lining
- Tanked or undrained tunnel lining: About four per cent of the tunnel would be fully lined with a waterproof membrane to control higher potential inflows (greater than one litre per second per kilometre) where the alignment is below sea level adjacent to the immersed tube harbour crossing. A tanked tunnel system negates the requirement for ongoing draining and dewatering and therefore reduces groundwater drawdown and potential environmental ` where gravity drainage and water transfers would transfer the accumulated seepage to the long-term wastewater treatment plants. During construction, separation would be maintained between the groundwater and contaminated wash water to optimise groundwater treatment. A shotcrete lining applied to the tunnels side wall minimises groundwater oxidation and hence the formation of iron oxide sludge.

1.3.2 Immersed Tube Tunnel Design

The Western Harbour crossing would utilise an immersed tube tunnel design from Birchgrove to Balls Head.. The required roadway grading across the harbour would be achieved with a constant 0.5 per cent slope, which would facilitate water drainage. Any water collected within the immersed tube tunnel would be pumped to the designated wastewater treatment plant. On completion, the immersed tube tunnel would be fully watertight under the applied external loading including potential sea level rise. Therefore, no inflows are anticipated.

1.3.3 Cavern Design

The Western Harbour Tunnel Project includes five mined caverns, three at Rozelle and two at St Leonards. Caverns would be situated at diverging and merging areas as well as exit and entry points. The length of the caverns would vary from 131 metres to 174 metres and the width would vary from 12 metres to 30 metres.

The Beaches Link and Gore Hill Freeway Connection Project would include six mined caverns, two at the Gore Hill entry and exit, two at the Warringah Freeway exit and entry and two at the Wakehurst Parkway exit and entry. Caverns would be situated at diverging and merging areas as well as exit and entry points. The length of the caverns would vary from 108 metres to 208 metres and the width would vary from 15 metres to 28 metres.

The caverns would be lined with 50 millimetre fibre reinforced shotcrete applied to the excavated rock surface. Weepholes would be drilled through the shotcrete layer with attached strip drains to drain groundwater from the surrounding rock mass. A further 50 millimetre shotcrete layer would be applied over the strip drains.

1.3.4 Other Tunnel Elements

Other, more minor, tunnel elements would be established which include ramps, cross passages, egress passages, ventilation tunnels, breakdown bays, substations and drainage sumps. The construction and groundwater management methodologies employed for these elements would be consistent with practices detailed above for the major tunnel elements. Typically, the other tunnel elements would be drained and, in some cases, utilise a waterproof umbrella.

1.4 Secretary’s Environmental Assessment Requirements.

The Secretary’s environmental assessment requirements (SEARS) relating to the Groundwater Impact Assessment and where these requirements are addressed are outlined in Table 1.1. As the SEARS relate to water more generally, several of the requirements are covered in other technical papers, namely:

- The potential for settlement to occur as a result of groundwater drawdown or changed flow conditions (SEAR 9.3b) is assessed in the Geotechnical Technical Paper
- Increased erosion, siltation or reduction of the stability of river banks and watercourses (SEAR 9.3d) may be affected by groundwater drawdown, but is more relevant to assessments of surface water runoff and geotechnical stability, and is assessed in surface water and geotechnical technical papers
- Final landform of sites including void management and rehabilitation (SEAR 9.4) is more closely related to geotechnical assessment, and is covered in the Geotechnical Technical Paper
- Identification of the rainfall event that the water quality objectives are designed to cope with (SEAR 10.1d) is covered in the Surface Water Technical Paper
- Identification of contamination risks is covered in the Contaminated Land Technical Paper.

Table 1.1: Secretary's environmental assessments requirements – Groundwater impact assessment

Key issue and desired performance outcome	Requirement (specific assessment requirements in addition to the general requirement above)	Where addressed
9. Water – Hydrology 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. The Proponent must describe (and map) the existing hydrological regime for any surface and groundwater resource (including reliance by users and for ecological purposes and groundwater dependent ecosystems) likely to be impacted by the project, including rivers, streams, wetlands and estuaries as described in Appendix 2 of the Framework for Biodiversity Assessment – NSW Biodiversity Offsets Policy for Major projects (OEH, 2014).	• Section 2.5 in this report
	2. The Proponent must prepare a detailed water balance for ground and surface water including the proposed intake and discharge locations (including mapping of these locations), volume, frequency and duration for both the construction and operational phases of the project.	• Section 6 of this report • Technical Paper Surface water quality and hydrology

Key issue and desired performance outcome	Requirement (specific assessment requirements in addition to the general requirement above)	Where addressed
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.	3. The Proponent must assess (and model if appropriate) the impact of the construction and operation of the project and any ancillary facilities (both built elements and discharges) on surface and groundwater hydrology in accordance with the current guidelines, including: (a) natural processes within rivers, wetlands, estuaries, marine waters and floodplains that affect the health of the fluvial, riparian, estuarine or marine system and landscape health (such as modified discharge volumes, durations and velocities), aquatic connectivity, water dependent fauna and flora and access to habitat for spawning and refuge; (b) impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, barriers to flows, implications for groundwater dependent surface flows, ecosystems and species, groundwater users and the potential for settlement; (c) changes to environmental water availability and flows, both regulated/licensed and unregulated/rules-based sources including the stormwater harvesting scheme implemented by North Sydney Council at the storage dam at Cammeray Golf Course; (d) direct or indirect increases in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses; (e) 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 systems where discharges are proposed through such systems; and (f) measures to mitigate the impacts of the proposal and manage the disposal of produced and incidental water.	• Section 8 and 11 in this report • Technical Paper Surface water quality and hydrology
	4. The assessment must provide details of the final landform of the sites to be excavated or modified (eg portals), including final void management and rehabilitation measures.	• Technical Working Paper: Urban Design, landscape character and visual impact
	5. The Proponent must identify any requirements for baseline monitoring of hydrological attributes.	• Section 2 in this report

Key issue and desired performance outcome	Requirement (specific assessment requirements in addition to the general requirement above)	Where addressed
		• Technical Paper Surface water quality and hydrology
	6. The assessment must include details of proposed surface and groundwater monitoring.	• Technical Paper Surface water quality and hydrology
	7. The Proponent must identify design approaches to minimise or prevent drainage of alluvium in the paleochannels.	• Technical Paper Surface water quality and hydrology
10. Water – Quality 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	1. The Proponent must: (a) describe the background conditions for any surface or groundwater resource likely to be affected by the development (b) state the ambient NSW Water Quality Objectives (NSW WQO) (as endorsed by the NSW Government [see www.environment.nsw.gov.au/ieo/index.htm]) and environmental values for the receiving waters (including groundwater where appropriate) relevant to the project and that represent the community's uses and values for those receiving waters, including the indicators and associated trigger values or criteria for the identified environmental values in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government; (c) identify and estimate the quality and quantity of all pollutants that may be introduced into the water cycle by source and discharge point and describe the nature and 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; (d) identify the rainfall event that the water quality protection measures will be designed to cope with; (e) assess the significance of any identified impacts including consideration of the relevant ambient water quality	• Section 5 in this report • Technical Paper Surface water quality and hydrology • Technical working Paper: Contamination

Key issue and desired performance outcome	Requirement (specific assessment requirements in addition to the general requirement above)	Where addressed
including estuarine and marine water (if applicable).	outcomes; (f) demonstrate how construction and operation of the project (including mitigating effects of proposed stormwater and wastewater management) 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; and - where the NSW WQOs are not currently being met, activities will work toward their achievement over time; (g) justify, if required, why the WQOs cannot be maintained or achieved over time; (h) demonstrate that all practical measures to avoid or minimise water pollution and protect human health and the environment from harm are investigated and implemented; (i) identify sensitive receiving environments (which may include estuarine and marine waters downstream including Quarry Creek and its catchment) and develop a strategy to avoid or minimise impacts on these environments; and (j) identify proposed monitoring locations, monitoring frequency and indicators of surface and groundwater quality.	
	2. The assessment should consider the results of any current water quality studies, as available, in the project catchment.	• Technical Paper Surface water quality and hydrology

1.5 Scope of Work

The scope of work for the groundwater modelling assessment included the following tasks:

1.5.1 Task 1: Data Collation

- Translate available hydrogeological, geological, water level, hydraulic testing, inflow and tunnel design information, as available, into a format that can be used in the numerical groundwater model
- Collate borehole and geological long-section data into a 3D conceptual model.

1.5.2 Task 2: Modelling

- Construct a 3D groundwater flow model using MODFLOW-USG. Use a conservative, yet sensible representation of expected groundwater behaviour
- Calibrate model to available data
- Carry out predictive groundwater modelling for proposed construction and post construction stages
- Provide groundwater flow model outputs for use in compiling the detailed site water balance
- Use model outputs to estimate the licensable take from both surface and groundwater. RMS, as a transport authority, is exempt from the requirement to hold Water Access Licences, according to Schedule 4, Part 1, Clause 2 of the Water Management (General) Regulation 2011 (https://www.legislation.nsw.gov.au/#/view/regulation/2011/469/sch5). However, it is a usual requirement of the Secretary's environmental assessment requirements (SEARs) that the licensable take be calculated.

1.5.3 Task 3: Preparation of Technical Appendix

- Document the groundwater model construction, calibration and results of predictions in a technical appendix. A summary of the results will be included within the main body of the Groundwater Technical Paper.

1.5.4 Task 4: Impact Assessment

- Provide model outputs to assist in addressing Level 1 Minimal Impact Considerations of the NSW Aquifer Interference Policy and assessment of Compliance with the Rules of the Water Sharing Plan
- Provide model outputs to assist in assessment of impacts on surrounding land uses, groundwater users, groundwater dependent ecosystems as well as impact on surface waters.

Groundwater modelling has been conducted in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012) as well as the MDBC Groundwater Flow Modelling Guideline (MDBC 2001). The groundwater modelling methodology and outputs were reviewed by a suitably qualified independent expert.

2. Existing Environment

2.1 Rainfall and Climate

Rainfall data from the BOM weather stations at Sydney Botanic Gardens (BoM Station 66006), Observatory Hill (BoM Station 66062), and Mosman Council (BoM Station 66184). Station locations are provided in Figure A1-4 and Figure A1-5 A summary of the rainfall information for each of these stations is provided on Table 2.1. Observatory Hill (BoM Station 66062) has the longest and most complete rainfall record with complete data for 160 years of observation.

Table 2.1: Rainfall record summary

Station	Rainfall record	Number of years of incomplete data (excluding 2017)
066006 (Botanic Gardens)	133 years (1985 to present)	14 (10.5%)
066062 (Observatory Hill)	160 years (1858 to present)	1 (0.6%)
066184 (Mosman Council)	22 years (1984 to 2007)	12 (54.5%)

Table 2.2 presents average monthly rainfall for the stations. Most rainfall occurs in the first half of the year, peaking in June, there is then an abrupt seasonal change with the lowest rainfalls occurring in September. Average annual rainfall is in the order of 1215 to 1230 mm/year across the three stations.

Table 2.2: Average monthly rainfall (mm)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
066006	103.6	113.2	134.5	123.1	120.8	135.4	98.2	86.4	68.6	75.2	85.2	82.2	1230.7
066062	102.2	117.6	130.9	128.5	118.6	133.2	97.1	81.1	68.4	76.4	83.8	77.6	1215.7
066184	110.3	139.4	95.7	147.6	123.3	122.8	77.4	76.1	63.0	79.6	111.0	91.8	1231.5

Evapotranspiration data for Observatory Hill from 1990 to present indicates that mean daily evapotranspiration ranged from 1.7 millimetres in June to 4.7 millimetres in December (Table 2.3). Average annual evapotranspiration for the monitoring period is 3.28 mm/day or 1198 mm/year.

Table 2.3: Mean daily evapotranspiration - Observatory Hill (BoM Station 66062)

Record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
ET (mm)	4.6	4.2	3.5	2.7	2.1	1.7	1.8	2.4	3.2	3.9	4.4	4.7	3.3

2.2 Topography and drainage

Figure A1-6 presents the main topography and drainage elements within the Western Harbour Tunnel Project area. The WHT Project alignment has one harbour crossing at the Sydney Harbour. At the southern extent of the WHT Project area is Whites Creek, which is a concrete lined artificial drainage that discharges to Rozelle Bay.

Topography and drainage features within the Beaches Link and Gore Hill Freeway Connection Project area are presented in Figure A1-7 The main bodies of water relevant to the project are Middle Harbour, a tidally influenced estuary and Manly Dam, a large freshwater lake. The project alignment has one harbour crossing at Middle Harbour.

The northern alignment of the project from Frenches Forest to North Balgowlah is situated above ground on a drainage divide between Seaforth Oval, to the west, and Bates Creek, Manly Creek and Manly Dam to the east.

The tunnel dives north of the Warringah Freeway to North Balgowlah, this part of the alignment underlies a topographic high with water sheds to the west and east of the alignment. The main surface drainage in the northern area is Burnt Bridge Creek in the North Balgowlah area. Burnt Bridge Creek flows east from North Balgowlah towards Manly Vale and intersects the project area at the Burnt Bridge Creek deviation.

Between Middle Harbour and the Warringah Freeway, the alignment crosses beneath Flat Rock Creek and the upper Willoughby Creek Catchment. Both Flat Rock Creek and Willoughby Creek drain to Middle Harbour. There are two crossings of Flat Rock Creek, one by the main Beaches Link alignment and one by the Gore Hill Freeway upgrade.

The drainage channels traversing the Beaches Link project footprint are typically highly modified, predominantly concrete lined channels, particularly within the upper reaches, and whilst having little ecosystem value they provide stability during stormwater overflows.

Flat Rock Creek is naturalised and forms a ravine at Flat Rock Gully between Naremburn and Willoughby. The substrate of Flat Rock Creek consists of bedrock at the valley floor and an alluvium bed where the creek becomes tidally influenced downstream. The natural drainage characteristics of the Flat Rock Creek catchment have been altered by residential, commercial and industrial development. The Creek is predominantly a concrete lined (open and closed) stormwater channel draining the suburbs of Artarmon, Naremburn and Willoughby. The channel travels underground from between Grandview Drive at Naremburn and Flat Rock Drive at Willoughby and has low flows during dry weather. Flat Rock Creek at its downstream reach drains a relatively steep catchment characterised by rocky riffle/runs with low to moderate flow during dry weather. The end point is a tidally influenced naturalised estuary at the base of Flat Rock Gully discharging into Long Bay.

Quarry Creek is a small natural estuarine tributary of Flat Rock Creek, which drains the Cammeray area and has a history of being quarried for sandstone. The creek has steep embankments on both sides and is now densely vegetated by weeds with limited accessibility.

Burnt Bridge Creek is an urban, intermittent waterway which flows through Balgowlah and Manly Vale into Manly Lagoon. Burnt Bridge Creek is a freshwater, first order stream, which receives multiple inflows of stormwater. The catchment contains a wide variety of land-uses including residential areas, the Balgowlah Industrial Estate, two golf courses and numerous roads. The creek is naturalised with rock, sand and mud substrate with narrow vegetated buffer zones. There are also a number of constructed waterway crossings, concrete and rock fill structures along the course of the creek. It is noted that Burnt Bridge Creek has been substantially degraded over the years largely due to the pressures generated from urban areas including a dense sewage system network and many stormwater outlets discharging to the creek. It is expected that increased stormwater runoff has contributed to the loss of coarse and fine grained sediments from the channel, leaving a scoured bedrock bed and eroded mud banks. This has resulted in Burnt Bridge Creek suffering from poor water quality, extensive weed infestation, erosion of creek banks, build-up of sediment and reduced biodiversity.

Manly Creek (or Curl Curl Creek) drains the urban areas of Frenchs Forest and flows through the Garrigal National Park into Manly Dam. The channel is formed of bedrock shelves, boulder and cobble runs and riffles, and pools that hold some sediment. The channel is generally two to three metres wide except at the ford where it is 20 metres wide and banks are generally low and stable.

Manly Dam is one of the largest freshwater lakes in Sydney which currently provides a valued facility for swimming, fishing, water-skiing, canoe/kayaking and boating. The gully/creeks contributing to the dam and the dam water body is unlikely to be susceptible to increased flows associated with the construction and operation of the project, given the bedrock controls and the anticipated small increase in flows relative to the range of flows that the gully/creeks experiences during storm events.

2.3 Stream Flow Monitoring

Water depth observations were made during the 2017-2018 dry season at locations shown in Figure A1-8 Table 2.4 presents approximate dry season water depths based on field observations.

Table 2.4: Water depths in watercourses.

Watercourse	Water depth above base (cm)	
	Upstream section	Downstream section
Flat Rock Creek	2	100
Manly Creek (Curl Creek) (1)	30 - 50	30 - 50
Burnt Bridge Creek	Dry	50
Willoughby Creek	1-2	1-2
Whites Creek	2-5	100

Notes. (1) Small intermittent pools with flow occurring as trickles that run between cracks in large boulders.

Preliminary flow gauging was carried out at Flat Rock Creek, Quarry Creek (tributary to Flat Rock Creek) and Burnt Bridge Creek in May 2018. Flow gauging was conducted with a portable flow meter where applicable, otherwise flow was indirectly measured using a velocity-cross sectional area relationship or measuring the time to fill a discrete volume. Flow monitoring sites are identified in Figure A1-9. The streamflow measurements were taken following a period of two weeks without rain. The estimated preliminary stream-flows were as follows.

- Flat Rock Creek – 18.4 L/s (1,590 m^3/day)
- Quarry Creek – 2.1 L/s (178 m^3/day)
- Burnt Bridge Creek – 1.5 L/s (130 m^3/day)

As indicated in Section 2.1, rainfall occurs mainly in the first half of the year, peaking in June. Rainfall is relatively high in May, when the streamflow measurements were taken. However, given that the streamflow measurements were taken during a drought year, following a period of two weeks without rainfall, the measured stream-flows were assumed to be indicative of typical dry season, dry weather conditions, without contribution from rainfall runoff. Dry season flows are typically sustained by groundwater discharges (baseflow).

Caution should be exercised when using the preliminary stream-flow measurements because the field measurements represent only one round of field observations. Jacobs recommend that continuous stream-flow monitoring is carried out along the three creeks to provide stream-flow hydrograph data that can be used to more accurately estimate baseflow by analysing streamflow-hydrograph recession curves. It is recommended that streamflow-rating curves are developed for the stream gauging stations to ensure that more accurate streamflow readings are collected.

Jacobs also recommend that further investigations are carried out to identify and quantify other surface water discharges to creeks that could affect creek low flows, including:

- Urban stormwater management practices that can potentially lead to temporary detention of stormwater to reduce peak stormflows by delaying natural stormwater discharge to streams.
- Excess irrigation
- Urban wastewater discharges
- Leakages from the water supply network

2.4 Geology

The geology of the alignment is dominated by the Hawkesbury Sandstone of the Permo-Triassic age Sydney Basin. In elevated areas the Hawkesbury Sandstone is overlain by the Ashfield Shale of the Wianamatta Group. An intermediate formation between the Hawkesbury Sandstone and the Ashfield Shale, the Mittagong Formation, is sometimes identified but is not mapped along the project alignment. In places the Sydney Basin sediments have been structurally deformed and includes faults, dykes, and joint swarms. Geology along the alignment is presented in Figure A1-10 and is summarised in Table 2.5.

Table 2.5: Summary of geology (Sources AECOM 2015 & WSP 2016)

AGE	GEOLOGICAL UNIT	DESCRIPTION
Quaternary	Fill	Typically comprising waste, emplaced material and engineered fill with a high potential for contamination. Reclaimed land areas are generally located adjacent to the harbour and include parkland, residential, industrial, and open space areas.
	Undifferentiated estuarine and alluvial sediments	Holocene and Pleistocene age, interbedded sands and clays with discontinuous “inter-fingered” lenses of sand and clay. May contain zones of colluvium. May be present as palaeochannel infill deposits.
	Marine sediments	Pleistocene age, primarily clayey sediments with intermittent sand lenses. Possibly containing gas, fissured.
Jurassic	Igneous Intrusion	Dykes
Mid-Triassic	Ashfield Shale	Consists of four variable thickness sub-units of siltstone and laminate.
	Mittagong Formation	Fine grained sandstone, and inter-bedded sandstone/siltstone.
	Hawkesbury Sandstone	Medium to coarse grained, quartzose sandstone. A combination of highly cross-bedded and massive sandstone units with interbedded siltstone.

2.4.1 Anthropogenic fill material

In general, a thin layer of fill (less than one metre-thick) is commonly encountered in urban areas and is associated with minor modifications to the topography, landscaping and pavement construction. Such fill can be highly variable in composition and compaction.

Thicker deposits of fill are expected towards the mouths of the infilled channels, associated with land reclamation, back-filled quarries, landfills, stream capture and urban development in these areas. There are no extensive areas of fill along the Western Harbour Tunnel project alignment but minor occurrences have been identified at Birchgrove Park (Figure A1-10) and in the vicinity of Whites Creek.

One of the main areas of fill is located at Flat Rock Creek. From the 1930’s Willoughby Council disposed of its garbage and waste, together with that from neighbouring councils, in an open tip at Flat Rock Creek. Drainage works enclosed the creek in a concrete tunnel and up to 50 metres of garbage and landfill was dumped over it (McKillop, 2012). In 1934 the Walter Burley Griffin Incinerator was built, with ash generated from the incineration of refuse deposited until the incinerator was closed in 1967 when it became obsolete. From the 1940s industrial and domestic waste were tipped and burnt in the area on both sides of Flat Rock Drive and into Flat Rock Gully. This ceased in 1985. The landscaped area on the east side of Flat Rock Drive is situated on about 30 metres of tip and soil fill.

Interpretation of historical records indicate that up to 40 metres of fill have been placed along Flat Rock Creek (WSP, 2016).

2.4.2 Palaeochannels

The occurrence of infilled palaeochannels or palaeovalleys is generally limited to beneath the main harbour areas. Some smaller occurrences of palaeochannel style deposits or basal sands may occur in the larger onshore drainages such as White Creek. The deeper sediments within these palaeovalleys are inferred to be of Pleistocene age.

Experience from previous tunnel projects in Sydney indicate that palaeovalleys are critical in tunnel design because the rock mass beneath palaeovalleys is often more structurally complex due to the association with geological structures such as faults and dykes and valley stress relief. Additionally, they can store and transmit large volumes of surface and groundwater resulting in increased groundwater inflow into tunnels and deep excavations.

Palaeovalley geometry along the project alignment is variable and generally increases in width and depth towards the palaeovalley axes in Sydney and Middle Harbours extending to a maximum depth of 85 metres below sea level near South Head at the entrance to Sydney Harbour.

The deepest palaeovalley sediments along the alignment are anticipated in a buried palaeovalley in Middle Harbour near Seaforth where they are inferred to be about 30 metres thick.

2.4.3 Jurassic Volcanics

Jurassic basaltic dykes intrude the shale and sandstone formations of the Sydney Basin. The dyke orientations are generally consistent with the main structural orientations and typically strike in two dominant directions: either between 90 and 120 degrees or between five and 35 degrees (Figure A1-10). The dykes are of variable thickness ranging from less than three metres up to 16 metres wide (AECOM, 2015). Dykes typically act as hydraulic barriers perpendicular to their orientation and can result in partitioning of groundwater. Dykes can also have elevated permeability parallel to strike resulting from jointing and alteration related to the original intrusion and subsequent weathering. As such they can present a risk to tunnelling. If unmanaged, dykes can result in a potentially hazardous situation as tunnelling through a depressurised aquifer can break through the dyke to encounter a fully pressurised formation. Dykes may also provide a conduit for higher groundwater inflows, especially when in close proximity to open water bodies such as the harbours.

Dykes are known to cross the project alignment at Seaforth and Balls Head, while another dyke also runs parallel with the alignment at Yurulbin Park (Figure A1-10). Other known dykes are projected to intercept the alignment at Waverton and Rozelle. It is also likely that there are other unidentified dykes in the project areas, which have not been identified due to the difficulty of mapping poorly defined outcrops in an urban environment.

2.4.4 Ashfield Shale

The Ashfield Shale consists of marine deposits made up of clay, silt and sand that has been mildly deformed and has developed into a laminated shale. It is generally a dark grey to black siltstone /mudstone or laminate (thin alternating layers of siltstone and sandstone). In some parts the shale may become carbonaceous with variable silt and clay particles throughout. The shale grades upwards into partly carbonaceous silty shale with siderite nodules and ironstone bands. The unit is laminated although retains bedding planes at some locations. Structural defects are present in the shale such as faults, fractures and shears (AECOM, 2015). Where it outcrops, the shale typically weathers to a stiff to hard clay with medium to high plasticity and the weathered profile generally extends down three metres to ten metres in depth.

The Ashfield Shale is only present along the project alignment at ridgelines and outcrops in the area from Willoughby to Neutral Bay Junction. The Warringah Freeway cuts through the Ashfield Shale, exposing the underlying Hawkesbury Sandstone at Naremburn and Cammeray (Figure A1-10).

2.4.5 Mittagong Formation

The Mittagong Formation is composed of a series of interbedded dark shale and sandstone of varying thicknesses and is the unit of change from the Ashfield Shale and underlying Hawkesbury Sandstone. The shale beds are very similar to the Ashfield Shale, though it is typically no more than 0.5 metres thick whilst the sandstone beds are up to 5 metres thick and are fine to medium grained and contain more silt than the Hawkesbury Sandstone (AECOM, 2015). Due to its reduced thickness, the Mittagong Formation rarely outcrops across the Sydney Basin. Hawkesbury Sandstone

2.4.6 Hawkesbury Sandstone

The Hawkesbury Sandstone was deposited in a fluvial palaeo-environment, likely to have been a braided river setting, and as such is highly stratified. The sandstone is ubiquitous across the Sydney Basin and is up to 290 metres thick. The majority of excavations for the Western Harbour Tunnel and Beaches Link would be within the Hawkesbury Sandstone unit.

Hawkesbury Sandstone is often described as medium to coarse grained and consists of three main depositional environments, namely; massive sandstone facies, cross-bedded or sheet facies, and shale/siltstone interbedded facies. The sheet facies make up about 70 per cent of the unit with primary beds that range in thickness from less than 0.5 metres to greater than five metres but generally occur between one metre and two metres. Secondary structural features such as joints, fractures and faults are also present.

The sandstone weathers to a clayey sandy soil, typically one to two metres thick. Within the upper ten metres of the profile a duricrust may be present where iron cementation has caused the development of ferricrete or coffee rock, or similarly silica cementation may cause the development of silcrete. Deep orange and red coloured iron staining is characteristic of the Hawkesbury Sandstone that can be concentrated along water bearing fractures and discontinuities (AECOM, 2015).

2.4.7 Structural geology

2.4.7.1 Bedding

Bedding surfaces in the Hawkesbury Sandstone in this part of the Sydney Basin typically dip gently toward the south at up to five degrees (locally up to 10 degrees). Local increases in dip are generally associated with depositional channel structures. Minor siltstone bands or siltstone breccia zones frequently occur in the base of these channel structures. Primary bedding planes are generally spaced between 0.5 metres and three metres and may be tight to open. Bedding related structures can include clay infills, crushed seams, in-situ weathering, iron-staining and limonite coating (AECOM, 2016a).

Laboratory testing has shown that the cross-bedded or sheet facies does not usually represent planes of weakness in fresh or slightly weathered rock. However, in moderately to highly weathered sandstone the cross beds can form surfaces of incipient parting or low shear strength. Both bedding and cross bed partings in the Hawkesbury Sandstone are typically planar to undulating and rough on a small scale with occasional clay, carbonaceous or mica films and infills (AECOM, 2015).

2.4.7.2 Faults

Figure A1-10 shows the main known structural features in the study area. Within the Sydney region there are four major north to northeast striking fault zones, and of most significance to the project alignment is the Luna park Fault Zone. These major fault zones are also interspersed with numerous smaller fault zones. The fault zones generally present as joint swarms or brecciated zones and often have associated gauge development. The fault zones have had an important influence on geomorphological development.

These structural features have been recorded at numerous locations within the Sydney Basin and are generally continuous, mappable and relatively predictable, although not always uniformly linear across the Sydney Region (Och et al., 2009).

The Luna Park Fault Zone has been shown to comprise up to three metre wide crushed zones with closely spaced jointing and faulting. The faulting shows normal and reverse movement, as well as strike-slip offset. Extensions of this fault have been identified at stages along a five kilometre strike length.

Joint spacing varies according to stratigraphy, proximity to near-surface weathering and proximity to major geological structures. Assessment of a more regional spread of geotechnical data, from projects such as North West Rail Link, WestConnex M4-M5 Link and Sydney Metro City & Southwest, indicates that jointing within the Hawkesbury Sandstone is typically extremely widely spaced (two metres to up to six metres) with zonal occurrences that are usually moderately widely spaced (60 millimetres to 200 millimetres). More widely spaced jointing of up to 25 metres also occurs (AECOM, 2015).

Localised areas of sub-vertical joints may also occur, especially for the NNE striking set, with spacing from 0.1 metres to 0.5 metres (e.g. Luna Park Fault Zone, Martin Place Joint Swarm and GPO Fault Zone). These localised areas are often associated with preferential groundwater flows, deeper weathered profiles and some discrete faulting and brecciation and have a greater vertical continuity than the general population of joints.

Faults, as with dykes, present risks to tunnelling (from a construction workplace health and safety risk perspective) in that they can act as conduits or as barriers to groundwater flow. Enhanced groundwater inflows to excavations or tunnels may occur when fault planes are intersected. Similarly, excavation through a fault plane may result in groundwater in-rush risk where the fault acts as a barrier to flow and pressure transmission.

It is also worth noting that tunnelling itself can enhance, or exacerbate, the inherent permeability of joints or brecciated zones through stress relief and dilation.

2.5 Hydrogeology

2.5.1 Groundwater occurrence

The most extensive aquifer in the project area is the Hawkesbury Sandstone, which is up to 250 metres thick in the Sydney region and outcrops over most of the Western Harbour Tunnel project and Beaches Link project areas. The sandstone is an unconfined aquifer at surface and may become increasingly confined with depth due to the highly stratified nature of the formation. Some units within the Hawkesbury Sandstone can exhibit remnant primary porosity, however, groundwater movement is typically controlled by secondary permeability and bedding.

The Hawkesbury Sandstone has a highly variable hydraulic conductivity, with horizontal hydraulic conductivity typically in the range 10^{-3} to 10^{-1} m/day. The highly stratified nature of the sandstone and the presence of interbedded shales can also result in multiple aquifer and aquitard zones within the sandstone. Faulting can result in areas of enhanced and reduced hydraulic conductivity.

The Hawkesbury Sandstone is overlain in places by the finer grained unit of the Ashfield Shale and Mittagong Formation which are generally considered as aquitards, however, secondary permeability can exist. When highly fractured, the hydraulic conductivity of the Ashfield Shale can be higher than in more uniform massive shale, but as it weathers to clay, it remains a very low conductivity material and as such behaves as an aquitard. The Ashfield Shale is only present along the alignment at ridgelines and outcrops in the area from Willoughby to Neutral Bay Junction. Therefore, the Ashfield Shale and Mittagong Formations are not considered to form significant groundwater systems within the project areas.

Unconsolidated alluvial materials, of Quaternary and Holocene age, occupy palaeo-topographic depressions in the underlying bedrock surface. The alluvial materials are predominantly composed of silty to peaty quartz sand, silt and clay, and where saturated, can comprise localised unconfined aquifers.

Due to the highly developed nature and history of the study area, some of the proposed alignment is overlain by man-made fill. This can act as a water bearing unit supporting perched water systems but with very high variability and unpredictability. The hydraulic properties of the fill are determined by the materials used for the fill as well as how it was laid down. Much like an alluvial layer, the fill is anticipated to behave as an unconfined aquifer or aquitard, and can potentially be a source of contamination, particularly with metropolitan waste. Areas of fill along the alignment include Birchgrove Park and Flat Rock Creek, among others.

There is a known history of dumping industrial and domestic waste at Flat Rock Creek in both whole and incinerated form. At Birchgrove Park, fill is recorded as potentially containing harbour dredging debris comprising estuarine sand and mud, demolition rubble, and industrial and domestic waste. At Flat Rock Creek, the site is known as a long running waste incineration and landfill site.

2.5.2 Groundwater levels and flow

The regional water table across the project area typically mimics topography and groundwater flow is from areas of high topographic relief to areas of low topographic relief, ultimately discharging at surface drainage features and to the harbours.

Water table elevation is highly variable and can range from close to ground surface in low lying areas and up to 100 metres below ground below elevated ridgelines (e.g. Bore GW109140 in Forestville). Localised perched water tables may also occur.

Figure A1-11 shows the groundwater table elevation contour map compiled from available water level monitoring data including monitoring for the WHT and BL projects, as well as water levels from the DPI Water Pinneena database, and water levels obtained from other adjacent projects, including; Sydney Metro, M4-M5, and the Northern Beaches Hospital upgrade.

The contours present a composite of water levels from various data sources and times and as such provide a general overview of key groundwater flow directions and trends along the alignment. Where available data is in time-series, average water levels have been applied.

The water level contours shown in Figure A1-11, confirm the general trend of the water table mimicking topography, with groundwater flow from elevated areas (recharge) toward the harbours and major drainages (discharge).

Deeper groundwater flow would be less controlled by topography and more influenced by the regional structure and stratigraphy of the Sydney Basin. Regional groundwater flow is inferred to be in an east to south-easterly direction towards Port Jackson and the Tasman Sea. There is also localised groundwater flow towards surface water features.

2.5.2.1 Groundwater Levels in Western Harbour Tunnel Project Area

Hydrographs from groundwater monitoring bores along the project alignment are provided in Figure 2.1, and bore locations are shown in Figure A1-12. The hydrographs are presented as both elevations, in metres above Australian Height Datum (mAHD), and depths below ground level.

Groundwater elevations range from highs of approximately 68 mAHD at monitoring bore B150 in North Sydney and 37 mAHD at monitoring bore B133 at Waverton, to close to sea level near to the harbour areas. Monitoring bore B104A at Birchgrove, Park, shows a water level of approximately 1.5 mAHD while B131A, on the Birchgrove peninsula fluctuates at around 0 mAHD. B131A also has a strong tidal oscillation.

B105A, also located at Birchgrove Park, shows water level below sea level. Following a period of fluctuation, B105A has stabilised at approximately -3 to -4 mAHD. This may be indicative of low permeability and slow recovery following bore development and purging. B105A shows a small-scale tidal oscillation overprinted by larger scale fluctuations that are currently not explained.

Outside of induced fluctuations, due to purging, sampling, and development, monitoring bores B154 and B209 show gradual declining trends, while B104A, B105A, B131A, and B181A show trends of rising water levels. Responses to rainfall events are observed at a number of the monitoring bores. B112 shows the most pronounced rainfall response with smaller responses observed at B154 and B209.

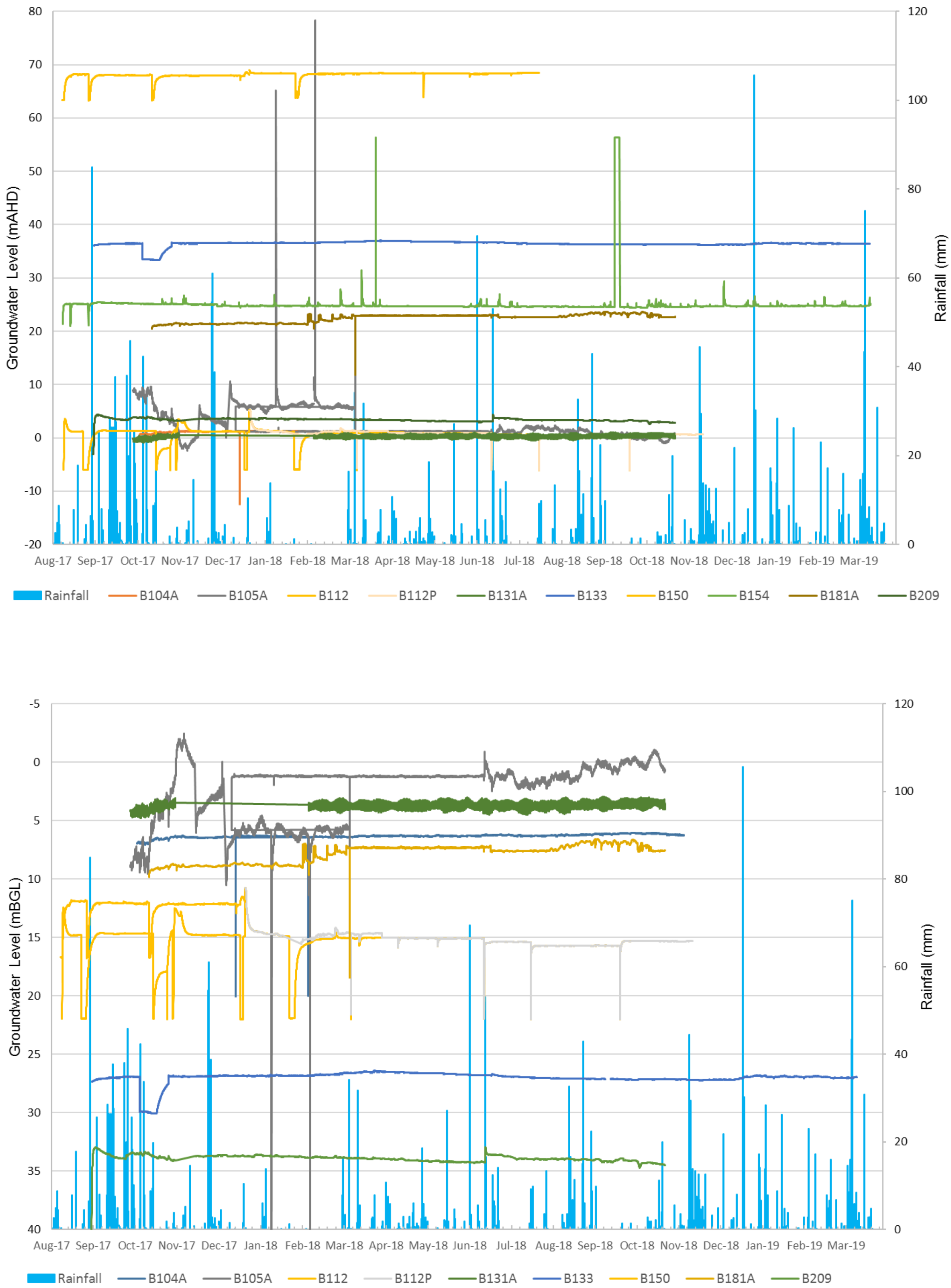


Figure 2.1: Monitoring bore hydrographs for WHT Project area

Three vibrating wire piezometer installations (VWP) have been installed along the project alignment at the locations shown in Figure A1-12.

At time of writing, data was available for one VWP, B132. The VWP installation is summarised below, with the hydrographs presented in Figure 2-2.

VWP B132 is located on Balls Head in close proximity to Sydney Harbour. Four sensors are installed at 10.4 mAHD (VWP4), -8.9 mAHD (VWP3), -28.6 mAHD (VWP2), and -74.2 mAHD (VWP1). The upper most sensor, VWP4, at 10.4 mAHD is above the water table and unsaturated. Sensors 1 to 3 display a general declining trend that may be a long term equilibration with natural formation pressure following installation, with the regression at the deepest sensor (VWP1) being most pronounced.

VWP 2 plots consistently lower than VWP 3, by around 0.5 metres, possibly indicating that it is actually installed shallower than recorded.

The hydrographs show a strong tidal response implying direct hydraulic connection with the harbour. Tidal loading can also lead to such a response, however, given the proximity to Sydney Harbour and the enhanced hydraulic conductivity of the Hawkesbury Sandstone beneath and next to the Harbour, it is considered that that there is direct hydraulic connectivity.

The amplitude of tidal fluctuations at VWP 2 is greater than at VWP 1 and 3, suggesting that VWP 2 is installed in a layer of locally higher hydraulic conductivity that is connected to either the harbour or harbour sediments. This is consistent with packer testing results which record an elevated permeability of 1.12 metres per day over this interval.

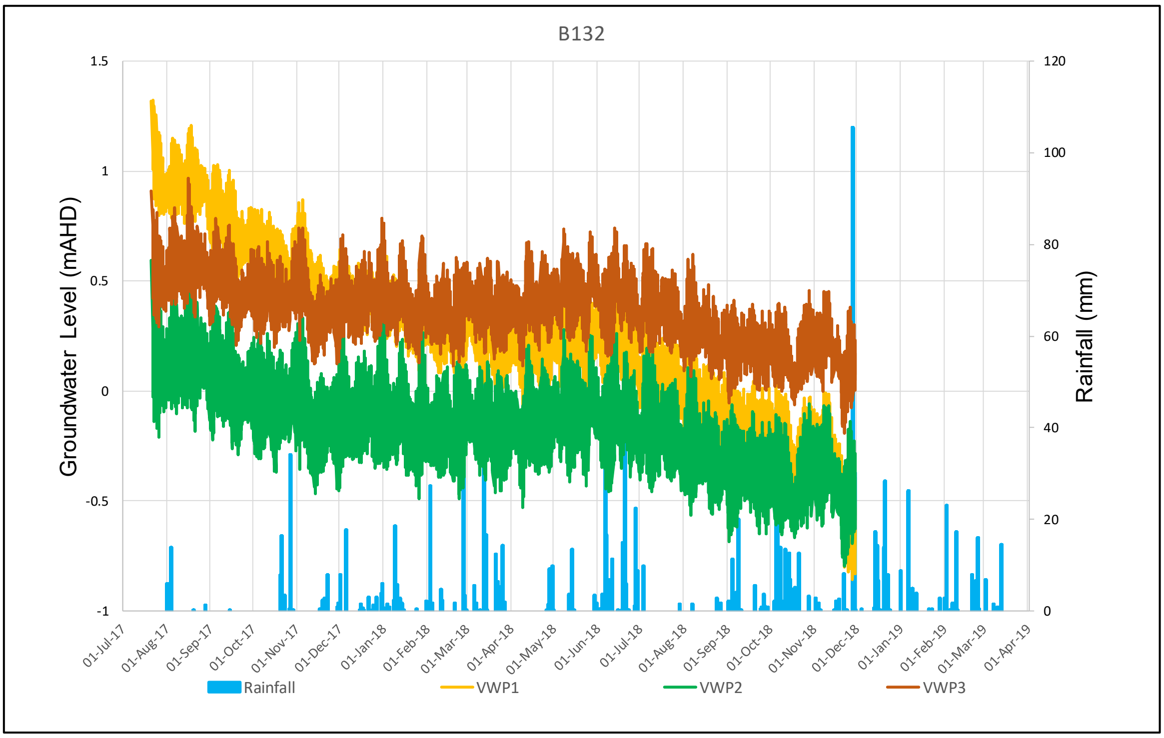


Figure 2-2: VWP hydrographs for Bore B132

2.5.2.2 Groundwater Levels in Beaches Link project Area

Hydrographs from groundwater monitoring bores along the alignment are provided in Figure 2-3, and bore locations are shown in Figure A1-13. The hydrographs are presented as both elevations (in metres above Australian Height Datum (mAHD)) and depths below ground level.

Groundwater elevations range from highs of around 110 mAHD and 120 mAHD at monitoring bores B173, and B174 and B175 respectively to less than 4mAHD at B140 in Seaforth. Monitoring bores B173, B174, and B175 are located in the vicinity of Wakehurst Parkway near Bantry Bay and Frenches Forest.

At Seaforth, water levels of the order of 60 mAHD are observed at monitoring bore B141, dropping down to approximately sea level in Balgowlah at monitoring bore B128, and 4 to 6 mAHD at monitoring bores B140 and B138, near the Seaforth harbour crossing.

Monitoring bore B128, located in the vicinity of the proposed Balgowlah dive structure, shows water levels at about 32 metres below ground level. This is about two metres below sea level. At the Gore Hill Freeway dive structure, at monitoring bore B114A, water levels are of the order of 50 mAHD.

At Flat Rock Creek, nested piezometers are installed within the fill material and weathered sandstone. The shallow water table at B134A-a is of the order of 21 metres below ground level (25 mAHD), and in the underlying sandstone (B134A-c) is approximately six metres deeper at 26.5 metres below ground level (19 mAHD). The intermediate monitoring bore (B134A-b) plots between B134A-a and B134A-c at about 23 metres below ground level (22 mAHD). The water levels indicate a downwards hydraulic gradient indicative of a recharging environment.

Monitoring bore B155, in North Bridge, shows a water level below sea level at around -8 mAHD, which is not considered to be representative of the local aquifer. This may be indicative of very low permeability and failure to recover post development, however, a number of small fluctuation in the monitoring data show that the bore is able to respond dynamically.

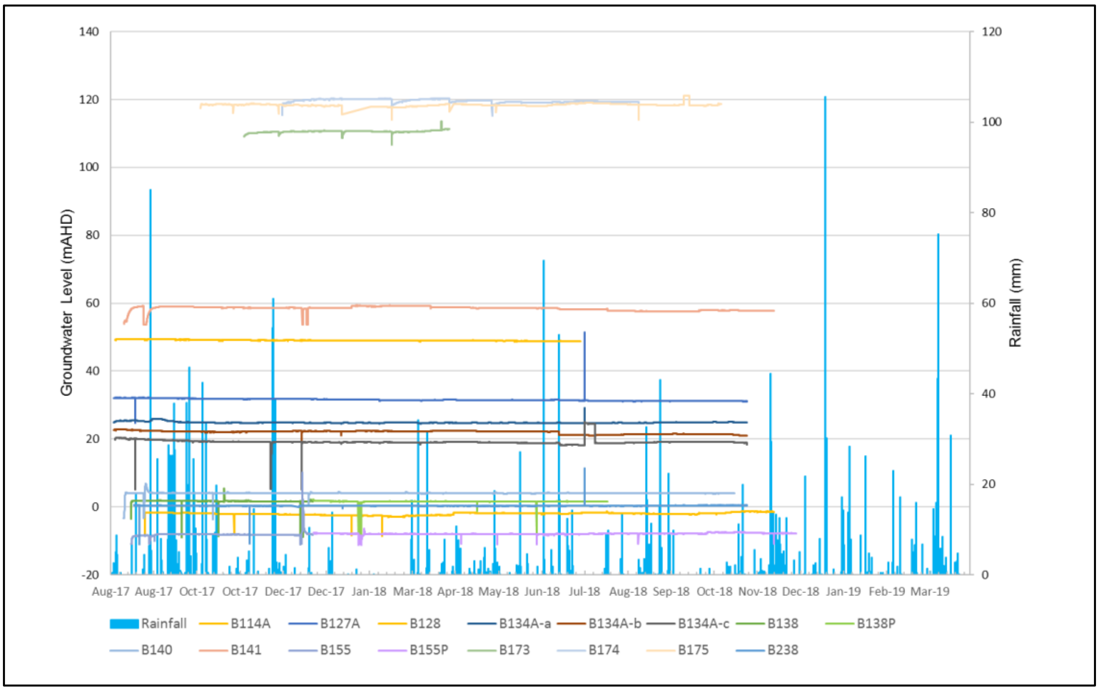
Outside of induced fluctuations, due to purging, sampling, and development, most monitoring bores display relatively stable water levels. No significant responses to rainfall event are evident.

Three vibrating wire piezometers (VWP) were installed along the Beaches Link alignment at locations shown in Figure A1-13. A summary of the observations from the monitoring data is as follows:

- **VWP B135** is located at Northbridge in proximity to an inferred fault zone and joint swarm. B135 is located over one kilometre from Middle Harbour crossing. Three sensors (VWP1, VWP2 and VWP3) have been installed at elevations of -71.0 mAHD, -29.9 mAHD and 7.1 mAHD, respectively. The shallowest sensor, VWP3, reports groundwater levels below the sensor. It is therefore suspected that this sensor was installed at greater depth than was reported, or it is faulty. VWP1 and VWP2 appear to be in general hydraulic equilibrium, with a slight downwards hydraulic gradient indicated from VWP2 to VWP1. At this location, it is possible that a shallow perched water table overlies a deeper water table at around sea level.

- **VWP B156** is located in North Balgowlah in the vicinity of the Wakehurst Parkway and is close to projected joint swarms of the Luna Park Fault Zone. Three VWP sensors (VWP1, VWP2 and VWP3) were installed at elevations of 29.7 mAHD, 43.5 mAHD and 53.9 mAHD, respectively. Elevated permeability of the order of 0.5 to 1.5 metres per day was recorded from packer testing at the elevation of VWP2. The shallowest sensor, VWP3, shows potential hydraulic disconnection from the two deeper sensors, indicating a potentially perched water table at about 58 mAHD (22 mbgl) overlying a deeper water table at about 45 mAHD (35 mbgl). VWP1 and VWP2 appear to be generally in hydraulic equilibrium, with a slight downwards hydraulic gradient indicated. A downwards hydraulic gradient in this area would be consistent with recharge and throughflow to the harbour to the north-northwest.

- **VWP B176A** is B176A is located at Flat Rock Creek and is next to fill and an inferred deep geological deformation zone. Four VWP sensors (VWP1, VWP2, VWP3 and VWP4) were installed at elevations of



19.2 mAHD, 12.2 mAHD, -12.9 mAHD, and -28.5 mAHD, respectively. The shallowest VWP, VWP1, shows groundwater levels above the sensor. It is expected to generally be dry. VWP2 and VWP3 are in general hydraulic equilibrium with an elevation of about 16.5 mAHD. There is a strong downwards gradient to VWP4, suggesting a hydraulic separation between the shallower and deeper horizons. Groundwater levels at VWP2 and VWP3 also lie below water levels recorded at the nearby nested monitoring bore installation at B134, suggesting that the valley fill material at Flat Rock Creek is a local source of recharge to the underlying sandstone.

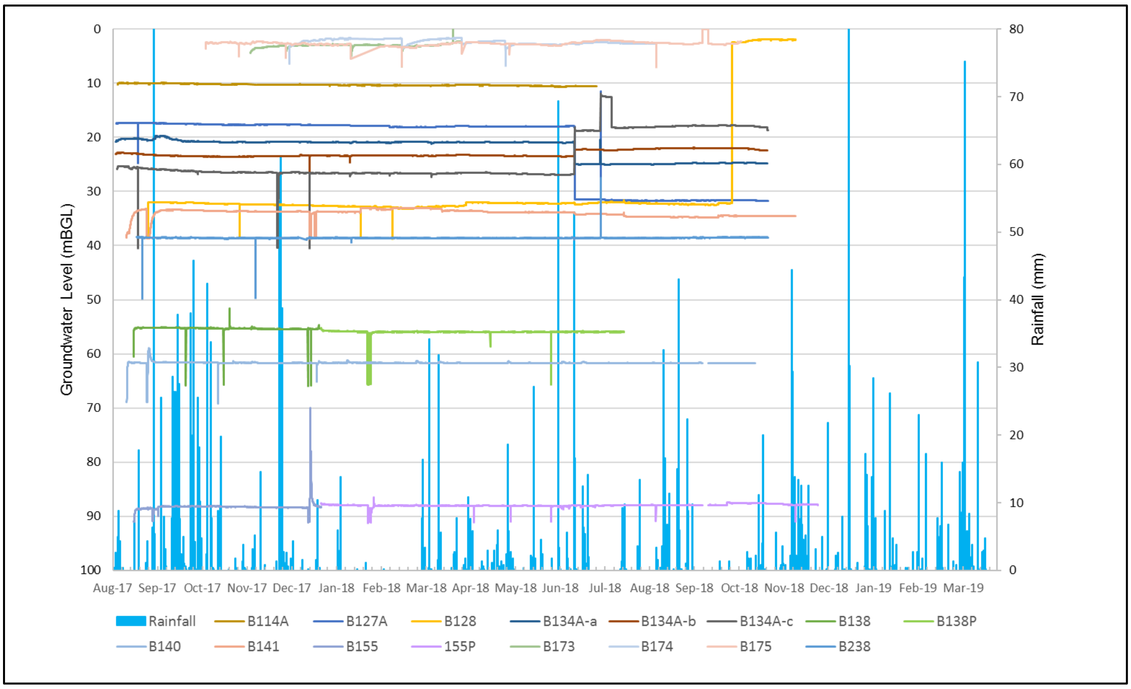


Figure 2-3: Monitoring bore hydrographs for Beaches Link project area.

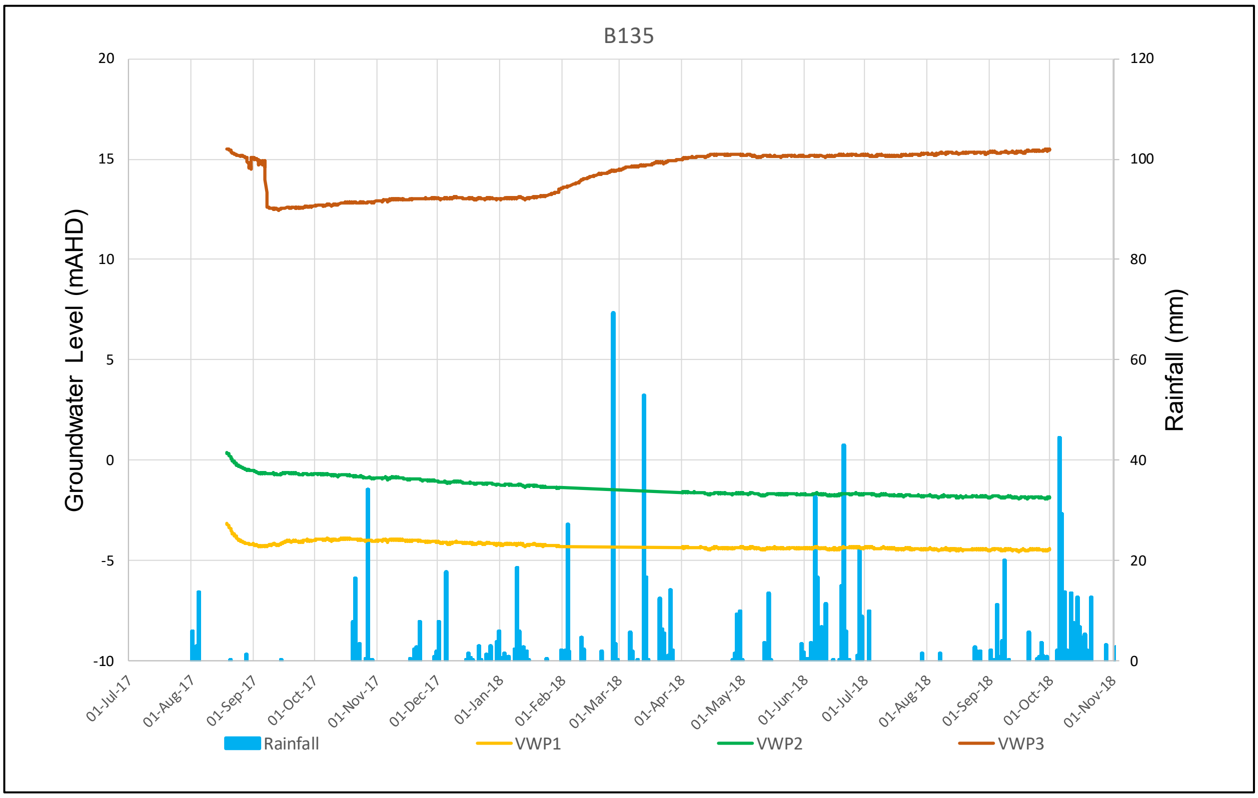


Figure 2-4: Hydrograph for VWP B135.

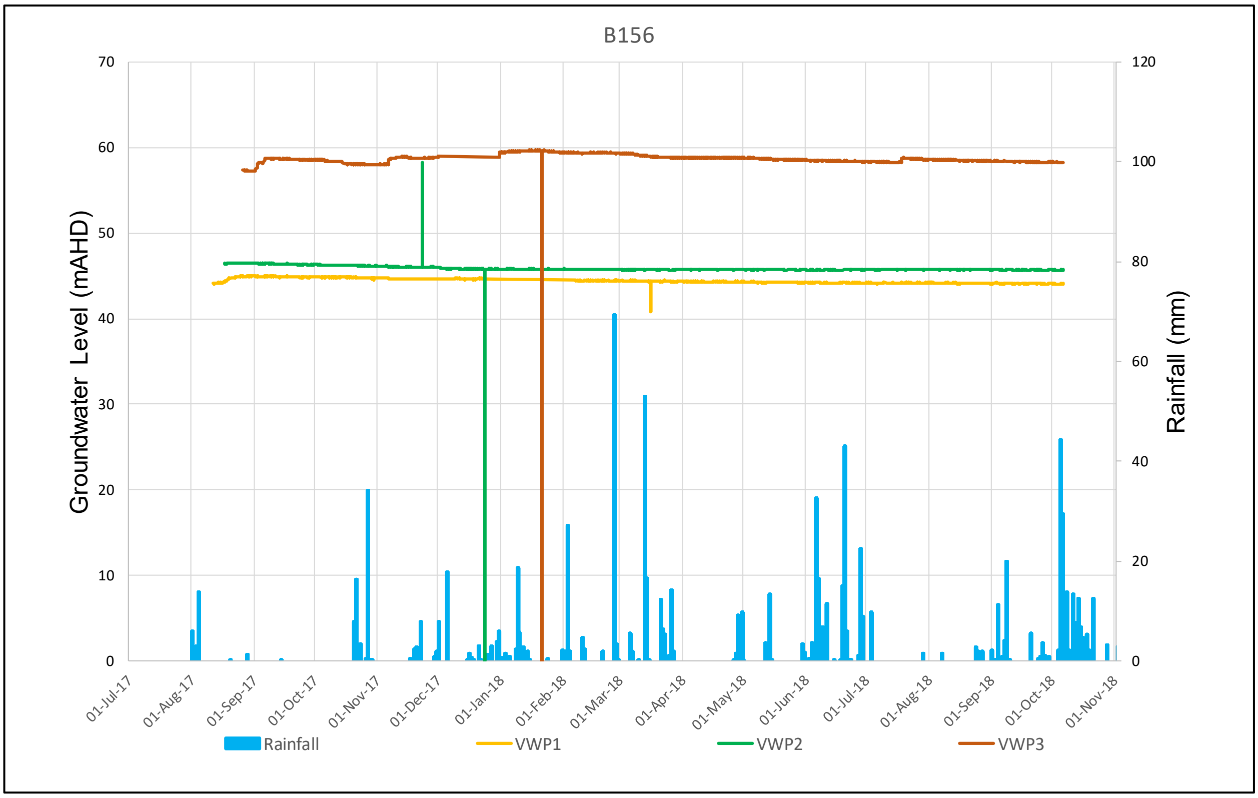


Figure 2-5: Hydrograph for VWP B156.

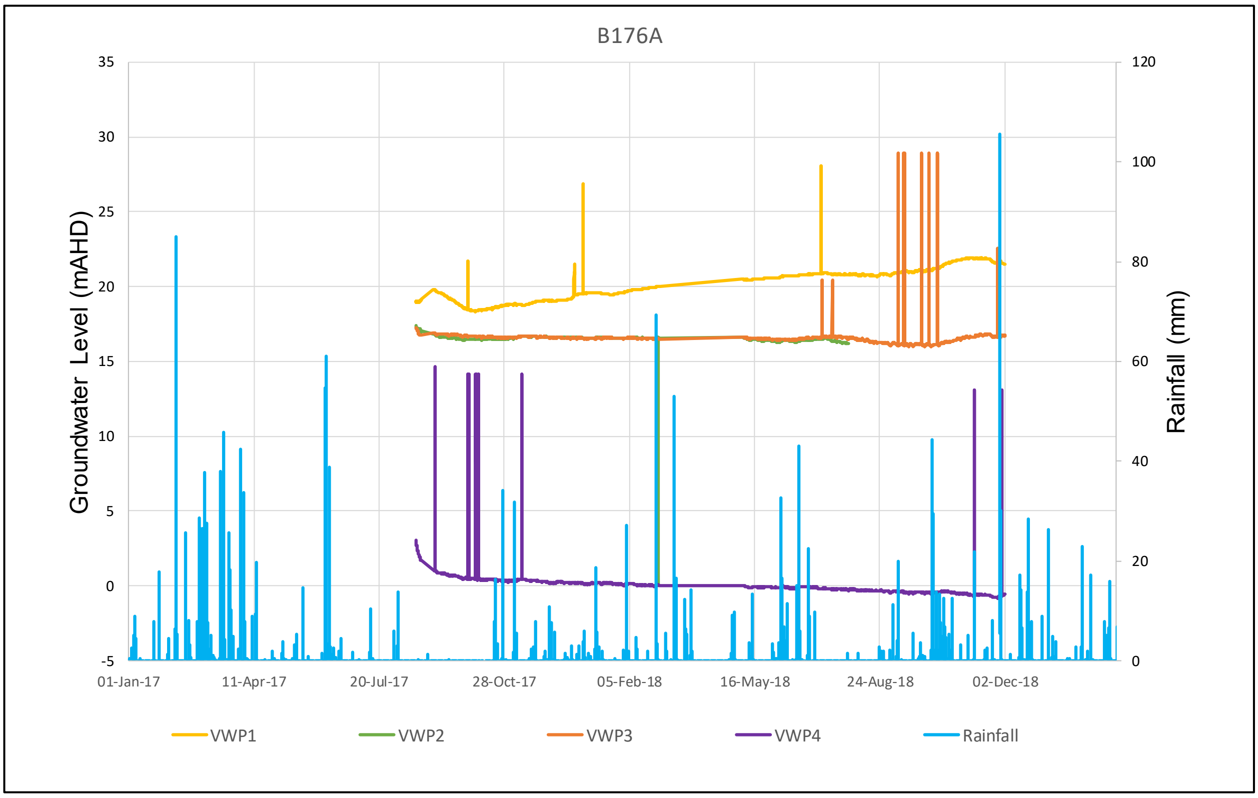


Figure 2-6: Hydrograph for VWP B176A.

2.5.3 Recharge and discharge

The primary groundwater recharge mechanism is direct rainfall infiltration. The proportion of rainfall recharging the groundwater systems depends largely on the characteristics of the surface geology, soils, the land use and depth to the water table. Recharge is expected to be lower in areas where the surface is covered by shale and residual clays with a low hydraulic conductivity and specific yield. This leads to relatively low recharge rates compared to areas where Hawkesbury Sandstone outcrops.

Recharge to the residual clays is associated with rainfall infiltration which typically characterises the behaviour of shallow perched water systems and limited vertical infiltration from the perched, shallow system down to the deeper regional Hawkesbury Sandstone bedrock system.

Historically, groundwater recharge would have predominantly been via diffuse infiltration of rainfall over areas of Hawkesbury Sandstone outcrop/subcrop, and from runoff from water courses overlying the Hawkesbury Sandstone. Most of the area in the vicinity of the project alignment has been subjected to urban development and contemporary groundwater recharge is largely constrained to areas of remnant vegetation, and park and grassed areas. In parks and playing fields recharge is often enhanced through irrigation. Enhanced recharge also arises from infiltration basins.

Given the hydraulic properties of the Hawkesbury Sandstone, highly stratified and typically of low bulk hydraulic conductivity, it is likely that the groundwater response time for the system is measured in decades if not centuries. It is possible that, away from any major groundwater stresses, the groundwater system would still be equilibrating to the new urbanised recharge regime.

A literature review for the Sydney region (HydroSimulations, 2017) indicated that the estimates for rainfall-recharge rates for hydrogeological units are in the following ranges:

- Botany sands: 6 to 100% of mean annual rainfall
- Hawkesbury Sandstone: 2 to 10% of mean annual rainfall
- Wianamatta Shale: 1 to 2% of mean annual rainfall.

In previous groundwater modelling by HydroSimulations (2017) different recharge zones were assigned to paved and unpaved areas. Table 2.6 shows the average rainfall-recharge rates applied in the HydroSimulations calibrated steady state model to paved and unpaved areas.

Table 2.6: Average recharge rates applied to paved and unpaved areas [1].

Zone	Recharge (m/day)	% Mean Annual Rainfall
Botany Sands (paved)	4×10^{-4}	12
Botany Sands (unpaved)	5×10^{-4}	15
Ashfield Shale (paved)	3×10^{-5}	1
Ashfield Shale (unpaved)	3×10^{-5}	1
Hawkesbury Sandstone (paved)	6×10^{-5}	2
Hawkesbury Sandstone (unpaved)	1×10^{-4}	3

Note, [1] Source: HydroSimulations (2017).

Groundwater discharge is expected to be through outflow to the harbour and evapotranspiration in low lying areas. The evapotranspiration rate depends on land use and depth to groundwater. In areas where the water table is shallow and within the rooting depth of vegetation evapotranspiration can be a large component of the water balance.

Extraction of groundwater through the use of existing bores in the study area may also be considered a groundwater discharge mechanism. Existing groundwater use is minor (Jacobs, 2020a & Jacobs 2020b). Groundwater would also continuously drain into existing underground workings such as unlined tunnels and sewers.

2.5.4 Hydraulic properties

The Hawkesbury Sandstone presents as a dual porosity aquifer with some remnant interstitial porosity, where not entirely overprinted by silicic and/or carbonate cementation. Secondary porosity is in the form of fracturing, which in turn can also be subject to infilling, either through mineral precipitation, or the chemical or mechanical development of clays and finer grained material. However, for the purposes of this groundwater assessment it is the bulk hydraulic properties, incorporating both primary and secondary permeability, that are of concern.

2.5.4.1 Horizontal hydraulic conductivity

Hydraulic conductivity is one of the key parameters that controls drawdown in response to tunnel inflows. Information on hydraulic properties is available from numerous previous tunnelling projects in the Sydney region that have included detailed field investigations, including permeability testing. Key tunnelling projects and associated permeability testing data are summarised in Section 2.6.

Table 2.7 summarises the hydraulic conductivity values estimated from hydraulic testing within the Sydney Basin. From Table 2.7 it is apparent that despite the Ashfield Shale being considered an aquitard relative to the Hawkesbury Sandstone, the range of horizontal hydraulic conductivity values derived from testing is very similar for the two formations, and, as shown from the New M5 and M4 East investigations, the Ashfield Shale and Hawkesbury Sandstone displayed identical median hydraulic conductivity values. From the M4-M5 Link, the maximum, and arithmetic mean hydraulic conductivity values of the Hawkesbury Sandstone were found to be an order of magnitude greater than the Ashfield Shale, while harmonic mean results return very similar values.

2.5.4.2 Project Permeability Testing

2.5.4.2.1 Overview

Packer testing was conducted to determine formation hydraulic conductivity on 74 individual drill holes across the Western Harbour Tunnel and Beaches Link projects, consisting of 491 individual packer tests. Most of the holes drilled were either in the Hawkesbury Sandstone, overlying sediments or fill. A small number of holes were initiated in either the Ashfield Shale or Mittagong Formation, but these typically only comprised a thin veneer and were not subject to any permeability testing.

Packer testing results are summarised in Table 2.7. The cumulative distribution of packer testing results for land based and marine based packer tests are plotted on Figure 2-7. From Figure 2-7 it is apparent that the permeability results from the marine based testing are typically 1 to 1.5 orders of magnitude greater that the land-based permeability values. This is inferred to reflect the increased occurrence and concentration of structure associated with the harbour areas.

A regional analysis of packer tests carried out in the Hawkesbury Sandstone across the Sydney Basin by Tammetta and Hawkes (2009) indicated a clear trend of decreasing hydraulic conductivity with depth below ground surface which was attributed to less frequent fracture spacing and increasing lithostatic pressure with depth. Data from Tammetta and Hawkes (2009) are provided in Figure 2-8.

Table 2.7: Hydraulic conductivity values derived from other investigations (m/day)

Source	Recharge (m/day)			Method
	Ashfield shale	MIttagong formation	Hawkesbury sandstone	
WestConnex New M5 groundwater assessment (AECOM, 2015)	<0.0001 to 0.07 Median = 0.003 n = 6	<0.0001 to 0.9 Median = 0.01 n = 10	<0.0001 to 4.3 Median = 0.003 n = 205	Packer tests (n = 221) Depth range 10 to 80m
Sydney Metro groundwater assessment (Jacobs, 2016)	<0.0086 to 0.05 n = 3 Depth range 12 to 29 m	<0.0086 to 0.52 n = 15 Depth range 7 to 33 m	<0.0086 to >0.86 n = 53 Depth range 12 to 46m	Packer tests (n = 72)
North West Rail Link (Hewitt, 2005)	No data	No data	Mean (near surface) = 0.1 Mean (50 m depth) = 0.002	Packer tests (n = 363)
M4 East groundwater assessment (GHD, 2015)	0.00022 to 0.73 Median = 0.011 n = 75 Depth range 10 to 40m	No data	0.00043 to 1.7 Median = 0.011 n = 83 Depth range 10 to 50m	Packer tests (n = 158)
M4 – M5 Link groundwater assessment (AECOM, 2017)	0.0086 to 0.12 Arithmetic Mean = 0.017 Harmonic mean = 0.010 n = 24	No data	0.0086 to 1.17 Arithmetic Mean = 0.1 Harmonic mean = 0.012 N = 181	Packer tests (n = 205)
Western Harbour Tunnel and Warringah Freeway Upgrade groundwater assessment (Jacobs, 2020a)	No data	No data	Land based Mean = 0.015 Median = 0.001 Marine Mean = 0.454 Median = 0.026	Packer Tests (n = 191)

Source	Recharge (m/day)			Method
	Ashfield shale	MIttagong formation	Hawkesbury sandstone	
Beaches Link and Gore Hill Freeway Connection groundwater assessment (Jacobs, 2020b)	No data	No data	Land based Mean = 0.053 Median = 0.001 Marine Mean = 0.187 Median = 0.017	Packer Tests (n = 300)

Notes: (1) n = number of tests

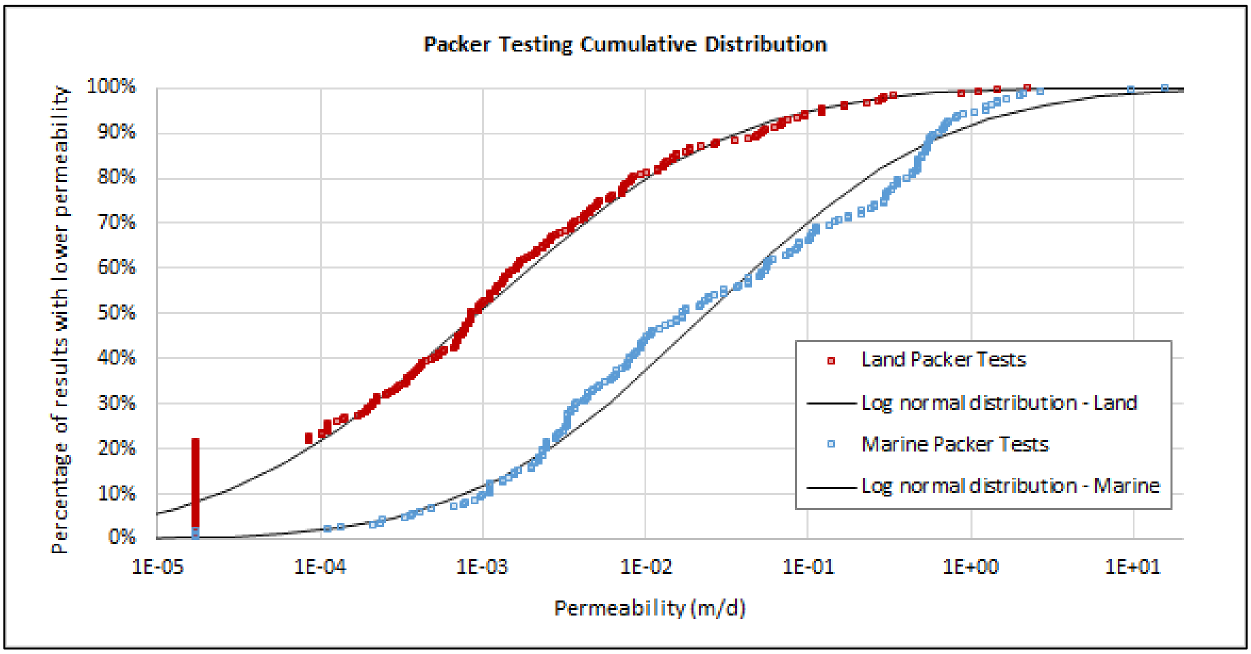


Figure 2-7: Packer testing cumulative distribution

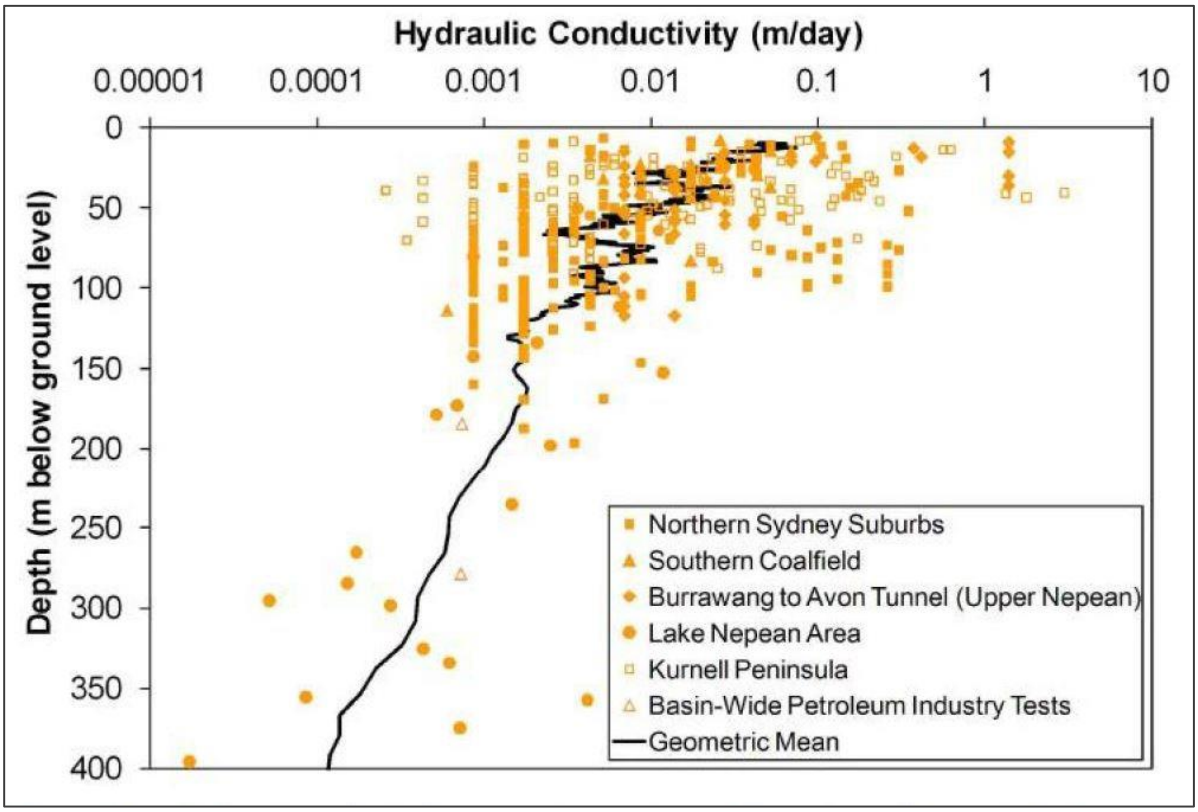


Figure 2-8: Tammetta and Hawkes (2009) hydraulic conductivity from packer testing in Sydney Basin.

Figure 2-9 shows the hydraulic conductivity plotted against depth below ground level for results of land-based packer tests carried out in areas located south of Sydney Harbour. Figure 2-9 also shows the geometric mean for Hawkesbury Sandstone hydraulic conductivity calculated by Tammetta and Hawkes (2009). The results indicate a general trend of decreasing hydraulic conductivity with depth. A comparison of hydraulic conductivity values derived for the Western Harbour Tunnel Project area packer tests (Figure 2-9) and the Tammetta and Hawkes (2009) regional assessment (Figure 2-8) shows that hydraulic conductivity values for the project area south of Sydney are generally below the basin-wide average but are well within the range of values assessed in Tammetta and Hawkes (2009).

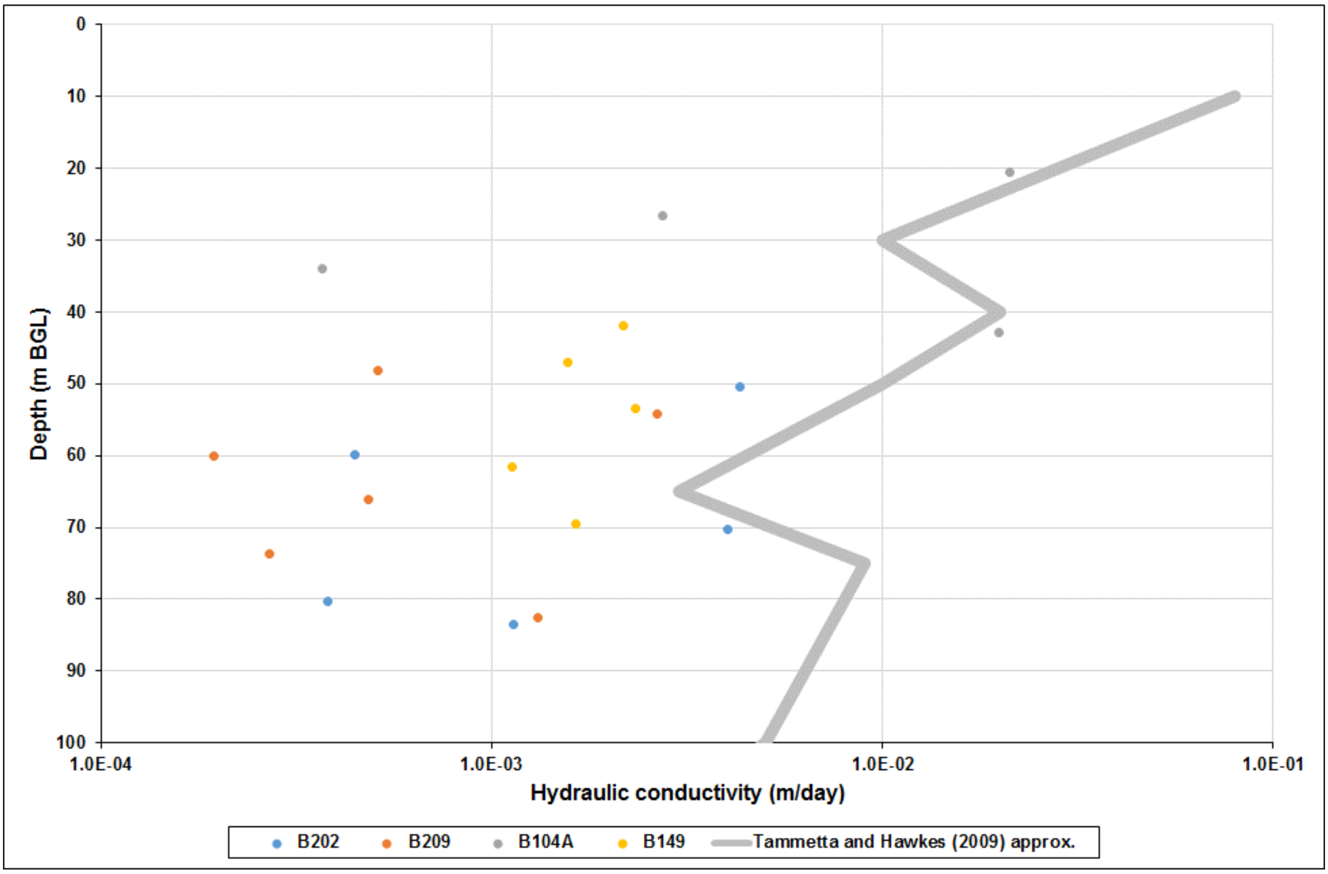


Figure 2-9: Hydraulic conductivity versus depth – south of Sydney Harbour.

Figure 2-10 shows the hydraulic conductivity plotted against depth below ground level for results of land-based packer tests carried out in areas located north of Sydney Harbour. The results presented in Figure 2-10 are highly variable but do indicate an upper limit to hydraulic conductivity that diminishes with depth. The data show a similar distribution and scatter to those assessed by Tammetta and Hawkes (Figure 2-8). Figure 2-10 shows a number of results plotting at the minimum derived value of 9 x 10^{-5} m/d. A hydraulic conductivity value of 9 x 10^{-5} m/d is considered to be the lowest hydraulic conductivity value that can be reasonably derived with certainty using conventional packer testing equipment.

In summary, hydraulic conductivity values estimated from packer tests carried out in areas located south of Sydney Harbour as part of the Western Harbour Tunnel Project (Figure 2-9) show some consistency with the regional assessment by Tammetta and Hawkes (2009), albeit being generally below average. The hydraulic conductivity values estimated for areas located north of Sydney Harbour (Figure 2-10) also show a general trend of diminishing hydraulic conductivity with depth, with a distinct upper bound to likely hydraulic conductivity values. The hydraulic conductivity values estimated for the project area show good agreement with the range of values assessed throughout the Sydney Basin.

The core samples from bores drilled as part of the Western Harbour Tunnel and Beaches Link Project show a decrease in fracture spacing and degree of weathering with depth. Therefore, the groundwater models used for the Western Harbour Tunnel and Beaches Link Projects incorporate vertical layering to represent the inferred trend of decreasing hydraulic conductivity with depth.

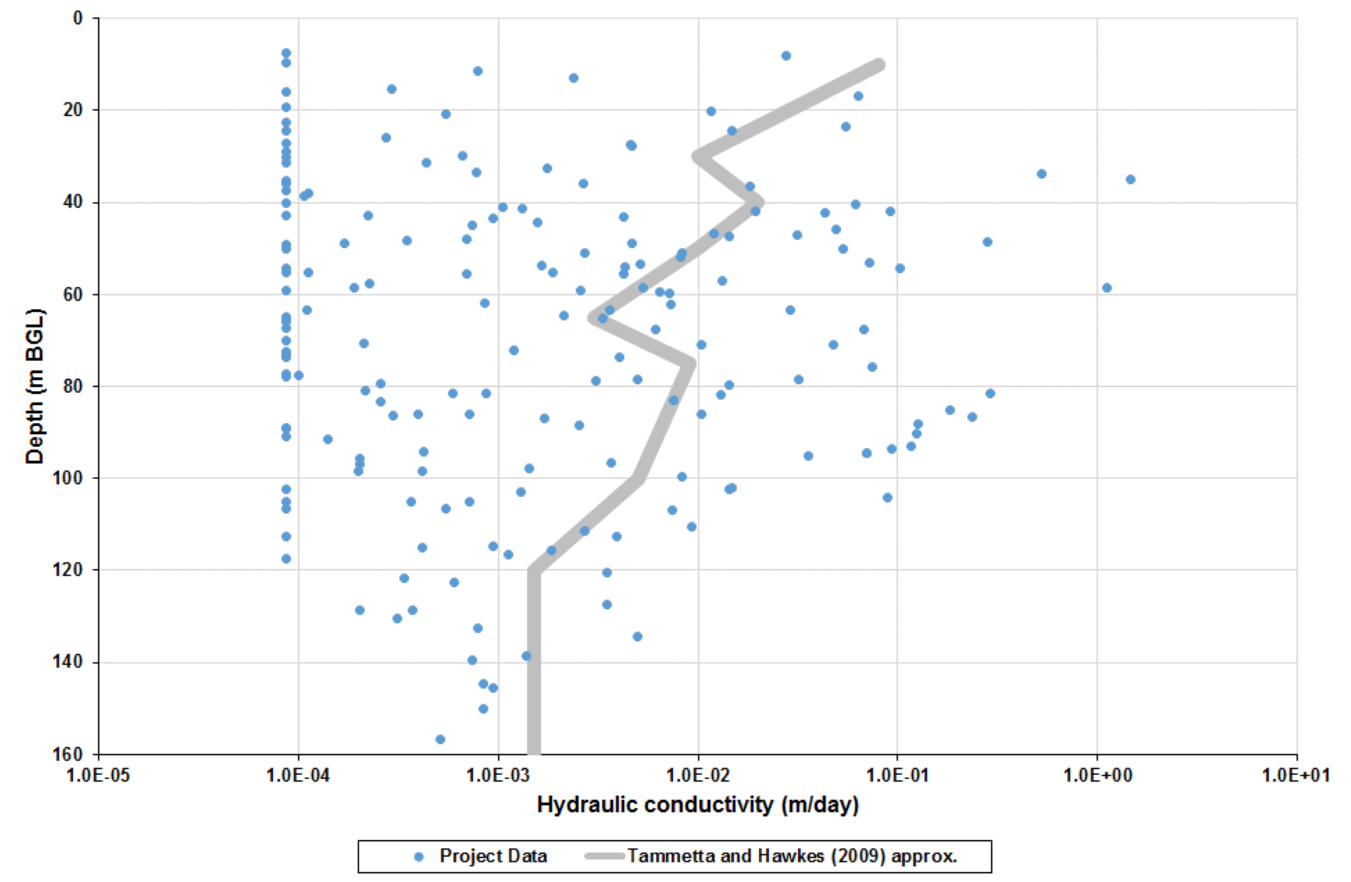


Figure 2-10: Hydraulic conductivity versus depth – north of Sydney Harbour.

2.5.4.2.2 Packer Testing Results for Western Harbour Tunnel Project Area

Table 2.8 provides a summary of the packer testing carried out along the Western Harbour Tunnel project alignment. Testing comprised a total of 49 land-based packer tests and 142 marine based packer tests.

Comparison of mean and median hydraulic conductivity values indicate that the elevated mean values are being skewed by a small number of higher permeability results. The mean hydraulic conductivity for the land-based Hawkesbury Sandstone is 0.015 m/d compared to the median values of 0.0012 m/d. The range of test results is significant and covers several orders of magnitude. As indicated by the cumulative distribution shown in Figure 2-7, the median marine hydraulic conductivity is an order of magnitude greater than the land-based value.

The derived hydraulic conductivity values are generally in agreement with the range of values from previous investigations as summarised in Table 2.7.

Table 2.8: Packer test summary and hydraulic conductivity in the Hawkesbury Sandstone for Western Harbour Tunnel Project

Test Location	Number of tests	Minimum Hydraulic Conductivity (m/d)	Maximum Hydraulic Conductivity (m/d)	Mean Hydraulic Conductivity (m/d)	Median Hydraulic Conductivity (m/d)
All land based tests	49	1.1E-05	0.17	0.015	0.0012
Rozelle to Birchgrove	18	5.1E-05	0.05	0.006	0.002
Waverton	31	1.1E-05	0.17	0.021	0.001
Western Harbour marine	142	2.8E-05	15.72	0.454	0.026

Note, for statistical analysis, all packer tests results recorded as less than $1x10^{-9}$m/s ($8.64x10^{-5}$m/d) have been set as $2x10^{-10}$m/s ($1.73x10^{-5}$m/d).

2.5.4.2.3 Packer Testing Results for Beaches Link Project Area

Table 2.9 provides a summary of the packer testing carried out along the alignment. Testing comprised a total of 192 land-based packer tests and 108 marine based packer tests.

Comparison of mean and median hydraulic conductivity values indicate that the elevated mean values are being skewed by a small number of higher permeability results.

Results obtained from 59 tests for Cremorne to Northbridge show a general agreement between the mean and median values, while at Flat Rock Creek the elevated mean hydraulic conductivity is skewed by increased permeability in the shallow regolith of the flanks of the paleo-valley.

The range of test results is significant and covers several orders of magnitude. The mean hydraulic conductivity for the land-based Hawkesbury Sandstone is 0.054 m/d compared to the median value of 0.001 m/d. As indicated by the cumulative distribution shown in Figure 2-7, the median marine hydraulic conductivity is an order of magnitude greater than the land-based value.

The derived hydraulic conductivity values are generally in agreement with the range of values from previous investigations as summarised in Table 2.7.

Table 2.9: Packer testing summary and hydraulic conductivity in the Hawkesbury Sandstone for Beaches Link Project.

Test Location	Number of tests	Minimum Hydraulic Conductivity (m/d)	Maximum Hydraulic Conductivity (m/d)	Mean Hydraulic Conductivity (m/d)	Median Hydraulic Conductivity (m/d)
All land-based tests	192	4.0E-06	2.25	0.053	0.001
Balgowlah to Seaforth	91	4.0E-06	1.47	0.045	0.003
Cremorne to Northbridge	59	4.0E-06	1.00	0.003	0.001
Flat Rock Creek	42	1.9E-05	2.25	0.146	0.005
Middle Harbour marine	108	1.4E-04	4.04	0.187	0.017

2.5.4.3 Permeability Distribution and Structural influence

Plots of packer testing results along the section of the entire main Western Harbour Tunnel and Beaches Link alignment are shown in Figure 2-11. Also shown in Figure 2-11 are drilling water returns observed during the drilling of the holes. There is a close correlation between the areas of elevated permeability and the areas of water loss (low return). Areas of elevated permeability and water loss, when within the Hawkesbury Sandstone, are inferred to be structurally controlled and primarily occur at the harbours and at Flat Rock Creek. Two secondary areas of elevated permeability also occur to the north of Western Harbour and Middle Harbour.

2.5.4.3.1 Western Harbour High Permeability Zone

The main structural zones, or areas of enhanced permeability on the Western Harbour Tunnel alignment, are immediately adjacent and underlying Western Harbour. This is to be expected as it is inferred that the underlying structural control has resulted in the palaeo-drainages in which the harbours are now located. The influence of structure on permeability in the harbour areas is also supported by the order of magnitude increase of mean hydraulic conductivities associated with the sub-harbour lithologies with respect to those away from the harbours as indicated in Figure 2-11. The average permeability derived from packer testing at Western Harbour is 0.45 m/d, with a median value of 0.026 m/d. A maximum hydraulic conductivity value of 15.7 m/d was returned from testing at Western Harbour. One other inferred structural zone on the Western Harbour Tunnel alignment is associated with an ancillary structure located to the north of Western Harbour.

The elevated permeability to the north of Western Harbour, in the vicinity of Waverton Park, is not associated with any mapped structures. Borehole B221 returned elevated permeability results of the order of 0.12 to 0.16 m/d between eight and 13 metres that are associated with shallow sandstone regolith beneath Waverton Park. The proposed tunnel alignment in this location is only at a depth of 15 to 20 m below ground level.

2.5.4.3.2 Middle Harbour High Permeability Zone

A structural zone of enhanced permeability also occurs immediately adjacent and underlying Middle Harbour. Average hydraulic conductivity value of 0.19 m/d and median of 0.017 m/d was obtained, with a maximum hydraulic conductivity value of 2.0 m/d at Middle Harbour.

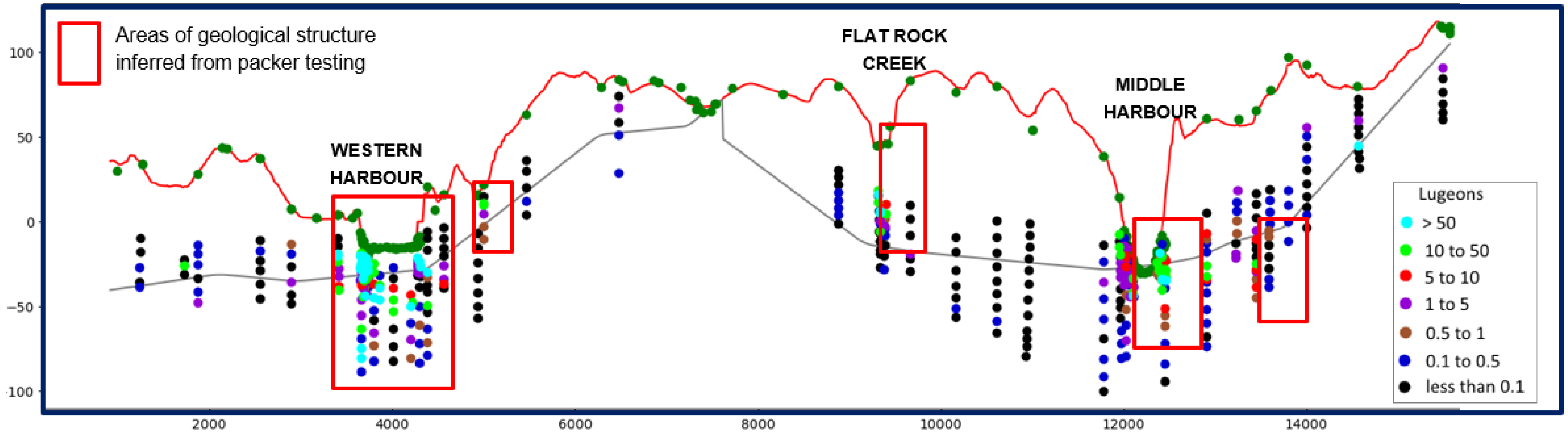
The elevated permeability to the north of Middle Harbour is possibly related to the occurrence of a dyke that is noted on the geotechnical sections in the vicinity of Grandview Grove. While the dykes themselves are typically weathered to clay and of very low permeability, the surrounding country rock can be fractured and weathered, providing enhanced permeability parallel to the strike (and dip) of the dyke. No dykes were intersected by either B140 or B124. Moderate permeability zones in B140 are associated with sandstone units and some minor zones of brecciation and core loss.

2.5.4.3.3 Flat Rock Creek High Permeability Zone

At Flat Rock Creek, hole B176A was drilled to 87 mBGL and intersected fill material to 30 mBGL. Elevated permeability (0.34 to 0.89 m/d) is associated with basal fill material and the upper weathered/fractured zone of the underlying sandstone to 36 mBGL (0.26 m/d). No intervals of significant permeability were encountered below 46 mBGL.

Borehole B134A-C was drilled to intersect the central valley fill material and underlying sandstone and encountered fill to 33 mBGL. Elevated permeability (2.2 m/d) was encountered in sandstone from 39 to 42 mBGL, with moderate permeability (0.017 to 0.027 m/d) to 54 mBGL. No significantly permeable intervals were encountered below 54mBGL.

Borehole B177A, drilled to the north of Flat Rock Creek encountered fill and clay to 11.8 mBGL. Moderate permeability was returned from sandstone from 33 to 42 mBGL of 0.09 to 0.28 m/d, with no significant permeability returned below 42 mBGL.



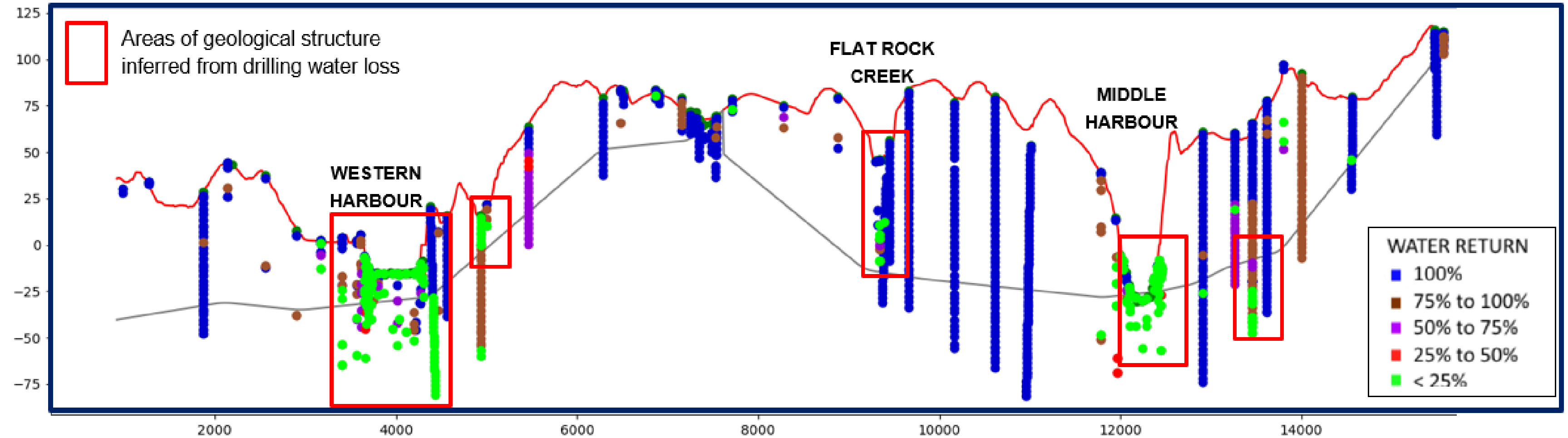


Figure 2-11: Inferred structural zones from drilling and packer testing

2.5.4.3.4 Dykes

Dykes in the Sydney region are typically highly weathered and represent barriers to groundwater flow across the dyke. Fracturing during intrusion can often result in a zone of marginally increased permeability parallel to strike in the surrounding country rock.

Borehole B202, located in Rozelle, was drilled to intersect the Great Sydney Dyke. The bore intersected the dyke from 92.5 to 95.15 mBGL, with the dyke logged as consisting of moderately weathered to highly weathered dolerite. The surrounding sandstone was noted as having increased jointing and shearing associated with the intrusion, with the lower sandstone contact logged as extremely weathered. Anecdotally, the dyke was noted as being very clayey and the drill hole would not stay open to allow the installation of vibrating wire piezometer sensors below the dyke.

There was no evidence from the packer test results to suggest that the hydraulic conductivity for the dykes in the project areas was significantly different from the hydraulic conductivity of the surrounding bulk rock. Therefore, the inferred dyke zones were assigned the same hydraulic conductivity as the surrounding bulk rock.

2.5.4.4 Vertical hydraulic conductivity

No site-specific data is available on the vertical hydraulic conductivity (K_v) along the alignment, however, given the highly stratified nature of the formations, and the indications of perched and/or multiple water tables, a strong vertical anisotropy is expected. HydroSimulations (2017) summarised K_v from previous studies in the Sydney Metropolitan area. K_v estimates from the previous studies are presented in Table 2.10.

Table 2.10: K_v estimates from previous studies (Source: HydroSimulations 2017).

Formation	Vertical Hydraulic Conductivity (m/d)	K_v/K_h
Alluvium	$8.60\ 10^{-3}$ to 5.00×10^{-2}	1:10 to 1:100
Ashfield Shale	1×10^{-4} to 8.00×10^{-4}	-
Hawkesbury Sandstone	5.00×10^{-4} to 1.00×10^{-2}	1:10 to 1:100

2.5.4.5 Specific storage and specific yield

Review of previous studies in the Sydney Metropolitan area by Golder indicated the specific storage ranges from 5×10^{-6} to 5×10^{-5} (HydroSimulations 2017).

Specific storage estimates were derived from geotechnical rock strength testing data on cores samples from the Western Harbour Tunnel and Beaches Link project areas. Rock strength characteristics are available for 36 core samples from land-based investigation from depths ranging from 1.5 to 120 mBGL. Most of the core samples are of Hawkesbury Sandstone, with one sample each also from laminate, shale breccia, and basalt. Specific storage was estimated from the product of the formation compressibility and the specific weight of water. Formation compressibility was derived from Young's Modulus and poisons Ratio. Estimates of specific storage values are summarised in Table 2.11.

Table 2.11: Formation Specific Storage

Lithology	Number of tests	Depth Range (mBGL)	Mean Specific Storage (m^{-1})	Median Specific Storage (m^{-1})
Hawkesbury Sandstone - massive	9	6-120	1.32×10^{-6}	9.13×10^{-7}
Hawkesbury Sandstone - bedded	24	1.5-105	2.22×10^{-6}	9.85×10^{-7}

Lithology	Number of tests	Depth Range (mBGL)	Mean Specific Storage (m^{-1})	Median Specific Storage (m^{-1})
Basalt	1	82	5.53×10^{-7}	5.53×10^{-7}
Laminite	1	57	3.55×10^{-6}	3.55×10^{-6}
Shale breccia	1	7	2.35×10^{-6}	2.35×10^{-6}

Mean and median values for specific storage for the Hawkesbury Sandstone are in close agreement, indicating a fairly uniform distribution of results with a mean specific storage for the Hawkesbury Sandstone overall of 1.9×10^{-6} m^{-1}. This should be considered a lower bound, as specific storage would be influenced by fracturing which typically is not represented in the core samples. Values for specific storage of 5×10^{-6} to 1×10^{-5} m^{-1} are considered reasonable depending on the degree of weathering and fracturing.

Literature values of specific yield for unconsolidated sands and gravel are typically high in the order of 15 to 20 per cent, for sandstone they are much lower, often of the order of five per cent for unconsolidated sandstone and reducing with consolidation/cementation. Studies conducted in the Sydney metropolitan area indicate a specific yield of between one per cent and two per cent is reasonable for Hawkesbury Sandstone (HydroSimulations 2017).

Porosity has not been recorded for core samples within the Western Harbour Tunnel and Beaches Link project alignments, however, total water content is reported, which, if the core was saturated would be equivalent to the porosity. The average water content for all core samples (disregarding outliers) was 4.6 per cent, while for samples below 50 metres was 4.5 per cent. Based on these results, representative values of specific yield for the Hawkesbury Sandstone of the order of two to five per cent are considered reasonable, depending on degree of weathering and jointing.

2.6 Existing infrastructure

2.6.1 Existing and proposed tunnels

Numerous other existing and proposed tunnels occur and are planned in the Sydney area. Where these tunnels are drained and have an ongoing water take they would need to be considered for potential cumulative impacts. Known inflows to existing tunnels and predicted inflows to proposed tunnels are provided in Table 2.12. It is noted that the Sydney Metro City & Southwest (Jacobs 2016) is proposed as a fully tanked construction for the main tunnel alignment and as such would have negligible inflows. Where these tunnels fall within the model domain they are included as groundwater stresses for the purpose of assessing cumulative impacts.

Table 2.12: Flow summary for existing and other proposed tunnels in Sydney

Tunnel	Year Opened	Type	Width (m)	Length (km)	Reported / Predicted Inflow (L/s/km)	Total Inflow (L/s)	Reference
Existing tunnels - inflows							
Eastern Distributor	1999	Twin – 3 lane, double deck	12	1.7	1	1.7	Hewitt 2005
Northside Storage	2000	Stormwater storage	6	20.0	0.9	18	Coffey 2012
M5 East	2001	Twin – 2 lane	8	3.8	0.9	3.42	Tammetta and Hewitt 2004

Tunnel	Year Opened	Type	Width (m)	Length (km)	Reported / Predicted Inflow (L/s/km)	Total Inflow (L/s)	Reference
Cross City	2005	Twin – 2 lane	8	2.1	>3	6.3	Hewitt 2005
Lane Cove	2007	Twin – 3 lane	9	3.6	0.6	2.16	Coffee 2012
Epping to Chatswood	2009	Twin rail	7.2	13.0	0.9	11.7	Best and Parker 2005
Proposed tunnels – predicted inflows							
M4 East	2020 (1)	Twin – 3 lane	-	5.5 each	1.5	17	GHD 2015
New M5	2020 (1)	Twin – 3 lane	14.1-20.6	9	0.63 to 0.67	12.9	AECOM 2015
Sydney Metro Chatswood to Sydenham	2020 (1)	Twin rail - Tanked	-	15.5	negligible	negligible	Jacobs 2016
Western Harbour Tunnel	n/a	Twin – 3 lane					Jacobs 2017
Beaches Link	n/a	Twin – 3 lane					Jacobs 2017

Notes (1) Assumed Completion of Tunnelling

3. Model Design and Construction

3.1 Modelling Objectives

The objectives of the groundwater modelling are to:

- Estimate groundwater inflows to the proposed Western Harbour Tunnel and Beaches Link projects
- Estimate groundwater drawdown due to both projects.
- Estimate changes in groundwater discharge to watercourses due to both projects.
- Estimate the rate of inland movement of the freshwater-saline water interface.

The modelling has been designed to meet Class 2 requirements of the Australian Groundwater Modelling Guidelines.

3.2 Model Extents

Two groundwater models were developed to cover the whole proposed tunnel alignment for the Western Harbour Tunnel and Beaches Link projects. Splitting the investigation area into two models has the following advantages:

- A more refined grid enables a more accurate model representation of proposed project components
- Shorter model run times are achieved for each model
- There is more efficient use of the model domain by minimising the number of inactive cells.

The two separate models, referred to in this report as “South Model” and “North Model”, are separated along Sydney Harbour (Figure 3-1). South Model includes components of the Western Harbour Tunnel project only. North Model includes components of the Western Harbour Tunnel project north of Sydney Harbour and all the components of the Beaches Link project.

Sydney Harbour was considered to be an appropriate physical boundary for splitting the models because it is unlikely that construction and operation activities of the Western Harbour Tunnel Project components south of Sydney Harbour would induce groundwater drawdown north of the harbour given that the proposed tunnel crossing of the Harbour is to be constructed using the immersed tube method. It has also been assumed that construction and operation of components of the Western Harbour Tunnel Project and Beaches Link Project located to the north of Sydney Harbour are unlikely to induce drawdown to the south of Sydney Harbour.

For the assessment of potential groundwater drawdown and tunnel inflows due to the Beaches Link Project only (i.e. excluding effects due to the Western Harbour Tunnel project and other projects), model boundary conditions representing components of the Western Harbour Tunnel project and other projects were de-activated in the North Model. Similarly, for assessment of potential groundwater drawdown and tunnel inflows due to the Western Harbour Tunnel project only, model boundary conditions representing components of the Beaches Link project and other projects were de-activated in the North Model.

Predicted tunnel groundwater inflows for the Western Harbour Tunnel Project presented in this report include combined flows along the proposed Western Harbour Tunnel project alignment in both the North and South models.

3.3 Modelling Software

3D groundwater flow modelling was carried out using the MODFLOW-USG modelling code. MODFLOW-USG simulates groundwater flow using a generalized control volume finite-difference approach (Panday et. al.,2013) The flexible grid design incorporated within MODFLOW-USG was used to focus resolution along key areas of interest including proposed tunnels and watercourses. Quadtree grid refinement was used to refine the model grid in areas along and surrounding the proposed tunnel alignment (Section 3.5). The Groundwater Vistas 7 Graphical User Interface was used for pre- and post-processing. Steep vertical hydraulic gradients usually develop when tunnel drainage occurs at depth. Steep vertical gradients have the potential to cause cells in upper model layers to become dry which may cause problems with model convergence and stability. MODFLOW-USG overcomes the ‘dry cell’ challenge using an approach similar to the Upstream Weighting (UPW) approach implemented in MODFLOW-NWT (Niswonger et.al. 2011) to keep cells specified as convertible (i.e. cells that oscillate between unconfined and confined conditions during the simulation) from desaturating.

The SMS Solver was used in the numerical simulations. SMS solver options used are presented in Annexure 2.

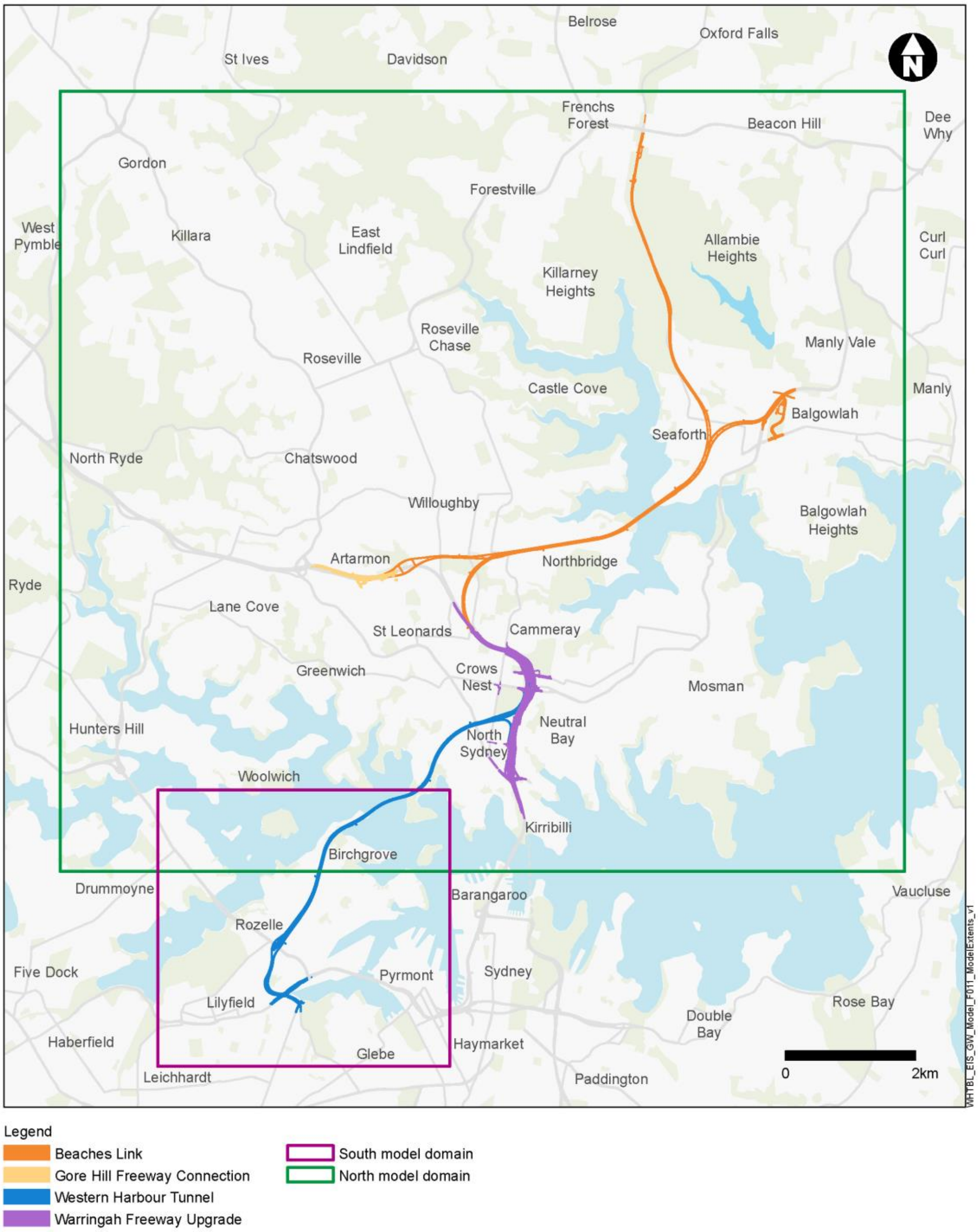


Figure 3-1: North and south model extents

3.4 Model Layers and Zones

3.4.1 Overview

The South Model and North Model have been sub-divided into seven layers based on the following considerations:

- The inferred decrease in hydraulic conductivity with depth within the Hawkesbury Sandstone based on packer tests data analysis, as discussed in Section 2.5.4.2.1.
- Observations from drill-core samples showing decrease in the degree of weathering and fracture network density with depth.
- The need to allow for more accurate representation of the tunnel geometry in the model.

Layer 1 in both models comprises Weathered Hawkesbury Sandstone, Ashfield Shale, Fill/Alluvium and Harbour Sediment zones. Layer 2 to Layer 7 represent Hawkesbury Sandstone with varying degrees of weathering, fracturing and permeability (Section 2.5.4.2.1). Table 3.1 summarises information on the layering and hydrostratigraphic units. The Unweathered Hawkesbury Sandstone hydrostratigraphic unit has been split into Layer 5 to Layer 7 mainly to allow more accurate model representation of tunnel geometry and to constrain the elevation at which inflows to tunnels are simulated.

Table 3.1: Model hydrostratigraphic units

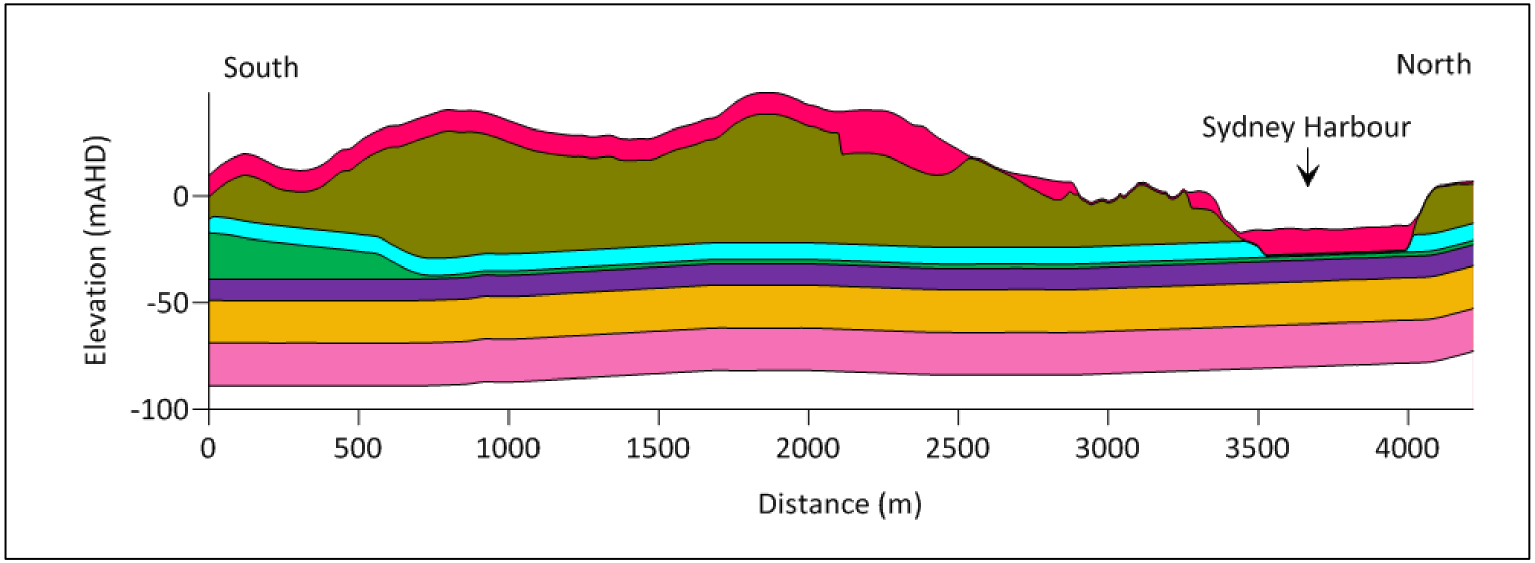
Model Layer	Hydrostratigraphic Unit
1	Weathered Hawkesbury Sandstone, Harbour Sediments, Ashfield Shale & Fill/Alluvium
2	Moderately Weathered Hawkesbury Sandstone
3	Slightly Weathered Hawkesbury Sandstone
4	Slightly Weathered/ Un-weathered Hawkesbury Sandstone
5 - 7	Unweathered Hawkesbury Sandstone

Layer 1 to Layer 6 in both models are simulated as fully convertible between confined and unconfined conditions (Layer-type = 4). With this layer- type option, when the calculated hydraulic head is below the top of the cell, all the options associated with water-table conditions are implemented. Saturated thickness and transmissivity are recalculated at each iteration based on the water depth of the upstream model cell. For this layer-type option, confined storage coefficient (specific storage × layer thickness) is used to calculate the rate of change in storage if the layer is fully saturated; otherwise specific yield is used.

The bottom layer (Layer 7) is modelled as a confined layer which has a constant transmissivity throughout the simulation. This approach was considered appropriate because the layer occurs at a considerable distance below the lowest tunnel invert depth and the layer also remains fully saturated during the model simulations.

3.4.2 South Model Layers and Zones

The cross-section in Figure 3-2 shows the model layers and elevations along the proposed tunnel alignment in the South Model. The location of the cross-section line is shown in Figure 3-3. Layer 1 comprises Weathered Hawkesbury Sandstone, Ashfield Shale, Fill/Alluvium and Harbour Sediment zones. Layer 2 to Layer 7 represent Hawkesbury Sandstone with varying degrees of weathering. As discussed in Section 3.4.1, the Unweathered Hawkesbury Sandstone hydrostratigraphic unit has been split into Layer 5 to Layer 7 mainly to allow more accurate model representation of tunnel geometry and to constrain the elevation at which inflows to tunnels are simulated. The main tunnel occurs mainly in model layer 5.



MODEL LAYERS

Layer 1 – Weathered Hawkesbury, Ashfield Shale, Fill/alluvium, Harbour Sediments

Layer 2 – Moderately Weathered Hawkesbury Sandstone

Layer 3 – Slightly Weathered Hawkesbury Sandstone

Layer 4 –Slightly weathered/Unweathered Hawkesbury Sandstone

Layer 5 – Unweathered Hawkesbury Sandstone

Layer 6 – Unweathered Hawkesbury Sandstone

Layer 7 – Unweathered Hawkesbury Sandstone

Figure 3-2: South model layer elevations along tunnel alignment

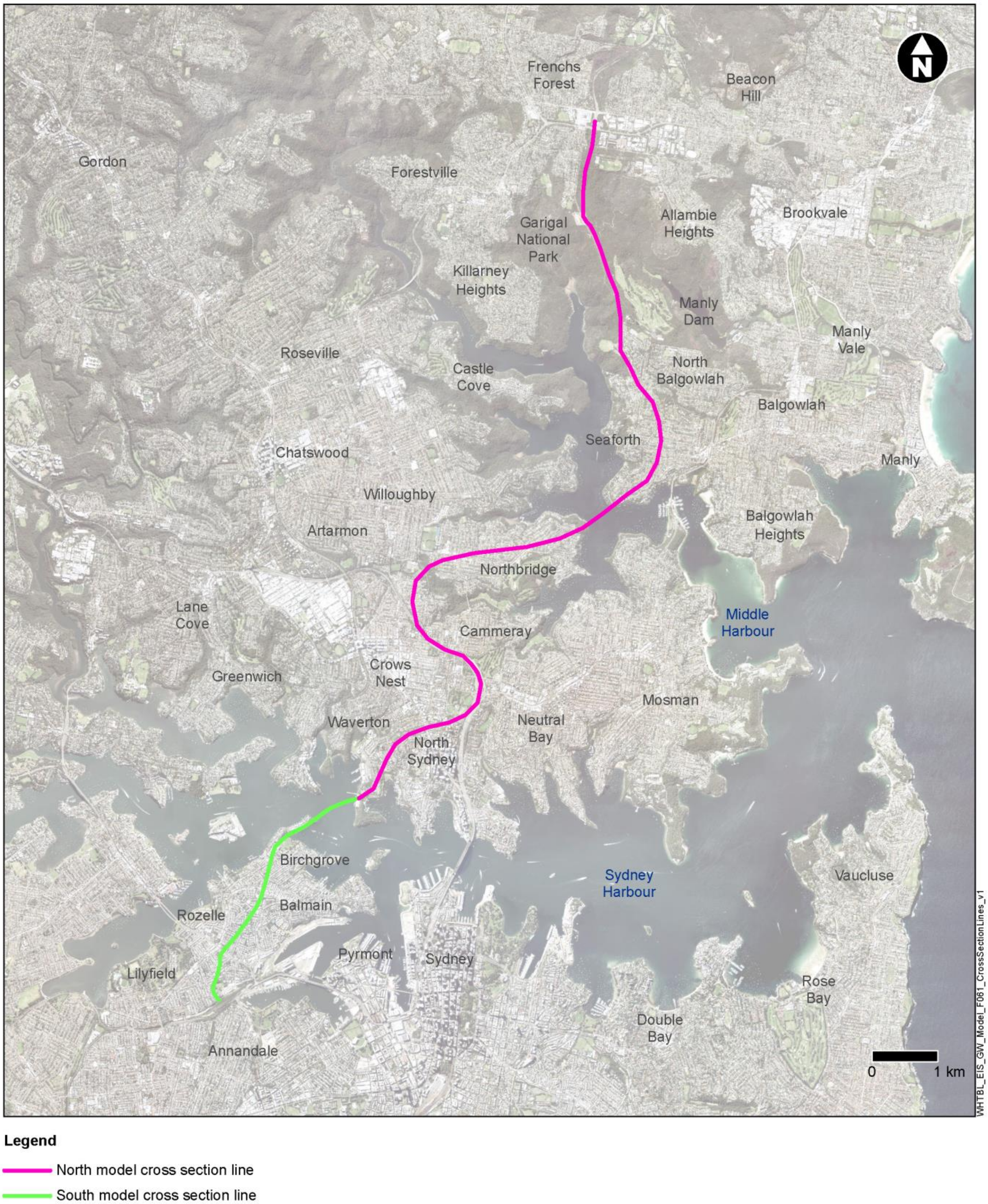


Figure 3-3: Location of cross-section lines

Model layer 5 has a constant thickness of 10 metres which would be the approximate height of the proposed main tunnel. Model layer 6 and layer 7 both have constant thicknesses of 20 metres.

As described in Section 3.4.1 the vertical layering applied to the model is based on the inferred decrease in hydraulic conductivity with depth within the Hawkesbury Sandstone (Section 2.5.4.2.1) and observations from drill-core samples showing decrease in the degree of weathering and fracture network density with depth.

Initial hydraulic conductivity values assigned to the model layers are presented in Table 3.2. Initial hydraulic conductivity values provided in Table 3.2 represent average bulk rock conditions. Some areas may have slightly higher or lower permeability. Areas of known elevated hydraulic conductivity such as fracture swarms were assigned high initial hydraulic conductivity values. The initial hydraulic conductivity of the high permeability zones was generally one order of magnitude higher than the bulk rock hydraulic conductivity. The initial hydraulic conductivity values were subsequently adjusted during the model calibration.

Table 3.2: Model layers, zones and initial hydraulic conductivity estimates

Model Layer	Hydrostratigraphic Unit	Model Zone	Hydraulic conductivity (m/d)	
			Horizontal hydraulic conductivity	Vertical hydraulic conductivity
1	Harbour Sediments [1]	3	1.00×10^{-2}	5.0×10^{-3}
	Fill/Alluvium [1]	4	1	4.3×10^{-1}
	Ashfield Shale [1]	1	6.0×10^{-2}	2.0×10^{-4}
	Weathered Hawkesbury Sandstone	1	1.4×10^{-1}	7.0×10^{-2}
2	Moderately Weathered Hawkesbury Sandstone	9	2.0×10^{-2}	1.0×10^{-2}
3	Slightly Weathered Hawkesbury Sandstone	10	4.3×10^{-3}	8.6×10^{-4}
4	Slightly Weathered Hawkesbury Sandstone	6	4.3×10^{-3}	8.6×10^{-4}
5 - 7	Un-weathered Hawkesbury Sandstone	17	1.3×10^{-3}	8.7×10^{-5}
2	High K_1	7	1.3×10^{-1}	6.5×10^{-2}
3	High K_2	11	8.0×10^{-2}	4.0×10^{-2}
4	High K_3	8	5.0×10^{-2}	2.5×10^{-2}
5-7	High K_4	15	5.0×10^{-2}	2.5×10^{-2}

Notes. [1] Source: HydroSimulations (2017).

The basis for the initial horizontal hydraulic conductivity values assigned to the Hawkesbury Sandstone was as follows:

- **Weathered Hawkesbury Sandstone (Layer 1)** - The average thickness for the weathered sandstone from bore geological logs is approximately 10 metres. However, there are no project-specific packer test results for depths less than 10 m. The initial hydraulic conductivity of 1.4×10^{-1} m/day assigned to the Weathered Hawkesbury Sandstone in the South Model was based on the following:
  - Projection of the hydraulic conductivity geometric mean line based on basin-wide testing (Figure 2-8 and Figure 2-9) indicates that the average hydraulic conductivity up to a depth of 10 m ranges from 8×10^{-2} to 2×10^{-1} m/day. The initial hydraulic conductivity value applied to the Weathered Hawkesbury Sandstone in the model is within this range.

- The initial hydraulic conductivity assigned to the Weathered Hawkesbury Sandstone in the model is similar to the hydraulic conductivity assigned in previous calibrated models (HydroSimulations, 2017) to Weathered Hawkesbury Sandstone occurring at similar depths.

- **Moderately Weathered Hawkesbury Sandstone (Layer 2)** –The maximum project specific hydraulic conductivity estimated from hydraulic testing for depths between 35 and 70 mBGL (which coincides with the depth range for the Moderately Weathered Hawkesbury Sandstone in model layer 2) was approximately 2 x 10^{-2} m/day (Figure 2-9). This maximum hydraulic conductivity value was assigned as the initial hydraulic conductivity for model Layer 2. The initial hydraulic conductivity is within the range of geometric means estimated by Tammetta and Hawkes (2009) for the same depth interval (Figure 2-9).

- **Slightly Weathered Hawkesbury Sandstone (Layer 3 and layer 4)** - The maximum project specific hydraulic conductivity estimated from hydraulic testing at depths between 50 and 85 mBGL was approximately 4.3 x 10^{-3} m/day (Figure 2-9). This depth interval roughly coincides with the average depth to the bottom of the Slightly Weathered Hawkesbury in Model layer 3 and layer 4. Therefore, an initial hydraulic conductivity value of 4.3 x 10^{-3} m/day was assigned to model layer 3 and layer 4. This initial value is within the range of the basin-wide geometric mean hydraulic conductivity for this depth interval (Figure 2-9).

- **Unweathered Hawkesbury Sandstone (Layer 5 to layer 7).** The Unweathered Hawkesbury Sandstone in layer 5 to layer 7 was assigned an initial hydraulic conductivity of 1.3 x 10^{-3} m/day. This initial value was based on the maximum project specific hydraulic conductivity estimated from hydraulic tests for the sandstone occurring at depths greater than 85 mBGL.

Figure 3-4 shows the spatial distribution of the different hydrogeological units in model layer 1. Figure 3-4 to Figure 3-8 show the additional zones defined in the model layers to represent high permeability fault/fracture zones (high K zones) as described in Section 2.4.7 and Section 2.5.4. Figure 3-4 to Figure 3-8 also show that Harbour sediments are represented in model layers 1 to 4 but not in layer 5 and 7 to conform with results obtained from field geological investigations. The geological cross-section along the tunnel alignment (Figure 3-2) indicates that the thickness of the Harbour sediments in layer 2 to layer 4 is very small.

High K zones in each model layer were assigned hydraulic conductivity values that were generally one order of magnitude higher than surrounding rock, based on the review of hydraulic testing results (Section 2.5.4).

Inferred Sydney dyke zones (Figure A1-10) were assigned the same hydraulic conductivity as the surrounding rocks based on the rationale discussed in Section 2.5.4.3.4.

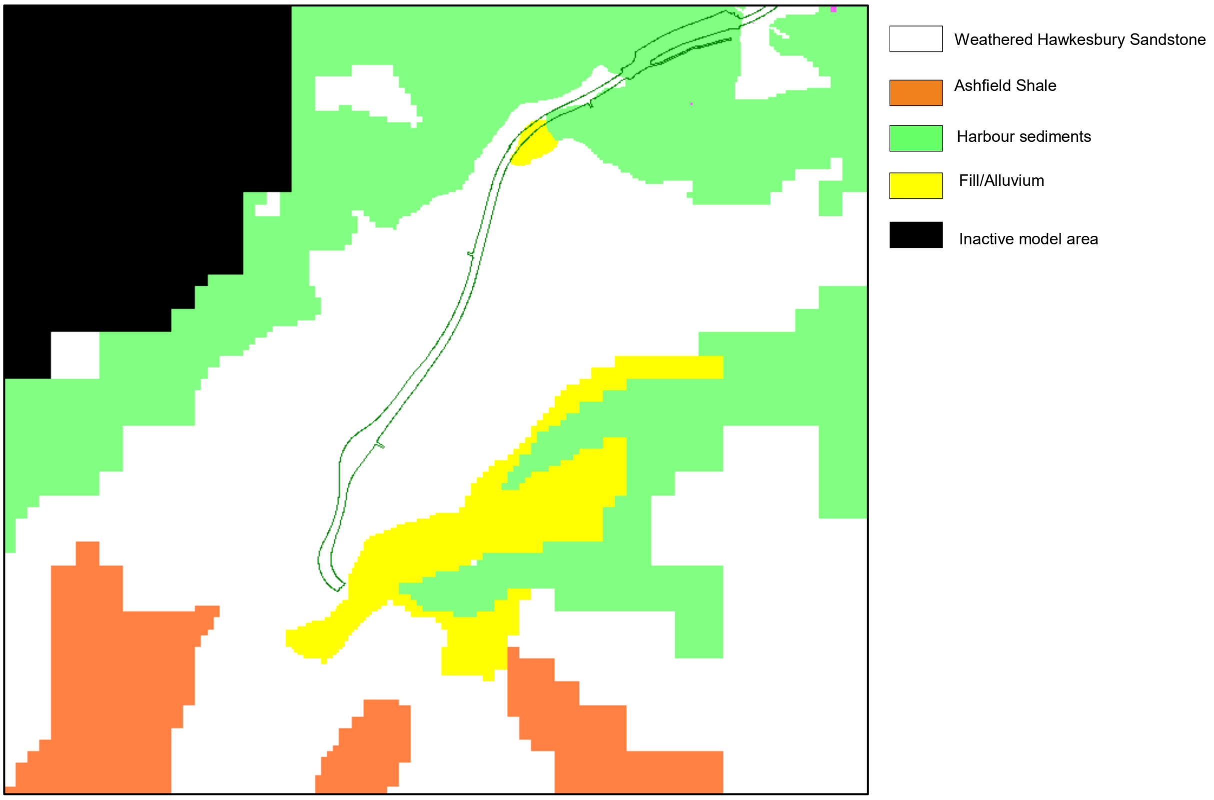


Figure 3-4: Hydrostratigraphic units in Layer 1 - South Model

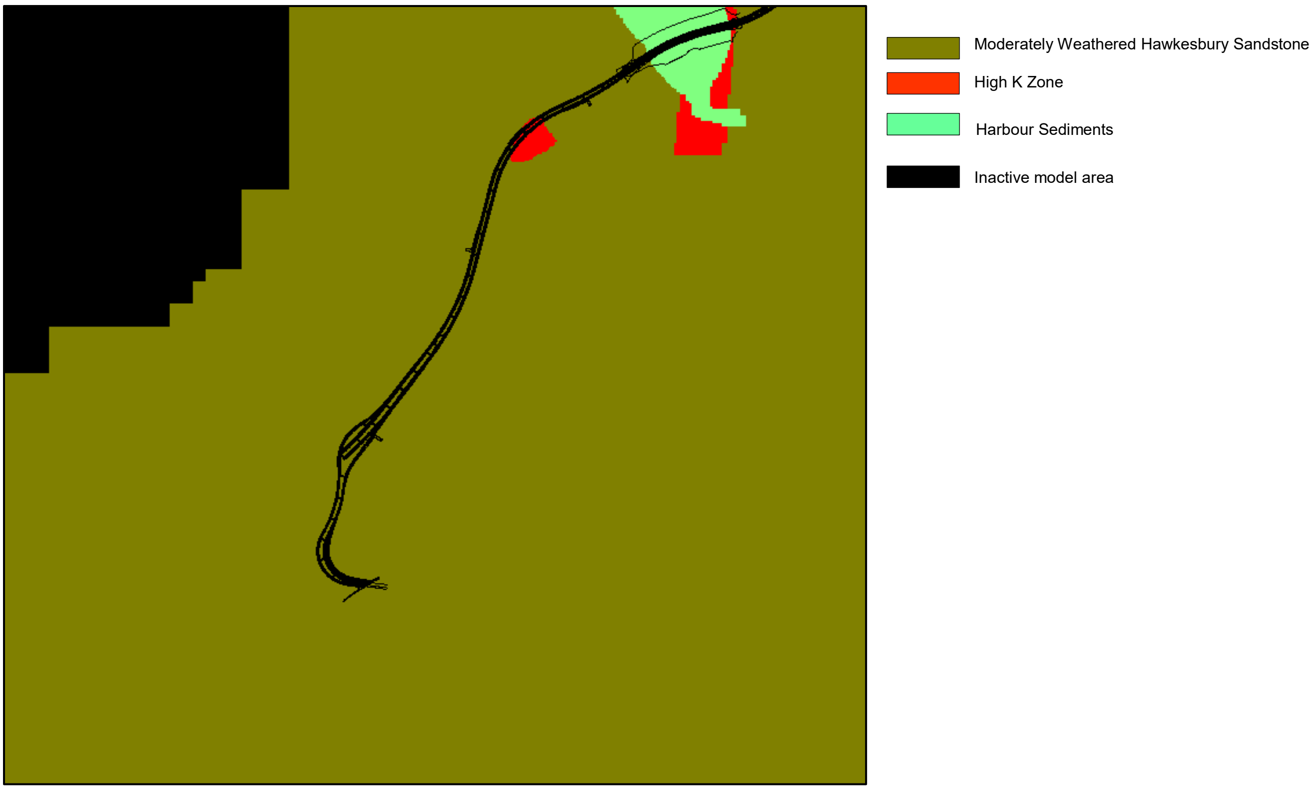


Figure 3-5: Hydrostratigraphic units in Layer 2 – South Model

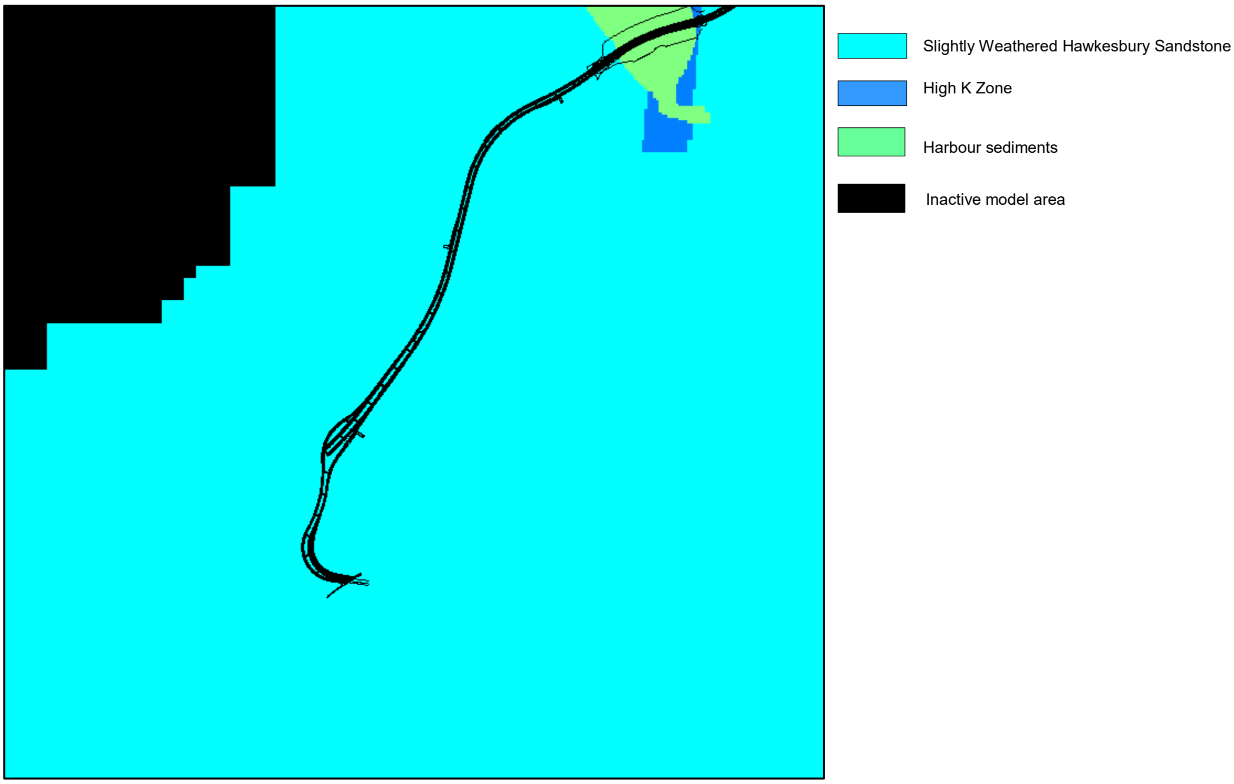


Figure 3-6: Hydrostratigraphic unites in Layer 3 – South Model

Figure 3-7: Hydrostratigraphic units in Layer 4 - South Model

Figure 3-8: Hydrostratigraphic units in Layer 5 to 7 – South Model

3.4.3 North Model Layer and Zones

The North Model has been divided into seven layers based on the same conceptual model described in Section 3.4.1 and Section 3.4.2. Figure 3-2 shows the model layers and elevations along the proposed tunnel alignment in the North Model. The location of the cross-section line is shown in Figure 3-3.

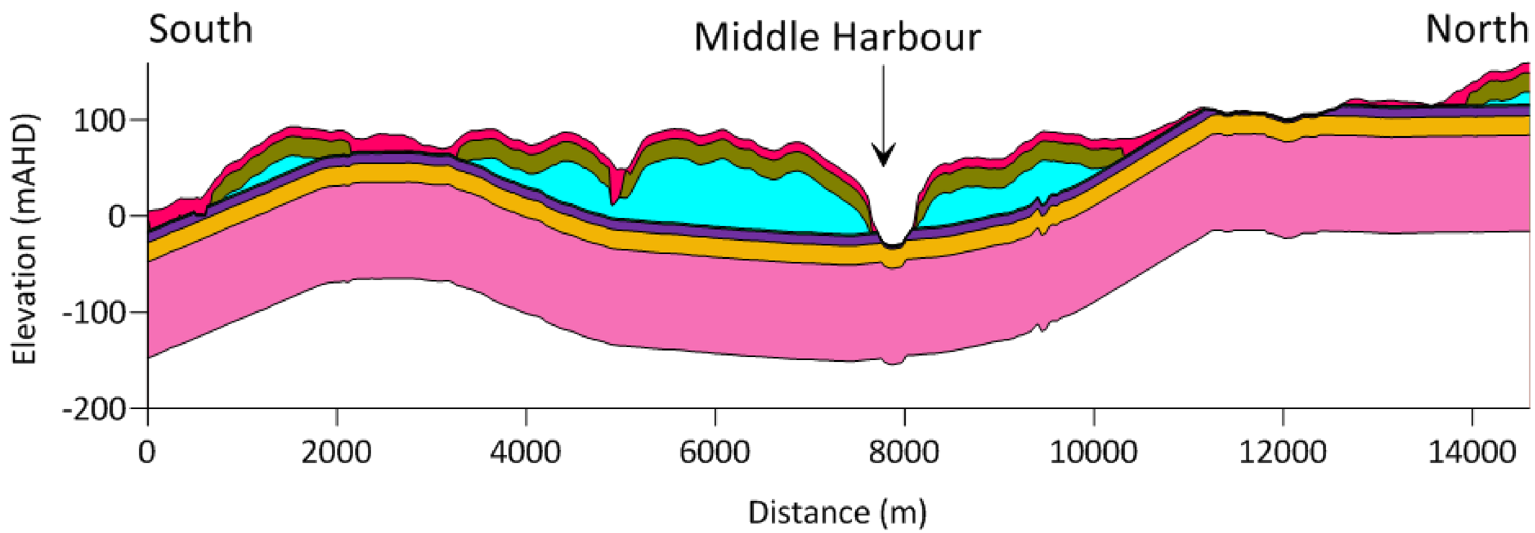
Layer 1 comprises Weathered Hawkesbury Sandstone, Ashfield Shale, Fill/Alluvium and Harbour Sediment zones. As discussed in Section 3.4.1, the Unweathered Hawkesbury Sandstone hydrostratigraphic unit has been split into layer 5 to layer 7 mainly to allow more accurate model representation of tunnel geometry and to constrain the elevation at which inflows to tunnels are simulated.

The main tunnel occurs mainly in model layer 5. Model layer 5 has a constant thickness of 10 metres which would be the approximate height of the proposed main tunnel. Layer 4 has a maximum thickness of 2 metres and is, therefore, not visible in Figure 3-9. Model layer 6 has constant thicknesses of 20 metres and Model 7 has a thickness of 100 metres.

As described in Section 3.4.1 the vertical layering applied to the model is based on the inferred decrease in hydraulic conductivity with depth within the Hawkesbury Sandstone (Section 2.5.4.2.1) and observations from drill-core samples showing decrease in the degree of weathering and fracture network density with depth. Initial hydraulic conductivity values assigned to the North Model layers are the same as the initial values assigned to the South Model (Table 3.2). The initial hydraulic conductivity values were subsequently adjusted during the model calibration. The spatial distribution of hydrogeological units in layer 1 is presented in Figure 3-10. Figure 3-11 to Figure 3-14 show the additional zones defined in the model layers to represent high permeability fault/fracture zones (high K zones) as described in Section 2.4.7 and Section 2.5.4.

High K zones in each model layer were assigned hydraulic conductivity values that were generally one order of magnitude higher than surrounding rock, based on the review of hydraulic testing results (Section 2.5.4).

Inferred Sydney dyke zones (Figure A1-10) were assigned the same hydraulic conductivity as the surrounding rocks based on the rationale discussed in Section 2.5.4.3.4.



MODEL LAYERS

- Layer 1 – Weathered Hawkesbury, Ashfield Shale, Fill/alluvium, Harbour Sediments
- Layer 2 – Moderately Weathered Hawkesbury Sandstone
- Layer 3 – Slightly Weathered Hawkesbury Sandstone
- Layer 4 –Slightly weathered/Unweathered Hawkesbury Sandstone
- Layer 5 – Unweathered Hawkesbury Sandstone
- Layer 6 – Unweathered Hawkesbury Sandstone
- Layer 7 – Unweathered Hawkesbury Sandstone

Figure 3-9: North Model layer elevations along tunnel alignment

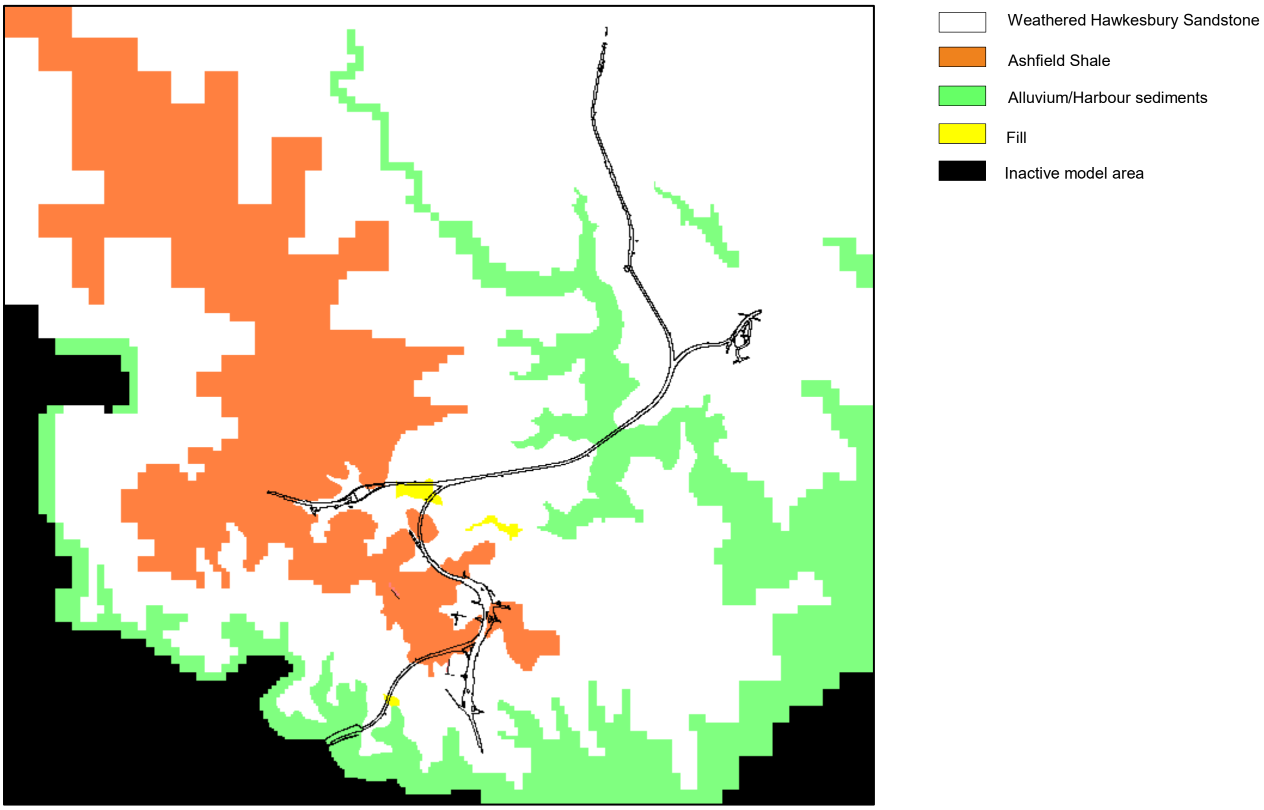


Figure 3-10: Hydrostratigraphic Units in Layer 1 – North Model

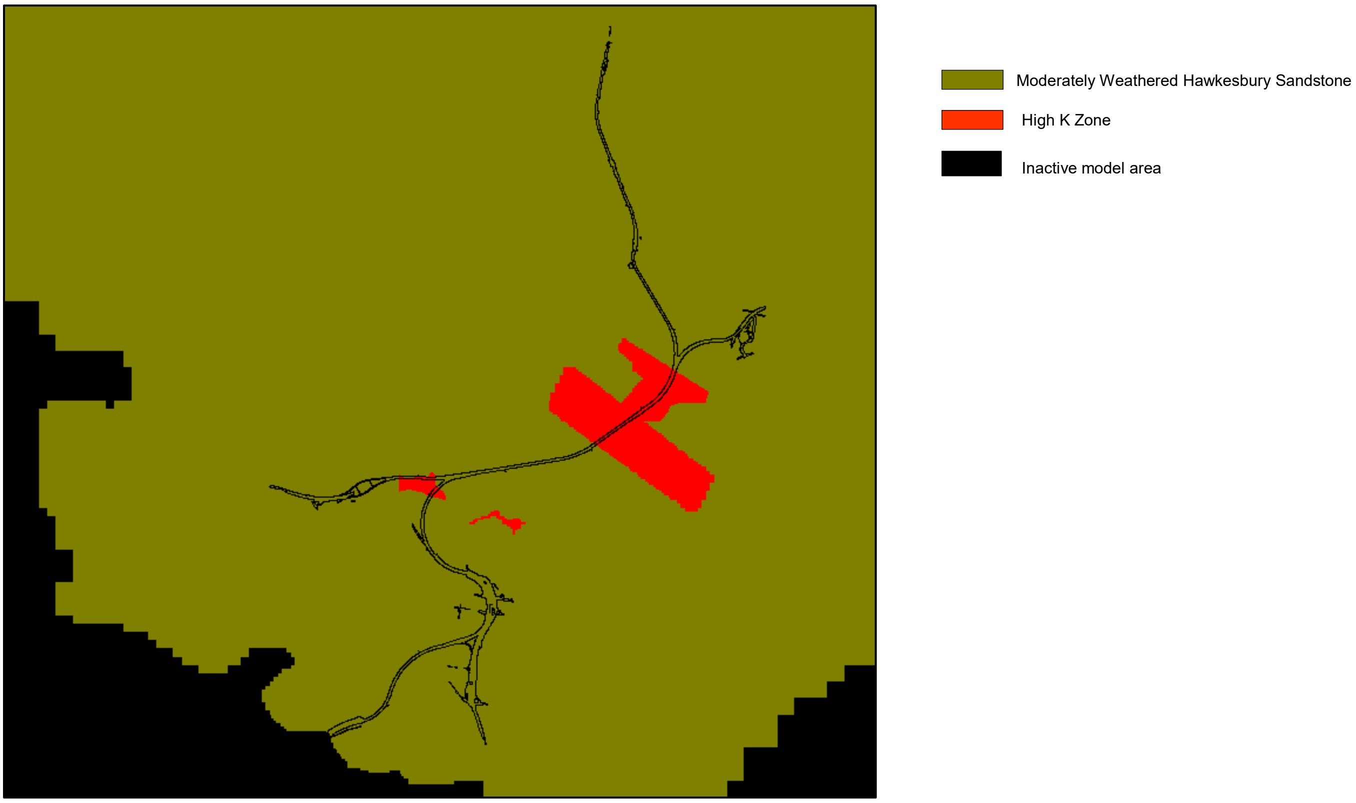


Figure 3-11: Hydrostratigraphic units in Layer 2 – North Model

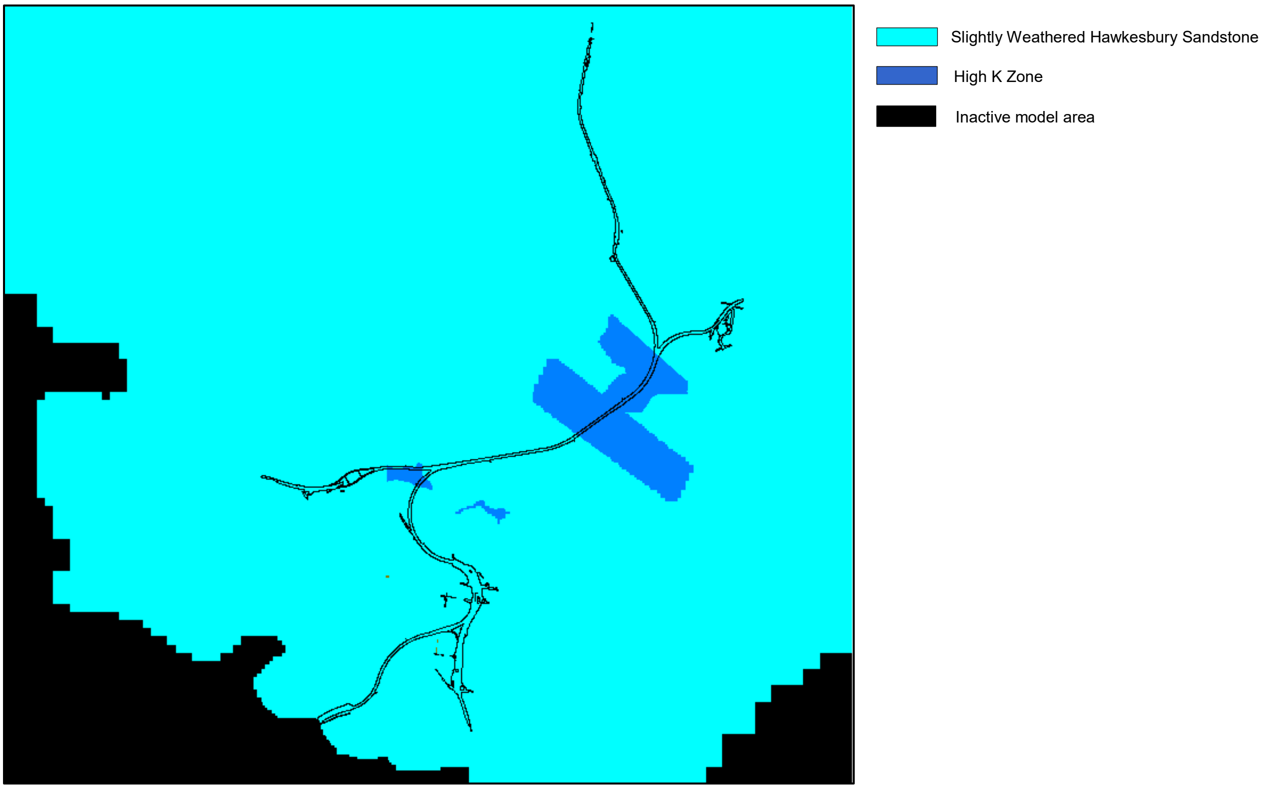


Figure 3-12: Hydrostratigraphic Units in Layer 3 – North Model

Figure 3-13: Hydrostratigraphic Units in Layer 4 – North Model

Figure 3-14: Hydrostratigraphic units in Layer 5 to Layer 7 – North Model.

3.5 Spatial Discretisation of Model

Quadtree grid refinement was used to refine the model grid in areas along and surrounding the proposed tunnel alignment. Figure 3-15 and Figure 3-16 show the North and South model grids respectively. Table 3.3 summaries spatial discretisation information. The smallest model grid dimensions used in the South Model and North Model are eight metres and 16 metres respectively. Approximately 88 per cent of the model domain is active in the North Model and 87 per cent for the South Model.

Table 3.3: Summary of Spatial Discretisation Information

Parameter	South Model	North Model
Minimum grid cell dimension (m)	8	16
Maximum grid cell dimension (m)	250	500
Number of layers	7	7
Total number of cells	284,550	570,801
Active cells	283,990	535,766
Total area (Hectares)	1913	15,600
Active area (Hectares)	1671	13,800

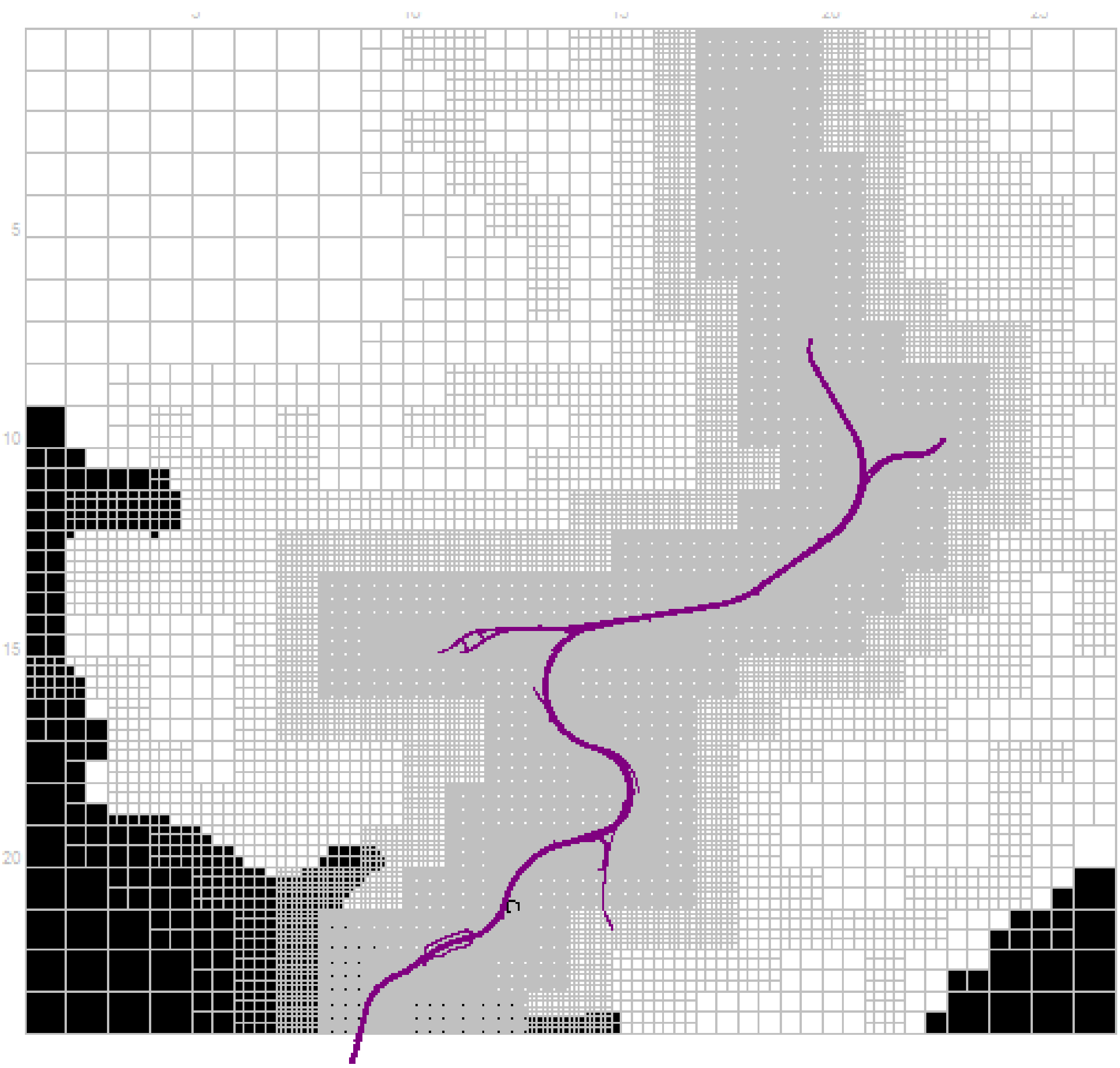


Figure 3-15: North Model Grid Design

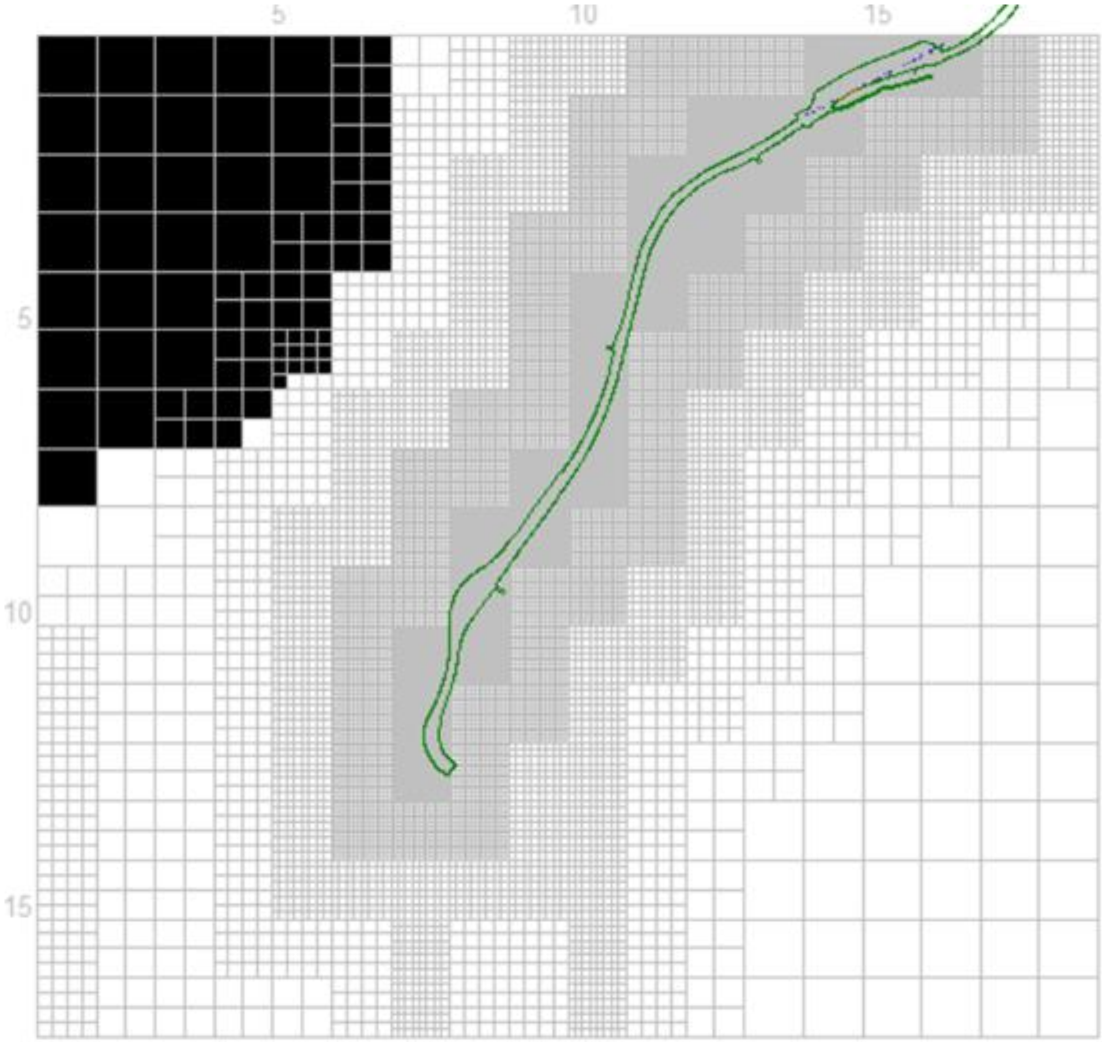


Figure 3-16: South Model Grid Design

3.6 Model Boundaries

3.6.1 Rainfall-recharge

Rainfall-recharge is represented in the model using the MODFLOW Recharge package (RCH). Recharge was estimated as a percentage of rainfall. Initial recharge rate estimates of between one and 10 per cent of average annual rainfall were assigned to the various hydrostratigraphic units based on the conceptualisation of groundwater recharge presented in Section 2.5.3.

Recharge rates applied to each hydrostratigraphic unit were also varied depending on whether the surface was paved or unpaved based on the New South Wales government environmental plan land use zoning map (http://data.environment.nsw.gov.au/dataset/standard-instrument-local-environmental-plan-land-zoning).The groundwater recharge zones assigned to the South Model and North Model are shown in Figure 3-17 and Figure 3-18. respectively.

Initial recharge rates assigned to the recharge zones are presented in Table 2.6. A recharge rate of 0 m/day was assigned to the open water surfaces. Recharge beneath open water surfaces occurs through constant head and stream boundary conditions.

Temporal variation in groundwater recharge rates applied to the models is discussed in Section 4 and Section 6.

3.6.2 Evapotranspiration

Evapotranspiration (ET) is simulated using the MODFLOW Evapotranspiration Package (EVT). Maximum ET rates assigned to the different groundwater models are presented in Table 3.4. An extinction depth of 0.5 metres below the ground surface was applied to the models.

Table 3.4: Maximum evapotranspiration rates applied to models.

Model	Maximum Evapotranspiration Rate [(1)]
Steady state calibration	Mean daily ET calculated from the long-term average annual record (Table 2.3)
Transient calibration	Mean daily ET, which varies by month (Table 2.3).
Predictive models	Mean daily ET, which varies by month (Table 2.3).

Notes. (1) Reference evapotranspiration (FAO Penman-Monteith Method) for Observatory Hill station 066062.

3.6.3 Watercourses

The watercourses within the model domain have lined and unlined channel segments (Section 2.2). Groundwater surface water interaction is expected to be higher along unlined stream reaches. MODFLOW River (RIV) boundary conditions and Drain (DRN) boundary conditions were used to simulate fluxes between streams and the groundwater system. RIV boundaries can be used to simulate both groundwater discharge to streams and leakage from streams to groundwater, depending on the relative difference between groundwater level and stream stage (stream water depth). For RIV boundaries, groundwater discharges to the stream when groundwater levels in areas adjacent to the stream are higher than the stream stage and leakage occurs from the stream when stream stage is higher than surrounding groundwater levels. DRN boundaries can only be used to simulate discharge of groundwater to streams when groundwater levels are higher than stream stage.

First and second order streams located further away from the proposed Western Harbour Tunnel and Beaches Link tunnel project areas were modelled using Drain (DRN) boundaries (Figure 3-19 & Figure 3-20) to allow for the simulation of the draining effect of the water courses in highland areas.

Streams located close to the proposed Western Harbour Tunnel and Beaches Link tunnel project areas including Whites Creek, Johnstons Creek, Bates Creek, Manly Creek, Burnt Bridge Creek, Flat Rock Creek, Quarry Creek and Willoughby Creek were represented in the model using River (RIV) boundaries. RIV boundaries were assigned along these streams to estimate stream leakage under existing conditions for use in the assessment of potential increase in stream leakage that could occur in the future due to construction and operation of the proposed tunnels. The very little information on stream stage obtained from observations during the 2017-2018 dry season (Section 2.2) indicates that the water depth in upstream areas during the dry season is generally less than 10 centimetres. River stage elevations assigned to the model were based on field water depth observations made during the period between November 2017 and January 2018 (Table 2.4). Since the field observations for stream water depth were made during the dry season, it is expected that simulated wet season river stage would be higher.

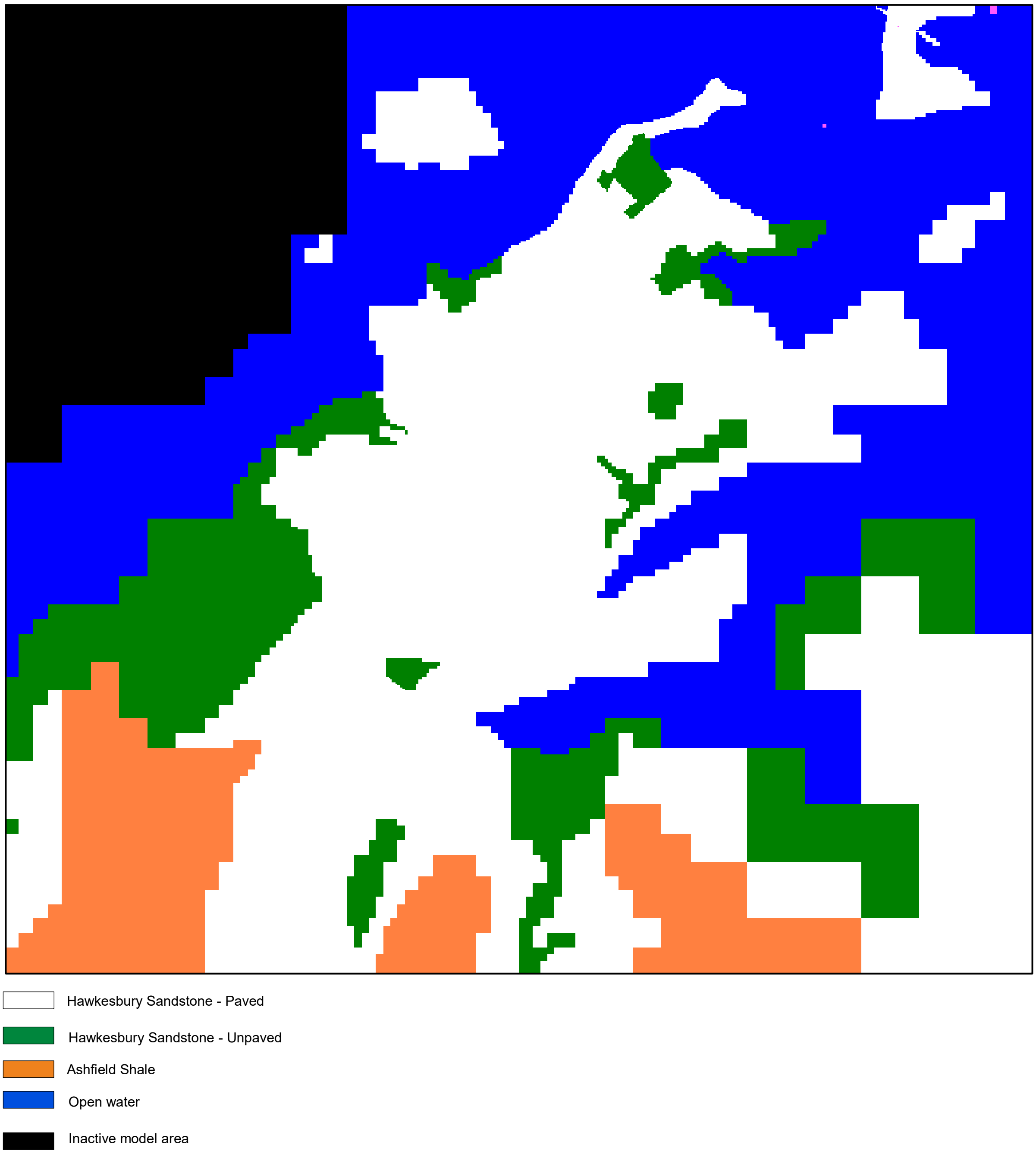


Figure 3-17: South Model groundwater recharge zones

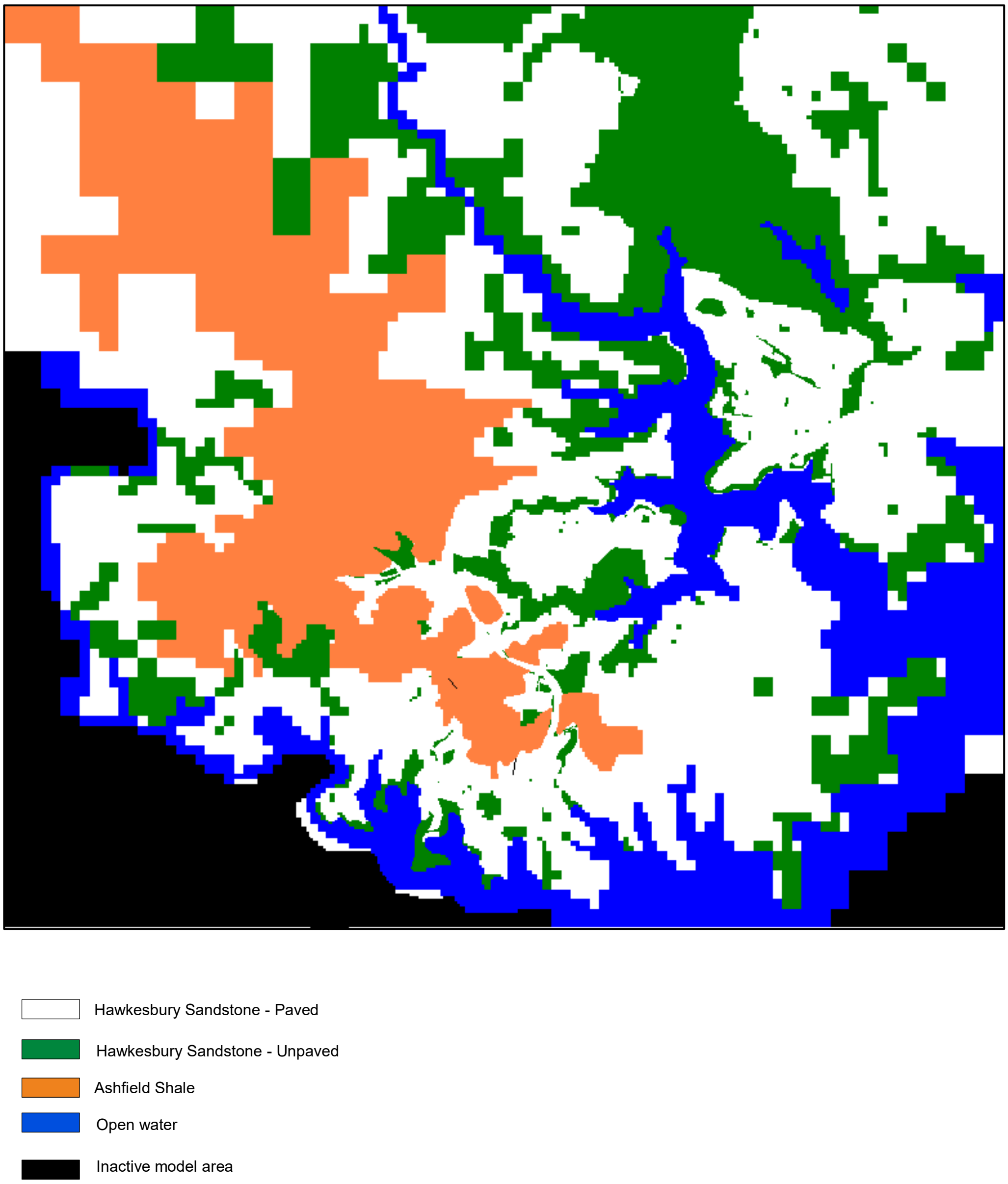


Figure 3-18: North Model groundwater recharge zones

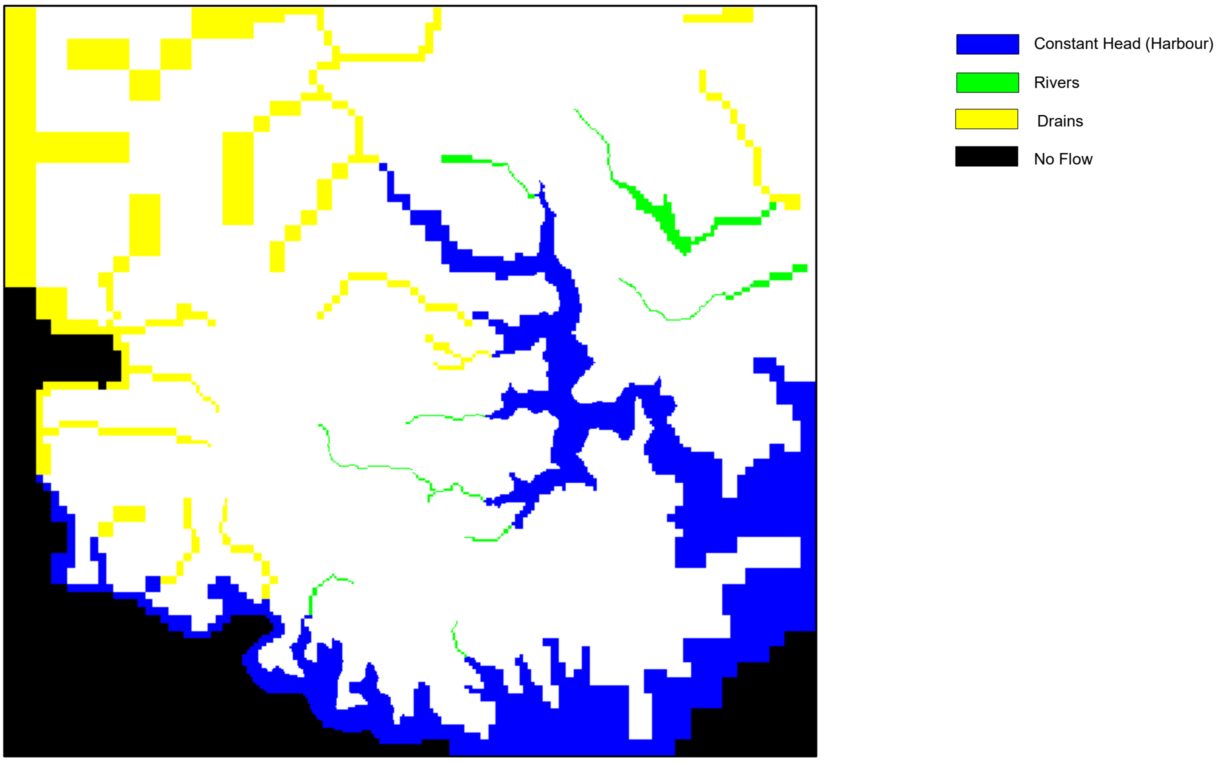


Figure 3-19: Model boundary conditions along watercourses – North Model

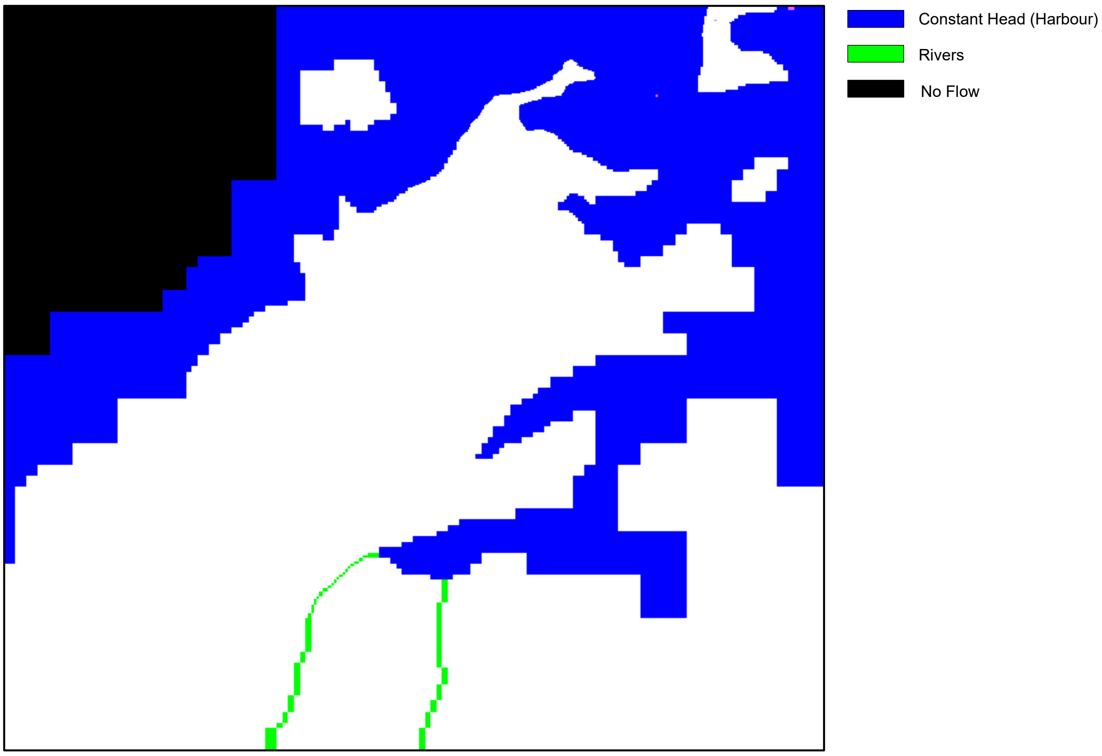


Figure 3-20: Model boundary conditions along watercourses – South Model

The conductance term assigned to the RIV boundaries was calculated as the product of the hydraulic conductivity and cell cross-section area divided by average distance between cell nodes. The hydraulic conductivity used to calculate the RIV cell conductance for unlined water course sections was based on the horizontal hydraulic of the cell containing the RIV boundary.

Figure A1-12 shows the distribution of lined and unlined stream segments in the vicinity of the WHT and BL Projects to the north of Sydney Harbour. Whites Creek, at the southern extent of the Western Harbour Tunnel alignment is concrete lined.

There were no conductance reduction factors applied to model cells along lined stream sections. Therefore, the model is likely to over-estimate stream baseflow volumes. As a result, the model is also likely to over-estimate the potential baseflow reduction due construction and operation of the Western Harbour and Beaches Link tunnels.

River boundary conditions were also used to represent Manly Dam and Cammeray Dam. River stage elevations were set as static across the model due to the lack of transient surface water gauge level data.

3.6.4 Harbours

Harbours are represented using the MODFLOW Constant Head Boundary Condition (CHD) with a specified head of 0 mAHD to represent sea level (Figure 3-21 & Figure 3-22).

3.6.5 General Head Boundaries

MODFLOW General Head Boundary conditions (GHB) are used along selected sections of the edges of the model domain to allow groundwater flow in and out of the model depending on the regional groundwater gradient. Information from the flow model properties (hydraulic conductivity and saturated thickness) were transferred to the GHB boundary conditions to calculate appropriate boundary conductance terms.

General head boundaries are used to allow groundwater flow between the South Model and Hawthorne Canal located approximately 700 metres to the southwest of the model (Figure 3-23). General head boundaries are also assigned along the eastern boundary of the North model to allow groundwater flow towards Manly Beach (Figure 3-24).

3.6.6 Proposed Tunnels

MODFLOW Drain Boundary conditions (DRN) are used to simulate groundwater flow into the proposed tunnel alignments for the Western Harbour Tunnel and Beaches Link project. Parameters applied to the drain boundary conditions are described in Section 6.3 and 7.1.1.

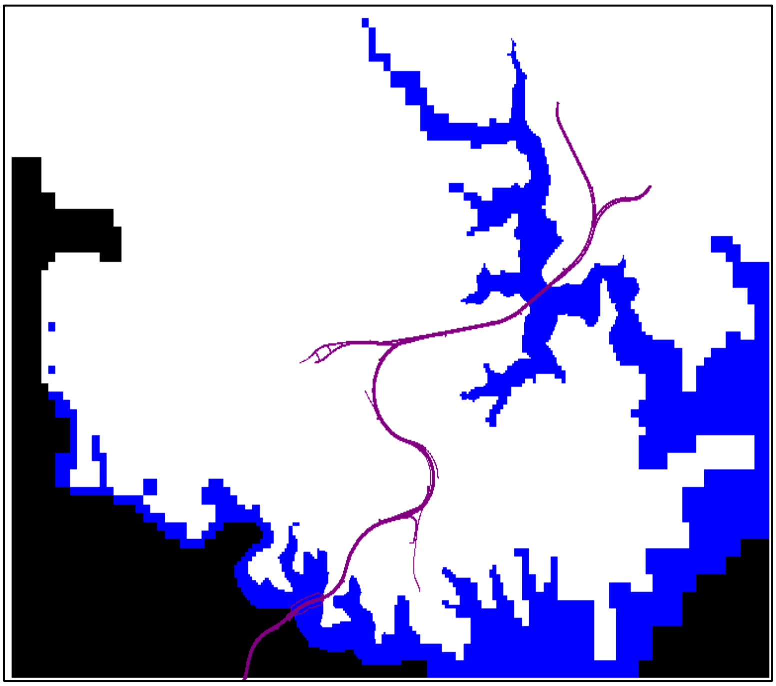


Figure 3-21: Constant Head Boundaries – North Model

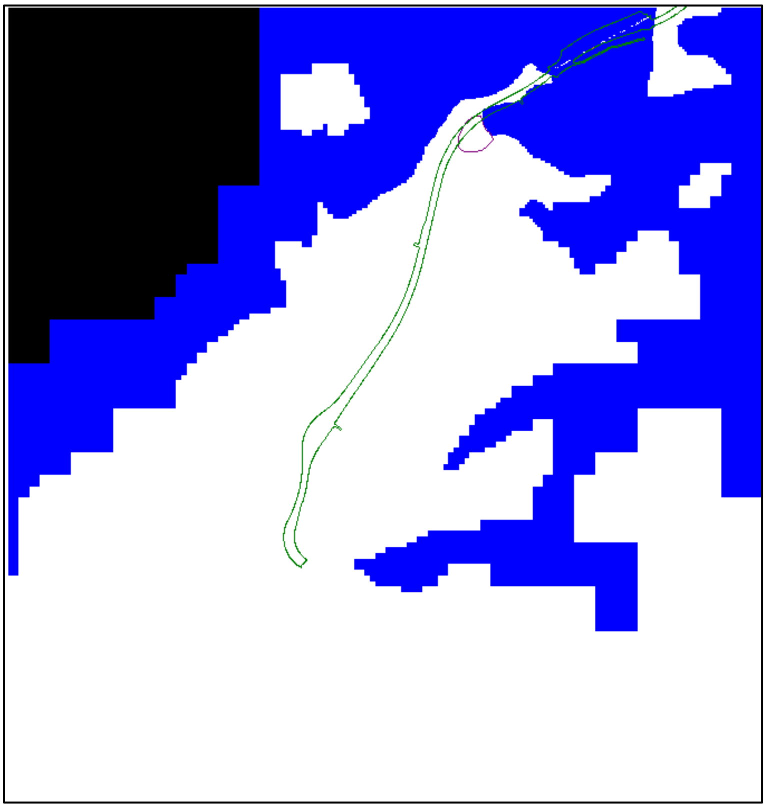


Figure 3-22: Constant Head Boundaries – South Model

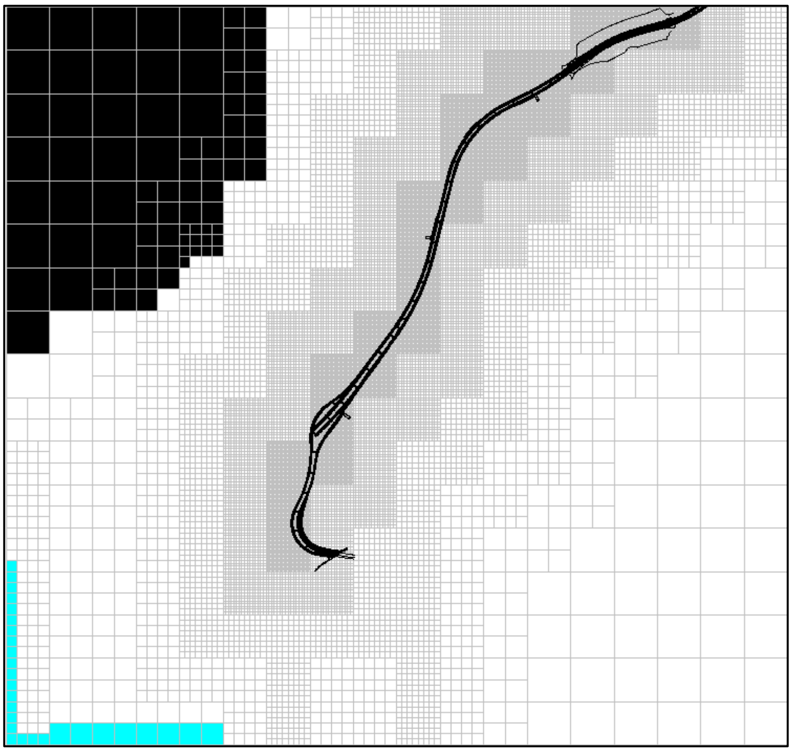


Figure 3-23: General Head Boundaries – South Model

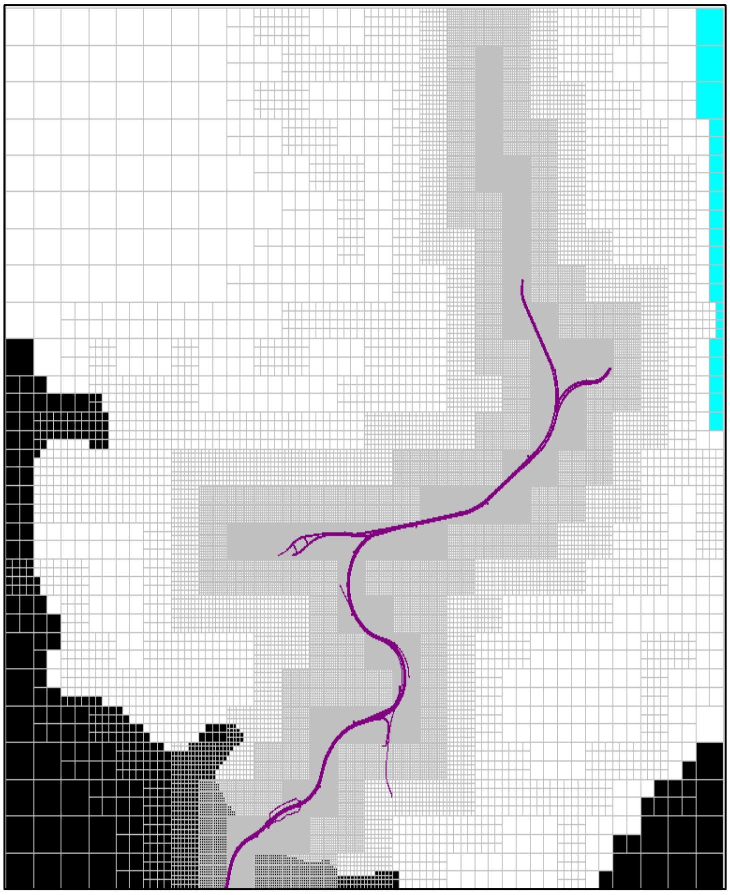


Figure 3-24: General Head Boundaries – North Model

4. Model Calibration

The North Model and South Model were both calibrated for steady state and transient conditions.

4.1 Steady State Calibration – North Model

4.1.1 Calibration for Head Targets

Calibration was conducted by iterative manual step-wise adjustment of hydraulic conductivity and recharge rates to achieve an acceptable match between simulated and observed heads (groundwater levels).

Model calibration head (groundwater level) targets for the steady state model represent mean values of head measured at different time periods. The model was calibrated using 73 head targets. The location of the bores used in calibrating the steady state model are presented in Figure A1-14. Information on bore construction, groundwater level monitoring dates and monitoring data suitability for calibration purposes is provided in Annexure 3. The suitability for calibration purposes, of groundwater level data obtained from the Department of Primary Industries (DPI) bore database search, was considered low for the following reasons:

- For bores where available groundwater levels were measured during or shortly after drilling, the observed groundwater levels may represent groundwater levels that are not fully recovered from drilling and not the long-term average static groundwater levels
- Bore screen/open hole intervals are not provided. Therefore, there is uncertainty in the depth/elevation interval associated with the observed heads.

Despite the suitability/reliability issues associated with water level data from the DPI bores, data for the DPI bores was included in the model calibration in order to provide a wider calibration target coverage in the model. Although no formalised weighting of calibration targets was implemented, lower priority was given during calibration to water level measurements from the DPI bores.

Initial recharge rates and hydraulic conductivity estimates assigned to the steady state North Model during calibration are presented Table 2.6 and Table 3.2 respectively. These initial estimates were adjusted during the model calibration. Evapotranspiration values were not changed from initial estimates presented in Table 2.3 during the calibration.

Calibration was conducted by iterative manual step-wise adjustment of model input parameters to achieve an acceptable match between simulated and observed heads (groundwater levels). Calibration was achieved by qualitatively assessing the match between modelled and observed heads as well as assessing statistical calibration measures.

Hydraulic conductivity values assigned to the calibrated steady state North Model are presented in Table 4.1. Recharge rates assigned to the calibrated steady state North Model are presented in Table 4.2.

Figure 4-1 shows the match between simulated groundwater levels (heads) in the calibrated model and observed heads. Qualitatively assessing the match between modelled and observed heads (Figure 4-1), the degree of calibration can be assessed according to how close the plotted points are to the diagonal line from the origin (i.e. along the line y=x that represents perfect calibration). Figure 4-1 shows a good match between simulated groundwater levels (heads) in the calibrated model and observed heads.

Table 4.3 presents a summary of the calibration statistics for the steady state model. Annexure 4 presents the error (residual) for each calibration target, showing the difference between the model-computed head and the observed head. The scaled root mean square (scaled RMS) is one of the statistics often used to quantitatively assess the goodness-of-fit between simulated groundwater levels and actual observed groundwater levels. A scaled RMS error less than ten per cent usually indicates a reasonably high degree of calibration. The scaled

RMS error of approximately three per cent obtained in the calibrated steady state model (Table 4.3) shows that the model is reasonably well calibrated to measured heads.

Given the reasonably good match between simulated and observed heads in Figure 4-1 and the acceptable calibration statistics (Table 4.3) it was concluded that the steady state model simulates average groundwater levels (heads) with reasonable accuracy.

Table 4.1: Calibrated steady state North Model hydraulic conductivity values.

Hydrostratigraphic Unit	Model Layer	Model Zone	Hydraulic conductivity (m/d)	
			Hydraulic conductivity	Vertical Hydraulic conductivity
Harbour Sediments	1	3	1.00×10^{-2}	5.00×10^{-3}
Fill/Alluvium	1	4	1	0.1
Ashfield Shale	1	2	4.00×10^{-2}	4.00×10^{-3}
Weathered Hawkesbury Sandstone	1	1	1.50×10^{-1}	7.50×10^{-2}
Moderately Weathered Hawkesbury Sandstone	2	9	7.50×10^{-2}	3.75×10^{-2}
Slightly Weathered Hawkesbury Sandstone	3	10	7.50×10^{-2}	3.75×10^{-2}
Slightly Weathered/ Un-weathered Hawkesbury Sandstone	4	6	1.00×10^{-2}	1.00×10^{-3}
Un-weathered Hawkesbury Sandstone	5 - 7	17	6.00×10^{-3}	6.00×10^{-5}
High K_1	2	7	7.50×10^{-1}	3.75×10^{-2}
High K_2	3	11	7.50×10^{-1}	3.75×10^{-2}
High K_3	4	8	1.00×10^{-1}	1.00×10^{-2}
High K_4	5-7	18	6.00×10^{-2}	6.00×10^{-3}

Table 4.2: Summary of calibrated North Model recharge rates

Zone	Recharge (m/day)	Equivalent Recharge (mm/yr)	% Mean Annual Rainfall
Ashfield Shale (paved)	6.74×10^{-5}	25	2
Ashfield Shale (unpaved)	6.74×10^{-5}	25	2
Hawkesbury Sandstone (paved)	1.68×10^{-4}	62	5
Hawkesbury Sandstone (unpaved)	2.02×10^{-4}	74	6

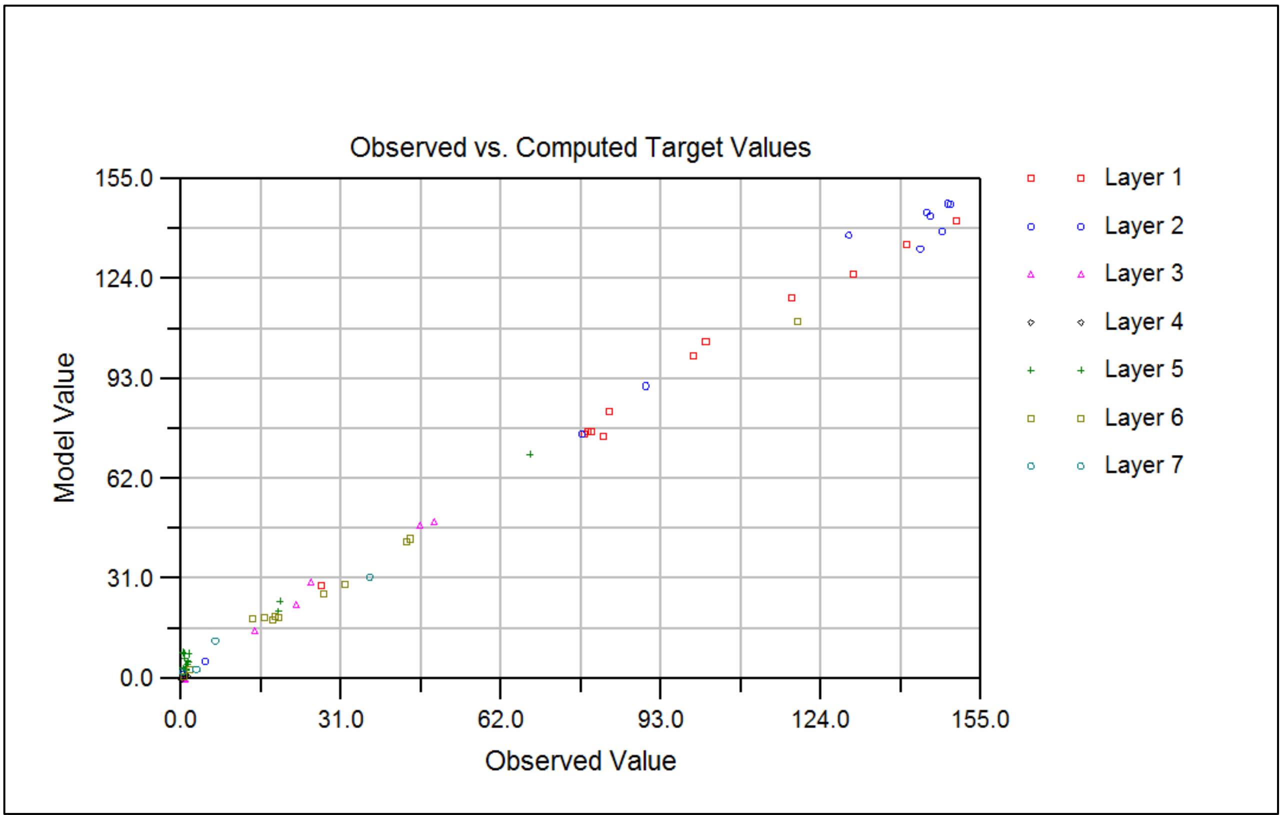


Figure 4-1: Comparison of modelled and observed heads – Steady State North Model.

Table 4.3: Calibration statistics summary – Steady state North Model.

Calibration Statistic	Value
Residual Mean	0.37
Residual Standard Deviation	3.82
Absolute Residual Mean	2.80
Residual Sum of Squares	1020
RMS Error	3.84
Minimum Residual	-7.97
Maximum Residual	9.95
Range of Observations	150.13
Scaled Residual Standard Deviation	0.025
Scaled Absolute Mean	0.019
Scaled RMS	0.026
Number of Observations	69

4.1.2 Calibration for Measured Stream-flows

As described in Section 2.3, preliminary flow gauging was carried out at Flat Rock Creek, Quarry Creek (tributary to Flat Rock Creek) and Burnt Bridge Creek. The flow monitoring was conducted to assess order of magnitude flows. Flow monitoring sites are identified in Figure A1-9 and the nature of the creek substrate is shown in Figure A1-12. Flow measurements were taken following a period of two weeks without rain in order to measure typical dry season, dry weather conditions, without contribution from rainfall runoff. Information on measured water depths is summarised in Table 2.4. Indicative measured creek discharges were as follows:

- Flat Rock Creek – 18.4 L/s (1,590 m^3/day)
- Quarry Creek – 2.1 L/s (178 m^3/day)
- Burnt Bridge Creek – 1.5 L/s (130 m^3/day

MODFLOW river (RIV) boundary conditions are used to represent the creeks in the groundwater model. The maximum initial value for the MODFLOW hydraulic conductance term (i.e., the product of hydraulic conductivity and cell cross-section areas divided by distance between the nodes) assigned to the initial model during calibration was 31.2 m^2/day based on a maximum hydraulic conductivity of 1 m/day and maximum dimensions for cells containing RIV boundaries of 31.2 m x 31.2 m. During the iterative manual calibration process, the conductance term assigned to RIV boundary cells was adjusted in order to achieve a reasonable match between modelled groundwater discharge to creeks (baseflow) and preliminary stream low-flow measurements. Table 4.4 shows the simulated stream-flows when uniform conductance values were assigned to the RIV boundary cells.

Table 4.4: Simulated baseflow

RIV Boundary Cell Conductance m^2/day	Simulated baseflow (m^3/day)		
	Flat Rock Creek	Quarry Creek	Burnt Bridge
10	742	30.8	13.3
50	795	31.7	13.6
100	806	31.8	13.8
500	807	32.4	14.0

Simulated baseflows presented in Table 4.4 range from 10 per cent to 50 per cent of measured stream low-flows. The modelling results presented in Table 4.4 indicate that increasing the RIV boundary conductance from 10 m^2/day to 500 m^2/day does not significantly increase the simulated baseflow.

Based on the results presented in Table 4.4 and the discussion on the maximum MODFLOW hydraulic conductance term presented above, a RIV boundary conductance of 100 m^2/day was considered appropriate for simulating the hydraulic connectivity between the creeks and the groundwater system.

As discussed in Section 2.3, the preliminary stream-flow measurements used in this calibration assessment represent only one round of field observations. Jacobs recommend that continuous stream-flow monitoring is carried out along the three creeks to provide stream-flow hydrograph data that can be used to more accurately estimate baseflow by analysing streamflow-hydrograph recession curves. It is recommended that streamflow-rating curves are developed for the stream gauging stations to ensure that more accurate streamflow readings are collected.

Jacobs also recommend that further investigations are carried out to identify and quantify other surface water discharges to creeks that could affect creek low flows, including:

- Urban stormwater management practices that can potentially lead to temporary detention of stormwater to reduce peak stormflows by delaying natural stormwater discharge to streams.
- Excess irrigation
- Urban wastewater discharges
- Leakages from the water supply network

4.1.3 Water Balance – Steady state North Model

Table 4.5 presents the water balance for the steady state North Model. Rainfall-recharge contributes the largest proportion of inflows to the modelled groundwater system. The largest proportion of groundwater discharge occurs through evapotranspiration.

Table 4.5: Model Water Balance – Steady State North Model

Modelling considerations	Inflow (m^3/day)	Outflow (m^3/day)
Rainfall-recharge	16,960	0
Constant head (tidal areas)	11	2314
River boundaries	533	1171
Evapotranspiration	0	13,607
General Head Boundaries	0	135
Drains	0	225
Total	**17,504**	**17,452**
Percentage error	**≈ 0.3%**	

4.1.4 Sensitivity Analysis – Steady State North Model

Following the manual calibration of the steady state model, automated sensitivity analysis was carried out with PEST_HP (Watermark Numerical Computing, 2016) to identify those parameters that have the greatest influence on model calibration.

The sensitivity analysis assessed the effect of changing hydraulic conductivity and recharge values on the objective function. The objective function is a measure of the level of agreement between observed water levels and model-simulated values.

Parameter sensitivities were calculated during the PEST_HP automated parameter estimation process. PEST_HP systematically varies each of the adjustable parameters (i.e. hydraulic conductivity and recharge), one at a time and runs the model with the adjusted parameter set to establish the change in the objective function. PEST_HP calculates a “composite sensitivity” for each parameter at the end of each optimisation iteration.

To calculate the composite sensitivity, the groundwater model is run at least ‘m’ times (where m is the number of adjustable parameters) during each PEST_HP optimisation iteration. PEST_HP calculates the Jacobian matrix during each optimisation iteration (Doherty, 2015). Based on the contents of the Jacobian matrix, PEST calculates the composite sensitivity for each parameter using the Jacobian matrix (Watermark Numerical Computing, 2016).

The parameters assessed during the sensitivity analysis are presented in Table 4.6. Vertical hydraulic conductivity was tied to horizontal hydraulic conductivity during the automated calibration. This means that only horizontal hydraulic conductivity values are estimated and then vertical hydraulic conductivity is scaled as PEST estimates horizontal hydraulic conductivity. The harbour sediments and zones of high hydraulic conductivity (Table 4.1) were not included in the automated calibration because there are no calibration targets (i.e. monitoring bores) located within these hydrostratigraphic units.

Table 4.6: Parameters assessed during sensitivity analysis

Parameter	Hydrostratigraphic Unit	Model Layer	Model Zone	Name	Variability allowed during calibration
Horizontal hydraulic conductivity	Fill/Alluvium	1	4	kx4	Minimum value was one order of magnitude lower than calibrated model value. Maximum value was one order of magnitude higher than calibrated model value.
	Ashfield Shale	1	2	kx2	
	Weathered Hawkesbury Sandstone	1	1	kx1	
	Moderately Weathered Hawkesbury Sandstone	2	9	kx9	
	Slightly Weathered Hawkesbury Sandstone	3	10	kx10	
	Slightly Weathered/ Un-weathered Hawkesbury Sandstone	4	6	kx6	
	Un-weathered Hawkesbury Sandstone	5 - 7	17	kx17	
Recharge	Ashfield Shale	1	1	r1	Maximum value was 200% of calibrated model value. Minimum value was 50% of calibrated model value.
	Hawkesbury Sandstone (paved)	1	2	r2	
	Hawkesbury Sandstone (unpaved)	1	3	r3	

Figure 4-2 shows composite sensitivity values for model hydraulic conductivity zones. The moderately weathered Hawkesbury Sandstone in layer 2 (Zone 9) and the slightly weathered Hawkesbury Sandstone in Layer 3 (Zone 10) are the most sensitive parameters. The very low sensitivity of the Weathered Hawkesbury Sandstone (Zone 1), Ashfield Shale (Zone 2) and Fill/Alluvium (Zone 4) in Layer 1 is probably because in most areas these hydrostratigraphic units are simulated to be in an unsaturated state. From the model sensitivity analysis, it was concluded that further refinement of hydraulic conductivity zones 1, 2 and 4 through improved or extended calibration would not provide any meaningful improvement in the reliability of the model since the calibration statistics are relatively insensitive to variation of these three parameters. Moreover, doing so could lead to assigning physically unrealistic values to the parameters in order to make model results fit the measurements.

Figure 4-3 show composite sensitivity values for model recharge zones. Recharge to the paved Hawkesbury Sandstone was found to be the most sensitive parameter

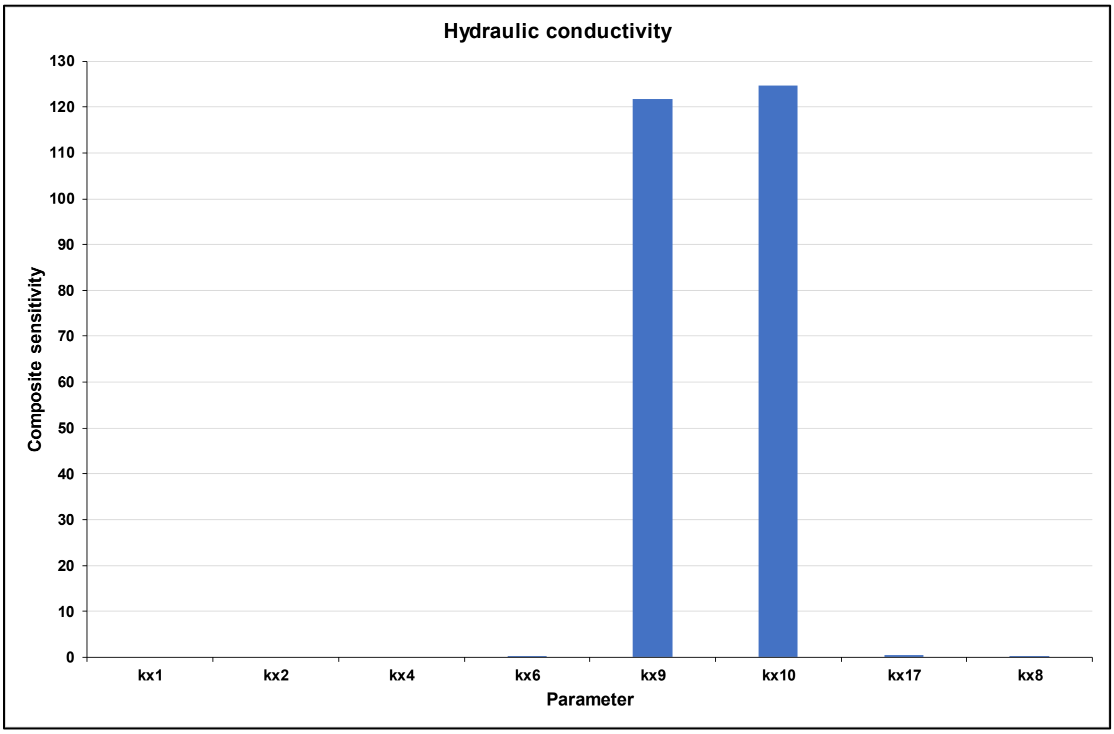


Figure 4-2: Hydraulic conductivity composite sensitivity

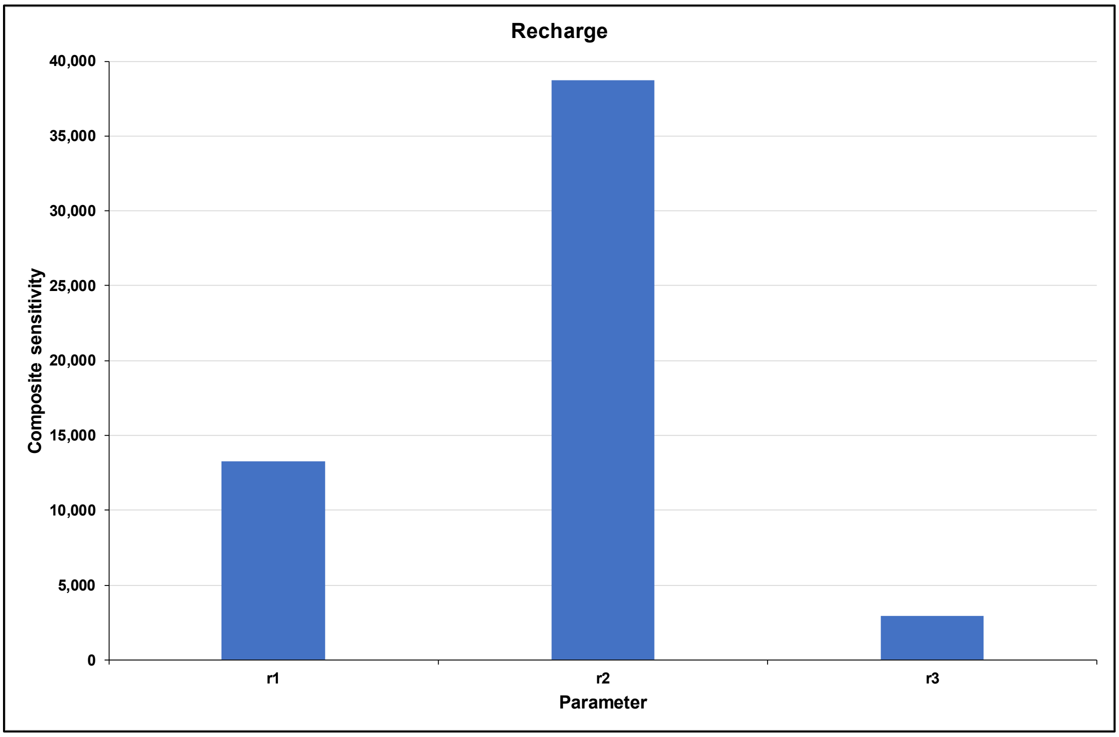


Figure 4-3: Recharge composite sensitivity

4.2 Transient Calibration – North Model

Transient calibration of the North Model was carried out for the period between January 2015 and September 2018 using monthly stress periods. The variable zonal recharge rate for each of the 45 monthly stress periods was assumed to be the product of average recharge rate and a scaling factor. Average recharge rates for each zone were obtained from the calibrated steady state model (Table 4.2).

Rainfall recorded for the Observation Hill Climate Station was used to calculate recharge scaling factor as follows:

$$recharge\ scaling\ factor = \frac{total\ rainfall\ recorded\ for\ the\ month}{mean\ monthly\ rainfall}$$

Mean monthly rainfall is the average monthly rainfall for the calibration period (i.e. January 2015 and September 2018)

Mean monthly evapotranspiration calculated from historical records was used to assign maximum monthly evapotranspiration rates to the transient calibration model.

The following time-series groundwater level monitoring data was available for calibration:

- Northern Beaches Hospital monitoring bores (GW1, GW2, GW4, GW5, GW8, GW9 GW10 and GW10a)- Groundwater level monitoring times-series data is available for the entire calibration period for most bores
- Sydney Metro project baseline monitoring bores (SRT_BH017, SRT_BH018, SRT-BH019 & SRT-BH020) - Time-series monitoring data only available for approximately 10 months
- Western Harbour Tunnel and Beaches Link project baseline monitoring bores.

Hydraulic conductivity values assigned to the calibrated steady state model (Table 4.1) were assigned as initial values in the transient model. Storage parameters (specific yield and specific storage) and, if necessary, hydraulic conductivity values were adjusted manually to obtain a suitable match between observed and simulated heads. During the calibration, storage parameters were adjusted within the range of values estimated from analysis of rock core strength tests and values obtained from previous groundwater studies in surrounding areas (Section 2.5.4.5). Initial storage parameters assigned during calibration are presented in Table 4.7.

Hydraulic heads from the calibrated steady state model were assigned as initial heads in the transient model during calibration.

Calibration was conducted by iterative manual step-wise adjustment of model input parameters to achieve an acceptable match between simulated and observed heads (groundwater levels). Calibration was achieved by visually comparing simulated and observed hydrographs, as well as by assessing the statistical calibration measures.

A reasonable level of calibration for the transient model was achieved with the same hydraulic conductivity values assigned to the calibrated steady state model (Table 4.1) (i.e. transient calibration was attained with no modification to the hydraulic conductivity data included in the steady state model).

Storage parameters assigned to the calibrated transient North Model are presented in Table 4.7. All storage parameter values assigned to the calibrated model, except specific yield for the weathered Hawkesbury, were the same as values applied to the initial model.

The initial variable recharge rates applied to each of the 45 monthly stress periods were calculated by applying recharge rate scaling factors as described above. Recharge rates were adjusted during the calibration from the initial values to achieve a reasonable match between simulated and observed groundwater level peaks and troughs. Simulated and observed hydrographs for the monitoring bores are presented in Annexure 5. The simulated groundwater level peak elevations were slightly lower than observed peaks because the model is formulated with monthly stress periods (Annexure 5). High intensity short duration rainfall events cannot be represented explicitly in the model and as a result the peaks in groundwater levels are under-predicted.

Table 4.7: Initial and calibrated model storage parameter values for transient North Model.

Hydrostratigraphic Unit	Model Layer	Specific Storage (m^{-1})		Specific yield (dimensionless)	
		Initial Model	Calibrated Model	Initial Model	Calibrated Model
Harbour Sediments	1	1×10^{-5}	1×10^{-5}	0.2	0.1
Fill/Alluvium	1	1×10^{-5}	1×10^{-5}	0.1	0.1
Ashfield shale	1	1×10^{-5}	1×10^{-5}	0.02	0.02
Weathered Hawkesbury Sandstone	1	1.9×10^{-6}	1.9×10^{-6}	0.02	0.05
Moderately Weathered to Un-weathered Hawkesbury Sandstone	2-7	1.9×10^{-6}	1.9×10^{-6}	0.02	0.02

Figure 4-4 shows that the transient model simulated the groundwater levels (heads) with reasonable accuracy. Table 4.8 presents a summary of the calibration target statistics. The scaled RMS error of approximately three per cent is within acceptable limits (i.e. less than 10 per cent), which indicates a reasonably good match between simulated and observed heads.

Given the reasonably good match between simulated and observed heads shown in Figure 4-4 and the hydrographs (Annexure 5) as well as the calibration statistics that are within acceptable limits, it was concluded that the transient North Model simulates the groundwater levels and observed variation over time reasonably well.

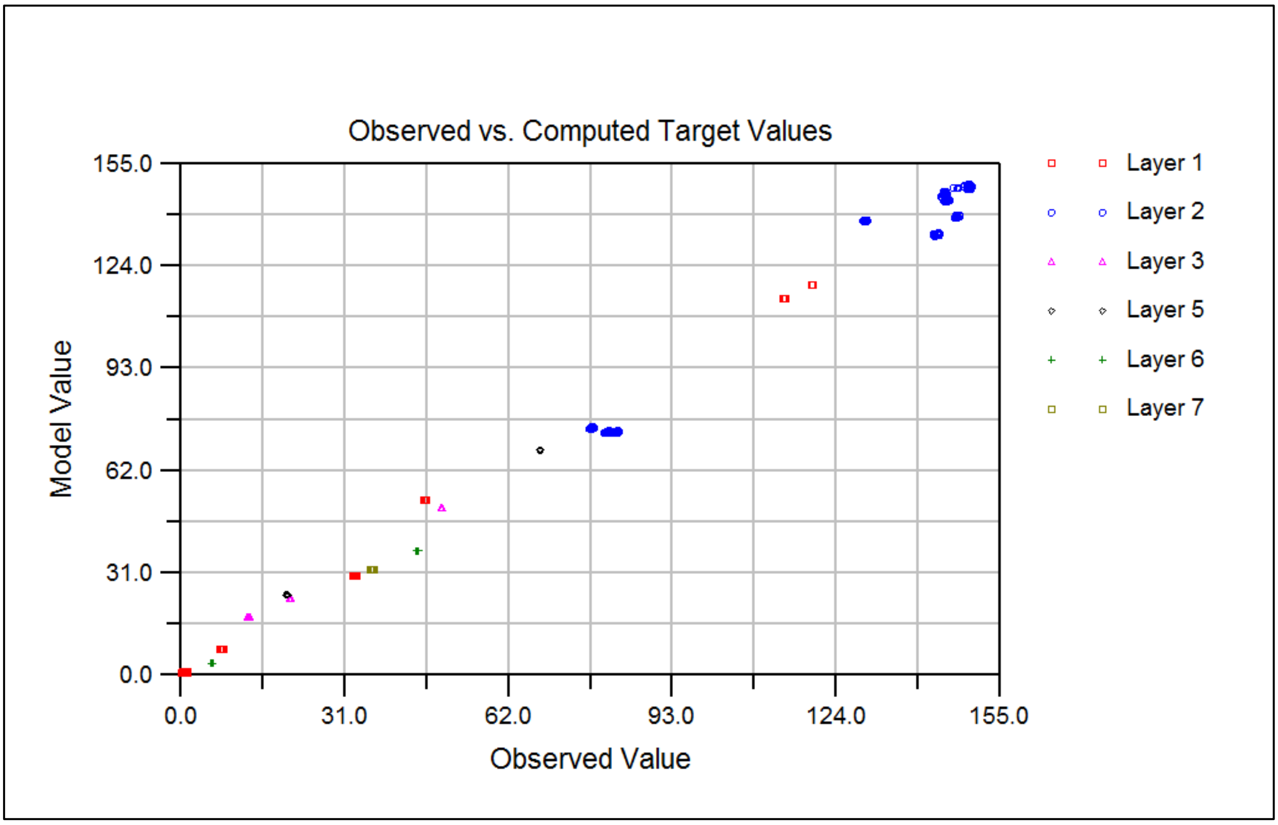


Figure 4-4: Comparison of modelled and observed heads – Transient North Model.

Table 4.8: Calibration statistics summary – Transient North Model.

Calibration Target Statistic	Value
Residual Mean	1.77
Residual Standard Deviation	3.46
Absolute Residual Mean	2.84
Residual Sum of Squares	3.95×10^5
RMS Error	3.89
Minimum Residual	-8.54
Maximum Residual	10.26
Range of Observations	149.73
Scaled Residual Standard Deviation	0.023
Scaled Absolute Mean	0.019
Scaled RMS	0.026
Number of Observations	26,125

Table 4.9 presents the water balance for the transient North Model. Rainfall-recharge contributes the largest proportion of inflows to the modelled groundwater system. Groundwater discharge occurs mainly through evapotranspiration and along the coastal areas.

Table 4.9: Model Water Balance – Transient North Model

	Inflow (m^3/day)	Outflow (m^3/day)
Rainfall-recharge	13,130	
Constant head (tidal areas)	15	2186
River boundaries	543	1229
Evapotranspiration		11,411
General Head Boundaries		133
Drains		213
Storage	5904	4265
Total	**19,593**	**19,437**
Percentage error	**≈ 0.8**	

4.3 Steady State Calibration - South Model

Model calibration targets for the steady state model represent mean values of head measured at different time periods. There was no flux data available to use in calibrating the model. Hydraulic conductivity and recharge rates were varied during the calibration.

Thirty-six head targets were used to calibrate the model. The location of the bores used in calibrating the steady state model are presented in Figure A1-15. Information on bore construction, groundwater level monitoring dates and monitoring data suitability for calibration purposes is provided in Annexure 6.

Initial recharge rates and hydraulic conductivity estimates assigned to the steady state South Model during calibration are presented Table 2.6 and Table 3.2 respectively. These initial estimates were manually adjusted during the calibration to obtain an acceptable match between simulated and measured heads for the South Model.

Hydraulic conductivity values assigned to the calibrated steady state South Model are presented in Table 4.10. Recharge rates assigned to the calibrated steady state South Model are presented in Table 4.11.

Table 4.10: Calibrated steady state South Model hydraulic conductivity values.

Hydrostratigraphic Unit	Model Layer	Model Zone	Hydraulic conductivity (m/d)	
			Hydraulic conductivity	Vertical Hydraulic conductivity
Harbour Sediments	1	3	1×10^{-2}	5×10^{-3}
Fill/Alluvium	1	4	1	0.1
Ashfield Shale	1	2	8.08×10^{-2}	8.08×10^{-3}
Weathered Hawkesbury Sandstone	1	1	1.50×10^{-1}	7.50×10^{-2}
Moderately Weathered Hawkesbury Sandstone	2	9	1.50×10^{-1}	7.50×10^{-2}
Slightly Weathered Hawkesbury Sandstone	3	10	1.00×10^{-2}	1.00×10^{-3}

Hydrostratigraphic Unit	Model Layer	Model Zone	Hydraulic conductivity (m/d)	
			Hydraulic conductivity	Vertical Hydraulic conductivity
Slightly Weathered/ Un-weathered Hawkesbury Sandstone	4	6	1.00×10^{-2}	1.00×10^{-3}
Un-weathered Hawkesbury Sandstone	5 - 7	17	6.00×10^{-3}	6.00×10^{-5}
High K_1	2	7	1.50×10^{-1}	1.50×10^{-2}
High K_2	3	11	1.00×10^{-1}	1.00×10^{-2}
High K_3	4	8	1.00×10^{-1}	1.00×10^{-2}
High K_4	5-7	15	6.00×10^{-2}	6.00×10^{-3}

Table 4.11: Calibrated steady state South Model recharge rates.

Zone	Recharge (m/day)	Equivalent Recharge (mm/yr)	% Mean Annual Rainfall
Ashfield Shale (paved)	3×10^{-5}	12	1
Ashfield Shale (unpaved)	3×10^{-5}	12	1
Hawkesbury Sandstone (paved)	8.42×10^{-5}	31	2.5
Hawkesbury Sandstone (unpaved)	1.18×10^{-4}	43	3.5

Figure 4-5 shows the match between simulated and observed heads for the calibrated steady state South Model. Table 4.12 presents a summary of the calibration statistics for the steady state model. Annexure 7 presents the error (residual) for each calibration target, showing the difference between the model-computed head and the observed head. The scaled RMS error of approximately 7 per cent obtained in the calibrated steady state model (Table 4.12) shows that the model is reasonably well calibrated to measured heads. Given the reasonably good match between simulated and observed heads in Figure 4-5, and the acceptable calibration statistics (Table 4.12) it was concluded that the steady state model simulates average groundwater levels (heads) with reasonable accuracy

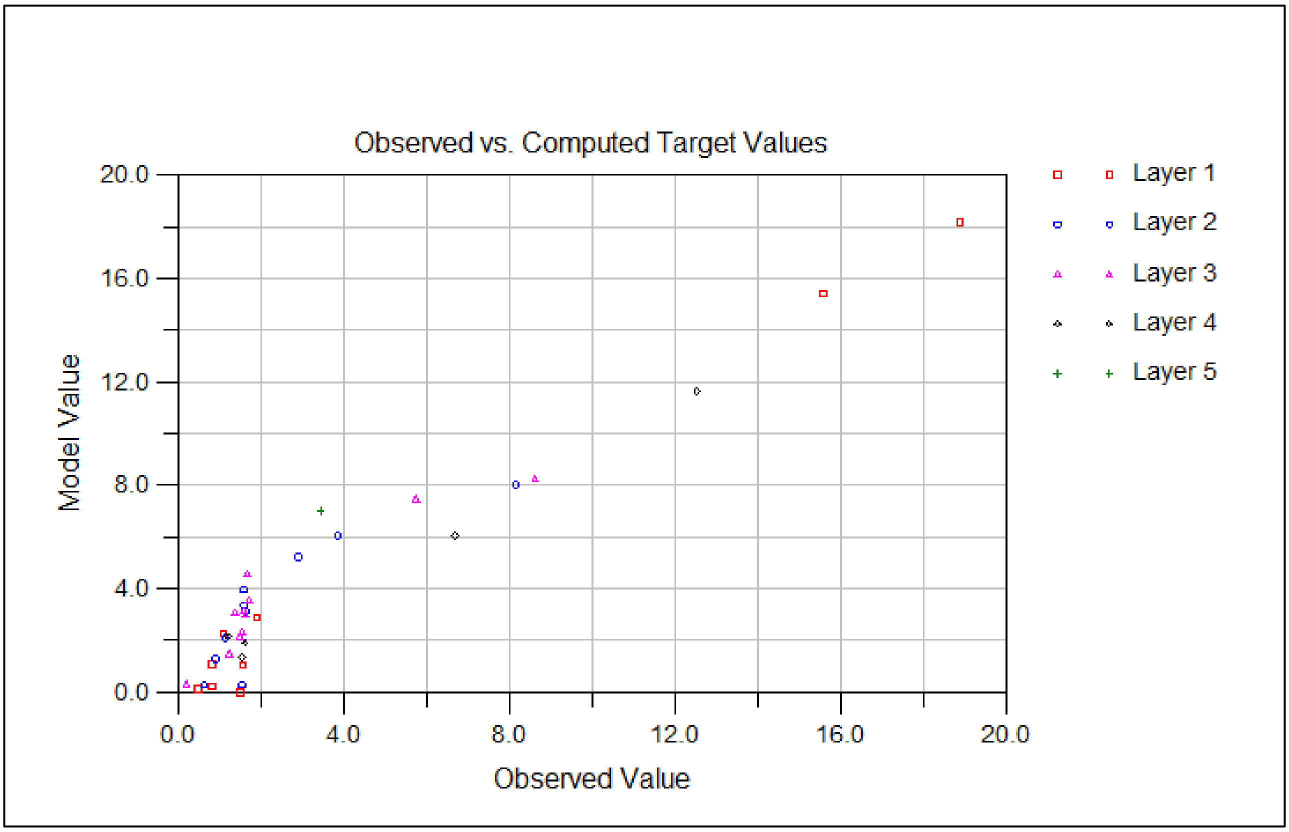


Figure 4-5: Comparison of modelled and observed heads – Calibrated Steady State South Model.

Table 4.12: Calibration statistics summary – Steady state South Model.

Calibration Target Statistic	Value
Residual Mean	-0.67
Residual Standard Deviation	1.21
Absolute Residual Mean	1.10
Residual Sum of Squares	68.7
RMS Error	1.38
Minimum Residual	-3.56
Maximum Residual	1.50
Range of Observations	18.70
Scaled Residual Standard Deviation	0.065
Scaled Absolute Mean	0.059
Scaled RMS	0.074
Number of Observations	36

Table 4.13 presents the water balance for the steady state South Model. Rainfall-recharge contributes the largest proportion of inflows to the modelled groundwater system. The largest proportion of groundwater discharge occurs along tidal zone boundary. Evapotranspiration also constitutes a large proportion of the groundwater discharge.

Table 4.13: Model Water Balance – Steady State South Model

	Inflow (m^3/day)	Outflow (m^3/day)
Rainfall-recharge	1138	0
Constant head (tidal areas)	13	501
River boundaries	3	283
Evapotranspiration	0.0	355
General Head Boundaries	0.0	22
Total	**1154**	**1161**
Percentage error	**≈ -0.6%**	

4.4 Transient Calibration – South Model

Transient calibration of the South Model was carried out for the period between January 2015 and September 2018 using monthly stress periods. The variable zonal recharge rate for each of the 45 monthly stress periods was assumed to be the product of average recharge rate and a scaling factor. Average recharge rates for each zone were obtained from the calibrated steady state model (Table 4.11). Monthly recharge scaling factors were calculated with the same method used for the North Model (Section 4.2)

Mean monthly evapotranspiration calculated from historical records was used to assign maximum monthly evapotranspiration rates to the transient calibration model.

Time-series groundwater level monitoring bore data for bores shown in Figure A1-15 was used to calibrate to transient groundwater model.

Hydraulic conductivity values assigned to the calibrated steady state model were assigned as initial values in the transient model. Initial storage parameter values assigned to the calibration are presented in Table 4.14. Initial specific storage parameter values were based on estimates from analysis of results rock core strength tests (Section 2.5.4.5). Initial specific storage estimates were based on a literature review of values from previous groundwater studies in surrounding areas (Section 2.5.4.5).

Table 4.14: Initial and calibrated model storage parameter values for transient South Model.

Hydrostratigraphic Unit	Model Layer	Specific Storage (m^{-1})		Specific yield (dimensionless)	
		Initial Model	Calibrated Model	Initial Model	Calibrated Model
Harbour Sediments	1	1×10^{-5}	1×10^{-5}	0.2	0.1
Fill/Alluvium	1	1×10^{-5}	1×10^{-5}	0.1	0.1
Ashfield shale	1	1×10^{-5}	1×10^{-5}	0.02	0.02
Weathered Hawkesbury Sandstone	1	1.9×10^{-6}	1.9×10^{-6}	0.02	0.05
Moderately Weathered to Un-weathered Hawkesbury Sandstone	2-7	1.9×10^{-6}	1.9×10^{-6}	0.02	0.02

Hydraulic heads from the calibrated steady state model were assigned as initial heads in the transient model during calibration.

Calibration was conducted by iterative manual step-wise adjustment of model input parameters to achieve an acceptable match between simulated and observed heads (groundwater levels). Calibration was achieved by visually comparing simulated and observed hydrographs, as well as by assessing the statistical calibration measures.

A reasonable level of calibration for the transient model was achieved with the same hydraulic conductivity values assigned to the calibrated steady state model (Table 4.10) (i.e. transient calibration was attained with no modification to the hydraulic conductivity data included in the steady state model).

Storage parameter values assigned to the calibrated model are presented in Table 4.14.

The initial variable recharge rates applied to each of the 45 monthly stress periods were calculated by applying recharge rate scaling factors as described in Section 4.2. Recharge rates were adjusted during the calibration from the initial values to achieve a reasonable match between simulated and observed groundwater level peaks and troughs. Adjustment of recharge rates during the calibration was done is such a way that ensured that the average recharge rate for the entire simulation period was comparable to the recharge rate applied to the steady state model.

The simulated groundwater level peak elevations were slightly lower than observed peaks because the model is formulated with monthly stress periods. High intensity short duration rainfall events cannot be represented explicitly in the model and as a result the peaks in groundwater levels are under-predicted.

Figure 4-6 shows that the transient model simulated the groundwater levels (heads) with reasonable accuracy. Table 4.15 presents a summary of the calibration target statistics. The scaled RMS error of approximately three per cent is within acceptable limits (i.e. less than 10 per cent), which indicates a reasonably good match between simulated and observed heads.

Hydrographs of observed and computed heads are presented in Annexure 8. The calibrated transient model simulates temporal trends observed in groundwater level monitoring data for the bores reasonably well.

Given the reasonably good match between simulated and observed temporal trends in heads and that the calibration statistics that are within acceptable limits, it was concluded that the transient model simulates the groundwater levels and observed variation over time with reasonable accuracy.

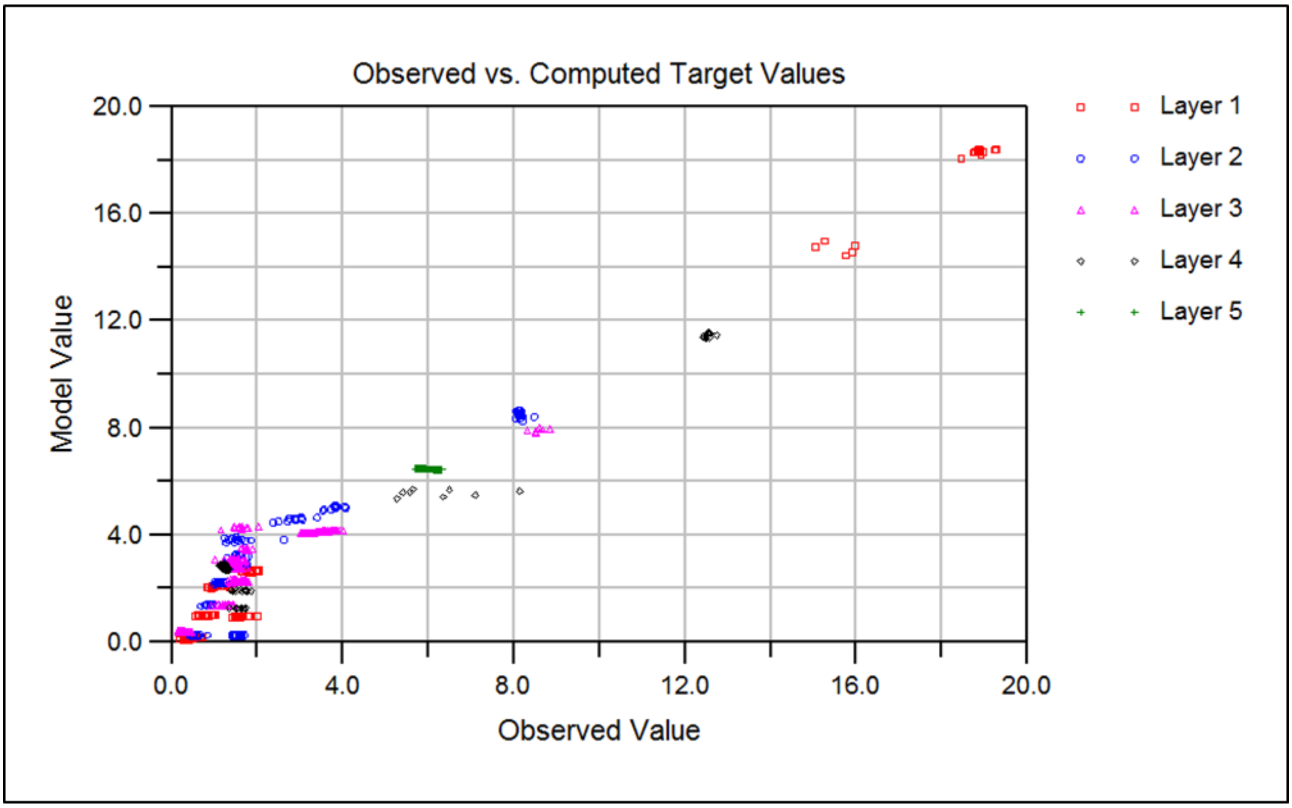


Figure 4-6: Comparison of modelled and observed heads – Transient South Model.

Table 4.15: Calibration statistics summary – Transient South Model.

Calibration Target Statistic	Value
Residual Mean	-0.51
Residual Standard Deviation	0.32
Absolute Residual Mean	0.53
Residual Sum of Squares	3.79×10^3
RMS Error	0.6
Minimum Residual	-3.02
Maximum Residual	2.51
Range of Observations	19.12
Scaled Residual Standard Deviation	0.017
Scaled Absolute Mean	0.028
Scaled RMS	0.032
Number of Observations	10,383

Table 4.16 presents the water balance for the steady state North Model. Rainfall-recharge contributes the largest proportion of inflows to the modelled groundwater system. Groundwater discharge occurs mainly along the coastal areas as well as through evapotranspiration. The average recharge rate for the calibrated transient South Model is comparable to the average recharge rate applied to the calibrated steady state South Model.

Table 4.16: Model Water Balance – Transient South Model

	Inflow (m^3/day)	Outflow (m^3/day)
Rainfall-recharge	1296	0
Constant head (tidal areas)	14	560
River boundaries	5	341
Evapotranspiration	0	528
General Head Boundaries	0	21
Storage	501	376
Total	**1816**	**1826**
Percentage error	**≈ -0.5%**	

5. Model Confidence Level Classification

Under the confidence level classification system suggested by Barnett et al. (2012), both the North Model and South Model would be classified as Confidence Level 2 groundwater models for the following reasons:

- Parameters assigned to the North Model and South Model are consistent with the conceptualisation.
- Temporal discretisation in the predictive models is the same as that used in calibration
- The spatial discretisation applied to the groundwater models is considered appropriate to the problem. The minimum cell dimensions along the proposed tunnel alignment for the South Model and North Model are approximately eight metres and 16 metres respectively which is comparable to the widths of the proposed tunnels
- Results of the model calibration presented in Section 4 for both the North Model and South Model indicate that the model is able to adequately represent historical and present-day groundwater conditions.
- Mass balance closure error for the North and South Model is less than one per cent of total flows.

The model falls short of higher (Class 3) classification because:

- Although groundwater head observations and bore logs are available along the proposed alignment, there is limited data available for surrounding areas
- The level of applied stresses (the magnitude of groundwater fluxes withdrawn from or added to the system) are expected to be significantly higher during tunnel construction than those present in the calibration.

Should the models be updated and re-calibrated by using observations during the early stages of tunnel construction, it may be possible to improve the confidence with which the model can be used in predictive mode.

6. Predictive Modelling Approach

6.1 North Prediction Model

6.1.1 North Model Predictive Model Scenarios

The following model scenarios were run for the North Model:

- **Scenario 1** ("Null" run) simulates existing groundwater conditions into the future. Scenario 1 does not include any components of the Wester Harbour Tunnel project, Beaches Link project and Chatswood to Sydenham Sydney Metro project (Metro)
- **Scenario 2** ("Null + Metro + Beaches Link" run) assesses potential future groundwater impacts when groundwater stresses associated with the Metro and Beaches Link projects are superimposed on Scenario 1. Components of the Western Harbour Tunnel project are not included in Scenario 2 simulations
- **Scenario 3** **(**"Null + Metro + Western Harbour Tunnel" run) assesses potential future groundwater impacts when groundwater stresses associated with Metro and Western Harbour Tunnel projects are superimposed on Scenario 1. Components of the Beaches Link project are not included in Scenario 3 simulations
- **Scenario 4** **(**"Null + Metro + Western Harbour Tunnel + Beaches Link" run) assesses potential future groundwater impacts when the cumulative groundwater stresses associated with Metro, Western Harbour Tunnel and Beaches Link projects are superimposed on Scenario 1.

Project specific and cumulative groundwater drawdowns and tunnel inflows were estimated by subtracting outputs from model scenarios as summarised in Table 6.1.

Table 6.1: Scenarios for predictive model runs – North Model.

project	Method for Calculating Impacts
Cumulative	Scenario 1 – Scenario 4
Western Harbour Tunnel ONLY	Scenario 2 – Scenario 4
Beaches Link ONLY	Scenario 3 – Scenario 4

The projected groundwater impacts of the approved Chatswood to Sydenham Sydney Metro Project, currently under construction, are included as part of the cumulative project impacts. Components of the Sydney North West Metro have not been included in the predictive model simulations based on the assumption that this project would be carried out in a different groundwater and surface water catchment. It was not considered appropriate to have a simulation that includes the Beaches Link project only without the Chatswood to Sydenham Sydney Metro project because the Metro project is already under construction.

6.1.2 Model Input Parameters and Stress Periods

Table 6.2 summaries the model stress periods used in the predictive model simulations. The first 45 stress periods in the predictive model were the same as the stress periods in the transient calibrated model (The transient calibration model has 45 monthly stress periods covering the calibration period from January 2015 to September 2018).

Table 6.2: Stress periods for predictive model simulations – North Model.

Dates	Stress Period	Stress Period Duration	Number of Time Steps	Time step multiplier
Jan 2015 – Dec 2035	1 - 252	1 month	3	1.2
Jan 2036 – Dec 2126	253 - 343	1 year	3	1.2

Parameters assigned to the first 45 stress periods of the predictive model, are the same as the stress periods applied to the transient calibration model. For example, rainfall-recharge rates and evapotranspiration rates applied to the preconstruction period over-lapping with transient calibration period (January 2015 to September 2018) were the same as recharge rates applied to the calibrated transient model. For the rest of the prediction model simulation period, average daily recharge rates for each zone from the calibrated steady state model were applied to the prediction model. The average daily evapotranspiration rate from the calibrated steady state model was applied to the prediction model.

Initial heads assigned to the predictive models were the same as the initial heads assigned to the transient model during calibration (Section 4.2).

6.2 South Prediction Model

6.2.1 South Model Predictive Model Scenarios

The following model scenarios were run for the South Model:

- **Scenario 1** ("Null" run) simulates existing groundwater conditions into the future. Scenario 1 does not include any components of the Western Harbour Tunnel (Western Harbour Tunnel) project or the M4-M5 Link project.
- **Scenario 2** ("Null + M4-M5" run) assesses potential future groundwater impacts when groundwater impacts associated with the proposed M4-M5 link project are superimposed on Scenario 1. Components of the Western Harbour Tunnel project are not included in Scenario 2 simulations.
- **Scenario 3** (Null + M4-M5 + Western Harbour Tunnel**)** assesses potential future cumulative groundwater impacts when groundwater impacts associated with the Western Harbour Tunnel and M4-M5 are superimposed on Scenario 1.

Project specific and cumulative groundwater drawdowns and tunnel inflows were estimated by subtracting outputs from model scenarios as summarised in Table 6.3.

Table 6.3: Scenarios for predictive model runs – South Model

Project	Method for calculating impacts
Cumulative	Scenario 1 – Scenario 3
Western Harbour Tunnel Only	Scenario 2 – Scenario 3

The proposed Beaches Link Project and Sydney Metro Northwest Project have not been included in the South Model predictive modelling based on the assumption that the projects would not have an impact on groundwater conditions south of Sydney Harbour given the proposed immersed tube tunnelling method for the Sydney Harbour Section. The harbour is expected to act as a constant head boundary that forms the low point in the regional potentiometric surface. As a result, it is expected that the harbour would act as a discharge site for groundwater on both the northern and southern sides of the harbour and hence the transmission of head responses from one side of the harbour to the other is highly unlikely.

Components of the Chatswood to Sydenham Sydney Metro project, located south of the Sydney Harbour, have not been included in the predictive model simulations based on the assumption that groundwater drawdown effects associated with the Chatswood to Sydenham Sydney Metro project are unlikely to extend to the east of Barangaroo, across Darling Harbour and White Bay to interfere with groundwater conditions in the vicinity of the Rozelle to Birchgrove section of the Western Harbour Tunnel project.

Following the approach by HydroSimulations (2017), it was not considered appropriate to have a simulation that includes the Western Harbour Tunnel project only without the proposed M4-M4 project because the Western Harbour Tunnel project would not operate in isolation without the Rozelle interchange link of the M4-M5 Link project.

6.2.2 Model Input Parameters and Stress Periods – South Model

Table 6.4 summaries the model stress periods used in the predictive model simulations. The first 45 stress periods in the predictive model were the same as the stress periods in the transient calibrated model (The transient calibration model has 45 monthly stress periods covering the calibration period from January 2015 to September 2018).

Table 6.4: Stress periods for predictive model simulations – South Model

Dates	Stress period	Stress period duration	Number of time steps	Time step multiplier
Jan 2015 – Dec 2035	1 - 252	1 month	3	1.2
Jan 2036 – Dec 2126	253 - 343	1 year	3	1.2

Parameters assigned to the first 45 stress periods of the predictive model, are the same as the stress periods applied to the transient calibration model. For example, rainfall-recharge rates and evapotranspiration rates applied to the preconstruction period over-lapping with transient calibration period (January 2015 to September 2018) were the same as recharge rates applied to the calibrated transient model. For the rest of the prediction model simulation period, average daily recharge rates for each zone from the calibrated steady state model were applied to the prediction model. The average daily evapotranspiration rate from the calibrated steady state model was applied to the prediction model.

Initial heads assigned to the predictive models were the same as the initial heads assigned to the transient model during calibration (Section 4.4).

6.3 Tunnel Inflow Simulation

Annexure 9 summarises the simplified construction staging used in the predictive groundwater modelling. Groundwater inflows along the proposed tunnel alignment were simulated using drain (DRN) boundary conditions for those cells that align with the tunnel. The following assumptions were made regarding groundwater inflows along tunnel sections:

- Tanked (undrained) tunnels: groundwater inflows occur only during the construction phase of the tunnels. Groundwater inflows to the tunnels cease at the end of the tanked tunnel construction phase. Therefore, model drain boundary cells are only active during the construction phase of the tanked tunnel
- Drained tunnels: groundwater inflows occur from the start of the construction phase and inflows continue in perpetuity. Therefore, model drain boundary cells are active from the time of construction through to the end of the model simulation
- Drained umbrella tunnels: it has been assumed that the overlying umbrella structure prevents groundwater inflows from the roof of the tunnel but, the diverted seepage water still has to be collected, pumped and treated before discharge. It has, therefore, been conservatively assumed that model drain boundary cells are active from the time of construction to the end of the model simulation
- Immersed Tube Tunnels: It has been assumed that no groundwater inflows occur during or after construction of immersed tube tunnels.

The elevation (stage) of the model drain boundary cells were set at the tunnel invert levels obtained from design reports prepared by WSP and ARUP (2019). Drain conductance were assigned to drain DRN boundary cells as described in Section 7.1.1.

7. Predicted Tunnel Inflows

7.1 Methodology

7.1.1 Drain Conductance

The groundwater discharge volume for each model drain (DRN) boundary cell representing a segment of the tunnel is calculated based on the conductance of the drain cell and the head difference between the head calculated for formations surrounding the DRN cell and the head condition assigned to the DRN cell.

In previous assessments for the M4-M5 Link project, conductance values of 0.1 m^2/day were generally applied to constrain groundwater inflows to less than 1 L/sec/km under the assumption that areas of high inflow would be "shotcreted" during construction (Hydrosimulations 2017).

A more conservative approach has been adopted for the Western Harbour Tunnel and Beaches Link groundwater assessments which involves calculating drain conductance for each DRN boundary cell based on the hydraulic conductivity and dimensions of the model-grid cell containing the drain boundary. This more conservative approach enables the identification of zones of potentially high groundwater inflows, where the design criteria of 1 L/s/km is likely to be exceeded. The approach for simulating groundwater inflows to tunnels also provides a more conservative approach for assessing potential groundwater drawdown and associated environmental impacts.

The conservative approach involves assigning artificially high conductance at drain cells which is the approach typically used for assessing tunnels with dimensions comparable to numerical cell sizes in the model (Zaidel et. al.,2010) as is the case for the North and South models. Using the recommended approach by Zaidel et. al. (2010), the drain conductance values assigned to the drain DRN cells were specified to be 2 orders of magnitude higher than the MODFLOW hydraulic conductance term (i.e., the product of hydraulic conductivity and cell cross-section areas divided by average distance between the nodes). Numerical experiments carried out by Zaidel et. al. (2010) indicated that applying drain conductance values of this magnitude generally results in negligible simulated flow resistance and that computed head at the location of an active drain node was always very close to the specified drain elevation.

Drain DRN conductance values assigned to simulate tunnel inflows in the North Model ranged from 0.13 m^2/day to 62 m^2/day. Drain conductance values assigned to the South Model ranged from 0.3 m^2/day to 469 m^2/day. The maximum conductance values assigned to the South Model were higher than the North Model maximum because higher drain conductance values were assigned in the South Model in the Rozelle area of the M4-M5 Project where grid cells along the proposed tunnel alignment were coarser than grid cells assigned along the proposed tunnel alignment for the Western Harbour Tunnel and Beaches Link projects.

7.1.2 Reporting of Tunnel Inflows

Predicted groundwater inflows are presented for each year of construction and at the end of the model simulation period in 2126.

Section 7.2.1 to Section 7.2.4 present groundwater inflows broken down into tunnel sections separated by harbours. The tunnel inflow reporting sections are shown in Figure A1-16. Predicted groundwater tunnel inflows are provided as L/s for sub-sections of each tunnel section. Average inflows in units of L/s/km are also provided for each tunnel section, where average inflow was calculated as follows:

$$Average\ inflow = \frac{Q}{L}$$

Where

Q = Predicted groundwater inflow for the tunnel section (L/s)

L = Length of tunnel section (km)

Section 7.2.5 presents project-wide groundwater inflows in megalitres per day (ML/day).

7.2 Results - Predicted Tunnel Inflows

7.2.1 Rozelle to Sydney Harbour Tunnel Section - Western Harbour Tunnel project Main Tunnel

Table 7.1 presents predicted groundwater inflows for the Rozelle to Sydney Harbour tunnel section of the Western Harbour Tunnel project. Figure A1-16 shows the tunnel inflow reporting sections. Groundwater inflows to the tunnel section are predicted to peak in 2022 at approximately 7.2 L/s (average inflow ≈ 0.7 L/s/km) and then gradually decrease to approximately 4.8 L/s (average inflow ≈ 0.5 L/s/km) by the end of the simulation period in 2126.

Table 7.1 summarises the predicted groundwater inflows to the Rozelle ventilation tunnels. It has been conservatively assumed that the ventilation tunnels would not be tanked. Maximum inflows to the Rozelle ventilation tunnels of approximately 2.0 L/s are predicted to occur in 2022.

It is recommended that groundwater discharges are monitored during the construction of this tunnel section. If measured groundwater inflows to the tunnel section exceed the design criteria of 1 L/s/km during construction, mitigation measures to reduce groundwater inflows should be implemented.

7.2.2 Sydney Harbour Tunnel to Warringah Freeway Section - Western Harbour Tunnel project Main Tunnel

Table 7.2 presents predicted groundwater inflows for the Sydney Harbour Tunnel to Warringah Freeway Section of the Western Harbour Tunnel project. Groundwater inflows to the tunnel section are predicted to peak in 2021 at 1.5 L/s (average inflow ≈ 0.2 L/s/km) and then gradually decrease to approximately 0.9 L/s (average inflow ≈ 0.1 L/s/km) by the end of the simulation period in 2126.

7.2.3 Cammeray to Middle Harbour Section - Beaches Link project Main Tunnel

Table 7.3 presents predicted groundwater inflows for the Cammeray to Middle Harbour Section of the Beaches Link project. Groundwater inflows to the tunnel section are predicted to peak in 2023 at approximately 23.8 L/s (average inflow ≈ 1.7 L/s/km) and then gradually decrease to approximately 16.5 L/s (average inflow ≈ 1.2 L/s/km) by the end of the simulation period in 2126. High inflow rates for the section, exceeding the 1 L/s/km threshold are associated with the following areas:

- High permeability zones adjacent to the proposed Middle Harbour tunnel crossing. High inflows from this zone are only expected to occur during the construction phase before the zone is tanked
- Fill material deposited in the Flat Rock Creek area overlying a highly permeable fracture zone along the proposed tunnel alignment. It is recommended that groundwater inflows are monitored during construction in this tunnel section and mitigation measures implemented to ensure inflows meet the 1 L/s/km threshold during construction.

7.2.4 Middle Harbour to Wakehurst/North Balgowlah - Beaches Link project Main Tunnel

Table 7.4 presents results for the Middle Harbour to Wakehurst/North Balgowlah Section of the Beaches Link project. Groundwater inflows to the tunnel section are predicted to peak in 2024 at approximately 9.3 L/s (average inflow ≈ 1.0 L/s/km) and then gradually decrease to approximately 5.9 L/s (average inflow ≈ 0.7 L/s/km) by the end of the simulation period in 2126.

Table 7.1: South Model Tunnel Inflows – Rozelle to Sydney Harbour Section of Western Harbour Tunnel project

Tunnel Sub-section [1]	Length	Tunnel Inflow (L/s)							
		2021	2022	2023	2024	2025	2026	2027	2126
NB - Entry Ramp - Rozelle Portal to Cavern	1047	1.557	0.803	0.727	0.692	0.681	0.668	0.746	0.746
NB Main Line Cavern	143	0.000	0.055	0.048	0.046	0.045	0.044	0.057	0.057
NB Main Line - Cavern towards Tunnel Stub	390	0.000	0.113	0.099	0.096	0.095	0.093	0.097	0.097
NB Main Line - Victoria Rd Site towards Yurulbin Park	1089	0.903	0.580	0.558	0.540	0.530	0.515	0.519	0.519
NB Main Line - Yurulbin Park to Sydney Harbour Transition Structure	130	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NB Main Line - Yurulbin Park towards Rozelle	1021	0.395	0.557	0.562	0.559	0.557	0.554	0.549	0.549
SB Main Line - Access Point to Cavern	94	0.000	0.049	0.044	0.042	0.041	0.039	0.040	0.040
SB Main Line Cavern	137	0.000	0.062	0.056	0.053	0.052	0.050	0.051	0.051
SB Main Line - Cavern to Tunnel Stub	292	0.000	0.075	0.064	0.061	0.060	0.059	0.059	0.059
SB Main Line - Victoria Rd Site towards Yurulbin Park	1059	0.500	0.608	0.586	0.566	0.556	0.539	0.521	0.521
SB Main Line - Yurulbin Park to Sydney Harbour Transition Structure	130	0.119	0.112	0.000	0.000	0.000	0.000	0.000	0.000
SB Main Line - Yurulbin Park towards Rozelle	1051	0.401	0.538	0.549	0.545	0.543	0.540	0.534	0.534
SB Exit Ramp - Rozelle Portal to Cavern (SB Ramp Cavern)	131	0.027	0.005	0.002	0.000	0.000	0.000	0.000	0.000
SB Exit Ramp - Rozelle Portal to Cavern (SB Exit Ramp - Eastern)	240	0.059	0.037	0.035	0.034	0.033	0.033	0.032	0.032

Tunnel Sub-section [1]	Length	Tunnel Inflow (L/s)							
		2021	2022	2023	2024	2025	2026	2027	2126
SB Exit Ramp - Rozelle Portal to Cavern (SB Exit Ramp - Western)	260	0.045	0.033	0.032	0.031	0.031	0.030	0.030	0.030
SB Exit Ramp - Rozelle Portal to Cavern (SB Exit Ramp - Main)	493	0.361	0.363	0.303	0.277	0.268	0.259	0.276	0.276
Rozelle Ventilation Tunnel	1620	0.000	1.996	1.613	1.399	1.335	1.263	1.294	1.294
Victoria Road Access Decline	570	0.000	1.208	0.970	0.837	0.791	0.739	0.000	0.000
TOTAL INFLOW (L/s)		**4.367**	**7.195**	**6.247**	**5.777**	**5.618**	**5.426**	**4.808**	**4.808**
		Tunnel Inflow (L/s/km)							
Year		**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2126**
AVERAGE INFLOW (L/s/km)		**0.441**	**0.727**	**0.631**	**0.584**	**0.568**	**0.548**	**0.486**	**0.486**

Notes. [1] NB = North Bound, SB = South Bound, EB = East Bound & WB = West Bound.

Table 7.2: North Model Tunnel Inflows – Sydney Harbour to Warringah Freeway Section of Western Harbour Tunnel Project

Tunnel Sub-section [1]	Length	Tunnel Inflow (L/s)							
		2021	2022	2023	2024	2025	2026	2027	2126
NB Main Line - Berrys Bay towards Sydney Harbour (Undrained)	140	0.064	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NB Main Line - Berrys Bay towards North Sydney	1348	0.323	0.426	0.407	0.389	0.383	0.379	0.378	0.343
NB Main Line - Cammeray Golf Course Access Point to NB North	937	0.215	0.093	0.071	0.059	0.054	0.032	0.051	0.032

Tunnel Sub-section [1]	Length	Tunnel Inflow (L/s)							
		2021	2022	2023	2024	2025	2026	2027	2126
NB North Sydney Cavern	159	0.223	0.062	0.050	0.039	0.035	0.025	0.031	0.016
NB Ramp - From NB North Sydney Cavern to Falcon Street Exit Portal	402	0.000	0.072	0.063	0.056	0.053	0.032	0.051	0.040
NB Main Line - NB North Sydney Cavern towards Sydney Harbour	204	0.086	0.000	0.000	0.000	0.000	0.052	0.000	0.000
SB Main Line - Berry Bay towards Sydney Harbour (Undrained)	90	0.162	0.132	0.134	0.132	0.132	0.000	0.132	0.136
SB Main Line - Berrys Bay towards North Sydney	1565	0.284	0.447	0.398	0.359	0.346	0.362	0.336	0.272
SB Main Line - Cammeray Golf Course Access Point to SB North Sydney Cavern	774	0.051	0.055	0.058	0.042	0.037	0.033	0.033	0.017
SB North Sydney Cavern	180	0.132	0.037	0.028	0.021	0.019	0.018	0.017	0.009
SB Ramp - SB North Sydney Cavern towards Berry St Entry Portal	210	0.000	0.072	0.049	0.036	0.032	0.030	0.029	0.017
SB Main Line - SB North Sydney Cavern towards Sydney Harbour	194	0.000	0.045	0.037	0.031	0.028	0.027	0.026	0.017
WHT - Berrys Bay Access Decline	100	0.000	0.000	0.026	0.025	0.025	0.025	0.000	0.000
TOTAL TUNNEL INFLOW (L/s)		**1.541**	**1.440**	**1.322**	**1.188**	**1.145**	**1.015**	**1.085**	**0.899**

Tunnel Sub-section [1]	Length	Tunnel Inflow (L/s)							
		2021	2022	2023	2024	2025	2026	2027	2126
		Average Inflow (L/s/km)							
Year		2021	2022	2023	2024	2025	2026	2027	2126
AVERAGE INFLOW (L/s/km)		**0.244**	**0.228**	**0.210**	**0.189**	**0.182**	**0.161**	**0.172**	**0.143**

Notes. [1] NB = North Bound, SB = South Bound, EB = East Bound & WB = West Bound.

Table 7.3: North Model Tunnel Inflows – Cammeray to Middle Harbour Section of Beaches Link Project

Tunnel Sub-section	Length	Tunnel Inflow (L/s)							
		2021	2022	2023	2024	2025	2026	2027	2126
NB Main Line – West of Northbridge Cavern	545	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NB Northbridge Cavern	185	0.000	0.000	0.155	0.106	0.103	0.101	0.101	0.095
NB Main Line - Northbridge Cavern towards Clive Park	1971	0.000	0.000	0.568	1.152	1.086	1.070	1.066	0.967
NB Main Line - Clive Park to Transition Structure (Undrained)	100	0.000	0.000	0.000	2.530	0.000	0.000	0.000	0.000
NB Main Line – North of Cammeray Cavern	1467	0.000	0.280	0.647	0.604	0.577	0.562	0.558	0.446
NB Cammeray Cavern	183	0.000	0.000	0.000	0.034	0.029	0.027	0.026	0.019
EB Entry Ramp - Gore Hill	1515	0.000	4.285	4.592	5.364	5.110	4.953	4.914	3.951

Tunnel Sub-section	Length	Tunnel Inflow (L/s)							
		2021	2022	2023	2024	2025	2026	2027	2126
SB Main Line - West of Northbridge Cavern	685	0.000	4.334	3.657	3.363	3.337	3.325	3.322	3.266
SB Northbridge Cavern	272	0.000	0.000	0.251	0.175	0.167	0.164	0.163	0.144
SB Main Line - Northbridge Cavern towards Clive Park	1737	0.000	0.000	0.000	1.105	1.008	0.995	0.991	0.888
SB Main Line - Clive Park to Transition Structure (Undrained Tunnel)	115	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SB Main Line - North of Cammeray Cavern	1450	0.000	0.299	0.662	0.552	0.525	0.512	0.509	0.411
SB Cammeray Cavern	136	0.000	0.000	0.000	0.023	0.018	0.016	0.016	0.009
WB Exit Ramp - Gore Hill Freeway to North Bridge Cavern	1755	0.000	5.463	13.184	7.631	7.268	7.087	7.046	6.323
WHT - Cammeray ventilation	1130	0.000	0.000	0.036	0.035	0.034	0.034	0.034	0.029
BL – Access sites	900	0.000	0.000	0.0079	0.054	0.052	0.051	0.050	0.000
TOTAL TUNNEL INFLOW (L/s)		**0.000**	**14.661**	**23.832**	**22.727**	**19.314**	**18.895**	**18.795**	**16.549**
		Average Inflow (L/s/km)							
Year		**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2126**
AVERAGE INFLOW (L/s/km)		**0.000**	**1.036**	**1.685**	**1.607**	**1.365**	**1.336**	**1.329**	**1.170**

Notes. (1) NB = North Bound, SB = South Bound, EB = East Bound & WB = West Bound.

Table 7.4: North Model Tunnel Inflows - Middle Harbour to Wakehurst/North Balgowlah Section of Beaches Link Project

Tunnel Sub-section (1)	Length	Tunnel Inflow (L/s)							
		2021	2022	2023	2024	2025	2026	2027	2126
NB Main Line - Burnt Bridge Creek Deviation to Seaforth Ramp	1098	1.300	1.673	1.597	1.559	1.547	1.539	1.536	1.477
NB Seaforth Cavern	145	0.000	0.000	0.012	0.001	0.001	0.001	0.001	0.000
NB Main Line - Seaforth Cavern towards Seaforth Bluff	1012	0.000	0.000	0.000	2.165	2.266	2.208	2.194	2.004
NB Main Line - Seaforth Bluff to Transition Structure (Undrained)	90	0.000	0.000	0.000	1.009	0.000	0.000	0.000	0.000
NB Exit Ramp - Wakehurst Park towards Seaforth Cavern	1604	0.000	0.000	0.021	0.008	0.006	0.005	0.004	0.001
NB Exit Ramp - Wakehurst Park towards Frenchs Forest	166	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SB Seaforth Cavern	129	0.000	0.000	0.544	0.270	0.237	0.222	0.218	0.144
SB Main Line - Seaforth Cavern towards Seaforth Bluff	976	0.000	0.000	1.753	2.534	2.506	2.431	2.413	2.165
SB Main Line - Seaforth Bluff to Transition Structure (Undrained)	125	0.000	0.000	0.000	1.405	0.000	0.000	0.000	0.000
SB Exit Ramp - Wakehurst Park towards Seaforth Cavern	1662	0.000	0.001	0.053	0.048	0.040	0.036	0.035	0.021
SB Exit Ramp - Wakehurst Park towards Frenchs Forest	145	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SB Main Line - Burnt Bridge Creek Deviation to Seaforth Ramp	1098	0.000	0.310	0.284	0.200	0.186	0.177	0.175	0.133
BL - Balgowlah Access Decline	220	0.000	0.000	0.117	0.108	0.106	0.105	0.104	0.000
BL - Wakehurst Parkway East	230	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL TUNNEL INFLOW (L/s)		**1.300**	**1.984**	**4.381**	**9.308**	**6.896**	**6.722**	**6.682**	**5.945**
		Average Inflow (L/s/km)							
Year		**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2126**
AVERAGE INFLOW (L/s/km)		**0.149**	**0.228**	**0.504**	**1.070**	**0.793**	**0.773**	**0.768**	**0.683**

Notes. (1) NB = North Bound, SB = South Bound, EB = East Bound & WB = West Bound.

7.2.5 Project-wide Tunnel Groundwater Inflows

Table 7.5 presents the total project-specific and cumulative groundwater tunnel inflows for each year of construction and the end of the simulation period (2126) to represent long- term operation phase inflows.

Table 7.5: Summary of modelled Tunnel Inflows – Western Harbour Tunnel Project

Year	Project Inflows		
	Western Harbour	Beaches Link	Cumulative (1)
	ML/day	ML/day	ML/day
2021	0.044	0.112	0.628
2022	0.746	1.438	2.619
2023	0.654	2.438	3.530
2024	0.602	2.768	3.774
2025	0.584	2.265	3.250
2026	0.557	2.213	3.170
2027	0.509	2.201	3.109
2126	0.493	1.944	2.743

Notes: (1) Includes modelled inflows to components of the Chatswood to Sydenham Sydney Metro project and the proposed Rozelle interchange portion of the M4-M5 Link project.

8. Predicted Drawdown

Predicted groundwater drawdown results from the North Model and South Model have been combined to provide predicted drawdown contours for:

- the Western Harbour Tunnel Project only;
- the Beaches Link Project only; and
- the cumulative drawdown effects.

Cumulative drawdown is the sum of the predicted drawdown due to the Beaches Link Project, Western Harbour Tunnel Project, M4-M5 Link Project and Chatswood to Sydenham Sydney Metro Project.

Drawdown predictions are provided for the water table and for model layer 5. Most of the tunnel is contained within model layer 5, therefore, predicted drawdown in this layer is considered to be representative of drawdown in the Hawkesbury Sandstone at the tunnel level.

Section 8.1 presents drawdown predictions for the Western Harbour Tunnel Project only. Section 8.2 presents drawdown predictions for the Beaches Link Project only. Section 8.3 presents cumulative drawdown predictions.

This section only presents the predicted drawdown magnitudes. The impacts due to the drawdown are presented in the groundwater technical papers for the Western Harbour Tunnel Project (Jacobs, 2020a) and the Beaches Link Project (Jacobs, 2020b).

8.1 Predicted Drawdown - Western Harbour Tunnel Project Only

8.1.1 Drawdown at End of Construction – Western Harbour Tunnel Project Only

Figure A1-17 indicates that maximum predicted water-table drawdown at the end of tunnel construction in December 2026 would be up to approximately 20 metres above the Rozelle ventilation tunnels, and 15 metres in the vicinity of Victoria Road. Water-table drawdown propagation is predicted to be limited, with the two metre water-table drawdown contour extending approximately 650 metres from the tunnel’s centreline, largely attenuated by proximity to the harbour. Figure A1-18 indicates that maximum drawdown in layer 5 at the end of tunnel construction in December 2026 would be up to approximately 45 metres along the tunnel section between Rozelle and Birchgrove.

Accentuated water-table drawdown of up to 18 metres is also predicted above the Victoria access decline (Figure A1-17). Drawdown in Layer 5 near the connection of the Victoria access decline to the main tunnel is approximately 43 metres (Figure A1-18).

North of Sydney Harbour predicted water-table drawdown is significantly less, with a maximum drawdown of 3 metres predicted in Waverton and North Sydney (Figure A1-17). The two metre water-table drawdown contour extends up to approximately 350 metres from the tunnel centrelines in the northern area.

North of Sydney, maximum drawdown in layer 5 at the end of tunnel construction is predicted to be approximately 25 metres (Figure A1-18).

8.1.2 Long-term Drawdown– Western Harbour Tunnel Project Only

The magnitudes of predicted drawdown at the water-table and in Layer 5 after approximately 100 years of operation (Figure A1-19 and Figure A1-20, respectively) are similar to drawdown predictions at the end of construction described in Section 8.1.1.

There is, however, a long-term water table drawdown recovery in the vicinity of the Victoria access decline (Figure A1-21), compared to water-table drawdown at the end of construction (Figure A1-17). There is also a minor long-term propagation of water-table drawdown towards Birchgrove and Balmain. North of the Sydney Harbour, maximum predicted water-table drawdown above the alignment increases to approximately 5 metres in Waverton and North Sydney, and a minor propagation of the water-table drawdown extent, away from the alignment, is predicted to occur.

Layer 5 also shows a minor long-term drawdown recovery in the vicinity of the Victoria access decline (Figure A1-20), compared to drawdown at the end of construction (Figure A1-19).

8.2 Predicted Drawdown – Beaches Link Project Only

8.2.1 Drawdown at End of Construction – Beaches Link Project Only

Figure A1-21 indicates water-table drawdown at the end of tunnel construction in June 2027 could be up to a maximum of approximately 31 metres immediately overlying the tunnel centreline in the Northbridge area. Predicted water-table drawdown propagates away from the tunnels, with the drawdown extending up to around 1.8 kilometres from the tunnel centrelines in the Willoughby/Chatswood area. Figure A1-22 indicates Layer 5 drawdown at the end of tunnel construction could be up to a maximum of around 55 metres immediately overlying the tunnel centreline in the Northbridge area.

North of Middle Harbour, the maximum water-table drawdown of approximately 21 metres is predicted to occur between Seaforth and Balgowlah (Figure A1-21). The water-table drawdown is predicted to reach the harbour on both sides of Middle Harbour. Maximum drawdown in layer 5 within the same area is expected to be similar to the drawdown predicted at the water-table (Figure A1-22).

8.2.2 Long-term Drawdown– Beaches Link Only

After approximately 100 years of operation, water-table drawdown in the Northbridge area would be up to 53 metres and up to 21 metres at Seaforth and Balgowlah (Figure A1-23).

The magnitude of predicted drawdown in Layer 5 after approximately 100 years of operation (Figure A1-24) is similar to Layer 5 drawdown predictions at the end of construction described in Section 8.2.1.

8.3 Cumulative Predicted Drawdown

8.3.1 Cumulative Drawdown at End of Construction

Figure A1-25 and A1-26 show the cumulative water table drawdown at the end of the Western Harbour Tunnel and Beaches Link construction period. Figure A1-27 and A1-328 show the cumulative drawdown in layer 5 for the same period.

The predicted end of construction cumulative drawdown at the water-table and in layer 5 around the Rozelle area (Figure A1-25 and Figure A1-27) is considerably greater than drawdown in the same area due to the Western Harbour Tunnel Only Project (Figure A1-17 and Figure A1-18). The maximum water-table drawdown near the Rozelle dive structure is predicted to be approximately 40 metres (Figure A1-25). The maximum layer 5 drawdown near the Rozelle dive structure is predicted to be approximately 59 metres (Figure A1-27). Approximately half of the predicted drawdown can be attributed to the Western Harbour Tunnel (Rozelle ventilation tunnels). However, the cumulative influence generally results in more significant drawdown regionally. For example, at Easton Park near the Rozelle dive structure, cumulative drawdown at the water-table is predicted to be up to 38 metres (Figure A1-25) whereas water-table drawdown due to the Western Harbour Tunnel Project only is predicted to be of the order of 3 metres (Figure A1-17).

In the Rozelle/Lilyfield area, there is also a greater lateral propagation of predicted drawdown in the cumulative scenario compared to the Western Harbour Tunnel Project only scenario. For example, the predicted two metre water-table drawdown contour extends up to 1.4 kilometres to the west of the alignment in the Rozelle / Lilyfield area (Figure A1-25).

Maximum cumulative water-table drawdown above the North Sydney Metro Station is predicted to be approximately 18 metres (Figure A1-25). Maximum cumulative drawdown in layer 5 is predicted to be approximately 21 metres above the North Sydney Metro Station (Figure A1-27).

For most of the Beaches Link Project area, the predicted cumulative drawdown is generally similar to the predicted project only drawdown.

8.3.2 Cumulative Long-term Drawdown

Figure A1-29 and A1-30 show the cumulative water table drawdown after approximately 100 years of operation for the southern and northern areas respectively. Figure A1-31 and A1-32 show the cumulative drawdown in layer 5 for the same period.

For the Western Harbour Project area, the predicted cumulative drawdown after approximately 100 years of operation is similar to the predicted cumulative drawdown at end of construction (Section 8.3.1). After 100 years of operation, the magnitude of drawdown is similar to that at end of construction, with a maximum drawdown of approximately 40 metres and 59 metres in Rozelle at the water-table and Layer 5 respectively. As with the Western Harbour project only scenario (Section 8.1.2), there is a recovery in the water-table at the location of the Victoria access decline, and a slight propagation of the extent of drawdown away from the alignment (Figure A1-29). North of the harbour there is no significant increase in the magnitude of drawdown above the alignment, however there are minor variations in the extent of propagation. As with the end of construction, cumulative drawdown is dominated by drawdown around the North Sydney Metro Station, and with extended drawdown to the north due to the Beaches Link Project.

For the Beaches Link Project area, cumulative drawdown after approximately 100 years of operation is predicted to be largely the same as the project only case. The only change would be in the south of the project area, where drawdown from the Beaches Link Project interacts with drawdown from the northern part of the Western Harbour Tunnel Project.

9. Predicted Baseflow Reduction

9.1 Introduction

This chapter reports on predicted reduction in baseflow due to the cumulative impacts of the Beaches Link, Western Harbour Tunnel, M4-M5 Link & Sydney Metro projects. Baseflow is considered in this report to be the groundwater contribution to streamflow.

Groundwater modelling results indicate that maximum predicted cumulative drawdown is negligible along all streams except Flat Rock Creek, Quarry Creek, Burnt Bridge Creek and Whites Creek. Predictions of baseflow reduction at these impacted creeks are presented in Section 9.2.2.

9.2 Stream Baseflow Impacts Modelling Assessment

9.2.1 Methodology

The groundwater models compute baseflow (groundwater discharge to streams) and leakage (groundwater recharge from streams) at MODFLOW River (RIV) boundary cells that are used to represent streams in the groundwater models. Negative flows computed at RIV cells represent groundwater (baseflow) and positive flows represent leakage from streams to the groundwater system.

Streams are represented in groundwater models by a group of RIV cells referred to as a “reach”. For each stream (reach) there would be gaining sections (negative flows) and losing sections (positive flows). Therefore, the “net flux” for a stream represents the overall volume difference between groundwater inflows and leakage outflows along the entire creek length. A negative net flux at the stream boundary indicates that the stream is predominantly groundwater fed (i.e. gaining stream) and a positive net flux at the stream boundary indicates that the stream is dominated by leakage (i.e. losing stream).

Results of the assessment of groundwater impacts on baseflow (i.e. groundwater discharge to streams) are presented in this section. There was insufficient historical stream-flow monitoring data to provide a reliable estimation of potential groundwater impacts on leakage (i.e. groundwater recharge from streams).

The baseflow impacts assessment was based on a comparison of model predicted baseflow for the scenario without the proposed developments (Null Scenario) and the scenario that includes the simulation of the proposed projects (Cumulative Scenario).

The impact assessment was carried out for Flat Rock Creek, Quarry Creek and Burnt Bridge, where groundwater drawdown effects are expected to occur.

Although Whites Creek is within the extent of predicted drawdown, the creek is almost entirely lined and as such groundwater inflows under existing conditions are expected to be negligible. There is a plan to rehabilitate Whites Creek by Sydney Water. However, Whites Creek is expected to still have a base which is largely impervious after rehabilitation and the groundwater inflow component is expected to still be negligible.

9.2.2 Stream Baseflow Assessment Results

This section presents the predicted cumulative stream baseflow reduction at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek for the following periods:

- End of Western Harbour Tunnel Project construction (December 2026)
- End of Beaches Link Project construction (June 2027)

- Approximately 100 years post-construction (December 2126)

The stream baseflow reduction predictions for the cumulative scenario are presented in the following tables:

- Flat Rock Creek (Table 9.1);
- Quarry Creek (Table 9.2); and
- Burnt Bridge Creek (Table 9.3).

The baseflow reduction at these three creeks is almost entirely due to the Beaches Link Project, as the impacts due to the Western Harbour Tunnel projects are assessed to be negligible.

Table 9.1. Predicted cumulative stream baseflow reduction at Flat Rock Creek.

Stream baseflow predictions	December 2026	June 2027	December 2126
Null model predicted baseflow (m^3/day)	661.7	657.5	502.5
Cumulative projects model predicted baseflow (m^3/day)	112.5	110.2	69.3
Predicted baseflow volume reduction (m^3/day)	549.2	547.3	433.2
Predicted baseflow percentage reduction (%)	83	83	86

Table 9.2. Predicted cumulative stream baseflow reduction at Quarry Creek.

Stream baseflow predictions	December 2026	June 2027	December 2126
Null model predicted baseflow (m^3/day)	50.1	49.8	36.2
Cumulative projects model predicted baseflow (m^3/day)	36.9	36.3	21.0
Predicted baseflow volume reduction (m^3/day)	13.2	13.5	41.9
Predicted baseflow percentage reduction (%)	26	27	42

Table 9.3. Predicted cumulative stream baseflow reduction at Burnt Bridge Creek.

Streamflow predictions	December 2026	June 2027	December 2126
Null model predicted baseflow (m^3/day)	22.5	22.3	13.5
Cumulative projects model predicted baseflow (m^3/day)	18.2	18.0	12.5
Predicted baseflow volume reduction (m^3/day)	4.3	4.3	1
Predicted baseflow percentage reduction (%)	19	19	7

For the Null scenario, the stream baseflow predicted at the three creeks in 2027 is less than baseflow predictions for 2126 mainly because of the average rainfall-recharge conditions used for the long-term model simulations. With respect to the predicted baseflow reductions, the following points are noted:

- Groundwater modelling assumes continuous saturation between the tunnel horizon and the shallow water table. In reality, the system would be stratified, possibly with disconnected aquifer horizons. The predicted maximum drawdowns are therefore unlikely to be realised and the predicted reduction in base flows are therefore conservative
- Large portions of Flat Rock Creek and Quarry Creek are highly altered, including concrete lining and tunnel sections (Figure A1-13). However, a conservative approach has been taken in the groundwater modelling for simulating groundwater seepage to and from creeks. The conservative approach assumes that there is minimal resistance to groundwater seepage flows to and from creeks. The lining of creek beds would largely attenuate any drawdown related impacts and baseflow reductions.

10. Uncertainty Analysis

10.1 Overview

The purpose of this uncertainty analysis is to investigate the sensitivity of model predictions to parameter values assigned to the model. The following parameters were assessed:

- Storage parameters
- Rainfall recharge
- Hydraulic conductivity and vertical hydraulic conductivity anisotropy
- Drain conductance.

During the manual calibration process, the North and South models showed similar responses (i.e. rate of change in simulated groundwater levels when model input parameter values were varied). Therefore, uncertainty analysis was only carried out for the North Model based on the assumption that predictions (drawdown and flows) for both models would be similar when model input parameters are varied. The decision to carry out uncertainty analysis for the North Model only was due to the higher potential impacts to groundwater users and groundwater dependent ecosystems (GDEs) in areas north of Sydney Harbour compared to areas located south of Sydney Harbour. There are no GDEs or existing licensed groundwater users (Water Access Licence users) that have been identified in the area around or close to the Western Harbour Tunnel and Warringah Freeway Upgrade project south of Sydney Harbour, which is covered by the South Model.

10.2 Uncertainty Analysis Methodology

10.2.1 Storage Parameter Uncertainty Analysis

Uncertainty analysis was carried out to assess the sensitivity of model predictions to varying the storage parameter values applied to the model. Storage parameter values from the high and low end of the range of plausible values for the hydrostratigraphic units, were assigned to the “High Storage” and “Low Storage” parameter scenarios respectively. Modelled groundwater drawdown and tunnel inflows for the Base Case model (prediction model; Section 6) were compared to model outputs for the high and low storage parameter scenarios. Storage parameters assessed during the uncertainty analysis were specific storage and specific yield.

Table 10.1 presents the specific storage values assigned to the high and low storage scenarios. The rationale for assigning the extreme specific storage values in Table 10.1 is as follows:

- A specific storage of 1.3 x 10^{-5} m^{-1} was assigned to all hydrostratigraphic units in the “High Storage” scenario. Rau (2018) considers this specific storage to be the physically plausible upper limit for unconsolidated materials. Given that the upper limit recommended by Rau (2018) was based on tests in unconsolidated Botany Sands, it was considered unlikely that the specific storage of fractured sandstone, which dominates the project area, would exceed 1.3 x 10^{-5} m^{-1}.
- Specific storage values assigned to hydrostratigraphic units in the low storage scenario were all one order of magnitude lower than values assigned to the base case model. The specific storage of 5 x 10^{-7} m^{-1} applied in the low storage scenario to the moderately weathered to un-weathered fractured sandstone is consistent with the lower limit for unfissured consolidated rock of approximately 7.5 x 10^{-7} m^{-1} suggested by Younger (1993).

Table 10.1: Specific storage values assigned to uncertainty analysis models

Hydrostratigraphic Unit	Model Layer	Specific storage (m^{-1})		
		Calibrated Model	Sensitivity Analysis Scenarios	
			High	Low
Harbour Sediments	1	1×10^{-5}	1.3×10^{-5}	1×10^{-6}
Fill/Alluvium	1	1×10^{-5}	1.3×10^{-5}	1×10^{-6}
Ashfield shale	1	1×10^{-5}	1.3×10^{-5}	1×10^{-6}
Weathered Hawkesbury Sandstone	1	1.9×10^{-6}	1.3×10^{-5}	1.9×10^{-7}
Moderately weathered to unweathered Hawkesbury Sandstone	2 - 7	1.9×10^{-6}	1.3×10^{-5}	1.9×10^{-7}

Table 10.2 presents the specific yield values assigned to the high and low storage scenarios. The specific yield values assigned to the “High Storage” scenario were 200 per cent of the values assigned to the base case model. Specific yield values assigned to the “Low Storage” scenario were 50 per cent of the values assigned to the base case model.

Table 10.2: Specific yield values assigned to uncertainty analysis models

Hydrostratigraphic Unit	Model Layer	Specific yield (-)		
		Calibrated Model	Sensitivity Analysis Scenarios	
			High	Low
Harbour Sediments	1	0.1	0.2	0.05
Fill/Alluvium	1	0.1	0.2	0.05
Ashfield shale	1	0.02	0.04	0.01
Weathered Hawkesbury Sandstone	1	0.05	0.1	0.025
Moderately to unweathered Hawkesbury Sandstone	2 - 7	0.02	0.04	0.01

10.2.2 Rainfall Recharge Uncertainty Analysis

Uncertainty analysis was carried out to assess the sensitivity of model predictions to varying rainfall-recharge model inputs. Recharge values from the high and low end of the range of plausible values for the hydrostratigraphic units, were assigned to the “High Recharge” and “Low Recharge” scenarios respectively. Modelled groundwater drawdown and tunnel inflows for the Base Case model (prediction model; Section 6) were compared to model outputs for the high and low recharge parameter scenarios.

Recharge rates assigned to the High Recharge Scenario were 200 per cent of the recharge rates assigned to the Base Case model (i.e. recharge rates were doubled). Considering the long-term average recharge rates assigned to the prediction model (Table 4.2), doubling the recharge would increase average recharge rates assigned to the paved and unpaved Hawkesbury Sandstone to approximately 10 and 12 per cent of mean annual rainfall. Given that the upper recharge limit assessed for the Hawkesbury Sandstone in the Sydney basin was assessed to be approximately 10 per cent (Crosbie 2015), the upper recharge limits used in the uncertainty analysis are considered to be reasonable.

Recharge rates assigned to the Low Recharge Scenario were 25 per cent of the recharge rates assigned to the Base Case model. Considering the long-term average recharge rates assigned to the prediction model (Table

4.2), reducing the recharge rates assigned to the Hawkesbury Sandstone by this amount would reduce average recharge rates to approximately 1.25 to 1.5 per cent of mean annual rainfall. Given that the lower recharge limit assessed for the Hawkesbury Sandstone in the Sydney Basin was assessed to be approximately 2 per cent (Crosbie 2015), the lower recharge limits used in the uncertainty analysis are considered to be reasonable.

10.2.3 Hydraulic Conductivity Uncertainty Analysis

Uncertainty analysis was performed to assess the sensitivity of model predictions to varying both the horizontal and vertical hydraulic conductivity (K_h and K_v respectively). K_h and K_v values assigned to the high hydraulic conductivity scenario (High K Scenario) were one order of magnitude higher than values assigned to the base case model. K_h and K_v values assigned to the low hydraulic conductivity scenario (Low K Scenario) were one order of magnitude lower than values assigned to the base case model.

Uncertainty analysis was also performed to assess the sensitivity of model predictions to varying the vertical hydraulic conductivity anisotropy. For the $High_{Kv/Kh}$ scenario, the K_v values assigned to the base case model were adjusted to achieve K_v/K_h ratios of one, except for the unweathered Hawkesbury Sandstone where the K_v/K_h ratio in the uncertainty analysis models was 0.1 (Table 10.3). An increase in the K_v/K_h ratio to 0.1 for the unweathered Hawkesbury Sandstone represents an order of magnitude increase in the K_v/K_h ratio by increasing K_v from 6.00×10^{-5} to 6.00×10^{-4}.

For the low Kv/Kh scenario, the K_v values assigned to the base case model were adjusted to achieve K_v/K_h ratios of 0.01, except for the unweathered Hawkesbury Sandstone where the K_v/K_h ratio in the uncertainty analysis models was 0.005 (Table 10.3). The reason for the selected K_v/K_h ratio for the unweathered Hawkesbury Sandstone is because the base case model already has a K_v/K_h ratio 0.01.

Table 10.3: K_v/Kh ratios assigned to uncertainty analysis models

Hydrostratigraphic Unit	Model Layer	Model Zone	K_v/K_h Ratio		
			Base Case Model	High K_v/K_h Scenario	Low K_v/K_h Scenario
Harbour Sediments	1	3	0.5	1	0.01
Fill/Alluvium	1	4	0.1	1	0.01
Ashfield Shale	1	2	0.1	1	0.01
Weathered Hawkesbury Sandstone	1	1	0.5	1	0.01
Moderately Weathered Hawkesbury Sandstone	2	9	0.5	1	0.01
Slightly Weathered Hawkesbury Sandstone	3	10	0.5	1	0.01
Slightly Weathered/ Un-weathered Hawkesbury Sandstone	4	6	0.1	1	0.01
Un-weathered Hawkesbury Sandstone	5 - 7	17	0.01	0.1	0.005
High K_1	2	7	0.5	1	0.01
High K_2	3	11	0.5	1	0.01
High K_3	4	8	0.1	1	0.01
High K_4	5-7	18	0.1	1	0.01

10.2.4 Drain Conductance Uncertainty Analysis

The uncertainty analysis assessed the effect of applying higher and lower conductance values to drain (DRN) boundary cells compared to conductance values assigned to the base case model. Conductance values assigned to DRN cells along the tunnel alignment in the "High Conductance" scenario were one order of magnitude higher than conductance values assigned to the base case model. Conductance values assigned to DRN cells along the tunnel alignment in the "Low Conductance" scenario were one order of magnitude lower than conductance values assigned to the base case model.

10.3 Uncertainty Analysis Results

10.3.1 Uncertainty in Modelled Tunnel Inflows

Table 10.5 presents North Model uncertainty analysis results compiled for the segment of the Western Harbour Tunnel and Warringah Freeway Upgrade project between Sydney Harbour and Warringah Freeway. Table 10.4 also compares projected peak groundwater inflows for the Base Case and uncertainty analysis model scenarios for this segment of the project.

The modelled tunnel inflows are most sensitive to changes in hydraulic conductivity and the ratio between vertical and horizontal hydraulic conductivity (Kv/Kh). Table 10.5 shows that modelled tunnel inflows are approximately 117 per cent higher when both the horizontal and vertical hydraulic conductivity values assigned to the Base Case model are increased by one order of magnitude. Results of the uncertainty analysis also indicate that modelled tunnel inflows are approximately 157 per cent higher when the horizontal and vertical hydraulic conductivity values assigned to most of the hydrostratigraphic units are the same (ie high Kv/Kh scenario, where Kv/Kh = 1)

The uncertainty analysis results presented in Table 10.5 also show that the tunnel inflows computed from the model are not very sensitive to increasing the drain conductance assigned to drain boundaries (DRN boundary conditions). An increase in conductance values assigned to the Base Case model by one order of magnitude results in an increase in modelled tunnel inflows of less than one per cent.

Table 10.4: Uncertainty Analysis Results – Peak Tunnel Inflows for Sydney Harbour to Warringah Freeway Section Western Harbour Tunnel Project).

Model Scenario	Total Inflow			Average Inflow	Percentage Difference in Annual Flows
	L/s	ML/day	ML/Year	L/s/km	%
Base case	1.322	0.114	42	0.210	0.0
Low Recharge	1.181	0.102	37	0.187	-10.7
High Recharge	1.513	0.131	48	0.240	14.4
Low Storage	1.275	0.110	40	0.202	-3.6
High Storage	1.393	0.120	44	0.221	5.4
Low K	0.249	0.022	8	0.040	-81.1
High K	2.862	0.247	90	0.454	116.5
Low Kv/Kh	0.897	0.078	28	0.142	-32.1
High Kv/Kh	3.399	0.294	107	0.539	157.1
Low drain conductance	1.331	0.115	42	0.211	0.7
High drain conductance	1.317	0.114	42	0.209	-0.4

Table 10.5 presents the North Model uncertainty analysis results compiled for the area subject to the Beaches Link and Gore Hill Freeway Upgrade project. Table 10.5 compares the projected peak groundwater inflows for the Base Case and uncertainty analysis model scenarios.

The model is most sensitive to changes in hydraulic conductivity. Table 10.5 shows that modelled tunnel inflows are approximately 312 per cent higher when the horizontal and vertical hydraulic conductivity values assigned to the Base Case model are increased by one order of magnitude. The uncertainty analysis results presented in Table 10.5 also show that the tunnel inflows computed from the model are not very sensitive to increasing the drain conductance assigned to drain boundaries (DRN boundary conditions). An increase in conductance values assigned to the Base Case model by one order of magnitude results in an increase in modelled tunnel inflows of less than one per cent.

Table 10.5: Uncertainty Analysis Results – Beaches Link Project Modelled Peak Tunnel Inflow

Model Scenario	Cammeray to Middle Harbour Section	Middle Harbour to Wakehurst Parkway Section	Whole project		Total annual inflows for whole project	Percentage Difference in Annual Flows
	L/s/km	L/s/km	L/s/km	ML/day	ML/ year	%
Base case	1.682	0.504	1.093	2.056	750	0.0
Low Recharge	1.667	0.436	1.052	2.038	744	-0.9
High Recharge	1.749	0.608	1.178	2.138	780	4.0
Low Storage	1.480	0.440	0.960	1.809	660	-12.0
High Storage	2.058	0.574	1.316	2.515	918	22.3
Low K	0.508	0.101	0.304	0.621	227	-69.8
High K	6.922	1.606	4.264	8.460	3088	311.5
Low Kh/Kv	1.403	0.363	0.883	1.715	626	-16.6
High Kh/Kv	2.655	0.762	1.708	3.244	1184	57.8
Low drain conductance	1.481	0.470	0.975	1.810	661	-12.0
High drain conductance	1.696	0.507	1.101	2.073	756	0.8

10.3.2 Uncertainty in Modelled Drawdown

10.3.2.1 Introduction

Drawdown predictions for the base case model are presented in Section 8. The impacts due to the drawdown are presented in the groundwater technical papers for the Western Harbour Tunnel Project (Jacobs, 2020a) and the Beaches Link Project (Jacobs, 2020b).

The aim of the uncertainty analysis is to assess how varying model input parameters can produce drawdown predictions that could result in impacts that are considered to be more than minimal. The NSW Aquifer Interference Policy (AIP) provides drawdown thresholds that should be used for minimal impact considerations. There are two levels of minimal impact considerations in the AIP. If the predicted impacts are less than Level 1 minimal impact considerations, then these impacts are generally considered acceptable.

The minimal impact considerations depend on the groundwater source which would be affected by the proposed development. All groundwater and surface water resources in the Western Harbour Tunnel and Beaches Link project areas are managed through the Greater Metropolitan Region Water Sharing Plan. The groundwater source relevant to the Western Harbour Tunnel and Beaches Link projects is the ‘Sydney Basin Central’ groundwater source. The groundwater source is classified as a “Less Productive Porous and Fractured Rock Water Source”. Table 10.6 presents the Level 1 minimal impact considerations applicable to this water source.

Table 10.6: AIP Level 1 minimal impact considerations

Level 1 Minimal Impact Considerations for Less Productive Porous and Fractured Rock Water Sources	
Water Table	**Water Pressure**
Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic “post-water sharing plan” variations, 40m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. A maximum of a 2m decline cumulatively at any water supply work.	A cumulative pressure head decline of not more than a 2m decline, at any water supply work.

Based on the AIP requirement for the maximum cumulative drawdown at any water supply work to be less than two metres to meet the minimal Level 1 impact consideration, the uncertainty analysis was carried out by:

- Comparing the lateral extents of the predicted two metre cumulative drawdown contours for the different model scenarios.
- Identifying any additional water supply works (bores) sites where the model predicts more than two metres drawdown when model input parameters are varied from the base case model parameters.

There are no high priority groundwater dependent ecosystems within the Western Harbour Tunnel and Beaches Link project areas. Therefore, the level 1 minimal impact considerations related to groundwater dependent ecosystems (GDEs) are not applicable. Therefore, uncertainty analysis based on AIP minimal impact considerations was not relevant.

10.3.2.2 Storage Parameter Drawdown Uncertainty Analysis

Figure A1-33 compares the predicted two metre cumulative water-table drawdown contours after 100 years of operation for the base case, high storage and low storage parameter scenario models. Generally, the lateral extent of the two-metre drawdown contour for the low storage parameter scenario is slightly greater than the extent in the base case model. In most areas, the lateral extent of the two-metre drawdown contour for the high storage parameter scenario is slightly less than the extent in the base case model.

Figure A1-33 shows that bores with more than two metres predicted drawdown are the same for the base case, high and low storage parameter scenario.

10.3.2.3 Hydraulic Conductivity Drawdown Uncertainty Analysis

Figure A1-34 compares the predicted two metre cumulative water-table drawdown contours after 100 years of operation for the base case, high hydraulic conductivity scenario and low hydraulic conductivity scenario models.

The lateral extent of the two-metre drawdown contour for the high hydraulic conductivity scenario is generally slightly greater than the extent for the base case, except in areas to the west of Middle Harbour (Middle Cove, Willoughby East, North Willoughby and Middle Cove) and Clontarf (north of Middle Harbour) where the difference is larger.

To the west of Middle harbour, in the Willoughby East, North Willoughby and Middle Cove areas, the lateral extent of the two-metre drawdown contour for the high hydraulic conductivity scenario is up to 1000 metres greater than the extent for the base case model (Figure A1-34). In the Clontarf area, north of Middle Harbour, the lateral extent of the two-metre drawdown contour for the high hydraulic conductivity scenario is up to 210 metres greater than the extent for the base case model.

Figure A1-34 shows that the lateral extent of the two-metre drawdown contour for the low hydraulic conductivity scenario is generally significantly less than the extent for the base case model.

The low hydraulic conductivity scenario model predicts less than two metres drawdown at bores GW107666 and GW107970 (Figure A1-34). However, the base case and low hydraulic conductivity scenario model predictions indicate that drawdown at these two bores would exceed two metres.

The high hydraulic conductivity scenario and the base case models have similar predicted drawdown impacts at existing bores (i.e. drawdown greater than two metres is predicted at the same bores in both models).

10.3.2.4 Vertical Hydraulic Conductivity Anisotropy Uncertainty Analysis Drawdown Uncertainty Analysis

Figure A1-35 compares the predicted two metre cumulative water-table drawdown contours after 100 years of operation for the base case, high kv/kh scenario and low kv/kh scenario models.

The lateral extent of the two-metre drawdown contour for the low kv/kh scenario is generally slightly less than the base case scenario extent.

Comparing the base case and the high Kv/Kh scenario models, the two-metre drawdown contour from the high Kv/Kh model extends further to the west in the Crows Nest and Wollstonecraft areas (Figure A1-35).

The high Kv/Kh scenario model predicts more than two metres drawdown at bores GW107764, GW108991 and GW107666. However, the base case and low Kv/Kh models predictions indicate that drawdown at these two bores would not exceed two metres (Figure A1-35).

10.3.2.5 Recharge Drawdown Uncertainty Analysis

Figure A1-36 compares the predicted two metre cumulative water-table drawdown contours after 100 years of operation for the base case, high recharge and low recharge scenario models.

For most areas the predicted drawdown effects are the same. The two-metre drawdown contour lateral extent for the low recharge scenario is slightly greater than the extent for the base case model. The drawdown predicted from the high recharge scenario is less extensive than drawdown predicted for the base case model. Varying the model recharge inputs causes a greater drawdown variation in the St Leonards, Artarmon and North Willoughby areas (Figure A1-36).

Whereas the low recharge scenario predicts more than two metres drawdown at bore GW107764, the base case and high recharge model predictions indicate that drawdown at this bore would not exceed two metres (Figure A1-36).

10.3.2.6 Drain Boundary Conductance Drawdown Uncertainty Analysis

Figure A1-37 compares the predicted two metre cumulative water-table drawdown contours after 100 years of operation for the base case, high drain boundary conductance scenario and low drain boundary conductance scenario models.

The lateral extents of the predicted two metre drawdown contours for the base case and high drain boundary conductance scenario are similar, except for minor differences at Balls Head and Castlecrag. There is much greater difference in predicted drawdown between the base case and high drain boundary conductance scenario models. Figure A1-37 shows that the predicted two metre drawdown contour does not extend very far from the proposed tunnel alignment.

While the predicted drawdown impacts at existing bores are very similar for the base case and high drain boundary conductance scenario models, drawdown predicted from the low drain boundary conductance scenario is significantly less. Drawdown is predicted to be less than two metres at all assessed bores for the low drain boundary conductance scenario (Figure A1-37).

11. Saline Water Intrusion Assessment

11.1 Introduction

Jacobs carried out a groundwater modelling assessment of the potential saline water intrusion that could occur due to the construction and operation of the following projects:

- Western Harbour Tunnel and Warringah Freeway Upgrade project (Western Harbour Tunnel project).
- The Beaches Link and Gore Hill Freeway Connection project (Beaches Link project).

Density dependent flow analysis was performed in the saline water intrusion assessment. The finite element program CTRAN/W coupled with SEEP/W was used for the density-dependent groundwater flow analysis. Two-dimensional groundwater models were constructed along cross section line shown in Figure 11-1. The saline water intrusion modelling assessment for the Western Harbour Tunnel project (South Model Cross-section) is described in Section 11.3 and the assessment for the Beaches Link project (North Model Cross-section) is described in Section 11.4.

11.2 Methodology – Density Dependent Flow Modelling

The density of saline water is higher than the density of freshwater and therefore, the density contrast would affect the flow dynamics of the groundwater system in coastal areas. CTRAN/W allows the simulation of density dependent flow analysis by coupling with SEEP/W using an iterative procedure. The density effect is accommodated by the addition of a body force term to the groundwater flow governing equation.

Since the body force term is added to the seepage governing equation in SEEP/W, there is no special treatment to the finite element formulation in CTRAN/W for density-dependent flow. For density-dependent problems, the groundwater velocities and concentrations must be solved for simultaneously at each time step because the groundwater velocities are dependent on saline water density and the saline water density is in turn dependent on concentration. At each time step, SEEP/W uses the saline water concentrations to calculate the density body force term for the groundwater flow governing equation and then solves for equivalent freshwater heads and groundwater velocities.

CTRAN/W then reads the groundwater velocities and solves for concentrations. Before proceeding to the next time step, the solution continues iteratively until the groundwater velocities and concentrations are compatible. The iterations are complete when either the percentage change in both the vector norm of nodal pressure head and nodal concentration are smaller than your specified convergence tolerances, or if the maximum number of iterations specified by the user are reached.

CTRAN/W assumes that density varies linearly with concentration. Therefore, the saline water relative density (density relative to freshwater), at some reference concentration has to be specified. Given that the density of seawater is assumed to be generally 1.025 times that of freshwater, the relative density value was specified as 1.025 at a reference concentration of 1.0. In this particular case the reference concentration is a relative concentration representing 100% seawater. The relative density and reference concentration values are specified in the input settings for the SEEP/W model simulation.

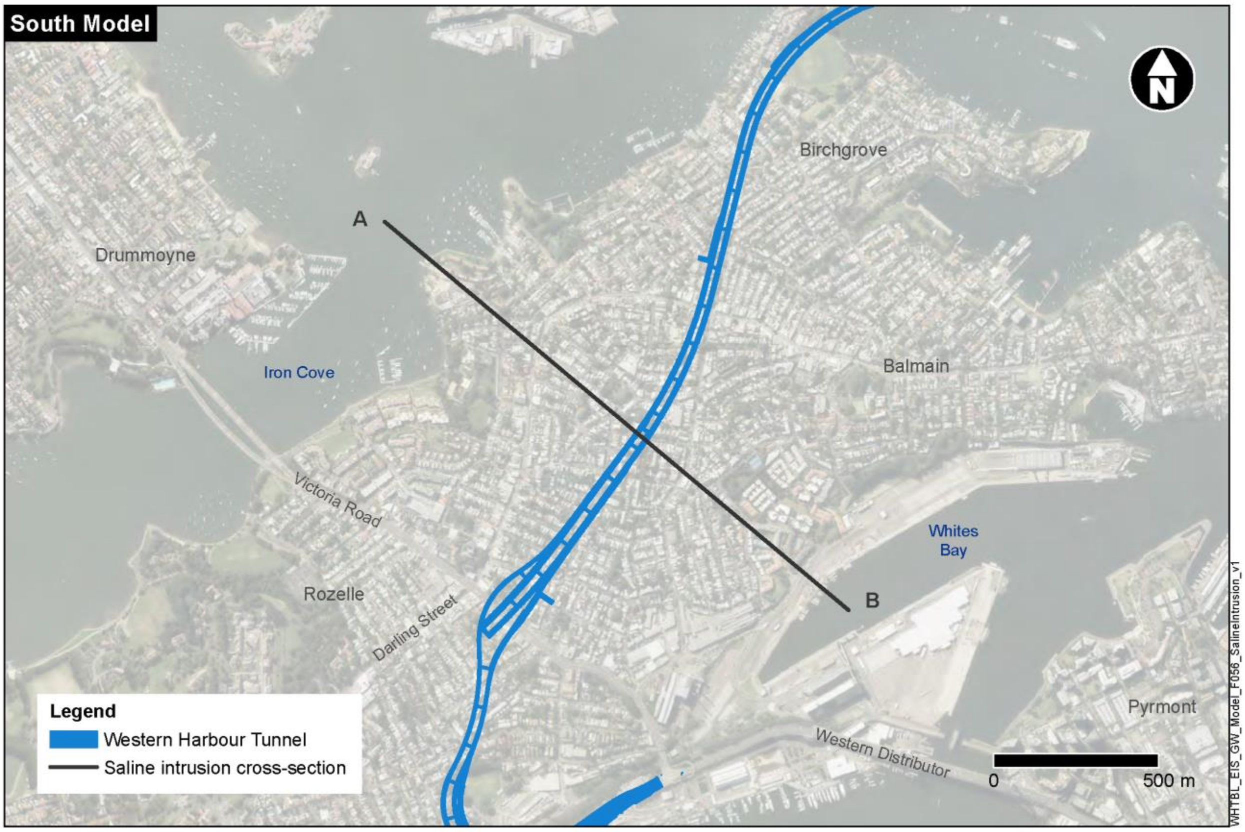


Figure 11-1: Location of model cross-sections.

11.3 Saline Water Intrusion Assessment – South Model Cross-section

Groundwater sampling indicates that saline water currently occurs along some areas of the proposed tunnel located south of Sydney Harbour. The proposed tunnel design would incorporate water treatment for saline water in these saline water areas. There is, however, a potential for changes in groundwater quality to occur through saline water migration in areas where saline water does not currently occur. The aim of the saline water intrusion assessment was to assess the potential saline water intrusion at areas of maximum drawdown along a cross-section line located to the south of Sydney Harbour (Figure 11-1). The location of the cross section was selected to pass through the deepest part of the proposed Western Harbour Tunnel alignment. The purpose of the modelling assessment was to provide an indication of the rate of the movement of the freshwater/saline water interface towards inland areas.

11.3.1 Model Structure and Input Parameters

The seven hydrogeological layers defined in the three-dimensional MODFLOW-USG model representing variably weathered zones within the Hawkesbury Sandstone were represented in the SEEP/W two-dimensional model as shown in Figure 11-2. The saturated hydraulic conductivity values assigned to the SEEP/W model were the same hydraulic conductivity values assigned to the three-dimensional MODFLOW-USG model. The ratios of horizontal to vertical hydraulic conductivity (k_h/k_v) for the model layers were also the same as ratios applied to the MODFLOW-USG model.

11.3.1.1 Hydraulic Conductivity Functions (SEEP/W)

Model Layer 1 to Layer 5 were modelled as saturated/unsaturated layers because of the potential for the layers to become partially saturated during the model simulation. Hydraulic conductivity functions defined for model Layer 1 to Layer 5 to simulate the decrease in hydraulic conductivity that occurs due to increasing desaturation are presented in Annexure 10. The saturated hydraulic conductivity assigned to the hydraulic conductivity function for each layer was based on hydraulic conductivity values assigned to the layer in the calibrated three-dimensional MODFLOW-USG model.

Model Layer 6 and Layer 7 were modelled as saturated layers for the entire simulation. Therefore, only the saturated hydraulic conductivity of 6.9×10^{-8} m/s (6.0×10^{-3} m/day) was used in simulations for these two layers.

11.3.1.2 Coefficient of Volume Compressibility (SEEP/W)

The coefficient of volume compressibility (*mv*) is the slope of the volumetric water content function in the positive pore pressure range. The coefficient characterises the volume of water stored or released from the formation when the pore-water pressure changes. The coefficient *mv* can be calculated from the specific storage (*Ss*) using Equation 11.1 below.

$$mv = \frac{Ss}{\rho g}$$

Where ρ = water density

g = gravitational constant

Specific storage values from the calibrated three-dimensional MODFLOW-USG model were used to provide mv estimates for the SEEP/W model layers. Table 11.1 presents specific storage values from the three-dimensional MODFLOW-USG model and the corresponding mv values applied to the SEEP/W model layers. The *mv* values are within the range of literature values for sound and jointed rocks (Bell, 2000).

Table 11.1: Coefficient of compressibility values assigned to SEEPW model

Model Layer	Specific Storage (1/m)	Water density [1] kg/m^3	Gravitational constant ms^{-2}	*mv* (1/Pa)	*mv* (1/kPa)
1	1×10^{-5}	1000	9.8	1.02×10^{-9}	1.02×10^{-6}
2- 7	1.9×10^{-6}	1000	9.8	1.94×10^{-10}	1.94×10^{-7}

Notes. (1) Measured at 4°C

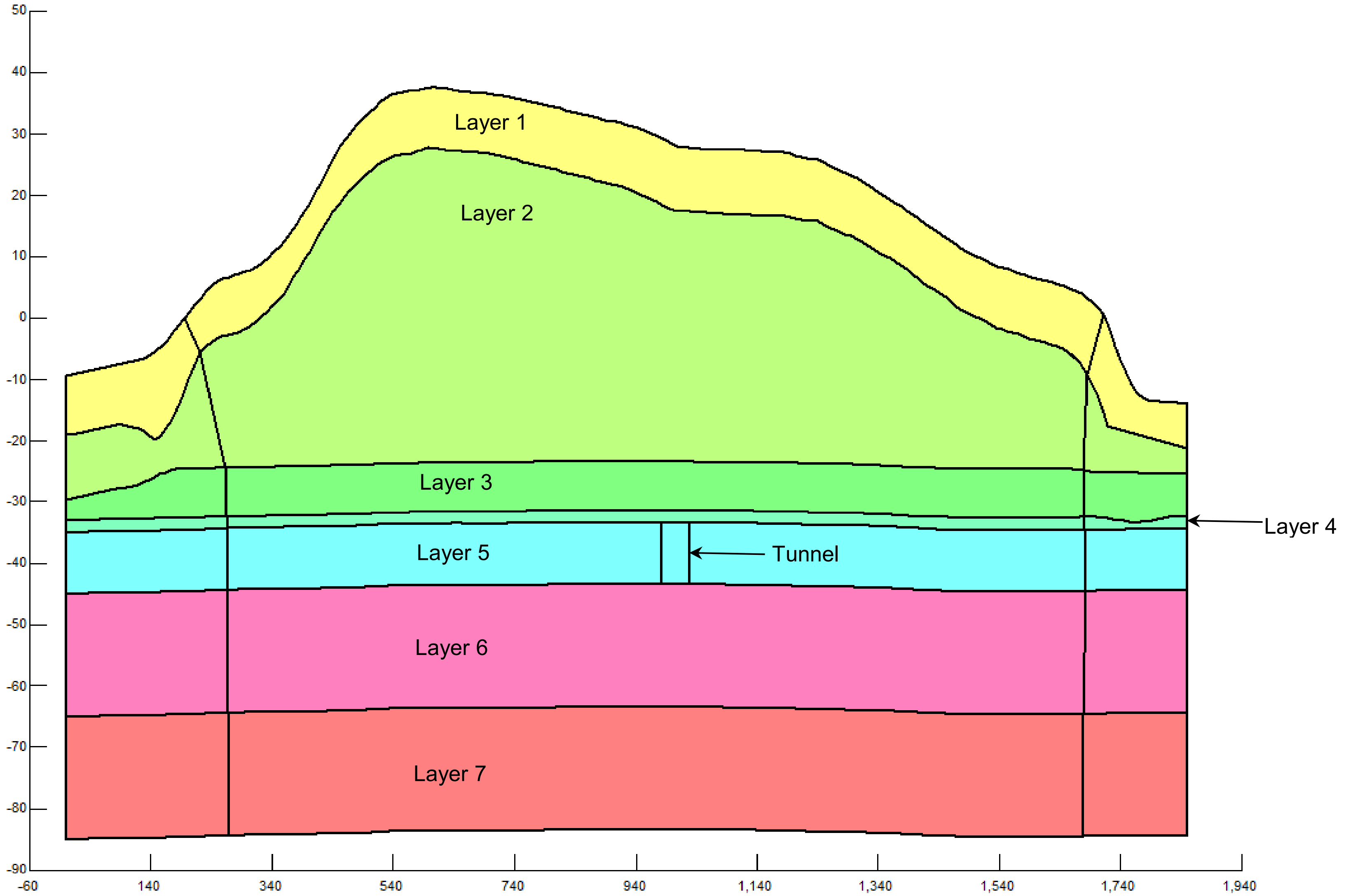


Figure 11-2: Hydrogeological layers in south cross section model

11.3.1.3 Water Content Functions (SEEP/W)

The water content function used in the SEEP/W model to represent the relationship between pore-water pressure and volumetric water content for the weathered Hawkesbury sandstone occurring in model Layer 1 is presented in Annexure 11. The saturated volumetric water content assigned to the function was based on the specific yield of 0.05 from the calibrated three-dimensional MODFLOW-USG model. The water content function assigned to moderately weathered to unweathered Hawkesbury sandstone in model Layer 2 to Layer 7 is presented in Annexure 11. The saturated volumetric water content assigned to function was based on the specific yield of 0.02 from the calibrated three-dimensional MODFLOW-USG model.

11.3.1.4 Boundary Conditions (SEEP/W)

Head and flux boundary conditions assigned to the SEEP/W model are shown in Figure 11-3 and listed below:

Constant head boundary conditions of 0 m were assigned along the harbours to the right and left of the model.

- Constant Total Flux (Q) boundary condition were assigned to nodes around the tunnel to simulate the tunnel groundwater discharge. The maximum predicted tunnel inflow rate for the South Model was approximately 0.73 L/s/km (Table 7.1). For this assessment a more conservative groundwater discharge rate to the tunnel of 1 L/s/km was assumed. This translates to a total combined flow at the flux boundary nodes of -1.0×10^{-6} $m^3/s/m$.
- A constant Unit Flux (q) boundary condition of 9.75×10^{-10} m/s was used to represent groundwater recharge, based on results from the 3D MODFLOW-USG model.
- The bottom of the model was assigned as no-flow boundary.

11.3.1.5 CTRAN/W Model Input Parameters

As described in Section 11.2, a reference concentration of 1.0 is used in the CTRAN/W model to represent 100% seawater.

Constant concentration boundary conditions of 1.0 (i.e. seawater) were assigned in the CTRAN/W model along the inferred current location of the freshwater-seawater interfaces to the left and right of the model (Figure 11-4). The locations of the freshwater/seawater interfaces were defined based on the Ghyben-Herzberg principle, which states the depth to the freshwater/saline water interface below sea-level is approximately 40 times the height of the groundwater table above sea-level. The groundwater table elevation under existing conditions was obtained from model results from the pre-construction SEEP/W steady state model (Section 11.3.2).

Freshwater located between the left-hand-side and right-hand-side freshwater/saline water interfaces was assigned an initial relative concentration of 0 g/m^3.

CTRAN/W requires longitudinal dispersivity and transverse dispersivity input values for the advection-dispersion solute transport simulation. The longitudinal dispersivity is scale-dependent (i.e. increases with flow distance). Schluze-Makuch (2005) provide Equation 11.2 for estimating the longitudinal dispersivity:

$\alpha = c(L)^m$ [Equation 11.2]

Where,

$\alpha =$ longitudinal dispersivity (m).
$c =$ parameter characteristic for the longitudinal dispersivity for a geological medium (m).
L= flow distance (m).
m = scaling exponent.

For computer simulations, the flow distance is considered to be the horizontal distance between the solute source and a sink (Schluze-Makuch, 2005). For the South Model cross-section, the solute source would be the harbours to the east and west of the tunnel. The sink is the tunnel along the cross-section line. Therefore, the flow distance is considered to between 700 metres and 800 metres.

Schluze-Makuch, 2005 recommend the following values for sandstone:

- c = 0.92 m
- m = 0.01

A longitudinal dispersivity of approximately 5 m was calculated based on Equation 11.2 and the parameter values provided above.

The transverse dispersivity is commonly set to be equal to 30% of the longitudinal dispersivity (Lovanh et.al., 2000). Therefore, a transverse dispersivity of 1.5 m was assigned to the advection-dispersion solute transport simulation.

There is no readily available local information on the diffusion coefficient for the Hawkesbury Sandstone. Therefore, a diffusion coefficient of 1 x 10^{-6} m^2/s was assigned to the Hawkesbury solute transport modelling assessment based on experimental work carried out on the Berea sandstone in Ohio (Sheng et.al., 2012).

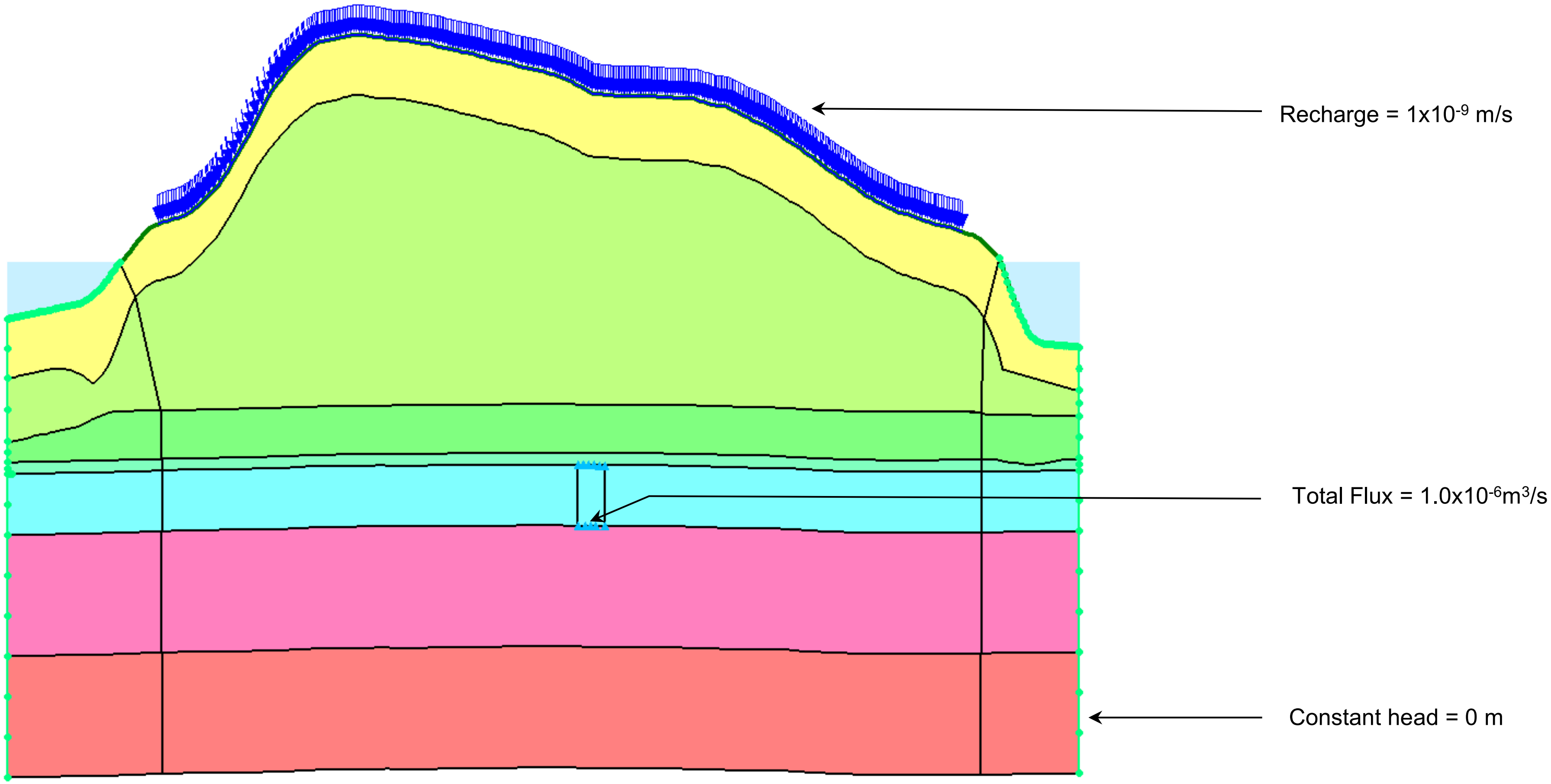


Figure 11-3: Head and flux boundary conditions – South SEEP/W model.

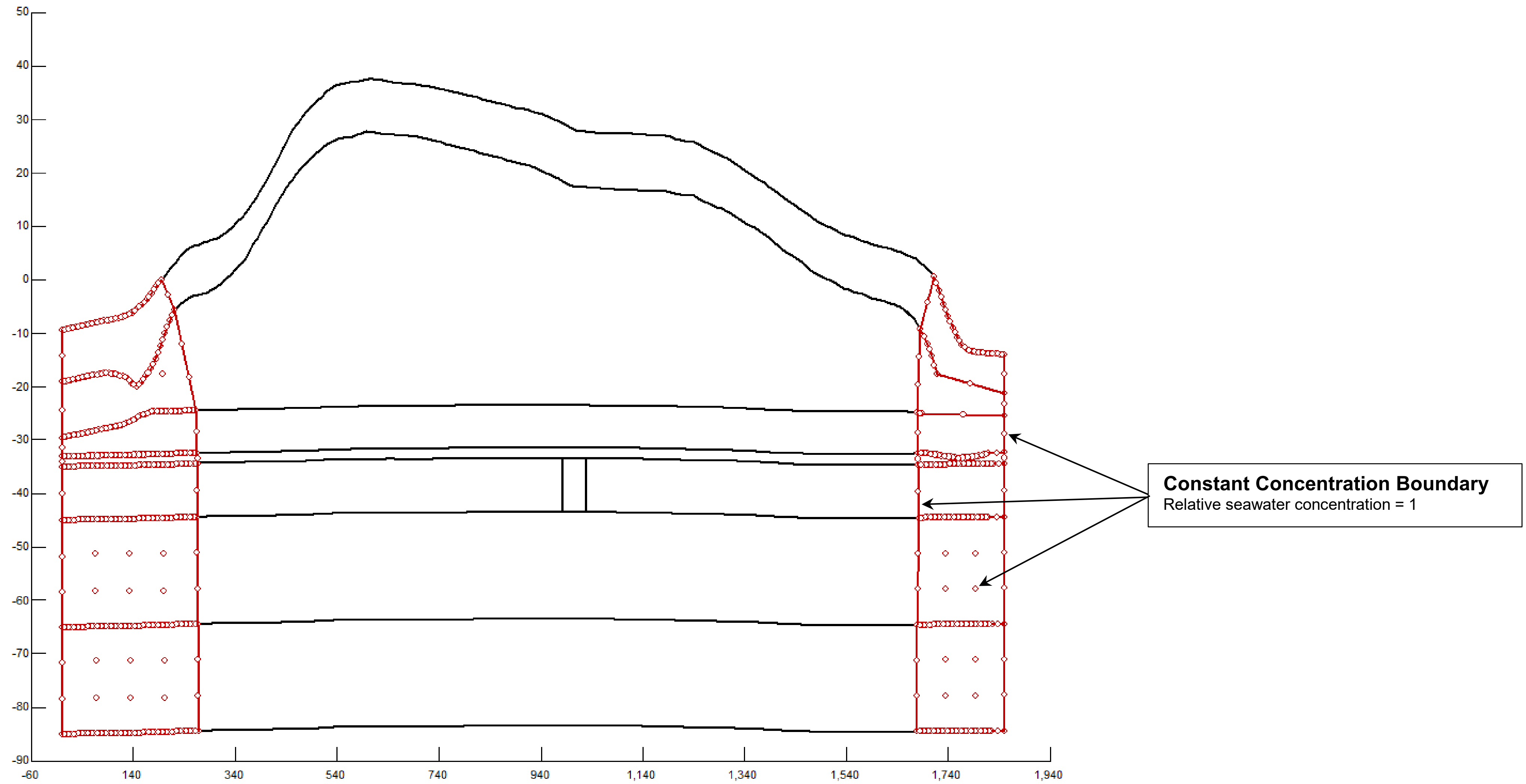


Figure 11-4: Unit relative concentration boundary locations – South CTRAN/W Model.

11.3.2 Results – South Cross-section Model

Figure 11-5 shows the model-predicted pre-construction total hydraulic head distribution and water table elevation (in blue) along the cross section. Figure 11-6 shows the predicted pre-construction relative seawater concentrations. A relative seawater concentration of 1 represents 100% seawater and a relative seawater concentration of 0 indicates background freshwater concentrations (Section 12.2). Figure 11-6 shows the locations of the sharp initial freshwater-saline water interface that have been simulated in the model.

Figure 11-7 shows the total hydraulic head distribution and water table elevation along the cross section at the end of the Western Harbour Tunnel project construction. Figure 11-8, presenting the predicted relative seawater concentrations at the end of the construction period, indicates that both the lateral and upward movement of the freshwater-saline water interface along the modelled cross-section would be negligible over the construction period of the Western Harbour Tunnel project.

Figure 11-9 and Figure 11-10 show the total hydraulic head and relative seawater concentrations, respectively, after 100 years of Western Harbour Tunnel project operation. Figure 11-10 indicates that the maximum lateral movement of saline water towards inland areas over the 100-year simulation period is approximately 154 m. The model indicates that a freshwater-saline water mixing zone would be developed towards the inland area. The maximum predicted width of the freshwater-saline water mixing zone of approximately 110 m is predicted to occur at depths greater than 80 m below sea level. However, in areas located adjacent to the harbours, the freshwater-saline water mixing zone has a predicted maximum width of less than 30 m at elevations higher than -50 mAHD, which suggests that saline water intrusion impacts in areas located adjacent to the harbours are likely to be minor to negligible.

It is important to note that the modelled cross-section location was selected because it passes through the deepest section of the proposed Western Harbour Tunnel project tunnel alignment.

The minor to negligible saline water intrusion impacts predicted from the modelling are considered to be due to the distance between the proposed tunnel and the location of the inferred initial seawater/freshwater interface.

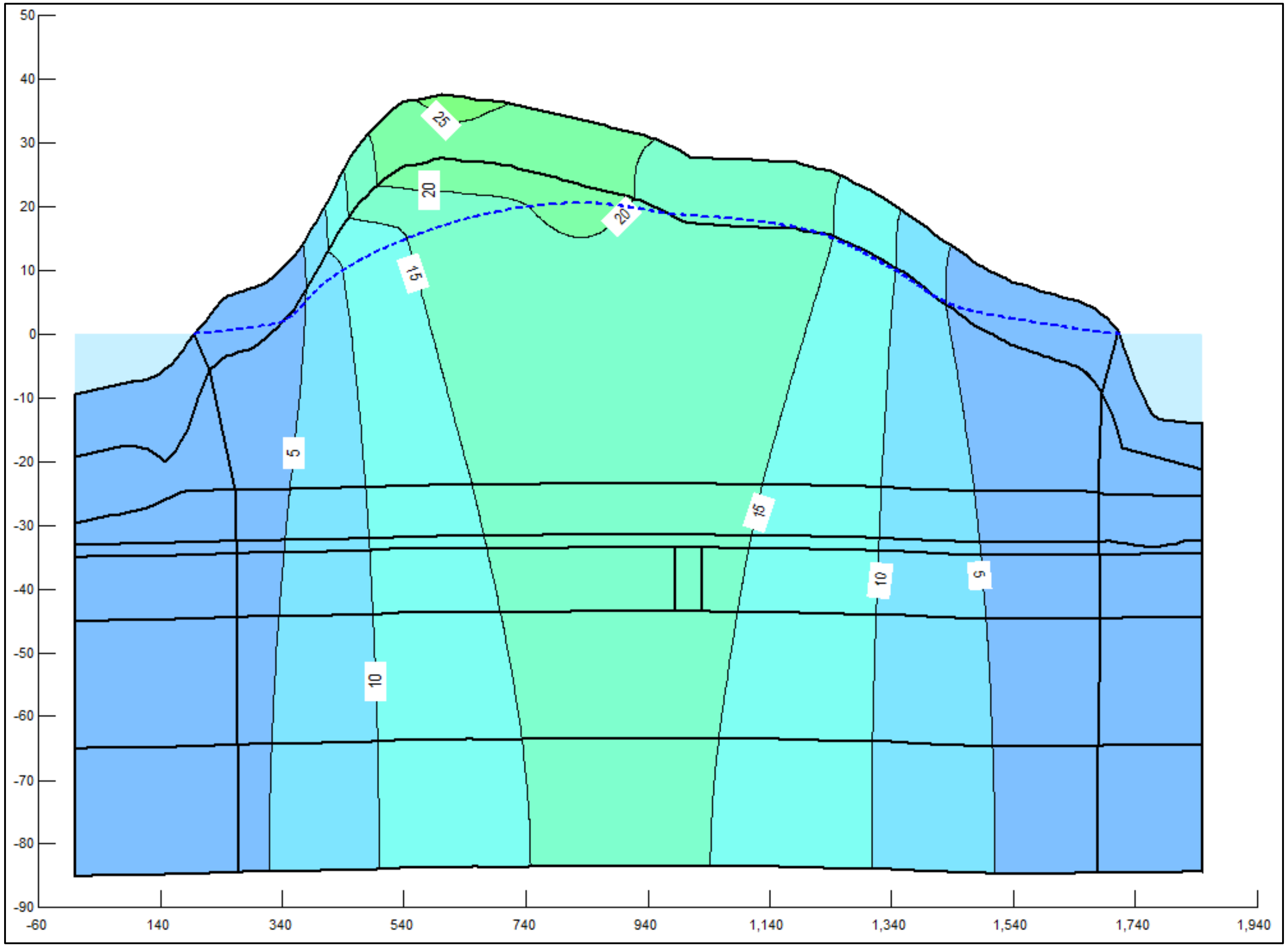


Figure 11-5: Predicted pre-construction heads – south model

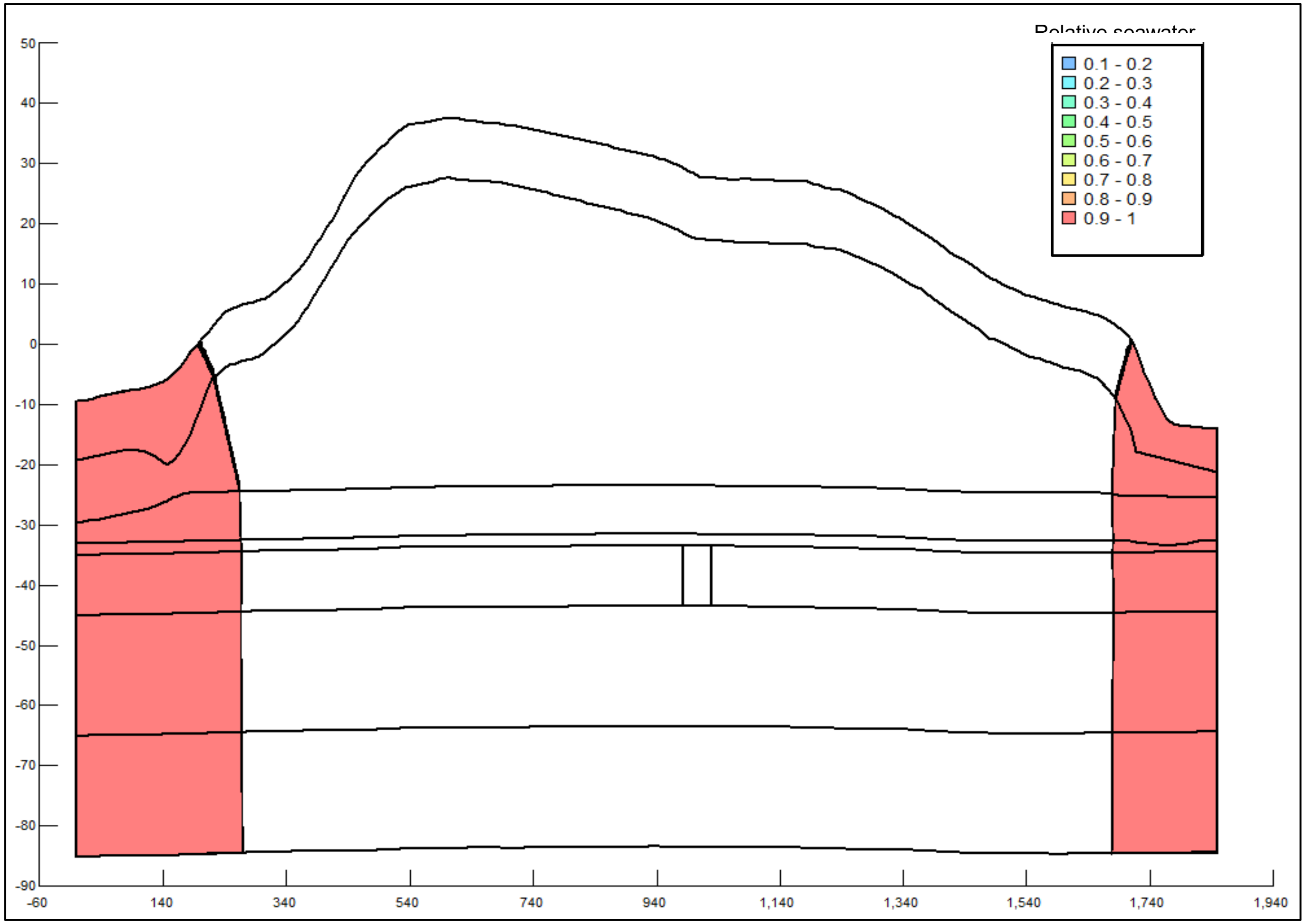


Figure 11-6: Predicted pre-construction relative seawater concentrations – south model

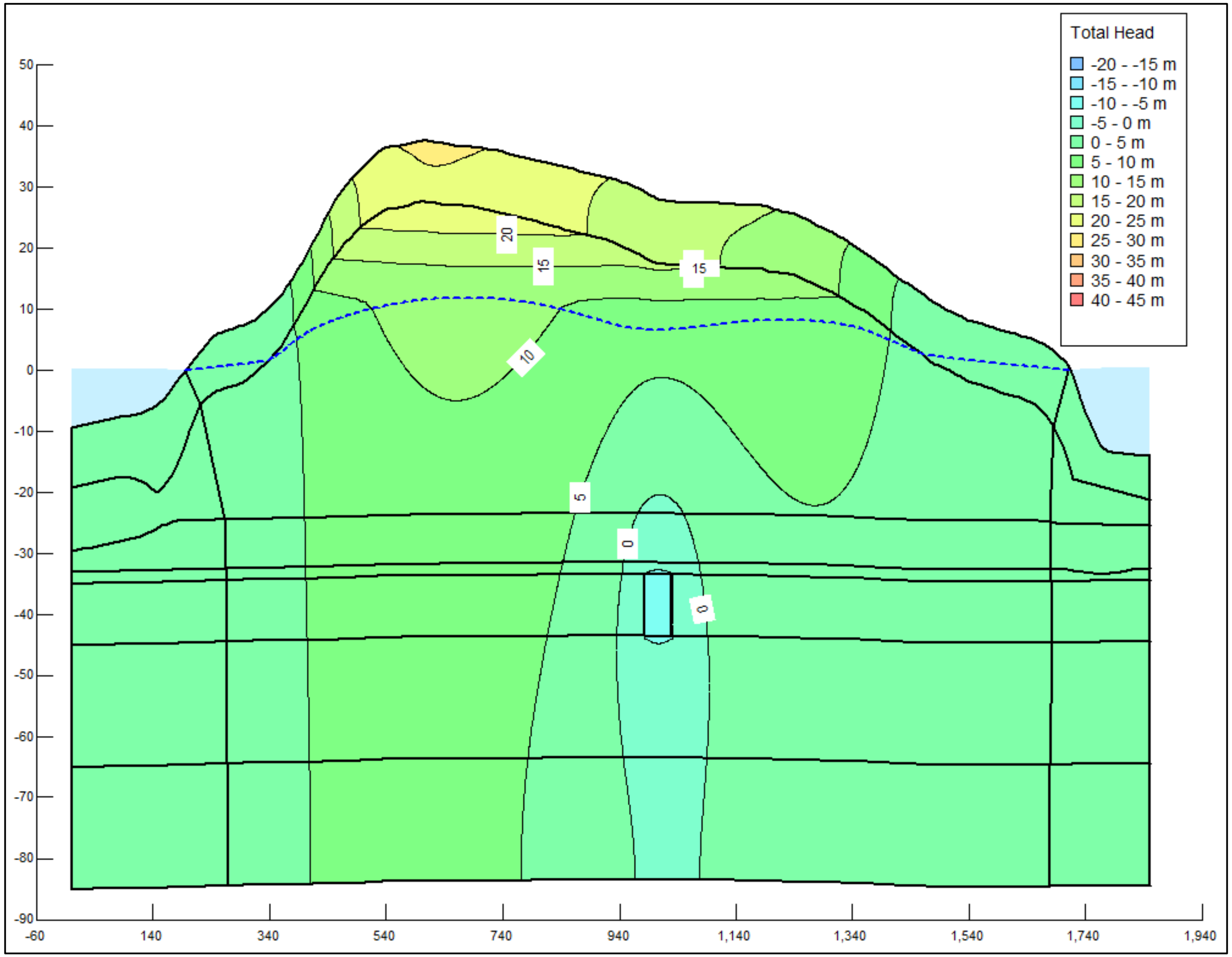


Figure 11-7: Predicted heads at the end of construction – south model

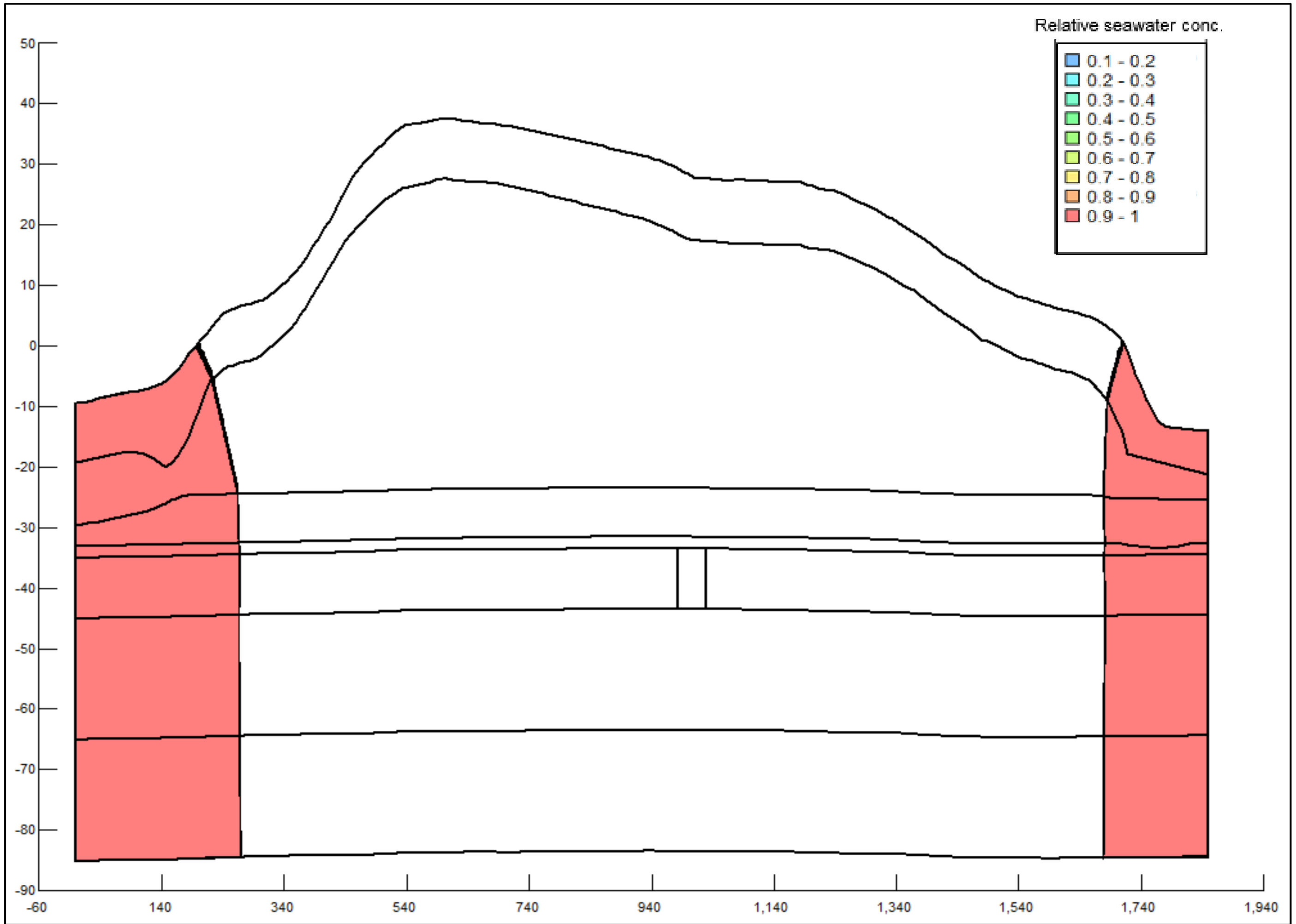


Figure 11-8: Predicted relative seawater concentration at the end of construction – south model

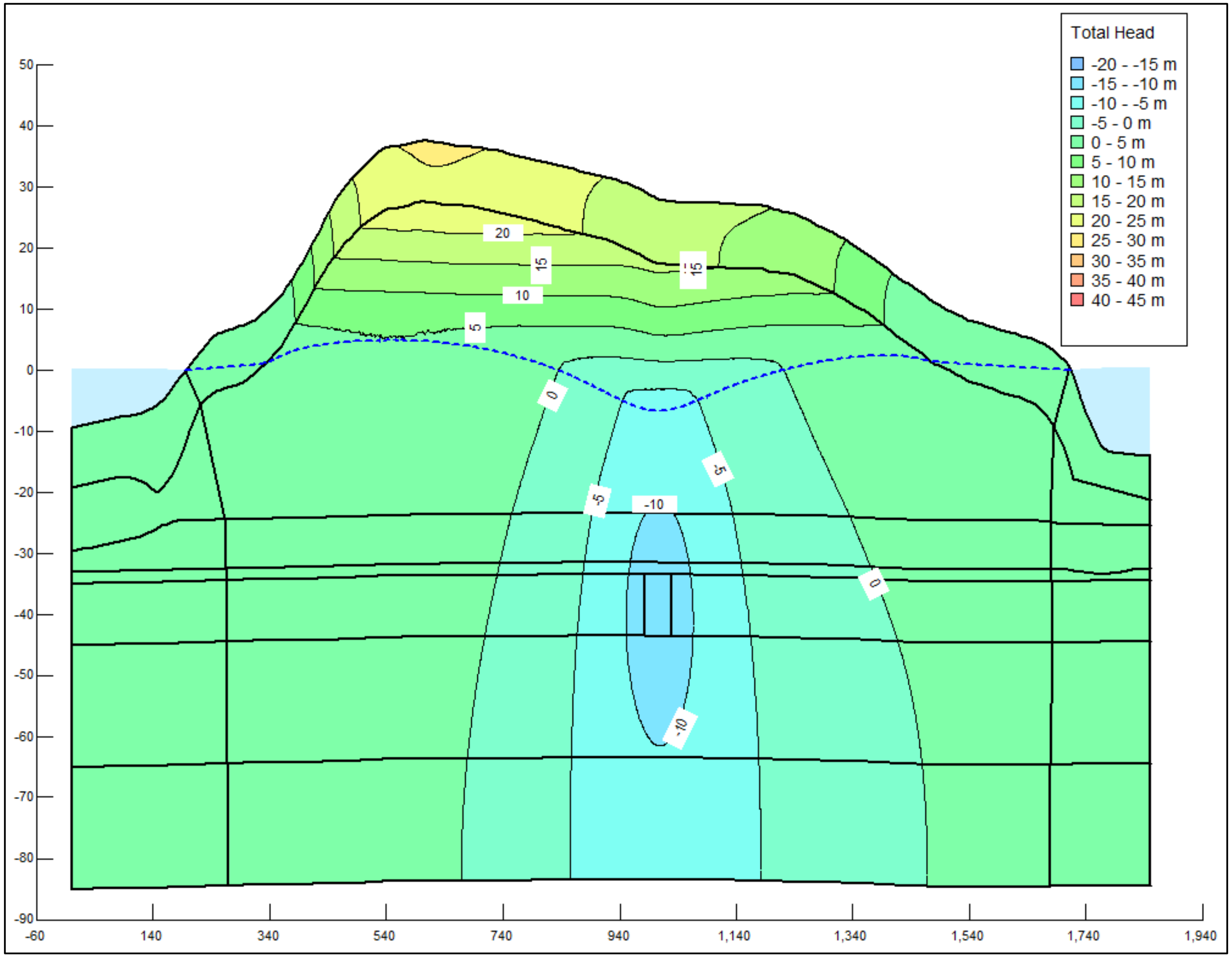


Figure 11-9: Predicted heads after 100 years of operation – south model

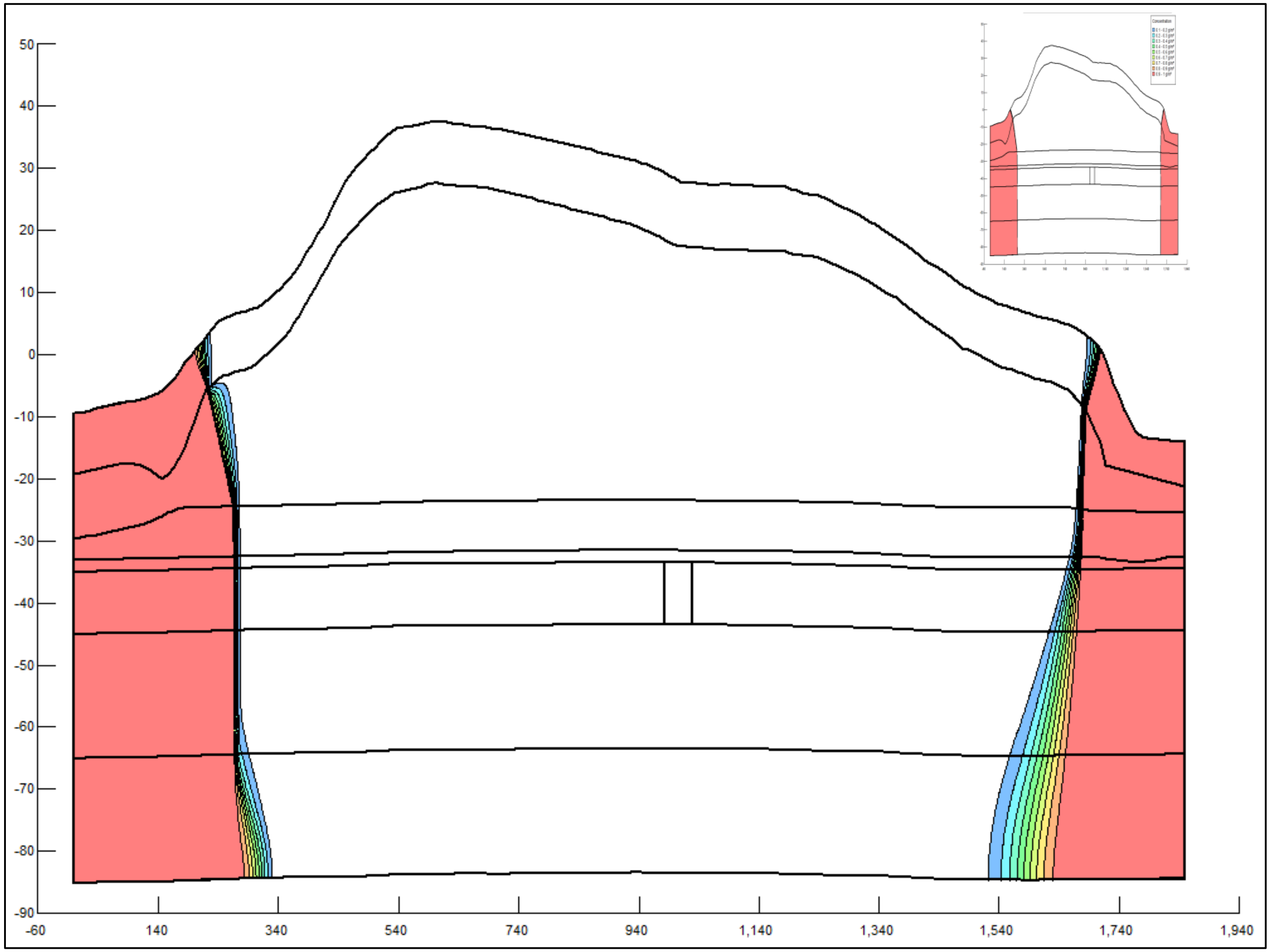


Figure 11-10: Predicted relative seawater concentration after 100 years of operation – south model

11.4 Saline Water Intrusion Assessment – North Model Cross-section

Groundwater sampling indicates that saline water currently occurs along some areas of the proposed tunnel located north of Sydney Harbour. The proposed tunnel design would incorporate water treatment for saline water in these saline water areas. There is, however, a potential for changes in groundwater quality to occur through saline water migration in areas where saline water does not currently occur. The aim of the saline water intrusion assessment was to assess the potential saline water intrusion at areas of maximum drawdown along a cross-section line located to the north of Sydney Harbour (Figure 11-1). The location of the cross section was selected to pass through the deepest part of the proposed Beaches Link Tunnel alignment. The cross-section line was also selected because the southern-end of the cross-section line is close to the outlet of Flat Rock Creek to the Harbour, where a potential groundwater dependent ecosystem has been identified.

11.4.1 Model Structure and Input Parameters

The seven hydrogeological layers defined in the three-dimensional MODFLOW-USG model representing variably weathered zones within the Hawkesbury Sandstone were also represented in the SEEP/W two-dimensional model as shown in Figure 11-11. The saturated hydraulic conductivity values assigned to the SEEP/W model were the same hydraulic conductivity values assigned to the three-dimensional MODFLOW-USG model. The ratios of horizontal to vertical hydraulic conductivity (k_h/k_v) for the model layers were also the same as ratios applied to the MODFLOW-USG model.

11.4.1.1 Hydraulic Conductivity Functions (SEEP/W)

Model Layer 1 to Model Layer 5 were modelled as saturated/unsaturated layers because the layers have the potential to become partially saturated during the model simulation. Hydraulic conductivity functions defined for model Layer 1 to Layer 5 to simulate the decrease in hydraulic conductivity that occurs due to increasing desaturation are presented in Annexure 10. The saturated hydraulic conductivity assigned to the hydraulic conductivity function for each layer was based on hydraulic conductivity values assigned to the layer in the calibrated three-dimensional MODFLOW-USG model. Model Layer 6 and Layer 7 were modelled as saturated layers for the entire simulation. Therefore, only the saturated hydraulic conductivity of 6.9 x 10^{-8} m/s (6.0 x 10^{-3} m/day) was used in simulations for these two layers

11.4.1.2 Coefficient of Volume Compressibility (SEEP/W)

Coefficient of volume compressibility (*mv*) values applied to the North cross-section model were similar to *mv* values assigned to the South Cross-section model (Table 11.1)

11.4.1.3 Water Content Functions (SEEP/W)

Water content functions applied to the North cross-section model were the same as functions applied to the South cross-section model.

11.4.1.4 Head and Flux Boundary Conditions (SEEP/W)

Head and flux boundary conditions assigned to the SEEP/W model are shown in Figure 11-12 and list below:

Constant head boundary conditions of 0 m were assigned along the harbours to the right and left of the model.

- Constant Total Flux (Q) boundary condition were assigned to nodes around the tunnel to simulate the tunnel groundwater discharge. The maximum predicted tunnel inflow rate for the North Model was approximately 1.7 L/s/km (Table 7.3). This translates to a total combined flow at the flux boundary nodes of -1.7 x 10^{-6} m^3/s/m.
- A constant Unit Flux (q) boundary condition of 1.94 x 10^{-9} m/s was used to represent groundwater recharge, based on results from the 3D MODFLOW-USG model.
- The bottom of the model was assigned as no-flow boundary.

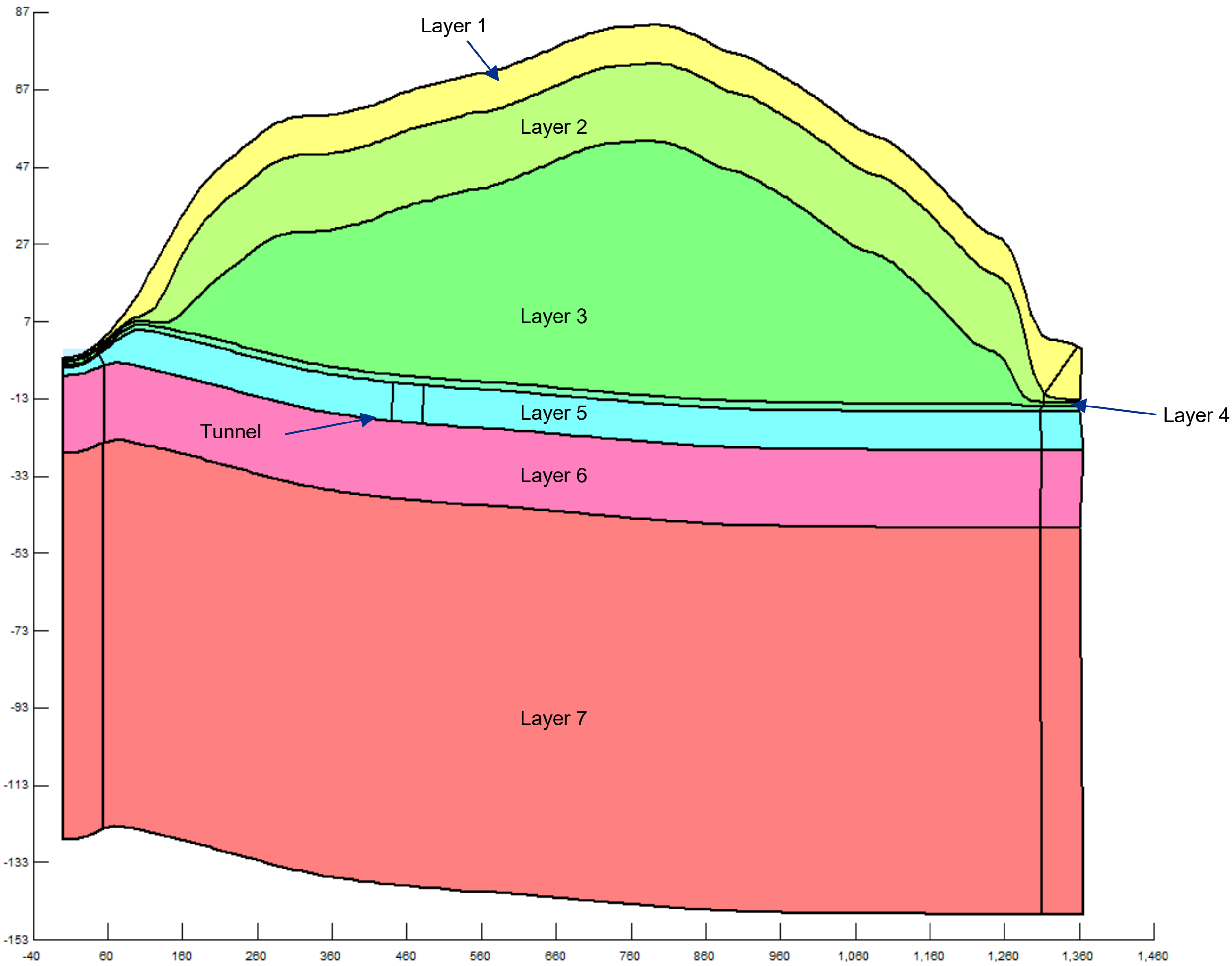


Figure 11-11: Hydrogeological layer in north cross section model

11.4.1.5 CTRAN/W Model Input Parameters

Constant concentration boundary conditions of 1.0 (i.e. seawater) were assigned to the CTRAN/W model along the inferred current location of the freshwater/seawater interfaces to the left and right of the model (Figure 11-12).The locations of the freshwater/seawater interfaces were defined based on the Ghyben-Herzberg principle, which states the depth to the freshwater/saline water interface below sea-level is approximately 40 times the height of the groundwater table above sea-level. The groundwater table elevation under existing conditions was obtained from model results from the pre-construction SEEP/W steady state model (Section 11.4.2).

Freshwater located between the left-hand-side and right-hand-side of the freshwater/saline water interfaces was assigned an initial relative concentration of 0 g/m^3.

Dispersivity and diffusion coefficient values applied to the North cross-section model were the same as the parameter values assigned to the South cross-section model (Section 11.3.1.5) based on the similarity of the hydrogeology along both cross-sections.

11.4.2 Results – North Cross-sectional Model

Figure 11-14 shows the model-predicted pre-construction total hydraulic head distribution and water table elevation (in blue) along the cross section. Figure 11-5 shows the predicted pre-construction relative seawater concentrations. Figure 11-15 shows the location of the sharp initial sharp freshwater-saline water interfaces that have been simulated in the model.

Figure 11-16 shows the total head distribution and water table elevation along the cross section at the end of the Beaches Link project construction. Figure 11-17, presenting the predicted relative seawater concentrations at the end of the construction period, indicates that both the lateral and upward movement of the freshwater-saline water interface along the modelled cross-section would be negligible over the construction period of the Beaches Link project.

Figure 11-18 and Figure 11-19 show the heads and relative seawater concentrations, respectively, after 100 years of Beaches Link project operation. Figure 11-19 indicates that the maximum lateral movement of saline water towards inland areas, over the 100-year simulation is negligible.

The modelled cross-section location was selected for the following reasons:

- The section passes through the deepest section of the proposed Beaches Link project tunnel alignment; and
- The southern-end of the cross-section line is close to the outlet of Flat Rock Creek to the Harbour, where a potential groundwater dependent ecosystem has been identified within the Flat Rock Creek catchment area.

The negligible saline water intrusion impacts predicted from the modelling are considered to be due to the distance between the proposed tunnel and the location of the inferred initial seawater/freshwater interface.

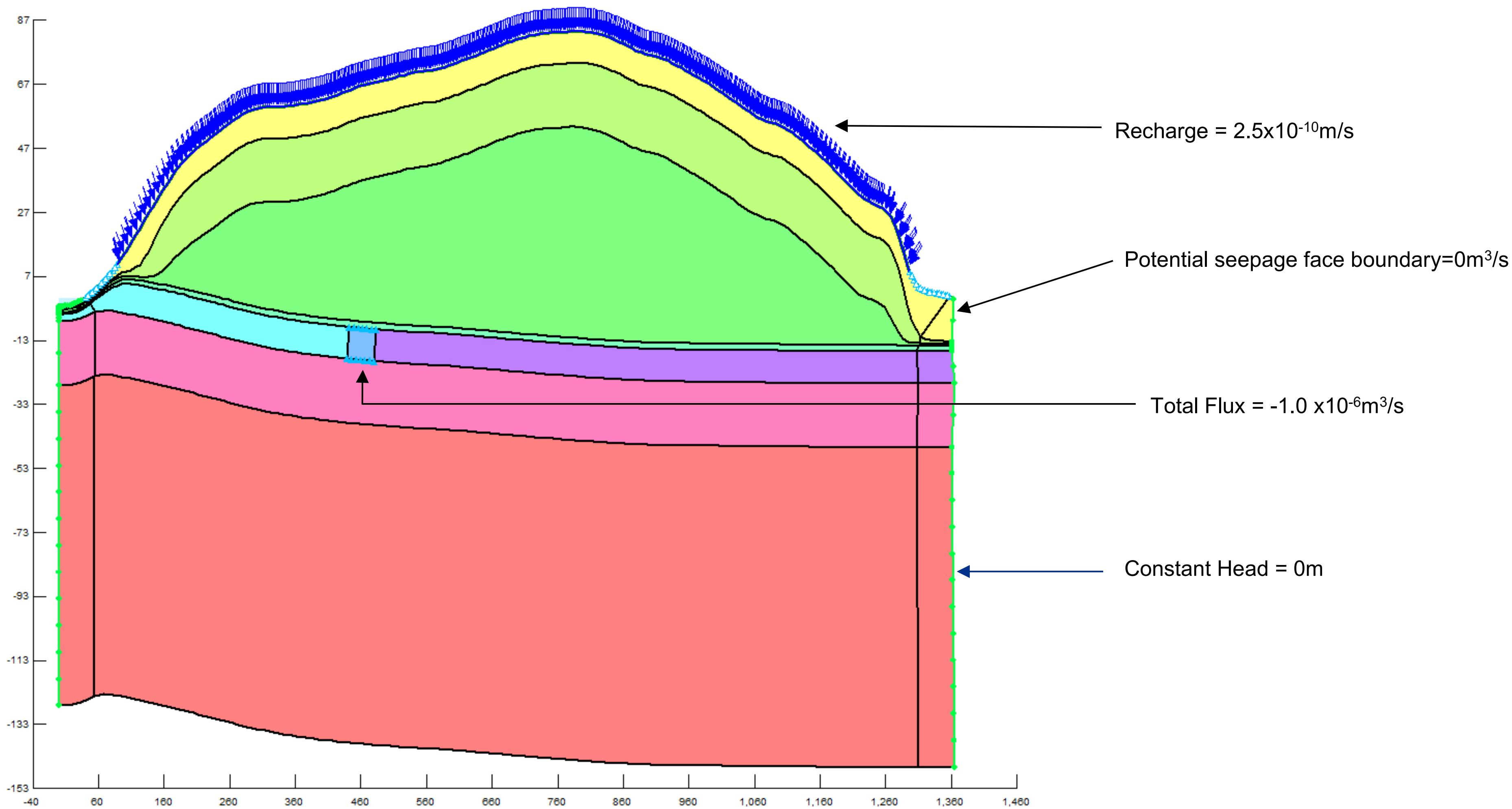


Figure 11-12: Head and flux boundary conditions – north SEEP/W model

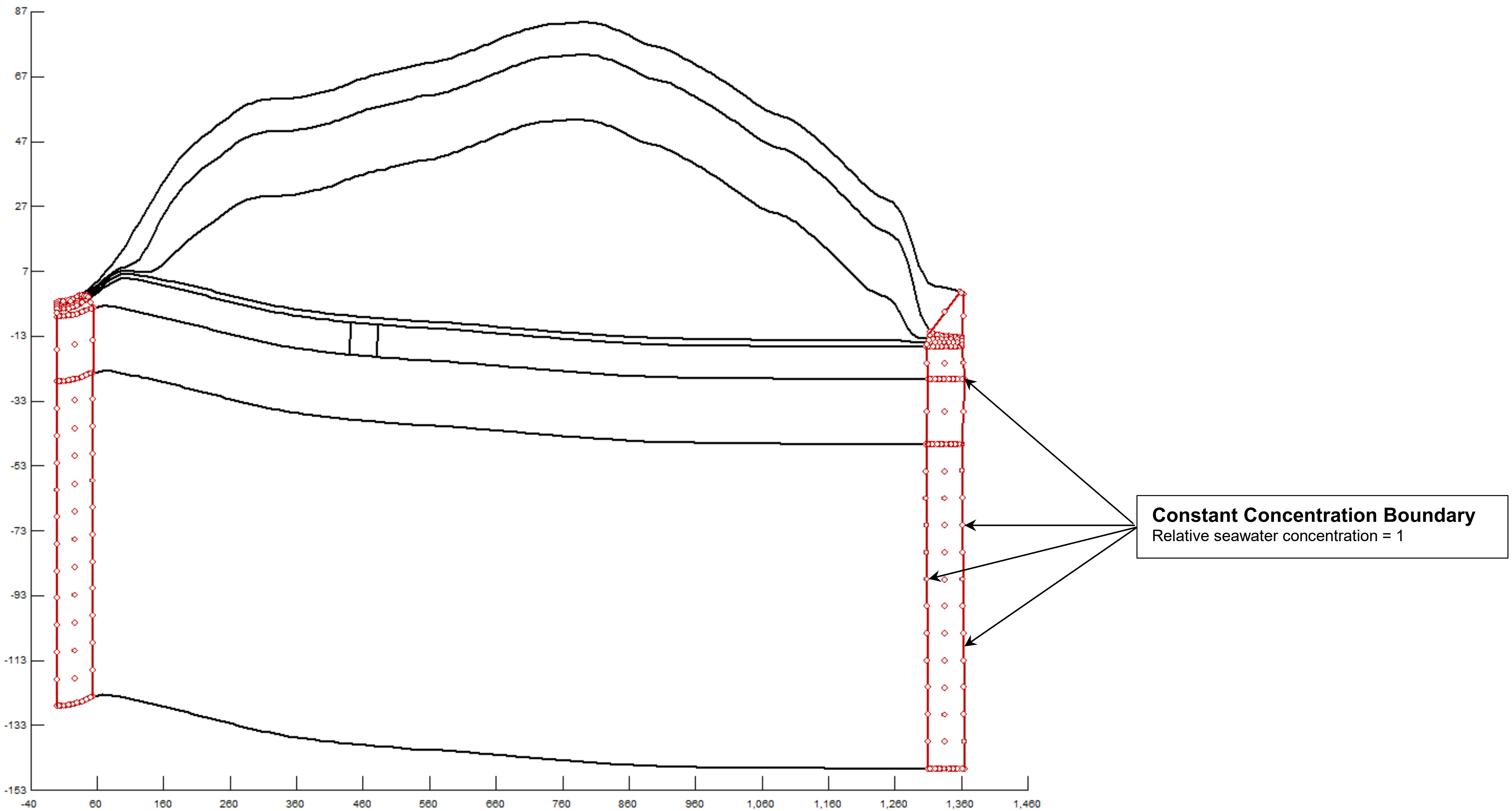


Figure 11-13: Constant unit relative seawater concentration boundary conditions – North CTRAN/W Model.

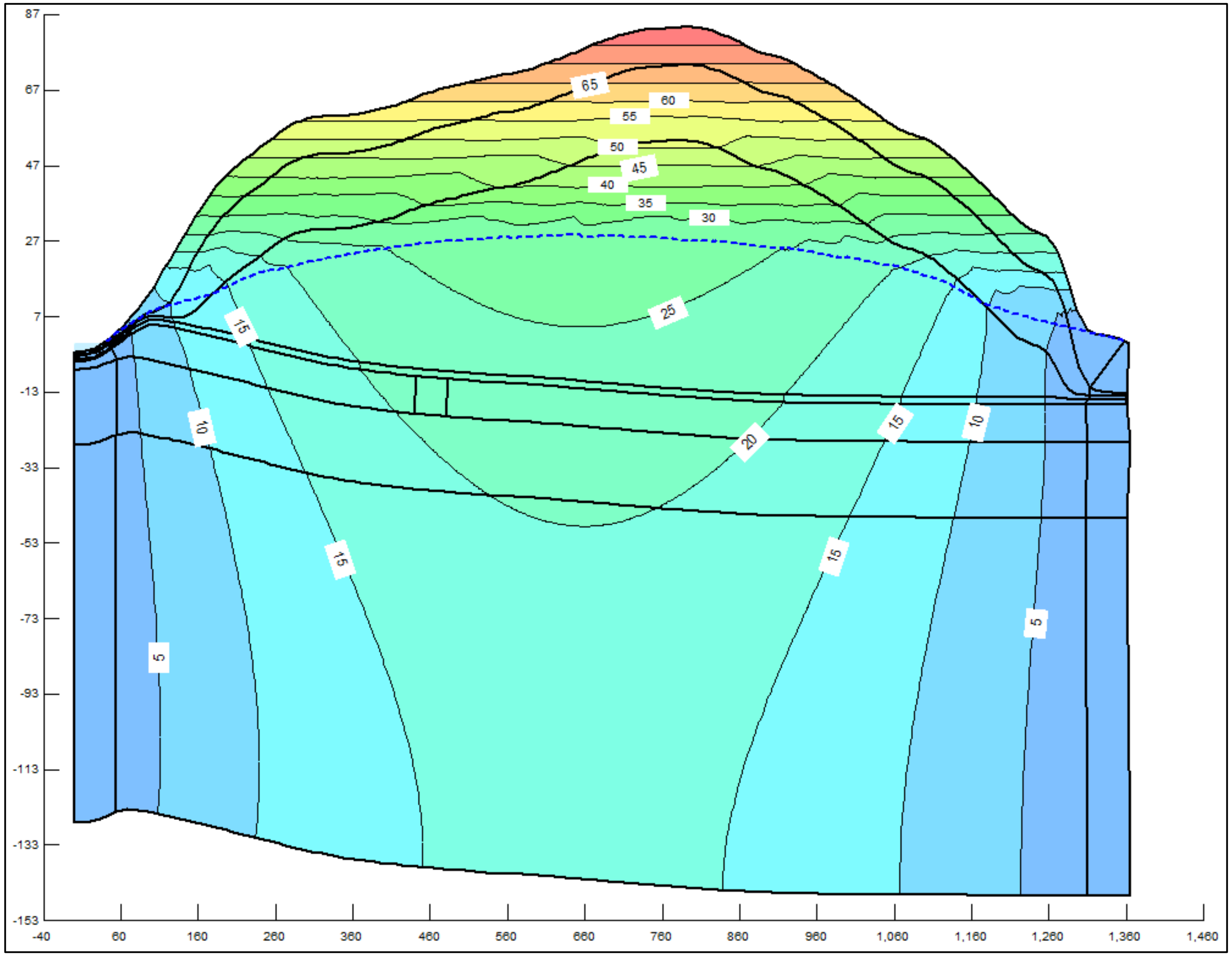


Figure 11-14: Predicted pre-construction heads – North Model

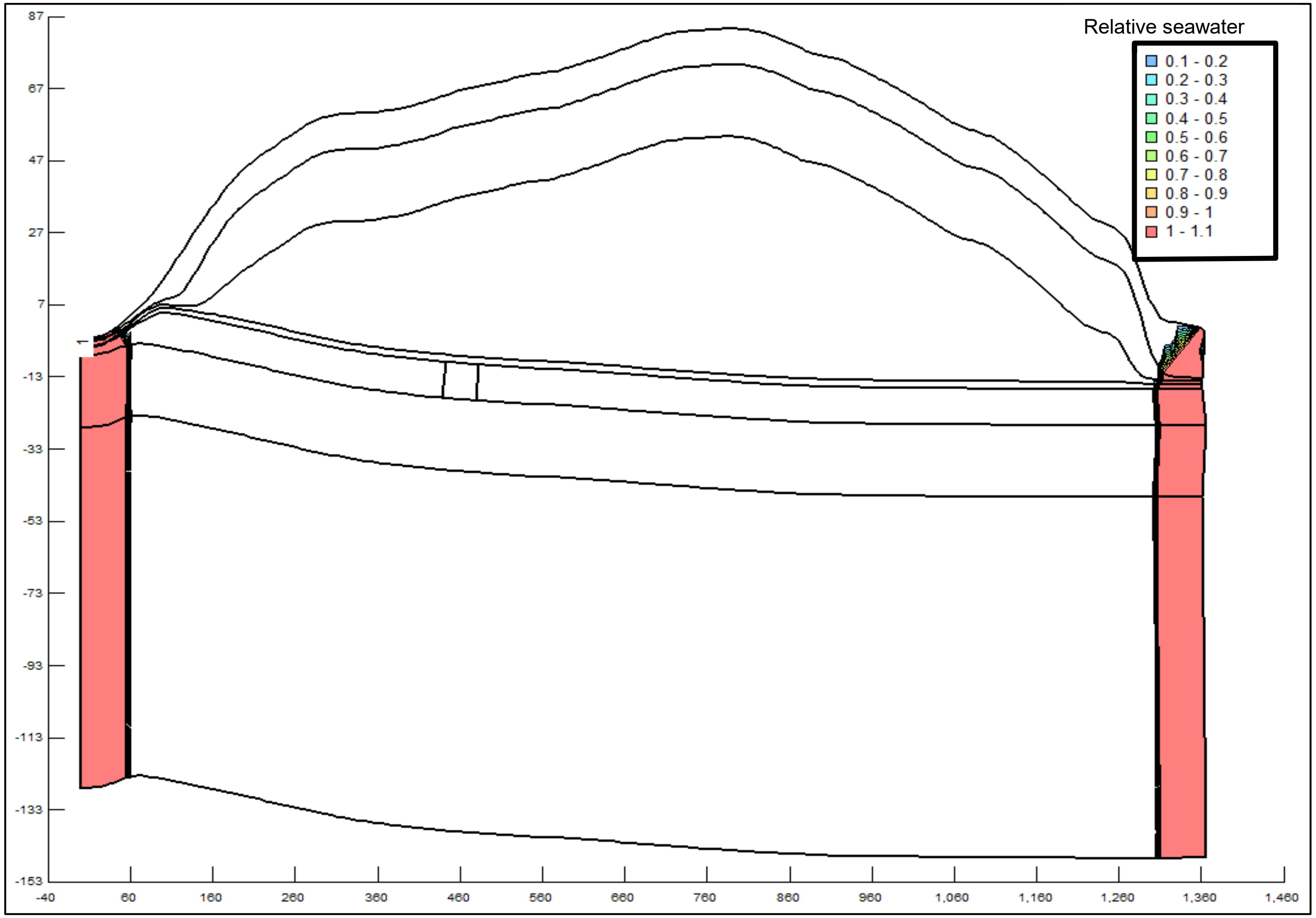


Figure 11-15: Predicted pre-construction relative seawater concentrations – North Model.

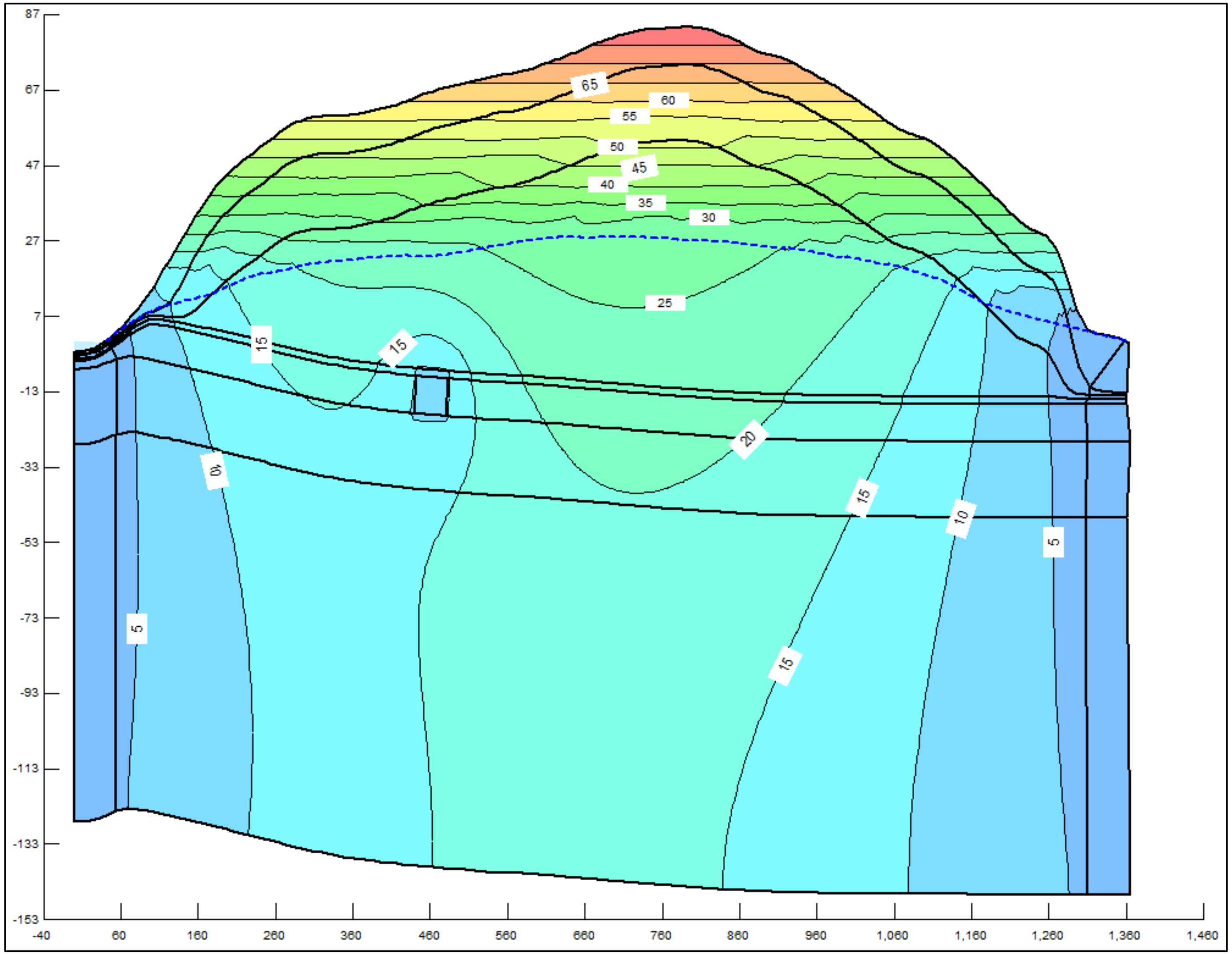


Figure 11-16: Predicted heads at end of construction – North Model

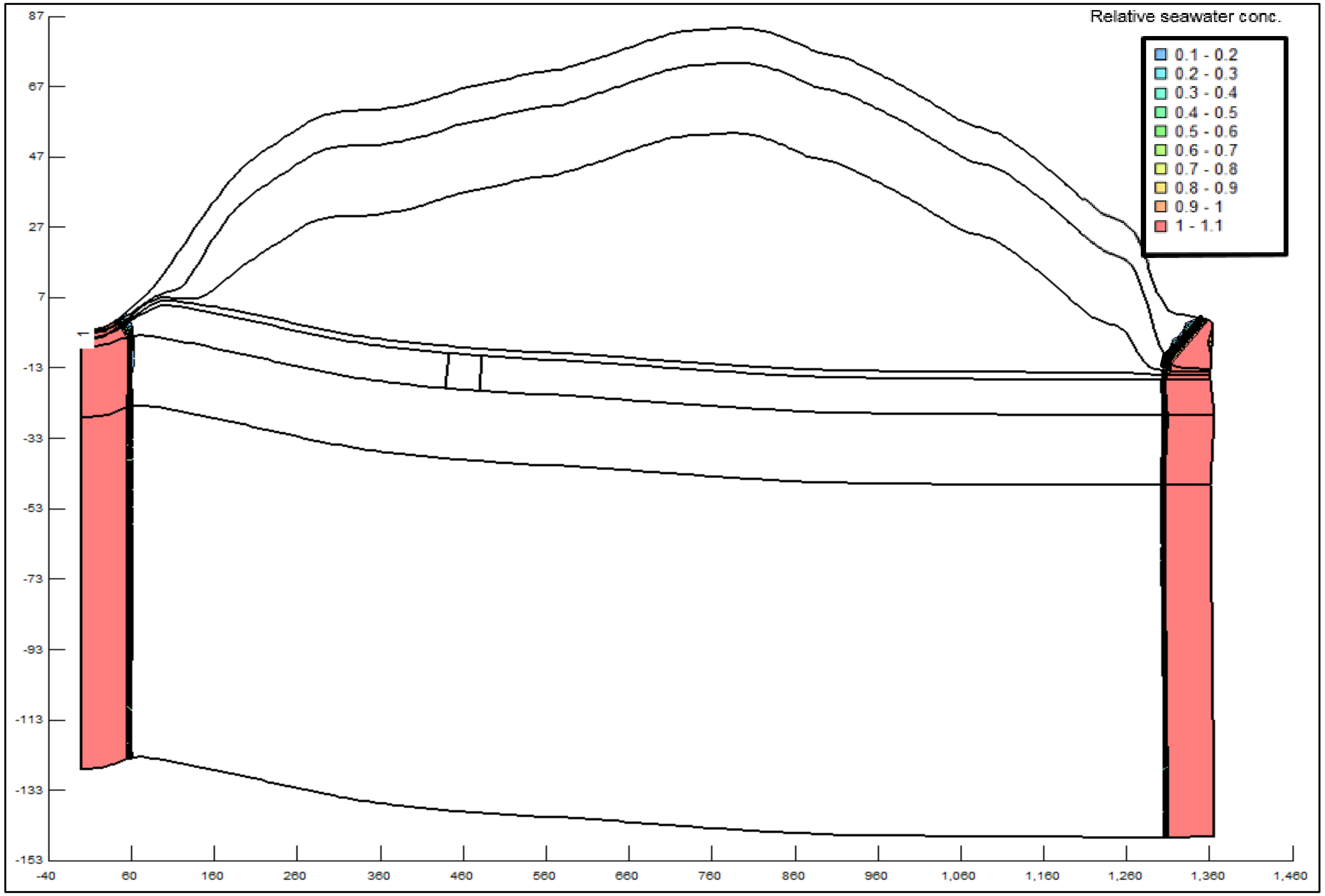


Figure 11-17: Predicted relative seawater concentrations at end of construction – North Model

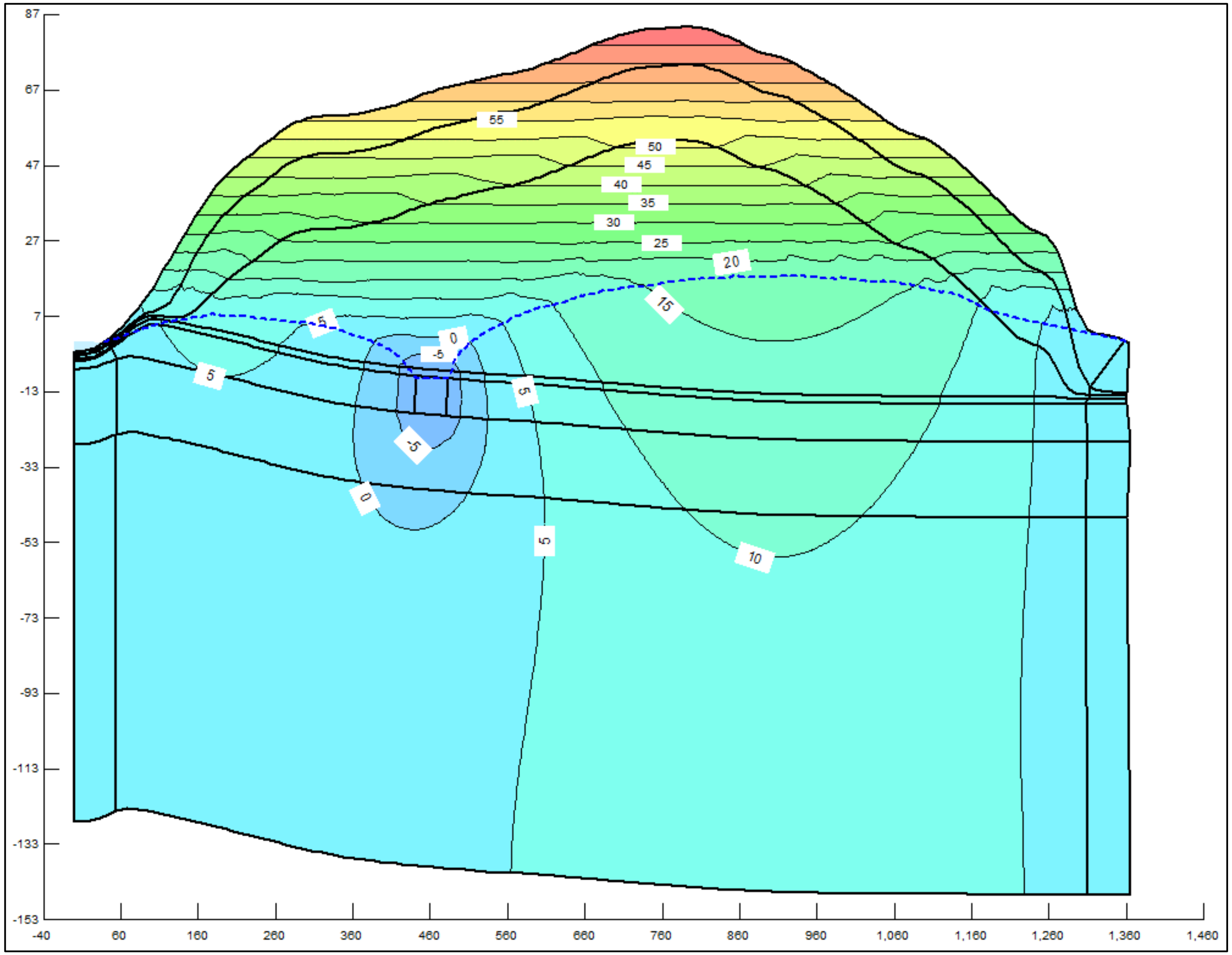


Figure 11-18: Predicted heads after 100 years of operation – North Model

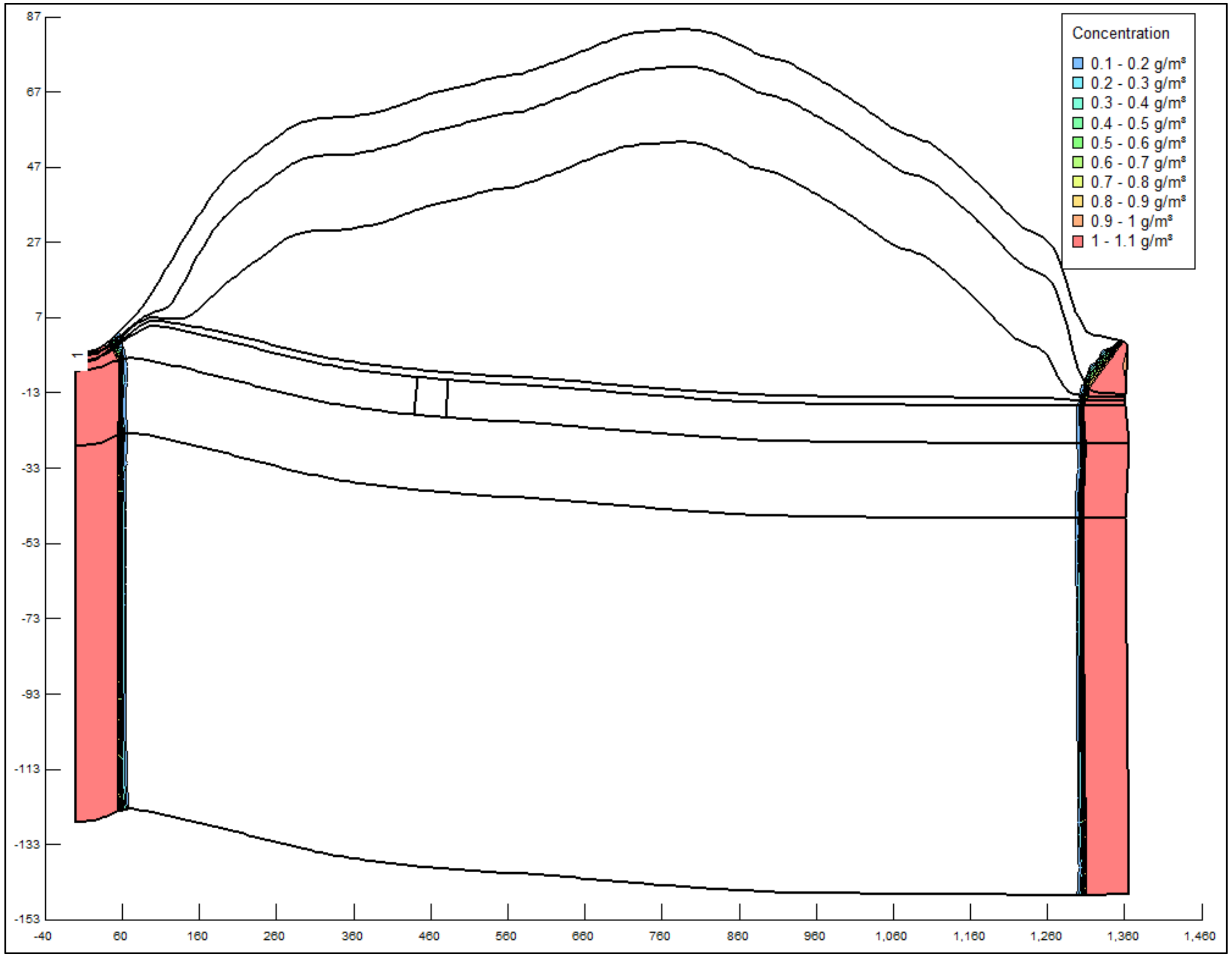


Figure 11-19: Predicted relative seawater concentrations after 100 years of operation – North Model

12. Modelling Limitations

The following sections describes the limitations associated with the modelling approaches used.

12.1 MODFLOW-USG 3D modelling

Predicted groundwater inflows and associated impacts are based on the design elements outlined in Section 0, which represent the ‘gold’ design version.

Field hydrogeological investigations carried out for the Western Harbour Tunnel and Beaches Link project have been carried out concurrently with the groundwater modelling. Hydraulic testing data and groundwater level monitoring collected after 1 December 2017 have not been included in the conceptual model development and model calibration.

Groundwater level data included in the model calibration, collected as part of the baseline investigations for the Western Harbour Tunnel and Beaches Link projects was for a monitoring period of less than one year. There is also very limited time-series groundwater level monitoring data from other projects. As a result, there is limited observation data that can be used to constrain storage parameters obtained from transient model calibration. If storability of geological formations in areas surrounding the proposed tunnel alignments is higher than values assigned to the predictive models, then actual initial tunnel groundwater inflows would be higher than predicted, however there should not be a significant real impact on long-term inflows to the tunnels.

Tidal variations of up to 1.5 metres, which occur on a bi-daily basis (HydroSimulations 2017) were not represented in the groundwater models. The monthly stress period adopted in the models precludes the simulation of tidal fluctuations. Therefore, it is assumed that the data used for calibration represents a median water level in areas that are tidally affected.

The groundwater models only include major tunnelling projects in the vicinity of the Western Harbour Tunnel and Beaches Link. The two other projects considered are the Rozelle Interchange section of the M4-M5 Link and the Chatswood to Sydenham Sydney Metro project. No other responses from pumping, dewatering activities or stormwater drainage channels have been assessed during the groundwater modelling.

The North Model and South Model were developed primarily for predicting groundwater drawdown and tunnel inflows for the purposes of assessing environmental impacts on surface water sources, their dependent ecosystems and existing licensed water users. The groundwater modelling described in this report is a regional scale investigation and more detailed site-specific analyses may be required to support detailed design.

The effect of sea level rise on coastal groundwater levels was not considered in the groundwater modelling assessments. However, given that the upper forecast for sea level rise around Sydney is approximately one metre by 2100. A variation of that magnitude is not considered material given the uncertainties in the groundwater modelling, particularly over the timeframe that sea level rise would be realised.

12.2 CTRAN/W-SEEP/W 2D modelling

The two-dimensional CTRAN/W-SEEP/W modelling was carried out along representative sections selected from the Western Harbour Tunnel project and Beaches Link project to provide indicative rates of the lateral and upward movement of the saline water interface due to the Western Harbour Tunnel and Beaches Link projects. The results of the modelling assessment do not provide an assessment of the maximum (cumulative) saline water intrusion impacts due to all of the projects.

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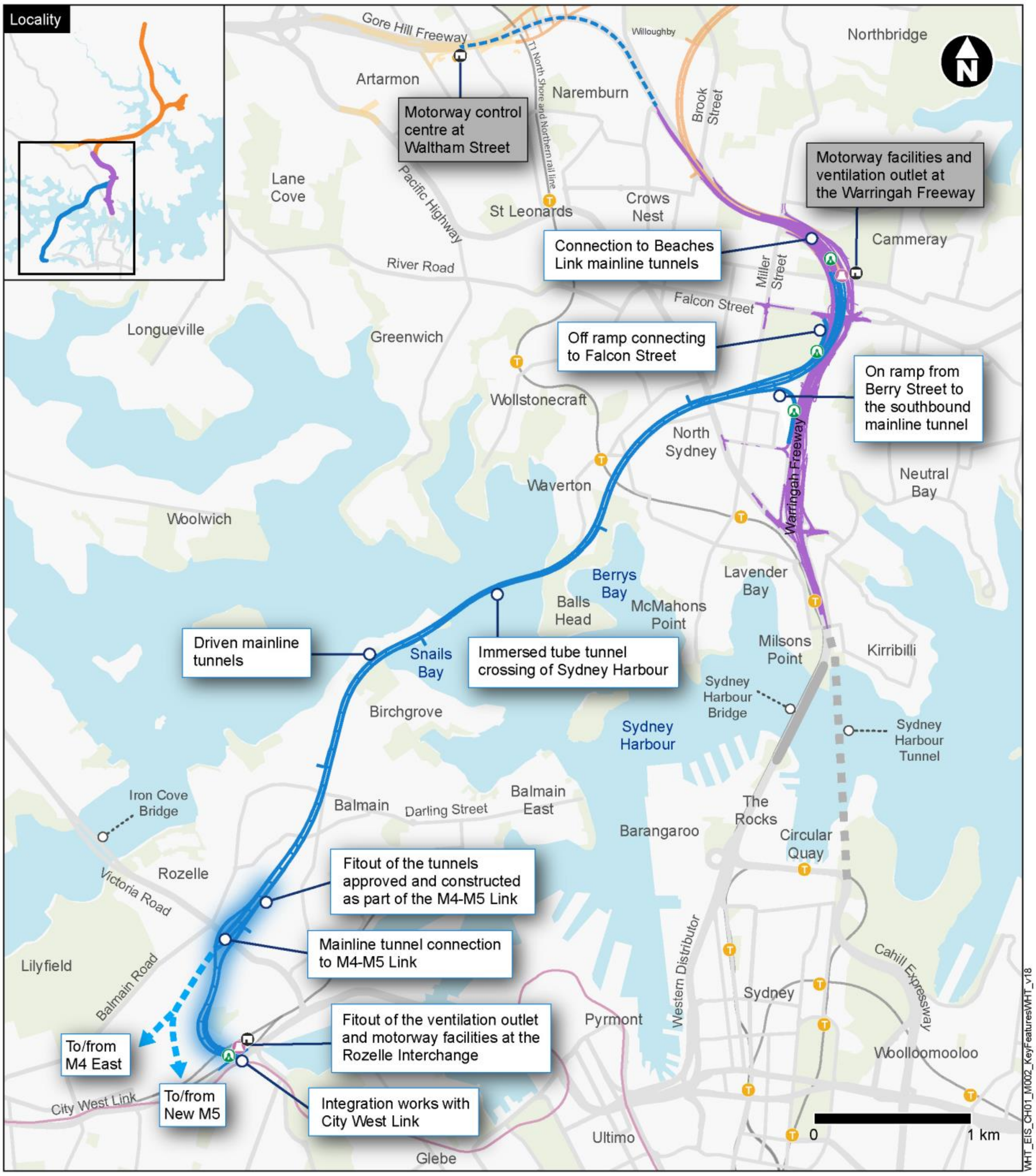
Annexure 1. Additional Figures



Legend

Operational features
- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Communications cable for motorway control centre
- M4-M5 Link tunnel fitout and commissioned as part of Western Harbour Tunnel
- Surface connection
- Permanent operational facility
- Ventilation outlet

Connecting projects
- Beaches Link
- Gore Hill Freeway Connection
- M4-M5 Link connections (indicative)

Existing rail network
- Heavy rail
- Light rail
- Train station

Figure A1-1 Key features of the Western Harbour Tunnel Project

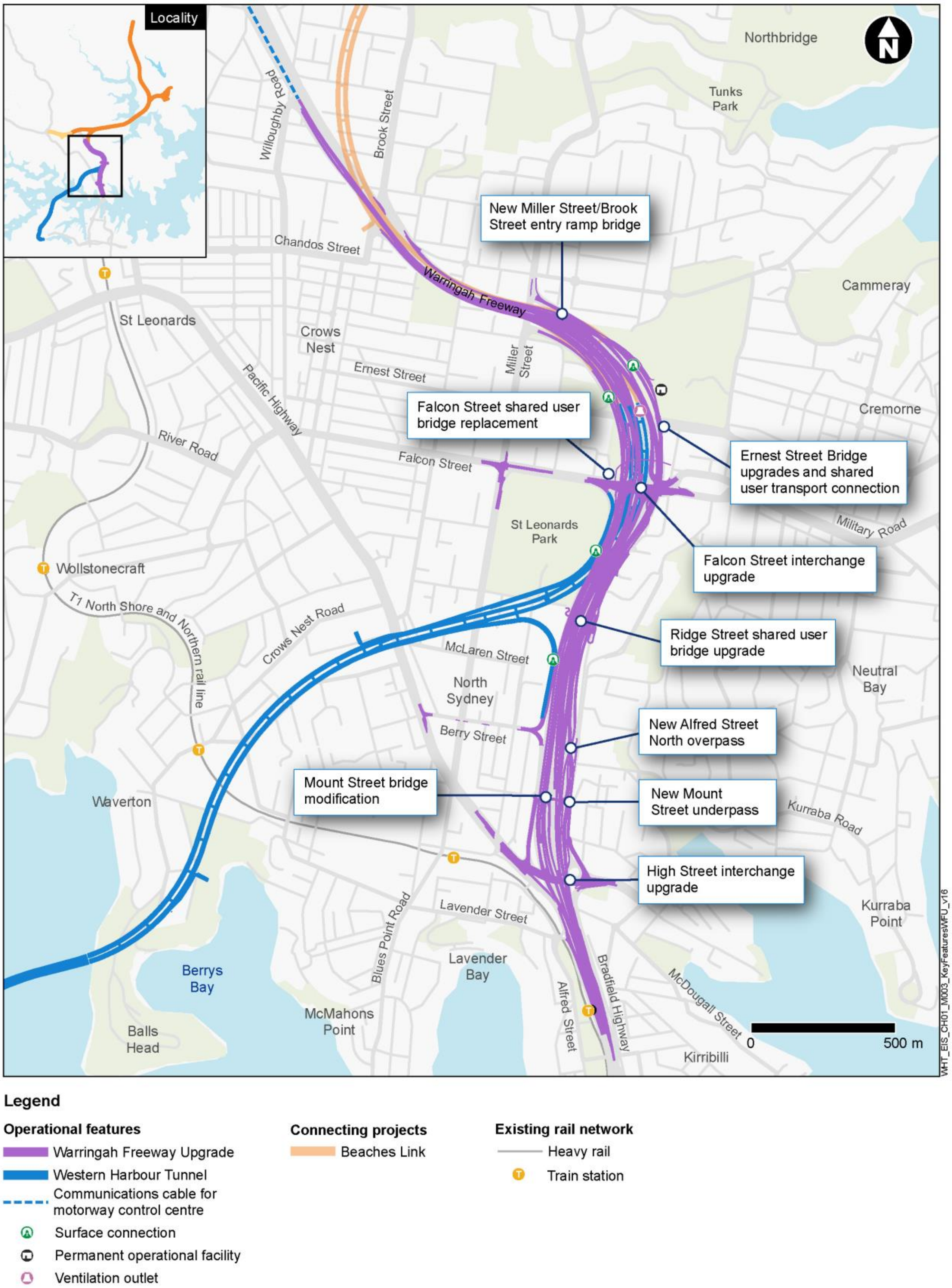


Figure A1-2. Key features of the Warringah Freeway Upgrade Project.

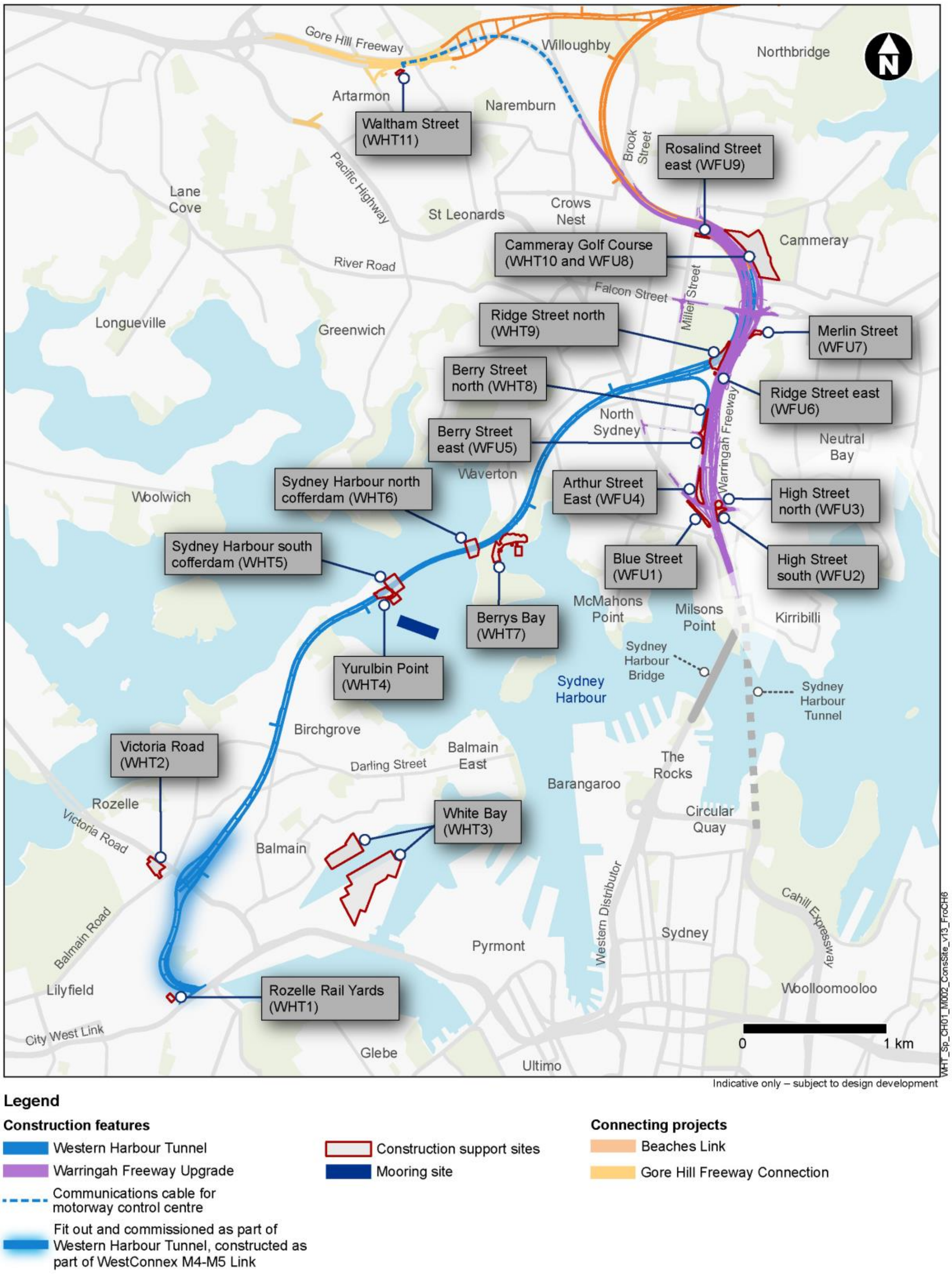


Figure A1-3. Overview of construction support sites for the Western Harbour Tunnel and Warringah Freeway Upgrade Project.

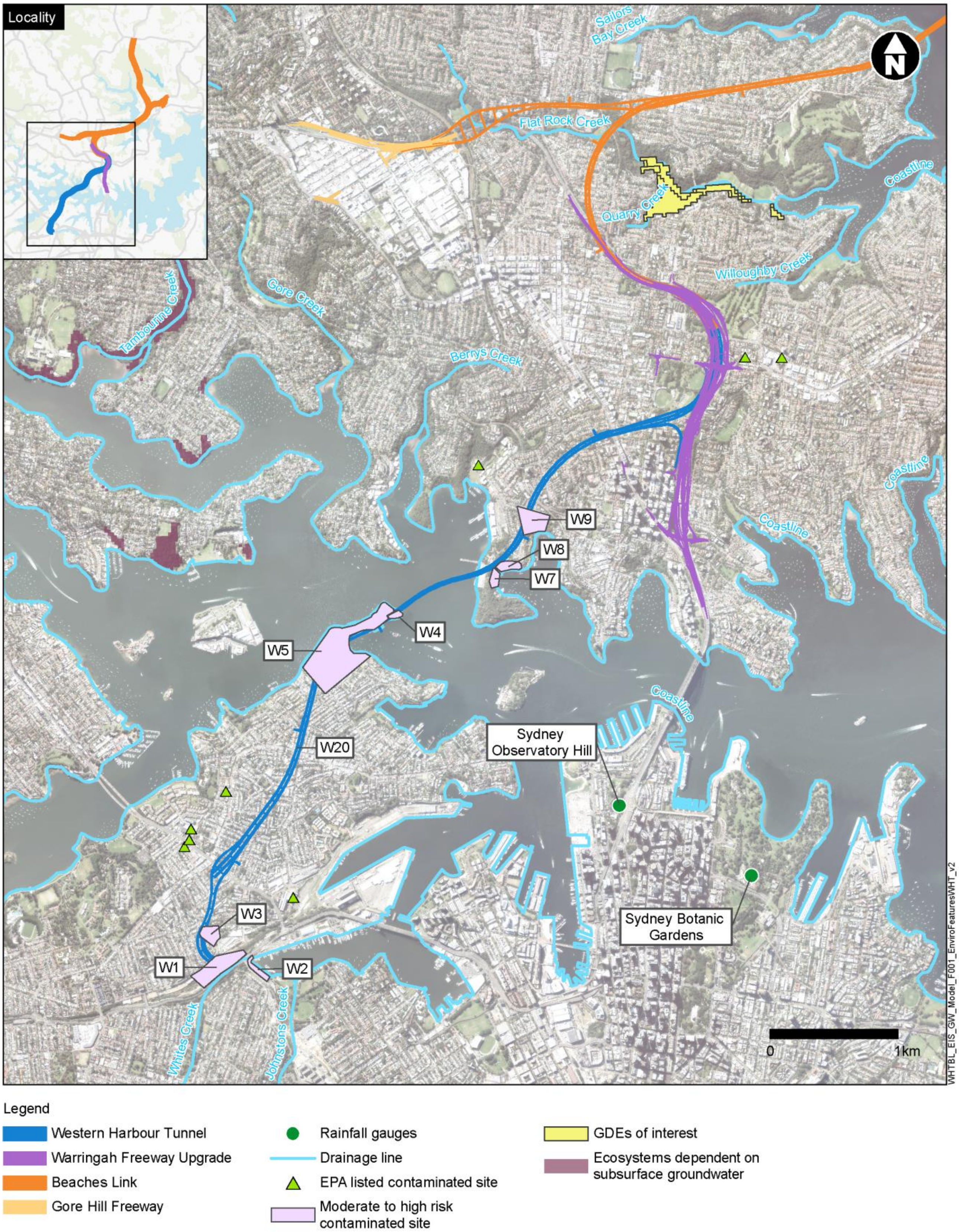


Figure A1-4. Location of rain gauge sites and other project and environmental features – Western Harbour Tunnel Project area.

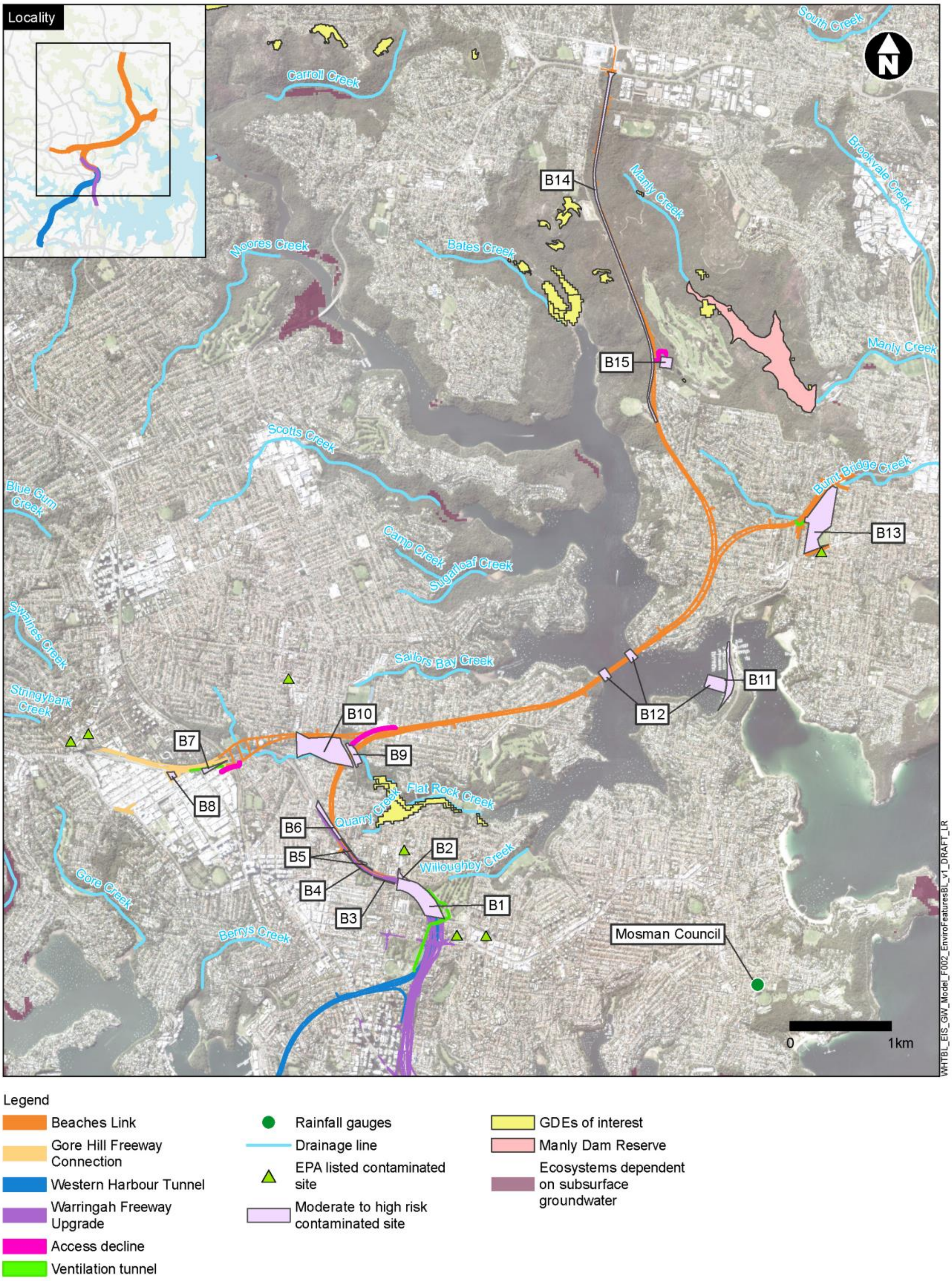


Figure A1-5. Location of rain gauge sites and other project and environmental features – Beaches Link Project area

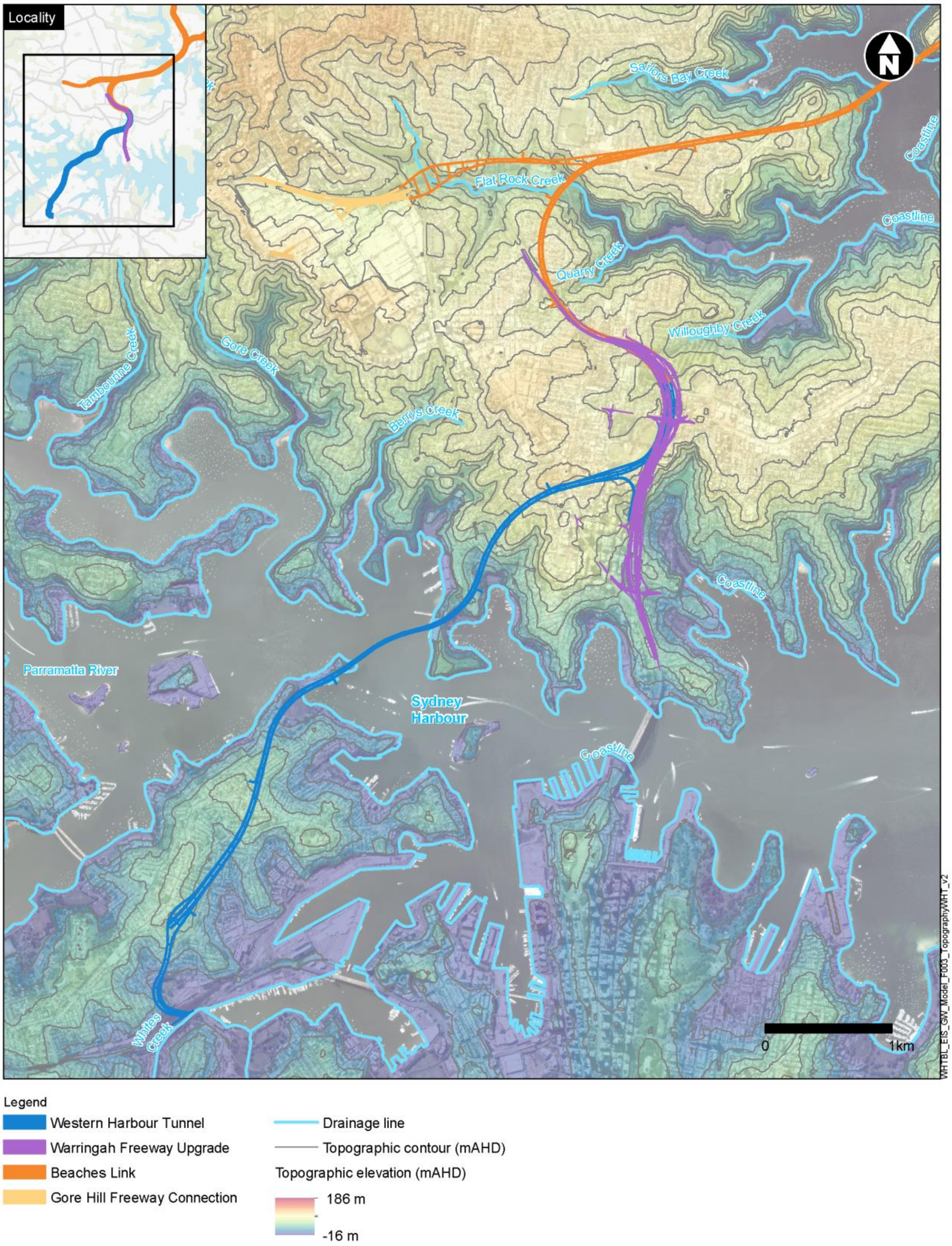


Figure A1-6. Topography and drainage – WHT Project area

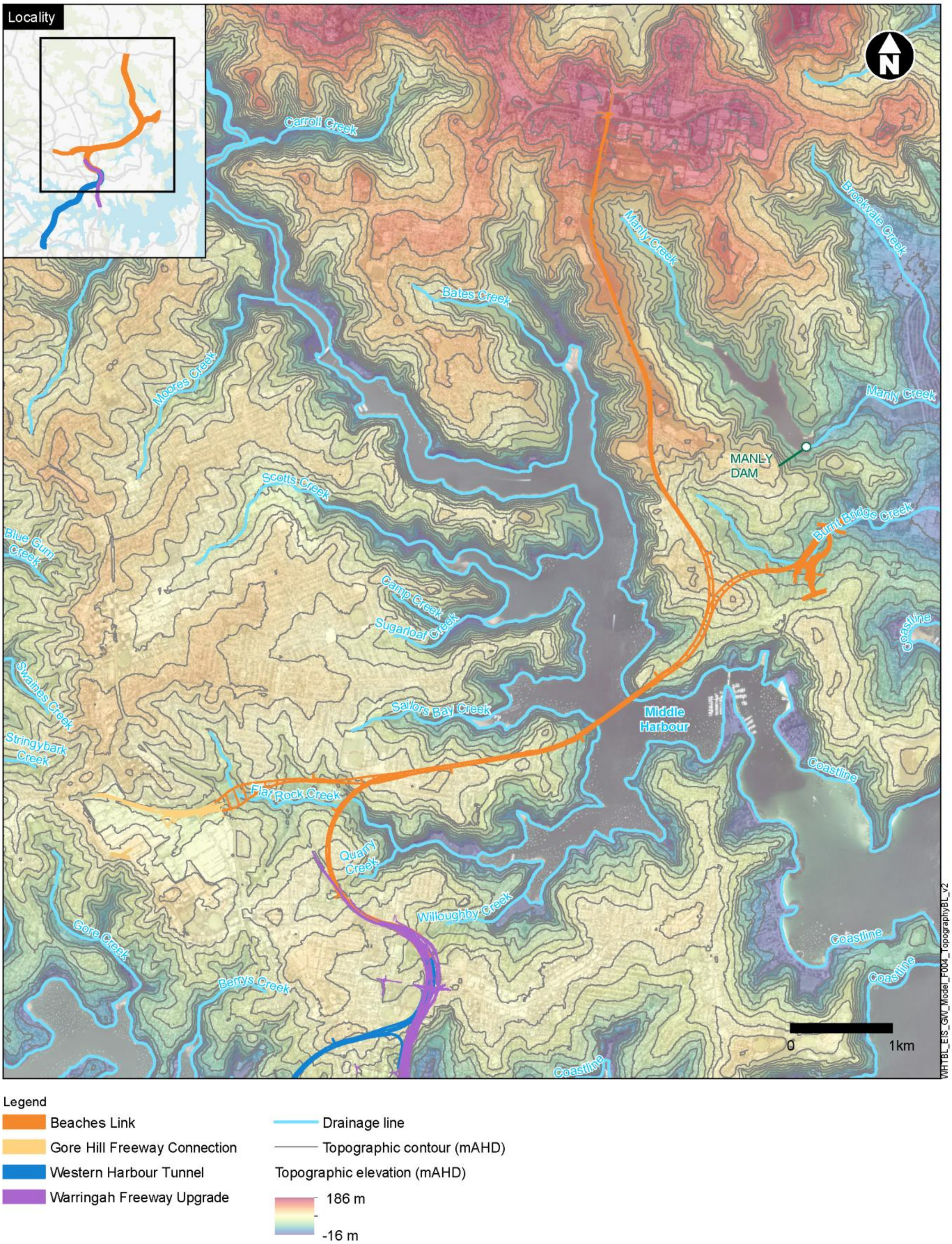


Figure A1-7. Topography and drainage - BL Project area

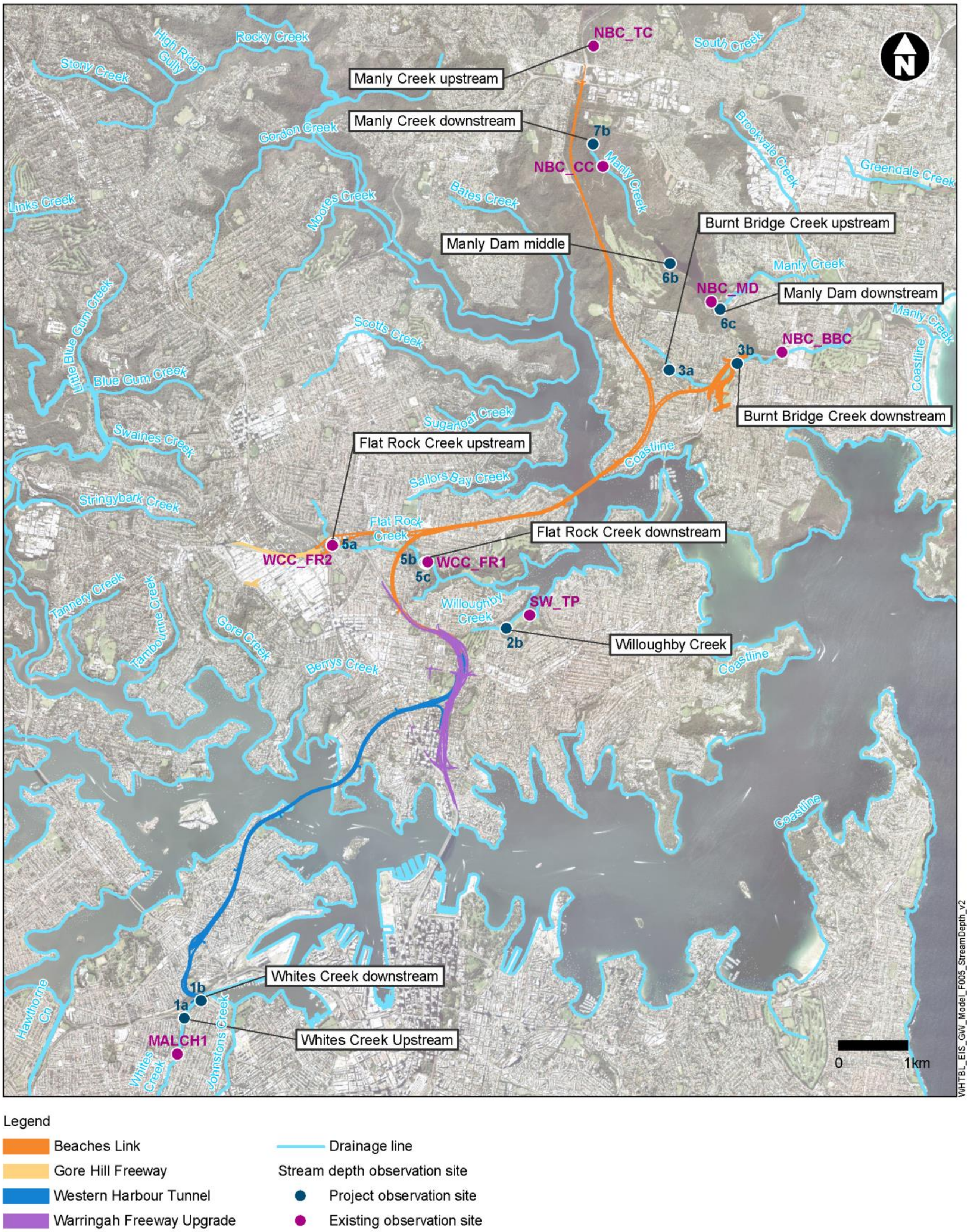


Figure A1-8 Location of stream water depth observation sites

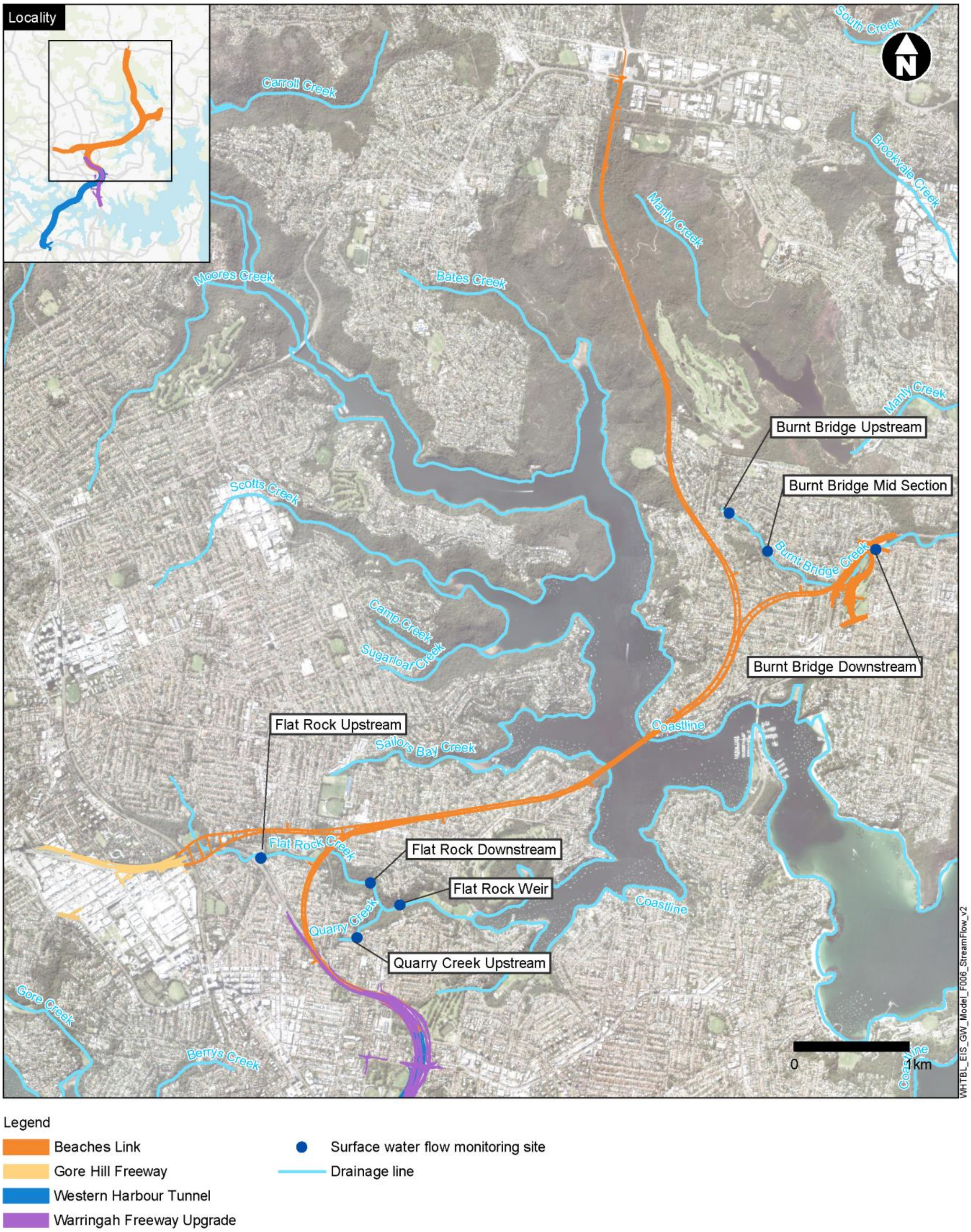


Figure A1-9. Location of streamflow measuring sites

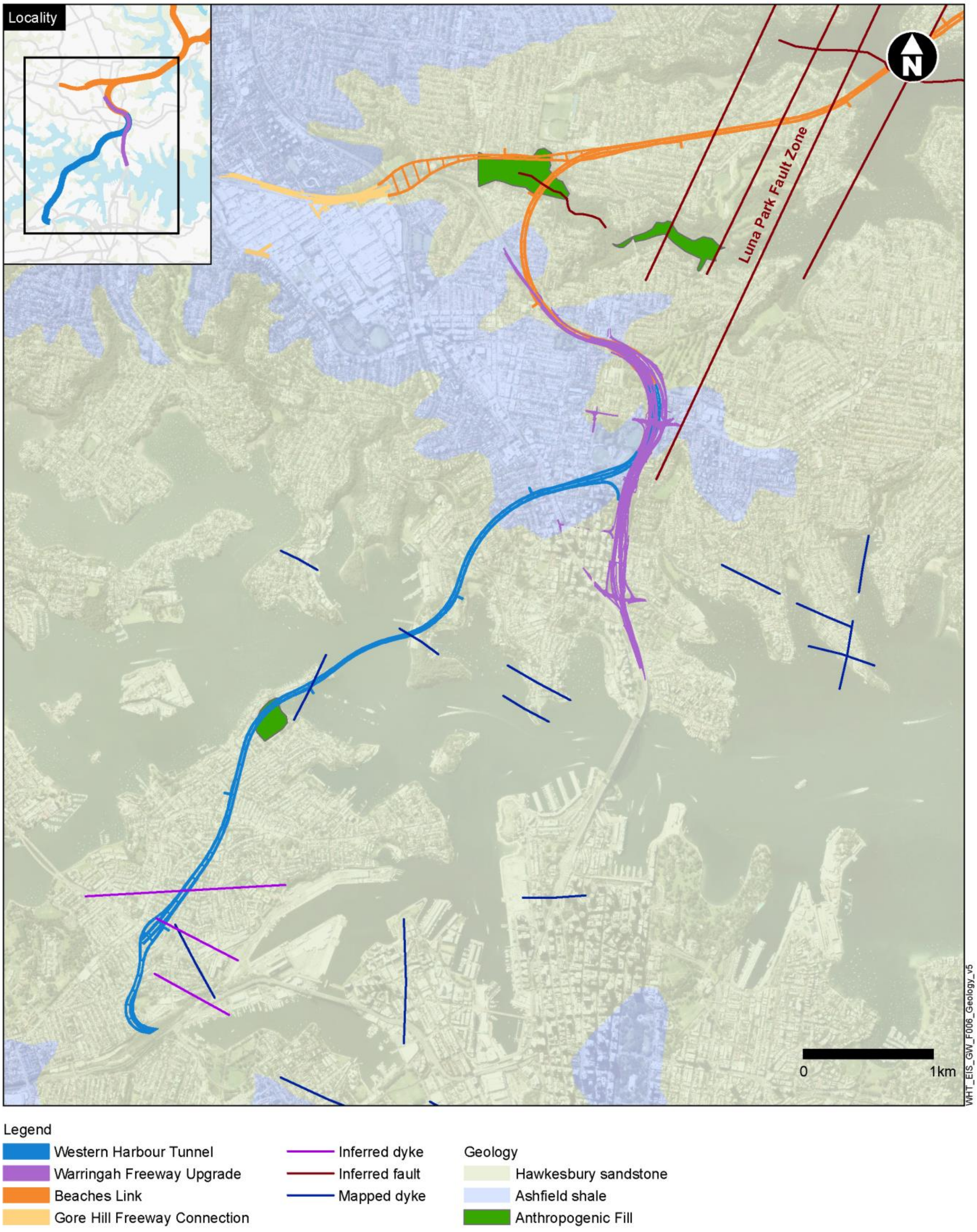


Figure A1-10. Geology of Area

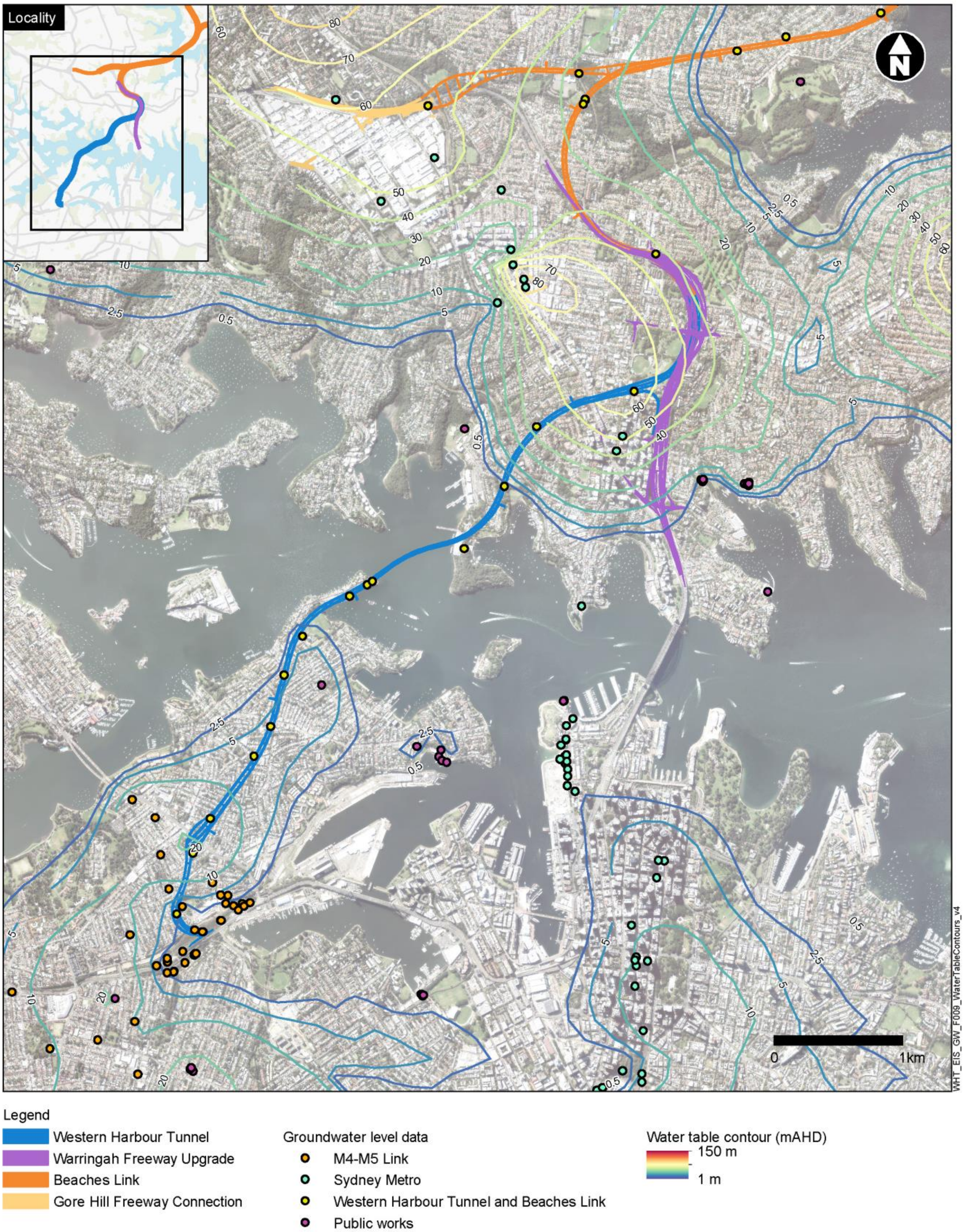


Figure A1-11 Groundwater table contour

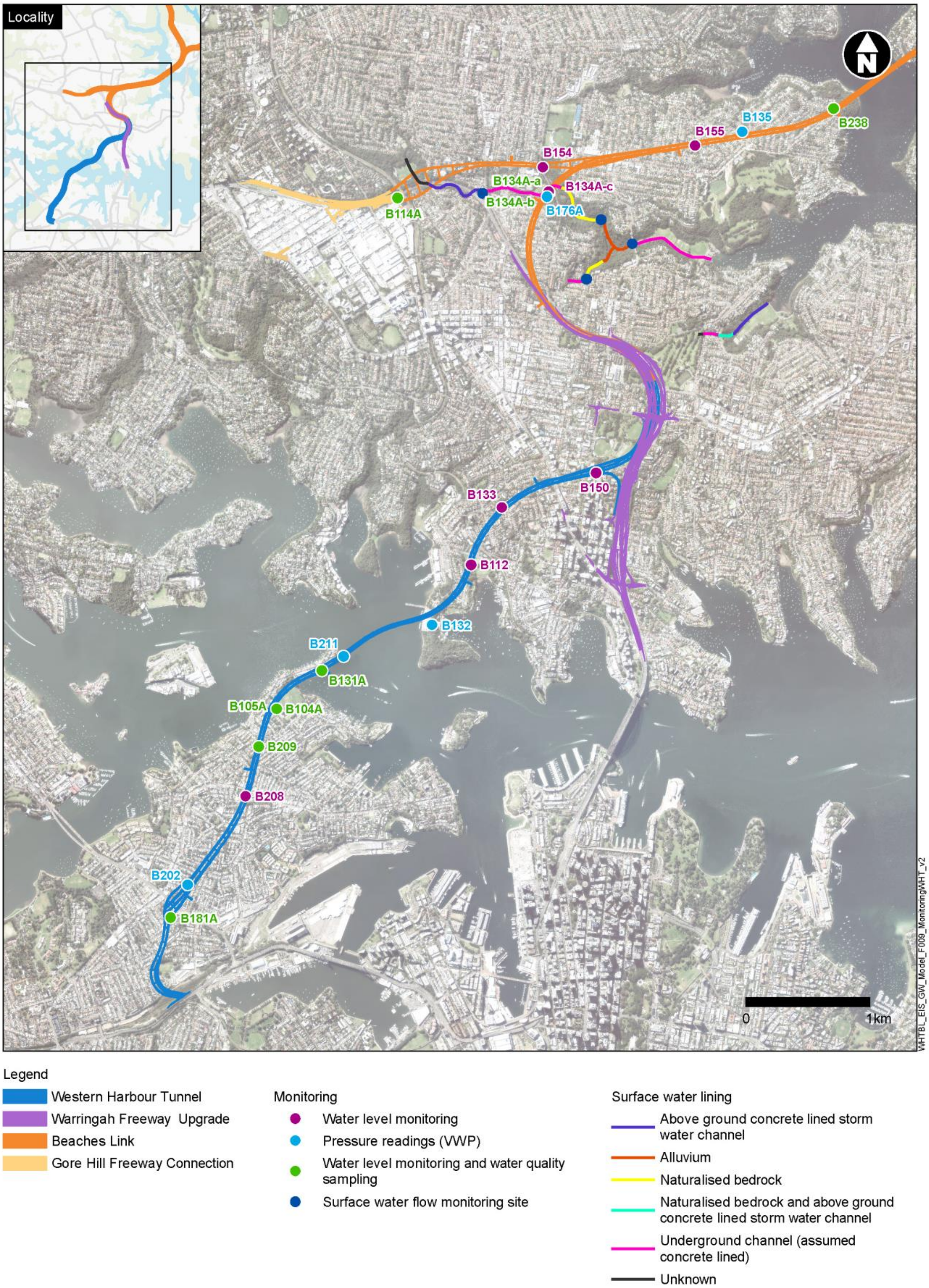


Figure A1-12. Groundwater level monitoring and packer testing locations – WHT Project area

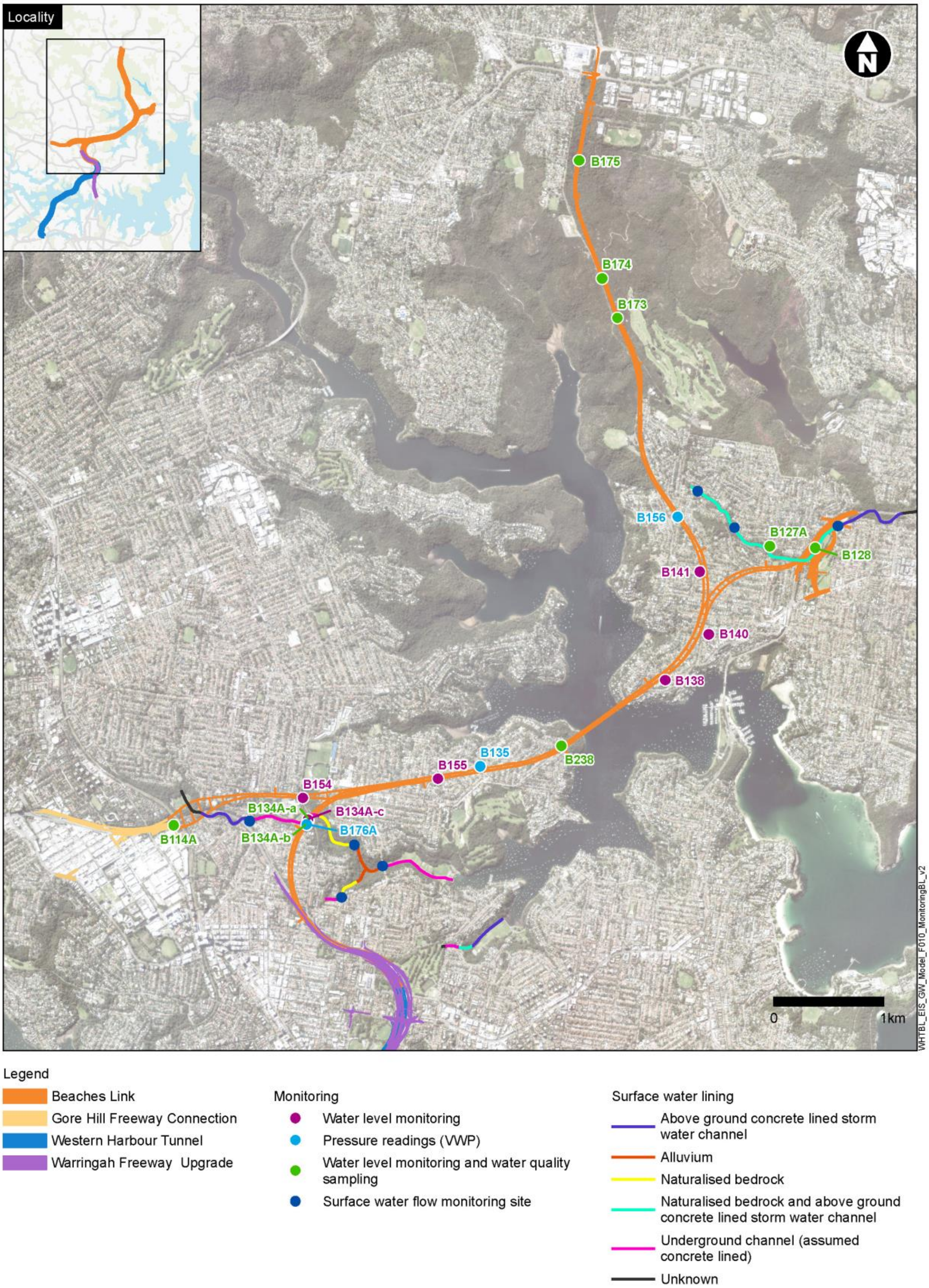


Figure A1-13. Groundwater level monitoring and packer testing locations – BL Project area

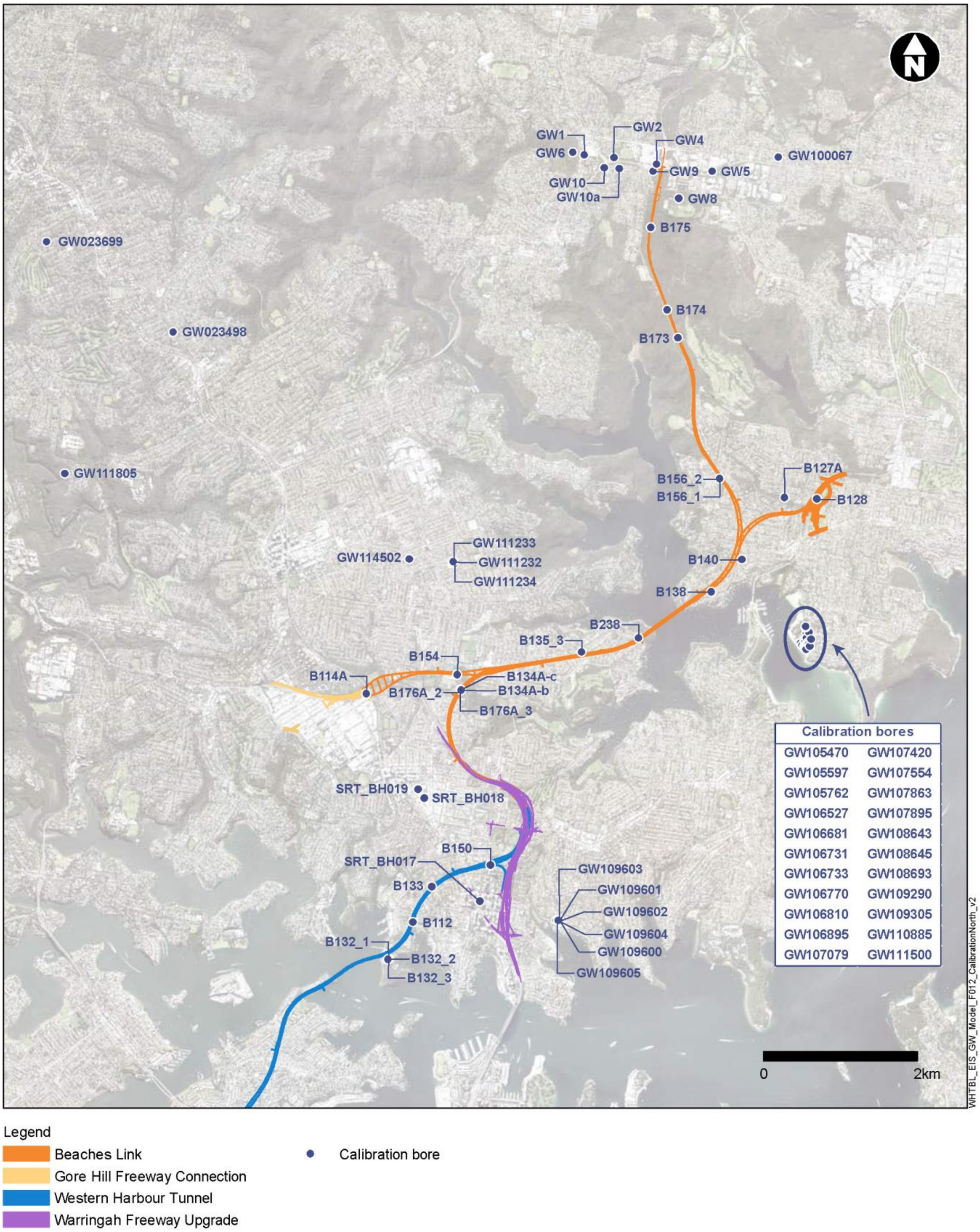


Figure A1-14: Bore locations – North Model steady state calibration

Figure A1-15: Bore locations – South Model Steady State calibration

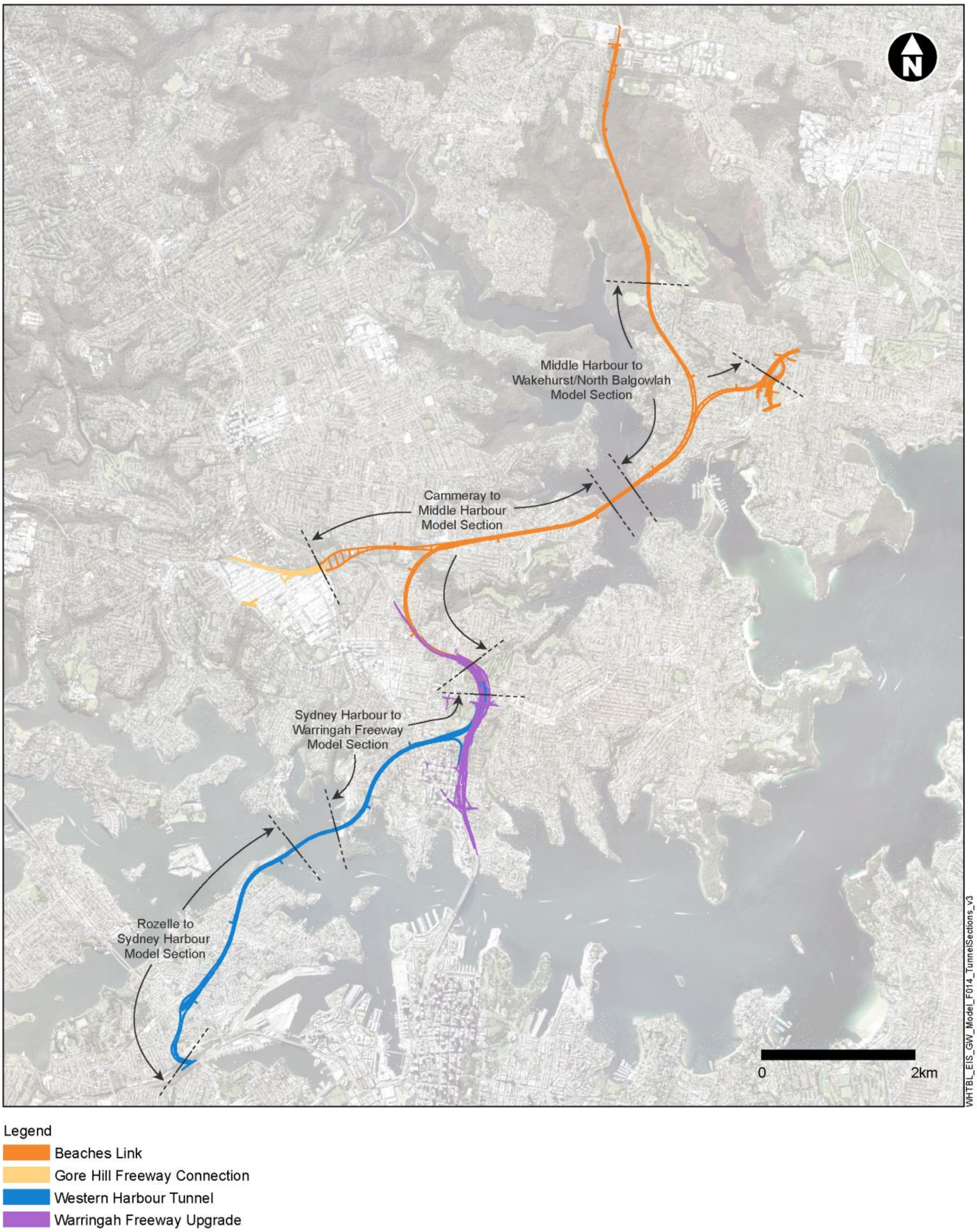


Figure A1-16: Tunnel sections used for reporting inflows

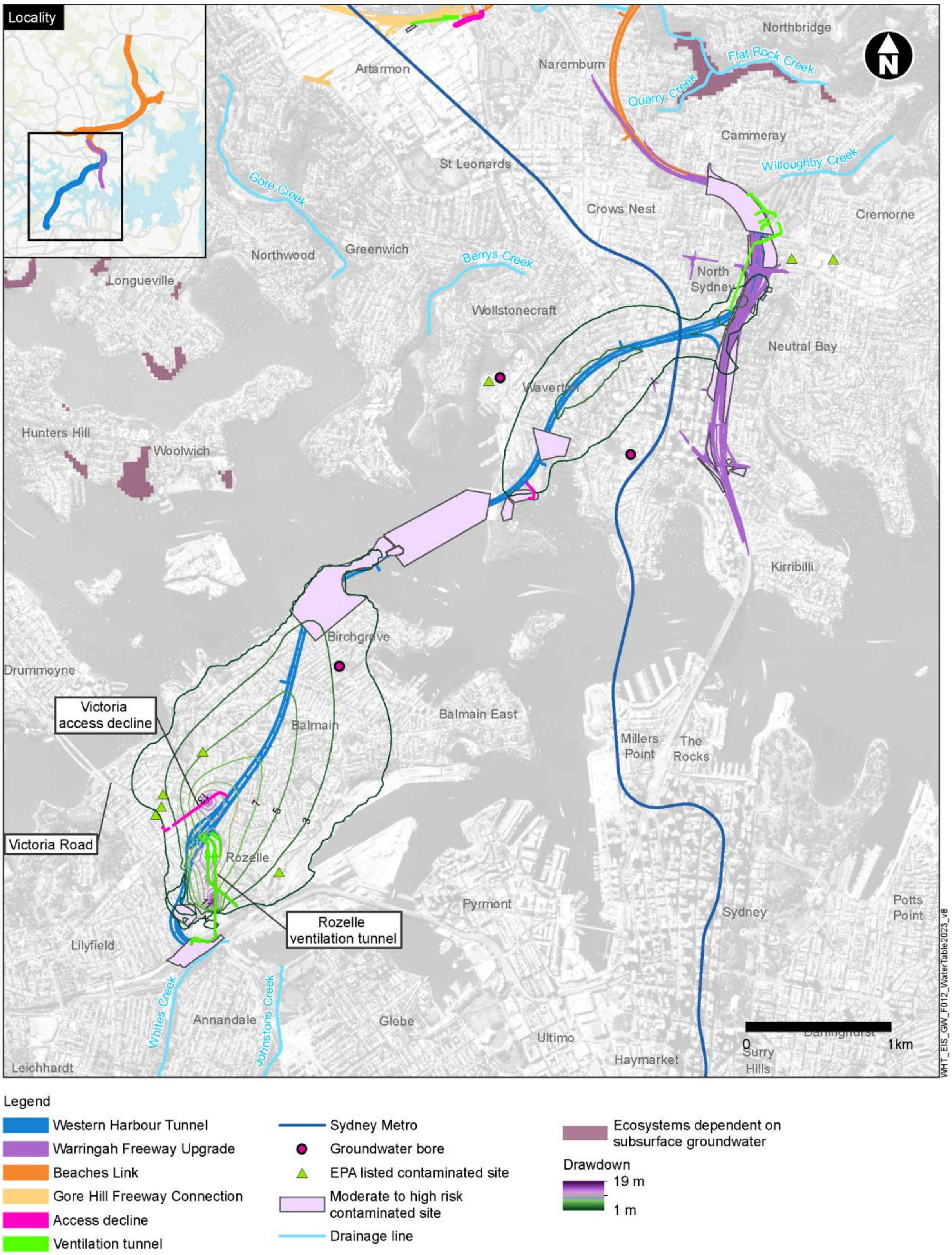


Figure A1-17: Western Harbour Tunnel Project – Water table drawdown at end of construction (Dec. 2026)

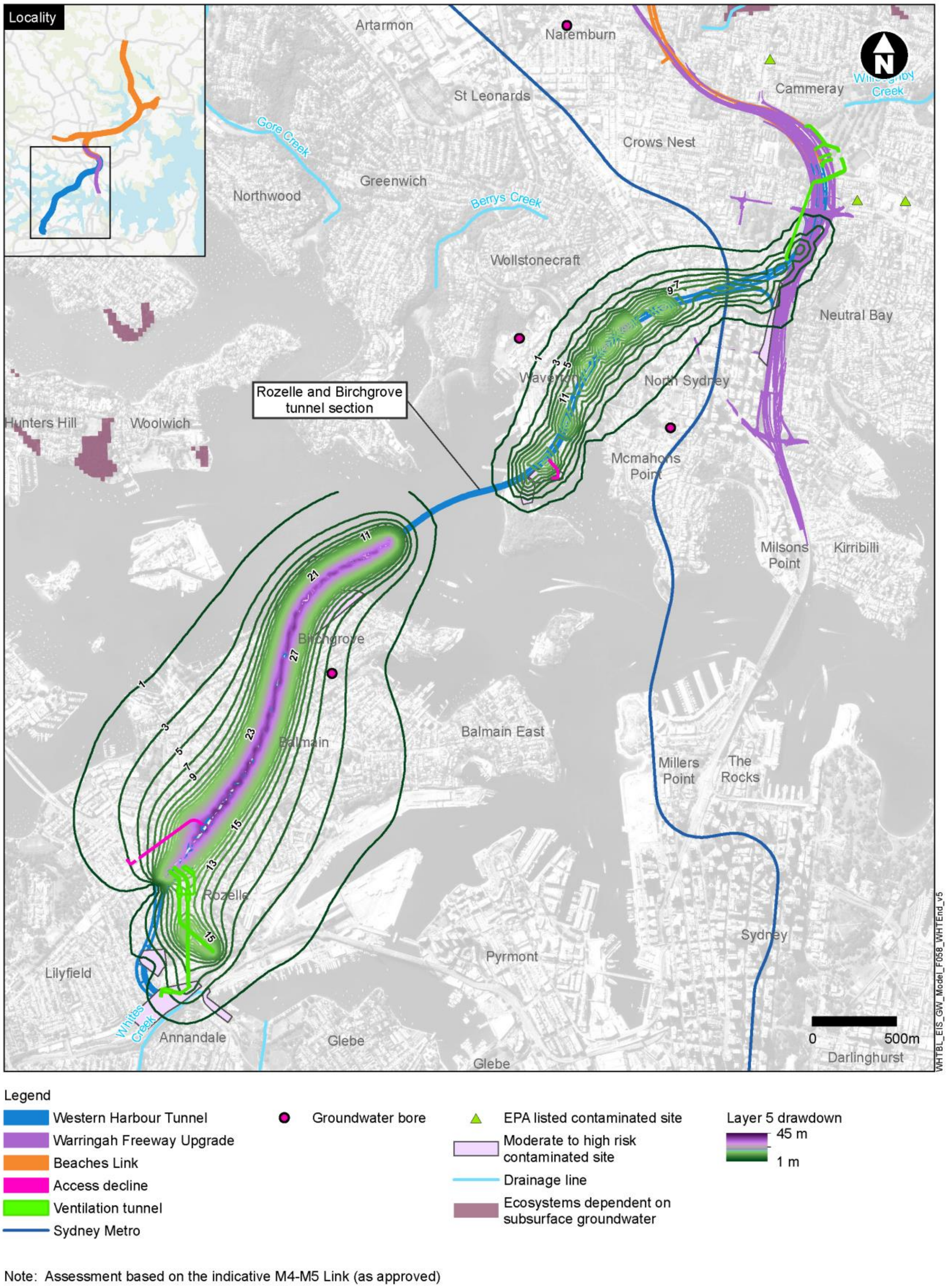


Figure A1-18: Western Harbour Tunnel Project – Layer 5 drawdown at end of construction (Dec. 2026)

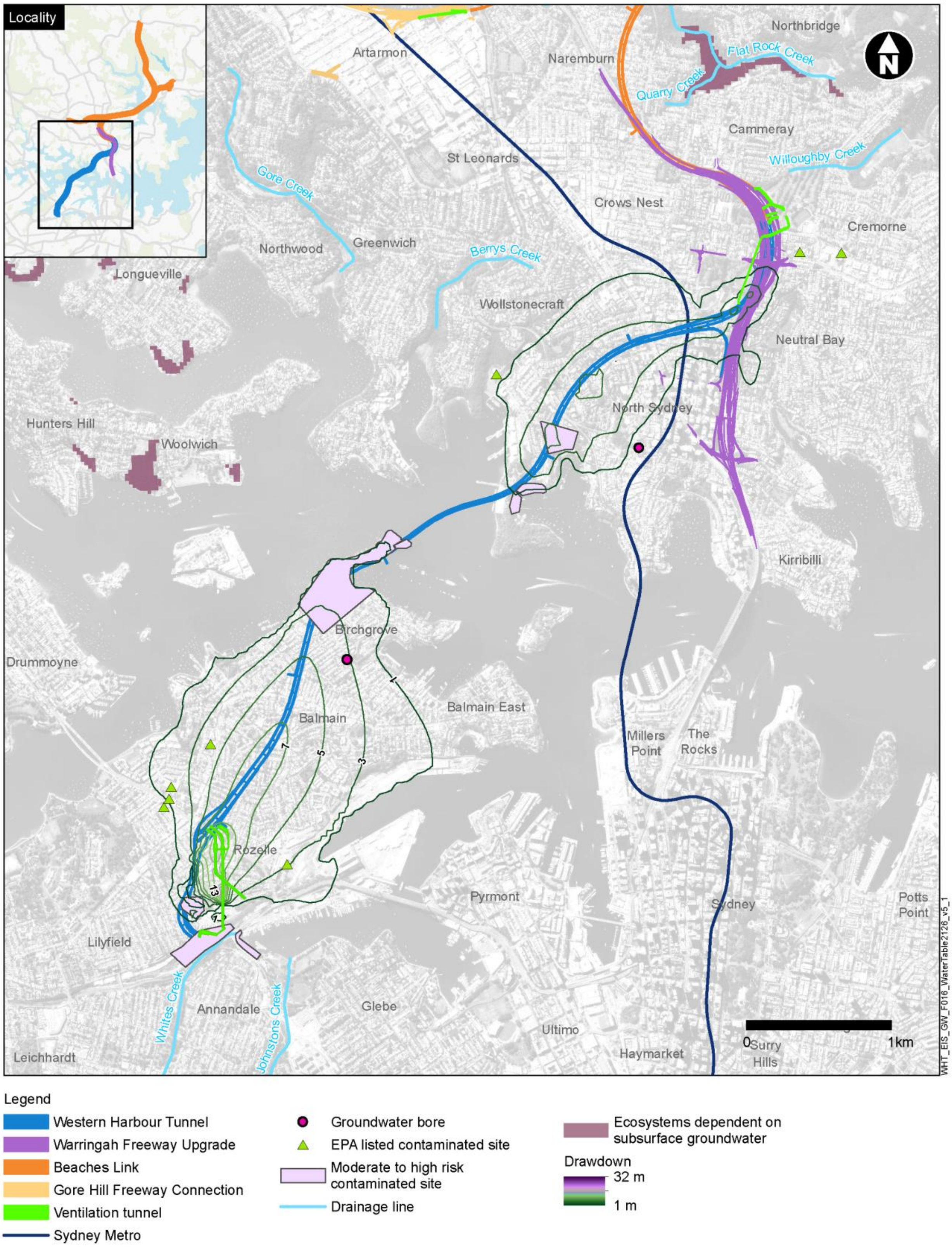


Figure A1-19: Western Harbour Tunnel Project – Water-table drawdown at approximately 100 years post-construction (Dec. 2126)

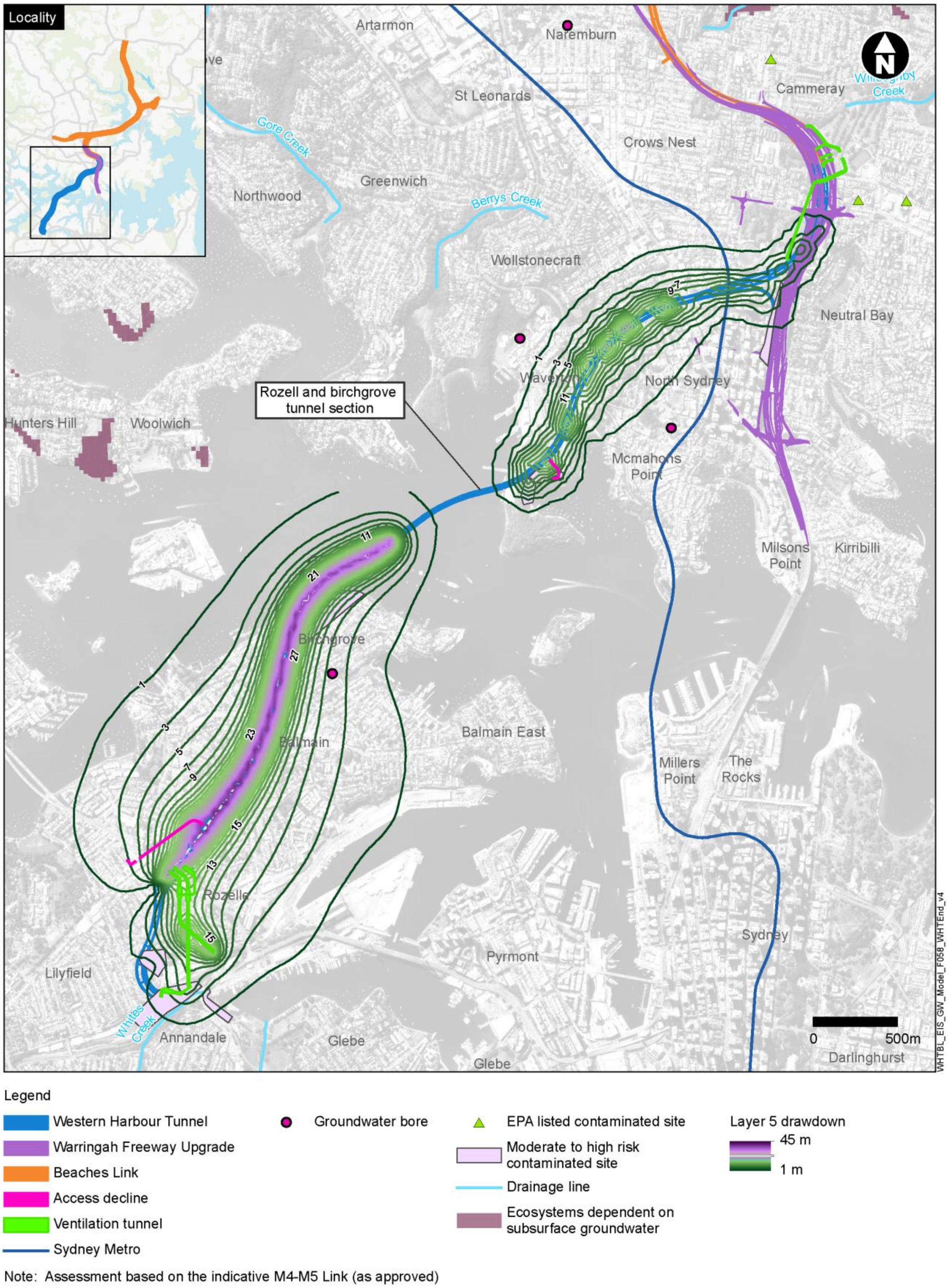


Figure A1-20: Western Harbour Tunnel Project – Layer 5 drawdown at approximately 100 years post-construction (Dec. 2126).

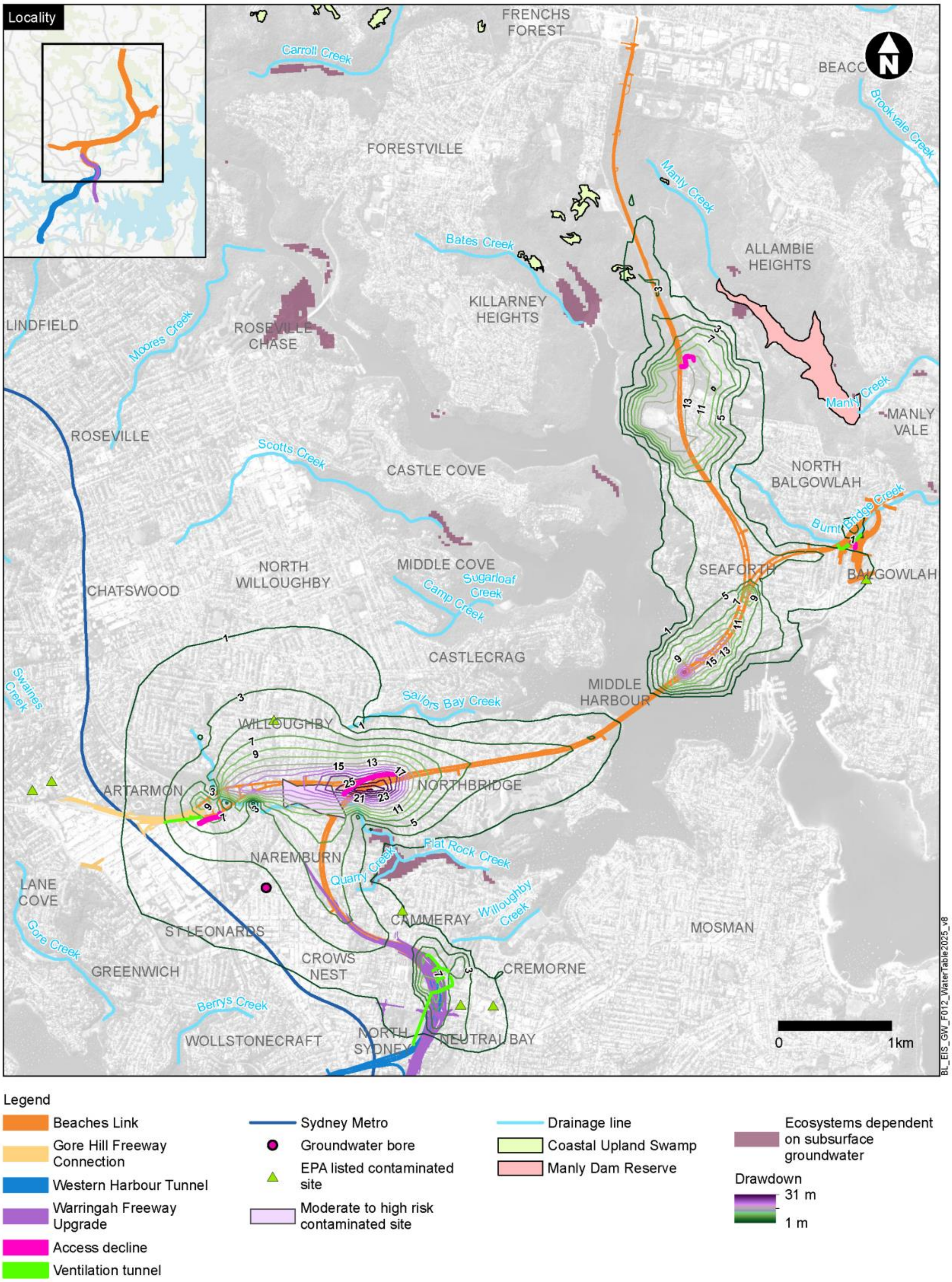
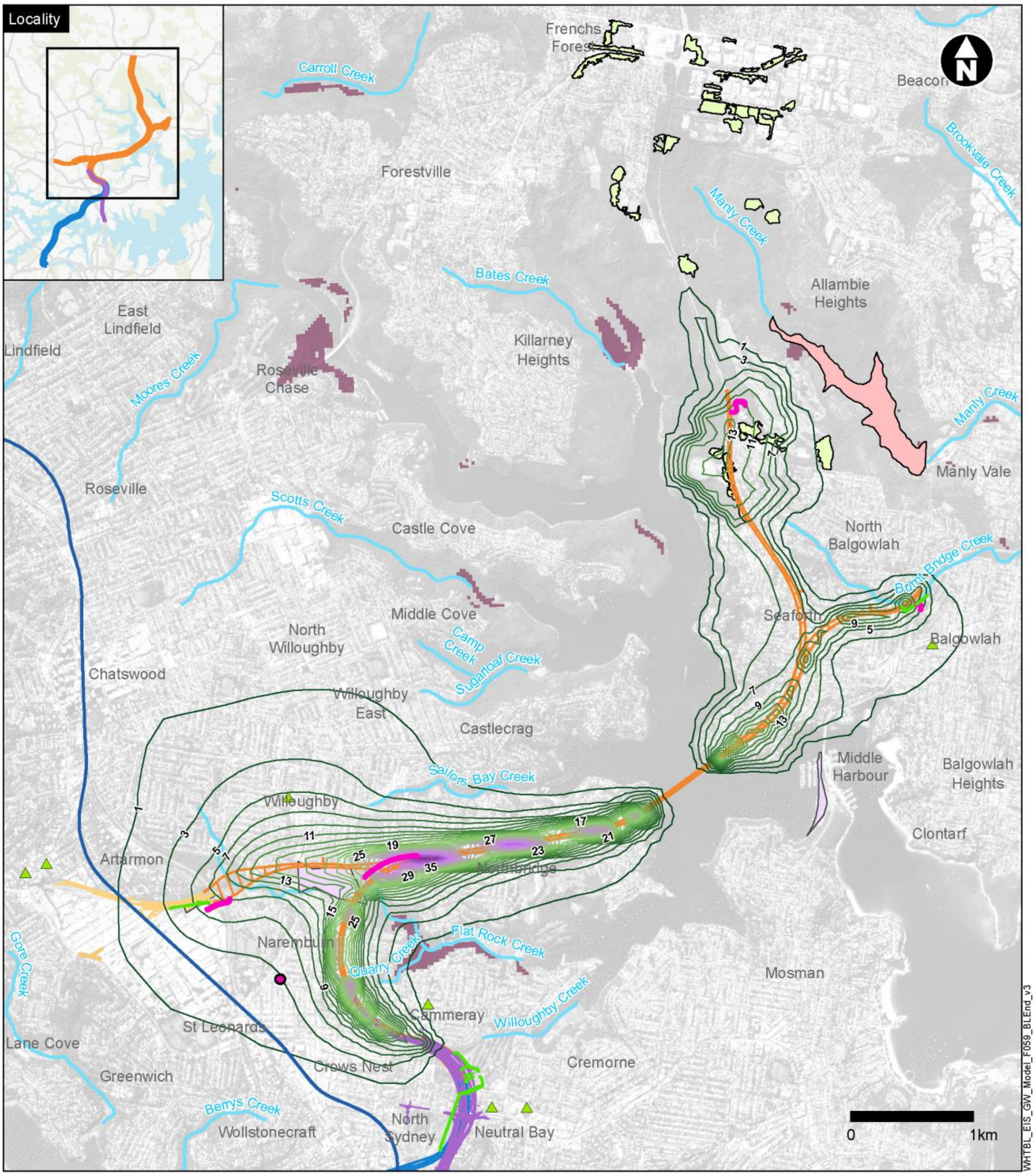


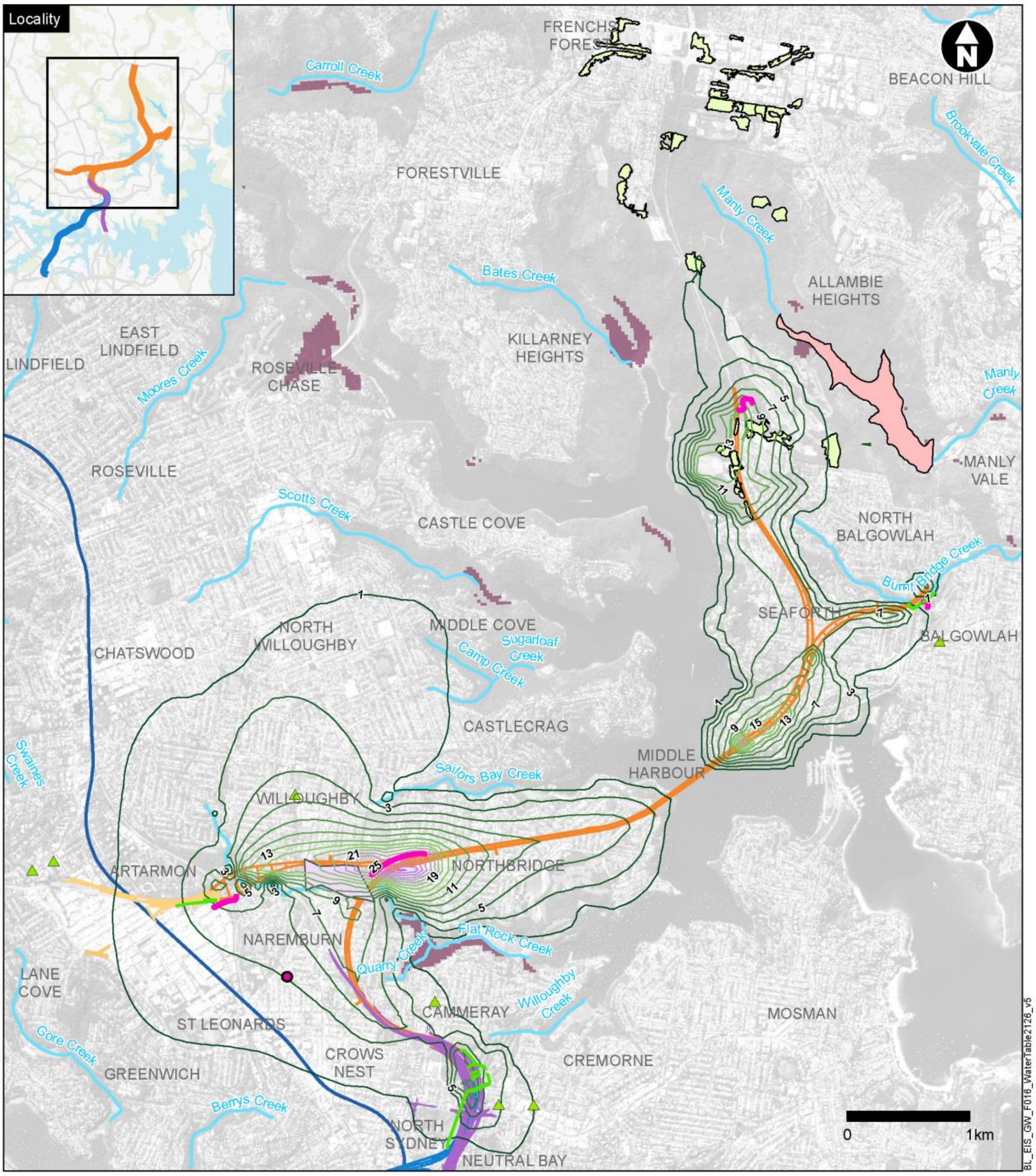
Figure A1-21: Beaches Link Project - Water-table drawdown at the end of tunnel construction (Jun. 2027)



Legend

- Beaches Link
- Gore Hill Freeway Connection
- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Access decline
- Ventilation tunnel
- Sydney Metro
- Groundwater bore
- EPA listed contaminated site
- Moderate to high risk contaminated site
- Drainage line
- Duffys Forest
- Manly Dam Reserve
- Ecosystems dependent on subsurface groundwater
- Drawdown: 55 m – 1 m

Figure A1-22: Beaches Link Project – Layer 5 drawdown at the end of tunnel construction (Jun. 2027)



Legend

Beaches Link	Sydney Metro	Drainage line	Ecosystems dependent on subsurface groundwater
Gore Hill Freeway Connection	Groundwater bore	Duffys Forest	Drawdown: 31 m – 1 m
Western Harbour Tunnel	EPA listed contaminated site	Manly Dam Reserve	
Warringah Freeway Upgrade	Moderate to high risk contaminated site		
Access decline			
Ventilation tunnel			

Figure A1-23 Beaches Link Project – Water-table drawdown at approximately 100 years post-construction (Dec. 2126)

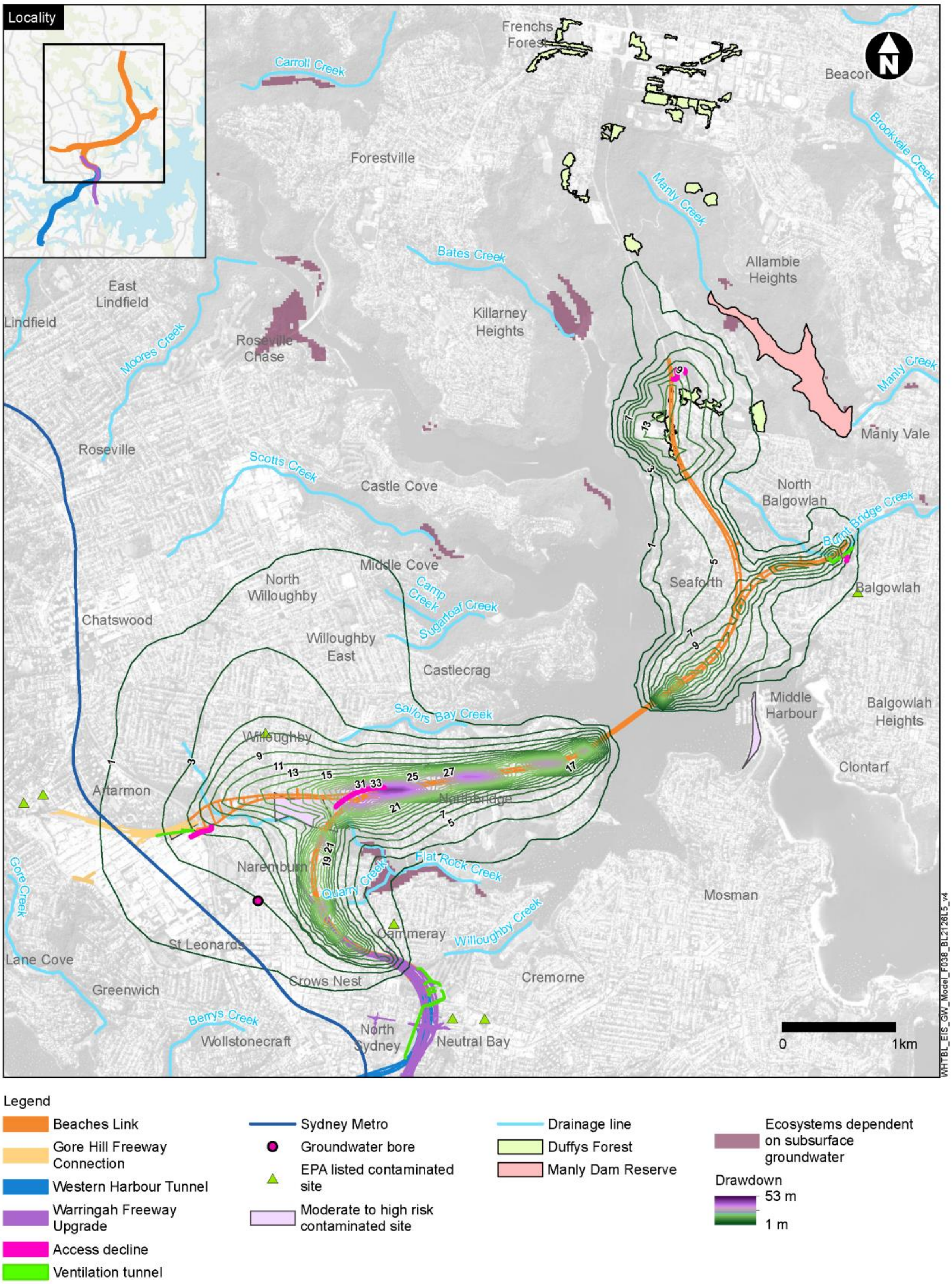


Figure A1-24: Beaches Link Project – Layer 5 drawdown at approximately 100 years post-construction (Dec. 2126)

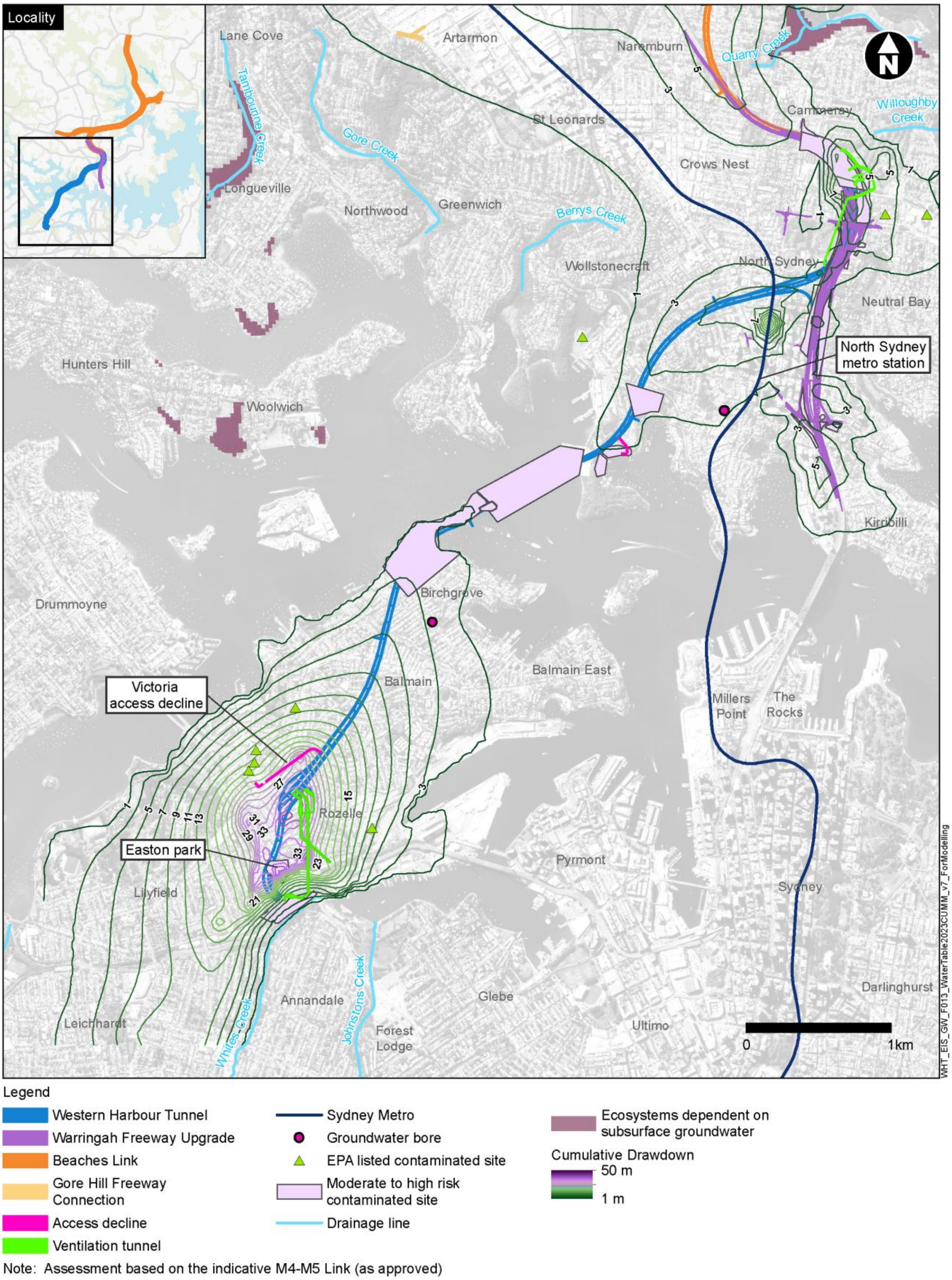


Figure A1-25: Cumulative water-table drawdown at the end of construction (South)

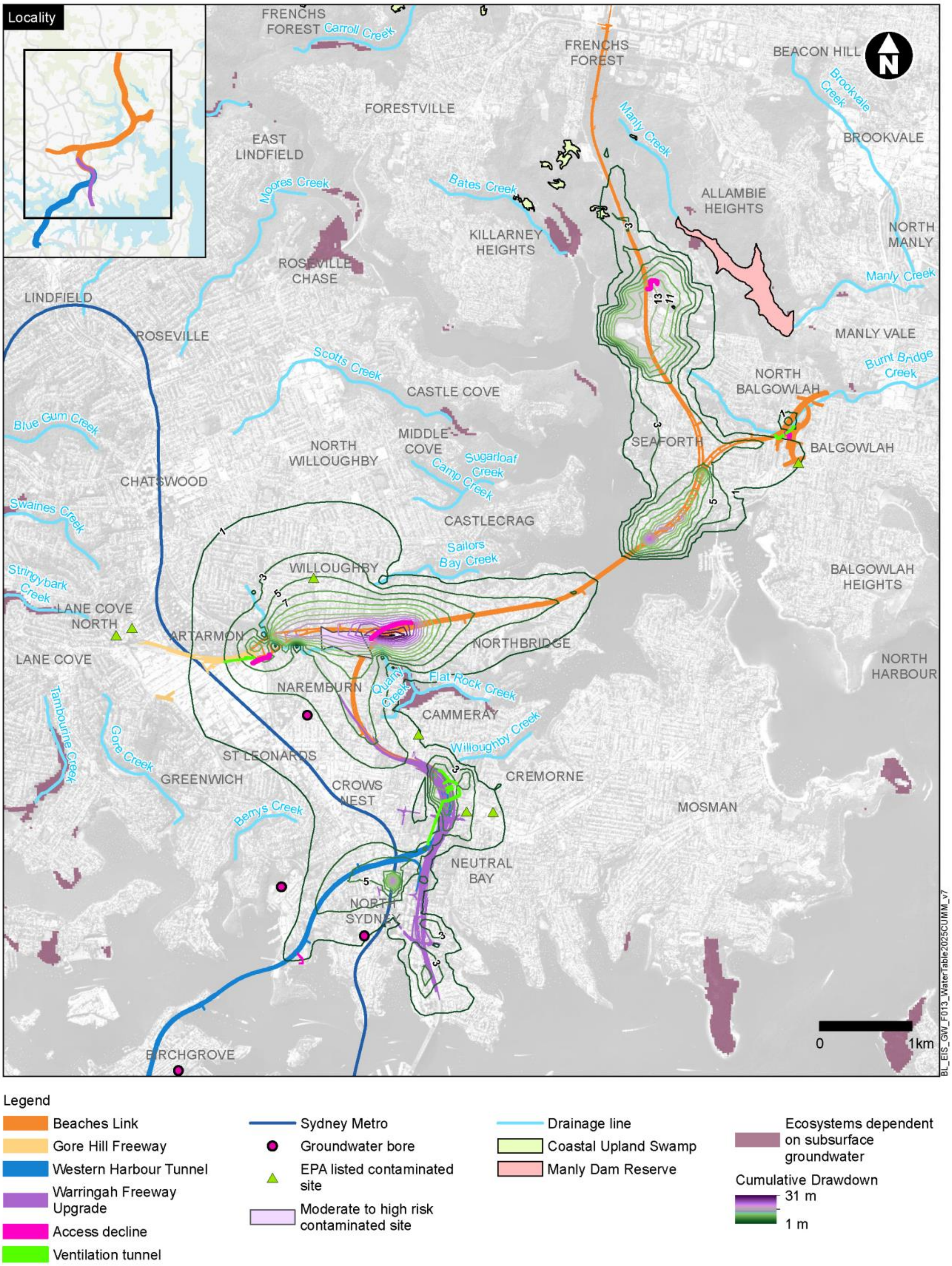


Figure A1-26: Cumulative water-table drawdown at the end of construction (North)

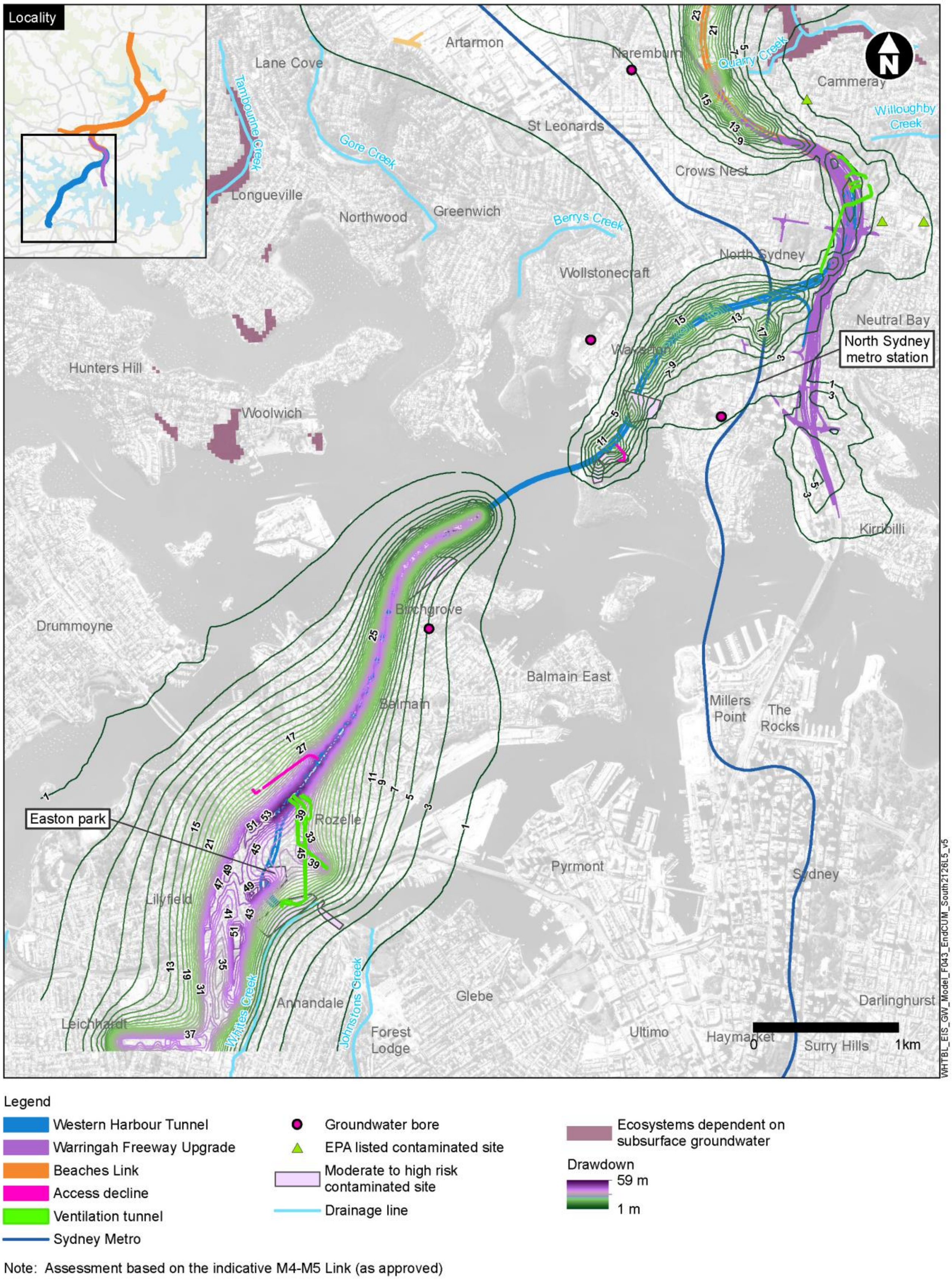


Figure A1-27: Cumulative Layer 5 drawdown at end of construction (South)

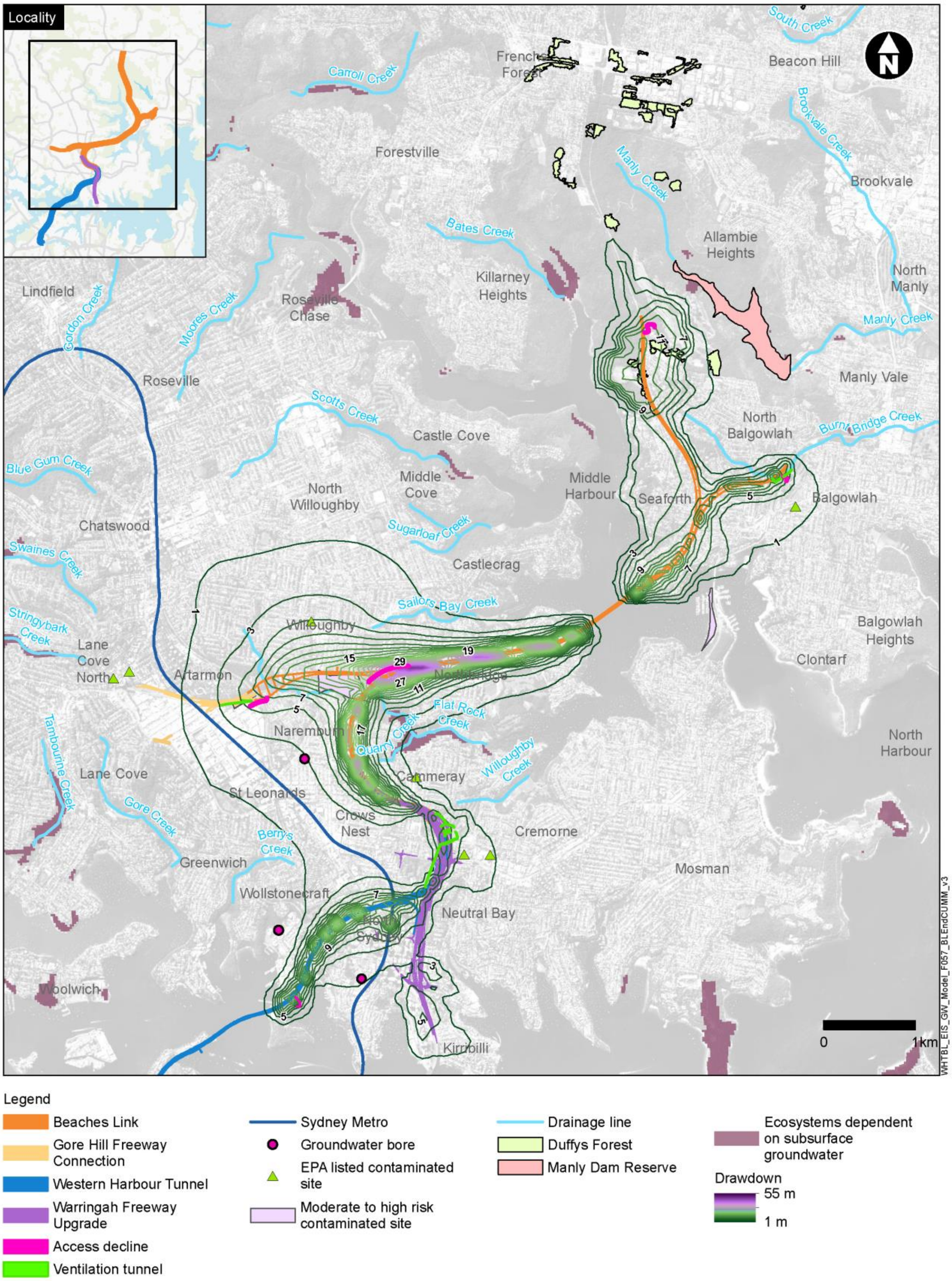


Figure A1-28: Cumulative Layer 5 drawdown at the end of construction (North)

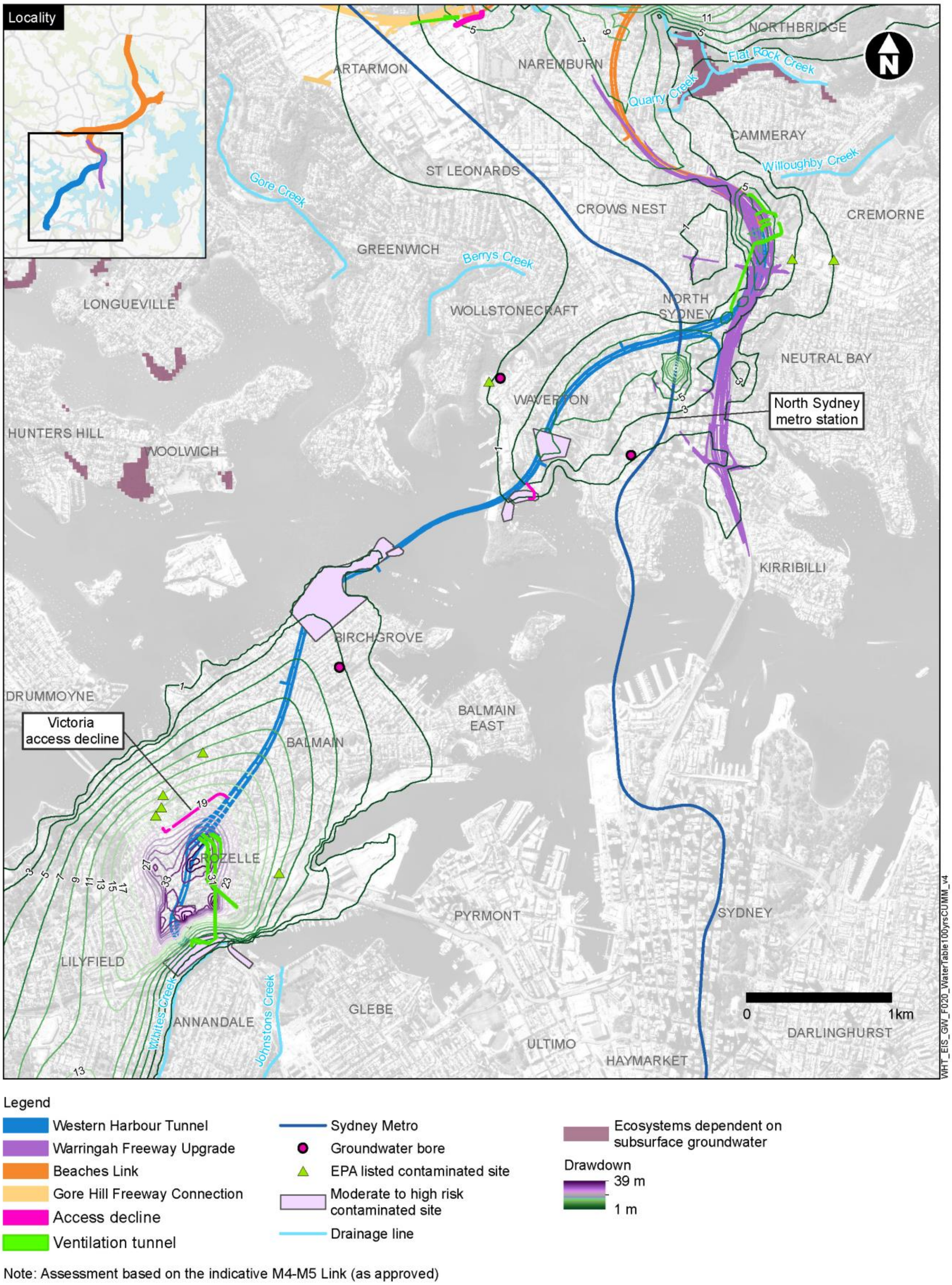


Figure A1-29: Cumulative water-table drawdown after approximately 100 years of operation (South)

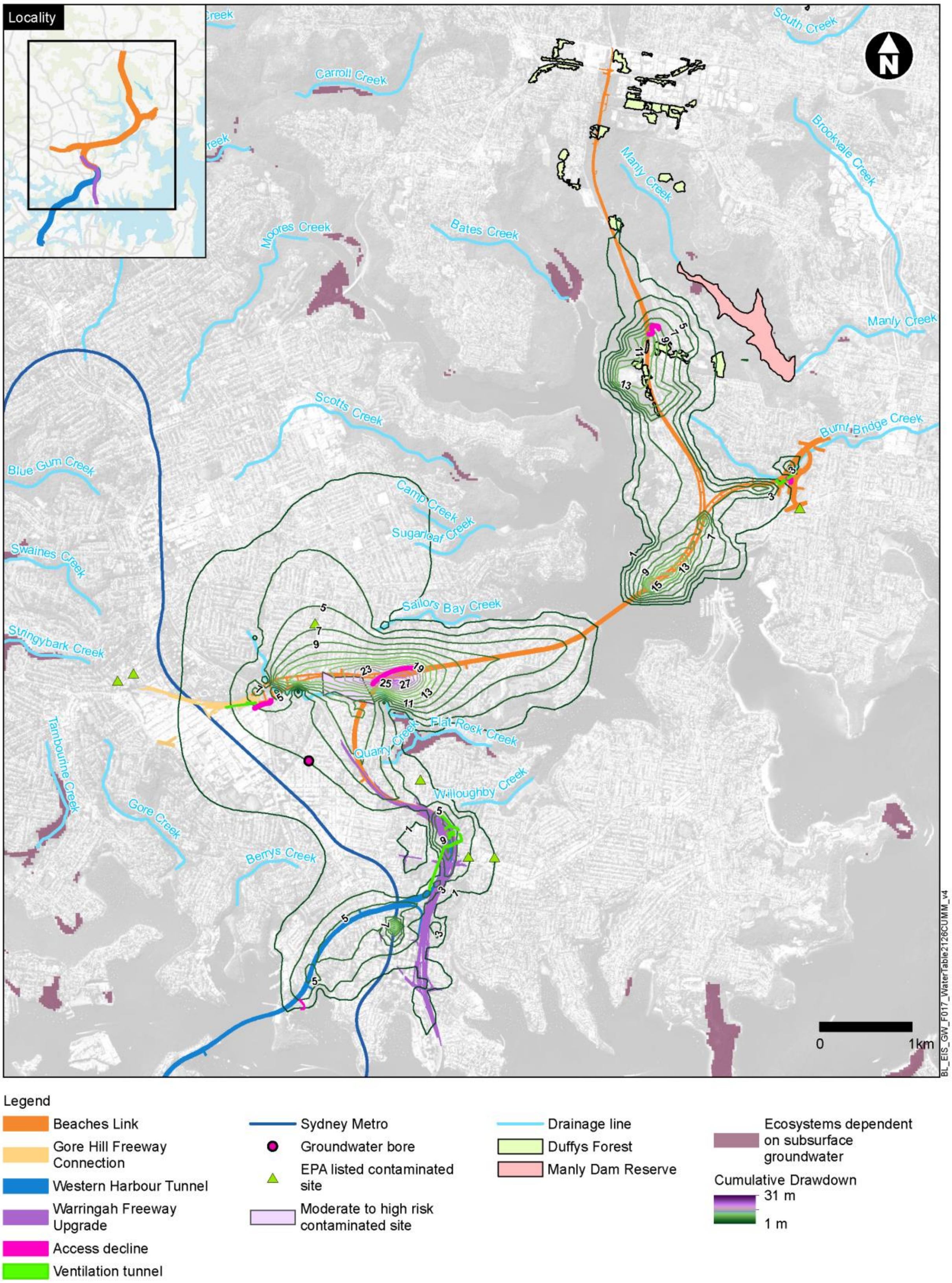
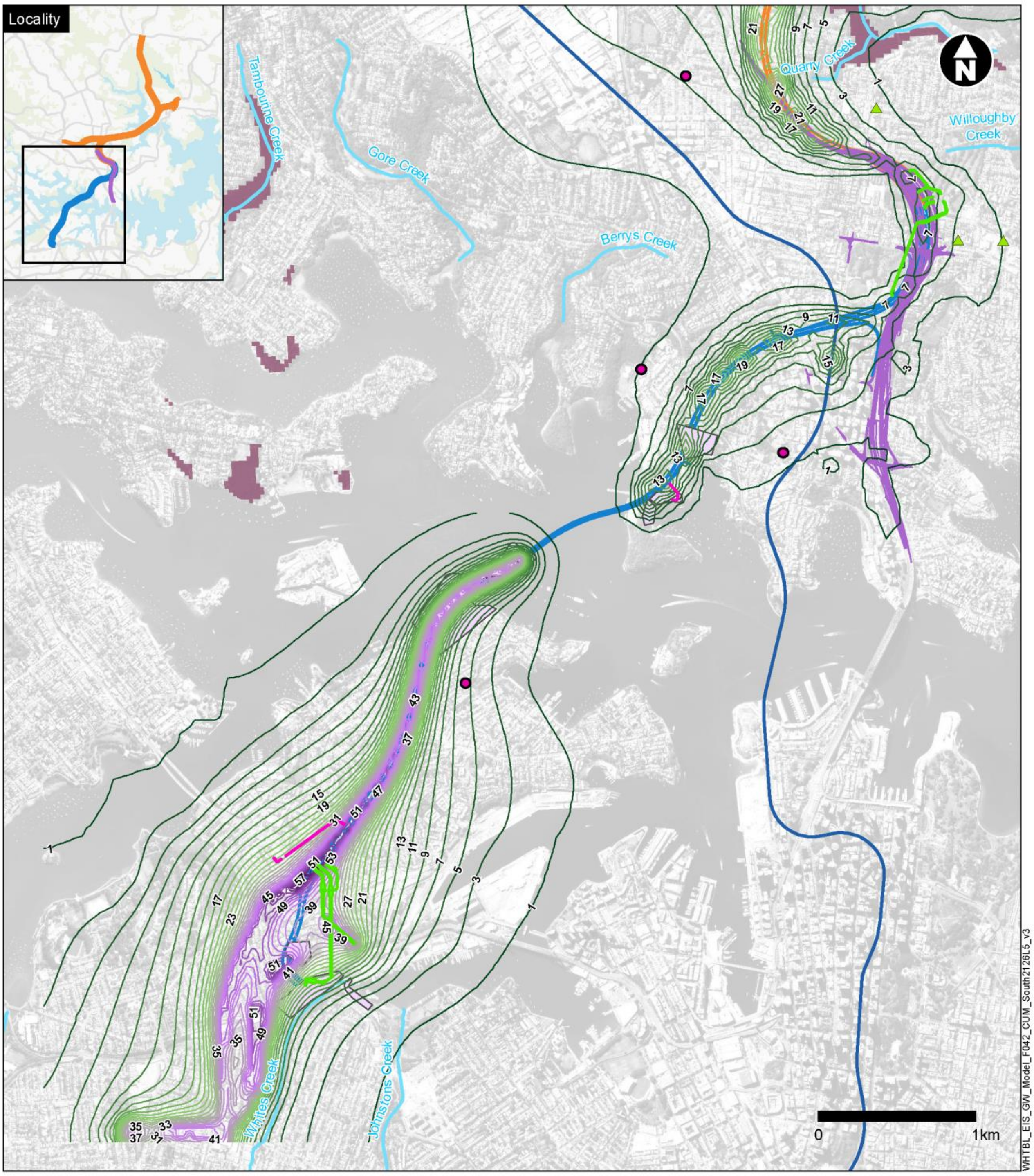


Figure A1-30: Cumulative water-table drawdown after approximately 100 years of operation (North)



Legend

- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Beaches Link
- Access decline
- Ventilation tunnel
- Sydney Metro
- Groundwater bore
- EPA listed contaminated site
- Moderate to high risk contaminated site
- Drainage line
- Ecosystems dependent on subsurface groundwater

Drawdown
59 m
1 m

Note: Assessment based on the indicative M4-M5 Link (as approved)

Figure A1-31: Cumulative Layer 5 drawdown after approximately 100 years of operation (South)

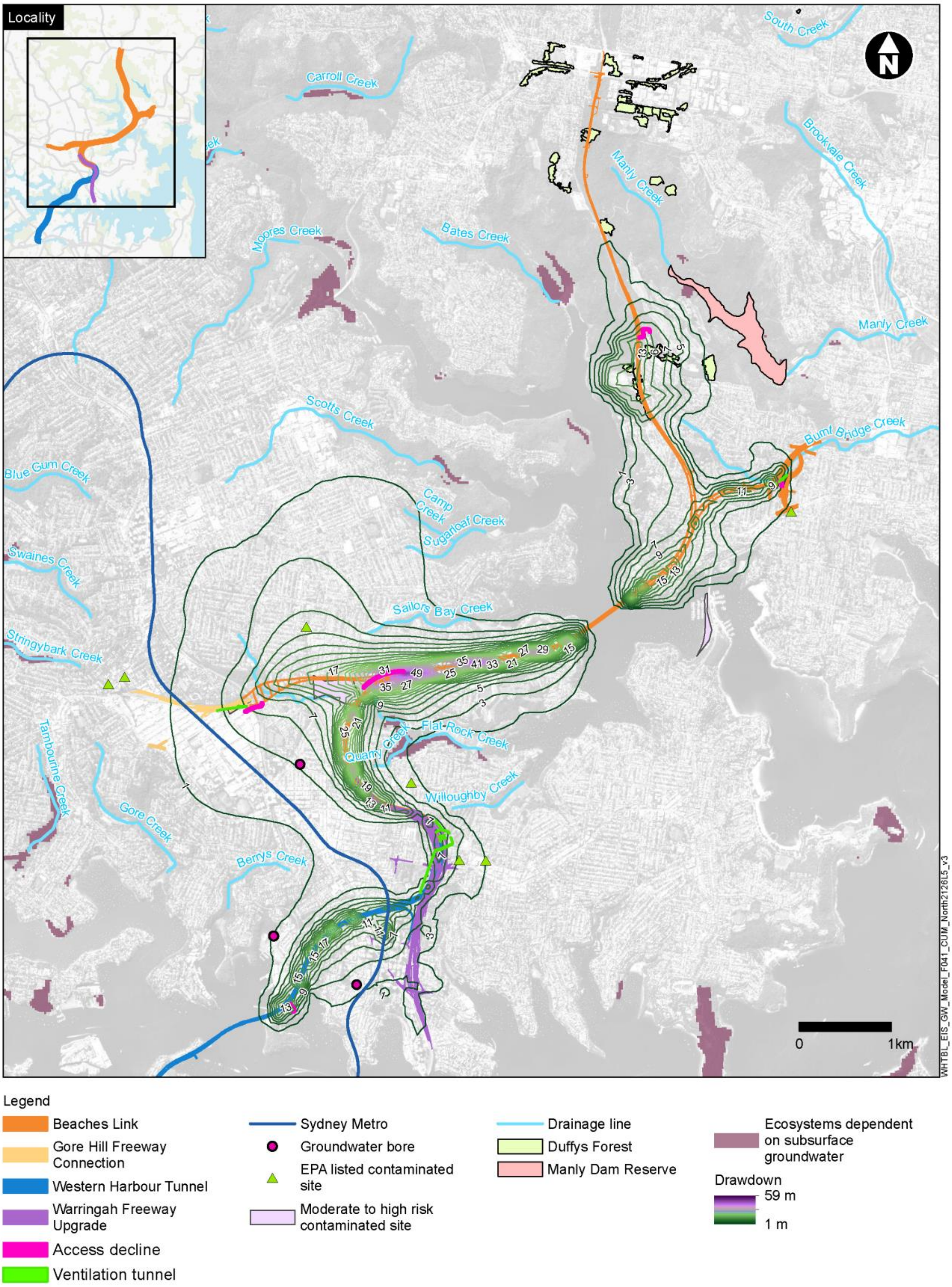


Figure A1-32: Cumulative Layer 5 drawdown after approximately 100 years of operation (North)

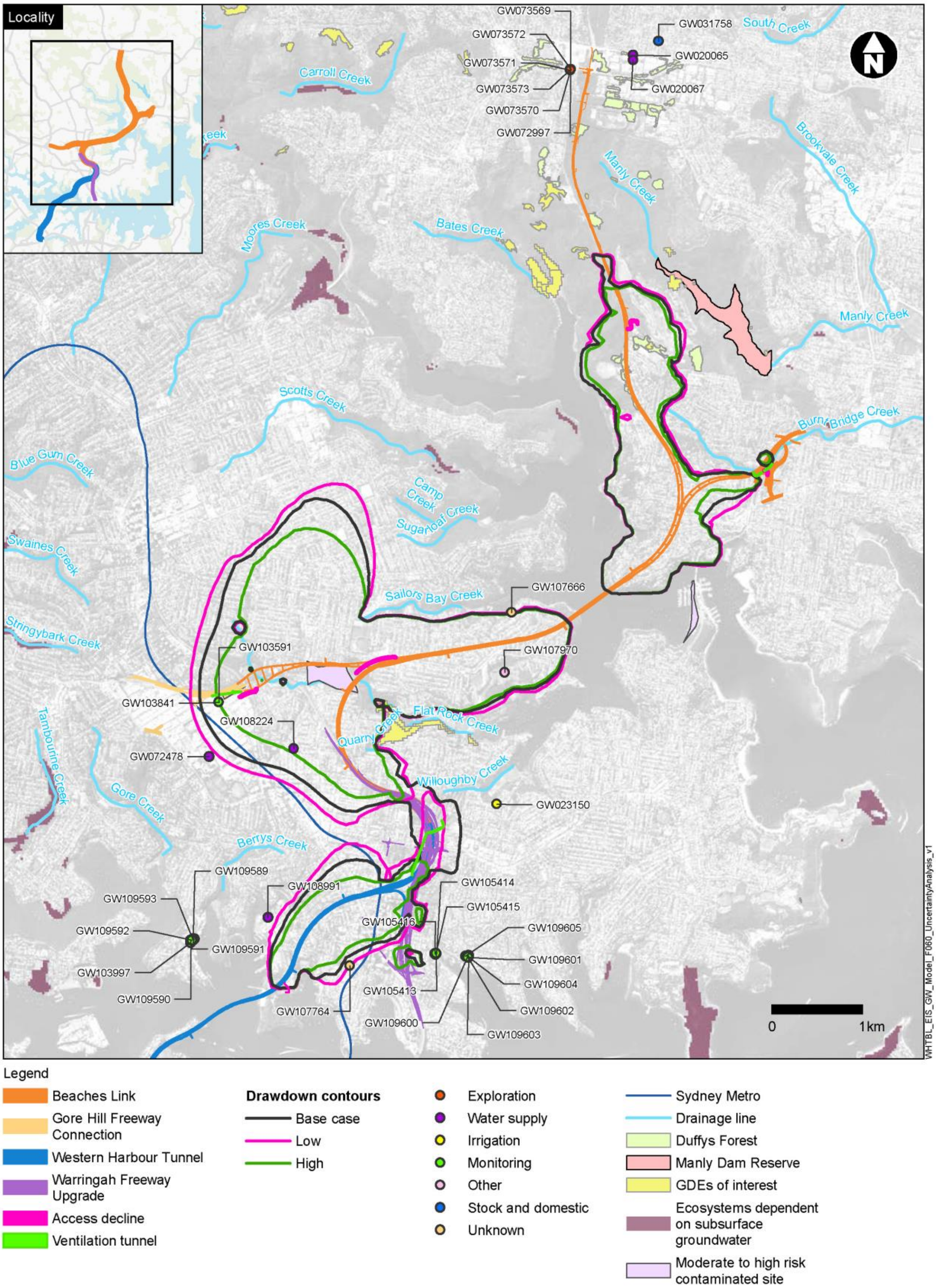


Figure A1-33: Storage parameter uncertainty analysis - 2 m water-table drawdown contours after 100 years of operation

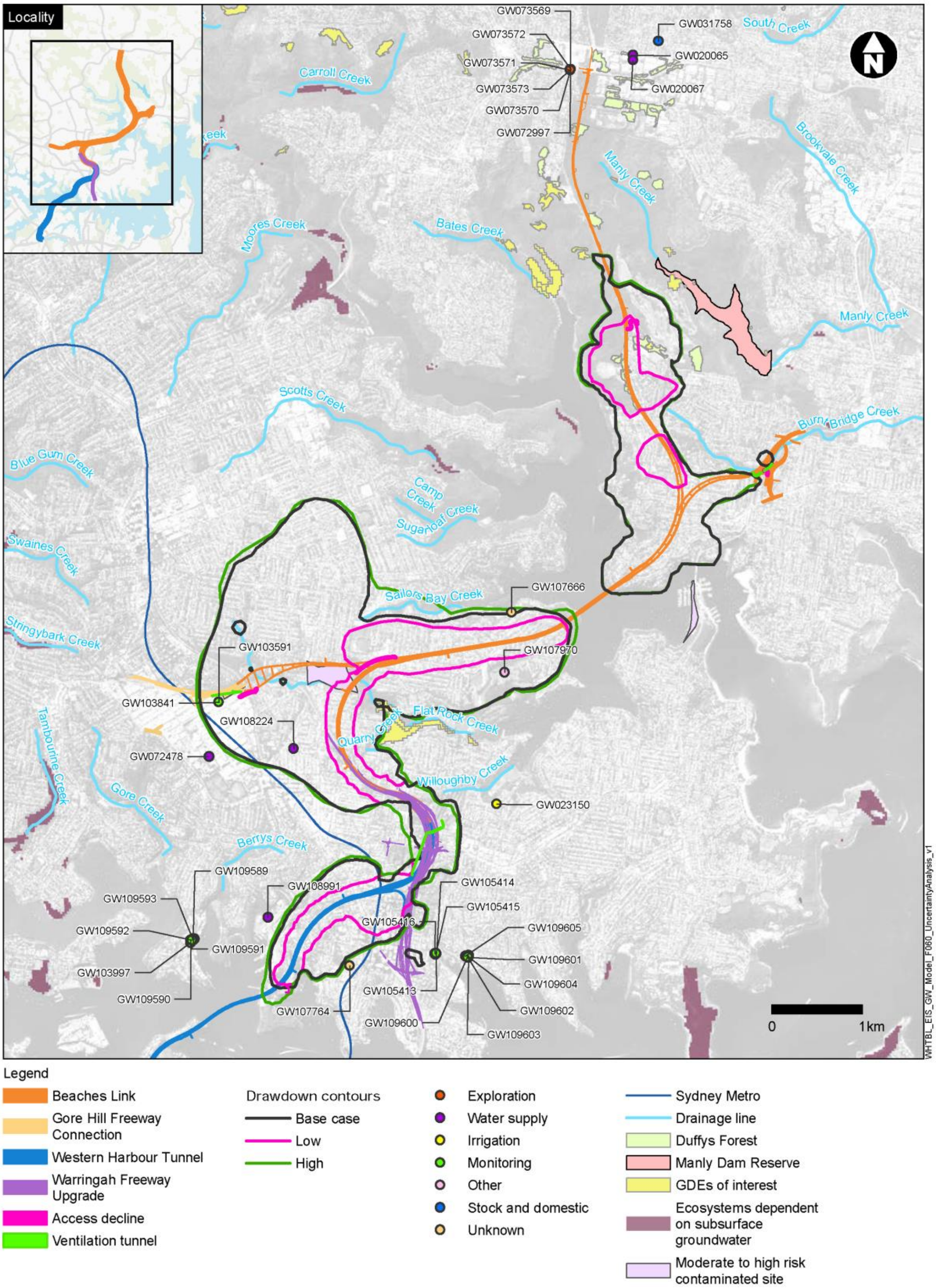


Figure A1-34: Hydraulic conductivity uncertainty analysis - 2 m water-table drawdown contours after 100 years of operation

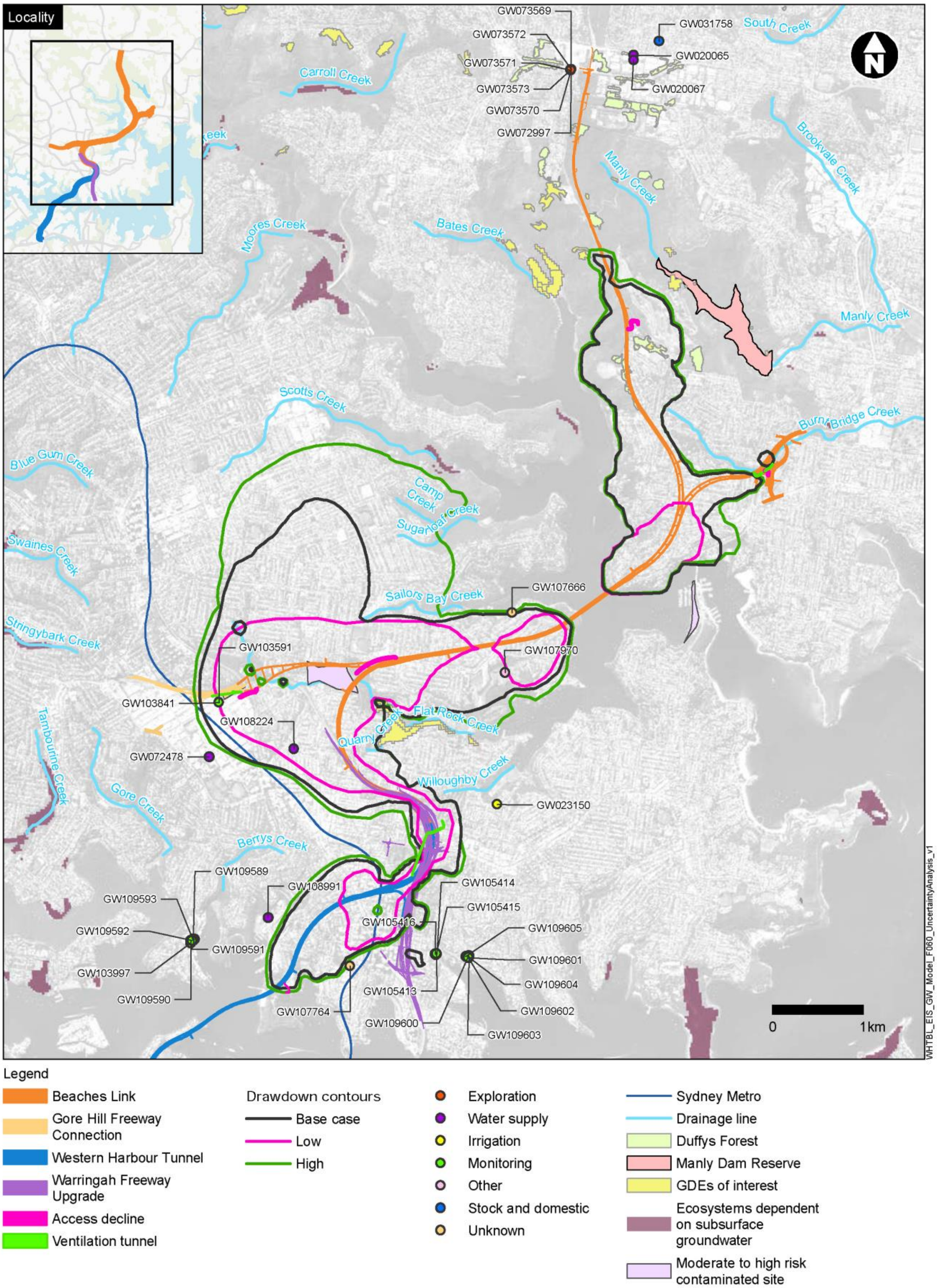


Figure A1-35: Vertical hydraulic conductivity anisotropy uncertainty analysis - 2 m water-table drawdown contours

after 100 years of operation.

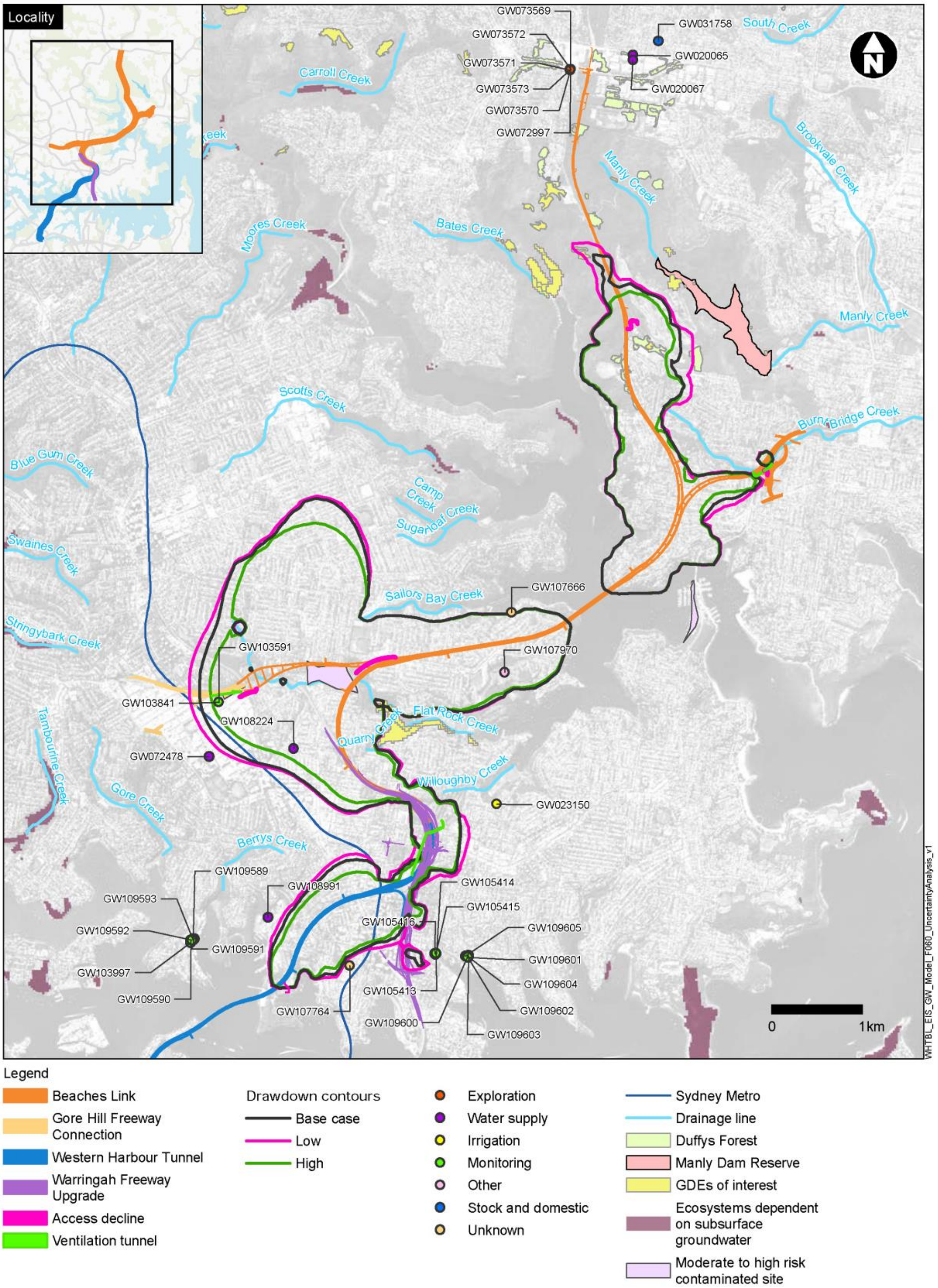


Figure A1-36: Recharge uncertainty analysis - 2 m water-table drawdown contours after 100 years of operation

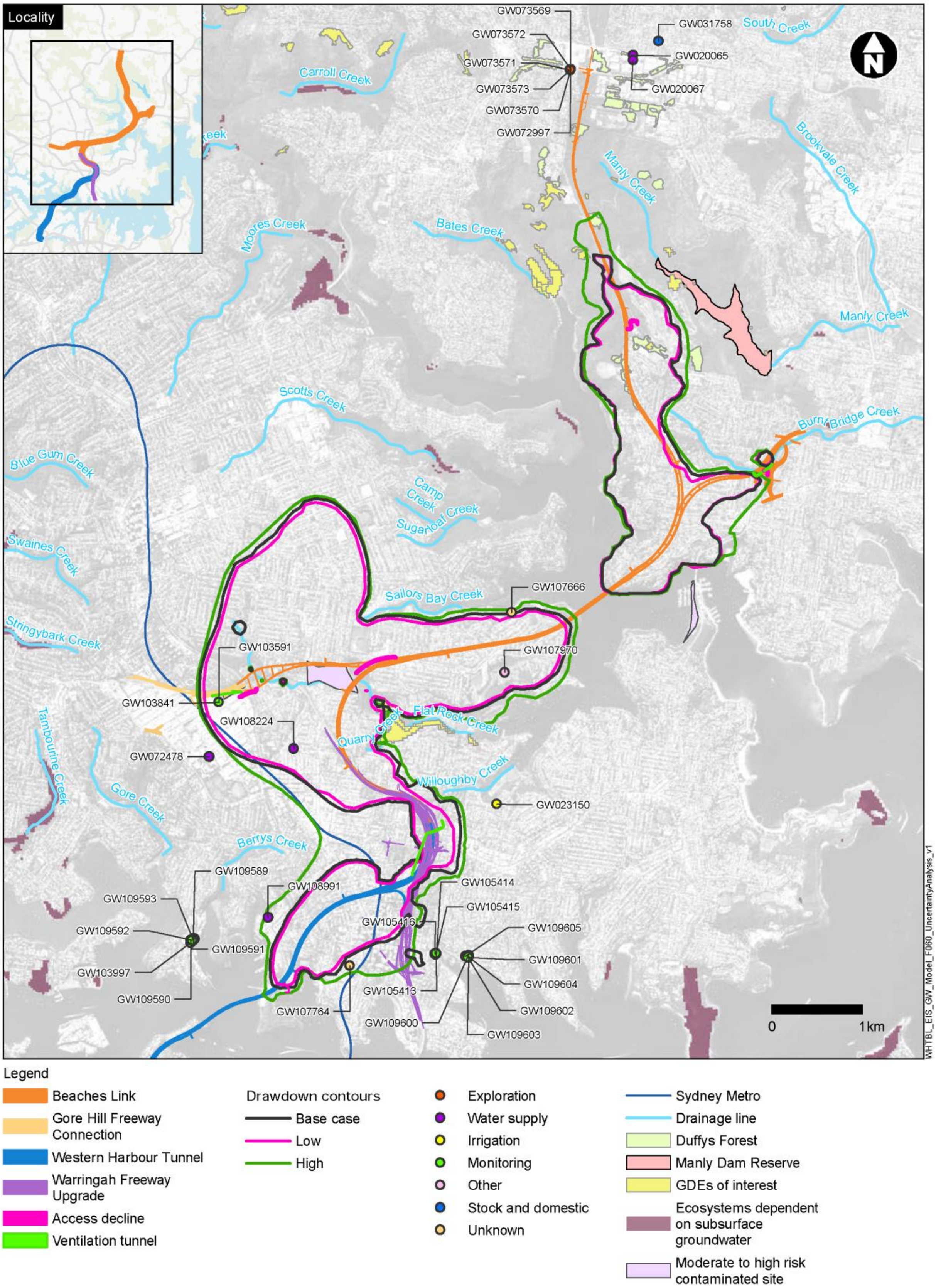
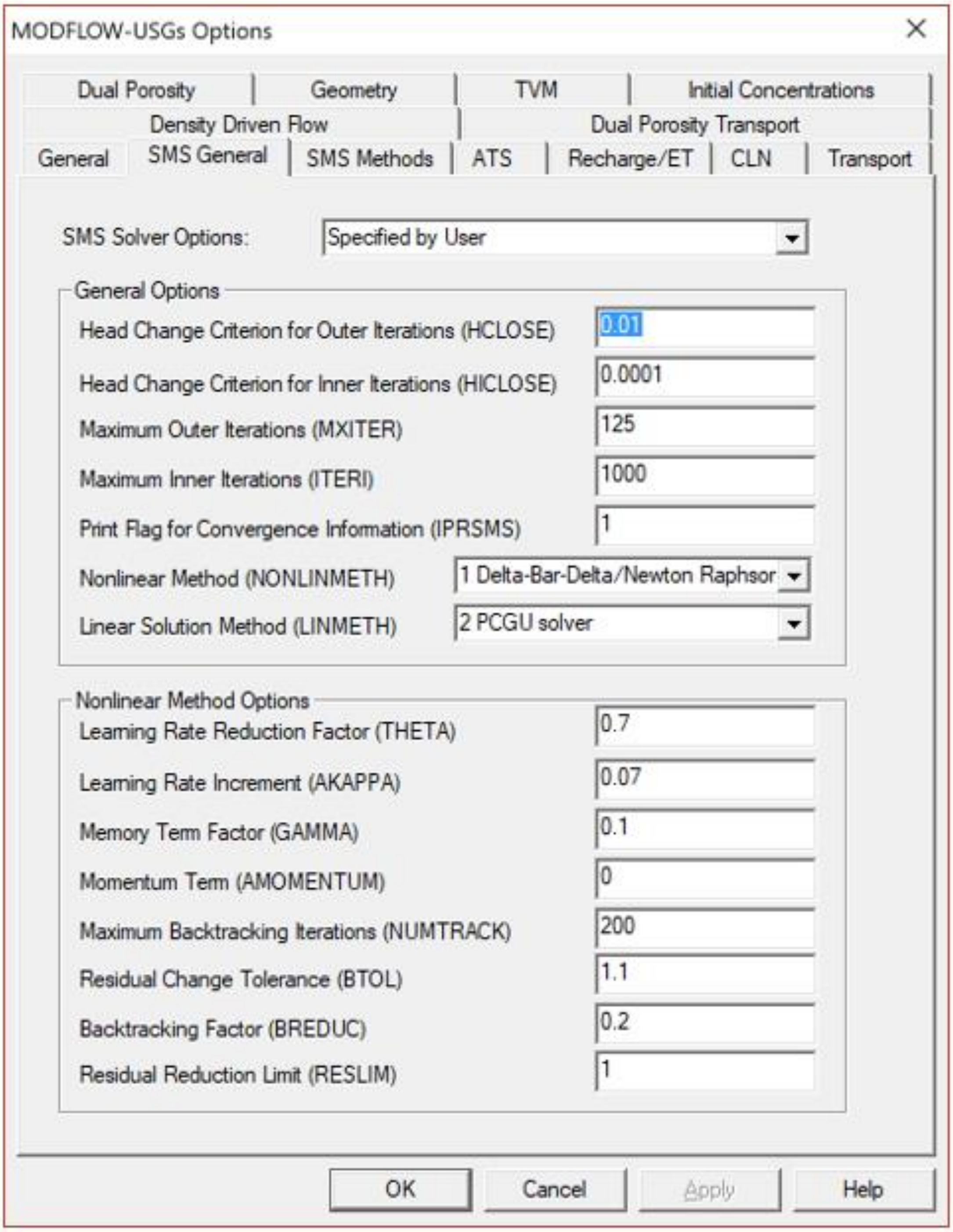
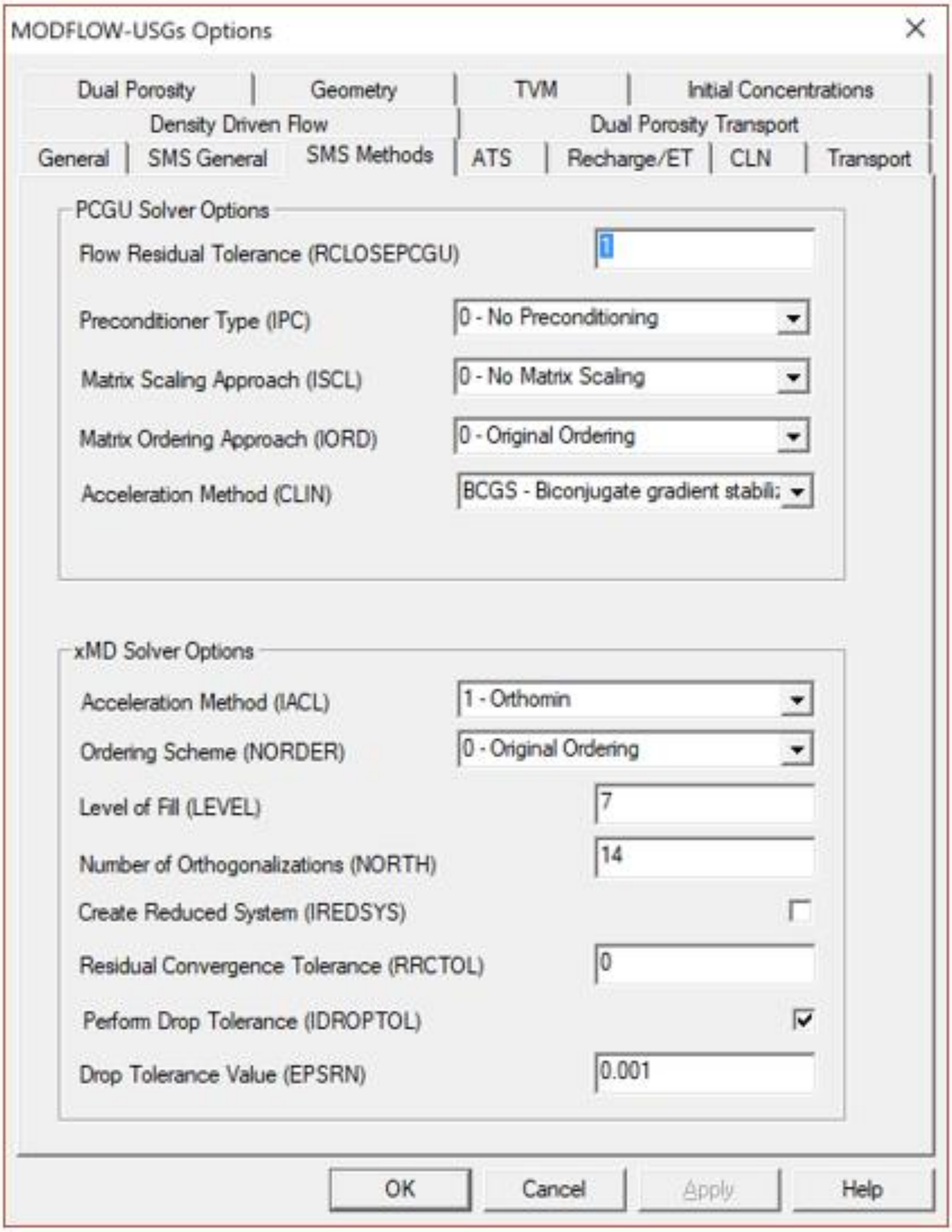


Figure A1-37: Drain conductance uncertainty analysis - 2 m water-table drawdown contours after 100 years of operation

Annexure 2. SMS Solver Options


MODFLOW-USGs Options
Dual Porosity
Geometry
TVM
Initial Concentrations
Density Driven Flow
Dual Porosity Transport
General
SMS General
SMS Methods
ATS
Recharge/ET
CLN
Transport
SMS Solver Options:
Specified by User
General Options
Head Change Criterion for Outer Iterations (HCLOSE)
0.01
Head Change Criterion for Inner Iterations (HICLOSE)
0.0001
Maximum Outer Iterations (MXITER)
125
Maximum Inner Iterations (ITERI)
1000
Print Flag for Convergence Information (IPRSMS)
1
Nonlinear Method (NONLINMETH)
1 Delta-Bar-Delta/Newton Raphsor
Linear Solution Method (LINMETH)
2 PCGU solver
Nonlinear Method Options
Learning Rate Reduction Factor (THETA)
0.7
Learning Rate Increment (AKAPPA)
0.07
Memory Term Factor (GAMMA)
0.1
Momentum Term (AMOMENTUM)
0
Maximum Backtracking Iterations (NUMTRACK)
200
Residual Change Tolerance (BTOL)
1.1
Backtracking Factor (BREDUC)
0.2
Residual Reduction Limit (RESLIM)
1
OK
Cancel
Apply
Help


MODFLOW-USGs Options
Dual Porosity
Geometry
TVM
Initial Concentrations
Density Driven Flow
Dual Porosity Transport
General
SMS General
SMS Methods
ATS
Recharge/ET
CLN
Transport
PCGU Solver Options
Flow Residual Tolerance (RCLOSEPCGU)
1
Preconditioner Type (IPC)
0 - No Preconditioning
Matrix Scaling Approach (ISCL)
0 - No Matrix Scaling
Matrix Ordering Approach (IORD)
0 - Original Ordering
Acceleration Method (CLIN)
BCGS - Biconjugate gradient stabili:
xMD Solver Options
Acceleration Method (IACL)
1 - Orthomin
Ordering Scheme (NORDER)
0 - Original Ordering
Level of Fill (LEVEL)
7
Number of Orthogonalizations (NORTH)
14
Create Reduced System (IREDSYS)
Residual Convergence Tolerance (RRCTOL)
0
Perform Drop Tolerance (IDROPTOL)
Drop Tolerance Value (EPSRN)
0.001
OK
Cancel
Apply
Help

Annexure 3. Calibration Bore Information - North Model Steady State Calibration

Name	X (mMGA)	Y (mMGA)	Z (mAHD)	Screen (mBGL)	Average SWL (mAHD)	project/Type	Date recorded	Suitability for calibration
SRT_BH017	334111	6254365	62.9	36.1-39.80	43.60	Metro	16/09/2015	High
SRT_BH018	333390	6255706	90.75	18.8-26.0	77.66	Metro	15/09/2015	High
SRT_BH019	333308	6255819	84.43	3.75-7.5	81.81	Metro	18/09/2015	High
B114A	332643	6257062	74.36	25-31	64.35	Western Harbour Tunnel - GDP	4/08/2017	High
B127A	338070	6259609	49.46	35-38	32.08	Western Harbour Tunnel - GDP	3/08/2017	High
B134A-b	333870	6257108	45.67	28.5-31.5	20.68	Western Harbour Tunnel - GDP	3/08/2017	High
B134A-c	333868	6257112	45.63	57.5-60.5	20.00	Western Harbour Tunnel - GDP	4/08/2017	High
B238	336173	6257786	38.91	129.9-132.9	2.93	Western Harbour Tunnel - GDP	17/08/2017	High
GW1	335472	6264060	149.08	9 to 12	143.23	Northern Beaches Hospital	1/01/2015	High
GW2	335852	6264028	148.96	5.5-9.99	145.18	Northern Beaches Hospital	1/01/2015	High
GW4	336410	6263945	151.75	5-11.4	149.07	Northern Beaches Hospital	1/01/2015	High
GW5	337131	6263848	156.86	9 to 12	148.55	Northern Beaches Hospital	1/01/2015	High
GW6	335324	6264099	150.57	8.8-14.6	148.13	Northern Beaches Hospital	1/01/2015	High
GW8	336698	6263502	130.87	6 to 12	129.41	Northern Beaches Hospital	1/01/2015	High
GW9	336363	6263849	148.4	6-11.86	144.42	Northern Beaches Hospital	1/01/2015	High
GW10	335727	6263897	151.73	7-14.87	147.50	Northern Beaches Hospital	1/01/2015	High
GW10a	335921	6263886	151.73	3-12.9	150.19	Northern Beaches Hospital	1/01/2015	High
B112	333240	6254091	15.99	62.5-65.5	0.76	Western Harbour Tunnel - AEC	10/08/2017	High
B128	338487	6259592	63.47	45.7-48.7	28.75	Western Harbour Tunnel - AEC	25/08/2017	High
B133	333489	6254554	60.97	123.5-126.5	35.73	Western Harbour Tunnel - AEC	1/09/2017	High
B138	337119	6258385	65.671	99.5-102.5	5.85	Western Harbour Tunnel - AEC	15/08/2017	High
B140	337516	6258803	92.37	48.2-51.2	3.81	Western Harbour Tunnel - AEC	10/08/2017	High
B150	334252	6254834	80.08	24-27	67.62	Western Harbour Tunnel - AEC	9/08/2017	High
B154	333821	6257311	56.29	50-53	24.79	Western Harbour Tunnel - AEC	9/08/2017	High
B173	336683	6261687	114	3 to 6	111.07	Western Harbour Tunnel - AEC	4/10/2017	High
B174	336546	6262050	121.94	3 to 6	119.51	Western Harbour Tunnel - AEC	3/10/2017	High
B175	336334	6263123	121.05	3 to 6	119.44	Western Harbour Tunnel - AEC	4/10/2017	High
GW109602	335138	6254101	18.372	8.4 (1)	13.872	DPI bore search	2/05/2003	Low
GW109601	335142	6254097	18.075	2 (1)	17.675	DPI bore search	2/05/2003	Low
GW109600	335144	6254122	20.508	6.5 (1)	18.208	DPI bore search	2/05/2003	Low
GW109605	335112	6254113	21.117	4 (1)	18.917	DPI bore search	6/05/2003	Low
GW109604	335133	6254111	19.535	1.7 (1)	18.835	DPI bore search	6/05/2003	Low
GW109603	335145	6254110	18.6	5 (1)	16.1	DPI bore search	1/05/2003	Low
GW111234	333787	6258751	80.596	4.5 (1)	78.196	DPI bore search	11/08/2010	Low
GW111233	333774	6258783	81.344	4.3 (1)	79.544	DPI bore search	11/08/2010	Low
GW111232	333770	6258773	81.135	4.5 (1)	78.735	DPI bore search	16/11/2010	Low
GW109305	338343	6257934	2.119	6.1 (1)	0.289	DPI bore search	8/09/2008	Low
GW109290	338347	6257922	2.243	6.1 (1)	0.393	DPI bore search	2/09/2008	Low
GW106770	338301	6257686	2.477	4 (1)	0.477	DPI bore search	3/12/2004	Low
GW108693	338388	6257861	3.498	4 (1)	1.498	DPI bore search	15/05/2007	Low
GW110885	338357	6257783	2.288	6 (1)	0.288	DPI bore search	11/04/2010	Low
GW106733	338342	6257712	3.011	4 (1)	1.011	DPI bore search	2/12/2004	Low
GW106731	338280	6257722	2.765	4 (1)	0.765	DPI bore search	14/01/2005	Low
GW107079	338329	6257676	2.965	4 (1)	0.965	DPI bore search	6/05/2006	Low
GW107863	338380	6257716	3.37	4 (1)	1.37	DPI bore search	16/03/2006	Low
GW111500	338338	6257648	2.927	4 (1)	0.927	DPI bore search	20/06/2003	Low
GW107420	338384	6257702	3.211	4 (1)	1.211	DPI bore search	6/01/2005	Low
GW105470	338338	6257741	2.981	4.5 (1)	0.981	DPI bore search	16/10/2003	Low
GW107895	338357	6257842	2.562	4 (1)	0.562	DPI bore search	13/03/2006	Low
GW105762	338351	6257758	2.44	4 (1)	0.44	DPI bore search	10/01/2004	Low
GW106895	338361	6257709	2.798	4 (1)	0.798	DPI bore search	2/12/2004	Low
GW108645	338336	6257660	2.901	4 (1)	0.901	DPI bore search	8/03/2007	Low
GW108643	338362	6257739	3.124	4 (1)	1.124	DPI bore search	13/03/2007	Low
GW107554	338383	6257726	3.373	4 (1)	1.373	DPI bore search	20/10/2005	Low
GW105597	338331	6257754	2.055	4 (1)	0.055	DPI bore search	15/11/2003	Low
GW106681	338395	6257675	2.661	4 (1)	0.661	DPI bore search	29/09/2004	Low
GW106810	338414	6257768	2.57	4 (1)	0.57	DPI bore search	8/12/2004	Low
GW106527	338349	6257636	3.128	4 (1)	1.128	DPI bore search	29/09/2004	Low
GW023498	330132	6261762	106.04	8.22 (1)	99.34	DPI bore search	7/08/1974	Low
GW023699	328490	6262935	85.753	4.87 (1)	83.053	DPI bore search	1/12/1965	Low
GW114502	333198	6258812	92.569	8 (1)	90.069	DPI bore search	28/10/2010	Low
GW111805	328722	6259920	36.548	12 (1)	27.048	DPI bore search	1/06/2009	Low
GW107745	339873	6262009	13.324	15 (1)	4.324	DPI bore search	13/10/2005	Low
GW100067	337993	6264034	144.865	5.1 (1)	140.565	DPI bore search	22/06/1995	Low
B132_1	332924	6253607	20.56	93.3	0.75	Vibrating wire piezometer - Western	Jul-Nov	High
B132_2	332935	6253616	20.56	48.1	0.50	Vibrating wire piezometer - Western	Jul-Nov	High
B132_3	332924	6253607	20.56	29.1	0.48	Vibrating wire piezometer - Western	Jul-Nov	High
B135_3	335435	6257599	53.93	47.0	13.19	Vibrating wire piezometer - Western	Jul-Nov	High
B156_1	337228	6259860	79.93	50.2	44.80	Vibrating wire piezometer - Western	Jul-Nov	High
B156_2	337228	6259860	79.93	36.4	46.33	Vibrating wire piezometer - Western	Jul-Nov	High

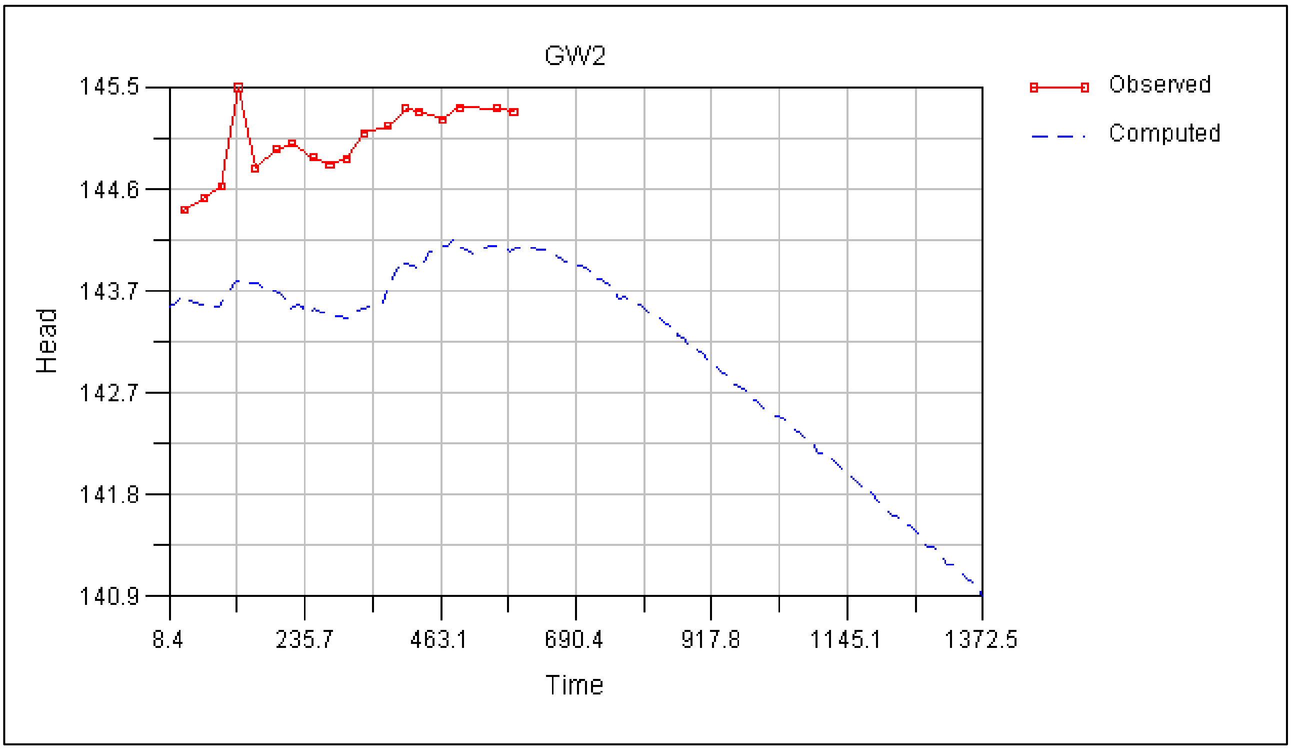
Notes: (1) Assumption: Screen is located at bottom of bore.

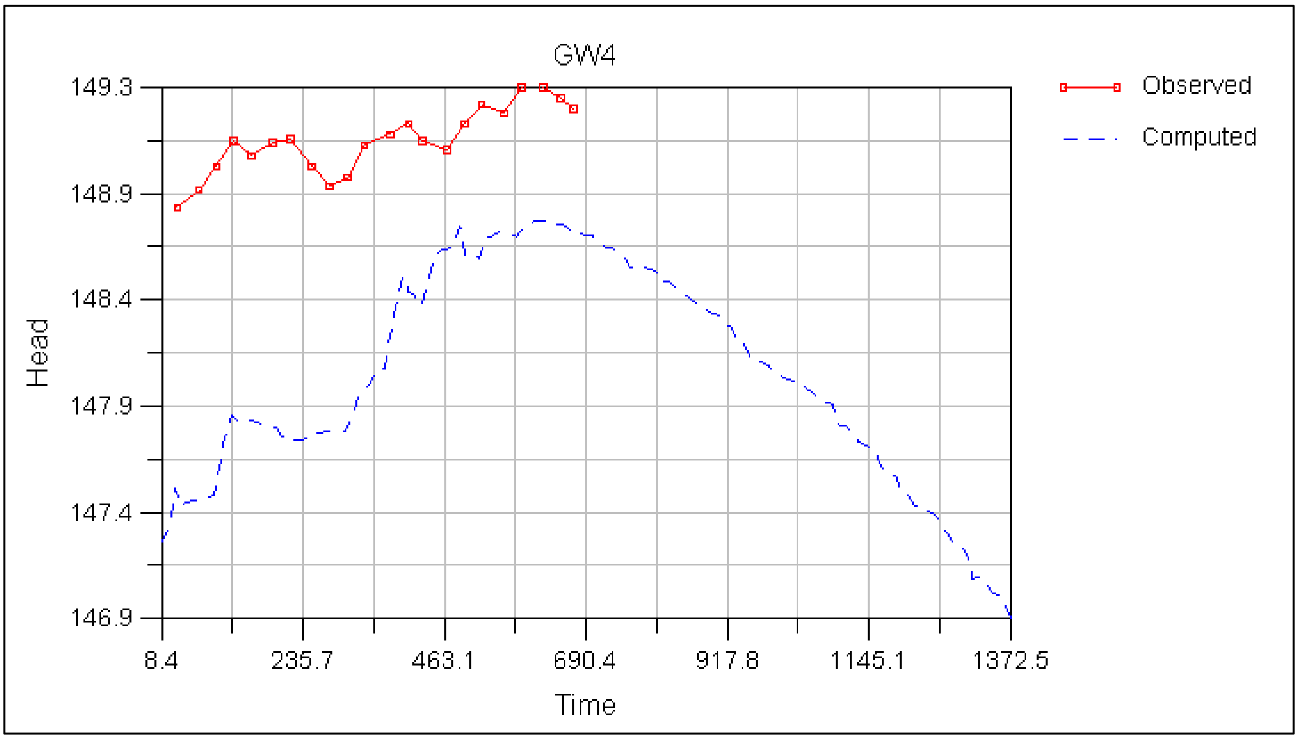
Annexure 4. Calibration Residuals – Steady State North Model

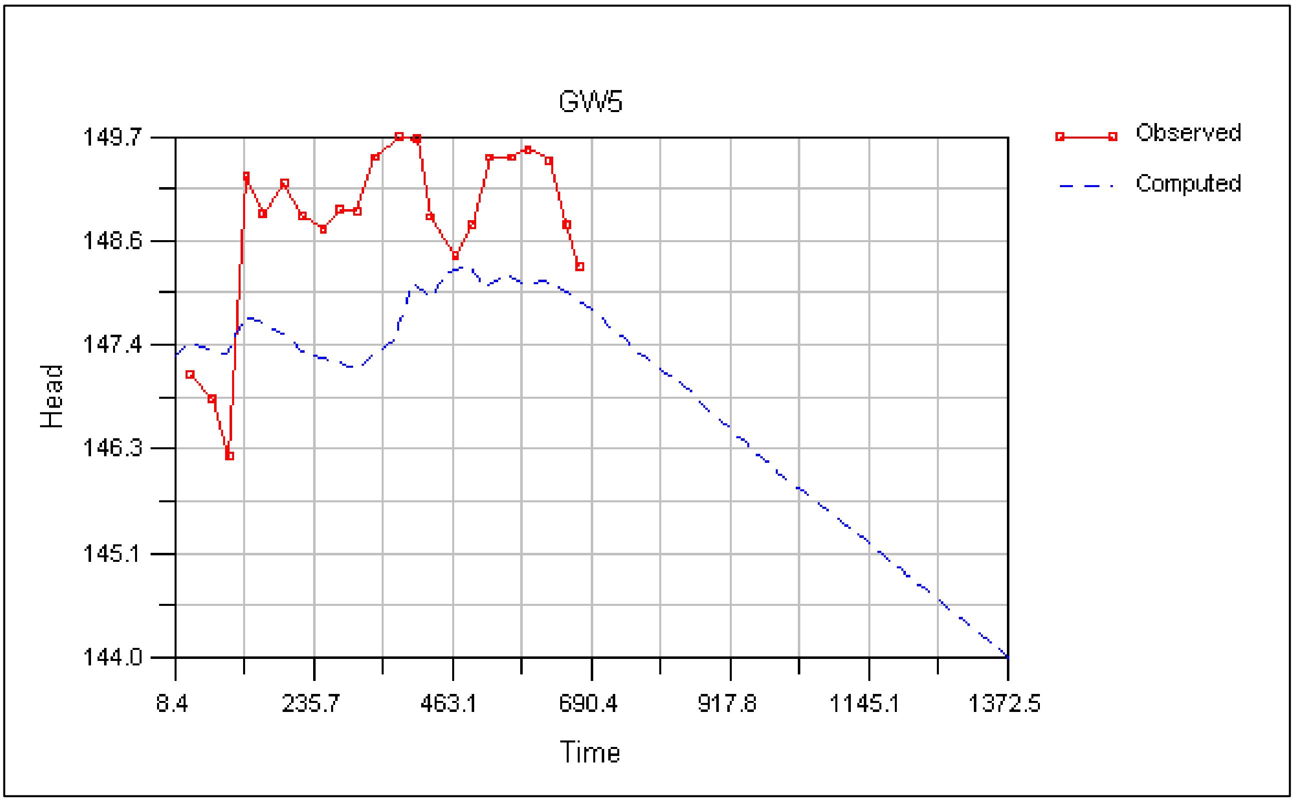
Name	X (mMGA)	Y (mMGA)	Z (mAHD)	Layer	Observed	Computed	Residual
GW106731	338280	6257722	2.765	3	0.77	-0.3	1.07
GW105597	338331	6257754	2.055	4	0.06	-0.27	0.32
GW105762	338351	6257758	2.44	3	0.44	0.07	0.36
B132_2	332935	6253616	20.56	6	0.5	0.15	0.16
GW107895	338357	6257842	2.562	3	0.56	0.25	0.29
GW106770	338301	6257686	2.477	4	0.48	0.37	0.10
GW106733	338342	6257712	3.011	4	1.01	0.39	0.62
B132_1	332924	6253607	20.56	7	0.34	0.4	-1.62
GW108643	338362	6257739	3.124	4	1.12	0.8	0.32
B132_3	332924	6253607	20.56	2	0.48	1.02	-0.81
GW106895	338361	6257709	2.798	4	0.8	1.09	-0.30
B138	337119	6258385	65.671	6	1.64	1.91	-1.22
GW105470	338338	6257741	2.981	5	0.98	2.1	-1.44
B238	336173	6257786	38.91	7	2.93	2.26	0.20
GW107079	338329	6257676	2.965	5	0.97	2.75	-2.07
GW110885	338357	6257783	2.288	5	0.29	2.79	-2.91
GW108645	338336	6257660	2.901	5	0.9	3.19	-2.61
GW111500	338338	6257648	2.927	5	0.93	3.46	-2.84
B140	337516	6258803	92.37	2	4.62	3.75	-0.62
GW106527	338349	6257636	3.128	5	1.13	4.13	-3.34
GW107863	338380	6257716	3.37	5	1.37	4.57	-3.66
GW107554	338383	6257726	3.373	5	1.37	4.71	-3.82
GW107420	338384	6257702	3.211	5	1.21	4.96	-4.22
GW106681	338395	6257675	2.661	5	0.66	5.82	-5.67
GW108693	338388	6257861	3.498	5	1.5	6.84	-6.15
GW109290	338347	6257922	2.243	5	0.39	6.97	-7.50
GW106810	338414	6257768	2.57	5	0.57	7.06	-7.17
GW109305	338343	6257934	2.119	5	0.29	7.17	-7.86
B112	333240	6254091	15.99	7	6.6	7.39	-5.02
B135_3	335435	6257599	53.93	3	14.24	11.15	-0.52
GW109601	335142	6254097	18.075	6	17.68	14.31	-0.58
GW109602	335138	6254101	18.372	6	13.87	14.42	-4.56
GW109603	335145	6254110	18.6	6	16.1	14.68	-2.77
GW109605	335112	6254113	21.117	6	18.92	14.7	0.06
GW109600	335144	6254122	20.508	6	18.21	14.97	-1.19
GW109604	335133	6254111	19.535	5	18.84	18.24	-1.91
B134A-c	333868	6257112	45.63	5	19.17	25.1	-4.75
B128	338487	6259592	63.47	6	27.61	25.23	1.39
B134A-b	333870	6257108	45.67	3	22.28	25.55	-0.64
B127A	338070	6259609	49.46	6	31.67	26.38	2.60
B156_2	337228	6259860	79.93	3	34	27.26	-1.36
B154	333821	6257311	56.29	3	25.14	28.19	-4.75
GW111805	328722	6259920	36.548	1	27.05	28.77	-1.72
B133	333489	6254554	60.97	7	36.56	32.11	5.06
B156_1	337228	6259860	79.93	6	44.41	35.2	1.13
SRT_BH017	334111	6254365	62.9	6	43.6	37.03	1.15
B114A	332643	6257062	74.36	3	49.05	48.63	0.53
B150	334252	6254834	80.08	5	67.62	70.55	-1.78
GW111234	333787	6258751	80.596	1	78.2	75.79	2.25

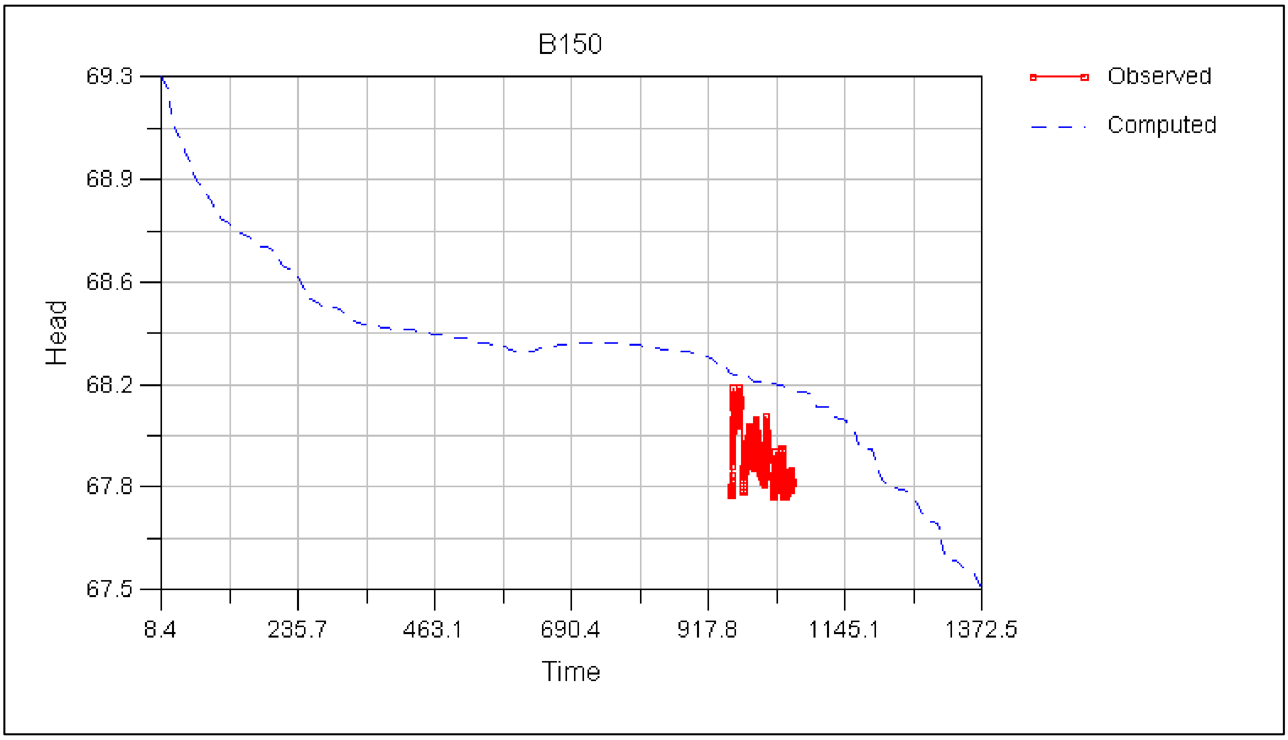
Name	X (mMGA)	Y (mMGA)	Z (mAHD)	Layer	Observed	Computed	Residual
GW111233	333774	6258783	81.344	1	79.54	76.47	2.92
GW111232	333770	6258773	81.135	1	78.74	76.47	2.11
SRT_BH019	333308	6255819	84.43	1	81.81	78.76	6.78
SRT_BH018	333390	6255706	90.75	2	77.66	78.95	1.97
GW023699	328490	6262935	85.753	1	83.05	82.76	0.29
GW114502	333198	6258812	92.569	2	90.07	90.11	-0.62
GW023498	330132	6261762	106.04	1	99.34	99.94	-0.60
B173	336683	6261687	114	1	101.67	104.3	-2.65
B174	336546	6262050	121.94	6	119.54	115.63	8.86
B175	336334	6263123	121.05	1	118.39	117.97	0.27
GW6	335324	6264099	150.57	1	130.26	125.61	4.83
GW8	336698	6263502	130.87	2	129.41	132.94	-7.97
GW100067	337993	6264034	144.865	1	140.57	133.61	6.12
GW1	335472	6264060	149.08	2	143.23	133.64	9.95
GW10	335727	6263897	151.73	2	147.5	138.88	8.92
GW9	336363	6263849	148.4	2	144.42	141.09	-0.17
GW10a	335921	6263886	151.73	1	150.19	141.71	8.31
GW4	336410	6263945	151.75	2	149.07	143.08	1.97
GW2	335852	6264028	148.96	2	145.18	143.32	1.69
GW5	337131	6263848	156.86	2	148.55	143.68	1.28

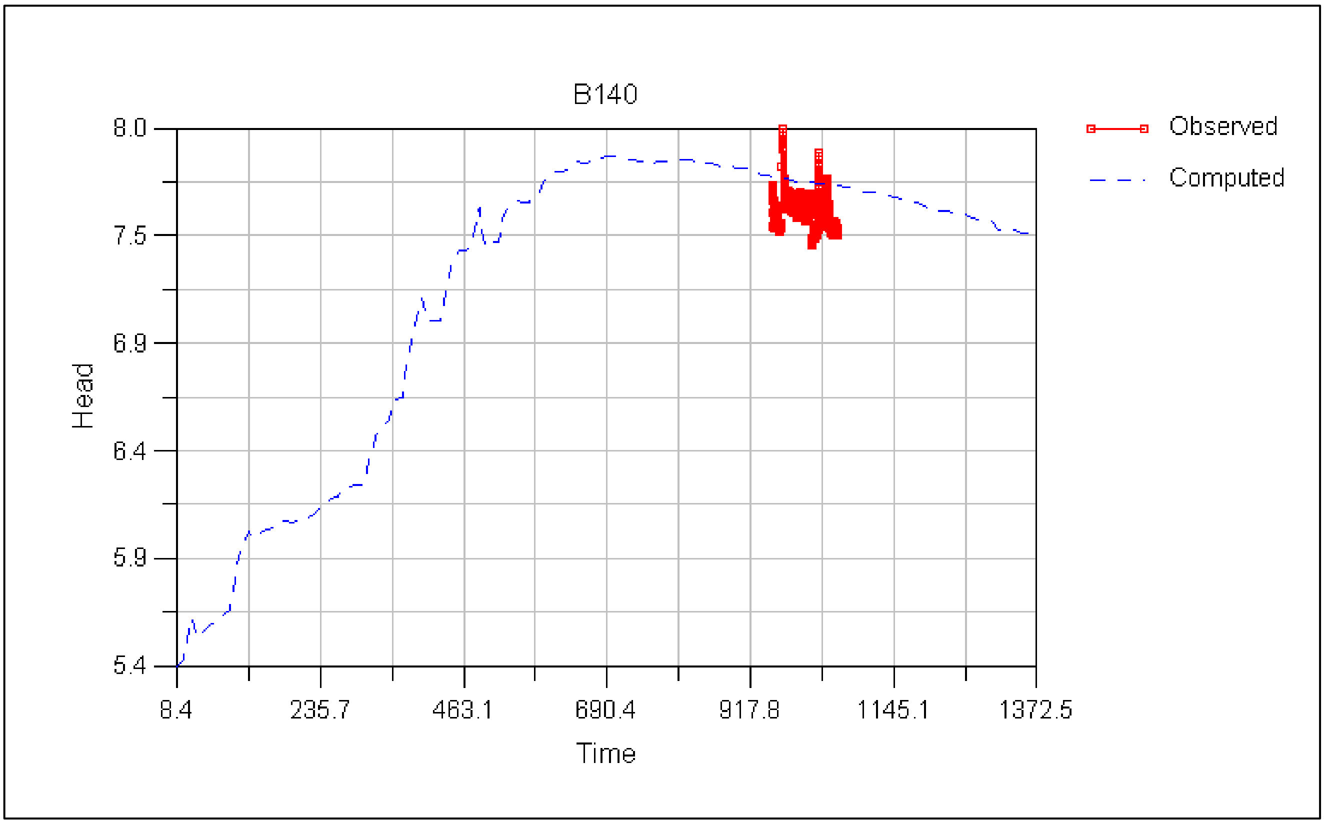
Annexure 5. Calibration Hydrographs – Transient North Model

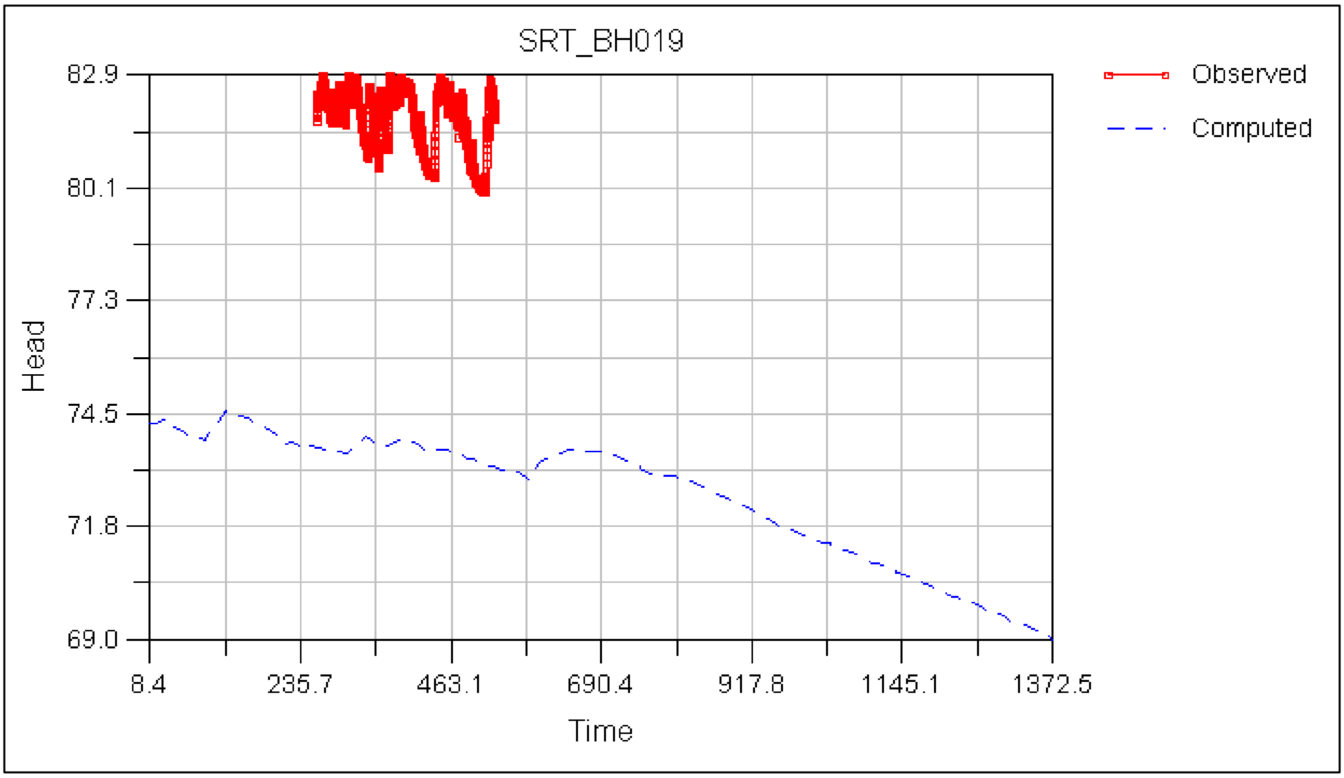

GW2
145.5
144.6
143.7
142.7
141.8
140.9
Head
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed

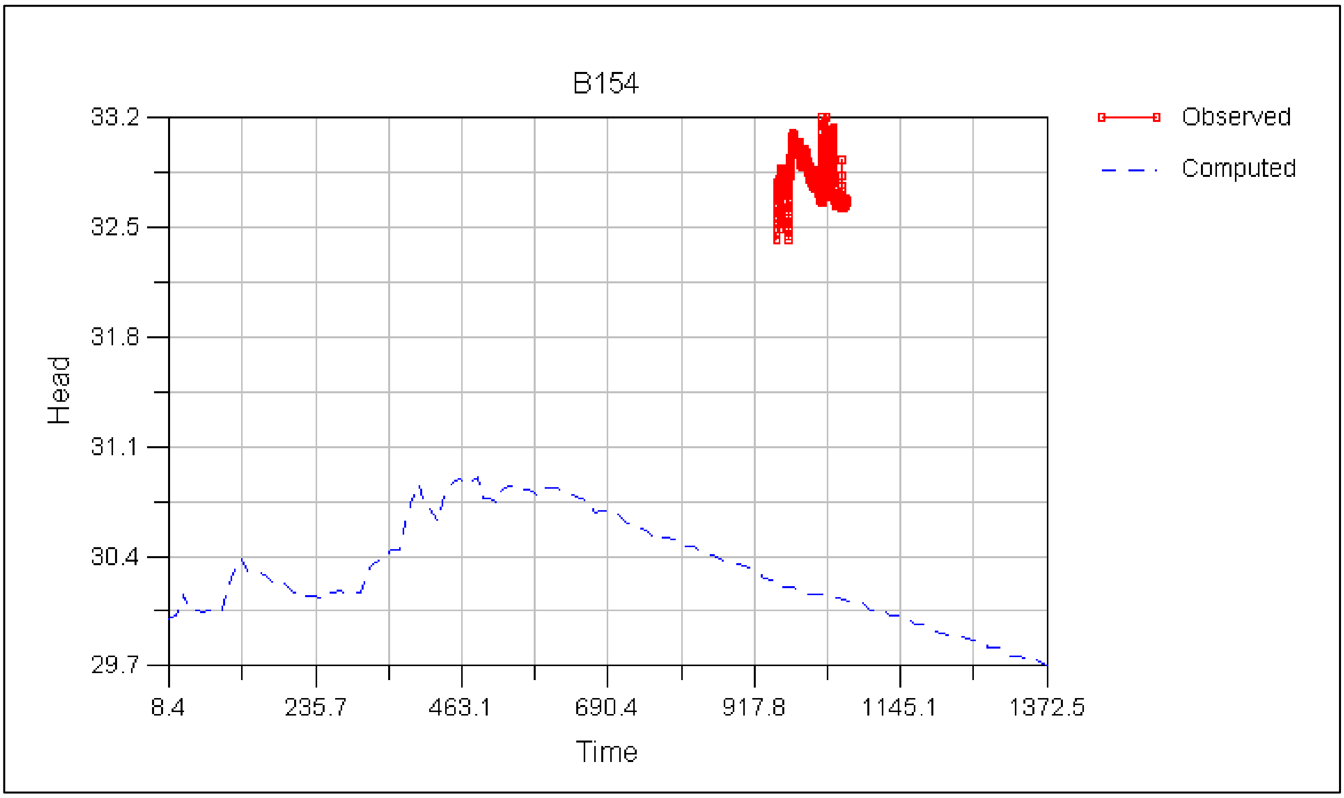

GW4
149.3
148.9
148.4
147.9
147.4
146.9
Head
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed

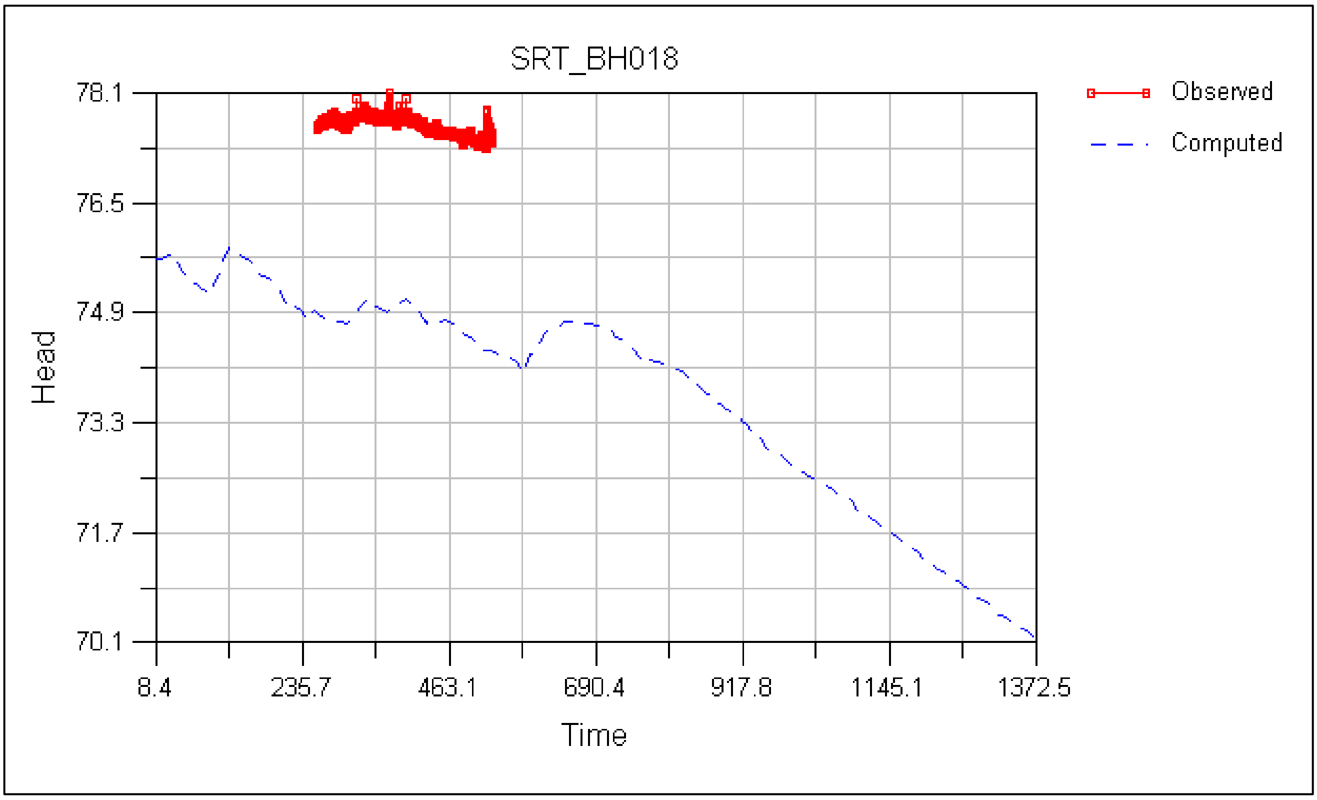

GW5
Observed
Computed
149.7
148.6
147.4
146.3
145.1
144.0
Head
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time

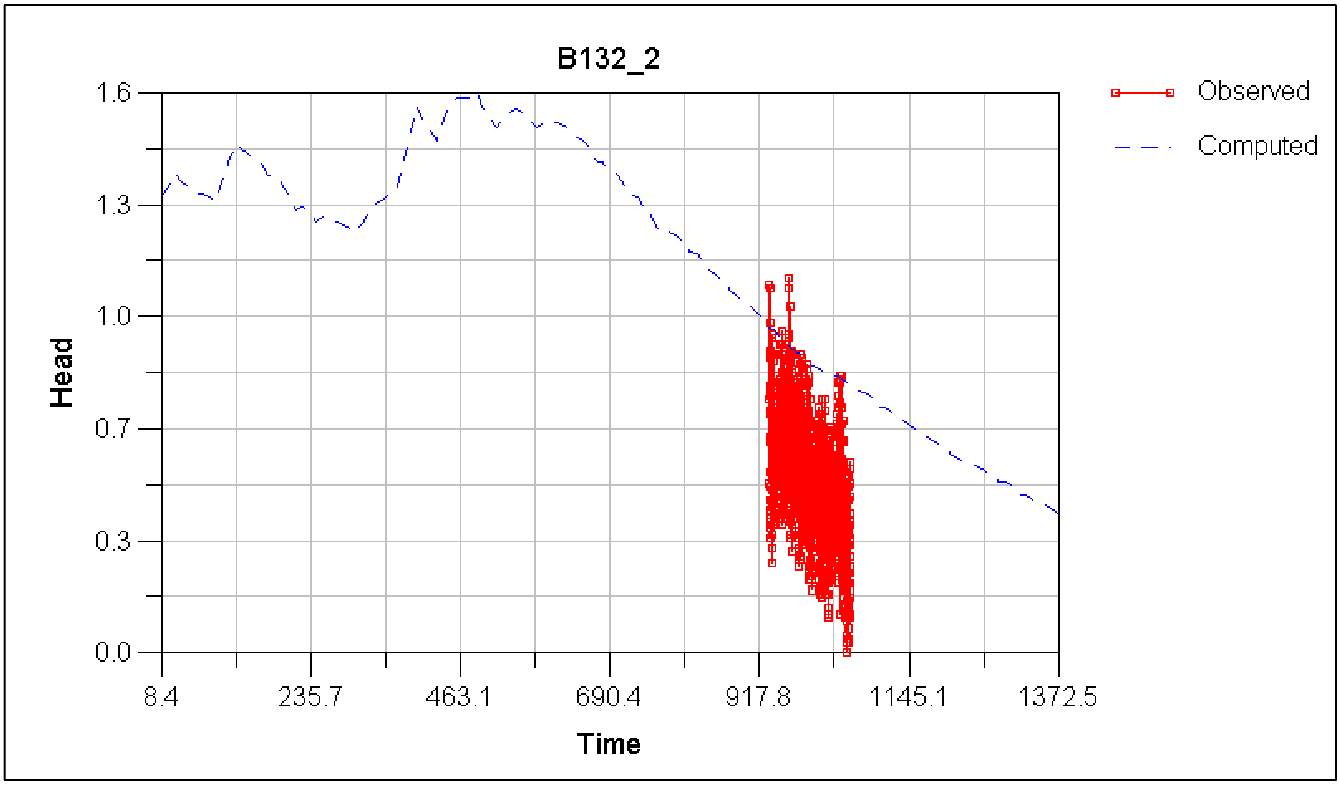

B150
Observed
Computed
69.3
68.9
68.6
68.2
67.8
67.5
Head
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time

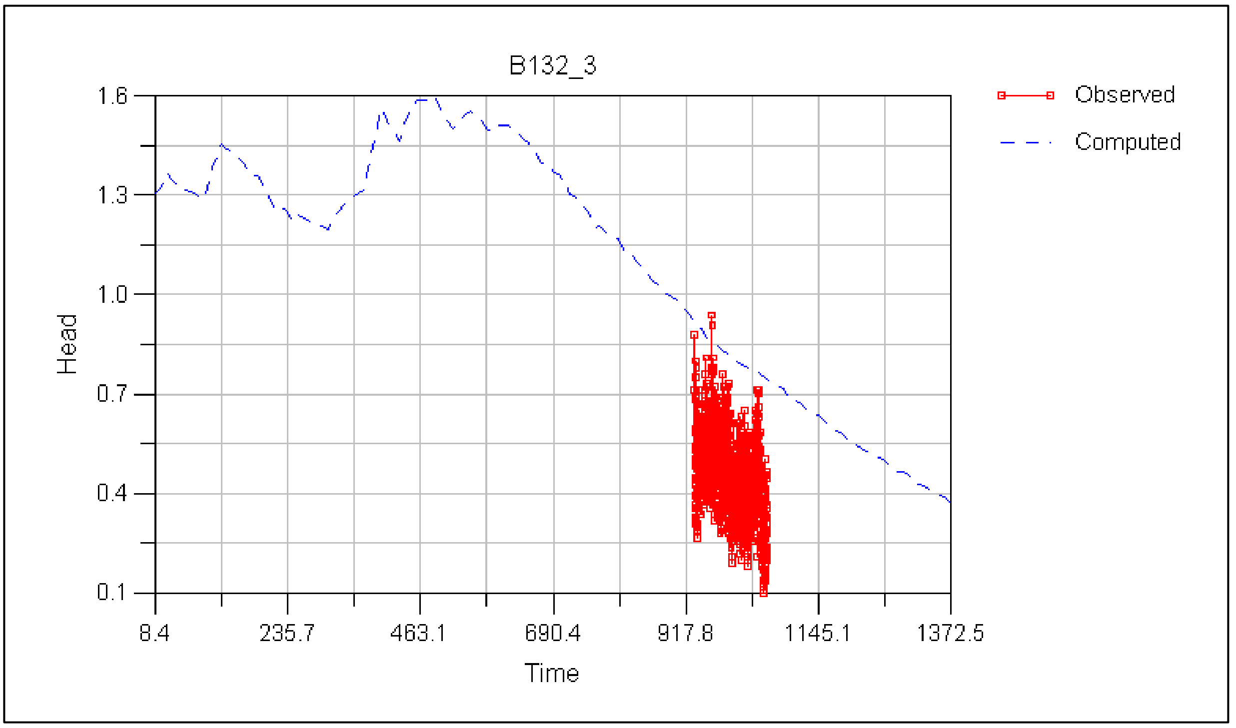

B140
Observed
Computed
Head
Time
8.0
7.5
6.9
6.4
5.9
5.4
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5

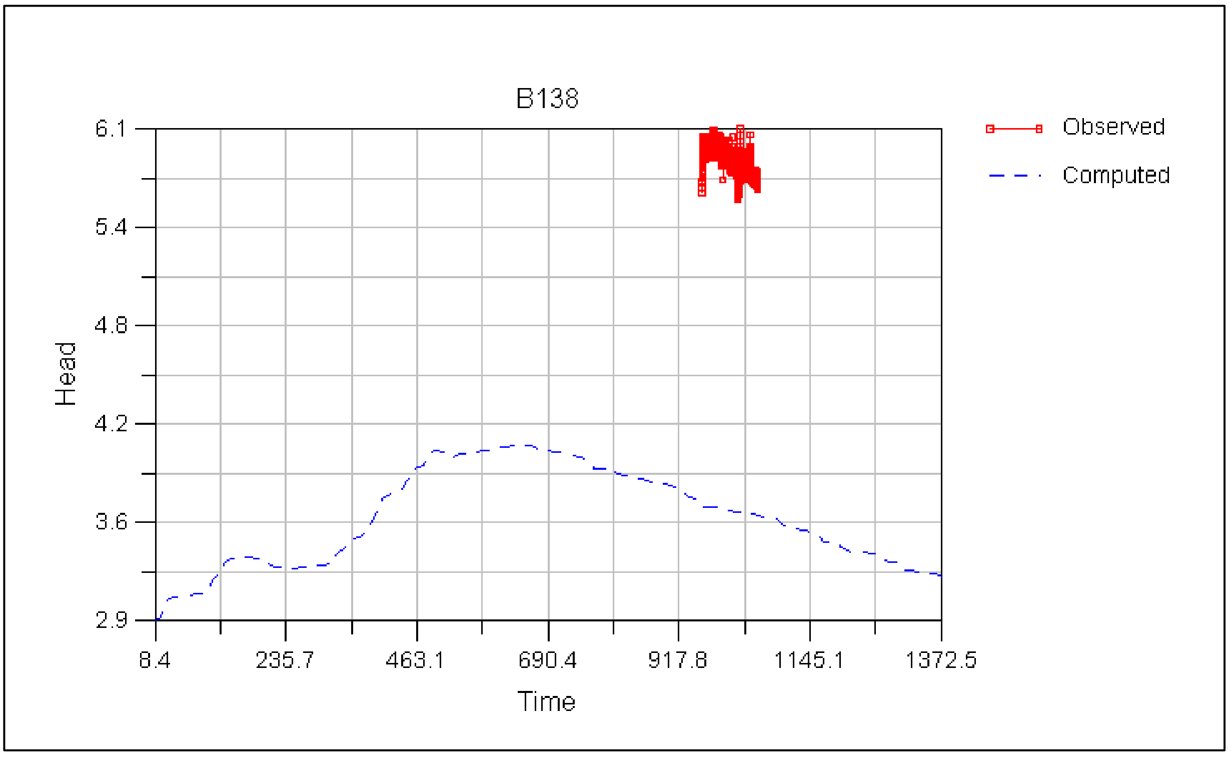

SRT_BH019
Observed
Computed
Head
Time
82.9
80.1
77.3
74.5
71.8
69.0
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5

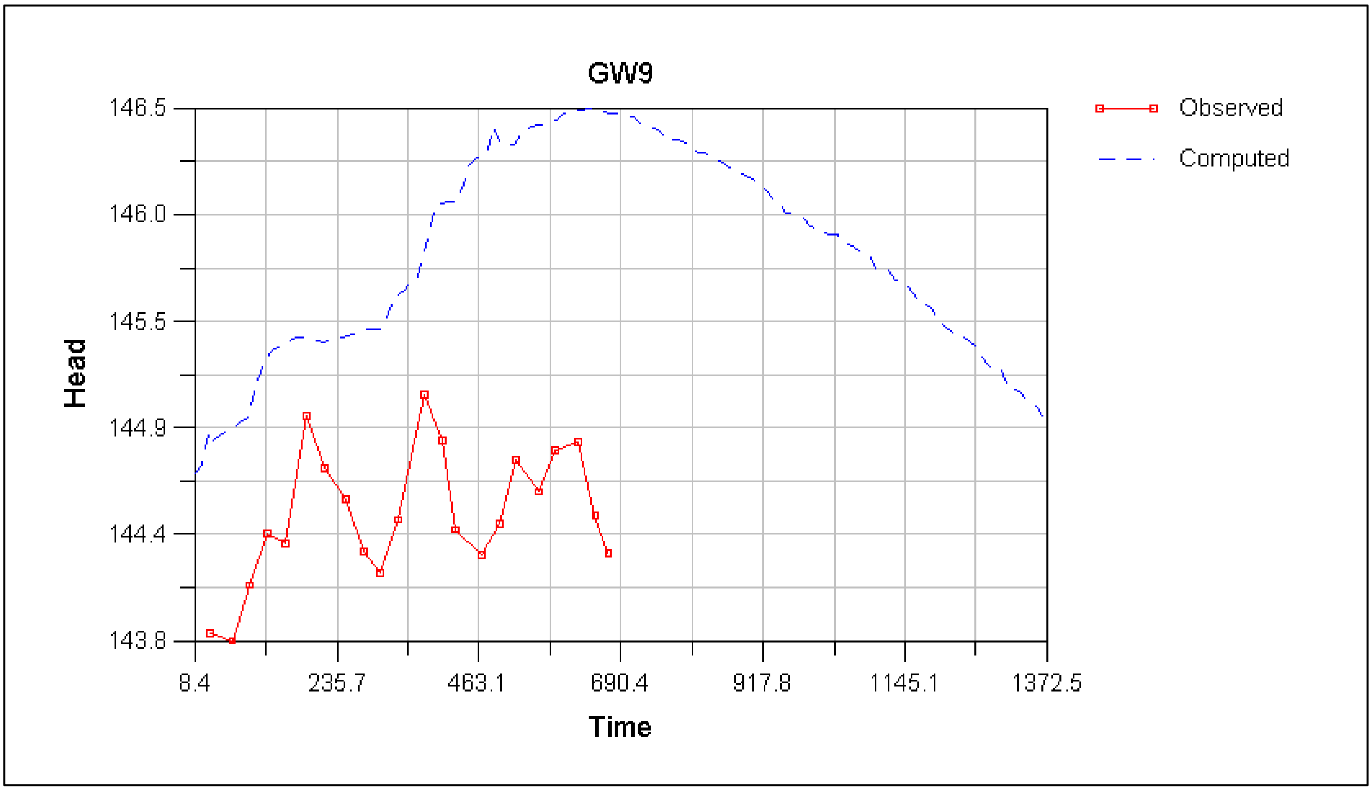

B154
33.2
32.5
31.8
31.1
30.4
29.7
Head
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed

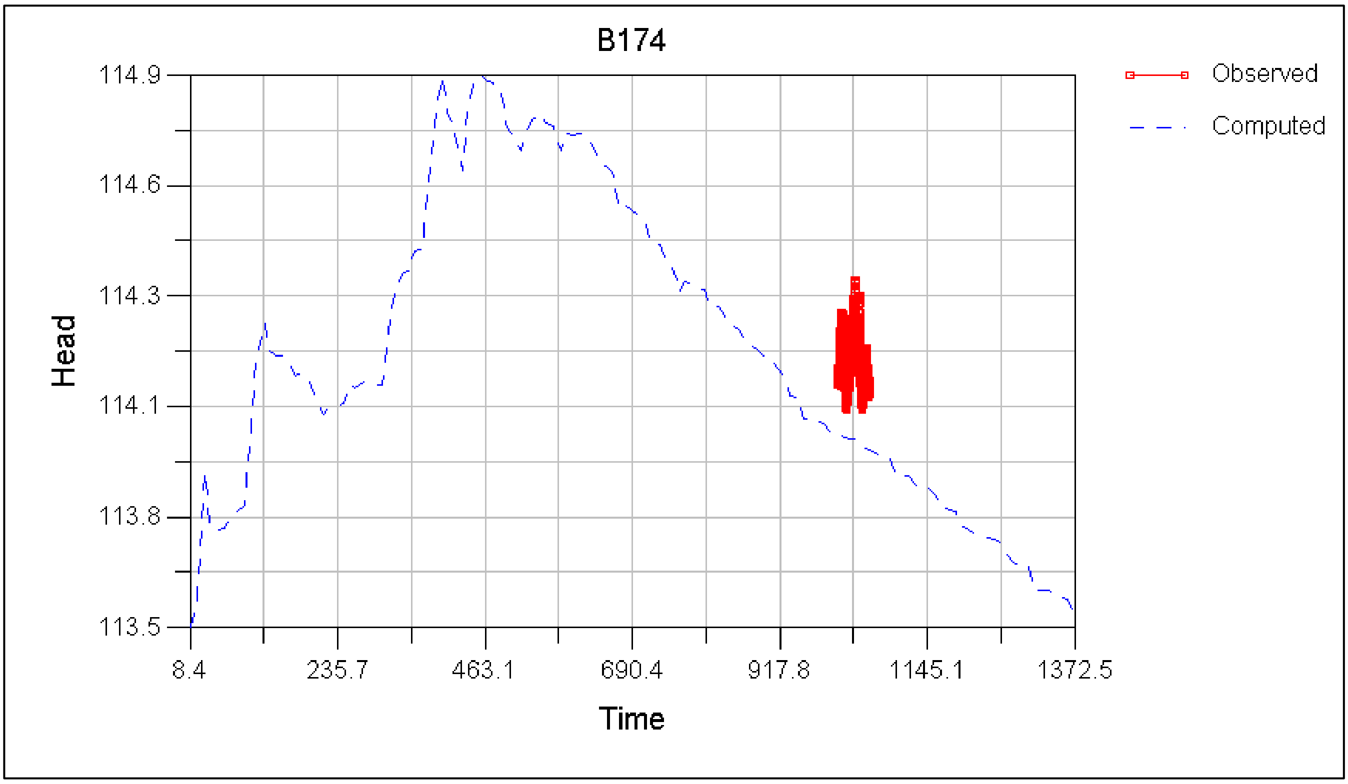

SRT_BH018
78.1
76.5
74.9
73.3
71.7
70.1
Head
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed

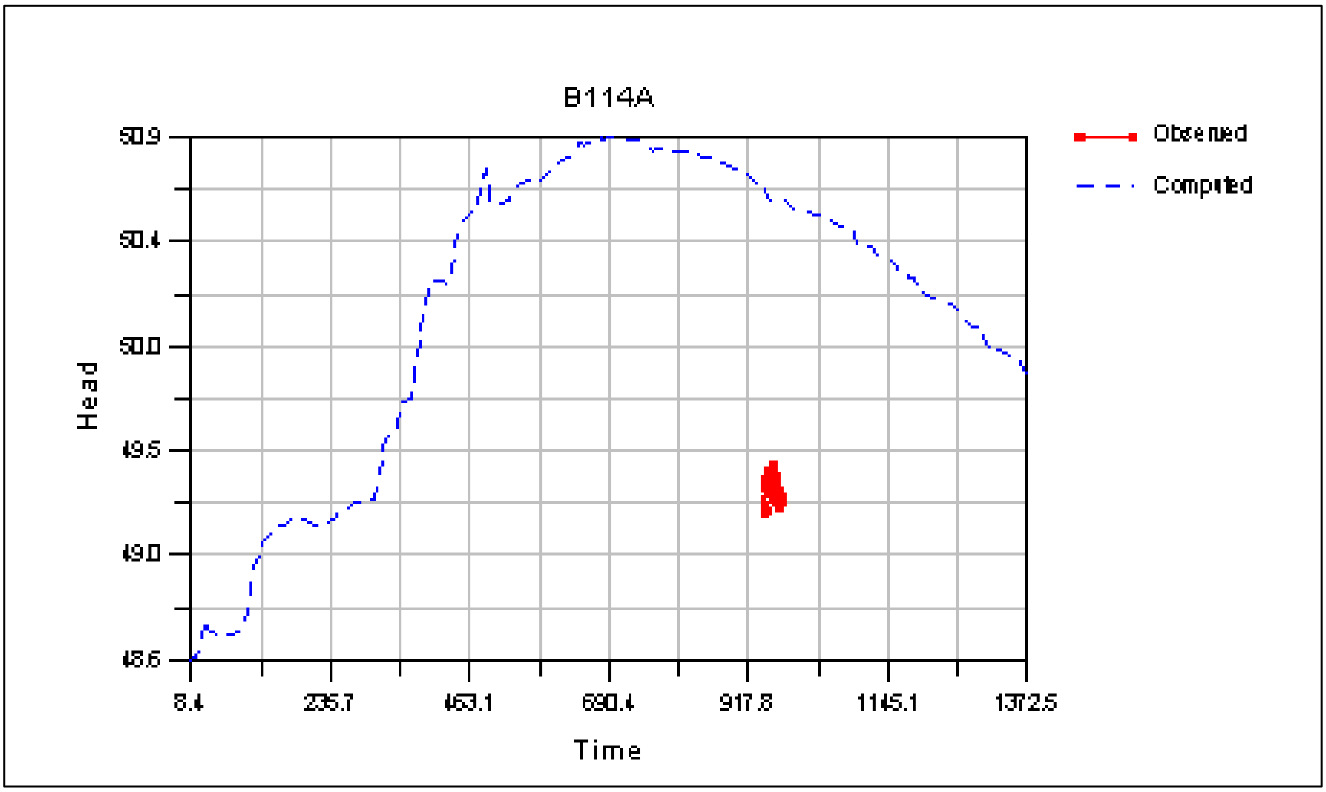

B132_2
Observed
Computed
Head
1.6
1.3
1.0
0.7
0.3
0.0
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time

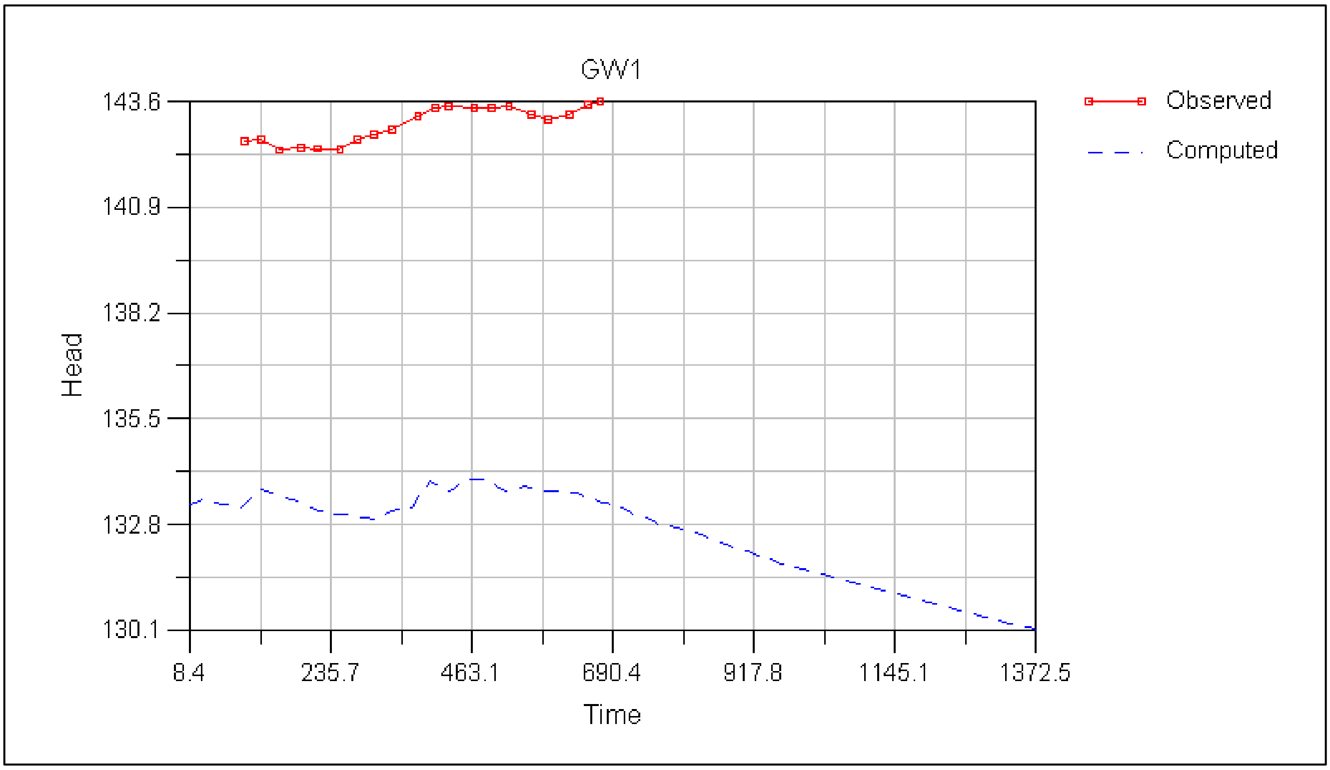

B132_3
Observed
Computed
Head
1.6
1.3
1.0
0.7
0.4
0.1
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time

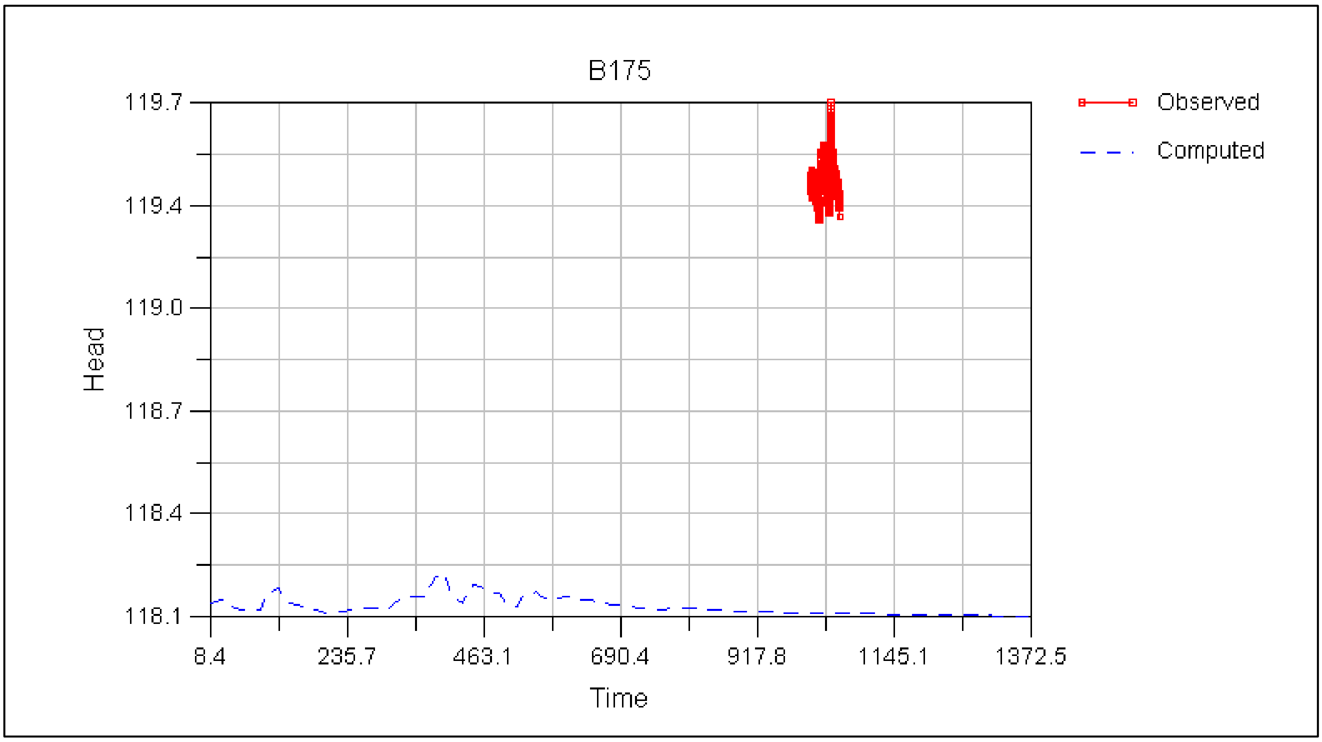

B138
Observed
Computed
Head
6.1
5.4
4.8
4.2
3.6
2.9
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time

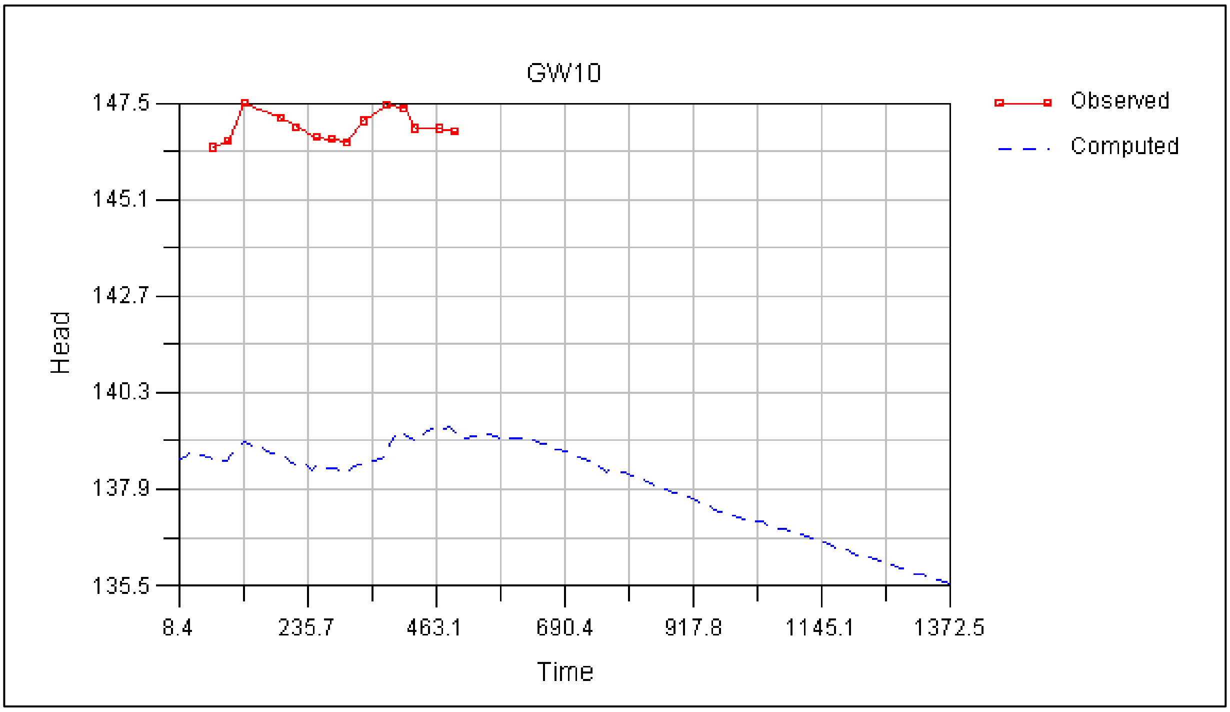

GW9
146.5
146.0
145.5
144.9
144.4
143.8
Head
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed

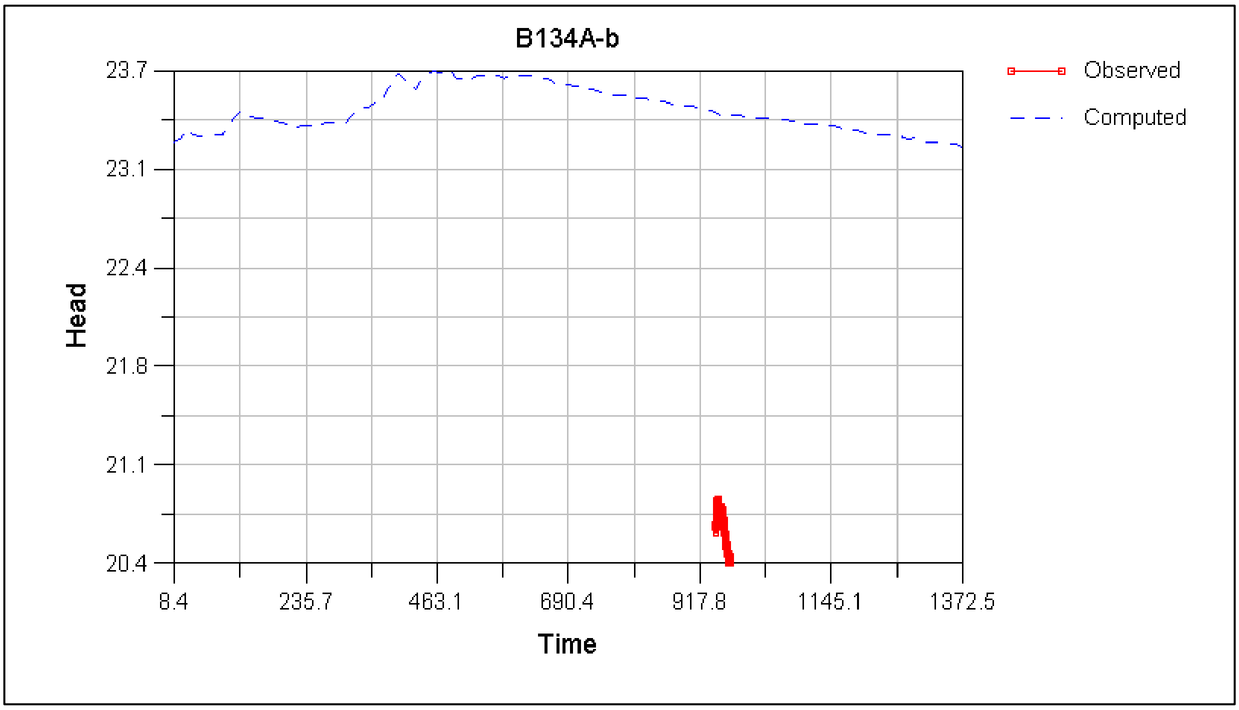

B174
114.9
114.6
114.3
114.1
113.8
113.5
Head
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed

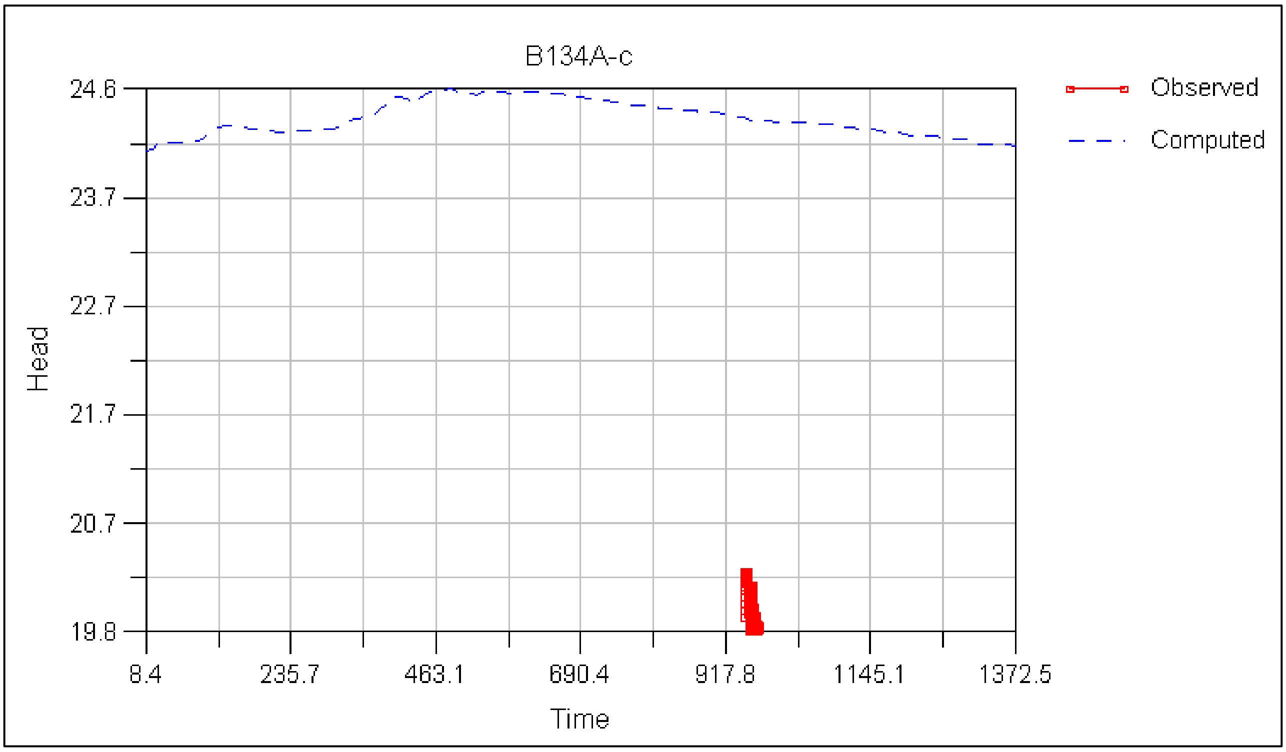

B114A
50.9
50.4
50.0
49.5
49.0
48.6
Head
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed

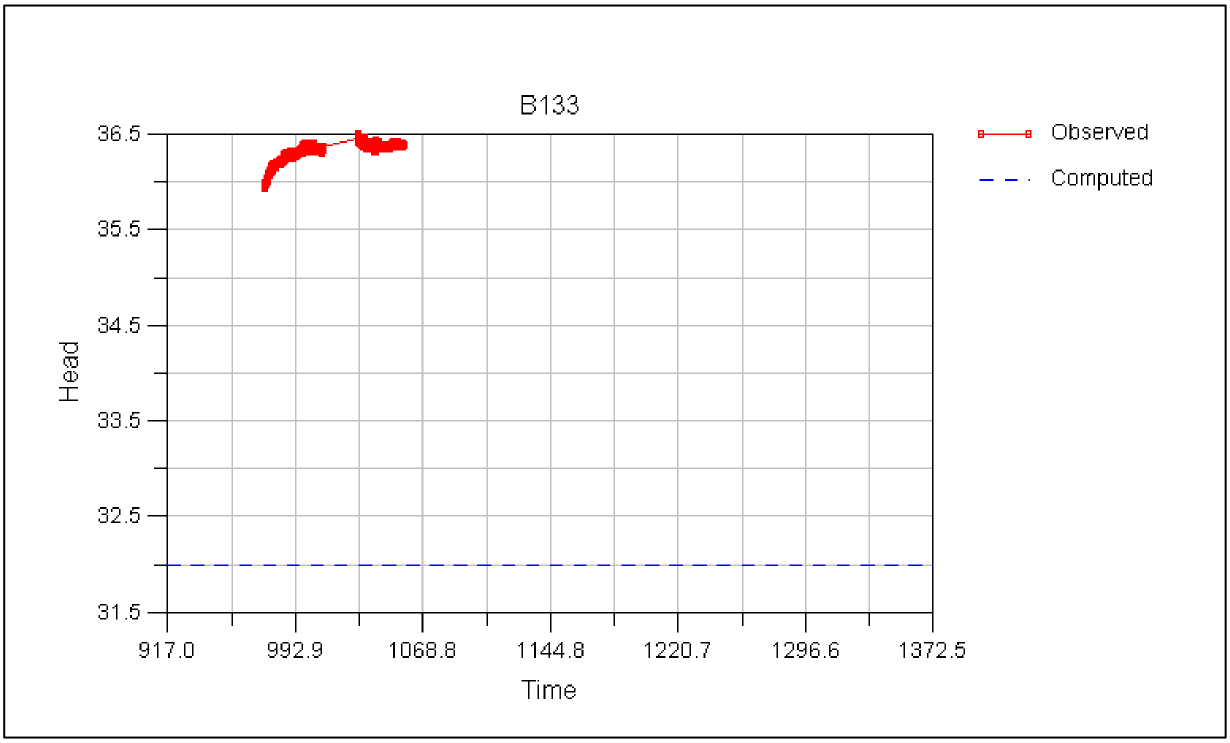

GW1
143.6
140.9
138.2
135.5
132.8
130.1
Head
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed

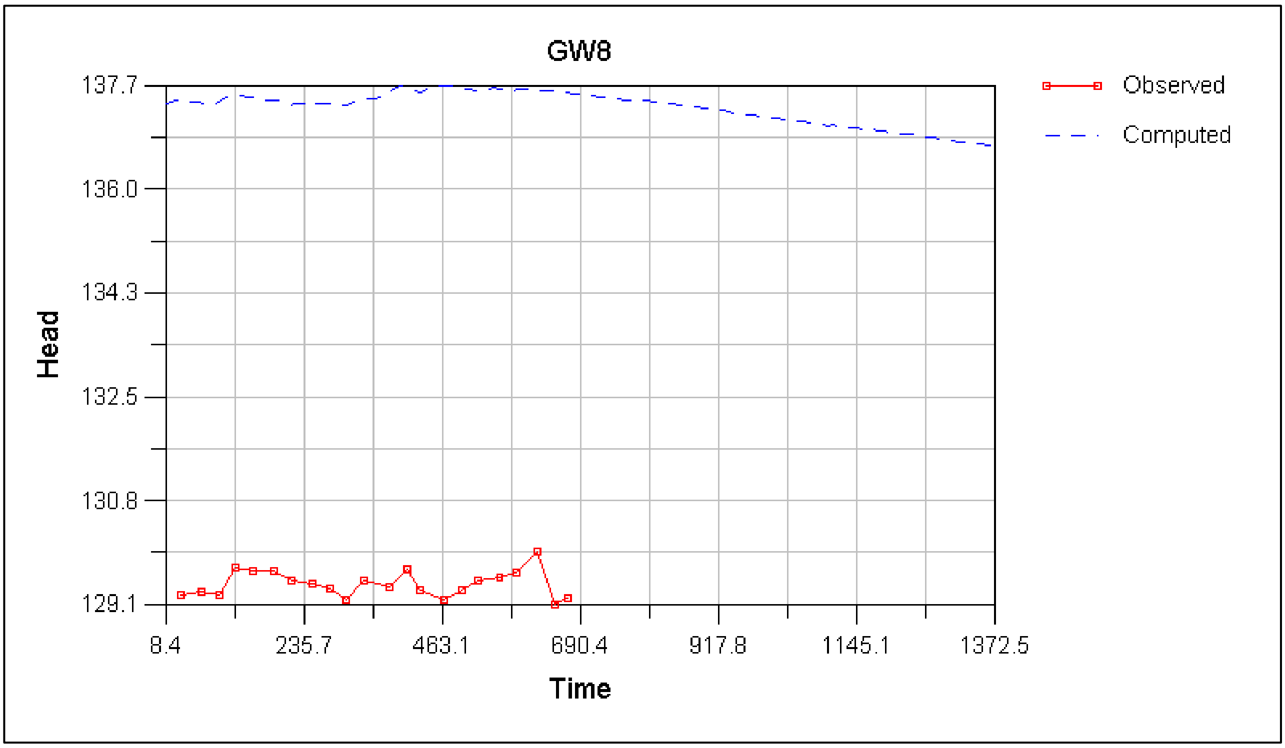

B175
119.7
119.4
119.0
118.7
118.4
118.1
Head
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed

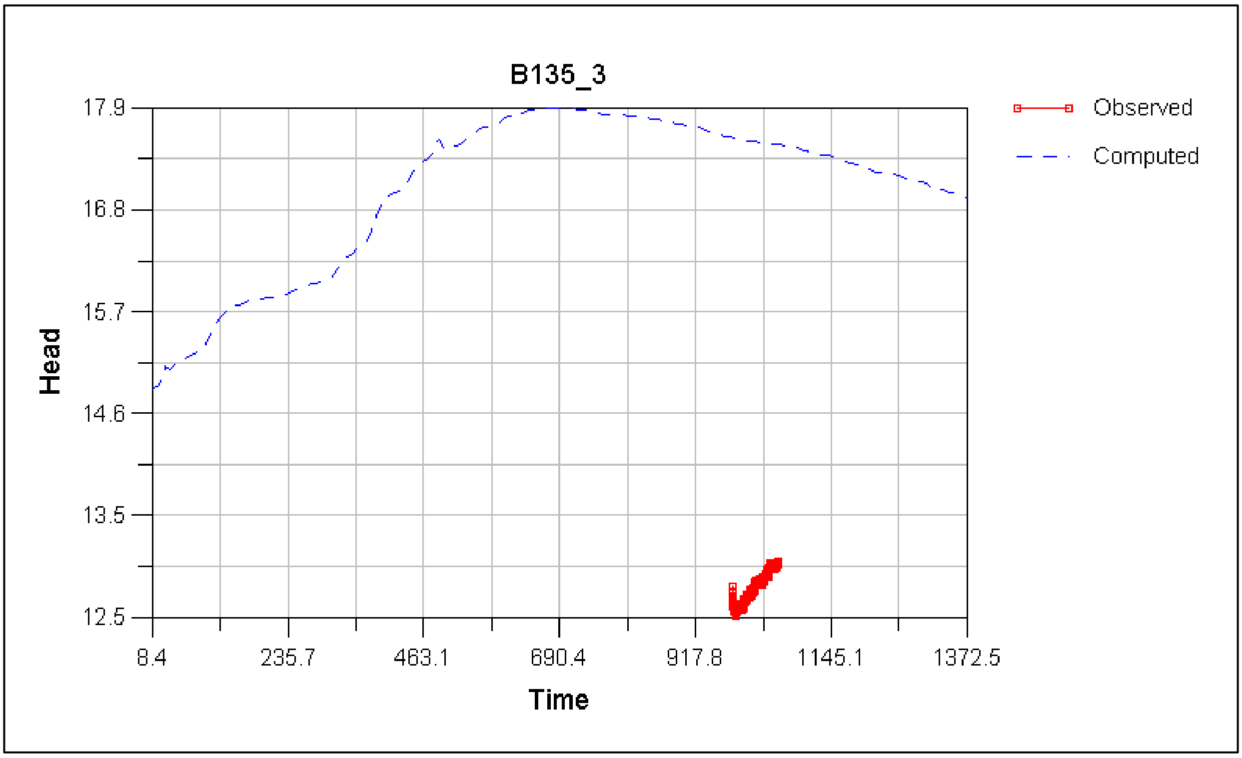

GW10
147.5
145.1
142.7
140.3
137.9
135.5
Head
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed

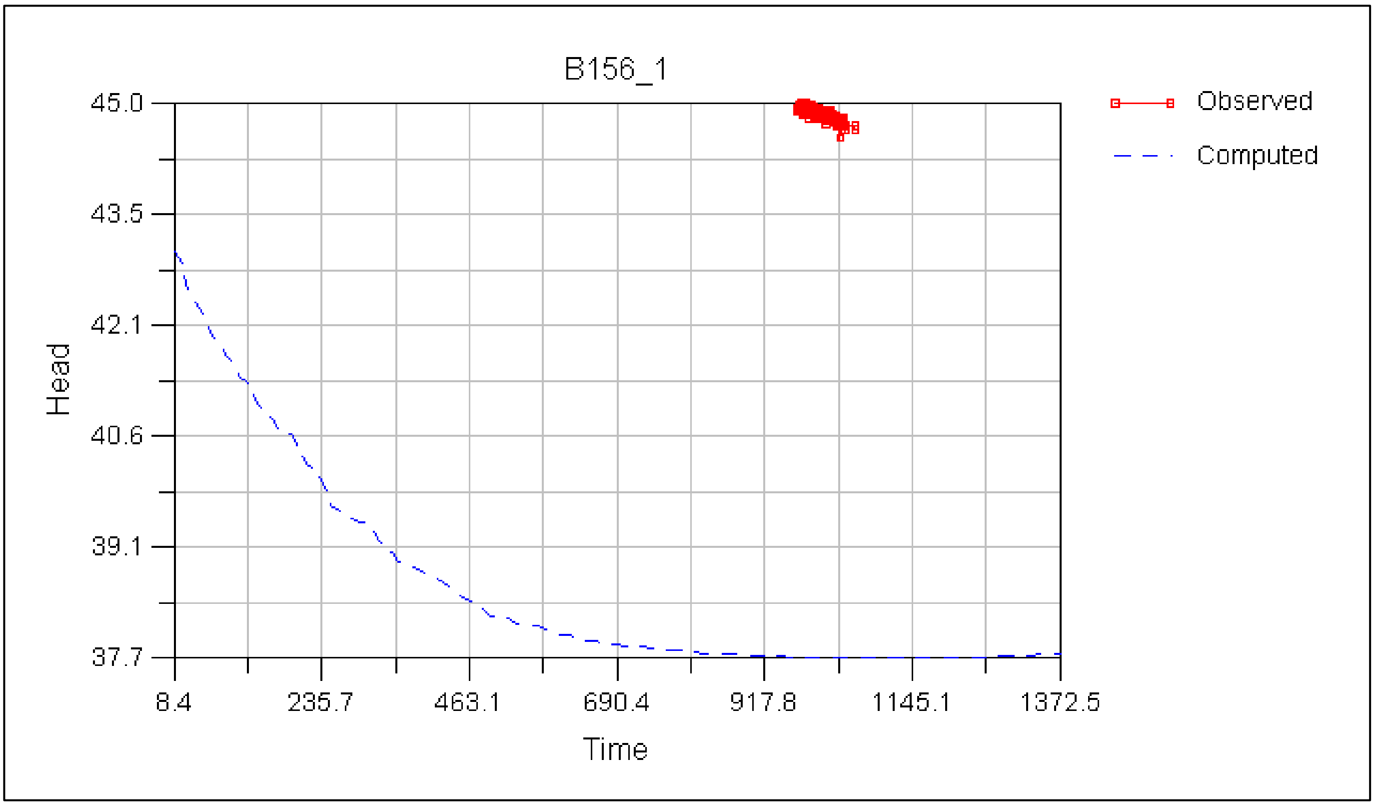

B134A-b
Observed
Computed
Head
23.7
23.1
22.4
21.8
21.1
20.4
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time

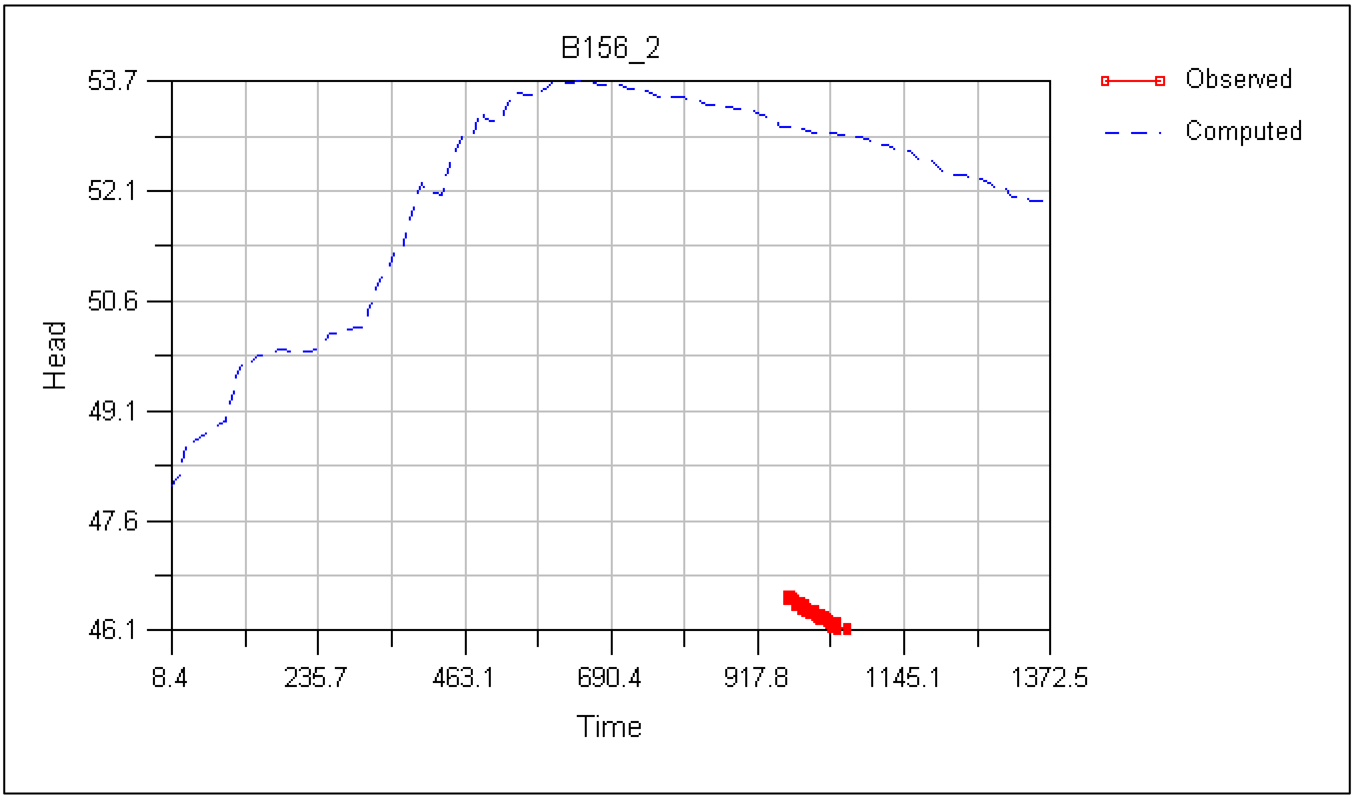

B134A-c
Observed
Computed
Head
24.6
23.7
22.7
21.7
20.7
19.8
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


B133
Observed
Computed
Head
36.5
35.5
34.5
33.5
32.5
31.5
917.0
992.9
1068.8
1144.8
1220.7
1296.6
1372.5
Time


GW8
Observed
Computed
Head
137.7
136.0
134.3
132.5
130.8
129.1
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


B135_3
Observed
Computed
Head
17.9
16.8
15.7
14.6
13.5
12.5
Time
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5


B156_1
Observed
Computed
Head
45.0
43.5
42.1
40.6
39.1
37.7
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


B156_2
Observed
Computed
Head
53.7
52.1
50.6
49.1
47.6
46.1
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time

Annexure 6. Calibration Bore Information – Steady State South Model

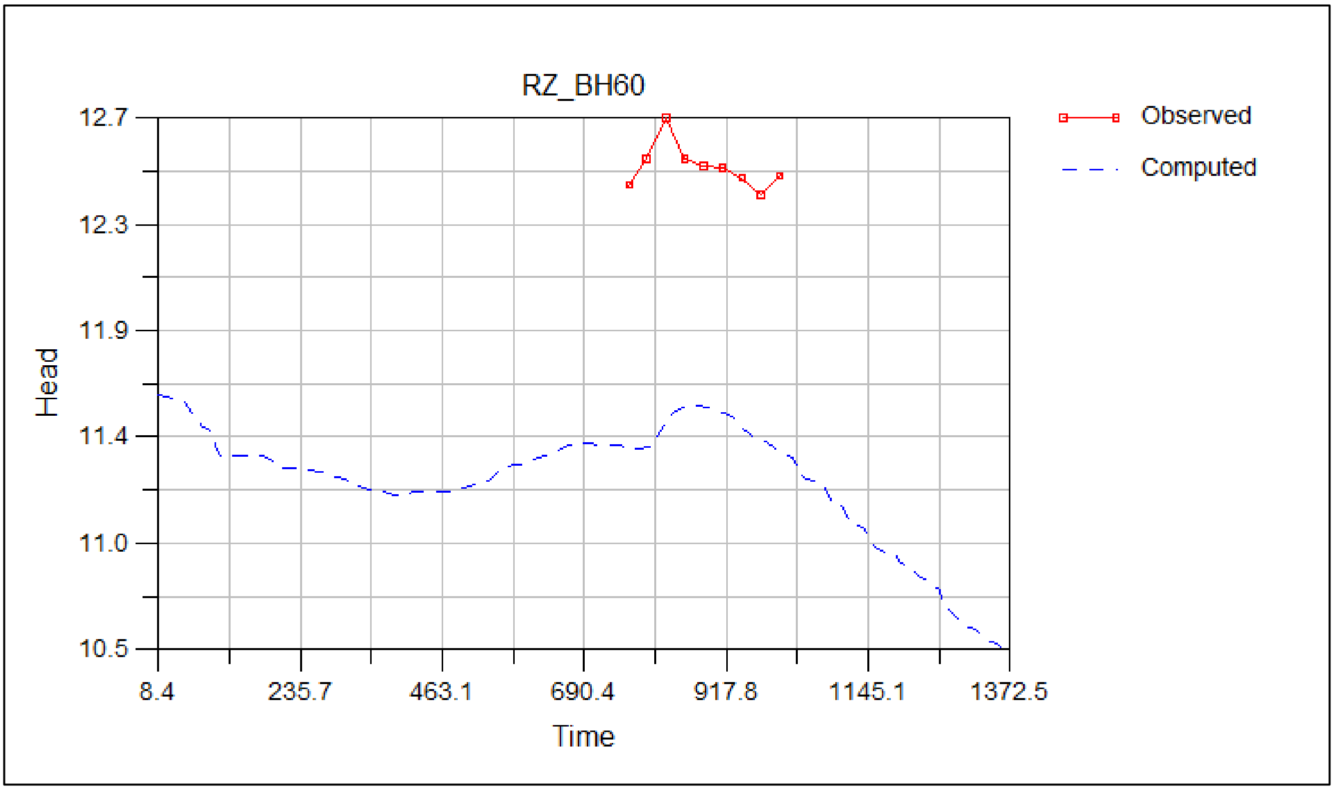
Name	Easting	Northing	Elevation (mAHD)	Screen (mBGL)	Project	Period	Suitability for calibration
B209	331520.7	6252619.2	37.29	77.5-83.5	Western Harbour Tunnel - GDP	Sep 2017 - June 2018	High
B104A	331665.8	6252920.8	7.59	39.7-43.7	Western Harbour Tunnel - GDP	Sep 2017 - June 2018	High
RZ_BH60	330317.83	6250589.57	24.96	56-59	M4-M5_Monthly	Jul 2016 - Aug 2017	High
EP_BH06	331025.39	6250903.92	7.6	10 to 13	M4-M5_Monthly	Jul 2016 - Aug 2017	High
EP_BH07	331082.28	6250898.8	10.48	10 to 13	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH26	331066.28	6250835.05	2.84	20-23	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH28d	331126.56	6250818.78	2.83	27-30	M4-M5_Monthly	Jul 2016 - Aug 2017	High
TC_BH07d	330746.03	6250373.57	2.03	19-22	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH51	331206.58	6250813.32	2.15	19-22	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH30	331192.9	6250834.96	2.04	16-19	M4-M5_Monthly	Jul 2016 - Aug 2017	High
TC_BH06s	330610.16	6250298.14	2.65	4.5-7.5	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH52	331163.77	6250784.58	2.53	32-35	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH47s	331027.87	6250703.96	2.5	15-18	M4-M5_Monthly	Jul 2016 - Aug 2017	High
TC_BH08s	330818.34	6250435.89	2.24	5 to 8	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH44d	330885.77	6250613.96	2.29	25-28	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH47d	331025.23	6250701.67	2.3	27-30	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH19	330822.45	6250626.95	2.46	19-22	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH44s	330884.43	6250613.29	2.25	12 to 15	M4-M5_Monthly	Jul 2016 - Aug 2017	High
TC_BH09d	330830.31	6250444.46	2.25	5 to 8	M4-M5_Monthly	Jul 2016 - Aug 2017	High
IC_BH01	330514.22	6251504.54	26.77	23-26	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH01d	330608.87	6250381.26	6.3	22-25	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH01s	330611.47	6250381.61	6.39	7 to 10	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH15	330522.59	6250349.91	6.02	18-21	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH16d	330609.43	6250409.41	5.82	17-20	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH49s	330730.38	6250461.58	5.99	13-16	M4-M5_Monthly	Jul 2016 - Aug 2017	High

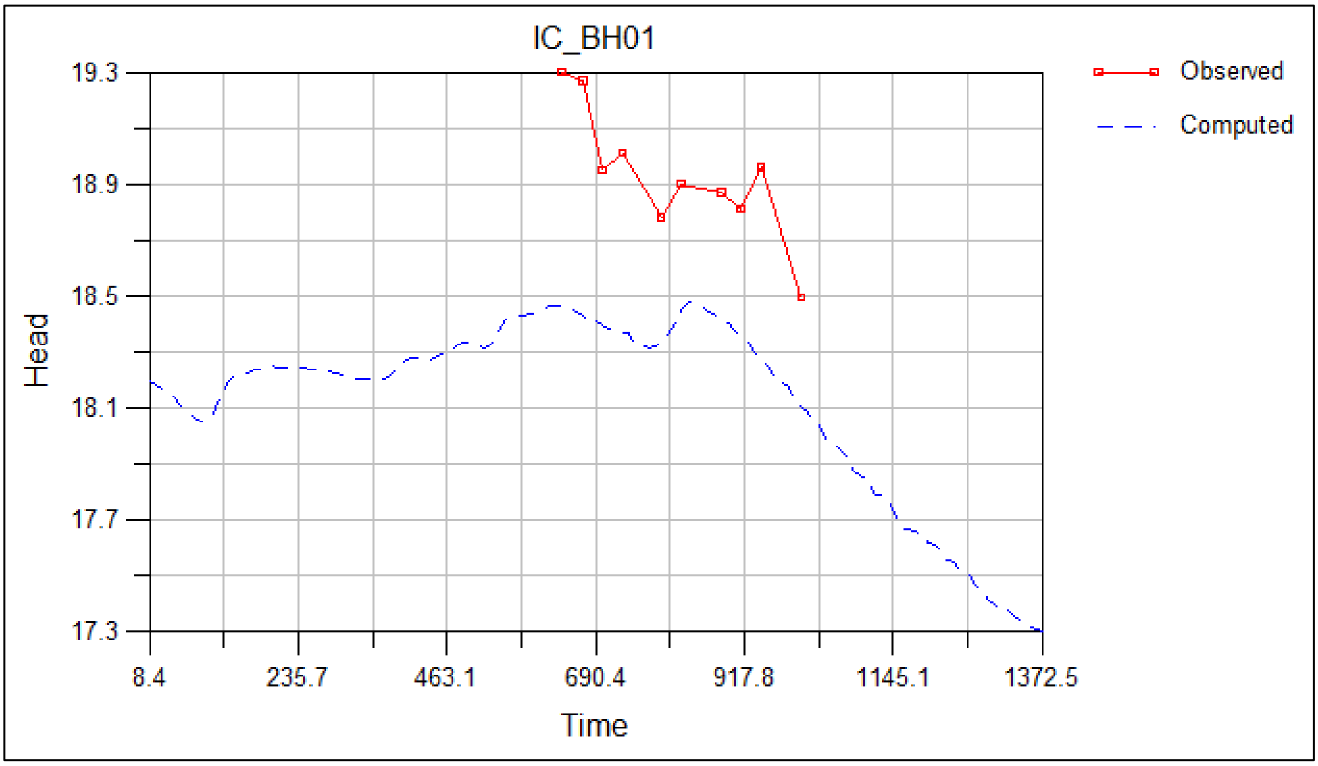
Name	Easting	Northing	Elevation (mAHD)	Screen (mBGL)	Project	Period	Suitability for calibration
TC_BH01d	330661.99	6250305.25	2.54	0	M4-M5_Monthly	Jul 2016 - Aug 2017	High
TC_BH01s	330660.57	6250304.92	2.55	3 to 6	M4-M5_Monthly	Jul 2016 - Aug 2017	High
TC_BH07s	330747.41	6250374.95	2.06	3 to 6	M4-M5_Monthly	Jul 2016 - Aug 2017	High
TC_BH09s	330832.7	6250445.81	2.29	2 to 5	M4-M5_Monthly	Jul 2016 - Aug 2017	High
B131A	332031.4	6253234.7	3.97	31.2-37.2	Western Harbour Tunnel - GDP	Sep 2017 - June 2018	High
HB_BH15	329396.41	6250144.74	17.8	19-22	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH38	330726.61	625012.07	2.27	28 - 31	M4-M5_Monthly	Jul 2016 - Aug 2017	High
RZ_BH69	330558.2	6251218	30.29	38 - 41	M4-M5_Monthly	Jul 2016 - Aug 2017	High
MT_BH02	329696.1	6249704	34.1	42-45	M4-M5_Monthly	Jul 2016 - Aug 2017	High
MT_BH07	330355.81	6249914.91	24.41	43-46	M4-M5_Monthly	Jul 2016 - Aug 2017	High
B208	331415.4	6252215.9	42.6	39.6-42.6	Western Harbour Tunnel - GDP	Sep 2017 - June 2018	High

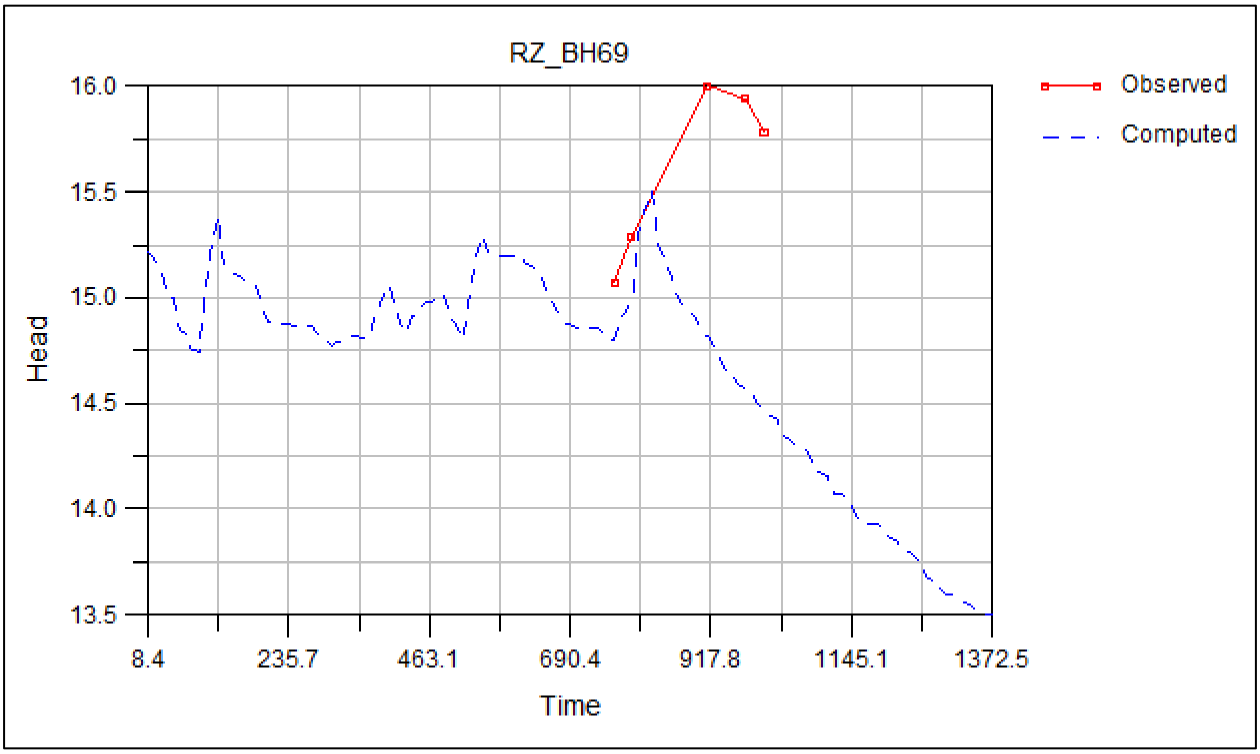
Annexure 7. Calibration Residuals – Steady State South Model

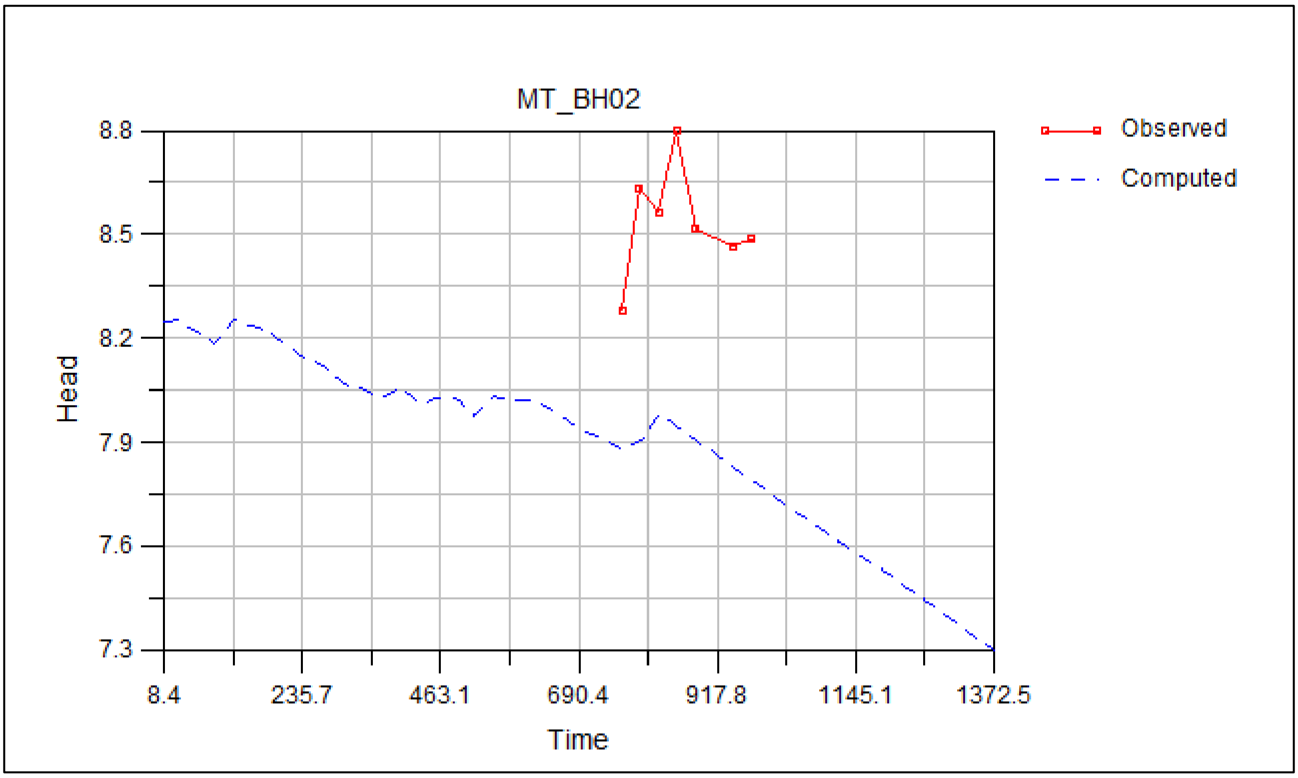
Name	X (mMGA)	Y (mMGA)	Layer	Observed (mAHD)	Computed (mAHD)	Residual (m)
B209	331520.7	6252619	5	3.435903	3.98824	-3.56
B104A	331665.8	6252921	4	1.194505	4.02164	-0.95
RZ_BH60	330317.8	6250590	4	12.53544	11.77133	0.90
EP_BH06	331025.4	6250904	2	3.851154	7.572873	-2.19
EP_BH07	331082.3	6250899	2	2.902538	6.580815	-2.34
RZ_BH26	331066.3	6250835	2	1.582688	4.746447	-2.37
RZ_BH28d	331126.6	6250819	3	1.710769	4.313679	-1.86
TC_BH07d	330746	6250374	4	1.5304	0.11904	0.18
RZ_BH51	331206.6	6250813	3	1.570714	3.765679	-1.59
RZ_BH30	331192.9	6250835	2	1.584455	3.992098	-1.77
TC_BH06s	330610.2	6250298	1	1.0852	2.50797	-1.18
RZ_BH52	331163.8	6250785	3	1.367067	3.527444	-1.72
RZ_BH47s	331027.9	6250704	2	1.130733	2.384327	-0.97
TC_BH08s	330818.3	6250436	2	0.620125	0.334109	0.34
RZ_BH44d	330885.8	6250614	4	1.6002	1.398401	-0.32
RZ_BH47d	331025.2	6250702	3	1.4902	2.474107	-0.68
RZ_BH19	330822.5	6250627	3	1.532533	2.674256	-0.79
RZ_BH44s	330884.4	6250613	2	0.907667	1.417438	-0.38
TC_BH09d	330830.3	6250444	2	1.54	0.330975	1.26
IC_BH01	330514.2	6251505	1	18.8945	19.28282	0.73
RZ_BH01d	330608.9	6250381	3	1.622625	3.417642	-1.38
RZ_BH01s	330611.5	6250382	1	1.89	3.185545	-0.97
RZ_BH15	330522.6	6250350	3	1.661375	4.840634	-2.92
RZ_BH16d	330609.4	6250409	2	1.619	3.483748	-1.50
RZ_BH49s	330730.4	6250462	3	1.22975	1.785032	-0.25
TC_BH01d	330662	6250305	1	1.560533	1.164722	0.52
TC_BH01s	330660.6	6250305	1	0.805667	1.202774	-0.27
TC_BH07s	330747.4	6250375	1	0.470313	0.121149	0.37
TC_BH09s	330832.7	6250446	1	0.812083	0.243692	0.61
B131A	332031.4	6253236	3	0.196839	0.291859	-0.14
HB_BH15	329396.4	6250145	2	8.160235	8.388394	0.16
RZ_BH38	330726.6	625012.1	1	1.500933	0	1.50
RZ_BH69	330558.2	6251218	1	15.5968	17.33577	0.17
MT_BH02	329696.1	6249704	3	8.616889	8.764097	0.34
MT_BH07	330355.8	6249915	4	6.687889	6.628578	0.66
B208	331415.4	6252216	3	5.75	7.147801	-1.73

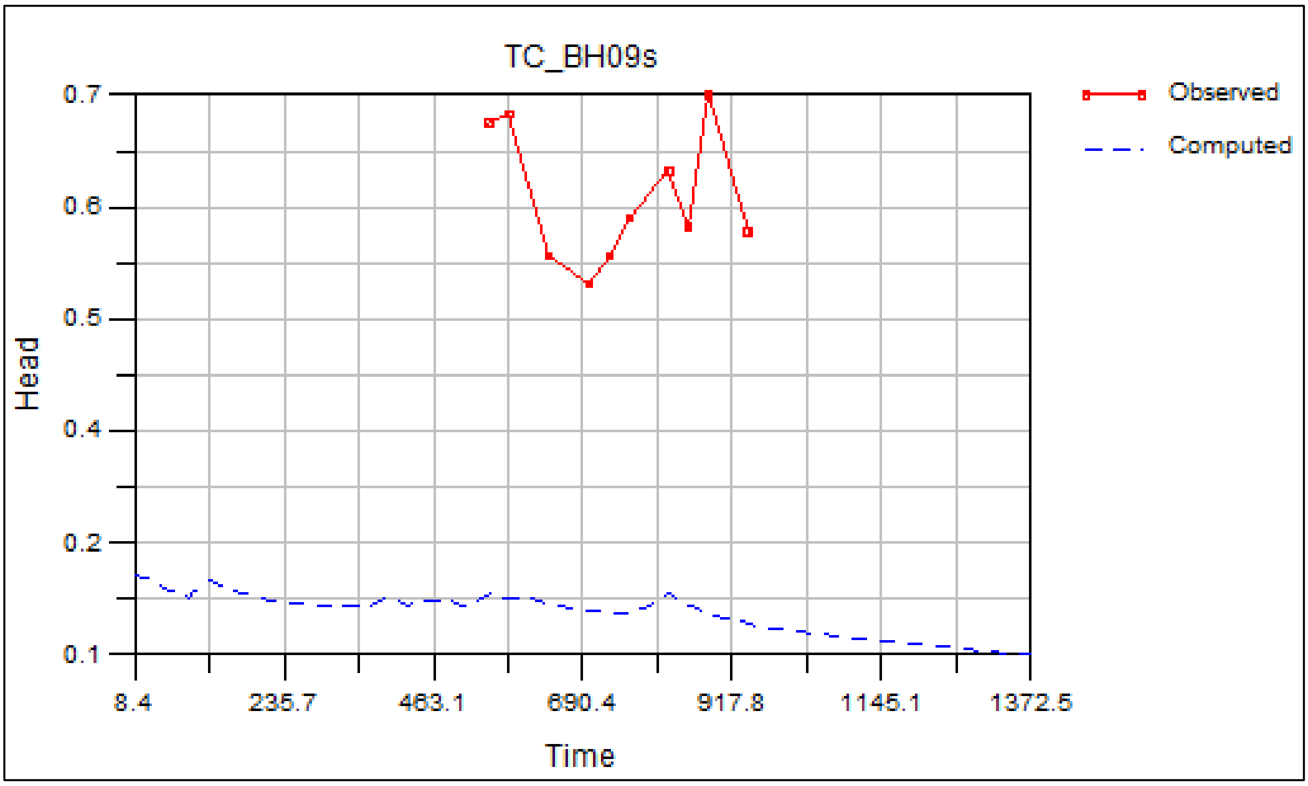
Annexure 8. Calibration Hydrographs – Transient South Model

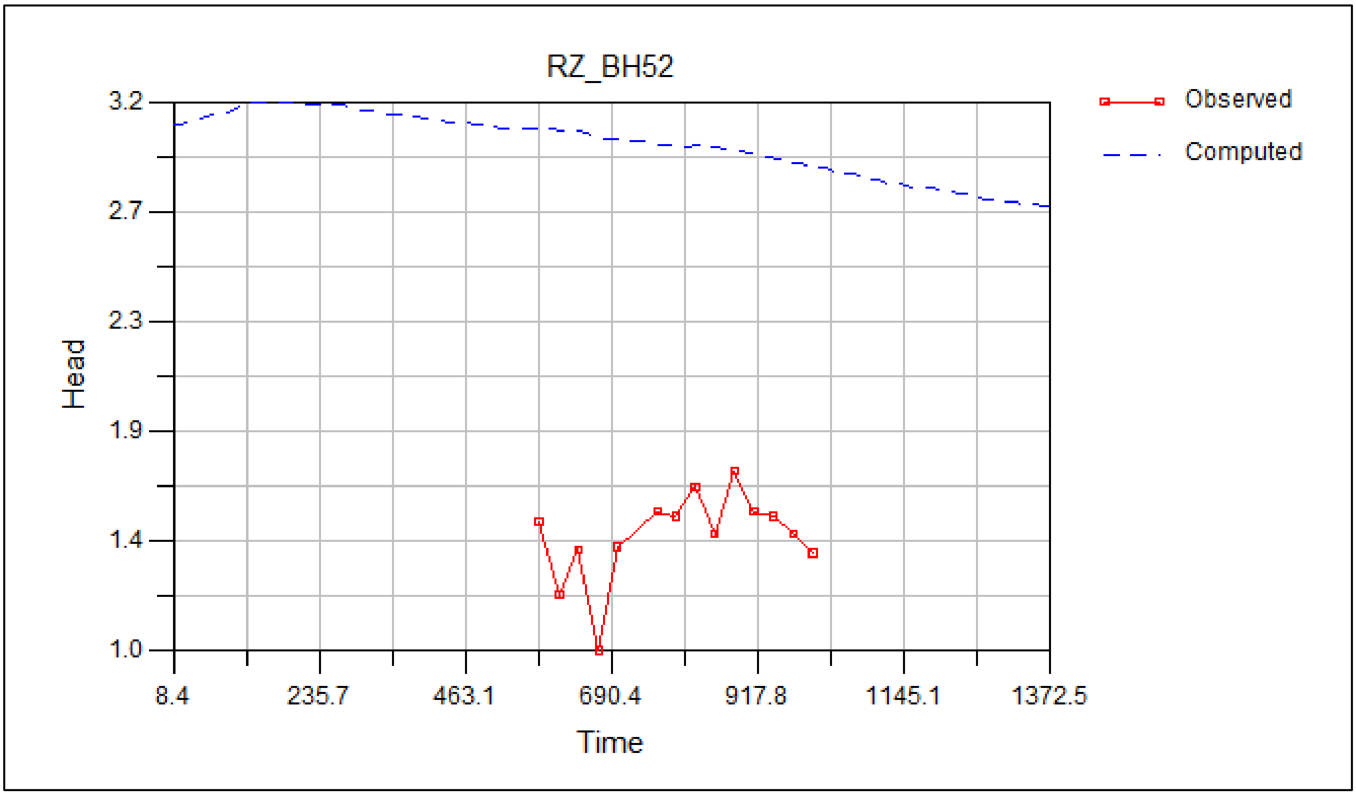

RZ_BH60
Observed
Computed
Head
12.7
12.3
11.9
11.4
11.0
10.5
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


IC_BH01
Observed
Computed
Head
19.3
18.9
18.5
18.1
17.7
17.3
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


RZ_BH69
Observed
Computed
Head
16.0
15.5
15.0
14.5
14.0
13.5
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


MT_BH02
Observed
Computed
Head
8.8
8.5
8.2
7.9
7.6
7.3
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


TC_BH09s
Observed
Computed
Head
0.7
0.6
0.5
0.4
0.2
0.1
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


RZ_BH52
Observed
Computed
Head
3.2
2.7
2.3
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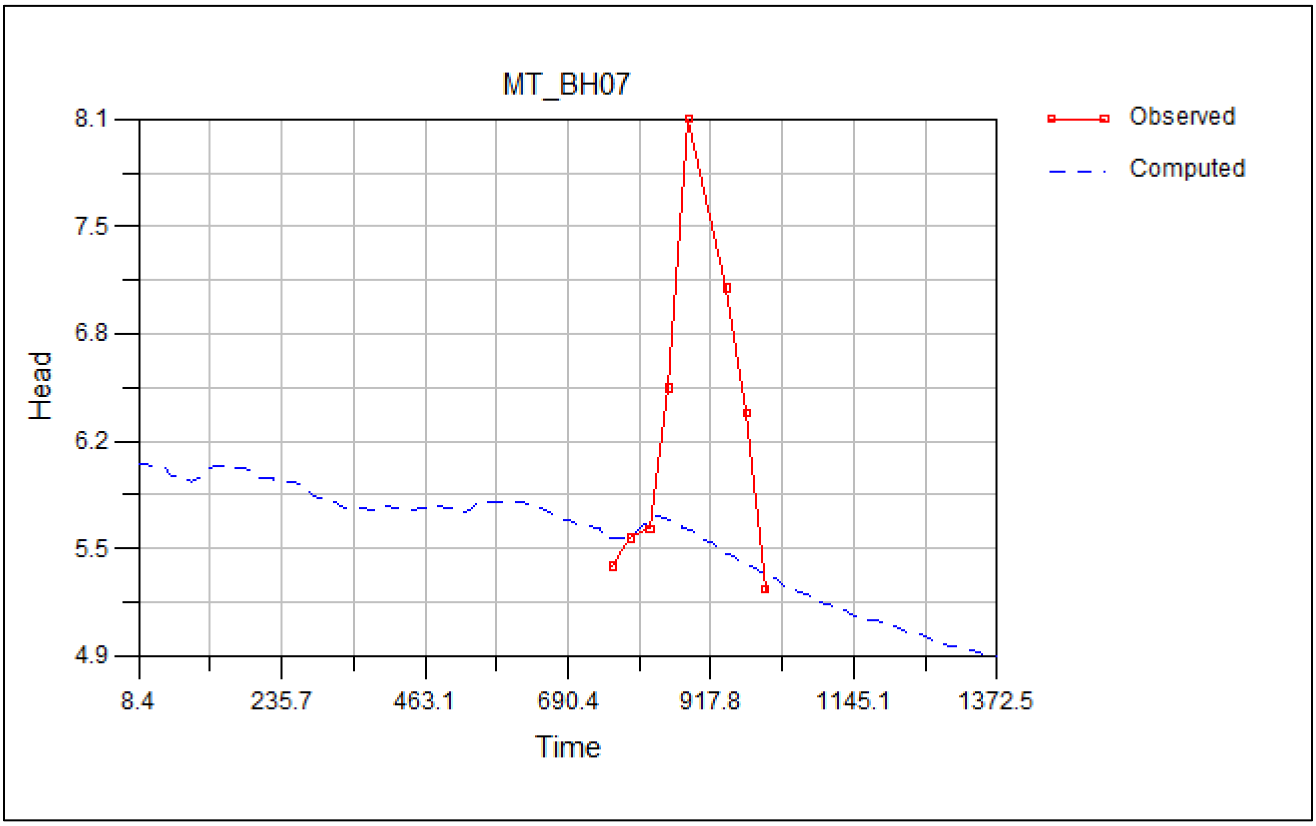
1.4
1.0
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


MT_BH07
Observed
Computed
Head
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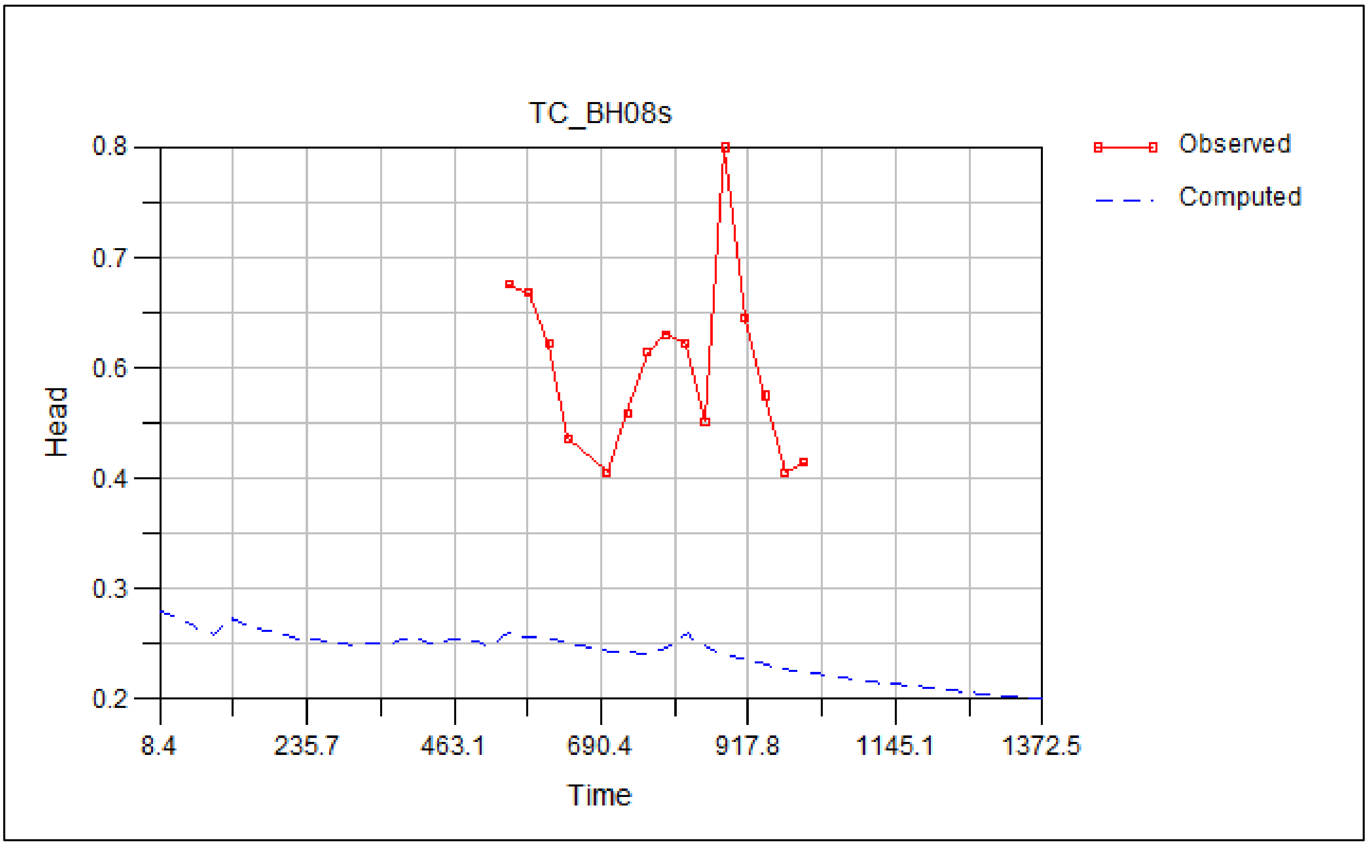
7.5
6.8
6.2
5.5
4.9
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


TC_BH08s
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Computed
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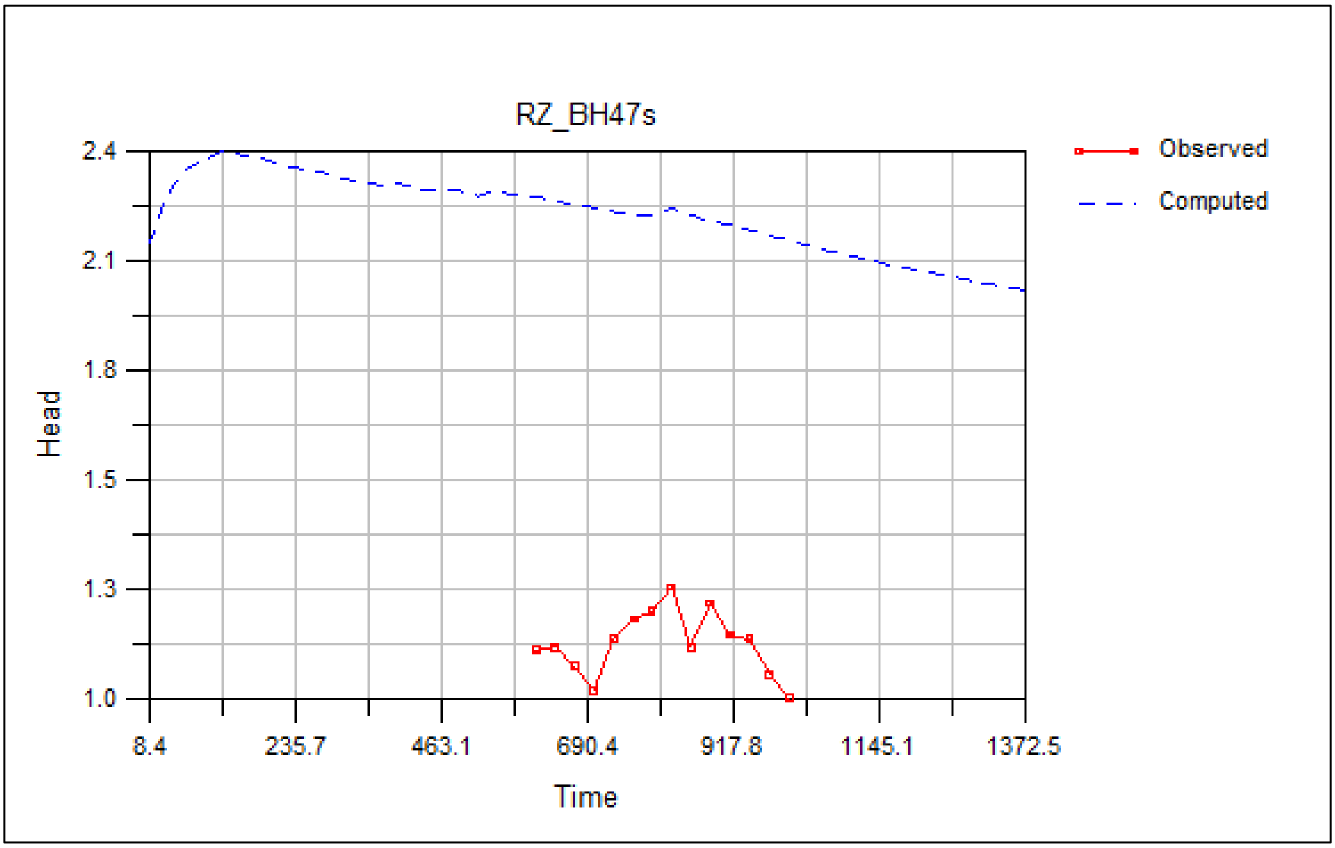
463.1
690.4
917.8
1145.1
1372.5
Time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Computed
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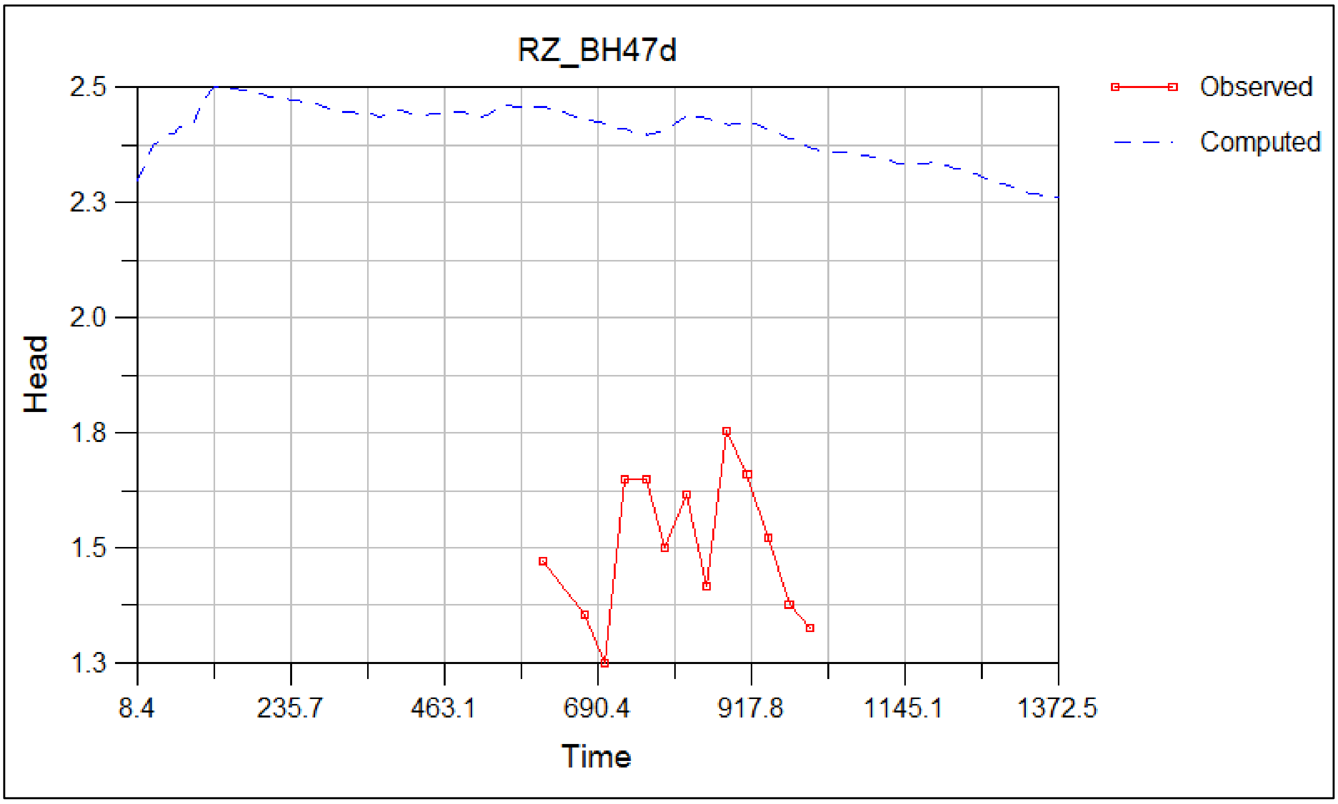
463.1
690.4
917.8
1145.1
1372.5
Time


RZ_BH47d
Observed
Computed
Head
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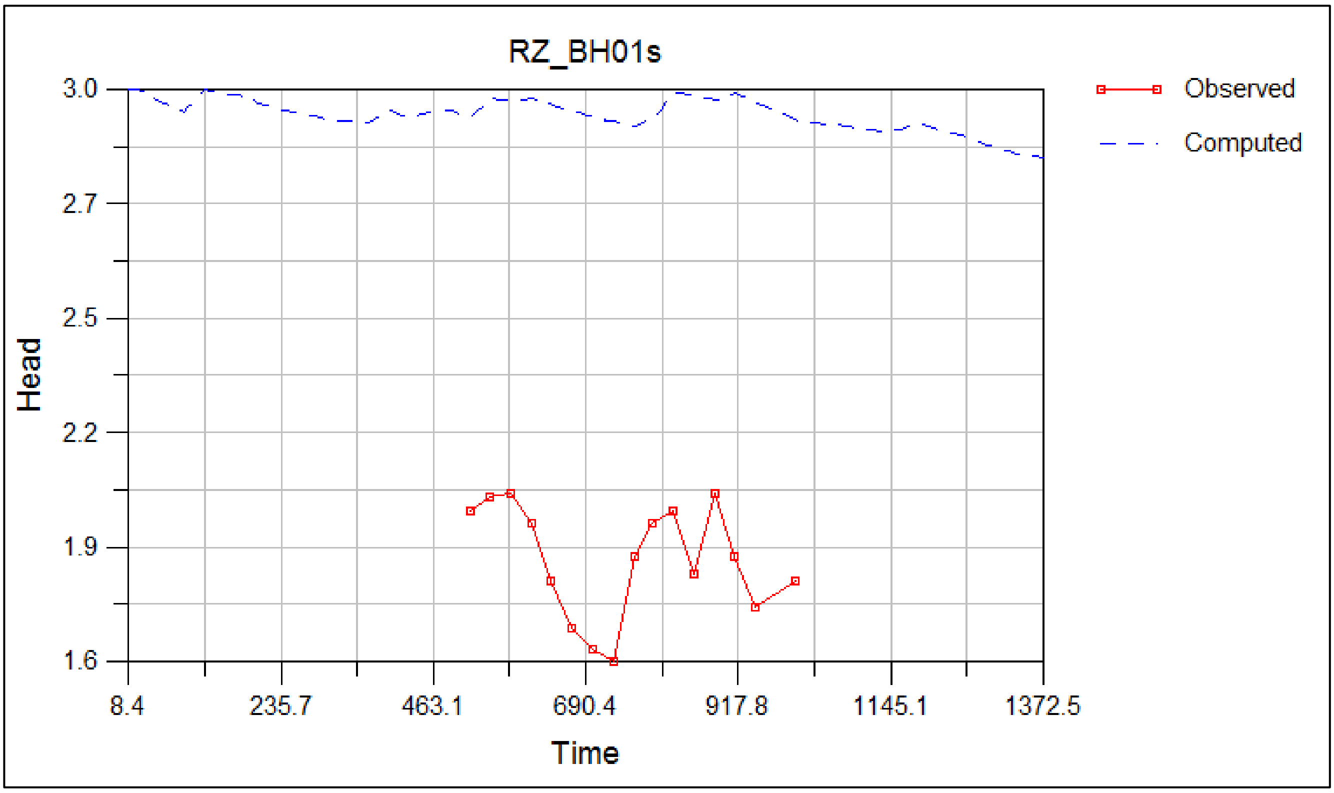
1.5
1.3
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


RZ_BH01s
Head
3.0
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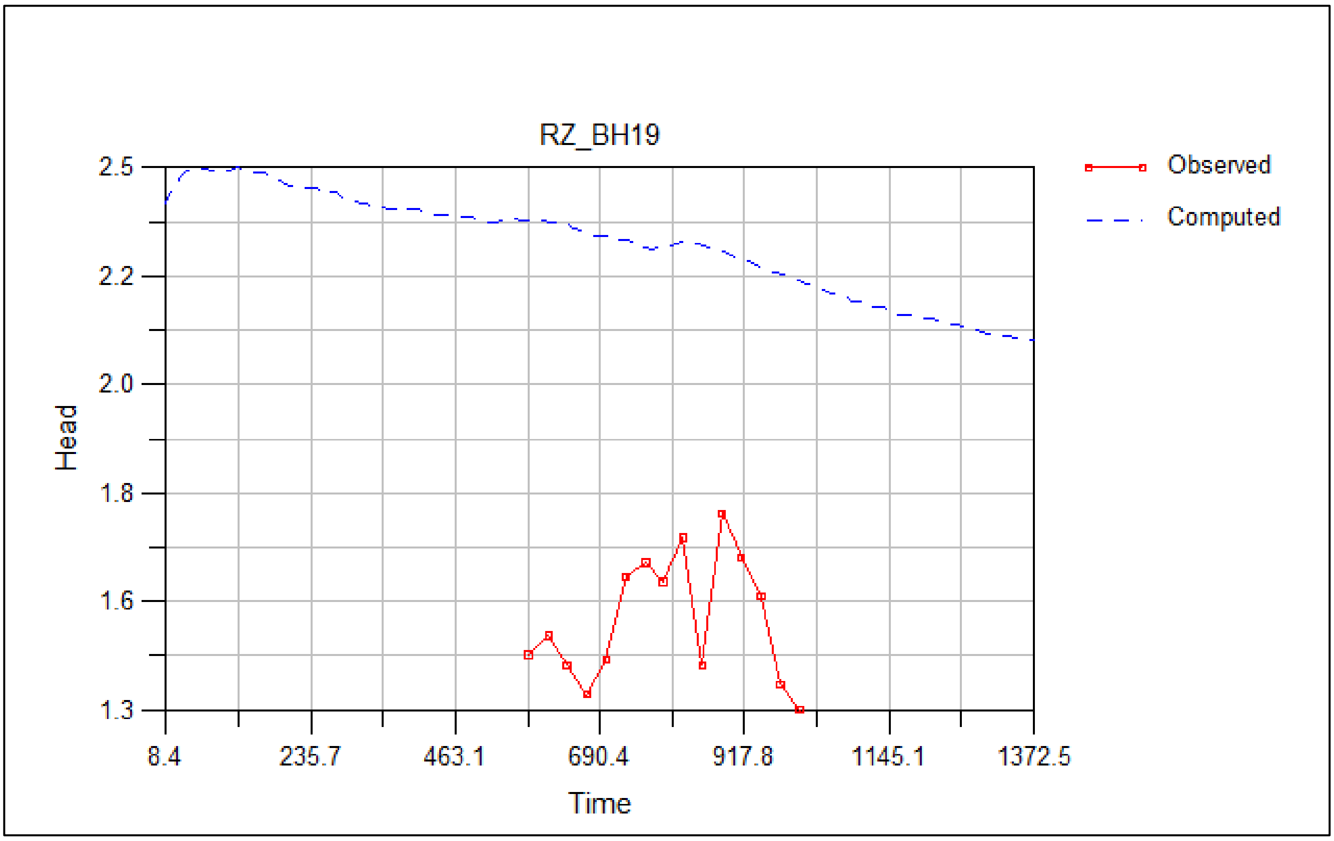
2.5
2.2
1.9
1.6
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed


RZ_BH19
Head
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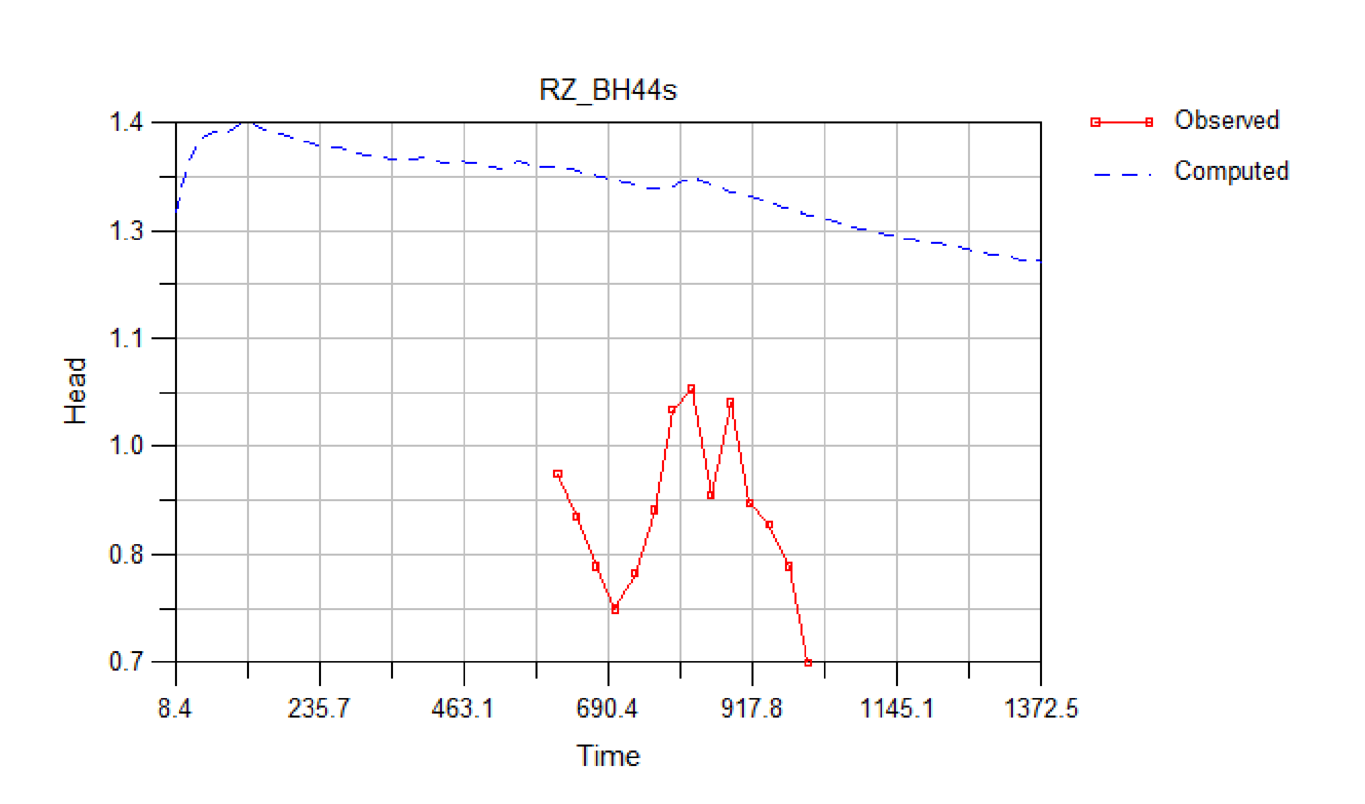
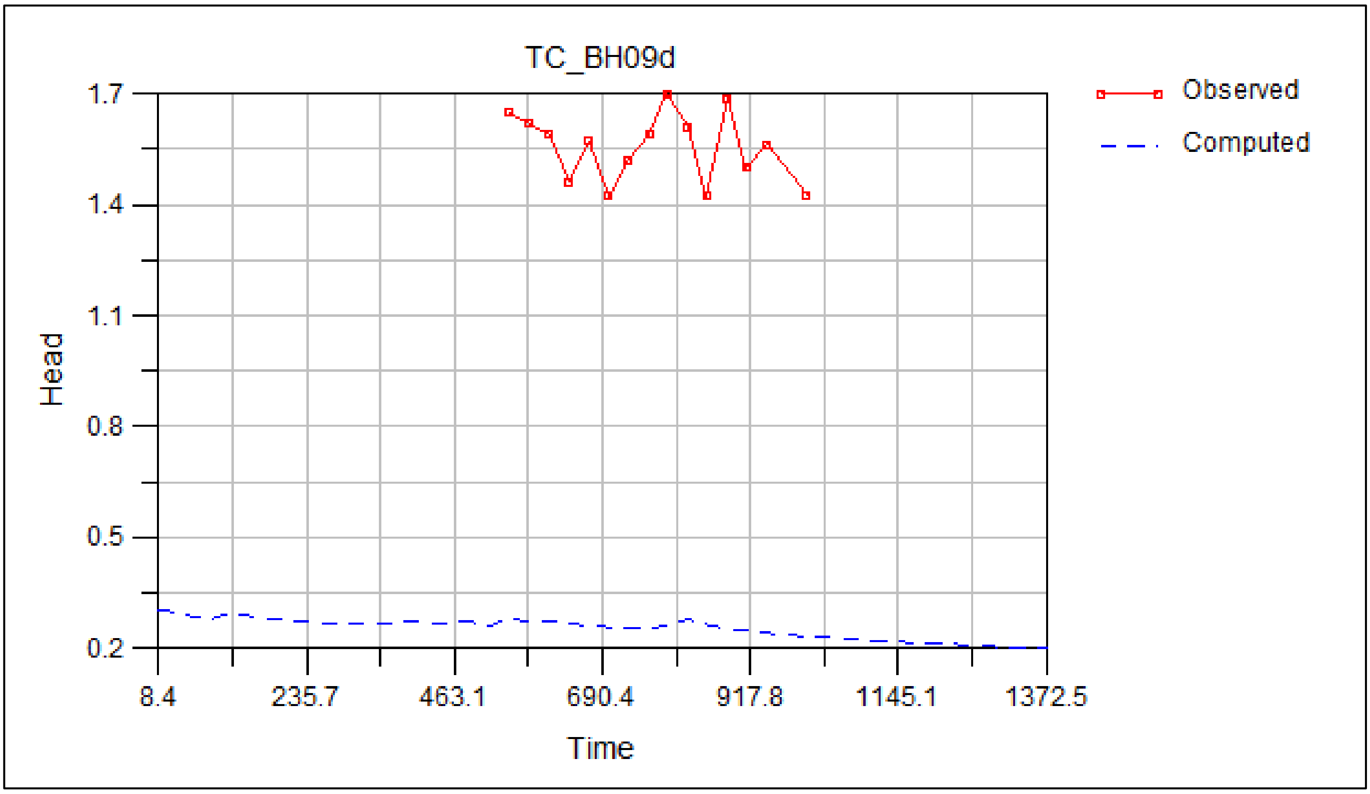
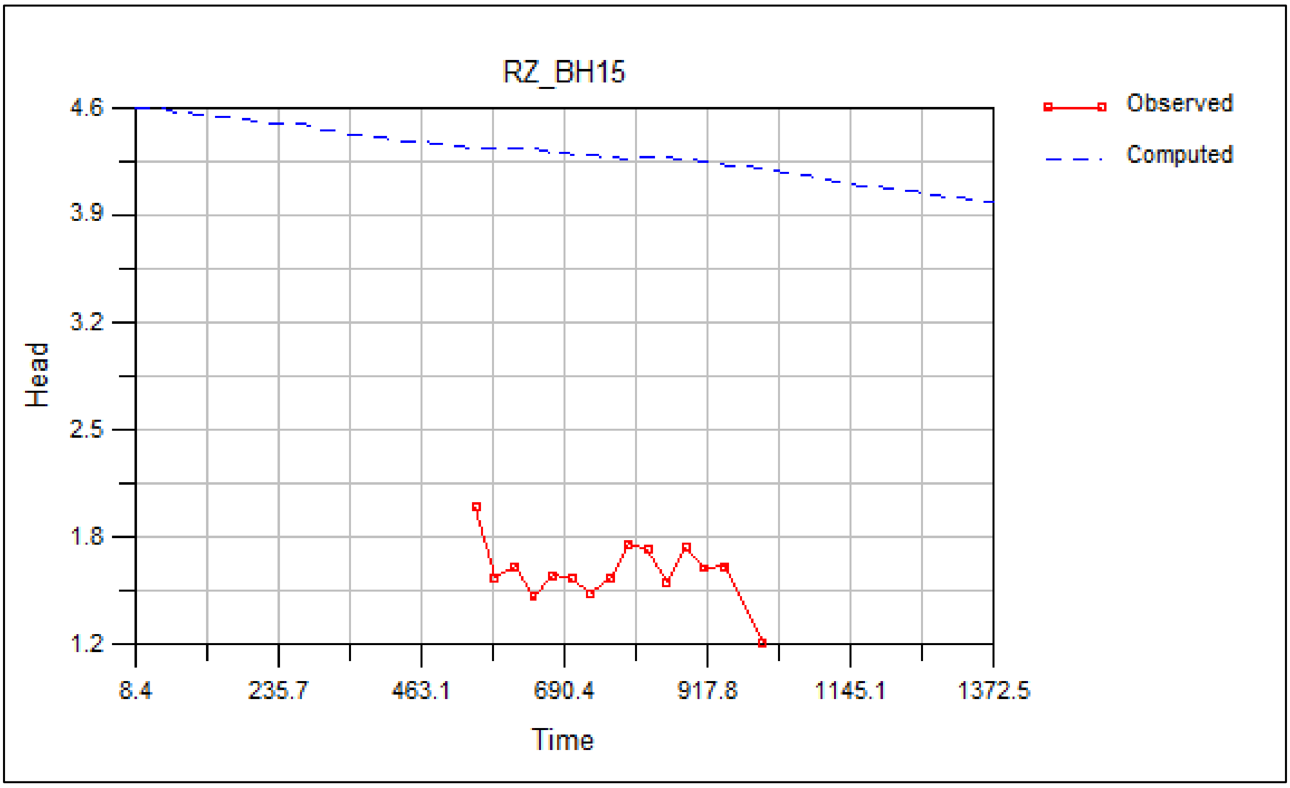
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed


RZ_BH44s
Head
1.4
1.3
1.1
1.0
0.8
0.7
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed


TC_BH09d
Head
1.7
1.4
1.1
0.8
0.5
0.2
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed


RZ_BH15
Observed
Computed
Head
4.6
3.9
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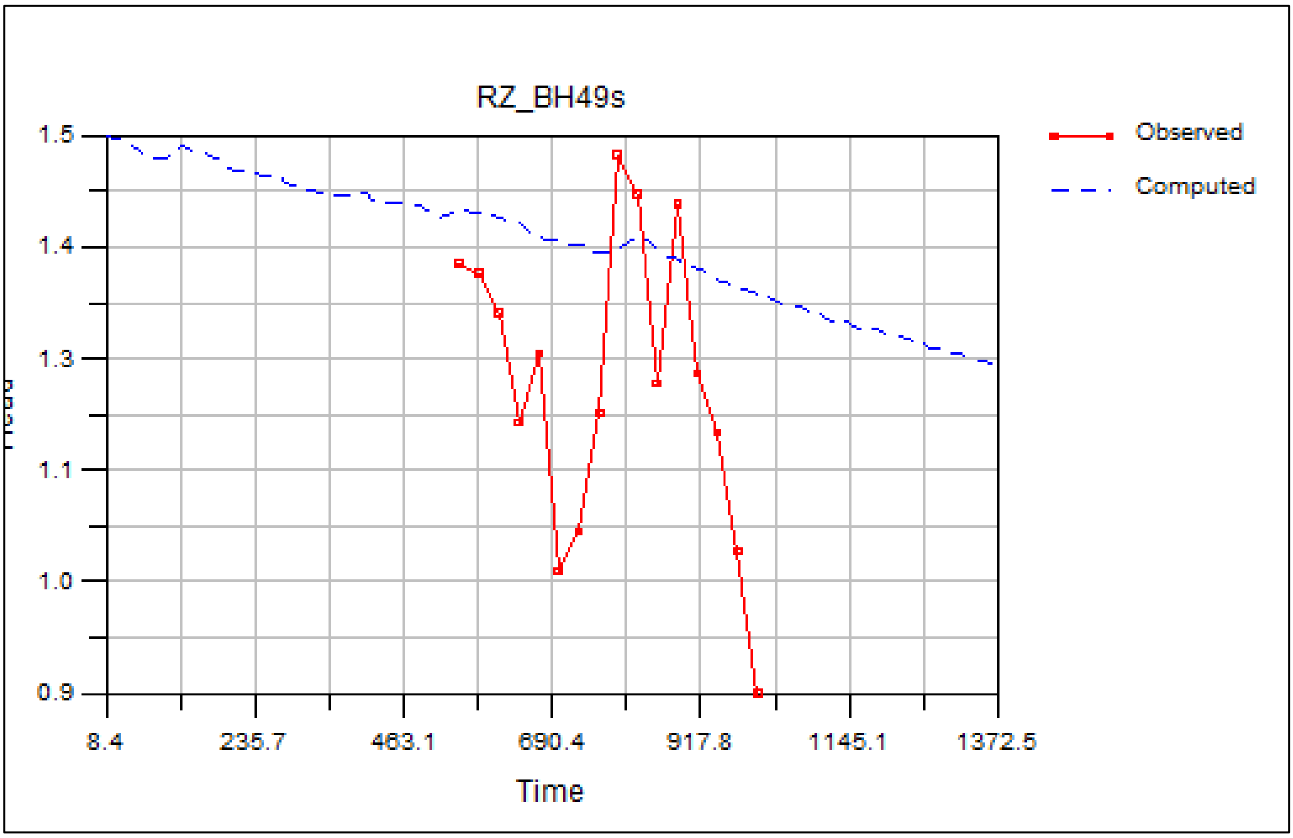
1.8
1.2
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


RZ_BH49s
Observed
Computed
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1.0
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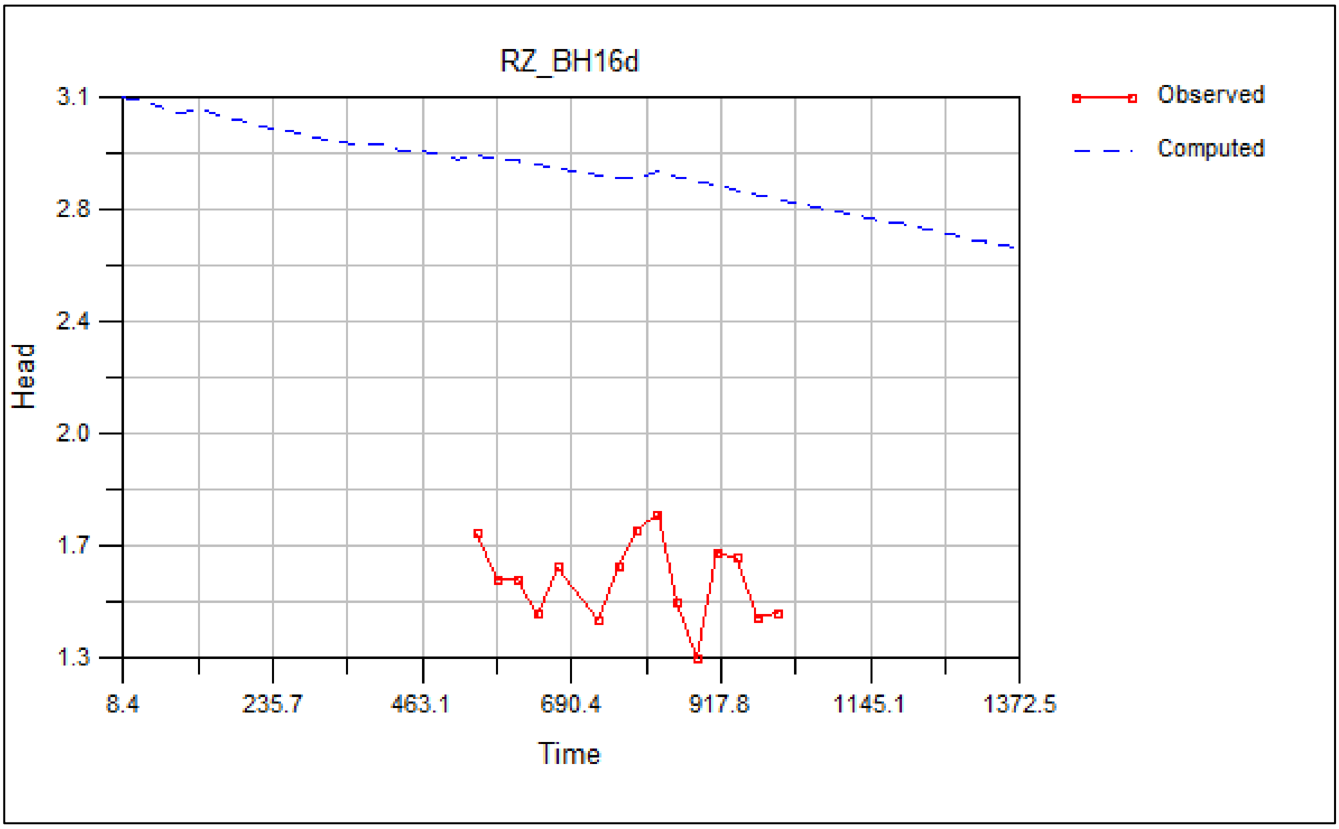
463.1
690.4
917.8
1145.1
1372.5
Time


RZ_BH16d
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Computed
Head
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2.8
2.4
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1.3
8.4
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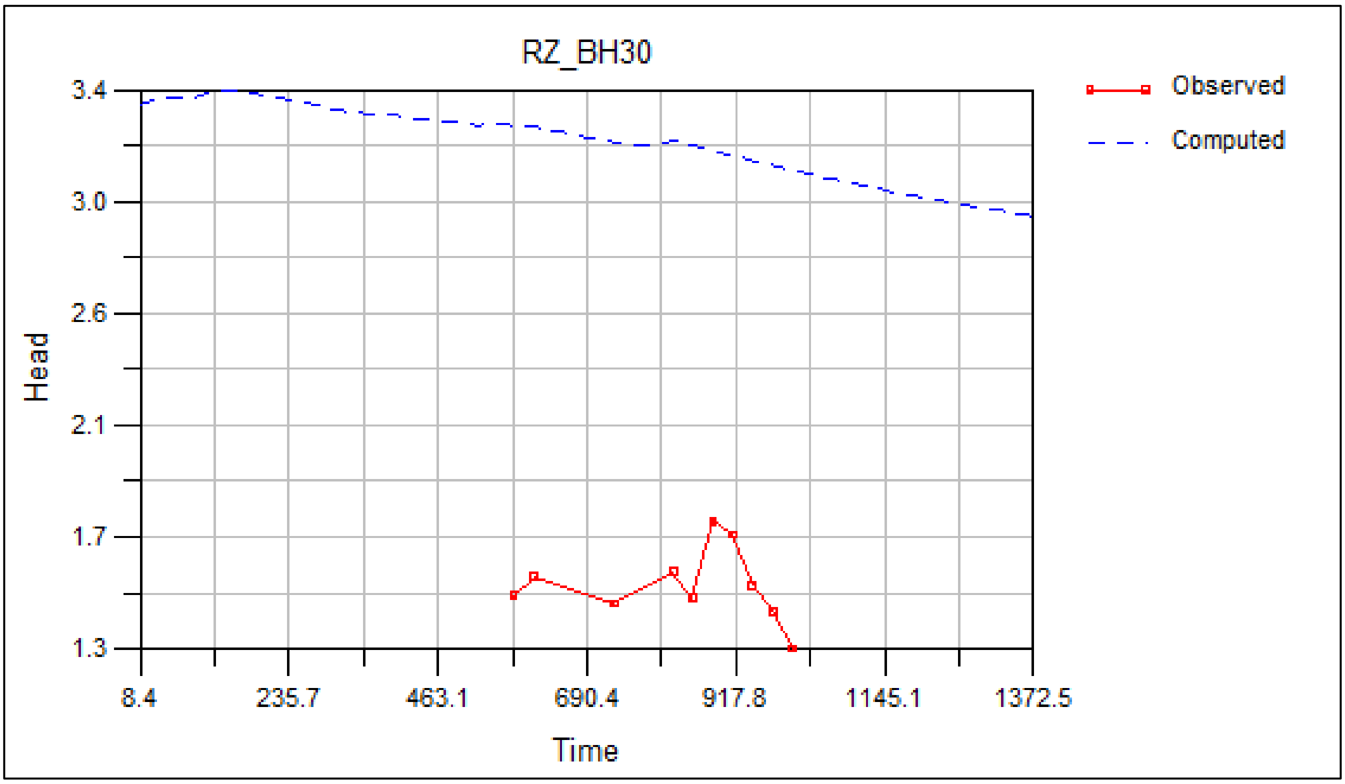
463.1
690.4
917.8
1145.1
1372.5
Time


RZ_BH30
Observed
Computed
Head
3.4
3.0
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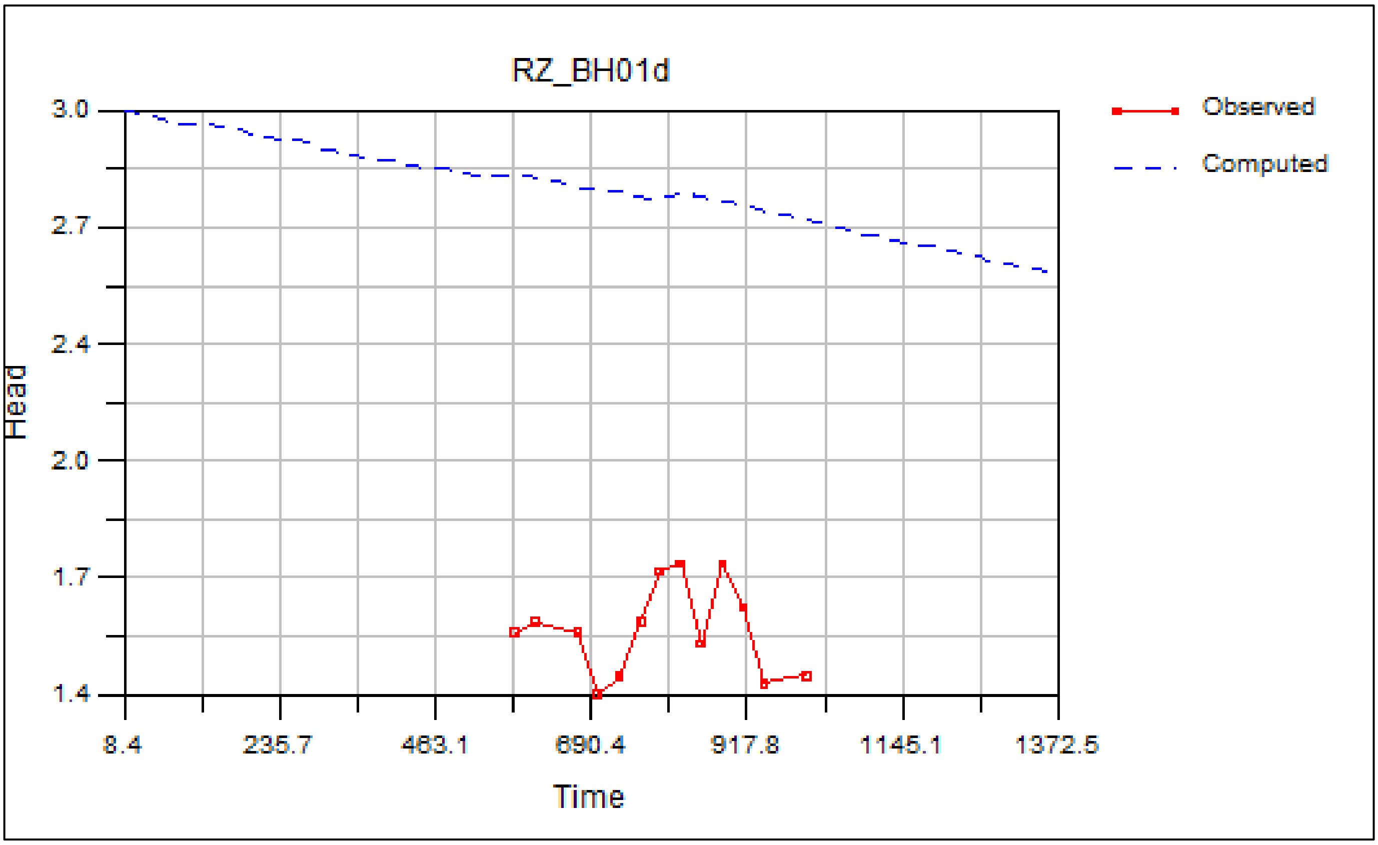
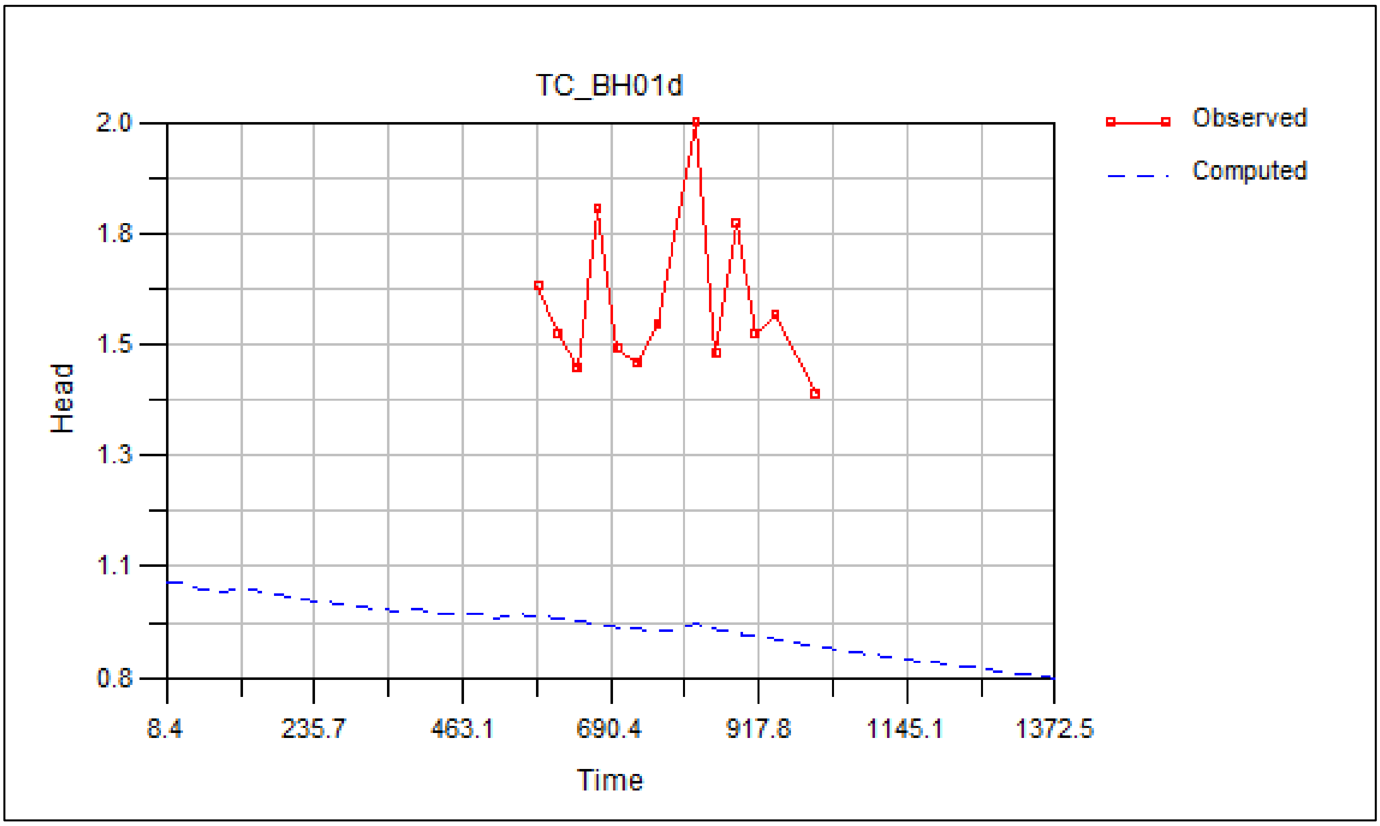
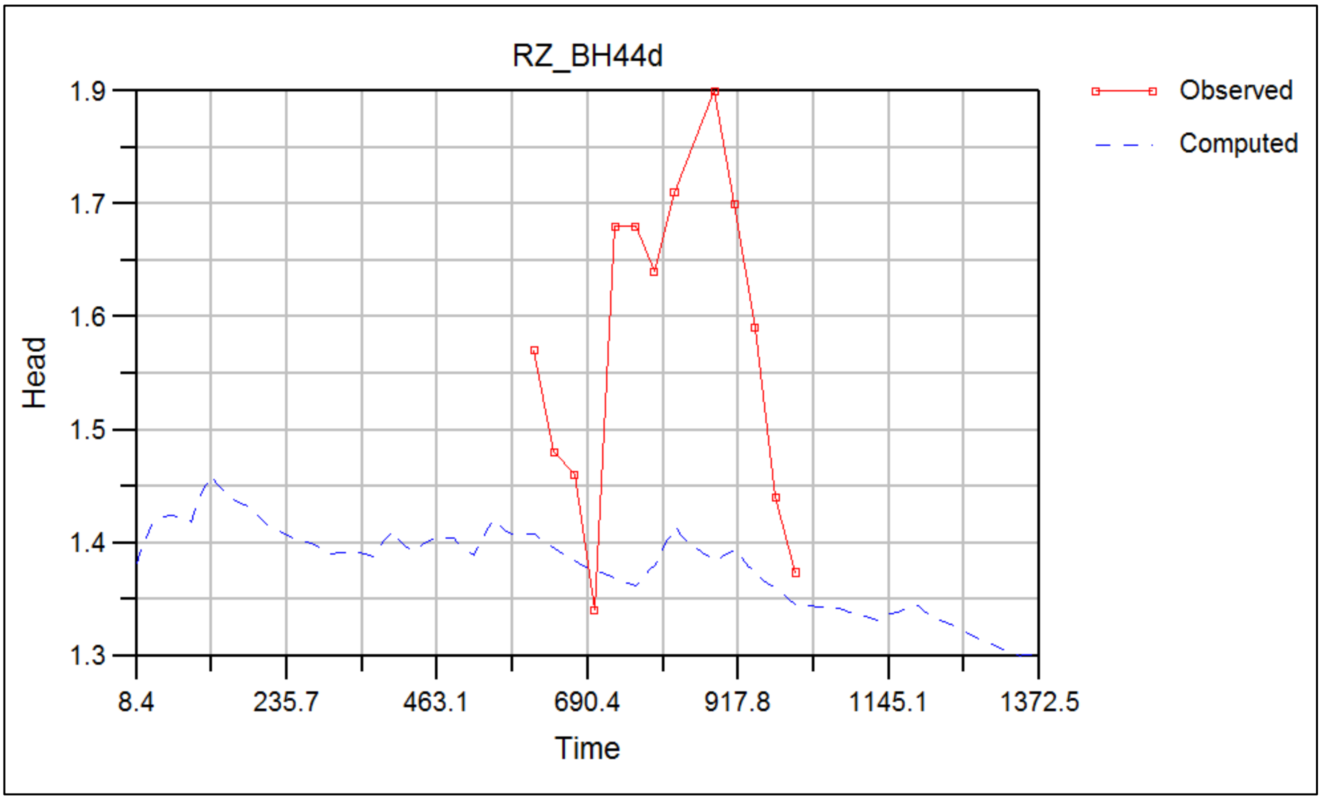
1.7
1.3
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


RZ_BH01d
Observed
Computed
Head
3.0
2.7
2.4
2.0
1.7
1.4
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


TC_BH01d
Observed
Computed
Head
2.0
1.8
1.5
1.3
1.1
0.8
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


RZ_BH44d
Head
1.9
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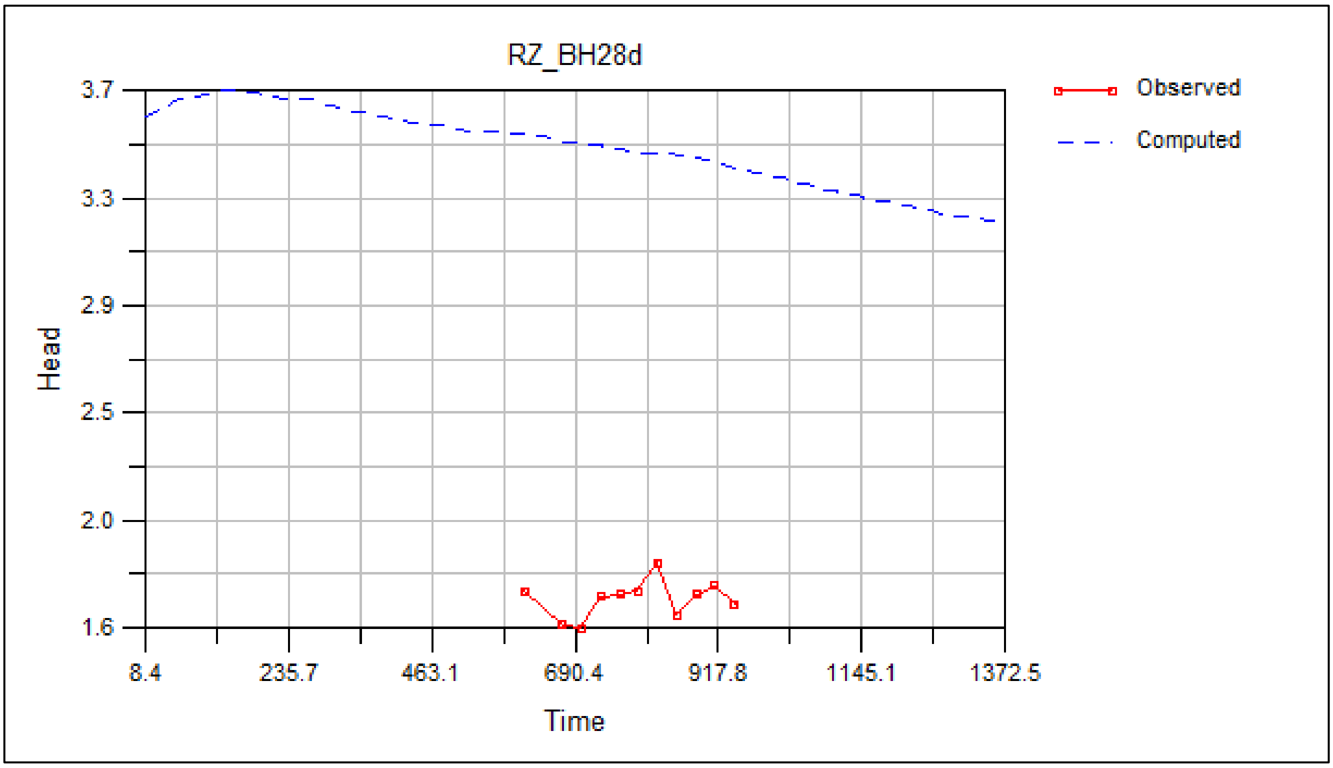
1.6
1.5
1.4
1.3
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed


RZ_BH28d
Head
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2.9
2.5
2.0
1.6
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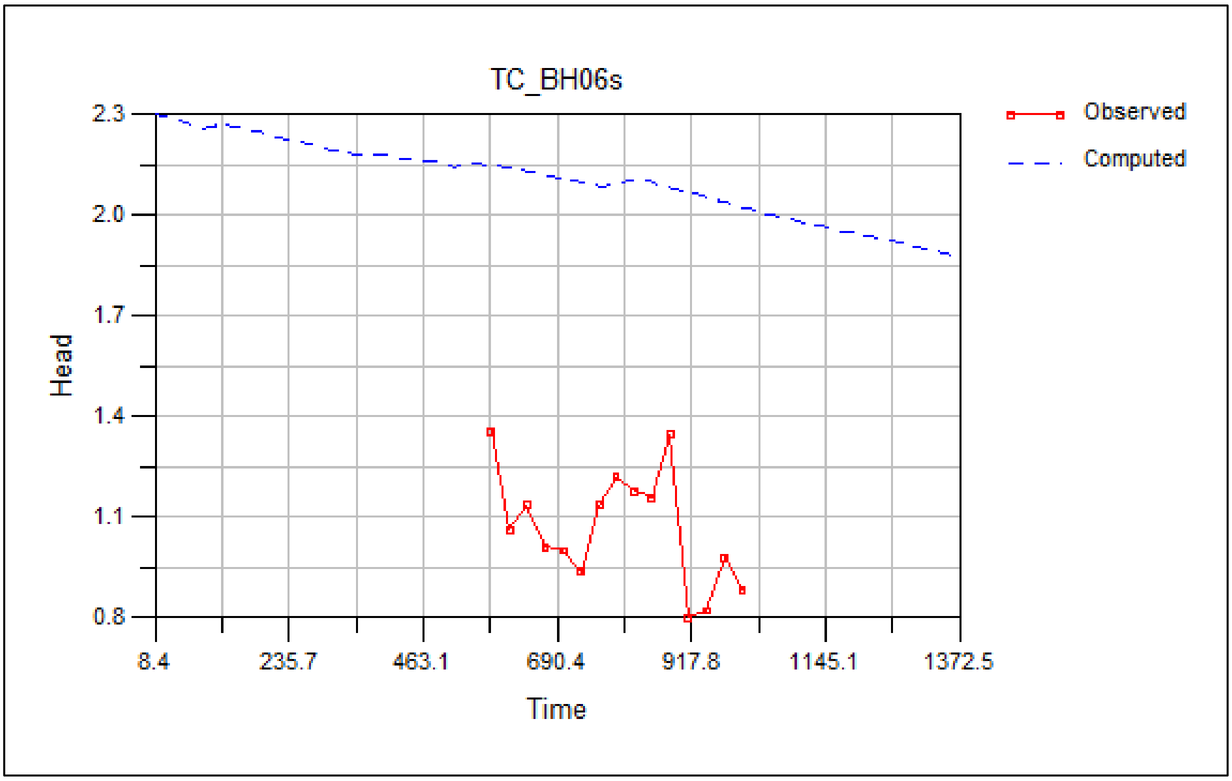
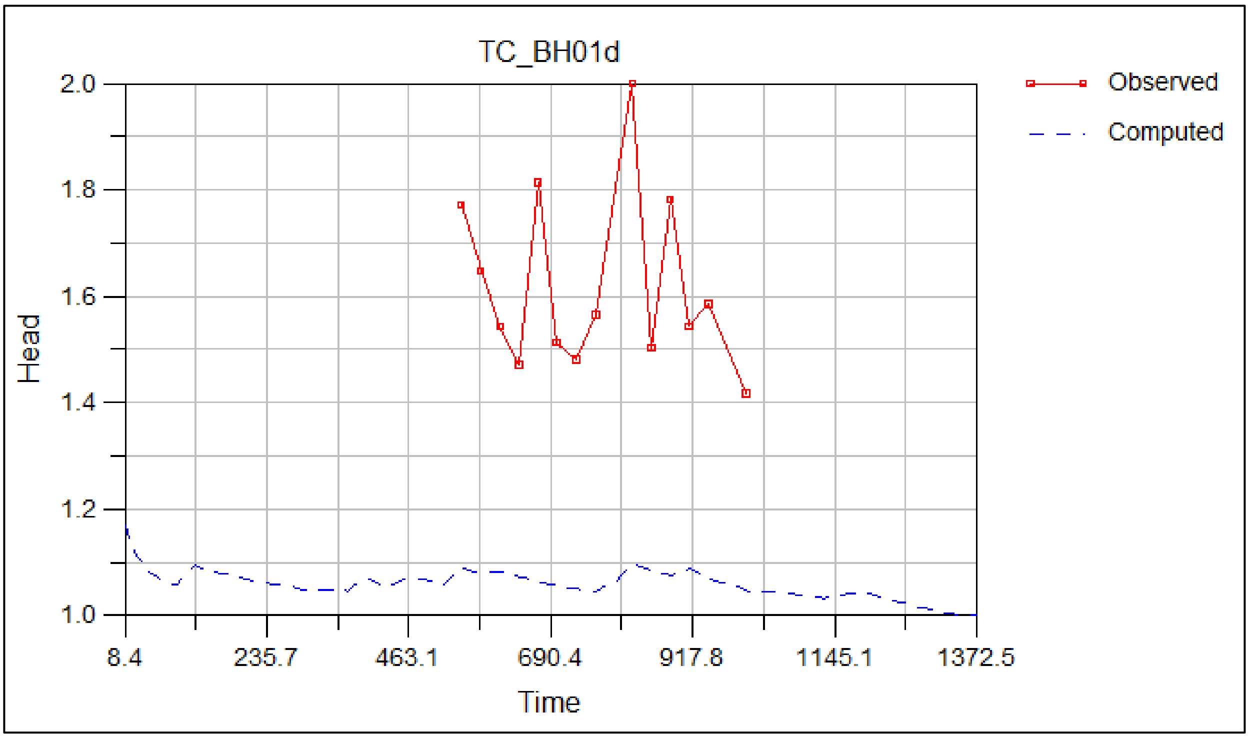
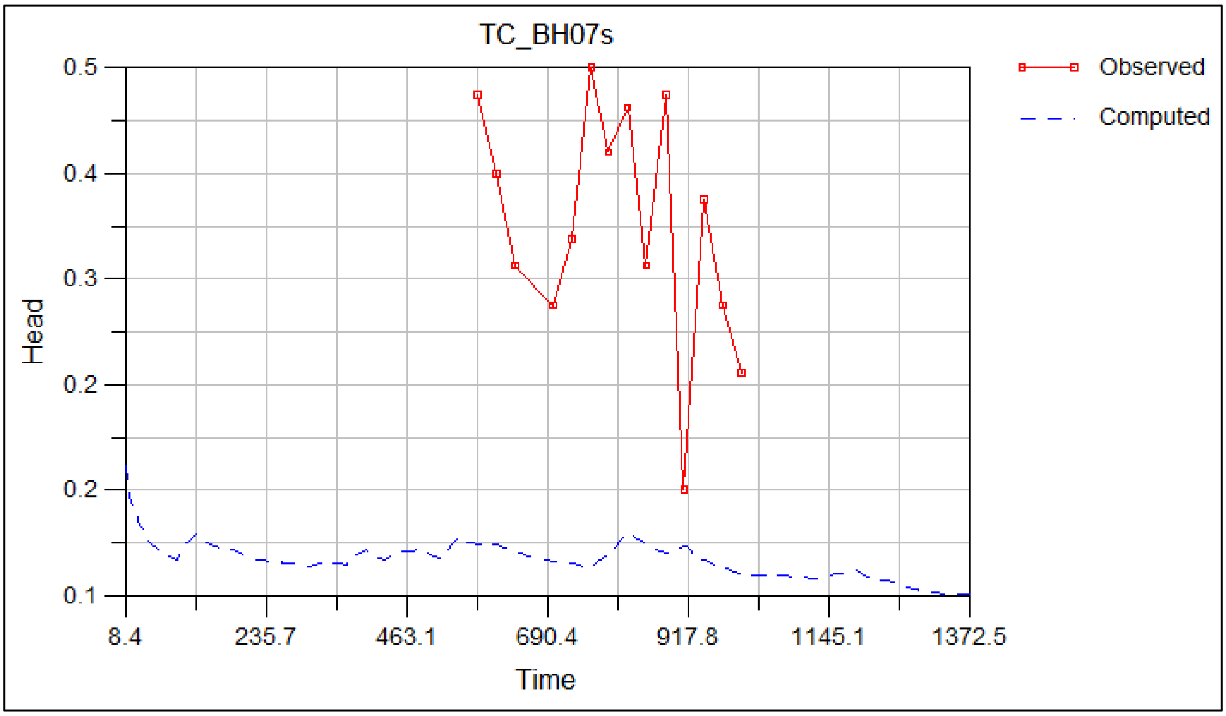
235.7
463.1
690.4
917.8
1145.1
1372.5
Time
Observed
Computed


TC_BH06s
Observed
Computed
Head
2.3
2.0
1.7
1.4
1.1
0.8
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


TC_BH01d
Observed
Computed
Head
2.0
1.8
1.6
1.4
1.2
1.0
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


TC_BH07s
Observed
Computed
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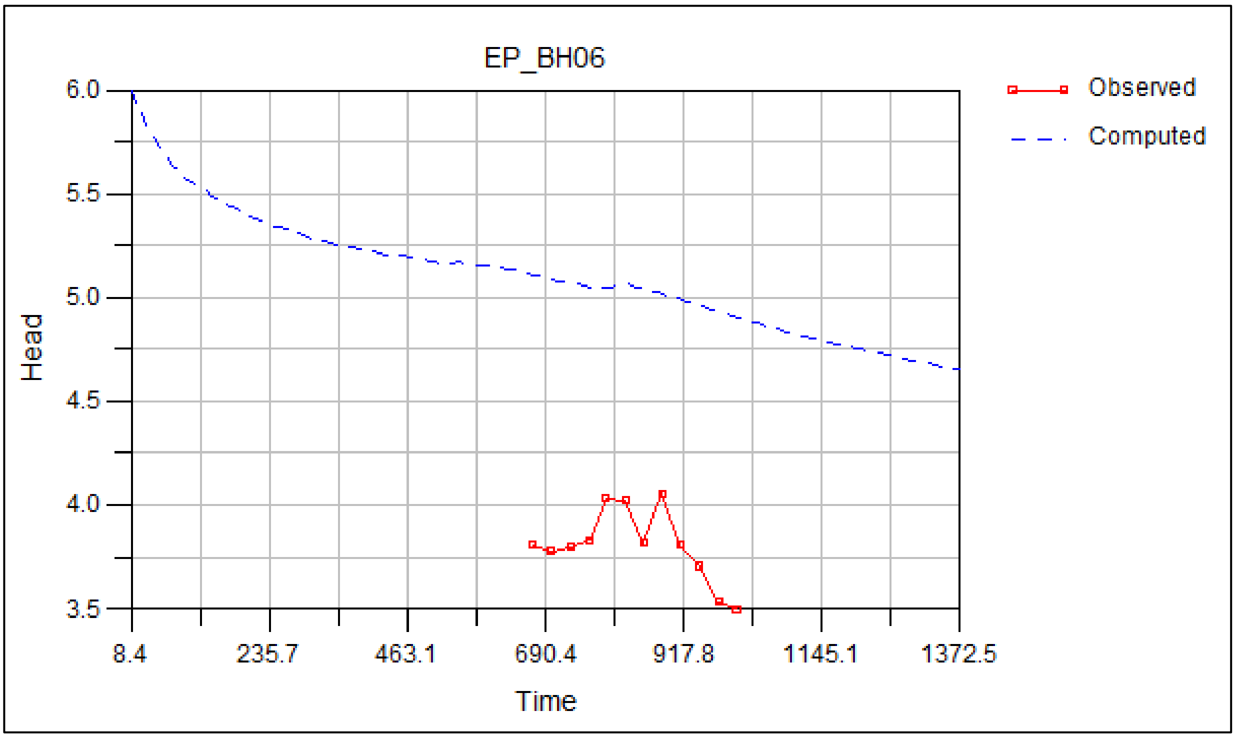
0.5
0.4
0.3
0.2
0.2
0.1
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


EP_BH06
Observed
Computed
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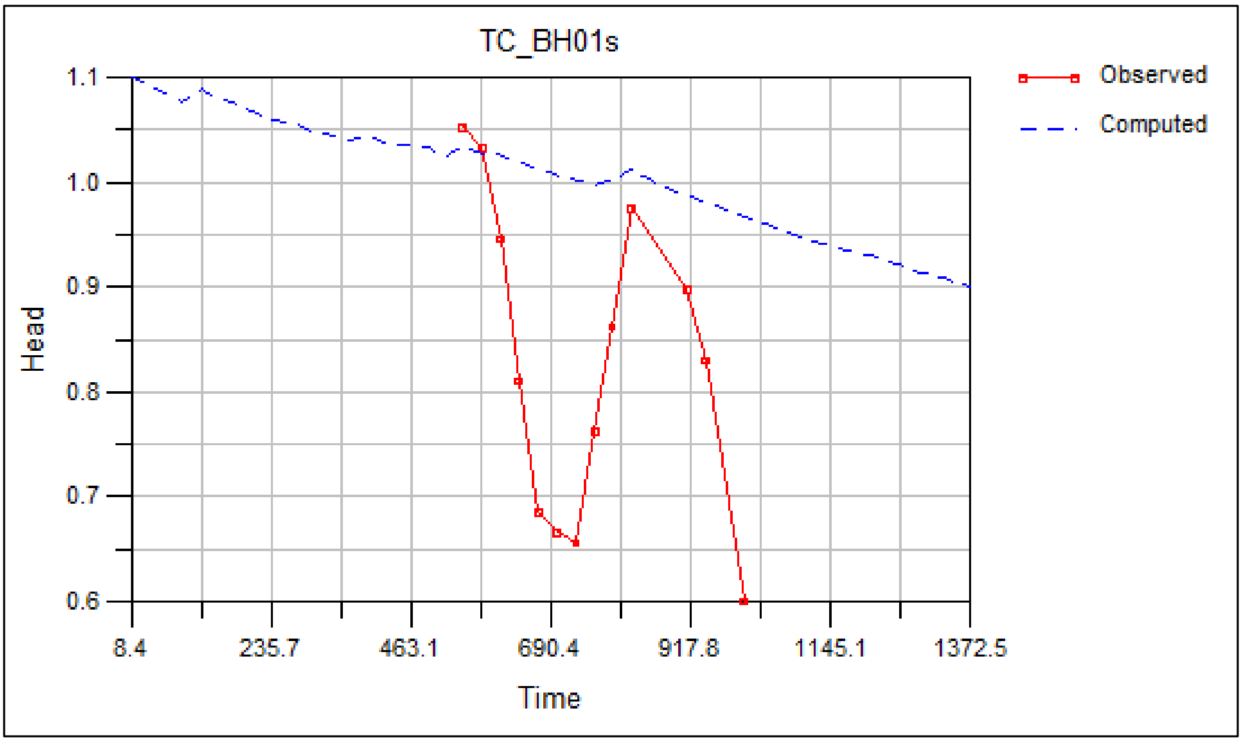
5.5
5.0
4.5
4.0
3.5
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


TC_BH01s
Observed
Computed
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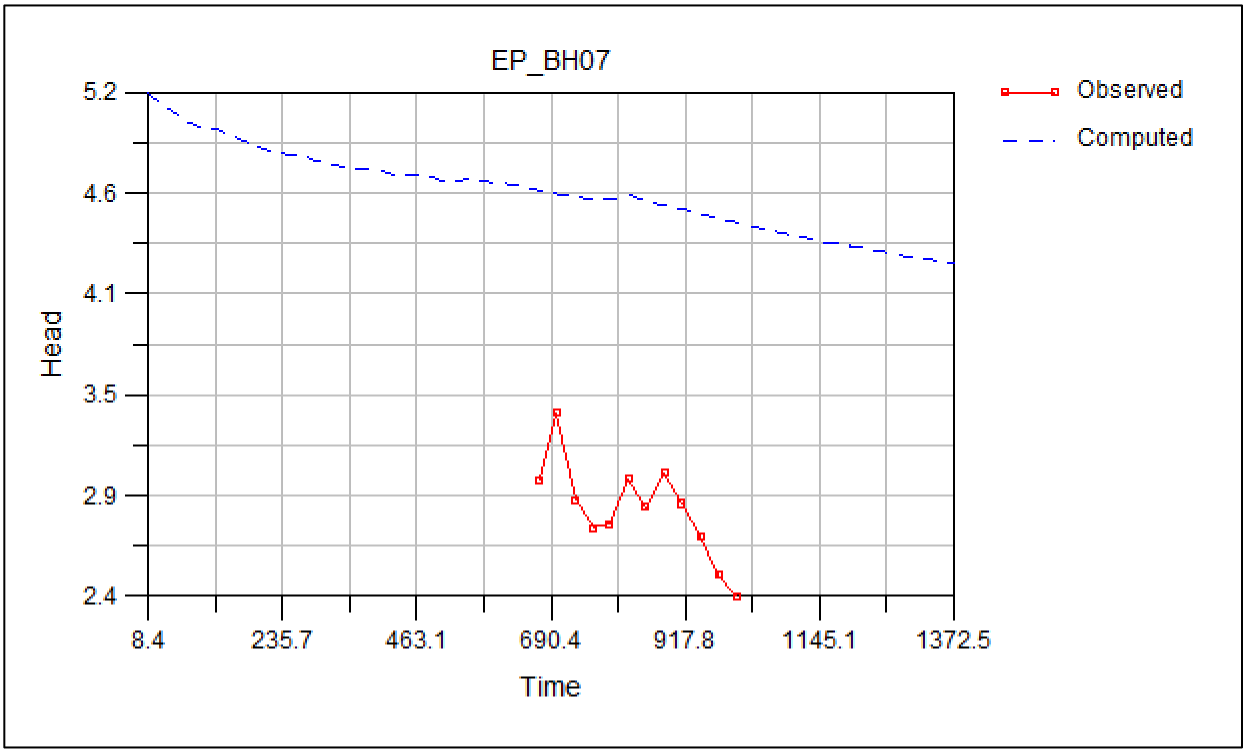
1.0
0.9
0.8
0.7
0.6
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


EP_BH07
Observed
Computed
Head
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4.6
4.1
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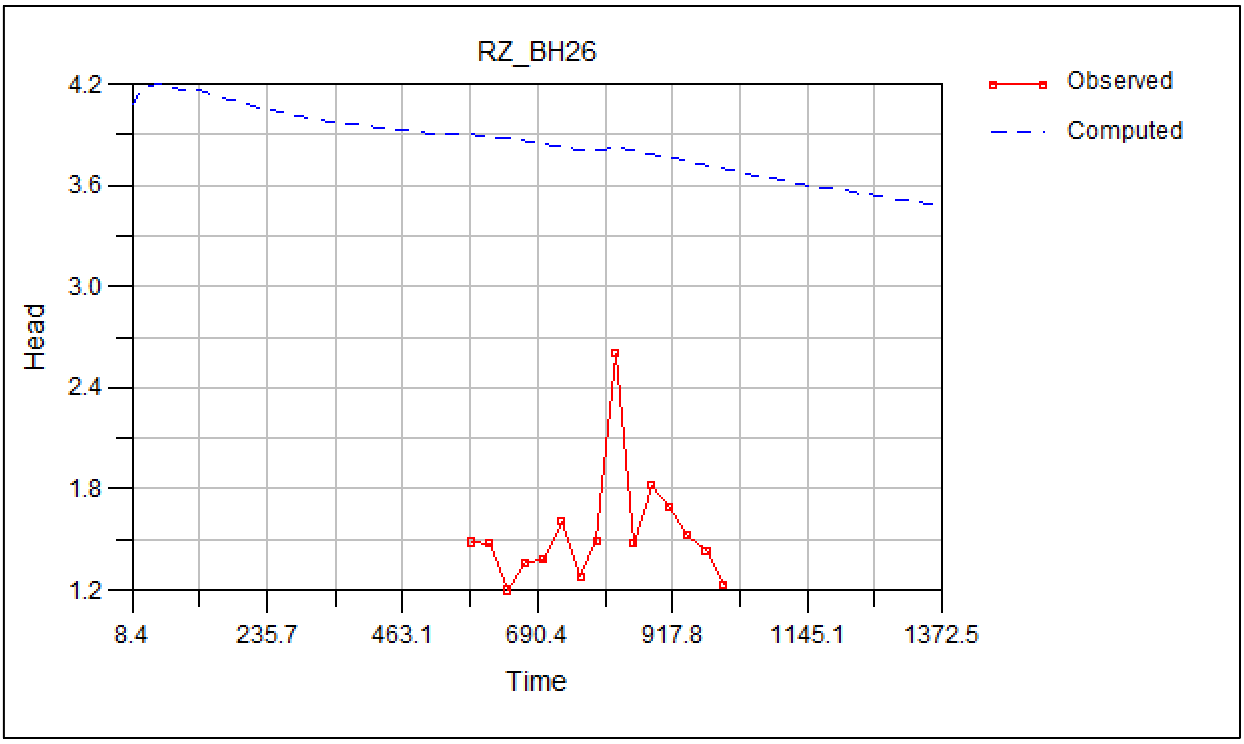
2.9
2.4
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


RZ_BH26
Observed
Computed
Head
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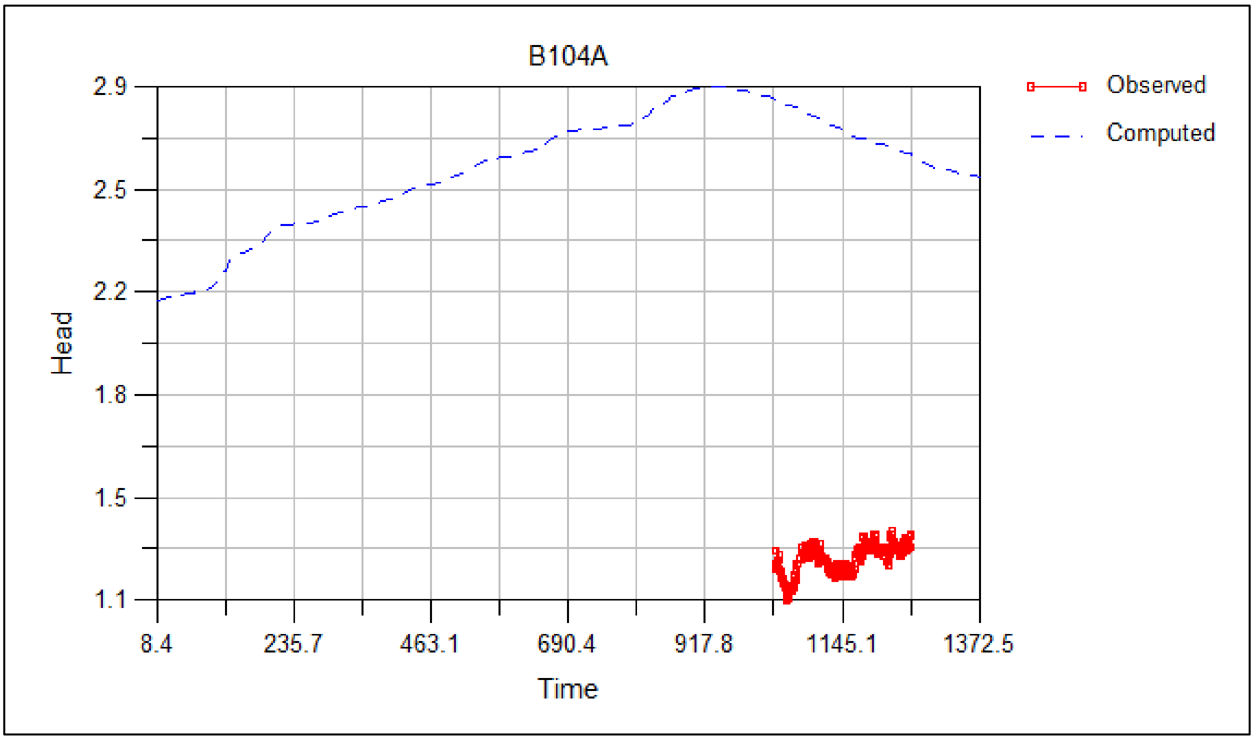
3.0
2.4
1.8
1.2
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


B104A
Observed
Computed
Head
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2.5
2.2
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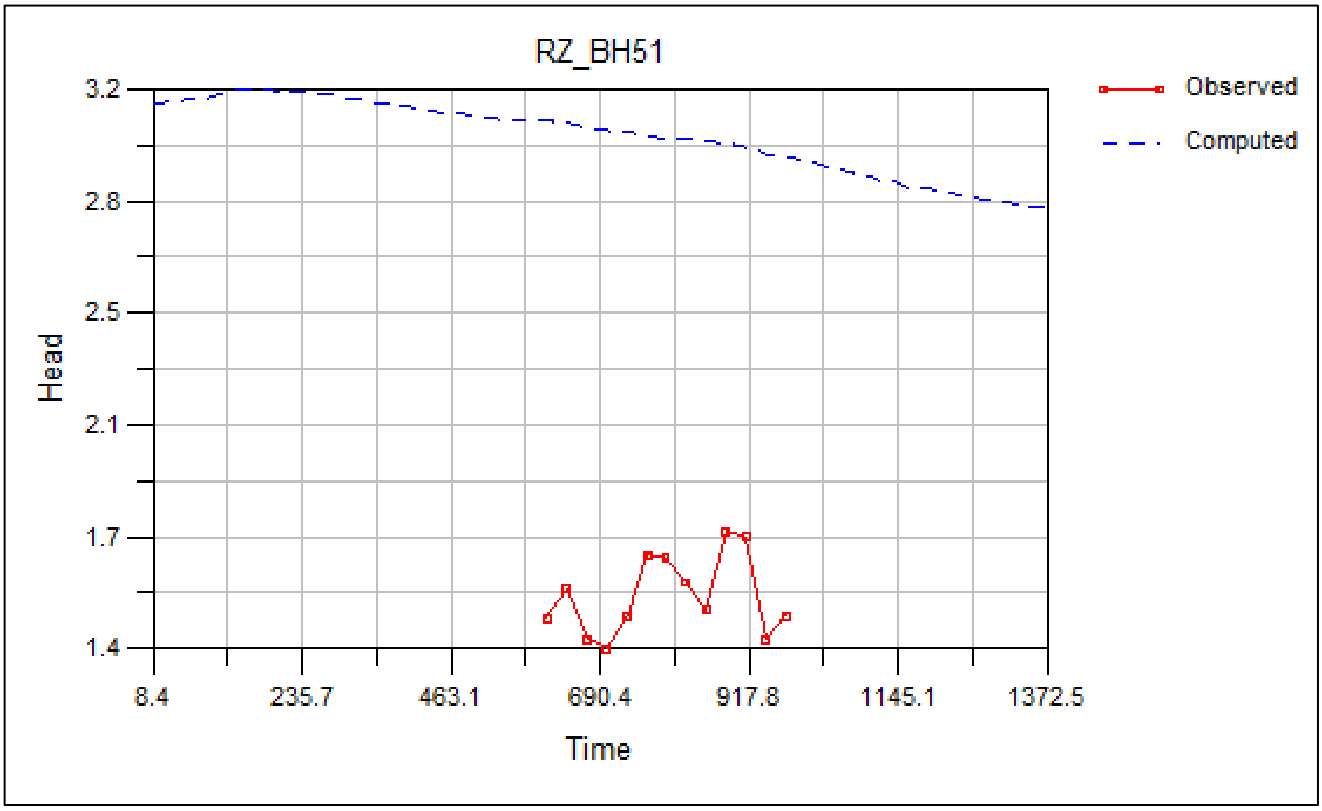
690.4
917.8
1145.1
1372.5
Time


RZ_BH51
Observed
Computed
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1.7
1.4
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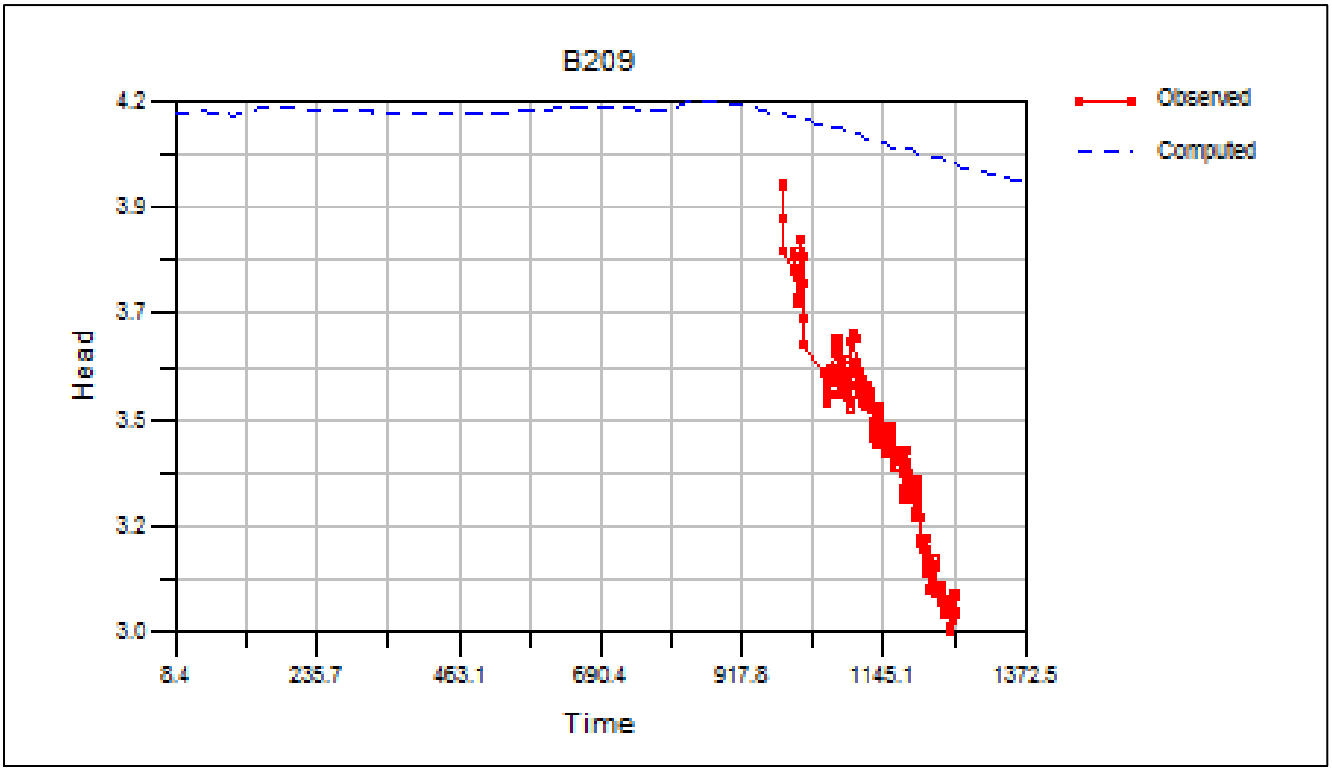
463.1
690.4
917.8
1145.1
1372.5
Time


B209
Observed
Computed
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3.0
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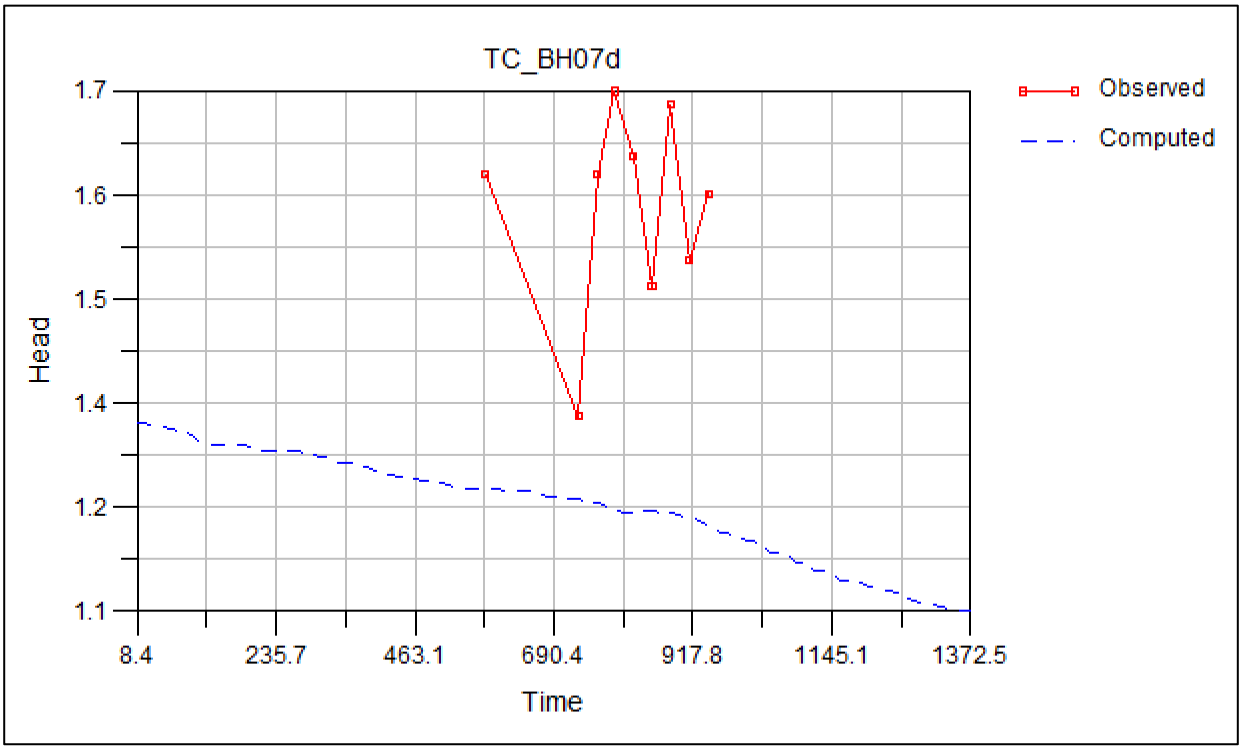
463.1
690.4
917.8
1145.1
1372.5
Time


TC_BH07d
Observed
Computed
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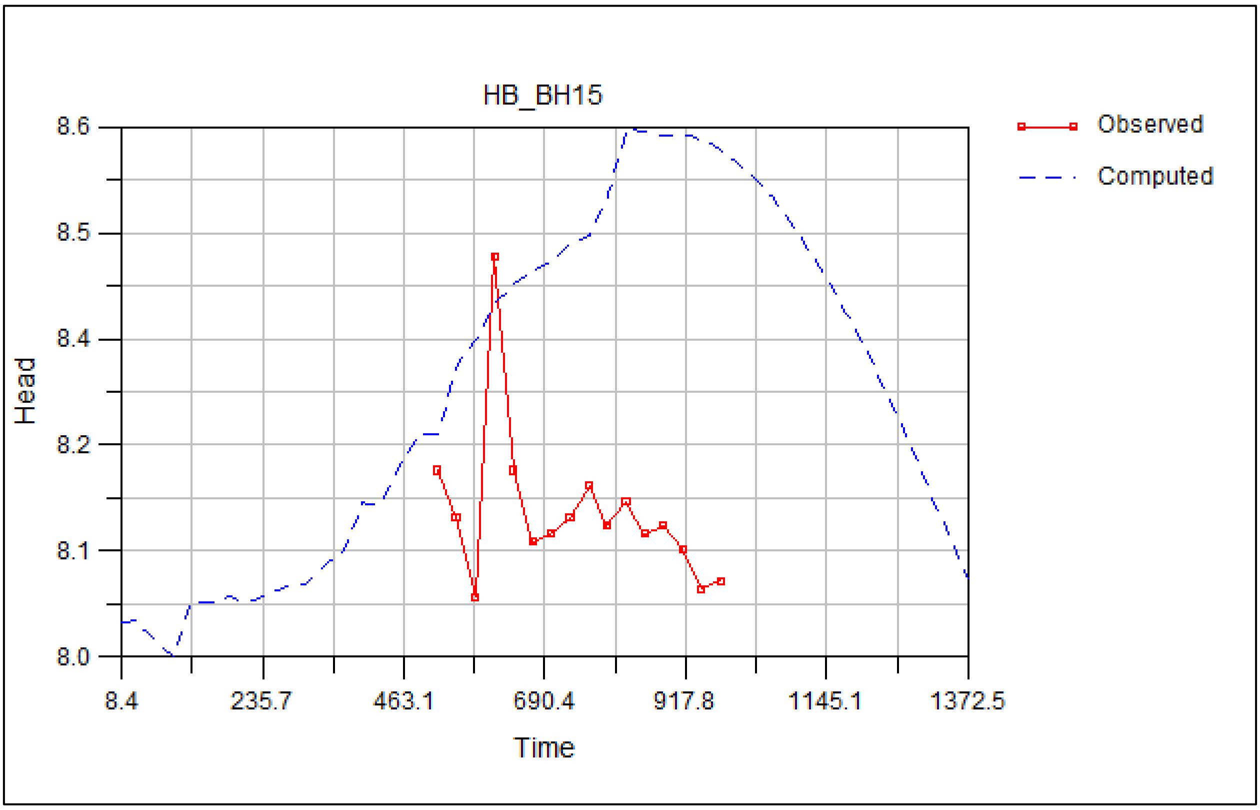
1.6
1.5
1.4
1.2
1.1
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


HB_BH15
Observed
Computed
Head
8.6
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8.4
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8.0
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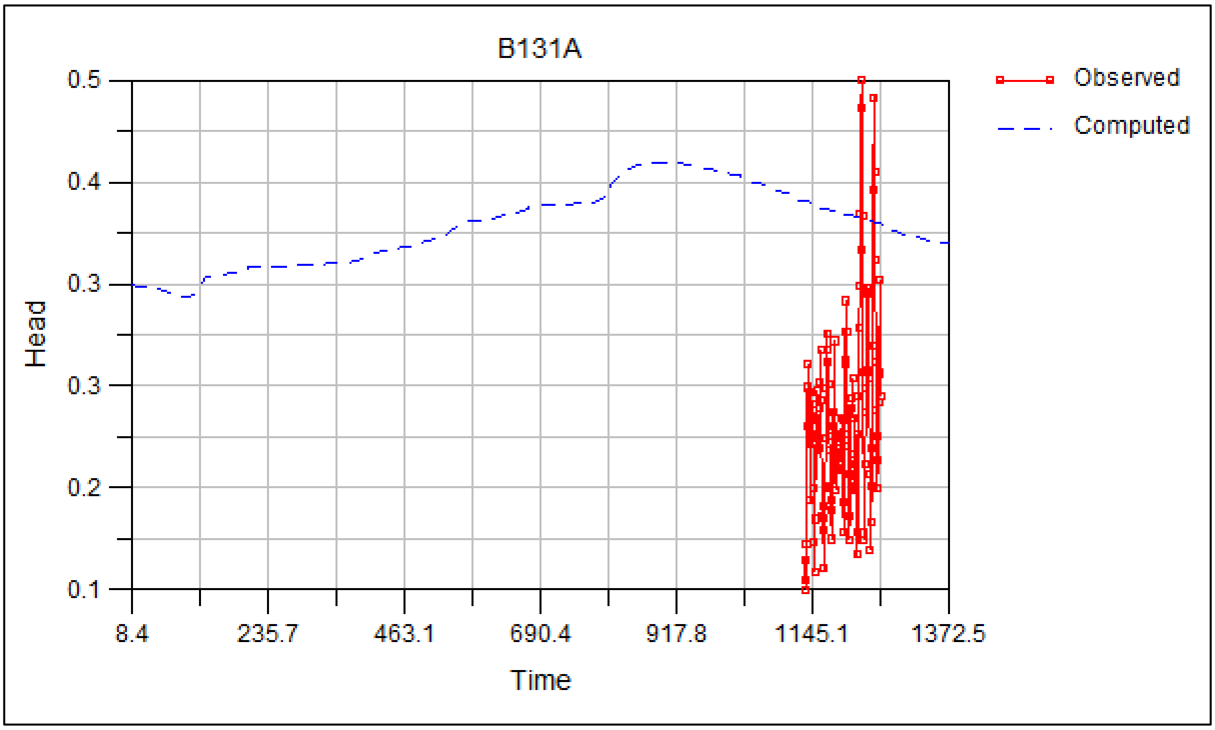
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


B131A
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Computed
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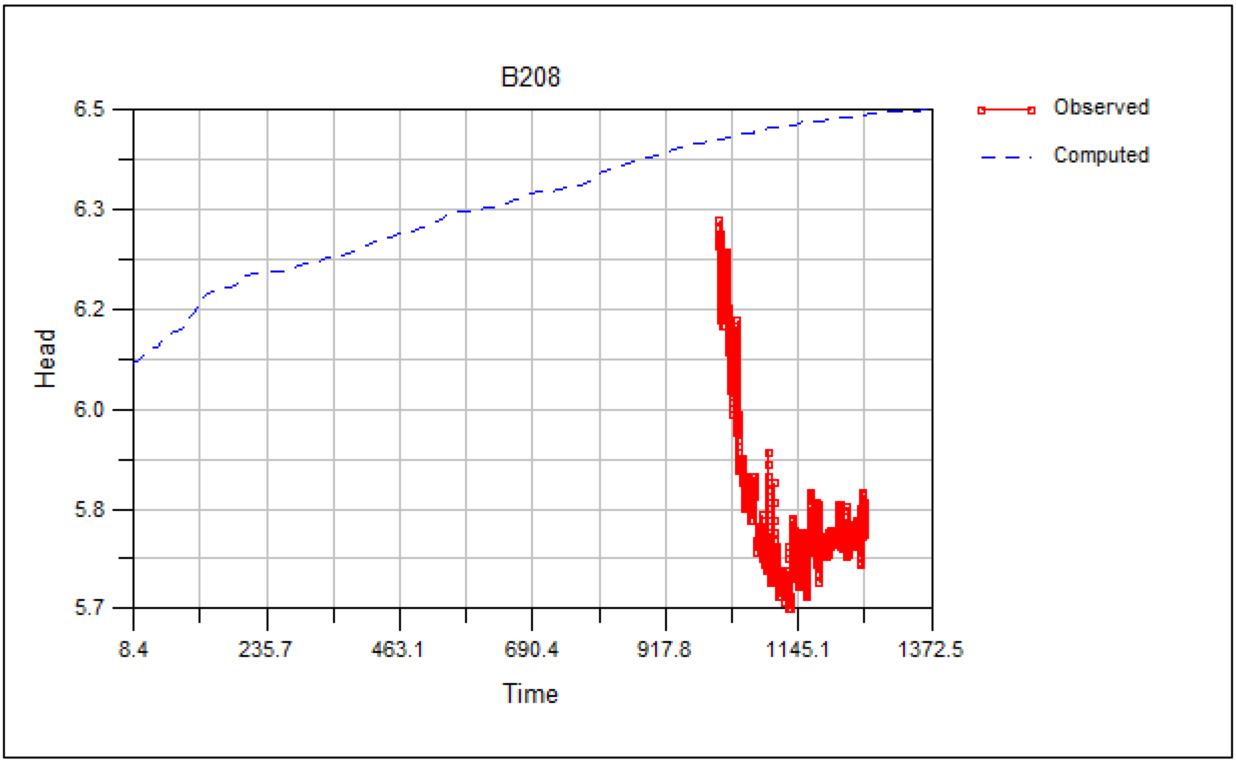
235.7
463.1
690.4
917.8
1145.1
1372.5
Time


B208
Observed
Computed
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6.3
6.2
6.0
5.8
5.7
8.4
235.7
463.1
690.4
917.8
1145.1
1372.5
Time

Annexure 9. Simplified Construction Staging Summary

Section	Section	Start Date	End Date
Rozelle Rail Yards	WHT1	Jan-2024	Jan-2027
Victoria Road	WHT2	Mar-2022	Jun-2026
White Bay	WHT3	Jan-2022	Mar-2026
Yurulbin Point	WHT4	Jan-2022	Jun-2026
Sydney Harbour south cofferdam	WHT5	Jun-2022	Oct-2026
Sydney Harbour north cofferdam	WHT6	Jun-2022	Oct-2026
Berrys Bay	WHT7	Jan-2022	Jun-2026
Cammeray Golf Course	WHT10	Oct-2021	Jun-2026
Waltham Street	WHT11	Jan-2024	Oct-2026

Annexure 10. SEEP/W Hydraulic Conductivity Functions

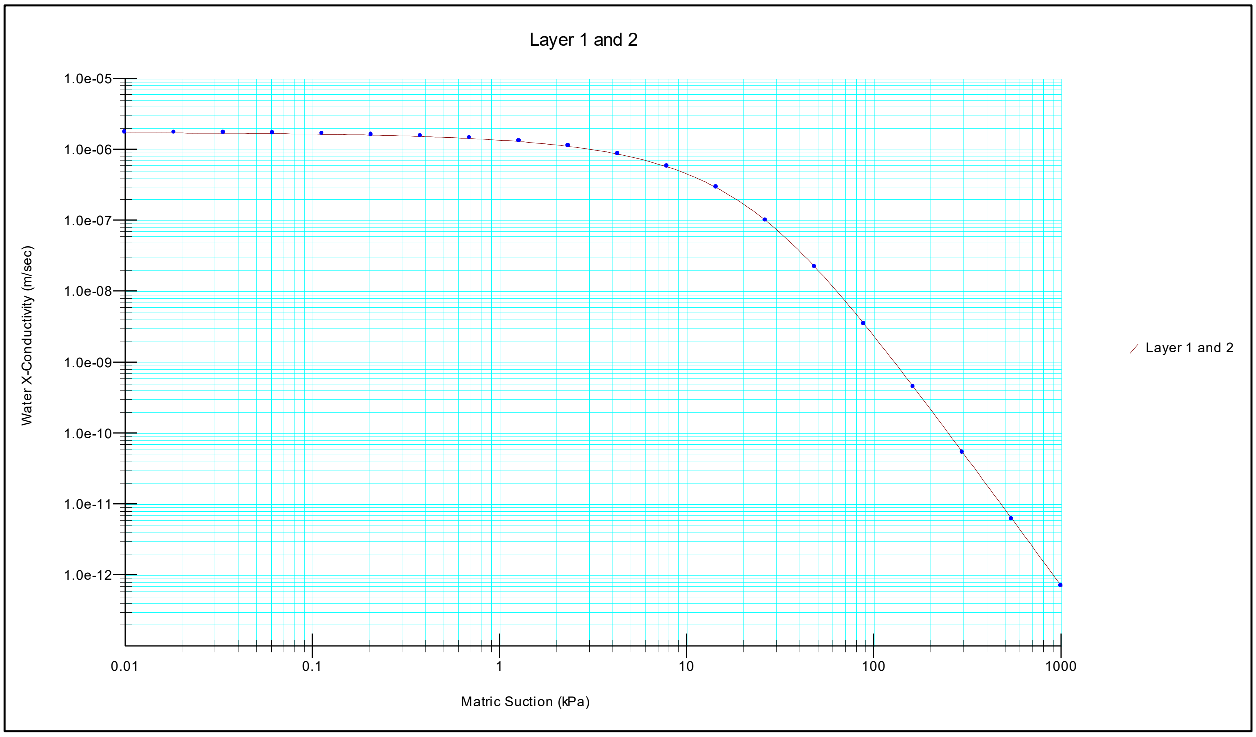

Figure A10-1: Layer 1 and 2 hydraulic conductivity function – South Model.

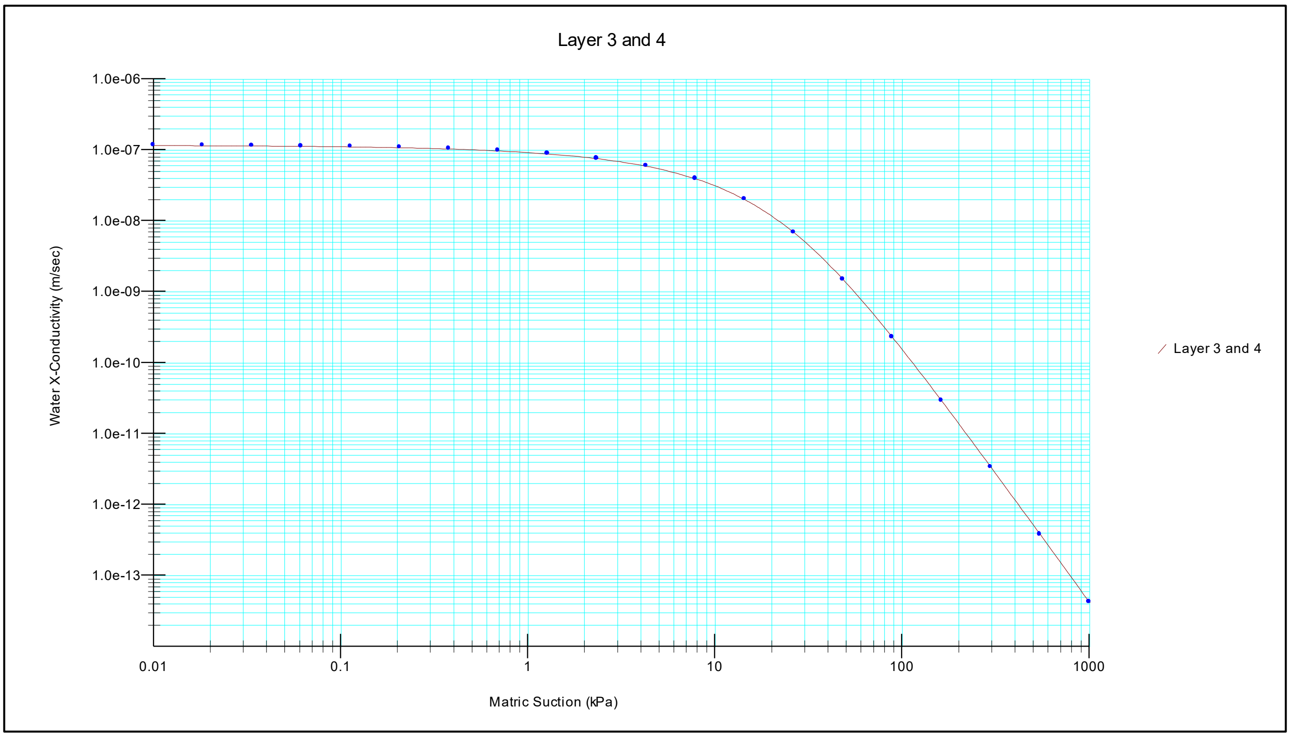

Figure A10-2: Layer 3 and 4 hydraulic conductivity function – South Model

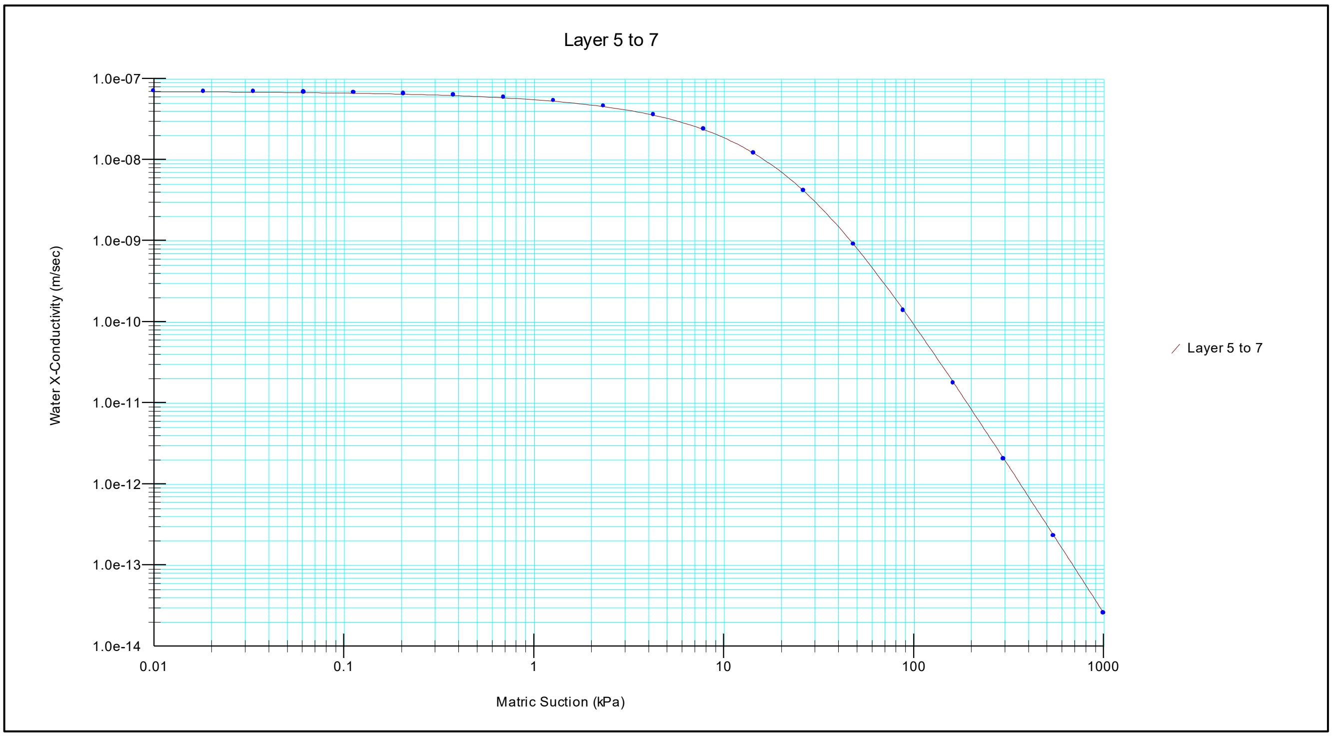

Figure A10-3: Layer 5 to 7 hydraulic conductivity function – South Model

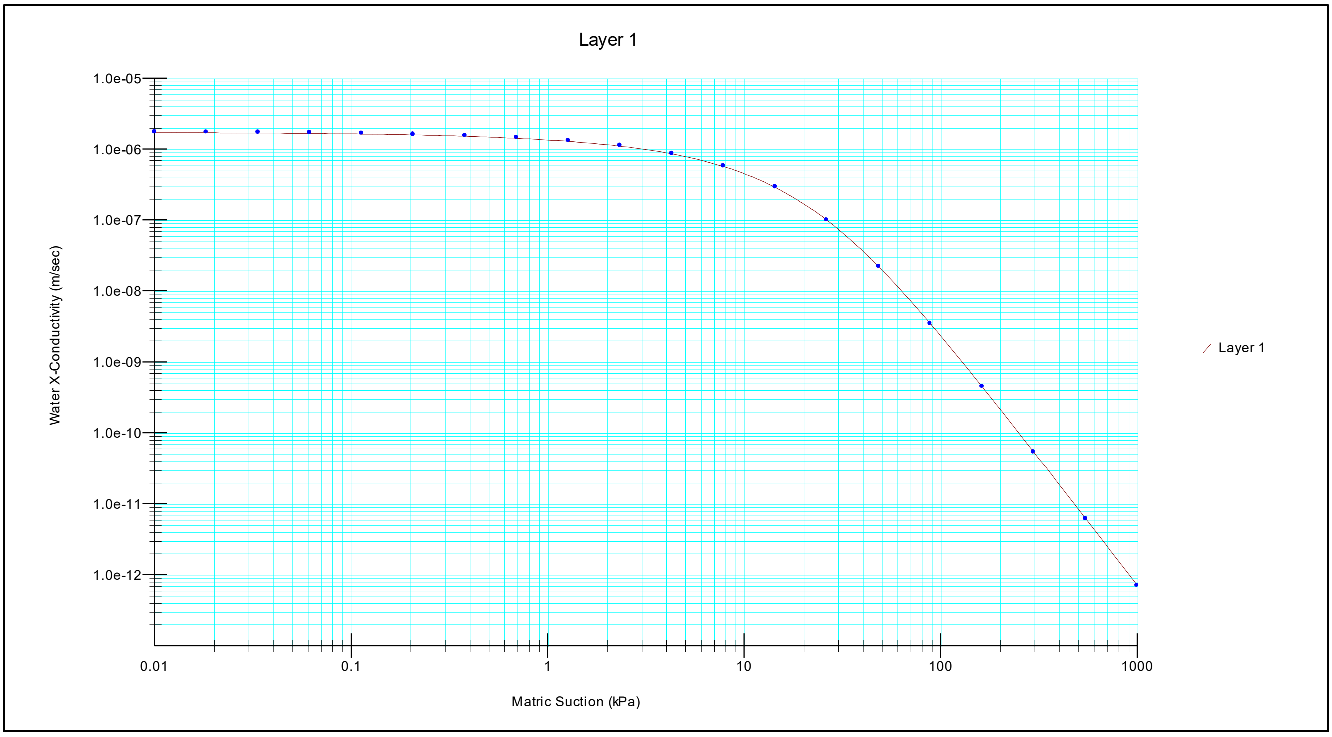

Figure A10-4: Layer 1 hydraulic conductivity function – North Model

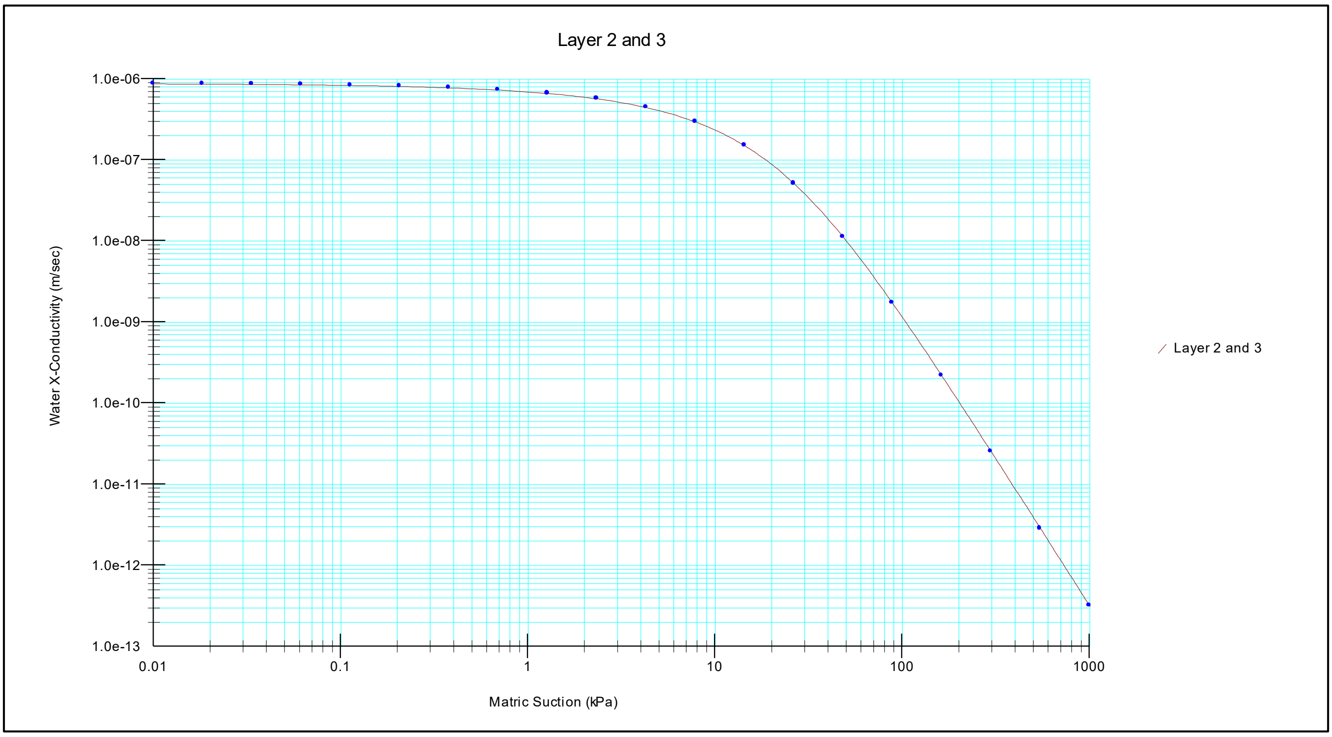

Figure A10-5: Layer 2 and 3 hydraulic conductivity function – North Model

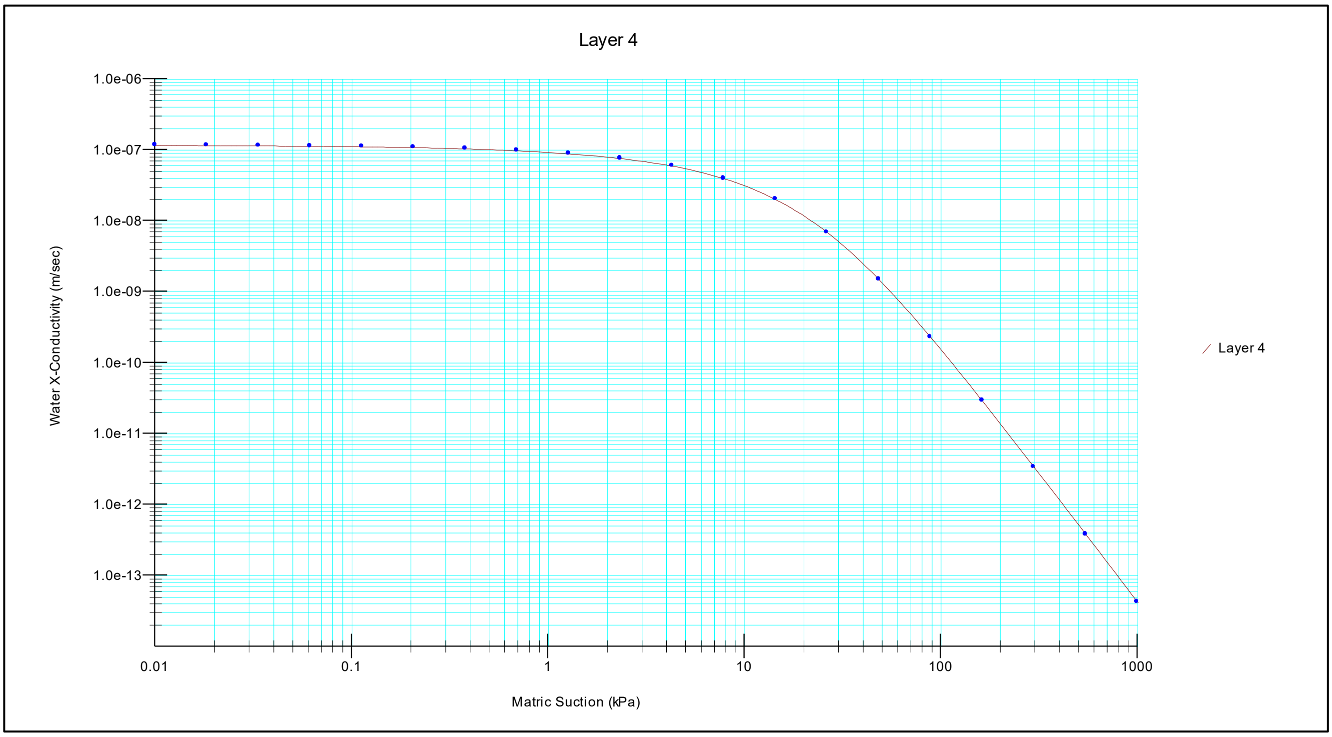

Figure A10-6: Layer 4 hydraulic conductivity function – North Model

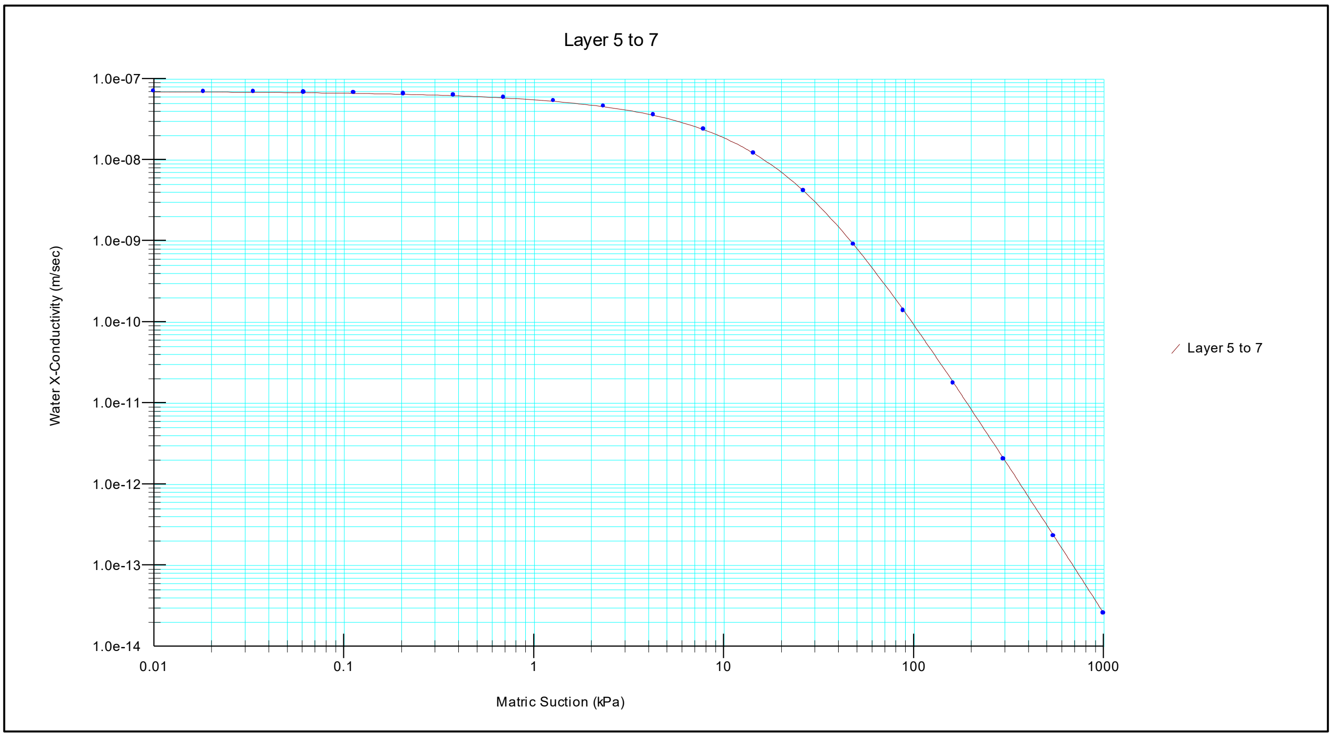

Figure A10-7: Layer 5 to 7 hydraulic conductivity function – North Model

Annexure 11. SEEP/W Water Content Functions

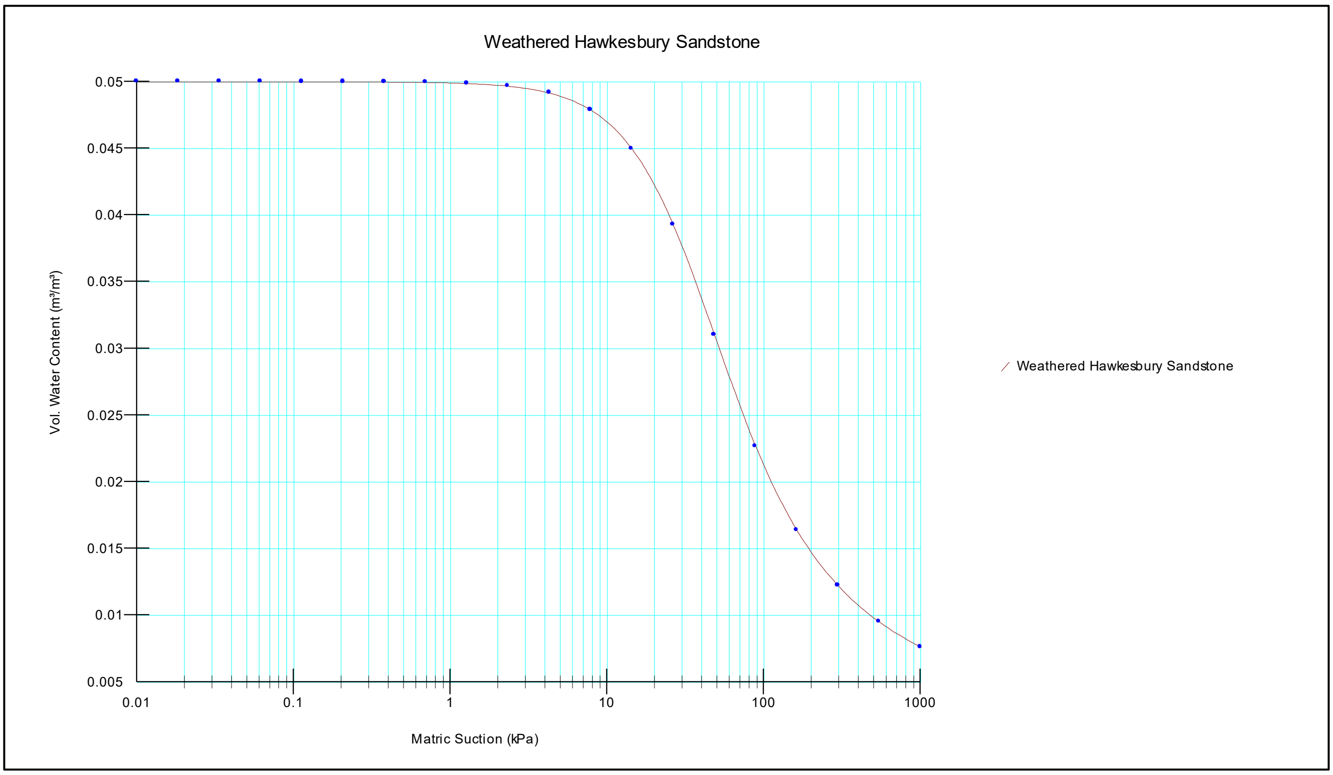

Figure A11-1: Water content function assigned to weathered Hawkesbury Sandstone in Layer 1 – South Model.

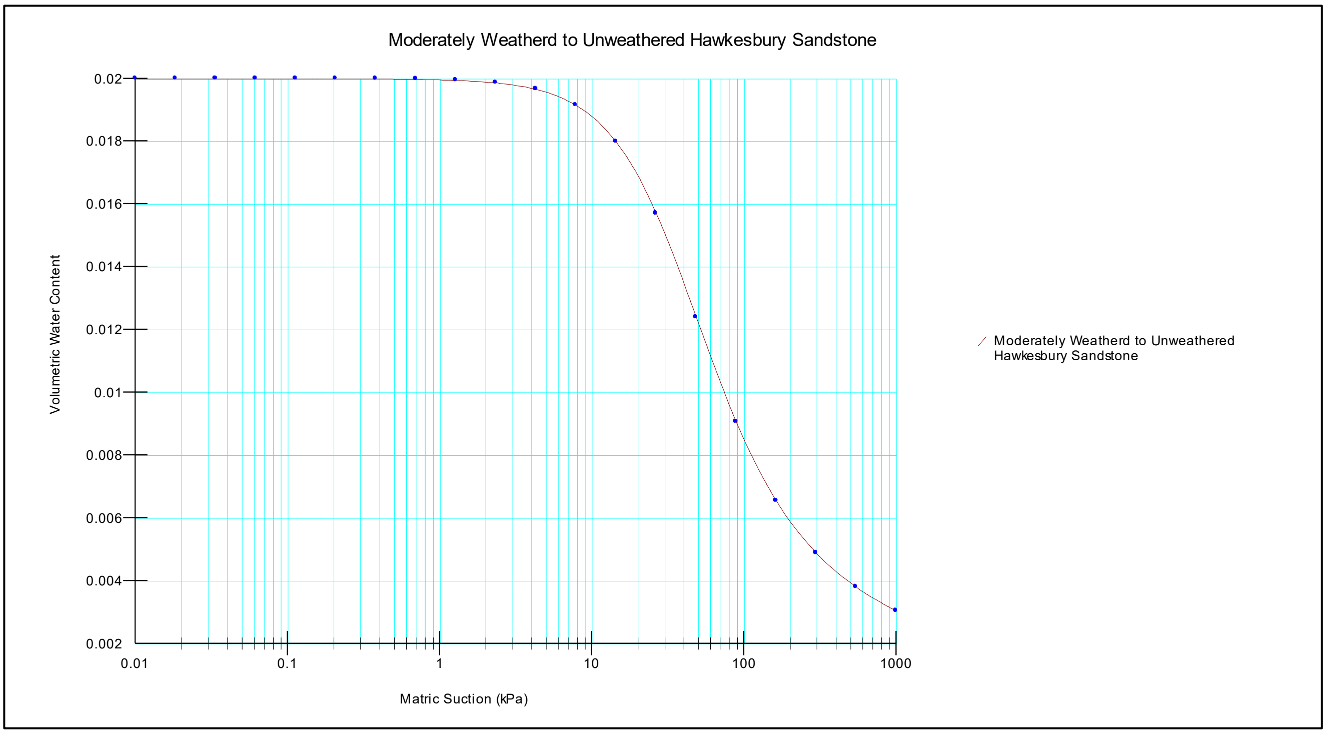

Figure A11-2: Water content function assigned to Layer 2 to Layer 7 – South Model.

NSW GOVERNMENT

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