NSW GOVERNMENT

Transport for NSW

Beaches Link and Gore Hill Freeway Connection

Appendix N

Groundwater

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Transport for NSW

Beaches Link and Gore Hill Freeway Connection

Technical working paper: Groundwater

December 2020

Prepared for

Transport for NSW

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Contents

Figures

Tables

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	NSW 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)	Beaches Link and Gore Hill Freeway Connection project
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 Beaches Link and Gore Hill Freeway Connection component of the works (the project) includes 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.

Transport for NSW is seeking approval under Part 5, Division 5.2 of the *Environmental Planning and Assessment Act 1979* to construct and operate the project, which would comprise two main components:

- Twin motorway tunnels connecting the Warringah Freeway at Cammeray and the Gore Hill Freeway at Artarmon to the Burnt Bridge Creek Deviation at Balgowlah and Wakehurst Parkway at Killarney Heights, and an upgrade of Wakehurst Parkway (the Beaches Link)
- Connection and integration works along the existing Gore Hill Freeway at Artarmon (the Gore Hill Freeway Connection).

Key features of the project are discussed in Section 1.4. A detailed description of the project is provided in Chapter 5 (Project description) of the environmental impact statement.

This technical working paper is one of a number of technical documents that forms part of the environmental impact statement for the project. The purpose of this technical paper is to identify and assess the potential impacts of the project during both construction and operation in relation to groundwater. In doing so, this paper responds directly to the Secretary's environmental assessment requirements, which are outlined in Section 1.7.

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.

Most of the construction footprint would be located underground within the mainline and ramp tunnels. However, surface areas would be required to support tunnelling activities and to construct the tunnel connections including the Wakehurst Parkway upgrade, tunnel portals and operational facilities. The project would be constructed mainly with roadheaders with twin immersed tube tunnels installed within Middle Harbour.

The 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 the immersed tube tunnel sections beneath Middle Harbour.

This report assesses the groundwater pressure, level and quality related impacts 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 were 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.

Assessment methodology

The following methodology has been carried out to assess the potential groundwater related impacts of the project by:

- 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 Aquifer Interference Policy and to address groundwater related issues raised in the Secretary's environmental assessment requirements
- 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. 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
- The groundwater modelling completed for this environmental impact statement is conservative in that it also assumed that the tunnels were unlined, with the exception of a 125 m section on either side of Middle Harbour and that groundwater inflows to the tunnels were constrained by the formation permeability only. In reality, tunnel linings are typically designed and installed within the tunnel to manage groundwater inflow to reduce environmental impacts and operational costs. Motorway tunnels constructed in Sydney are designed for a maximum inflow of one litre per second per kilometre of tunnel (i.e. a maximum of seven litres per second total for a tunnel length of seven kilometres).

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

The Western Harbour Tunnel and Warringah Freeway Upgrade and the Sydney Metro City and Southwest projects are in the vicinity of the Beaches Link and Gore Hill Freeway Connection project. Together these projects could result in greater cumulative impacts on groundwater levels and flow. The impact assessment has reported on impacts due to the Beaches Link 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)
- Reduced baseflow to potentially connected surface water systems, with potential to impact ecosystems reliant on surface water
- Reduced groundwater availability to groundwater dependent ecosystems
- 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 culturally significant sites were identified in the project area.

Potential impacts during construction

The groundwater modelling methodology adopted is conservative and does not account for the progressive installation of tunnel linings to minimise groundwater inflows. The predicted potential impacts from groundwater drawdown presented here are therefore likely to be greater than those of the final constructed project.

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

- Drawdown is predicted to be two metres or more at three groundwater supply bores (GW107970, GW108224, GW108991). While the assessed impact at these bores exceeds the minimal impact levels specified in the Aquifer Interference Policy, a preliminary assessment indicates that the bores would not be affected substantially. Although make good provisions are unlikely to be necessary, monitoring should be carried out if these bores are found to be viable
- Groundwater baseflow impacts due to drawdown at potentially connected surface water systems Flat Rock Creek, Quarry Creek, and Burnt Bridge Creek are predicted to occur due to the project. This could impact ecosystems reliant on the water within these creeks. However, the assessment of baseflow reduction is conservative and is likely to overestimate actual baseflow reduction because:
    i. modelling does not constrain tunnel inflows to one litre per second per kilometre, and drawdowns are therefore exaggerated
    ii. the alluvial and rock aquifers are assumed to be fully connected, which may not be the case, and
    iii. discharge of collected tunnel waters to some watercourses could offset baseflow reductions.
- There remains uncertainty regarding the existing baseflow to potentially affected watercourses and waterbodies, and the connectivity between the aquifer systems in the vicinity of these watercourses. Additional field investigations are likely to reduce this uncertainty
- Drawdown of up to five metres is predicted at the Flat Rock Creek/Quarry Creek groundwater dependent ecosystems. This is based on a conservative estimate of drawdown, without tunnel linings present (except for a 125 m section on either side of Middle Harbour). The estimated drawdown could affect ecosystem health. The potential significance of these impacts is discussed in Appendix S (Technical working paper: Biodiversity development assessment report).

- Water table drawdown is predicted at the following areas of environmental interest for contamination: unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray (up to 17 m), Punch Street at Artarmon (up to 19 m), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (up to 22 m), Balgowlah Golf Course at Balgowlah (up to 11 m), and Waverton Park at Woolcott Road, Waverton (up to 12 m). This drawdown could cause migration of contaminants. If contaminants were mobilised from these areas of environmental interest for contamination, they would travel towards the tunnel during construction, presenting a potential risk to human health and potential damage to tunnel structures. This risk should be managed through monitoring the water quality of tunnel inflows and monitoring groundwater levels and water quality. Contaminants migrating into this section of the tunnel would be collected and treated at the wastewater treatment plants. The modelling indicates that water table drawdown could occur within sediments immediately adjacent to the lower reaches of Flat Rock Creek, and the waters of Middle Harbour, Balls Head Bay, Berrys Bay and Clontarf Beach, where acid sulfate soils (ASS) could be present. However, these sediments are expected to remain saturated (due to constant recharge from harbour waters) and are not expected to experience oxidation due to the project beyond historical levels. Therefore, impacts to groundwater dependent ecosystems, sensitive sites, and groundwater users from oxidation of acid sulfate soils due to groundwater drawdown are not expected
- Modelling of saline intrusion due to the project indicates that both the lateral and upward movement of the saline interface is predicted to be negligible over the project construction period for the modelled cross section through the deepest part of the tunnel alignment. The potential migration of saline intrusion during construction is therefore not considered significant and, as such, impacts on groundwater users, or the beneficial use of the aquifer are not expected. There may be locations where migration of saline waters into freshwater aquifers is more significant than predicted by the modelling, or where groundwater is already slightly saline or becomes more saline due to the project.
- All project components are expected to experience ground surface settlement impacts of over 10 millimetres.

  A maximum long-term total surface settlement of 85 millimetres is predicted at Flat Rock Gully Reserve. This is due to predicted groundwater drawdown assuming no measures to limit groundwater inflows, resulting in consolidation of the deep fill that was historically placed in the valley. As the tunnel will be designed to limit groundwater inflows to the tunnel, the actual groundwater drawdown and associated settlement is expected to be significantly less. For comparison, when a fully lined tunnel (no inflow) is considered in the vicinity of Flat Rock Gully, the predicted maximum settlement at the Flat Rock Reserve reduces to 35 millimetres

  A maximum long-term surface settlement of over 30 millimetres is predicted around the Warringah Freeway portal, Burnt Bridge Creek portal, Wakehurst Parkway portal/access decline, and the Balgowlah ventilation tunnel/access decline. All other project components are anticipated to be subject to total settlement of 30 millimetres or less.

  The assessed potential degree of severity for damage resulting from settlement was ‘slight’ for identified utilities and Aboriginal and non-Aboriginal heritage sites. This equates to potential aesthetic damage such as cracks that require redecoration, repointing for weather-tightness, and door/windows sticking slightly.

  The assessed potential degree of severity for damage resulting from settlement was ‘very slight’ for 61 buildings across the project alignment. This equates to potential aesthetic damage such as fine cracks to decorations; internal wall finishes and external brickwork or masonry. No buildings were assessed to be in the slight, moderate, severe, or very severe categories.

  No buildings, utilities or heritage sites were assessed to be in the ‘moderate’, ‘severe’ or ‘very severe’ categories for potential damage. It should be noted that the risk categories are relevant to buildings and may not be suitable for application to utilities. The potential for predicted ground movement to impact utilities should be confirmed with the respective utility service provider/asset owner.
- Average groundwater inflows (without tunnel linings, except for a 125 m section on either side of Middle Harbour) are predicted to range from 0.41 litres per second per kilometre to 1.39 litres per second per kilometre or 0.75 megalitres per day to 2.45 megalitres per day during construction. Peak inflows are

expected to occur in 2025. Inflows are predicted to exceed the design criteria of one litre per second per kilometre for the year 2025.

Potential impacts during operation

The groundwater modelling methodology adopted is conservative and does not account for the design requirement to limit tunnel inflows to one litre per second per kilometre. The predicted potential impacts from groundwater drawdown presented here are therefore likely to be greater than those of the final constructed project, which would include the effects of the tunnel linings.

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

- Drawdown is predicted to be two metres or more at six groundwater supply bores (GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991). While the predicted drawdown at these bores exceeds the minimal impact levels, a preliminary assessment indicates that the viability of the bores would not be affected substantially. Although make good provisions are unlikely to be necessary, monitoring should be carried out if these bores are found to be viable
- Groundwater baseflow impacts due to drawdown are predicted to potentially occur at connected surface water systems including Flat Rock Creek, Quarry Creek and Burnt Bridge Creek. This could impact ecosystems reliant on the water within these creeks. However, the assessment of baseflow reduction is conservative and is likely to overestimate actual baseflow reduction because:
    i. modelling does not constrain tunnel inflows to one like per second per kilometre, and drawdowns would therefore be exaggerated
    ii. the alluvial and rock aquifers are assumed to be fully connected, which may not be the case, and
    iii. discharge of collected tunnel waters to some watercourses could offset baseflow reductions. There remains uncertainty regarding the existing baseflow to watercourses and waterbodies, and the connectivity between the aquifer systems in the vicinity of watercourses. Additional field investigation should be carried out to reduce this uncertainty
- Drawdown of up to 12 metres at the Flat Rock Creek/Quarry Creek groundwater dependent ecosystem is predicted, which has the potential to impact ecosystem health. This is based on a conservative estimate of drawdown, without tunnel linings present (except for a 125 m section on either side of Middle Harbour). The potential significance of these impacts is discussed in Appendix S (Technical working paper: Biodiversity development assessment report)
- Predicted water table drawdown (without tunnel linings installed, except for a 125 m section on either side of Middle Harbour) is predicted at the following areas of environmental interest for contamination: unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray (up to 19 metres), Punch Street at Artarmon (up to 21 metres), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (up to 27 metres), Balgowlah Golf Course at Balgowlah (up to 11 metres), and Waverton Park at Woolcott Road, Waverton (up to 13 metres). This drawdown could cause migration of contaminants. If contaminants were mobilised from these areas of environmental interest for contamination, they would travel towards the tunnel during construction, presenting a potential risk to human health and potential damage to tunnel structures. This risk would be managed through monitoring the water quality of tunnel inflows and monitoring groundwater levels and water quality. Contaminants migrating into this section of the tunnel would be collected and treated at the operational wastewater treatment plant at Artarmon
- The modelling indicates that water table drawdown could occur within sediments immediately adjacent to the lower reaches of Flat Rock Creek, and the waters of Middle Harbour, Balls Head Bay, Berrys Bay and Clontarf Beach where ASS could be present. However, these sediments are expected to remain saturated (due to constant recharge from harbour waters) and are not expected to experience oxidation due to the project beyond historical levels. Therefore, impacts to groundwater dependent ecosystems, sensitive sites, and groundwater users from oxidation of ASS due to groundwater drawdown are not expected

- The predicted migration of the saline interface along the modelled cross section through the deepest part of the tunnel alignment is considered negligible after 100 years of operation and, as such, impacts to groundwater users, groundwater dependent ecosystems or the beneficial use of the aquifer are not expected. There may be locations where migration of saline waters into freshwater aquifers is more significant than predicted by the modelling, or where groundwater is already slightly saline is becomes more saline due to the project.
- Ground settlement during operation is not expected to exceed that which would occur during construction, because the excavation-induced settlement and groundwater drawdown-related settlement would be realised during the construction phase
- Average groundwater inflows (without tunnel linings, except for a 125 m section on either side of Middle Harbour) are predicted to be 0.86 litres per second per kilometre at the beginning of operation in 2028, declining to 0.69 litres per second per kilometre after 100 years of operation. The annual total groundwater inflow is predicted to be 551 megalitres in 2028, declining to 436 megalitres per year after 100 years of operation. Predicted inflows are below the design criteria upper limit of one litre per second per kilometre during operation.

Environmental management measures

Construction

Safeguards would be implemented to minimise and manage impacts during construction. The project construction environmental management plan should include a groundwater monitoring program for the construction phase that takes into consideration the groundwater monitoring being carried out ahead of the Beaches Link project for the Western Harbour Tunnel and Warringah Freeway Upgrade project. The monitoring regime should 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
- While the project is assessed to cause negligible impact to identified groundwater supply bores, site inspections should be carried out to confirm the current viability of these bores. If viable, make good measures should be implemented as required
- To further quantify the risk from groundwater contamination to construction of the project (including dewatering), further investigations should occur at the unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray (AEI B1), Punch Street at Artarmon (AEI B7), Flat Rock Gully Reserve at Northbridge (AEI B9), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10), Balgowlah Golf Course at Balgowlah (AEI B13), and Waverton Park – Woolcott Road, Waverton (AEI B8). If unacceptable contamination risks are established, suitable tunnel design measures (such as waterproof linings) should be implemented at detailed design to reduce the risk of contamination migration during the construction phase of the project
- If bores GW107970, GW108224, GW108991 are found to be viable, additional studies should be carried out to confirm how the bore might be affected, and appropriate make good provisions implemented (if required) to maintain viability. Identified make good provisions should be implemented as appropriate. The bores should be monitored throughout construction to confirm that impacts are as expected. Additional make good provisions should be implemented as required to maintain the viability of the bores. If loss of yield results from tunnel dewatering, make good measures to be considered should include deepening the bore or connection to an alternative water supply
- A focussed study should be carried out to confirm potential baseflow reductions in Burnt Bridge Creek, Flat Rock Creek and Quarry Creek due to groundwater drawdown, and what affect this might have on freshwater ecology in the affected watercourses and nearby groundwater dependent ecosystems. The study should consider how existing site features affect the interaction between surface water and groundwater along the affected reaches of these watercourses, and the hydraulic connectivity in the underlying geology. Where unacceptable ecological impacts are predicted, feasible and reasonable mitigation measures to address the

impacts should be identified, incorporated into the design, and implemented during construction. The mitigation measures considered should include tunnel linings

- Monitoring the quality and quantity of groundwater inflow into tunnels during construction
- Monitoring of the quality and quantity of the treated wastewater discharges from the construction wastewater treatment plants
- Potential impacts from settlement should be managed through the development of detailed predictive settlement models for areas of concern, to guide tunnel design and construction methodology, including the selection of options to minimise settlement where required. Building/structure condition surveys should be prepared for properties (and heritage assets) within the zone of influence of predicted tunnel settlement prior to the commencement of construction activities. Agreements with utility and infrastructure owners identifying acceptable limits of settlement, settlement monitoring and actions if settlement limits are exceeded should be reached before tunnel construction starts
- Ongoing settlement monitoring should be carried out.

Operation

Measures would be included in the project's operational environmental management plan to manage operational impacts. Groundwater inflows and water table drawdown monitoring would be developed in consultation with the Environmental Protection Agency and Department of Planning, Industry and Environment. Operational monitoring should include:

- Monitoring the quality and quantity of groundwater inflows into tunnels next to the unsealed areas next to the Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray (AEI B1), Punch Street at Artarmon (AEI B7), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10), Balgowlah Golf Course at Balgowlah (AEI B13), and Waverton Park – Woolcott Road, Waverton (AEI B8)
- While the project is assessed to cause negligible impact to identified groundwater supply bores, site inspections should be undertaken at groundwater supply bores GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991, if they are found to be viable
- Monitoring of the quality and quantity of the treated wastewater discharges from the wastewater treatment plant
- Ongoing settlement monitoring, as per the independent property impact assessment requirements.

1. Introduction

This section provides an overview of the Beaches Link and Gore Hill Freeway Connection (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), 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 Middle 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 the Gore Hill Freeway to Balgowlah and Killarney Heights and including the surface upgrade of the 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 areas 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 existing harbour crossings.

1.2 The project

Transport for NSW is seeking approval under Part 5, Division 5.2 of the Environmental Planning and Assessment Act 1979 to construct and operate the Beaches Link and Gore Hill Freeway Connection project, which would comprise two components:

- Twin tolled motorway tunnels connecting the Warringah Freeway at Cammeray and the Gore Hill Freeway at Artarmon to the Burnt Bridge Creek Deviation at Balgowlah and the Wakehurst Parkway at Killarney Heights, and an upgrade of the Wakehurst Parkway (the Beaches Link)
- Connection and integration works along the existing Gore Hill Freeway and surrounding roads at Artarmon (the Gore Hill Freeway Connection).

A detailed description of these two components is provided in Section 1.4.

1.3 Project location

The project would be located within the North Sydney, Willoughby, Mosman and Northern Beaches local government areas, connecting Cammeray in the south with Killarney Heights, Frenchs Forest and Balgowlah in the north. The project would also connect to both the Gore Hill Freeway and Reserve Road in Artarmon in the west.

Commencing at the Warringah Freeway at Cammeray, the mainline tunnels would pass under Naremburn and Northbridge, then cross Middle Harbour between Northbridge and Seaforth. The mainline tunnels would then split under Seaforth into two ramp tunnels and continue north to the Wakehurst Parkway at Killarney Heights and north-east to Balgowlah, linking directly to the Burnt Bridge Creek Deviation to the south of the existing Kitchener Street bridge.

The mainline tunnels would also have on and off ramps from under Northbridge connecting to the Gore Hill Freeway and Reserve Road east of the existing Lane Cove Tunnel. Surface works would also be carried out at the Gore Hill Freeway in Artarmon, Burnt Bridge Creek Deviation at Balgowlah and along the Wakehurst Parkway between Seaforth and Frenchs Forest to connect the project to the existing arterial and local road networks.

1.4 Key features of the project

Key features of the Beaches Link component of the project are shown in Figure 1-1 and would include:

- Twin mainline tunnels about 5.6 kilometres long and each accommodating three lanes of traffic in each direction, together with entry and exit ramp tunnels to connections at the surface. The crossing of Middle Harbour between Northbridge and Seaforth would involve three lane, twin immersed tube tunnels
- Connection to the stub tunnels constructed at Cammeray as part of the Western Harbour Tunnel and Warringah Freeway Upgrade project
- Twin two lane ramp tunnels:
  - Eastbound and westbound connections between the mainline tunnel under Seaforth and the surface at the Burnt Bridge Creek Deviation, Balgowlah (about 1.2 kilometres in length)
  - Northbound and southbound connections between the mainline tunnel under Seaforth and the surface at the Wakehurst Parkway, Killarney Heights (about 2.8 kilometres in length)
  - Eastbound and westbound connections between the mainline tunnel under Northbridge and the surface at the Gore Hill Freeway and Reserve Road, Artarmon (about 2.1 kilometres in length).
- An access road connection at Balgowlah between the Burnt Bridge Creek Deviation and Sydney Road including the modification of the intersection at Maretimo Street and Sydney Road, Balgowlah
- Upgrade and integration works along the Wakehurst Parkway, at Seaforth, Killarney Heights and Frenchs Forest, through to Frenchs Forest Road East
- New and improved open space and recreation facilities at Balgowlah
- New and upgraded pedestrian and cyclist infrastructure
- Ventilation outlets and motorway facilities at the Warringah Freeway in Cammeray, the Gore Hill Freeway in Artarmon, the Burnt Bridge Creek Deviation in Balgowlah and the Wakehurst Parkway in Killarney Heights
- Operational facilities, including a motorway control centre at the Gore Hill Freeway in Artarmon, and tunnel support facilities at the Gore Hill Freeway in Artarmon and the Wakehurst Parkway in Frenchs Forest
- Other operational infrastructure including groundwater and tunnel drainage management and treatment systems, surface drainage, signage, tolling infrastructure, fire and life safety systems, roadside furniture, lighting, emergency evacuation and emergency smoke extraction infrastructure, Closed Circuit Television (CCTV) and other traffic management systems.

Key features of the Gore Hill Freeway Connection component of the project are shown in Figure 1-2 and would include:

- Upgrade and reconfiguration of the Gore Hill Freeway between the T1 North Shore & Western Line and T9 Northern Line and the Pacific Highway
- Modifications to the Reserve Road and Hampden Road bridges
- Widening of Reserve Road between the Gore Hill Freeway and Dickson Avenue
- Modification of the Dickson Avenue and Reserve Road intersection to allow for the Beaches Link off ramp
- Upgrades to existing roads around the Gore Hill Freeway to integrate the project with the surrounding road network
- Upgrade of the Dickson Avenue and Pacific Highway intersection
- New and upgraded pedestrian and cyclist infrastructure
- Other operational infrastructure, including surface drainage and utility infrastructure, signage and lighting, CCTV and other traffic management systems.

A detailed description of the project is provided in Chapter 5 (Project description) of the environmental impact statement.

Subject to obtaining planning approval, construction of the project is anticipated to commence in 2023 and is expected to take around five to six years to complete.

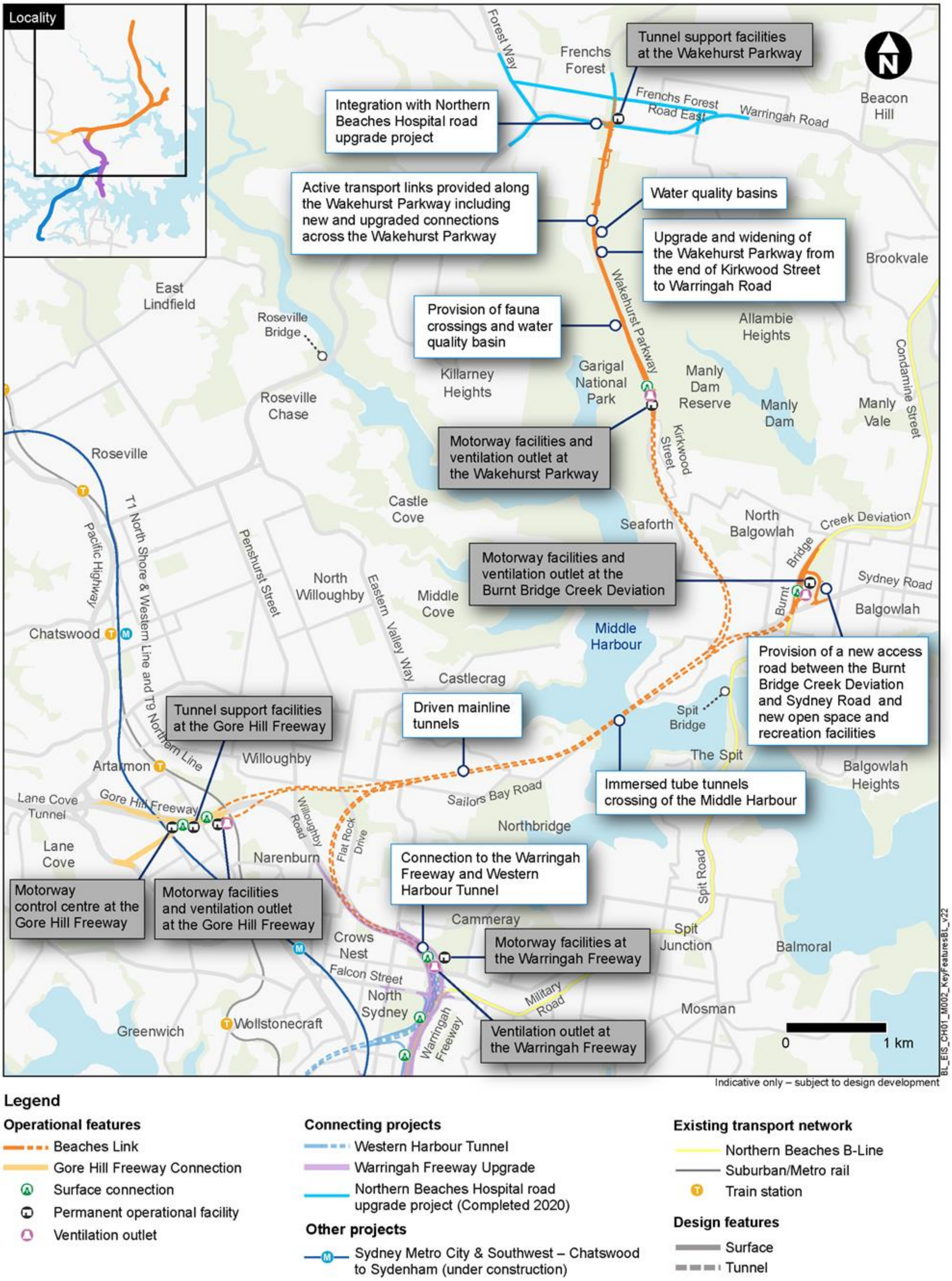


Figure 1-1 Key features of the Beaches Link component of the project

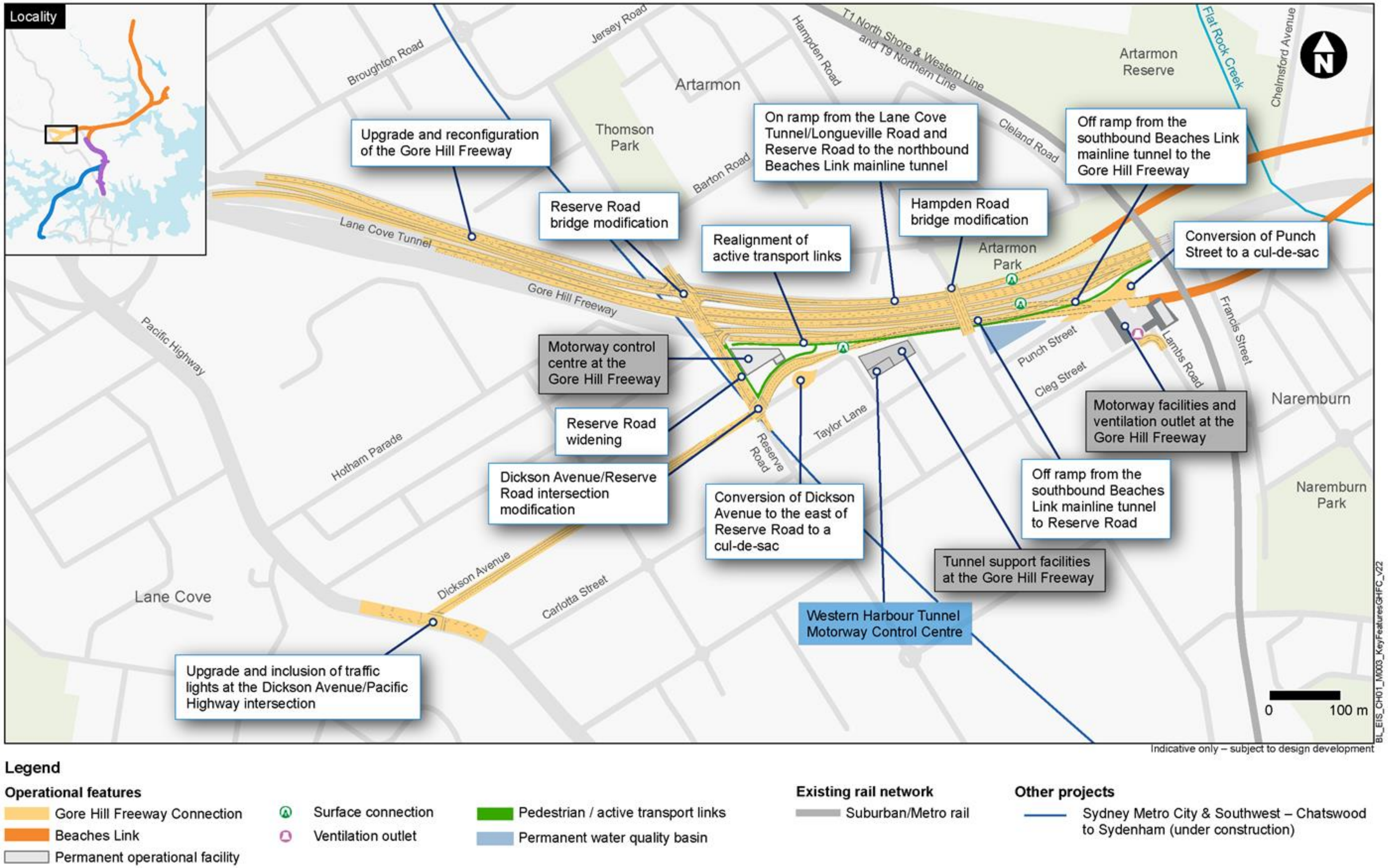


Figure 1-2 Key features of the Gore Hill Freeway Connection component of the project

1.5 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 and ramp tunnels. However, surface areas would also be required to support tunnelling activities and to construct the tunnel connections, tunnel portals, surface road upgrades and operational 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), traffic management controls, vegetation clearing, earthworks, demolition of structures, building 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 and/or provision of alternative facilities (mooring or marina berth) within Middle Harbour
- Construction of the Beaches Link, with typical activities being excavation of tunnel construction access declines, construction of driven tunnels, cut and cover and trough structures, construction of surface upgrade works, construction of cofferdams, dredging and immersed tube tunnel piled support 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:
  - A motorway control centre at the Gore Hill Freeway in Artarmon
  - Tunnel support facilities at the Gore Hill Freeway in Artarmon and at the Wakehurst Parkway in Frenchs Forest
  - Motorway facilities and ventilation outlets at the Warringah Freeway in Cammeray (fitout only of the Beaches Link ventilation outlet at the Warringah Freeway (being constructed by the Western Harbour Tunnel and Warringah Freeway Upgrade project), the Gore Hill Freeway in Artarmon, the Burnt Bridge Creek Deviation in Balgowlah and the Wakehurst Parkway in Killarney Heights
  - A wastewater treatment plant at the Gore Hill Freeway in Artarmon
  - Installation of motorway tolling infrastructure
- Staged construction of the Gore Hill Freeway Connection at Artarmon and upgrade and integration works at Balgowlah and along the Wakehurst Parkway with typical activities being earthworks, bridgeworks, construction of retaining walls, stormwater drainage, pavement works and linemarking and the installation of roadside 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 would include:

- Cammeray Golf Course (BL1)
- Flat Rock Drive (BL2)
- Punch Street (BL3)
- Dickson Avenue (BL4)
- Barton Road (BL5)
- Gore Hill Freeway median (BL6)

- Middle Harbour south cofferdam (BL7)
- Middle Harbour north cofferdam (BL8)
- Spit West Reserve (BL9)
- Balgowlah Golf Course (BL10)
- Kitchener Street (BL11)
- Wakehurst Parkway south (BL12)
- Wakehurst Parkway east (BL13)
- Wakehurst Parkway north (BL14).

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

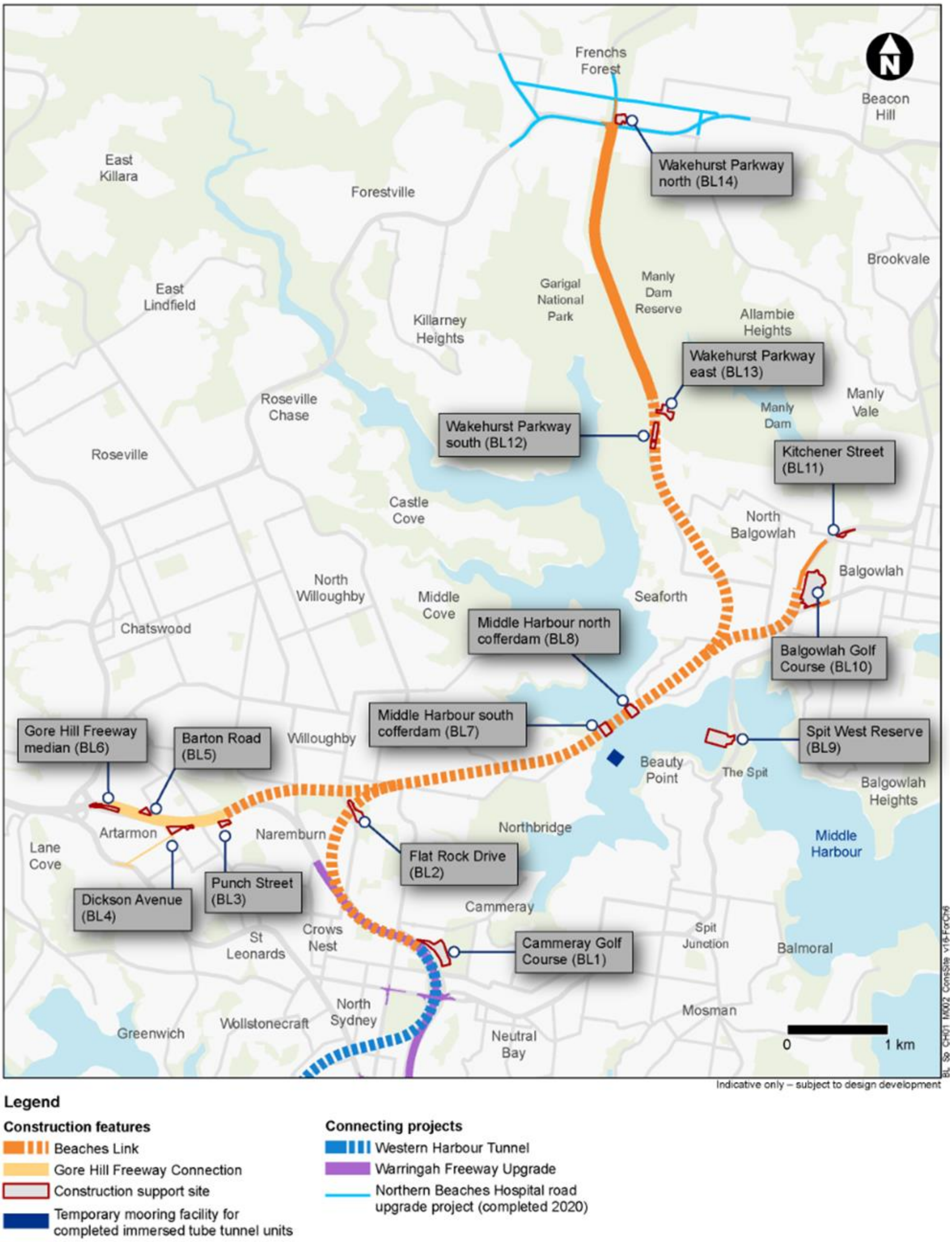


Figure 1-3 Overview of construction support sites

1.6 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 (formerly the Department of Planning and Environment) ('the Secretary's environmental assessment requirements').

The purpose of this report is to assess 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 to Groundwater Dependent Ecosystems (GDEs), reducing baseflow contributions to surface water courses and reducing the availability of water to local groundwater users. This assessment also seeks to establish the presence of potentially contaminated groundwater, as tunnel inflows in contaminated areas have the potential to lead to environmental and human health risks, and the requirements and potential impacts of water disposal need to be assessed accordingly.

1.7 Secretary's environmental assessment requirements

The Secretary's environmental assessment requirements (SEARs) relating to the groundwater impact assessment and where these requirements are addressed in this report are outlined in Table 1-1.

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 Appendix O (Technical working paper: Surface water quality and hydrology)
- Identification of the rainfall event that the water quality objectives are designed to cope with (SEAR 10.1d) is covered in Appendix O (Technical working paper: Surface water quality and hydrology)
- Identification of contamination risks is also covered in Appendix M (Technical working paper: Contamination).

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

Key issue and desired performance outcome	Requirement in relation to groundwater	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 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.	(a) 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 5.5 Appendix O (Technical working paper: Surface water quality and hydrology) Appendix S (Technical working paper: Biodiversity development assessment report
	(b) 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.	Appendix O (Technical working paper: Surface water quality and hydrology)
	(c) 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;	Section 5 Appendix R Appendix O (Technical working paper: Surface water quality and hydrology) Appendix S (Technical working paper: Biodiversity development assessment report)

Key issue and desired performance outcome	Requirement in relation to groundwater	Where addressed
	(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.	
	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.	Chapter 5 (Project description)
	5. The Proponent must identify any requirements for baseline monitoring of hydrological attributes.	Appendix O (Technical working paper: Surface water quality and hydrology)
	6. The assessment must include details of proposed surface and groundwater monitoring.	Appendix O (Technical working paper: Surface water quality and hydrology)
	7. The Proponent must identify design approaches to minimise or prevent drainage of alluvium in the paleochannels.	Section 7.1 Section 7.2

Key issue and desired performance outcome	Requirement in relation to groundwater	Where addressed
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 including estuarine and marine water (if applicable).	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 would 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 would continue to be protected; and – where the NSW WQOs are not currently being met, activities would work toward their achievement over time;	Section 5.5.6 Section 6 Section 6 Section 7 Appendix O (Technical working paper: Surface water quality and hydrology)

Key issue and desired performance outcome	Requirement in relation to groundwater	Where addressed
	(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. (k) identify how the development meets the objectives of the Coastal Management Act 2016 and management objectives of relevant Coastal Management Areas defined under the Coastal Management Act 2016. (l) demonstrate consistency with any relevant certified Coastal Management Program (or Coastal Zone Management Plan).	
	2. The assessment should consider the results of any current water quality studies, as available, in the project catchment.	Section 5.5.6

2. Specific aspects of the project relating to groundwater

The project tunnelling would be carried out mainly with the use of roadheaders (driven) with twin immersed tube tunnels installed within Middle 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 Driven tunnel and lining methods

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

It is anticipated that the tunnel lining system would comprise the following three methods:

- Typical drained tunnel lining: The vast majority of the tunnel would be drained via a typical drained tunnel lining. This method is proposed to limit groundwater inflows to less than one litre per second per kilometre. The lining would comprise of permanent shotcrete
- Drained tunnel with waterproof umbrella: A minor length 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 watercourses and portals. The waterproof umbrella would comprise permanent shotcrete and a waterproof membrane over conduit drains that direct seepage to the floor drains (to prevent dripping onto trafficable parts of the roadway).
- Tanked or undrained tunnel lining: A minor length of the tunnel would be fully lined with a waterproof membrane to exclude inflows where the alignment is below sea level next to the immersed tube tunnel harbour crossing or to reduce groundwater drawdown and potential environmental impacts relative to a drained system.

For the purposes of this modelling report it was assumed that the tunnel was unlined, with the exception of a 125 metre section on either side of Middle Harbour, and that groundwater inflows to the tunnel were constrained by the formation permeability. Appropriate tunnel linings would be investigated during further design development and implemented to achieve the design requirements and mitigate unacceptable settlement due to groundwater drawdown associated with the tunnels.

2.1.2 Groundwater collection method

During construction, groundwater inflows would be collected in sumps at the cutting face 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 wastewater treatment plant. During construction, separation is typically 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 Middle Harbour crossing would utilise an immersed tube tunnel design from Northbridge to Seaforth. 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 tunnels 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 would include seven mined caverns, two at Cammeray, one at the Gore Hill connection entry and exit, two under Northbridge, and two under Seaforth. 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 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 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 Appendix O (Technical working paper: Surface water quality and hydrology) and Appendix Q (Technical working paper: Marine water quality) for details in discharge criteria for receiving waters.

During construction, the treated wastewater would be discharged to the local stormwater network, watercourses and Middle Harbour via discharge points associated with each treatment plant, the locations of which are shown in Table 2-1 and Figure 2-1.

Table 2-1 Groundwater drainage to treatment facilities during construction

Wastewater treatment plant location	Discharge point
Cammeray Golf Course (BL1)	Willoughby Creek via local stormwater system
Flat Rock Drive (BL2)	Flat Rock Creek via local stormwater system
Punch Street (BL3)[1]	Flat Rock Creek via local stormwater system
Balgowlah Golf Course (BL10)	Burnt Bridge Creek via local stormwater system
Wakehurst Parkway East (BL13)	Burnt Bridge Creek and local stormwater system

An operational wastewater treatment plant would be located at the motorway facilities at the Gore Hill Freeway, Artarmon and would treat tunnel inflows during the operational stage of the project. The location of the proposed wastewater treatment plant is shown in Figure 2-2.

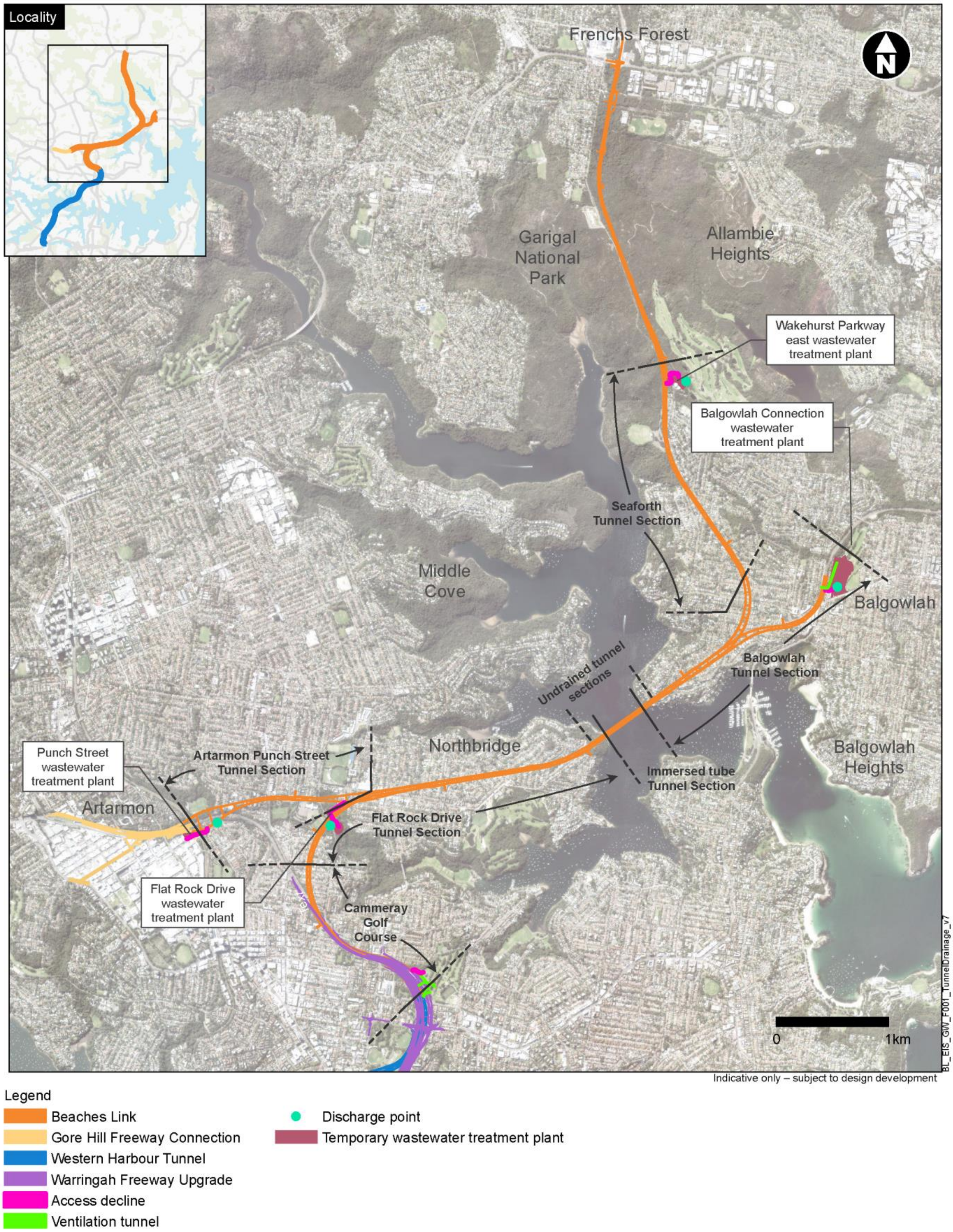


Figure 2-1 Waste treatment plants and associated drained sections

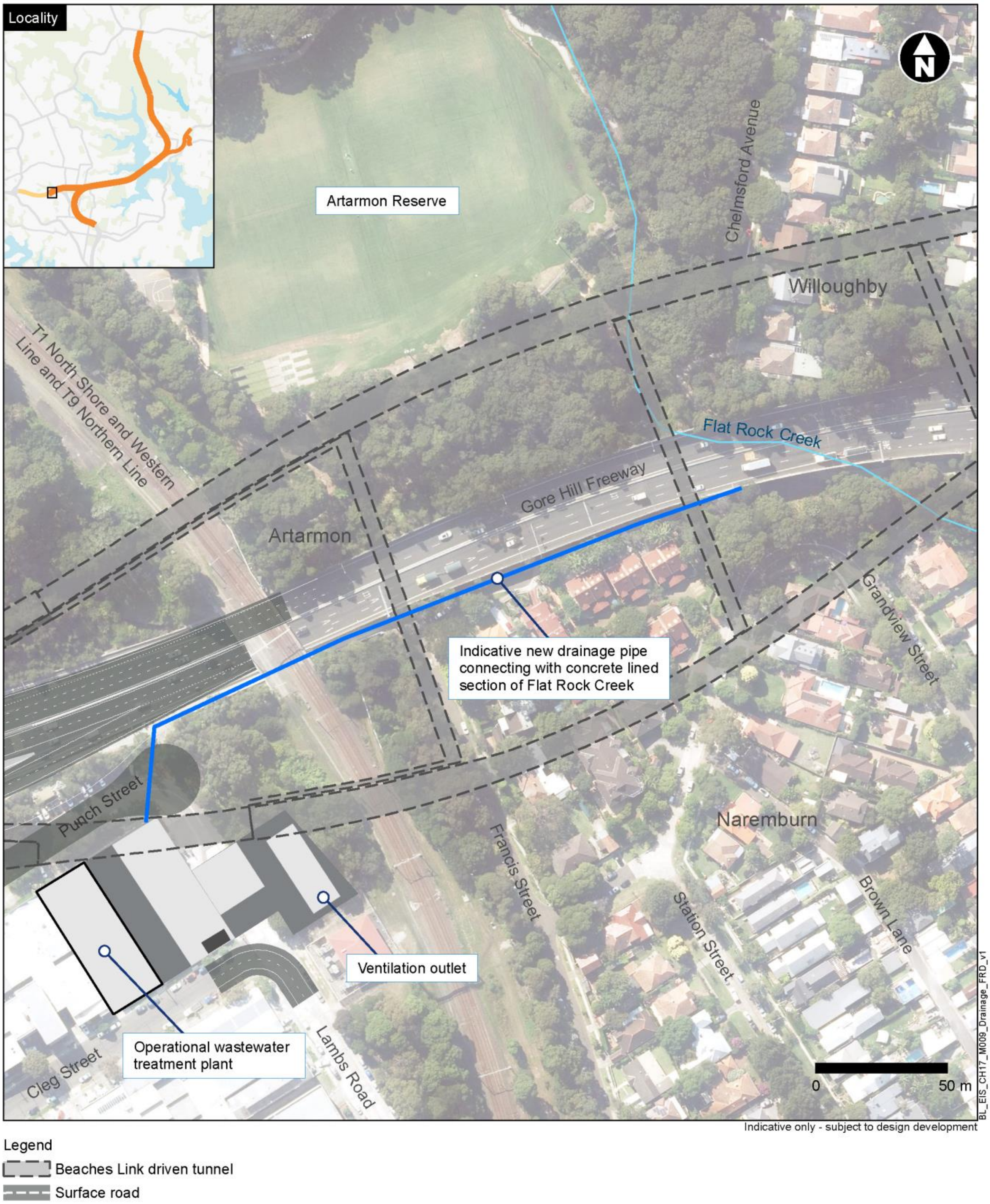


Figure 2-2 Location of the operational wastewater treatment plant

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 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. If the project could have a significant impact on the groundwater environment in terms of groundwater levels and quality, approval might be required under the EPBC 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 several 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 (termed environmental values), including for aquatic ecosystem protection, primary industries, recreational use, drinking water, industrial water and cultural values. Based on water quality criteria (Section 5.5.6), the highest beneficial use category of groundwater along the project alignment is use by aquatic ecosystems (both groundwater dependent ecosystems, and ecosystems that use surface water that is sourced from groundwater baseflow).

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/National Health and Medical Research Council/Natural Resource Management Ministerial Council (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 Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) for numerical health investigation levels of various contaminants, and to the NWQMS for numerical investigation levels for different beneficial uses.

An extensive list of additional guidelines relating to the identification and management of contamination is included in Appendix M (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, a 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 Annexure 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 (WSPs) have commenced. The WSP for the project area has commenced and the area is 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*.

Transport for NSW 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. Transport for NSW 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 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 commenced 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. The long term average annual extraction limit 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 2,592 megalitres per year. As such there is up to 43,323 megalitres per year of water available under the long term average annual extraction limit, 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 several 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 NSW Aquifer Interference Policy 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 several 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 predicted impacts are less than the Level 1 minimal impact considerations, then these impacts would be considered as acceptable. Where predicted impacts are more than the Level 1 minimal impact consideration (i.e. Level 2), further studies are required to identify if predicted impacts are acceptable or make good provisions would be required.

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

The NSW Aquifer Interference Policy 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 NSW Aquifer Interference Policy minimal impact considerations are summarised in Table 3-1. The predicted impacts are assessed against the minimal impact considerations in Section 6.

Table 3-1 NSW Aquifer Interference Policy minimal impact considerations

Minimal impact consideration – less productive porous and fractured rock groundwater source	
Water Table **1.** 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. **2.** If more than 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 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 2m decline cumulatively at any water supply work then make good provisions should apply.	**Water Pressure** 1. A cumulative pressure head decline of not more than a 2m 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 would not prevent the long-term viability of the affected water supply works unless make good provisions apply.
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.	**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 would 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 would 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.

3.2.4 Groundwater Dependent Ecosystems Policy

The NSW *State Groundwater Dependent Ecosystems Policy* (Department of Land and Water Conservation, 2002) implements the *Water Management Act 2000* by providing guidance on the protection and management of groundwater dependent ecosystems. 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 groundwater dependent ecosystems in the vicinity of the project are discussed in Section 5.5.9.

3.2.5 NSW State Groundwater Quality Projection 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 the *National Water Quality Management Strategy's Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ, 2000). The water quality objectives relate to fresh and estuarine surface waters. Changes in quantity and quality of discharged groundwater have the potential to affect water quality in the receiving surface water environments. Further discussion of these guidelines is included in Appendix O (Technical working paper: Surface water quality and hydrology) and Appendix Q (Technical working paper: Marine water quality).

3.2.7 Guidelines for the Assessment and Management of Groundwater Contamination

Guidelines for the Assessment and Management of Groundwater Contamination (Department of Environment and Conservation NSW, 2007) 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 if 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 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
- 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. The modelling assumes that the tunnels are not lined (except for a 125 m section on either side of Middle Harbour) and therefore provides a relatively conservative estimate of groundwater inflows to the tunnel and associated groundwater level drawdown
- 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
- 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 Department of Planning, Industry and Environment (Water) database (NSW Government) for groundwater level and quality data at monitoring bores
- The Water Register (http://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, http://www.bom.gov.au/water/groundwater/gde/) to identify the location and groundwater dependence of surface water systems and vegetation
- The NSW Environmental Protection Agency list of contaminated sites notified to the NSW Environmental Protection Agency (https://www.epa.nsw.gov.au/your-environment/contaminated-land/notified-and-regulated-contaminated-land/list-of-notified-sites)
- 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 investigations and assessments for construction projects provided useful information on geological and hydrogeological properties along the Beaches Link and Gore Hill Freeway Connection project area. These included:

- WestConnex New M5 Environmental Impact Statement – Technical working paper: Groundwater, Appendix Q (AECOM, 2015)
- WestConnex M4 – M5 Link Environmental Impact Statement – Technical working paper: Groundwater, Appendix T (AECOM, 2017a)
- Geotechnical Interpretative Report. North West Rail Link (Coffey Geotechnics, 2012)
- WestConnex M4 East Groundwater Impact Assessment, Environmental Impact Statement, Appendix R (GHD, 2015a)
- Northern Beaches Hospital Network Enhancement Stage 2: Groundwater Assessment, Environmental Impact Statement, Appendix M (GHD, 2015b)
- Groundwater Control for Sydney Rock Tunnels. Geotechnical aspects of tunnelling for infrastructure projects (Hewitt, 2005)
- Sydney Metro Chatswood to Sydenham, Technical Paper 7: Groundwater Assessment (Jacobs, 2016)
- HarbourLink – Geotechnical investigations, Preliminary Environmental Assessment (WSP | Parsons Brinckerhoff, 2016).

Several more 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 3, 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 and is still in progress at the time of writing.
The hydrogeological investigation program occurred in conjunction with the geotechnical and contaminated land field investigation 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 investigations for both the Western Harbour Tunnel and Warringah Freeway Upgrade project, 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 Annexure A and Annexure 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
- 23 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.

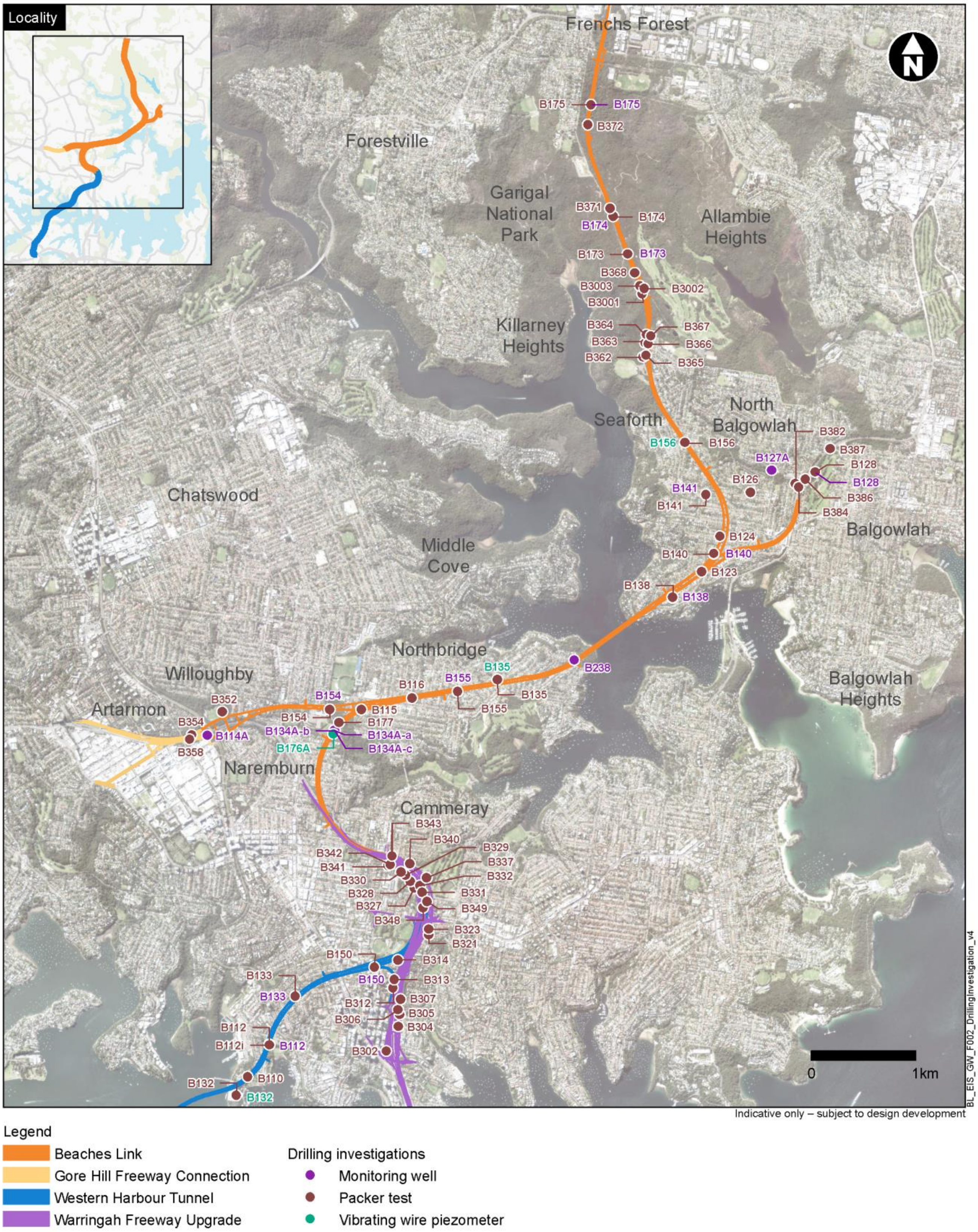


Figure 4-1 Drilling investigation locations

4.3.2 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 millimetre 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 two 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 provided in Annexure A and Annexure B respectively.

4.3.3 Vibrating wire piezometer installation

Vibrating wire piezometer (VWP) installations and construction details are outlined in the bore logs in Annexure A. 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.

4.3.4 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 Figure 4-3, groundwater level results are reported in Section 5.5.2 and quality results are presented in Section 5.5.6.

4.3.5 Flow monitoring

Preliminary flow gauging has been 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 for comparison with modelled baseflow contributions to the surface water courses. Flow monitoring sites are identified on Figure 4-2, Figure 4-3 and Figure 5-6. Flow measurements were taken following a period of two weeks without rain which is representative of typical dry flow conditions, without contribution from rainfall runoff. It is noted that there are likely to be unknown upstream contributions to surface water flow from discharges to the stormwater network.

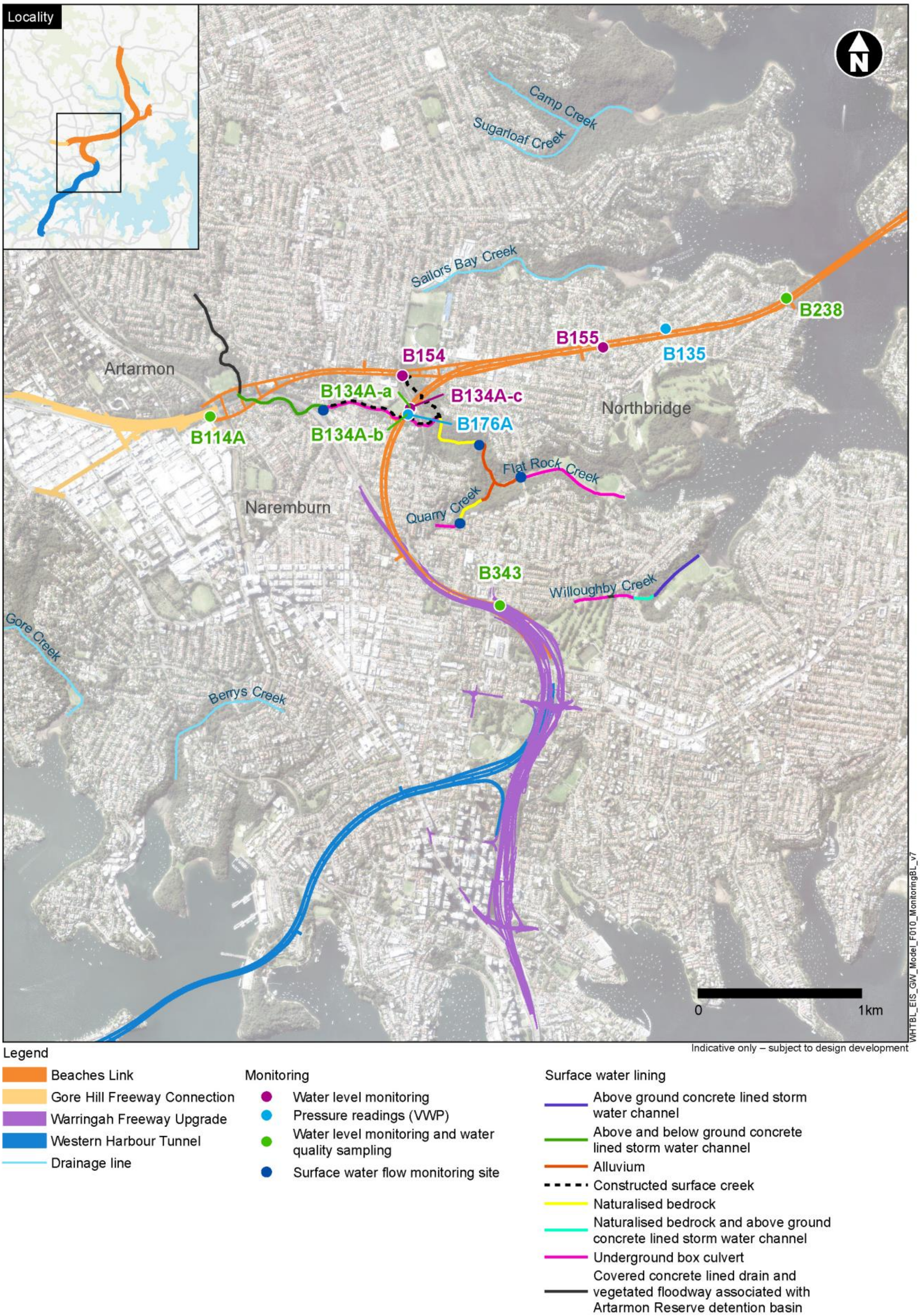


Figure 4-2 Groundwater and surface water monitoring sites (south)

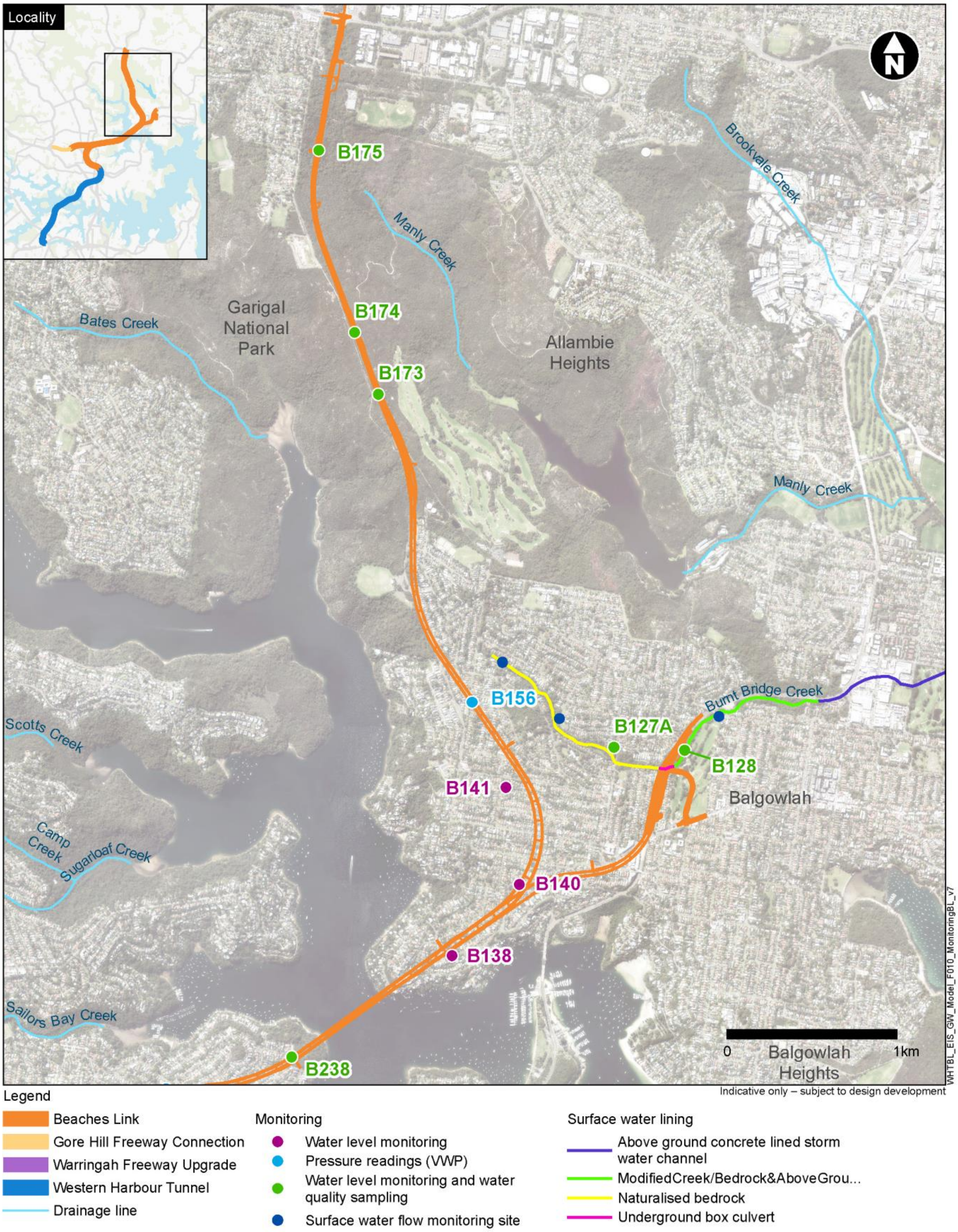


Figure 4-3 Groundwater and surface water monitoring sites (north)

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 (Unstructured Grid) model code with the Groundwater Vistas 7 Graphical User Interface and employing quadtree grid refinement.

The groundwater modelling predicts drawdown of the water table, as well as the hydraulic depressurisation in each model layer. The tunnels are predominantly in layer 5 of the model and therefore this layer demonstrates the greatest initial drawdown response.

The modelling results should be considered as a conservative assessment. The modelling approach assumes no designed tunnel linings are installed (except for a 125 metre long section on either side of Middle Harbour). The modelling approach also assumes a single water table with hydraulic connection to the depth of tunnelling, with the degree of connectivity controlled by the vertical hydraulic conductivity. The data indicate the potential for multiple water tables, or disconnected aquifers, that if present would act to attenuate the propagation of depressurisation and drawdown. Therefore, in these areas, the predicted water table decline is expected to be an over-estimate.

Other tunnelling projects in the region include Sydney Metro Chatswood to Sydenham. Tunnel construction for that project commenced in 2018 and is expected to be completed in 2020. This project comprises a fully lined tunnel, therefore the contribution to cumulative impacts in respect to drawdown is considered to be relatively small due to the tunnels. The proposed Victoria Cross Station, located at North Sydney, will be a drained station, and this is included in the model.

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 of section through the region of maximum predicted drawdown in the Northbridge 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 Annexure 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 Groundwater settlement assessment

An assessment of ground settlement induced by tunnel excavation due to both stress redistribution in the surrounding ground (due to the removal of subsurface materials during tunnelling activities) and groundwater drawdown around drained tunnels has been carried out (Arup & WSP, 2020). 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 ventilation tunnels and tunnel access declines
- Settlement impacts to heritage items
- Management of settlement impacts.

Arup & WSP (2020) 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, 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.	15 to 25 but also depends on number of cracks	>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]
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
- 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
- Assessment of baseflow reduction is conservative and is likely to overestimate actual baseflow reduction for the following reasons:
  - The modelled groundwater inflows to the tunnels were controlled by the formation permeability, which in some cases causes inflows to the tunnels greater than one litre per second per kilometre. However, a construction requirement for the project is that the tunnel inflows do not exceed 1 litre per second per kilometre on average, and the tunnels would be treated during construction to ensure that this is the case. Therefore, the actual tunnel inflows would be less than predicted by the modelling
  - It is assumed that there is a single connected groundwater system in between the watercourses present and the proposed underlying tunnel. In reality, the system will be stratified, possibly with disconnected aquifer horizons. The predicted maximum drawdowns beneath the creek are therefore unlikely to be fully realised and the predicted reductions in baseflows are therefore conservative
  - For watercourses and waterbodies other than Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, the whole length or area at the base of the creek or dam is considered to be unlined. This means that surface water and groundwater are linked, and changes in groundwater could affect surface water in the watercourses and waterbodies. At the time of modelling there was no information on the nature of creek bottom surfaces for Willoughby Creek and Sailors Bay Creek. Should any of these watercourses be lined, the reduction baseflow would be less than that predicted
  - Groundwater inflows to the tunnels would be collected and discharged to local waterways (Willoughby Creek, Flat Rock Creek and Burnt Bridge Creek). This is expected to offset baseflow reduction to these waters, as the additional creek flows could partially feed the surrounding groundwater system.
- 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 should be considered during the detailed design 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 Beaches Link and Gore Hill Freeway Connection and the Western Harbour Tunnel and Warringah Freeway Upgrade 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 the Western Harbour Tunnel and Warringah Freeway Upgrade project.

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 receivers 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). The nearest BOM weather station is Mosman Council (BoM Station 66184) as shown in Figure 5-1.

The rainfall record and reliability of data for each of these stations are provided in

Table 5-1, with average monthly rainfall provided in Table 5-2. 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 5-2 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.

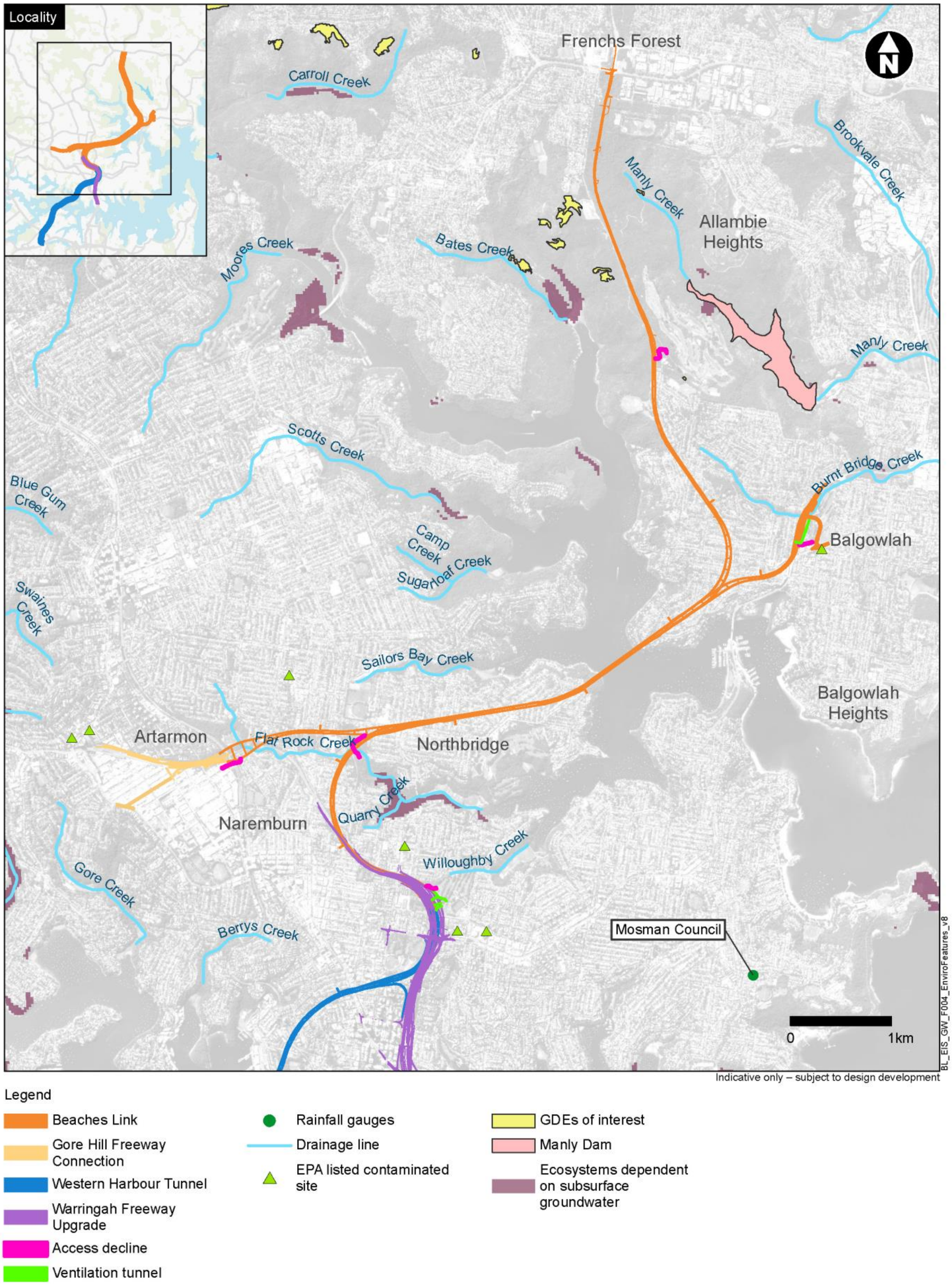


Figure 5-1 Project alignment and environmental features

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

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	1,230.7
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	1,215.7
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	1,231.5

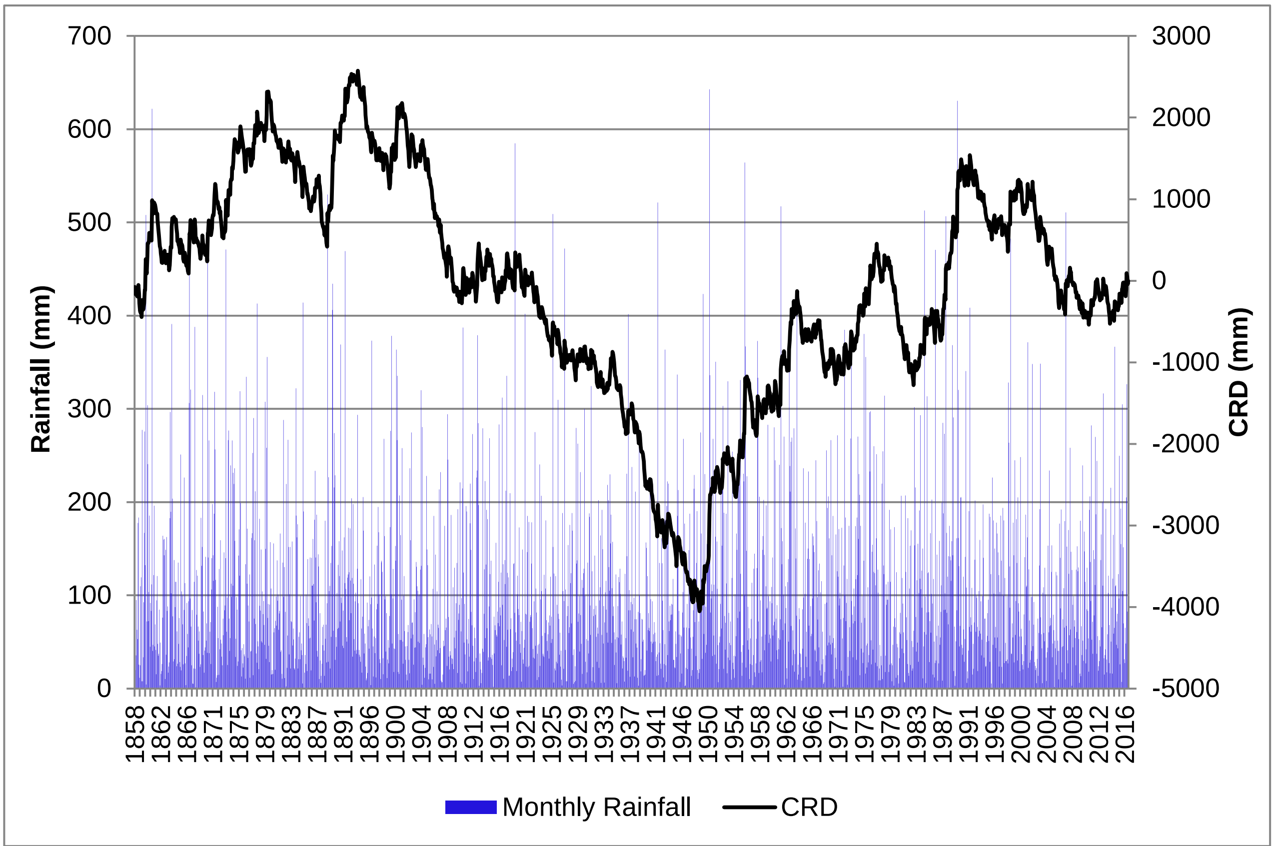


Figure 5-2 Observatory Hill (BOM Station 66062) rainfall

Temperature and evapotranspiration data for Observatory Hill (BOM Station 66062) are provided in Table 5-3. 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 in Figure 5-3. The main bodies of water relevant to the project are Middle Harbour, a tidally influenced estuary, and Manly Dam, a large freshwater lake/reservoir. The project alignment has one harbour crossing at Middle Harbour.

For more information on these features, see Appendix O (Technical working paper: Surface water quality and hydrology).

The tunnels extend north from both the Warringah Freeway and the Gore Hill Freeway to Balgowlah and Killarney Heights. The southern part of the alignment underlies an area of high topographic elevation, with water sheds to the west and east of the alignment. The northern part of the alignment from Killarney Heights to Frenchs Forest is situated above ground on a drainage divide between Bates Creek and Bantry Bay to the West and Manly Creek and Manly Dam to the East.

Between Warringah Freeway/Gore Hill Freeway and Middle Harbour, the alignment crosses beneath Flat Rock Creek and the upper Willoughby Creek catchment. The project would involve underground crossings of Flat Rock Creek by the mainline tunnel and the Gore Hill Freeway Connection entry and exit ramp tunnels.

The main surface drainage feature in the north of the project area is Burnt Bridge Creek in North Balgowlah. Burnt Bridge Creek flows east from North Balgowlah towards Manly Vale and intersects the project area at the Burnt Bridge Creek Deviation.

The drainage channels traversing the project footprint are typically highly modified and predominantly concrete lined channels, particularly within the upper reaches.

The main drainage feature, Flat Rock Creek, is predominantly a concrete lined (open and closed) stormwater channel draining areas of the suburbs of Artarmon, Naremburn, Willoughby and Northbridge. It begins in Artarmon, but its specific origins are unknown. In the upper reaches it has been observed to be a covered, concrete lined drain and vegetated floodway associated within the Artarmon Reserve detention basin and is concrete lined as it crosses the Gore Hill Freeway for the first time. The creek meanders on the southern side of the Gore Hill Freeway before it crosses back under the freeway and continues east. At this location, Flat Rock Creek enters an underground box culvert, although a made-made surface creek which captures surface runoff is also present; and continues in an easterly direction until it reaches Flat Rock Gully Reserve at a point 150 metres east of Flat Rock Drive, where it continues along natural bedrock. About halfway through Flat Rock Gully Reserve and upstream of the confluence with Quarry Creek, Flat Rock Creek transitions to a naturalised creek on alluvium until it enters Tunks Park, where it becomes an underground box culvert. The end point is a tidally influenced naturalised estuary at the eastern end of Tunks Park, discharging into Long Bay. A constructed surface creek that is a tributary to Flat Rock Creek extends from Sailors Bay Road southwards.

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.

The surface lining of Flat Rock Creek and Quarry Creek are shown in Figure 5-4.

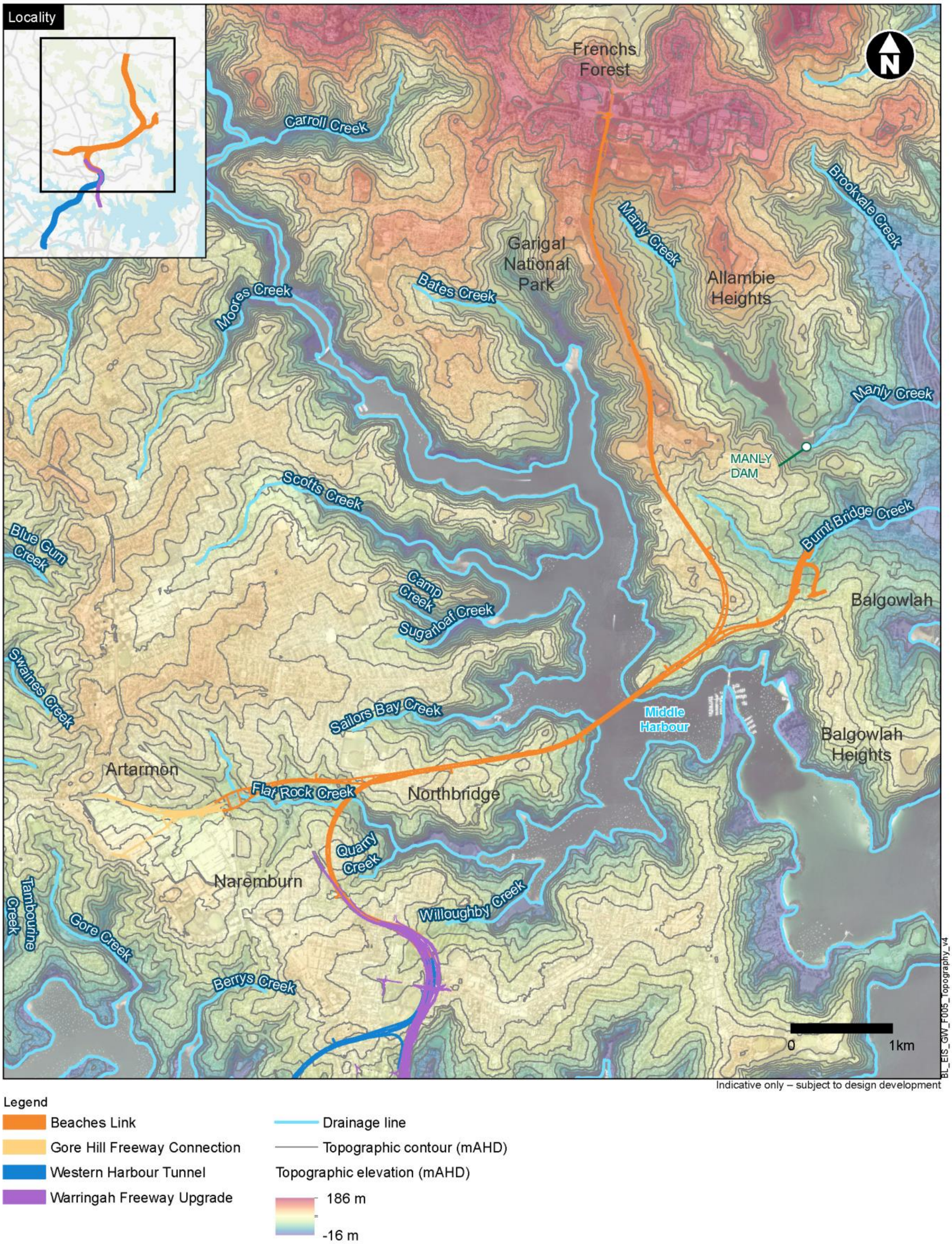


Figure 5-3 Topography and drainage

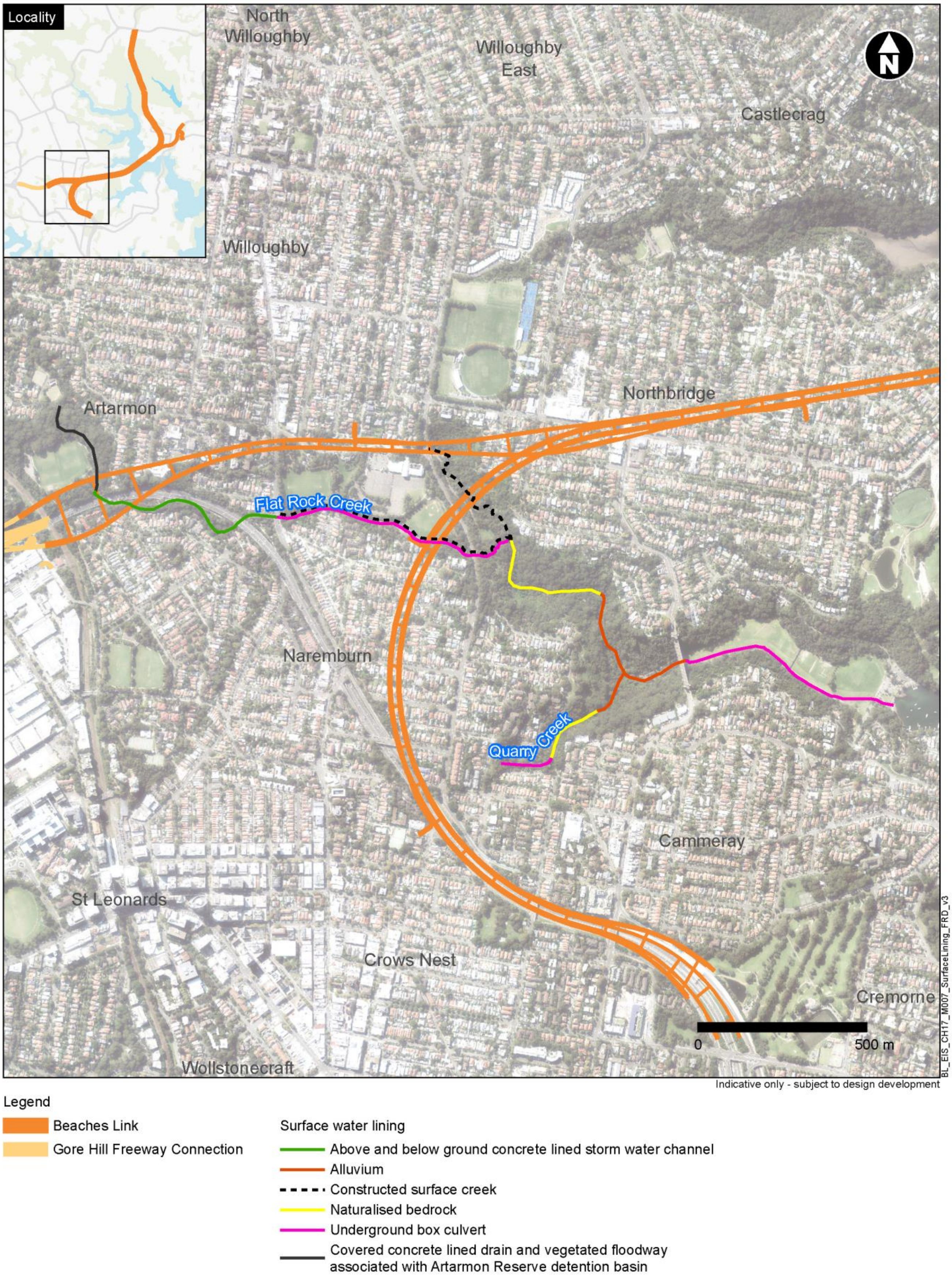


Figure 5-4 Surface lining of Flat Rock Creek

Burnt Bridge Creek is an urban, intermittent waterway which flows through North Balgowlah, 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 surface water lining of the creek consists of naturalised bedrock, comprising sand and mud substrate with narrow vegetated buffer zones. As it crosses the Burnt Bridge Creek Deviation (via underground box culvert), the lining of the creek becomes modified in nature as a result of its history of being realigned and impacted upon on numerous occasions in order to accommodate adjacent transport infrastructure and the golf course. The creek continues in this condition along the southern fringes of the Burnt Bridge Creek Deviation corridor until it transitions to an aboveground concrete lined stormwater channel close to the junction of Condamine Street. There are several constructed waterway crossings, concrete and rock fill structures along the course of the creek.

The surface linings of Burnt Bridge Creek are shown in Figure 5-5.

Manly Dam is one of the largest reservoirs in Sydney and drains a catchment of 5.11 square kilometres, which is bounded by major roads and has both a stormwater and wastewater network (including three wastewater overflows within it). Many Dam was built in 1892 as a water supply dam for the Manly area, and at times neighbouring suburbs. It supplied drinking water up until 1933, although was briefly used in 1942 during a period of drought. Today, Manly Dam and its catchment are used primarily for public recreation. The dam provides a facility for swimming, fishing, water-skiing, canoe/kayaking and boating. The project has the potential to reduce groundwater baseflow contributions to this water body.

Figure 5-5 Surface lining of Burnt Bridge Creek

5.2.1 Creek flow measurements

Preliminary flow gauging has been carried out at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek on 8 May 2018 following a period of two weeks without rainfall at the locations shown in Figure 5-6. The creek flow measurements were taken to better understand the predicted drawdown impact at these watercourses. Recorded flows were as follows:

- Flat Rock Creek: 18.4 litres per second (1590 kilolitres per day)
- Quarry Creek: 2.1 litres per second (178 kilolitres per day)
- Burnt Bridge Creek: 14.4 litres per second (1242 kilolitres per day).

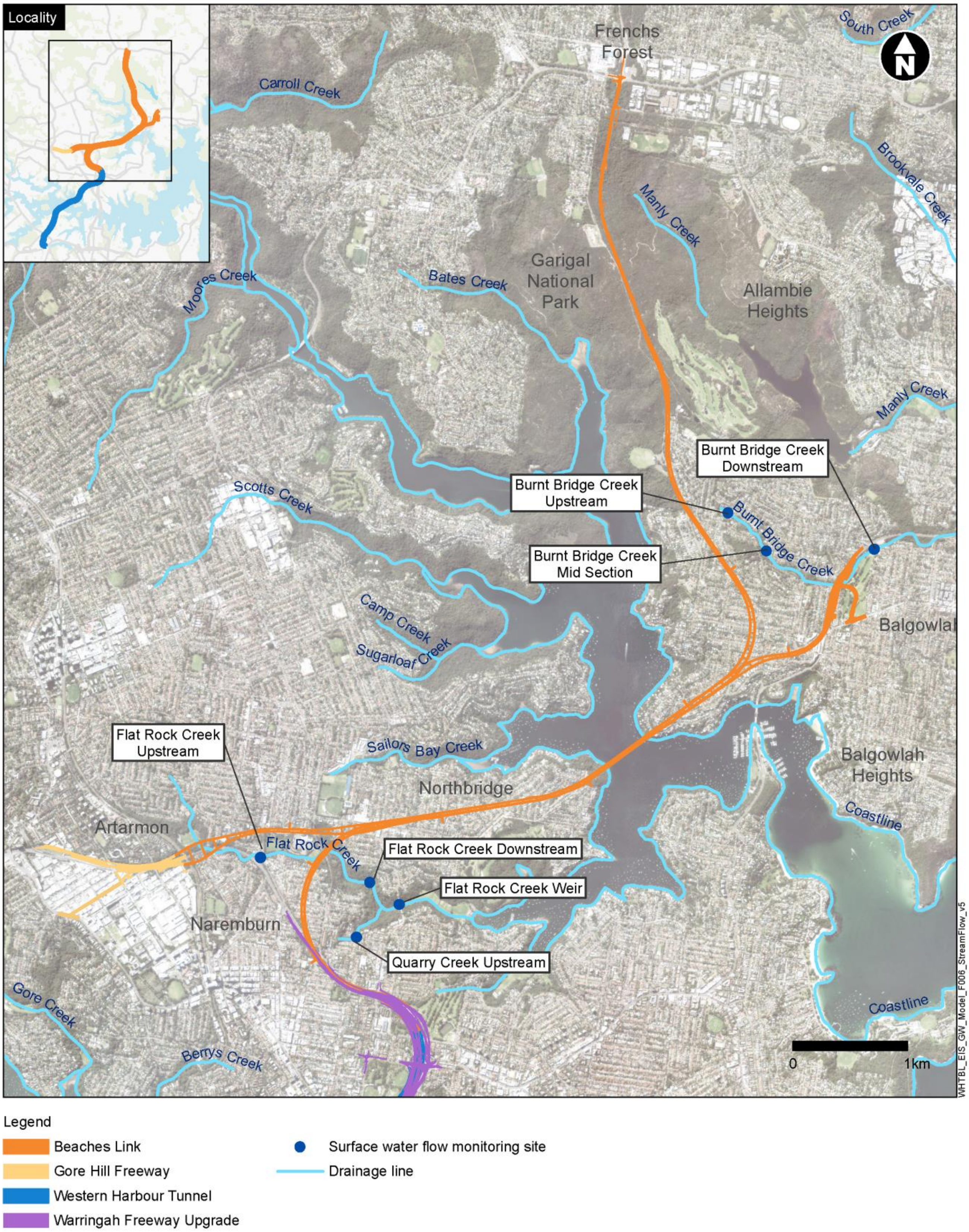


Figure 5-6 Surface water monitoring locations

5.3 Geology

The geology of the alignment is dominated by the Hawkesbury Sandstone of the Permo-Triassic age Sydney Basin sediments. 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 include the presence of faults, dykes and joint swarms. Geology along the alignment is presented in Table 5-4 and in Figure 5-7.

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.

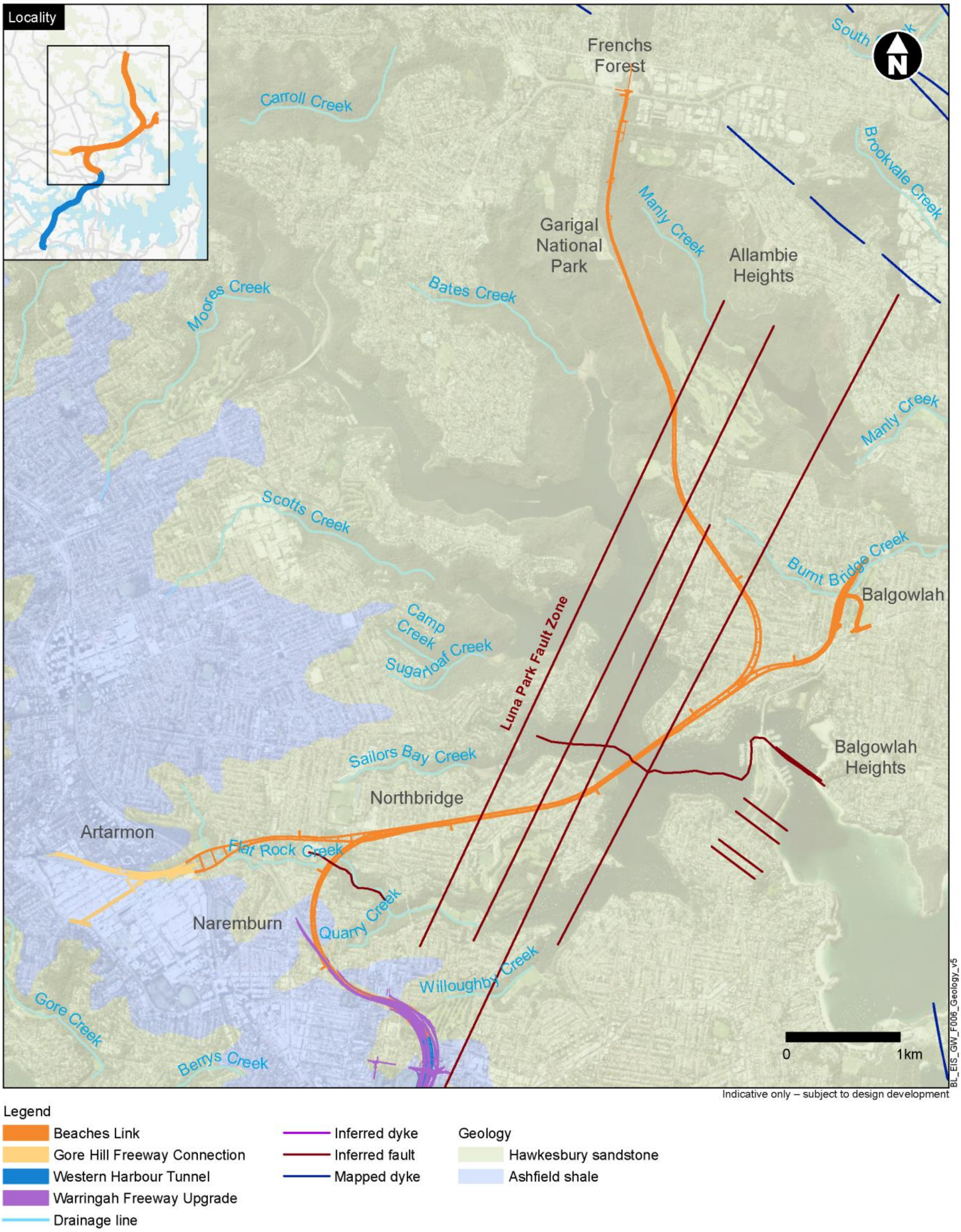


Figure 5-7 Geology along the project alignment

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.

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 box culvert and up to 160 feet (about 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 Reserve, which 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 indicates that up to 40 metres of fill have been placed along Flat Rock Creek (WSP, 2016).

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 as Flat Rock Creek. The deeper sediments within these 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 in 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. The floor of these sediments is unknown and has been inferred to be about 30 metres deep (to a depth of -60 mAHD).

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 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 the harbour.

Dykes are known to cross the project alignment at Seaforth. It is also likely that numerous other unidentified dykes would be encountered. However, 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 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 (refer to Figure 5-7). 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 to10 metres in depth. However, it has been noted 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 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 Beaches Link and Gore Hill Freeway Connection would be within the Hawkesbury Sandstone unit.

Hawkesbury Sandstone is often described as a 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 and 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 are 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 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).

5.3.7.2 Faults

Figure 5-7 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 the 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). The Luna Park Fault Zone, and an associated parallel trending joint swarm mapped at Willoughby Creek, are projected to intersect the alignment at Middle Harbour.

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 5-8.

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, Lambert and Hawkesbury soil types is extensive within the project area, occurring in Cammeray, Balgowlah and to the northern end of the alignment. Areas of colluvium occur in steeper areas around Middle Harbour.

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 Soils along the project alignment

Soil Type	Landscape	Characteristics
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.
Hawkesbury	Rugged, rolling to very steep hills on Hawkesbury Sandstone, with slopes greater than twenty-five 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
Lucas Heights	Gently undulating crests and ridges on plateau surfaces of the Mittagong formation (alternating bands of shale and fine-grained sandstones). Local relief to 30m, slopes <10 per cent. Rock outcrop is absent. Extensively or completely cleared, dry sclerophyll low forest and woodland.	Moderately deep (50-150 cm), hardsetting Yellow Podzolic Soils and Yellow Soloths, Yellow Earths on outer edges. Limitations of this soil landscape include stony soil, low soil fertility, low available water capacity.
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 (30–100 centimetres), 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.

Soil Type	Landscape	Characteristics
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.
Glenorie	Low rolling and steep hills. Local relief 50-120 m, slopes 5-20%. Convex narrow (20-300 m) ridges and hillcrests grade into moderately inclined sideslopes with narrow concave drainage lines. Moderately inclined slopes of 10-15% are the dominant landform elements.	Shallow to moderately deep (<100cm) red, brown and yellow podzolic soils on crests and slopes. Siliceous sands, leached sands and humic gleys on shale lenses and along drainage lines.
Somersby	Gently undulating to rolling rises on deeply weathered Hawkesbury Sandstone plateau. Local relief to 40m, slopes <15%. Rock outcrop is absent. Crests are broad and convex; valleys are narrow and concave. Extensively cleared, low open woodland and scrubland.	Moderately deep to deep (100-300cm) Red Earths and Yellow Earths overlying laterite gravels and clays on crests and upper slopes; Yellow Earths and Earthy Sands on mid slope; Grey Earths, Leached Sands and Siliceous Sands on lower slopes and drainage lines; Gleyed Podzolic Soils in low-lying poorly drained areas. These soils are considered to have localised permanently high water tables, areas of laterite, and stony soil, very low soil fertility, highly permeable soil.

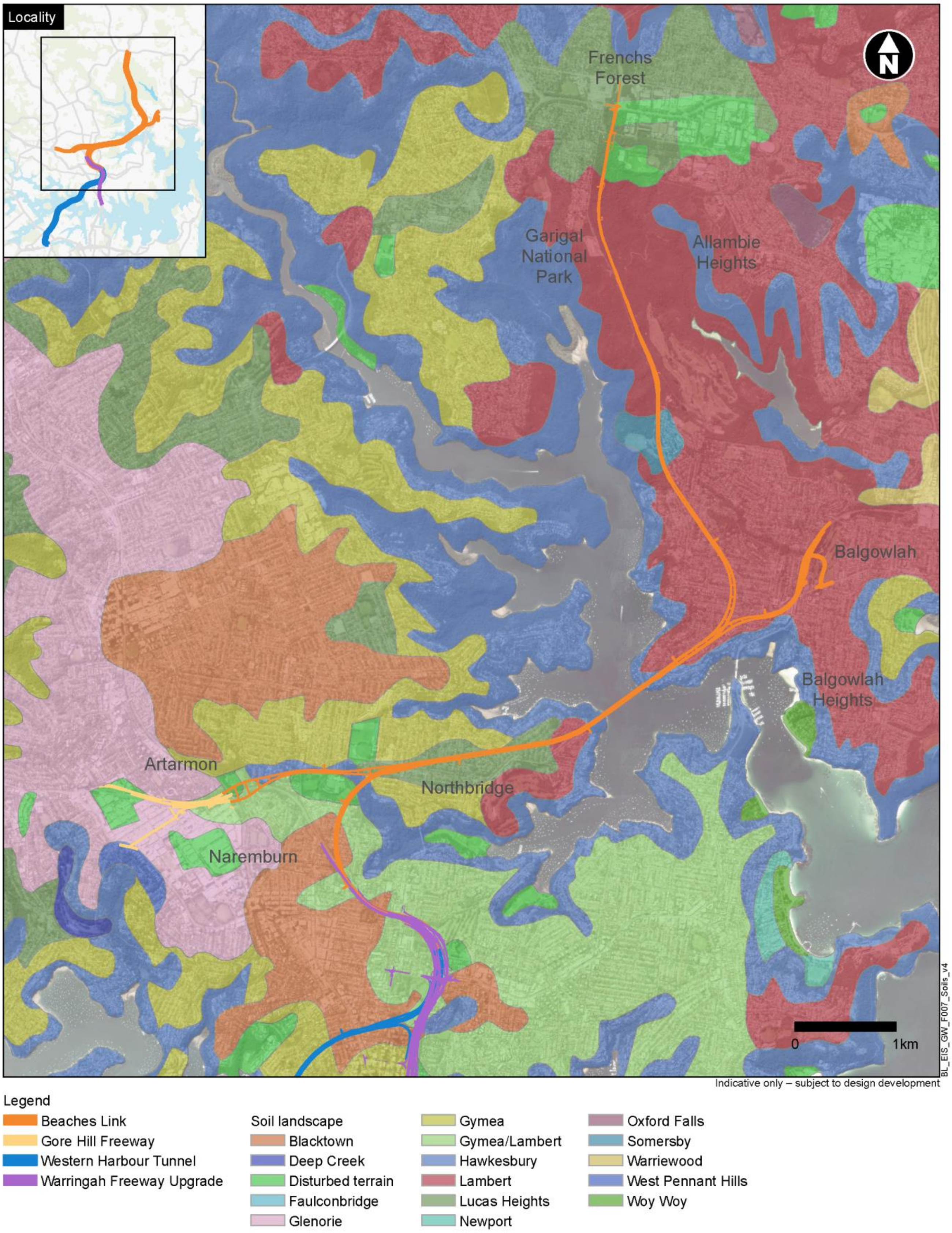


Figure 5-8 Major soil types identified along the alignment

5.4.1 Acid sulfate soils

Acid sulfate soils 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 acid sulfate soils 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 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 risk maps classify the risk of encountering acid sulfate soils and, where previously identified, map actual acid sulfate soils (AASS). Based on this information, the generalised acid sulfate soils probability across the project area has been assessed as follows:

- Cammeray to Naremburn – B4 low probability/very low confidence
- Naremburn to Northbridge – C4 extremely low probability/very low confidence
- Artarmon to Naremburn - B4 low probability/very low confidence
- Seaforth to North Balgowlah – Predominantly categorised as ‘built up’ with some inclusion of C4 extremely low probability/very low confidence.

A review of the acid sulfate soils risk maps from the *Willoughby Local Environmental Plan 2012* and the *Manly Local Environmental Plan 2013* indicated that the project is located within areas of Class 5 ASS risk or areas with no probable ASS risk (unclassified). The acid sulfate soils risk maps from the *Warringah Local Environmental Plan 2011* did not classify the project area as an acid sulfate soils risk. The *North Sydney Local Environmental Plan 2013* does not contain acid sulfate soils risk maps. Acid sulfate soils risks along the project alignment are presented in Figure 5-9.

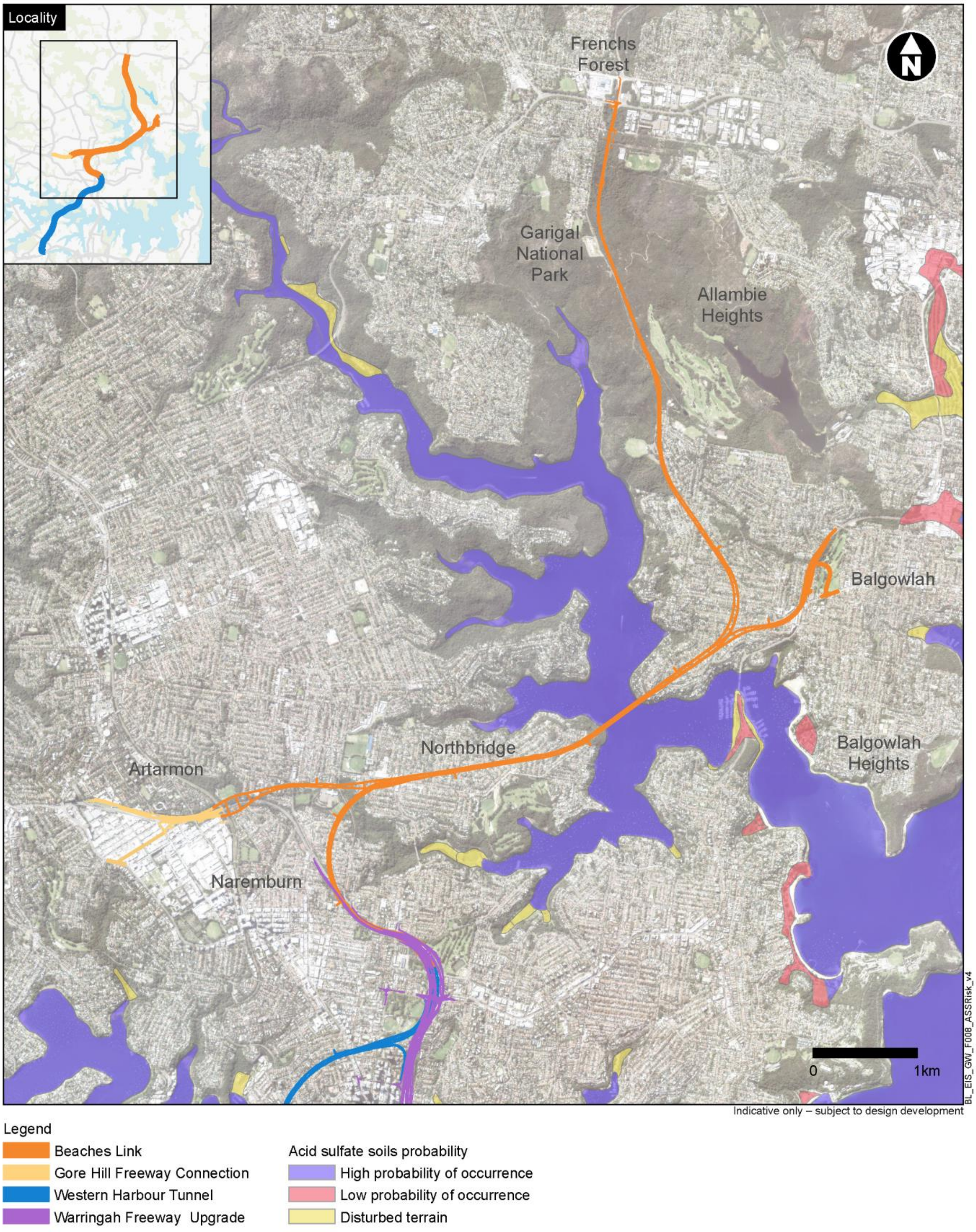


Figure 5-9 Acid sulfate soil risk

5.5 Hydrogeology

For the most part, tunnel excavation would occur through the Hawkesbury Sandstone, although some construction in the Ashfield Shale is expected to be required for the Gore Hill Freeway Connection component of the project as well as in the area around the Warringah Freeway where the southern end of the Beaches Link is proposed to connect to the network (refer to Figure 5-7). At the Middle Harbour crossing, the tunnels comprise of 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 tunnels are near Flat Rock 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, which is up to 250 metres thick in the Sydney region and outcrops over most of the Beaches Link project area. 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} 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. 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 Formation 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 Flat Rock Creek and Cammeray Golf Course, among others.

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 harbours.

Depth to the water table 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. 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 alignment has been compiled and is presented in Figure 5-10. These contours have been created using data from monitoring for the project, as well as water levels from the

Department of Planning, Industry and Environment (Water) database (WaterNSW, 2020), 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 5-10 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.

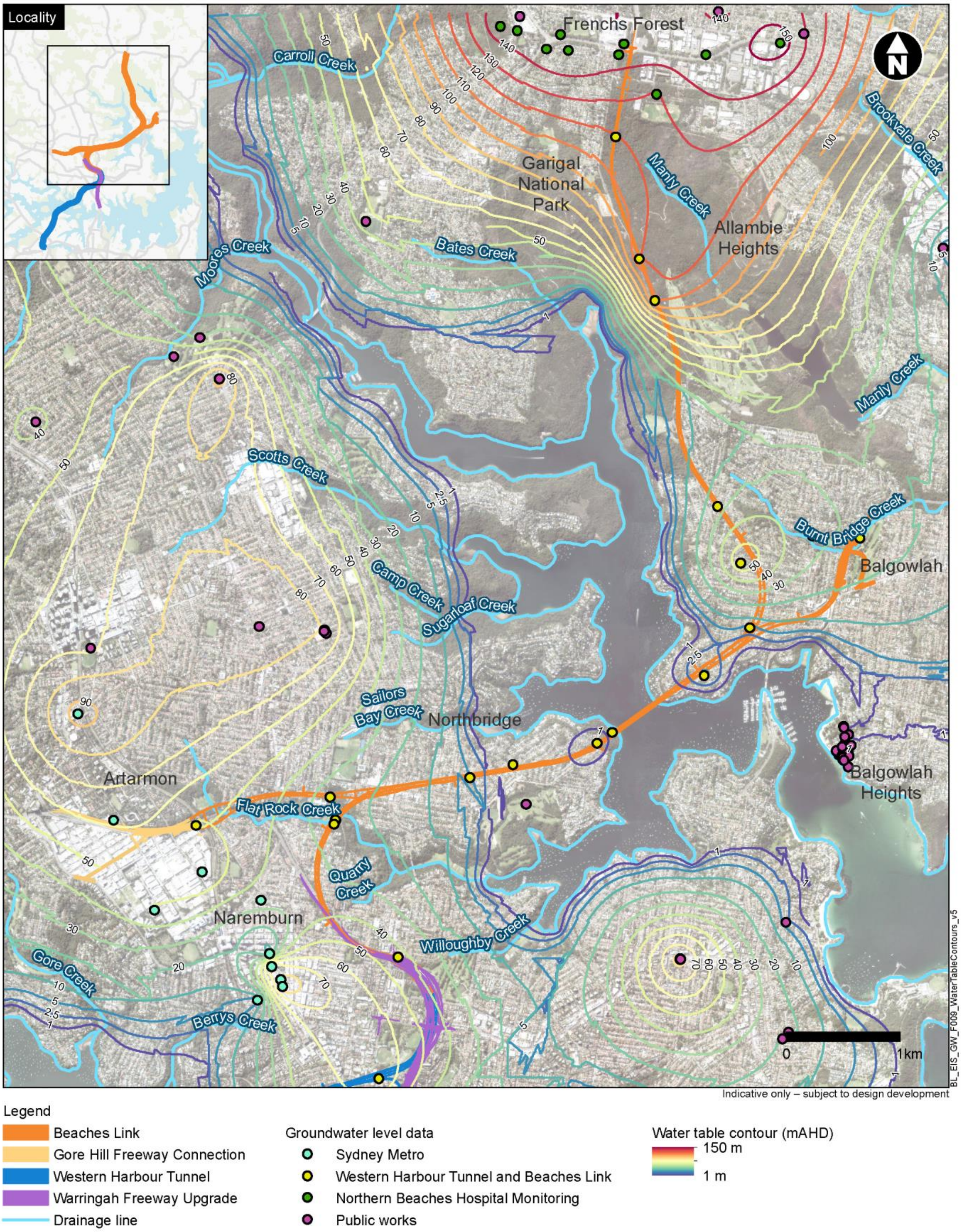


Figure 5-10 Composite water table contours

5.5.2.1 Monitoring bore hydrographs

Hydrographs from groundwater monitoring bores along the alignment are provided in Figure 5-11 and bore locations are shown in Figure 4-2 and Figure 4-3. 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 metres Australian Height Datum (mAHD) and 120 mAHD at monitoring bores B173, and B174 and B175, respectively, in the vicinity of Wakehurst Parkway near Bantry Bay and Frenchs Forest to less than 4 mAHD at B140 in Seaforth.

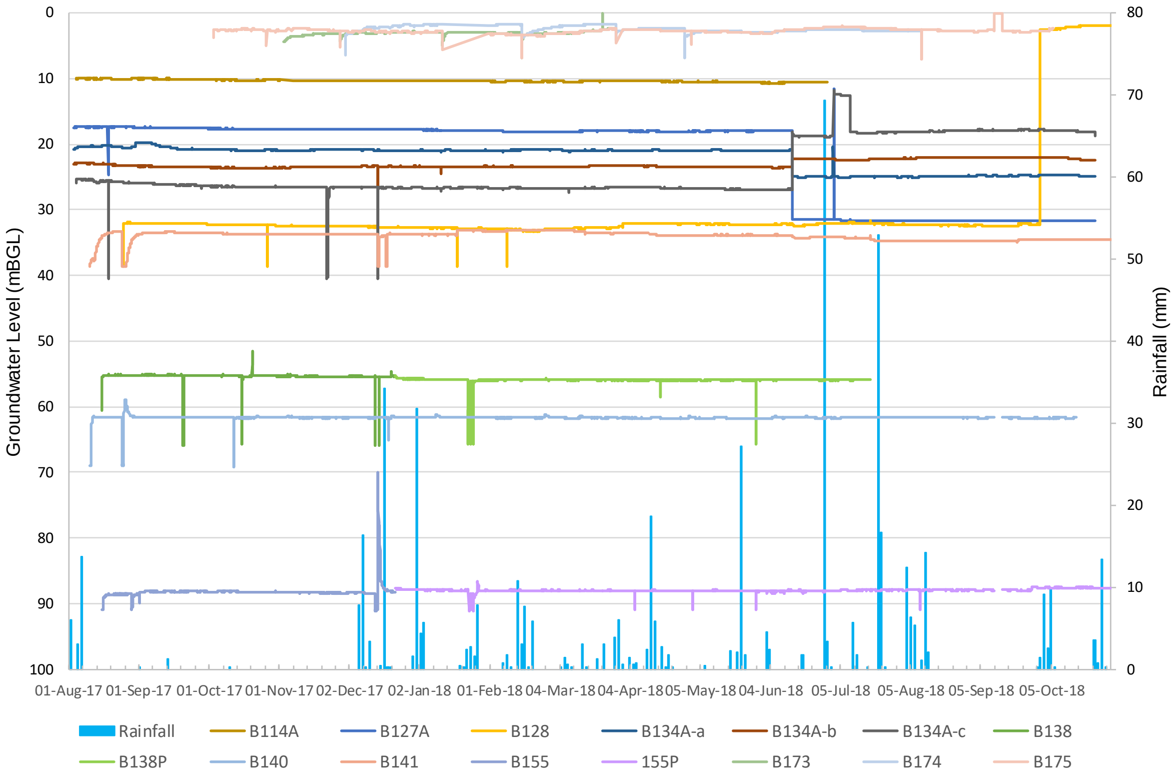
In Seaforth, water levels of the order of 60 mAHD are observed at monitoring bore B141, dropping down to around -2 mAHD in Balgowlah at monitoring bore B128, and one to four mAHD at monitoring bores B138 and B140, near the Middle Harbour crossing.

Monitoring bore B128, located in the vicinity of the Balgowlah connection portal, shows water levels at about 32 metres below ground level. This is about two metres below sea level (-2 mAHD). 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 in the fill material at B134A-a is of the order of 21 metres below ground level (25 mAHD), and in the underlying sandstone (B134A-c) is about 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 Northbridge, 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 fluctuations 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 notable responses to rainfall events are evident.



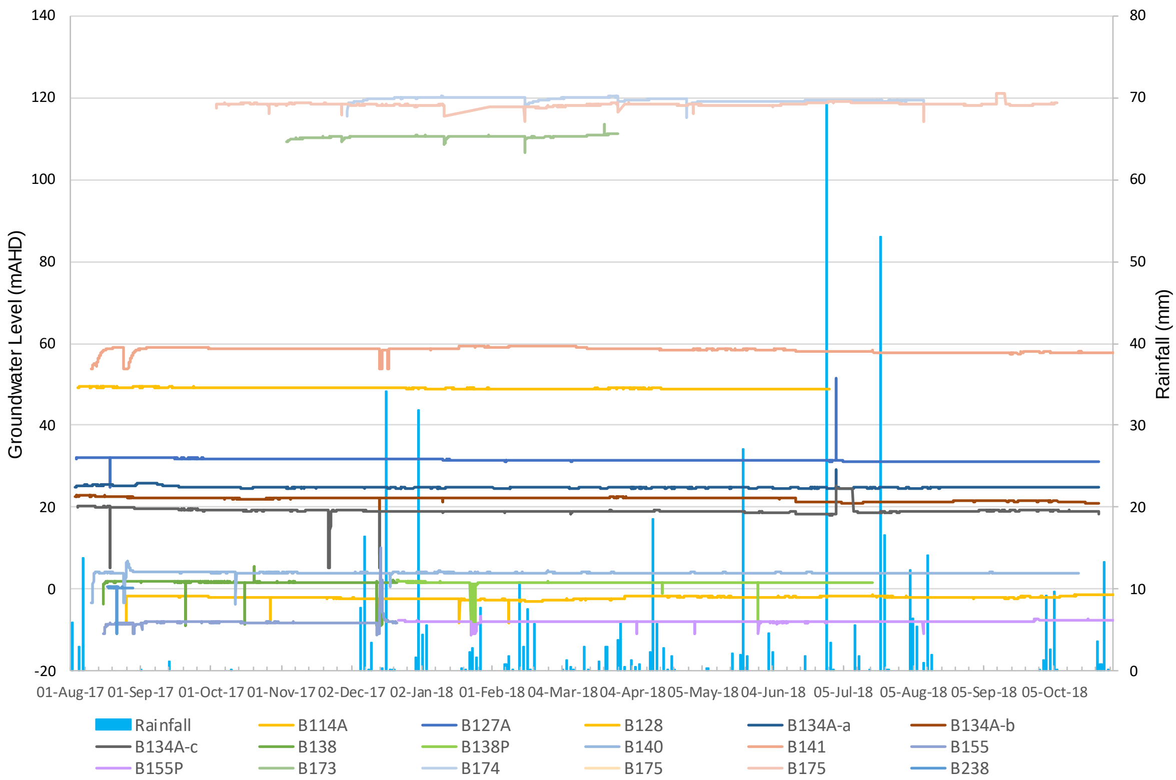


Figure 5-11 Monitoring bore hydrographs

5.5.2.2 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 hydrogeological conditions within the aquifer.

Water pressure responses recorded at the VWPs are summarised below, hydrographs presented in Figure 5-12. The hydrostatic profiles were compiled using the average pore pressure recorded over the monitoring period.

B135 is located in 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.

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 metres below ground level (mbgl)) overlying a deeper water table at about 45 mAHD (35 mbgl).

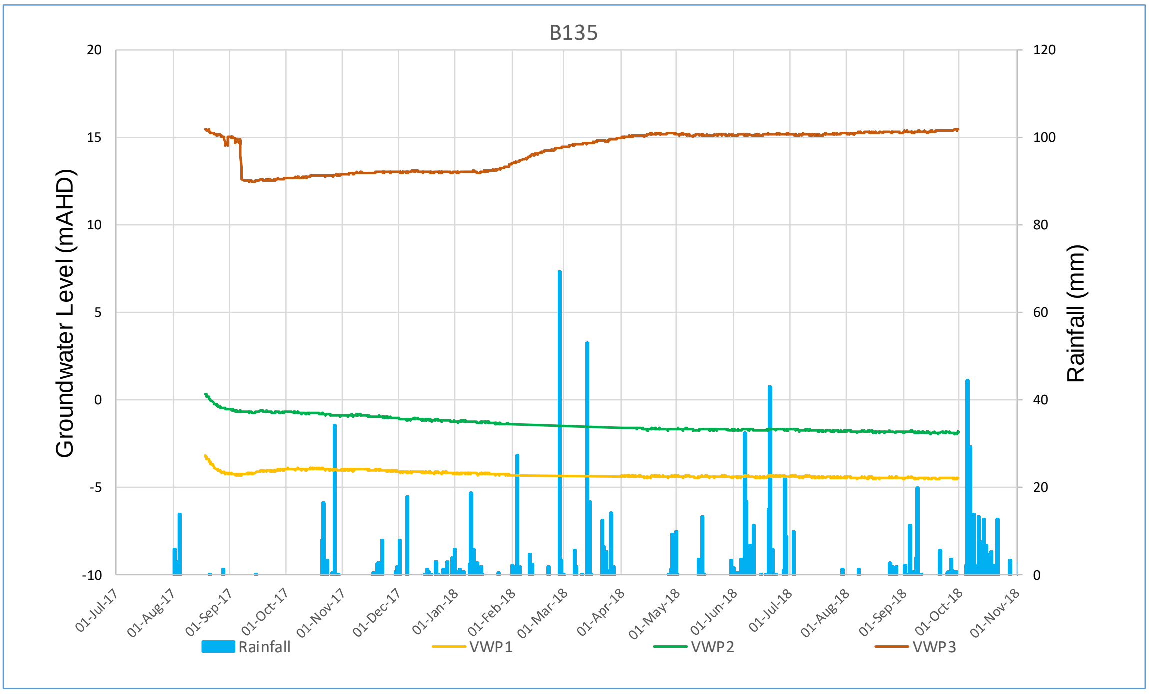
VWP1 and VWP2 appear to be generally in hydraulic equilibrium, with a slight downwards hydraulic gradient indicated. A downwards hydraulic gradient in this area would be consistent with recharge and through flow to the harbour to the north-northwest.

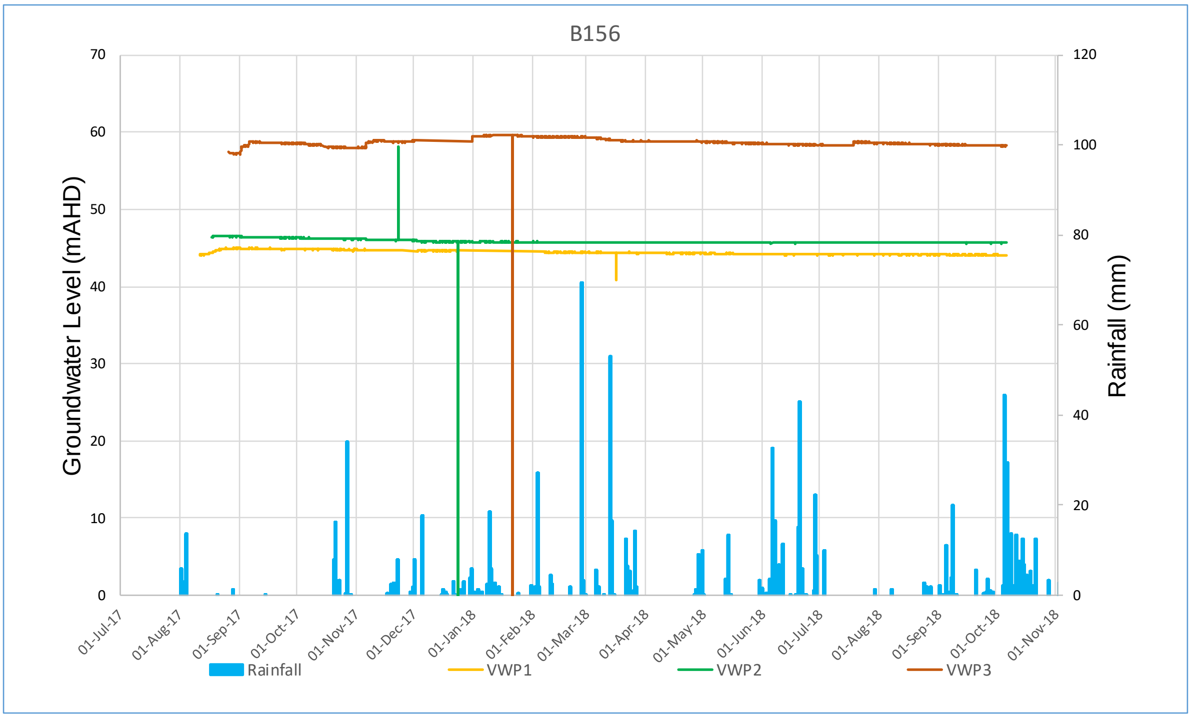
B176A is located at Flat Rock Creek and is next to fill and an inferred deep geological deformation zone.

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.


B135
Groundwater Level (mAHD)
Rainfall (mm)
20
15
10
5
0
-5
-10
120
100
80
60
40
20
0
01-Jul-17
01-Aug-17
01-Sep-17
01-Oct-17
01-Nov-17
01-Dec-17
01-Jan-18
01-Feb-18
01-Mar-18
01-Apr-18
01-May-18
01-Jun-18
01-Jul-18
01-Aug-18
01-Sep-18
01-Oct-18
01-Nov-18
Rainfall
VWP1
VWP2
VWP3


B156
Groundwater Level (mAHD)
Rainfall (mm)
70
60
50
40
30
20
10
0
120
100
80
60
40
20
0
01-Jul-17
01-Aug-17
01-Sep-17
01-Oct-17
01-Nov-17
01-Dec-17
01-Jan-18
01-Feb-18
01-Mar-18
01-Apr-18
01-May-18
01-Jun-18
01-Jul-18
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01-Sep-18
01-Oct-18
01-Nov-18
Rainfall
VWP1
VWP2
VWP3

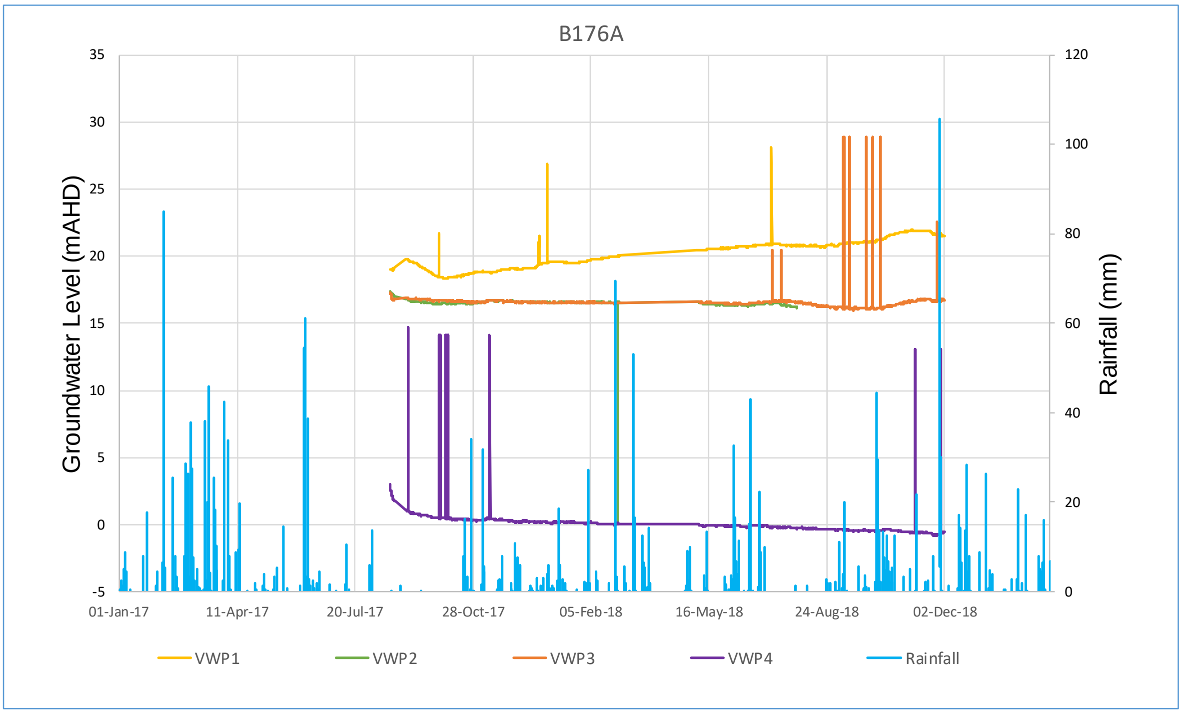

Figure 5-12 VMP hydrographs for B135, B156 and B176A

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 of Hawkesbury Sandstone outcrops.

Historically, most groundwater recharge would have been via diffuse infiltration of rainfall over areas of Hawkesbury Sandstone outcrop/subcrop, as well as runoff from watercourses overlying the Hawkesbury Sandstone. Most of the area in the vicinity of the project alignment has been developed, which substantially reduces potential infiltration, and contemporary groundwater recharge is reliant on areas of remnant vegetation, and park and grassed areas. In parks and grassed areas, 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 5.5.7. 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 groundwater flow toward the east to south-east.

5.5.4 Hydrogeological cross sections

This section summarises hydrogeological cross sections along the proposed project alignment. These hydrogeological cross sections are indicative and not intended for any purpose other than the groundwater impact assessment carried out as part of the environmental impact assessment.

The location of the cross-section line is shown on a map in Figure A2-1 in Attachment 2 of Annexure F. In addition:

- Figure A2-2 to Figure A2-4 in Attachment 2 of Annexure F shows the hydrogeology along the proposed project alignment from Warringah Freeway to Middle Harbour
- Figure A2-5 in Attachment 2 of Annexure F shows the hydrogeology along the project alignment from the Gore Hill Freeway tunnel connection to the proposed Beaches Link mainline tunnel
- Figure A2-6 in Attachment 2 of Annexure F shows the hydrogeology along the project alignment from Seaforth to Balgowlah
- Figure A2-7 in Attachment 2 of Annexure F shows the hydrogeology along the project alignment from Seaforth to Frenchs Forest.

The cross-sections indicate that the Hawkesbury Sandstone is the dominant hydrogeological unit occurring along the project alignment.

The Mittagong Formation/Ashfield Shale occurs along ridgelines at the following locations:

- Warringah Freeway to Middle Harbour Section: Between Merrenburn Avenue and Market Street (Figure A2-2 in Attachment 2 of Annexure F)
- Gore Hill Freeway Connection to mainline tunnel section: Ashfield Shale/Mittagong Formation occurs along the ridgeline between Gore Hill Freeway and Willoughby Road (Figure A2-5 in Attachment 2 of Annexure F).

Marine sediments occur at the bottom of Middle Harbour (Figure A2-2 and Figure A2-4 in Attachment 2 of Annexure F).

Anthropogenic fill material occurs at the following locations:

- Flat Rock Creek (Figure A2-2 and Figure A2-3 in Attachment 2 of Annexure F). There is a known history of dumping industrial and domestic waste at Flat Rock Creek/Flat Rock Gully Reserve area in both whole and incinerated form. The site is known as a long running waste incineration and landfill site. Flat Rock Creek is wholly within a box culvert through this area.
- Cammeray Golf Course (Figure A2-5 in Attachment 2 of Annexure F)
- Fill has been mapped beneath the North Shore rail line and in the depression between Willoughby Road and Small Street (Figure A2-5 in Attachment 2 of Annexure F).

The cross sections show the locations and orientations of mapped and inferred fault zones. Packer testing was carried out on a few of the fault zones to estimate hydraulic conductivity (Figure A2-2 to and Figure A2-7 in Attachment 2 of Annexure F). Results of packer tests along faults zones at Flat Rock Creek (Figure A2-3) and Kameruka Road (Figure A2-2) do not show higher hydraulic conductivity values in the Hawkesbury Sandstone compared to the bulk rock. However, packer tests in the faulted Hawkesbury Sandstone at the Luna Park Fault zone (below Middle Harbour) indicated hydraulic conductivity values which are up to four orders higher than the bulk rock hydraulic conductivity (Figure A2-4 in Attachment 2 of Annexure F).

A summary of the inferred groundwater table information shown on the cross-sections is as follows:

- Warringah Freeway to Middle Harbour Section: The inferred groundwater table elevation ranged from approximately 10 metres below ground surface at Warringah Freeway to approximately 100 metres below ground surface at Tunk Street (Figure A2-2 in Attachment 2 of Annexure F)

- Gore Hill Freeway Connection to mainline tunnel section: The groundwater table beneath Lambs Street, near the North Shore rail line, was measured at approximately 50 mAHD or approximately 10 metres below ground surface (Figure A2-5 in Attachment 2 of Annexure F)
- Seaforth to Balgowlah section: The inferred groundwater table range along the section ranges from approximately 10 metres below ground surface to 70 metres below ground surface (Figure A2-6 in Attachment 2 of Annexure F)
- Seaforth to Wakehurst Parkway section: The inferred groundwater table range along the section ranges from approximately 2 metres below ground surface to 70 metres below ground surface (Figure A2-7 in Attachment 2 of Annexure F).

5.5.5 Hydraulic properties

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.

5.5.5.1 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 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.

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

Source	Hydraulic conductivity (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)

Source	Hydraulic conductivity (m/day)			Method
	Ashfield Shale	Mittagong Formation	Hawkesbury Sandstone	
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, 2019a)	No data	No data	Land based Mean = 0.015 Median = 0.001 Marine Mean = 0.454 Median = 0.026	Packer Tests (n = 191)
Beaches Link and Gore Hill Freeway Connection groundwater assessment (Jacobs, 2019b)	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

5.5.5.1.1 Project specific packer testing

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.

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 one to 1.5 orders of magnitude greater that the land-based permeability values. This is inferred to reflect the increased occurrence and concentration of geological structure (such as fractures in the bedrock due to faulting or stress relief) associated with the harbour areas.

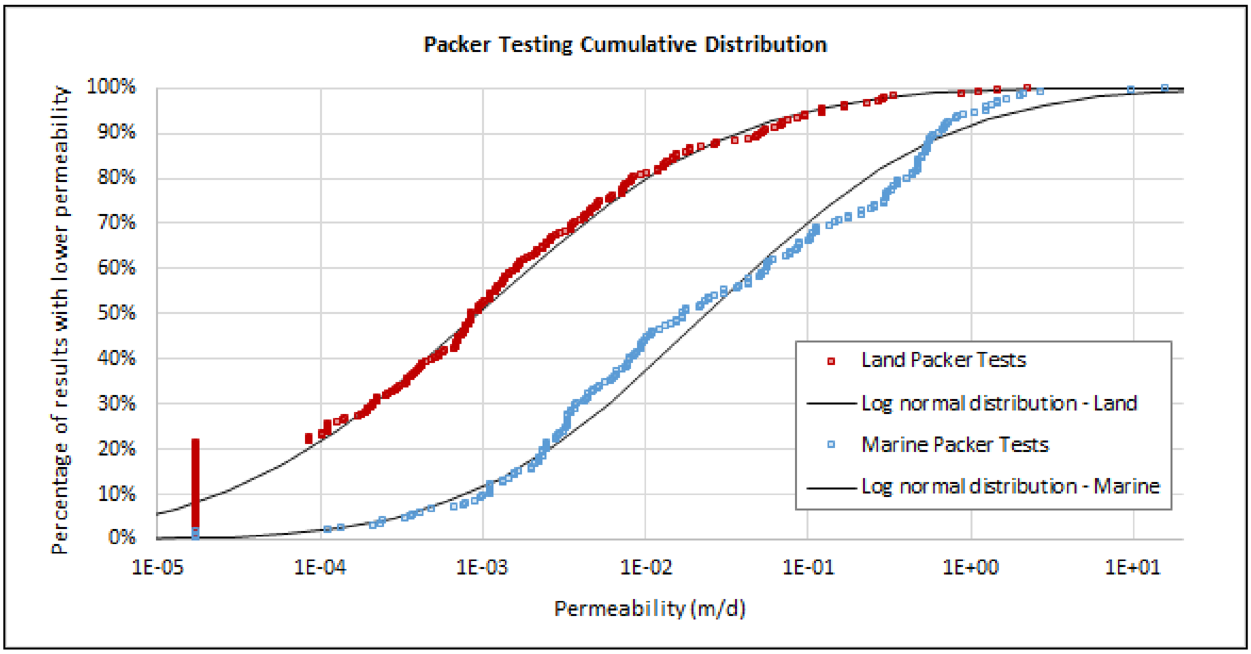

Figure 5-13: Packer testing cumulative distribution

Packer testing results for areas north of Sydney Harbour

Table 5-7 provides a summary of the packer testing carried out for the Western Harbour Tunnel Project and Beaches Link project in areas located north of Sydney Harbour. All the packer tests, except the tests at Western Harbour marine and Waverton, are within the Beaches Link project area. Testing comprised a total of 223 land-based packer tests and 250 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 0.054 metres per day compared to the median values of 0.002 metres per day. The range of test results is significant and covers several orders of magnitude. 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 5-7.

Table 5-7: Project specific packer test 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	223	4.0×10^{-6}	2.25	0.054	0.002
Waverton	31	1.1×10^{-5}	0.17	0.021	0.001
Balgowlah to Seaforth	91	4.0×10^{-6}	1.47	0.045	0.003
Cremorne to Northbridge	59	4.0×10^{-6}	1.00	0.003	0.001
Flat Rock Creek	42	1.9×10^{-5}	2.25	0.146	0.005

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)
Western Harbour marine	142	2.8×10^{-5}	15.72	0.454	0.026
Middle Harbour marine	108	1.4×10^{-4}	4.04	0.187	0.017

Note for statistical analysis, all packer tests results recorded as less than 1×10^{-9}m/s (8.64×10^{-5}m/d) have been set as 2×10^{-10}m/s (1.73×10^{-5}m/d).

5.5.5.1.2 High permeability zones and structural influence

Known fractures occurring in the project are described in Section 5.3 and shown on cross sections presented in Section 5.5.4. 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.

Away from harbour areas there was no evidence from the packer test results to suggest that the hydraulic conductivity of the fractured zones and dykes in the project areas was significantly different from the hydraulic conductivity of the surrounding bulk. It is important to note that packer tests were not carried out at all the known and inferred fracture zones and dykes within the project area. However, the modelling includes all the known dykes and fault zones, and these are modelled with higher hydraulic conductivity than the surrounding rock (see Annexure F for further information). This provides a conservative (relatively high) estimate of inflows.

High permeability zones were identified at the following locations:

- Middle Harbour
- Flat Rock Creek and
- Sydney Harbour.

Areas of moderately high permeability were identified at the following locations:

- Near Grandview Grove at Seaforth at the locations of bores B140 and B124
- Near Waverton (north of Sydney Harbour in the Western Harbour Tunnel Project area).

Middle Harbour high permeability zone

Zones of enhanced permeability occur immediately adjacent and underlying Middle Harbour. Table 5-8 provides summary statistics for Hawkesbury Sandstone hydraulic conductivity values estimated from packer tests carried out beneath the harbour and along the northern and southern flanks. The maximum hydraulic conductivity value of 3.1 metres per day was estimated at the zone beneath the harbour. Hawkesbury Sandstone hydraulic conductivity values estimated along the northern and southern flanks were about one order of magnitude lower than hydraulic conductivity values beneath the harbour.

Table 5-8: Hawkesbury Sandstone hydraulic conductivity values for zones at Middle Harbour

Packer test location	Mean hydraulic conductivity (m/d)	Maximum hydraulic conductivity (m/d)
North of harbour	0.10	0.54
South of harbour	0.03	0.24
Beneath harbour	0.53	3.10

Flat Rock Creek high permeability zone

At Flat Rock Creek, the relatively high hydraulic conductivity values obtained from packer testing at Bore B176A (0.26 to 0.6 metres per day) were associated with tests within the basin fill material and the upper weathered/fractured zone of the underlying Hawkesbury Sandstone to 36 mbgl. Relatively high hydraulic conductivity of approximately 0.21 metres per day was also obtained from testing in the weathered/fractured interval between 36 mbgl and 46 mbgl. No intervals of elevated permeability were encountered below 46 mbgl in Bore B176A.

Borehole B134A-C was drilled to intersect the central valley fill material and underlying sandstone and encountered fill to 41 mbgl. Elevated permeability (2.2 metres per day) was encountered in the sandstone from 41 to 43 mbgl, with moderate permeability (0.017 to 0.027 metres per day) to 54 mbgl. No significantly permeable intervals were encountered below 54 mbgl.

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 0.06 to 0.29 metres per day, with no significant permeability returned below 42 mbgl.

Sydney Harbour high permeability zone

High permeability zones associated with geological structure occur immediately adjacent 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 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. The average permeability derived from packer testing at Western Harbour is 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 the harbour in the vicinity of the proposed location of the Western Harbour Tunnel.

Grandview Grove moderately high permeability zone

A zone of moderately high permeability in the vicinity of Grandview Grove at Seaforth, north of Middle Harbour, was identified from packer testing results at Bore 140 (Annexure A). The zone of moderately high permeability does not appear to be associated with a geological structure (fault or dyke). Intervals of moderately high hydraulic conductivity were identified in bore B140 from 65 mbgl to 75 mbgl (0.03 to 0.08 metres per day) and from 95 mbgl to 105 mbgl (0.03 to 0.09 metres per day). Moderate permeability zones in B140 are associated with sandstone units and some minor zones of brecciation and core loss.

Waverton Park moderate permeability zone

The elevated permeability to the north of the 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 (Jacobs 2020).

5.5.5.1.3 Permeability-depth relationship in Hawkesbury Sandstone

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 5-14.

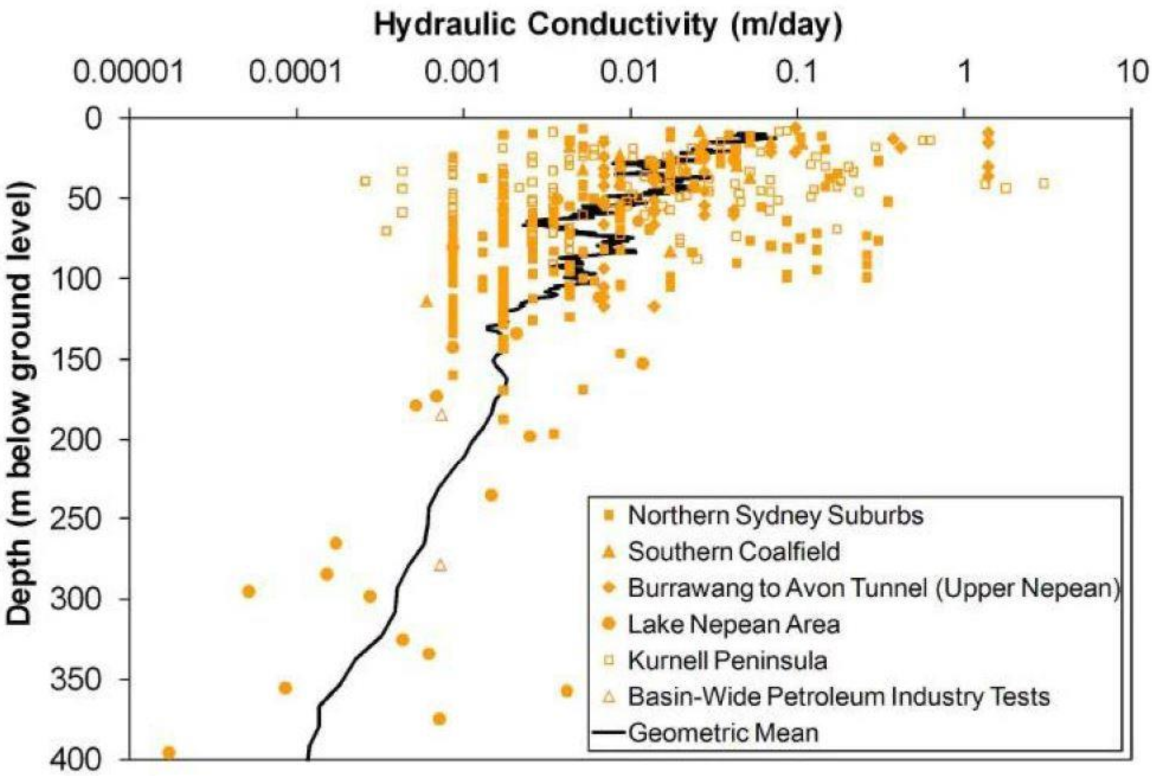

Figure 5-14: Tammetta and Hawkes (2009) hydraulic conductivity from packer testing in Sydney Basin.

Figure 5-15 shows the Hawkesbury Sandstone hydraulic conductivity plotted against depth below ground level for results of land-based project specific packer tests carried out in the project area located north of Sydney Harbour. The project specific packer test results are highly variable but do indicate an upper limit to hydraulic conductivity that diminishes with depth. Figure 5-15 shows several results plotting at the minimum derived hydraulic conductivity value of 9×10^{-5} metres per day, which is the lowest hydraulic conductivity value that can be reasonably derived with certainty using conventional packer testing equipment.

Figure 5-15 also shows the geometric mean values for Hawkesbury Sandstone hydraulic conductivity estimates from project specific packer tests and regional packer tests (Tammetta & Hawkes, 2009). The project specific packer testing results do not show a decreasing trend with depth in the geometric mean for hydraulic conductivity estimates which is observed in the regional packer testing results. However, as has already been indicated, the project specific data shows an upper limit to hydraulic conductivity that diminishes with depth.

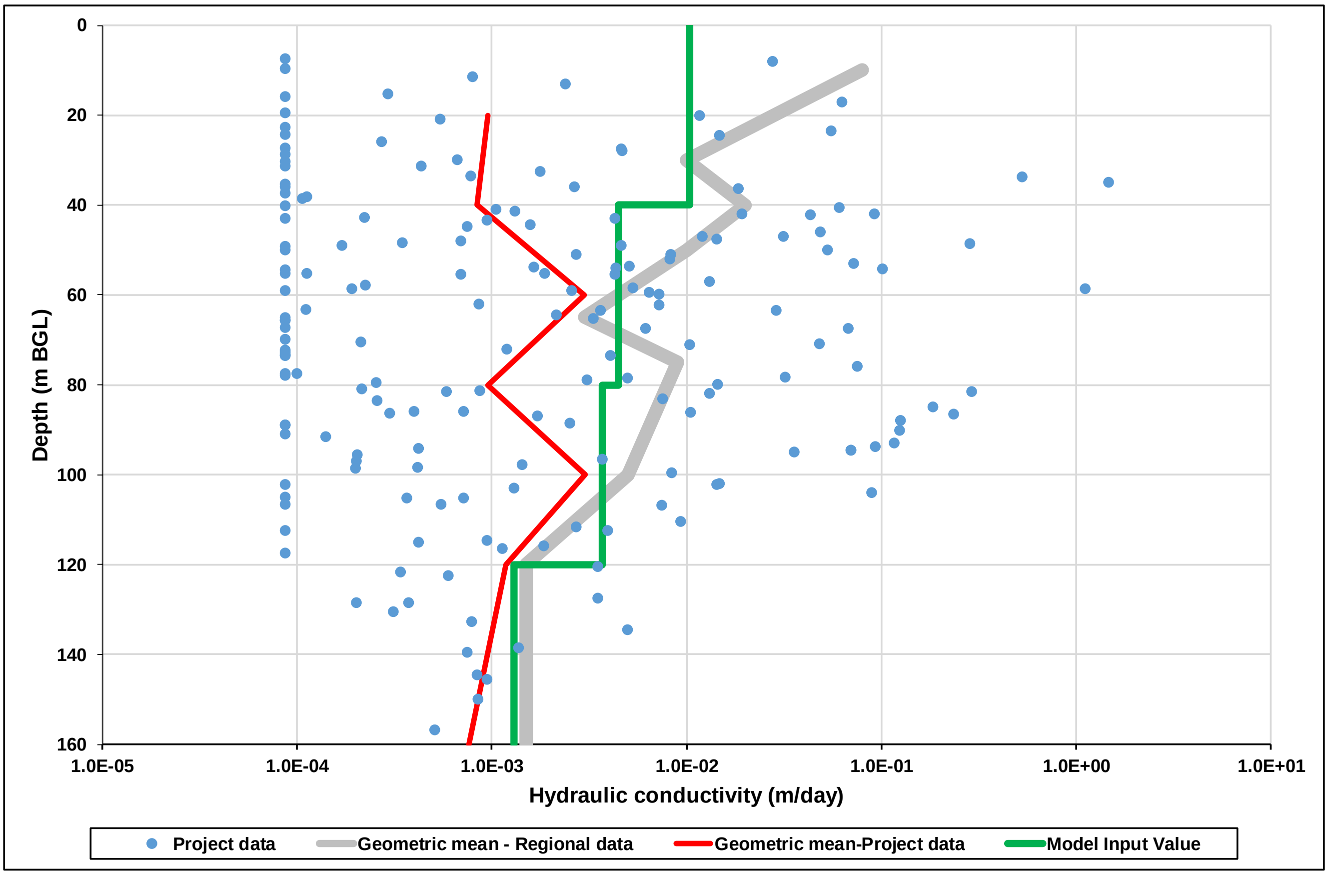

Figure 5-15: Hydraulic conductivity versus depth – north of Sydney Harbour.

The decreasing hydraulic conductivity with depth relationship for the Hawkesbury Sandstone observed in the regional data has been adopted for the purposes of this assessment given that:

- The project specific packer test results indicate an upper limit to hydraulic conductivity that diminishes with depth
- Lithological observations from drill-core samples indicate that the sandstone has variable degrees of weathering, grain size distribution and cementation observed with depth, suggesting that permeability may correspondingly change with depth
- Structural observations from drill core samples indicate that the degree of fracturing (fracture density, and fracture aperture opening diameter) decrease with depth
- Geotechnical assessment results for drill-core samples indicate that the rock strength increases with depth, which suggests that hydraulic conductivity is likely to decrease with depth within the project area.

The green line in Figure 5-15 shows the hydraulic conductivity values assigned at 40 metre depth intervals in the conceptual hydrogeological model. The hydraulic conductivity values assigned to each 40 metre depth intervals in the conceptual hydrogeological model is based on the arithmetic mean of the following, for the corresponding depth intervals:

- Geometric mean of hydraulic conductivity estimates from project specific packer testing, and
- Geometric mean of hydraulic conductivity estimates from regional packer testing (Tammetta & Hawkes, 2009).

Figure 5-15 indicates that the hydraulic conductivity values assigned to the conceptual hydrogeological model are higher than the geometric mean of project specific values, at corresponding depths. This provides a conservative estimate of inflows to the tunnels and corresponding groundwater level drawdown.

5.5.5.1.4 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 high ratio of horizontal hydraulic conductivity to vertical horizontal conductivity 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 5-9.

Table 5-9: K_v estimates from previous studies (Source: HydroSimulations 2017).

Formation	Vertical hydraulic conductivity (m/d)	K_v/K_h
Alluvium	8.6×0^{-3} to 5×10^{-2}	1:10 to 1:100
Ashfield Shale	1×10^{-4} to 8×10^{-4}	-
Hawkesbury Sandstone	5×10^{-4} to 1×10^{-2}	1:10 to 1:100

5.5.5.2 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 Poisson's Ratio. Estimates of specific storage values are summarised in Table 5-10.

Table 5-10: 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 to 120	1.32×10^{-6}	9.13×10^{-7}
Hawkesbury Sandstone - bedded	24	1.5 to 105	2.22×10^{-6}	9.85×10^{-7}
Basalt	1	82	5.53×10^{-7}	5.53×10^{-7}
Laminate	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 reasonably uniform distribution of results with a mean specific storage for the Hawkesbury Sandstone overall of 1.9×10^{-6} per metre. 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} per metre 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.

The values adopted for specific storage and vertical conductivity (anisotopy) in the model are conservative in that they would yield relatively greater estimates of predicted groundwater level drawdown.

5.5.6 Groundwater quality

Project specific groundwater quality monitoring has been conducted from a series of standpipe piezometers installed in the Hawkesbury Sandstone. Whilst 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 typically found within the Hawkesbury sandstone is of low salinity and neutral to slightly acidic. This is due to the sandstone being dominated by clean quartz/feldspar sand grains. Groundwater contained within the shale unit is generally of a much lower 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 City and Southwest project (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 higher water quality aquifers.

Water quality data collected from previous tunnelling assessments are summarised in Table 5-11.

Table 5-11 Sydney tunnel investigations water quality

Tunnel/formation	TDS (mg/L)	EC (µS/cm)	pH	No. Samples
Sydney Metro City and Southwest (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	-	-

Tunnel/formation	TDS (mg/L)	EC (µS/cm)	pH	No. Samples
Ashfield Shale	1000-12,000	1600-20,000	-	-
Hawkesbury Sandstone	490-1100	760-1700	-	-
New M5 (AECOM, 2015)				
Ashfield Shale	4250 (av.)	-	6.2 (av.)	3
Hawkesbury Sandstone	3190 (av.)	-	7.5 (av.)	11

Routine monthly groundwater quality monitoring commenced during October 2017 and would be ongoing during construction and into early phases of operation of the project. Groundwater quality data has been reported from six sampling events at four standpipe piezometers. Details of the monitoring sites are shown in Table 5-12 and the locations are shown on Figure 4-2 and Figure 4-3. Full groundwater quality analytical results are provided in Annexure D.

Table 5-12 Groundwater quality monitoring locations

Bore ID	Location (Figure 3-1)	Monitored formation	Number of samples	Comments
B114A	Artarmon	Hawkesbury Sandstone	6	Complete results
B127A	North Balgowlah	Hawkesbury Sandstone	6	Complete results
B128	Balgowlah	Hawkesbury Sandstone	5	Complete results
B134A-a	Flat Rock Baseball Diamond, Naremburn	Fill	5	Complete results
B134A-b	Flat Rock Baseball Diamond, Naremburn	Fill and Hawkesbury Sandstone	6	Complete results
B134A-c	Flat Rock Baseball Diamond, Naremburn	Hawkesbury Sandstone	3	Complete results
B138P	Seaforth	Hawkesbury Sandstone	1	Complete results
B155P	Northbridge	Hawkesbury Sandstone	1	Complete results
B173	Wakehurst Parkway	Hawkesbury Sandstone	5	Complete results
B174	Wakehurst Parkway	Hawkesbury Sandstone	5	Complete results
B175	Wakehurst Parkway	Hawkesbury Sandstone	4	Complete results
B238	Northbridge	Hawkesbury Sandstone	6	Metals results considered unreliable due to high pH[1]
B343	Cammeray	Hawkesbury Sandstone	2	Complete results

Note: 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 concentration data for the analytes shown in Table 5-13.

Table 5-13 Groundwater quality analytes

Suite	Analytes	
Physiochemical 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)

5.5.6.1 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 207 microsiemens per centimetre at B173 to 4800 microsiemens per centimetre at B238A. The variation shown in the data represents proximity to the Harbour with the closest bores showing greater influence from proximity to the saline interface. An EC measurement of 39,000 microsiemens per centimetre about correlates with seawater salinity.

Elevated levels of EC (1800 to 2400 microsiemens per centimetre), ammonia 0.7 to 0.95 milligrams per litre) and heavy metals (cobalt, copper, cadmium, lead, manganese and nickel in excess of ANZECC (2000) guideline trigger values) at B134A-a at the Flat Rock Baseball Diamond is indicative of poor water quality, it is noted that groundwater in the fill material (B134A-a) shows elevated EC (1800 to 2400 microsiemens per centimetre) compared to the underlying sandstone (1100 to 1700 microsiemens per centimetre) in the deeper monitoring bores (B134A-b and B134A-c).

Anomalously high pH values have been obtained at B238A, with extremely alkaline values in the range 11.7 to 12.2 pH units. These values are not considered to be representative of the Hawkesbury Sandstone. pH is influenced by several 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 B238A have been discounted from this assessment. The remaining pH data set ranges from 3.51 at B173 to 8.19 at B134A-a.

Major ions

The relative concentrations of major ions have been plotted on a Piper diagram on Figure 5-16 to assess the hydrogeochemical distribution of major ions to aid in the identification of water types based on bore location. Most bores sampled are in the Hawkesbury sandstone, with B134A-a being constructed in fill material above the Flat Rock Creek box culvert.

In the cation field most bores display water with a dominance of sodium although B134A-a and B134A-b show a dominance of calcium over sodium. Likewise, in the anion field there is a trend towards chloride dominance with B134A-a being sulfate dominant and B134A-b being bicarbonate dominant. B127A and to a lesser extent B238 are relatively evenly chloride-bicarbonate types with B238 show variable calcium dominance.

At the nested piezometers above and below the Flat Rock Creek box culvert, the deepest monitoring bore (B134A-c) is strongly sodium-chloride dominant and typical of mature groundwater. The shallower monitoring bores are potentially influence by contamination within the fill material and ion exchange as the water recharges the sandstone.

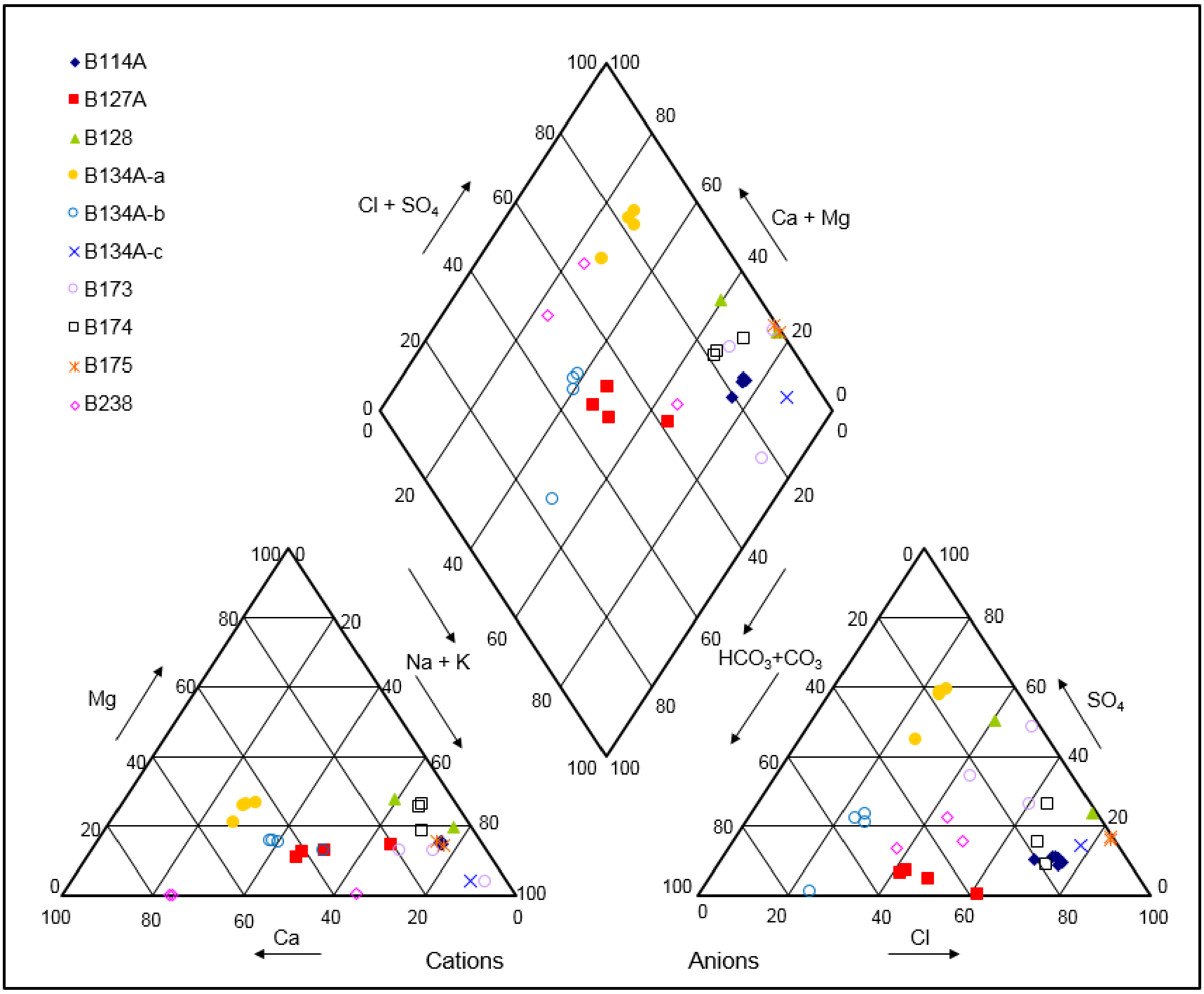

Figure 5-16 Groundwater Piper diagram

Heavy metals

Dissolved metal concentrations have been compared against the ANZECC 2000 guidelines for both marine and freshwater (95 per cent level of protection), or where a guideline trigger level exists. Data from B238 considered unreliable due to high pH 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 Annexure E.

- Cobalt concentrations met or exceeded the marine guideline value of 0.001 milligrams per litre in all samples from B114A (0.001 to 0.003 milligrams per litre), in one out of six samples at B128 (0.06 milligrams per litre), all samples at B134A-a (0.006 to 0.023 milligrams per litre), one out of five samples from B134A-b (0.001 milligrams per litre), B138P (0.005 milligrams per litre), B155P (0.001 milligrams per litre), three out of seven samples at B173 (0.001 to 0.002 milligrams per litre), and all samples at B174 (0.029 to 0.077 milligrams per litre). One unfiltered sample from B127A also exceeded the guideline value at 0.018 milligrams per litre
- Copper showed exceedances of the freshwater and marine guideline values (0.0014 milligrams per litre and 0.0013 milligrams per litre respectively) in one out of seven samples at B128 (0.002 milligrams per litre), seven out of eight samples at B173 (0.002 to 0.003 milligrams per litre), one out of eight samples at B174 (0.002 milligrams per litre), three out of eight samples at B175 (0.002 to 0.004 milligrams per litre), and five out of eight samples at B343 (0.002 to 0.007 milligrams per litre). One unfiltered sample each from B134A-a and B134A-b also exceeded the guideline value at 0.032 and 0.08 milligrams per litre respectively
- Manganese concentrations exceeded the freshwater guideline value of 1.9 milligrams per litre at numerous samples from B143A-a (1.93 to 2.47 milligrams per litre), and all samples at B174 (2.09 to 2.72 milligrams per litre)
- Zinc concentrations met or exceeded the freshwater and marine guideline values (0.008 milligrams per litre and 0.015 milligrams per litre respectively) at three samples from B114A (0.008 to 0.009 milligrams per litre), four out of seven samples at B128 (0.017 to 0.035 milligrams per litre), numerous samples at B134A-a (0.008 to 0.057 milligrams per litre), numerous samples at B173 (0.018 to 0.042 milligrams per litre), five out of seven samples at B174 (0.026 to 0.201 milligrams per litre), and five out of eight samples at B175 (0.009 and 0.027 milligrams per litre), one sample at B238 (0.008 milligrams per litre), and one sample at B343 (0.008 milligrams per litre). Several unfiltered samples are also noted as exceeding guideline values at B127A (0.318 milligrams per litre), B134A-a (0.342 milligrams per litre), B134A-b (0.467 milligrams per litre), B134A-c (0.039 milligrams per litre), and B238 (0.012 milligrams per litre).

Hydrocarbons

Positive results for total petroleum hydrocarbons (TPH) and total recoverable hydrocarbons (TRH) are noted at B114A, B127A, B134A-a, B134A-b, B238A and B343. Positive results for B114A, B127A and B134A-a were only noted for the first round of sampling. Positive results for benzene, toluene, ethylbenzene, and xylene (BTEX) are noted at B114A, B134A-a, B134A-b, B134A-c, B238A and B343.

5.5.6.2 Potential areas of contamination

From the data available, the groundwater quality at B134A, situated within the fill material at the area around Flat Rock Creek, shows poor groundwater quality with high electrical conductivity and high levels of sulfate, ammonia and hydrocarbons. Groundwater at this location is likely heavily influenced by contamination from the Willoughby Leisure Centre and Bicentennial Reserve areas that were used extensively for waste landfilling purposes historically. Consequently, groundwater inflows to the tunnel in this location are likely to be affected by contamination and might have the potential to impact the integrity of construction materials.

Positive results for hydrocarbons for B114A, B127A, and B134A during the first round of sampling only suggests the hydrocarbons may have been introduced during drilling or sampling. More consistent results, such as at B238A, may be indicative of hydrocarbon contamination. Other areas of potential contamination in the project area are discussed in Section 5.6.

5.5.6.3 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 sea water is denser than fresh water, density driven flow results in a gradual increase in the density and salinity of groundwater with depth close to the 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 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 Annexure 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).

5.5.7 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.

Groundwater works (water bores) listed in the Department of Planning, Industry and Environment (Water) database (WaterNSW, 2020) as being for the purpose of supply/irrigation/recreational/industrial use, and located within the vicinity of the predicted extent of groundwater level drawdown (see Section 6.1), are listed in Table 5-14.

Table 5-14 Groundwater works (bores)

Bore ID	Bore depth (m)	Drilled date	Purpose	Status
GW023093	2.4	1/12/1965	Water supply	Unknown
GW023150	1.8	1/01/1966	Irrigated agriculture	Unknown
GW026513	64	1/12/1966	Irrigated agriculture	Unknown
GW029731	21.6	1/04/1967	Recreation	Unknown
GW065075	150	15/02/1994	Recreation	Functioning
GW072478	180.5	#N/A	Household	Functioning
GW103127	138	31/07/2000	Recreation	Unknown
GW107187	8	1/01/1950	Household	Unknown
GW107757	162.6	29/07/2005	Recreation	Unknown

Bore ID	Bore depth (m)	Drilled date	Purpose	Status
GW107895	4	13/03/2006	Household	Functioning
GW107970	199	1/01/2004	Recreation	Unknown
GW108224	132.4	5/09/2006	Household	Functioning
GW108693	4	15/05/2007	Household	Functioning
GW108792	174	25/05/2007	Household	Functioning
GW108991	168	8/07/2008	Household	Unknown
GW109290	6.1	2/09/2008	Recreation	Unknown
GW109305	6.1	8/09/2008	Recreation	Unknown

Source: Department of Planning, Industry and Environment (Water) database (WaterNSW, 2020), BoM Groundwater Explorer

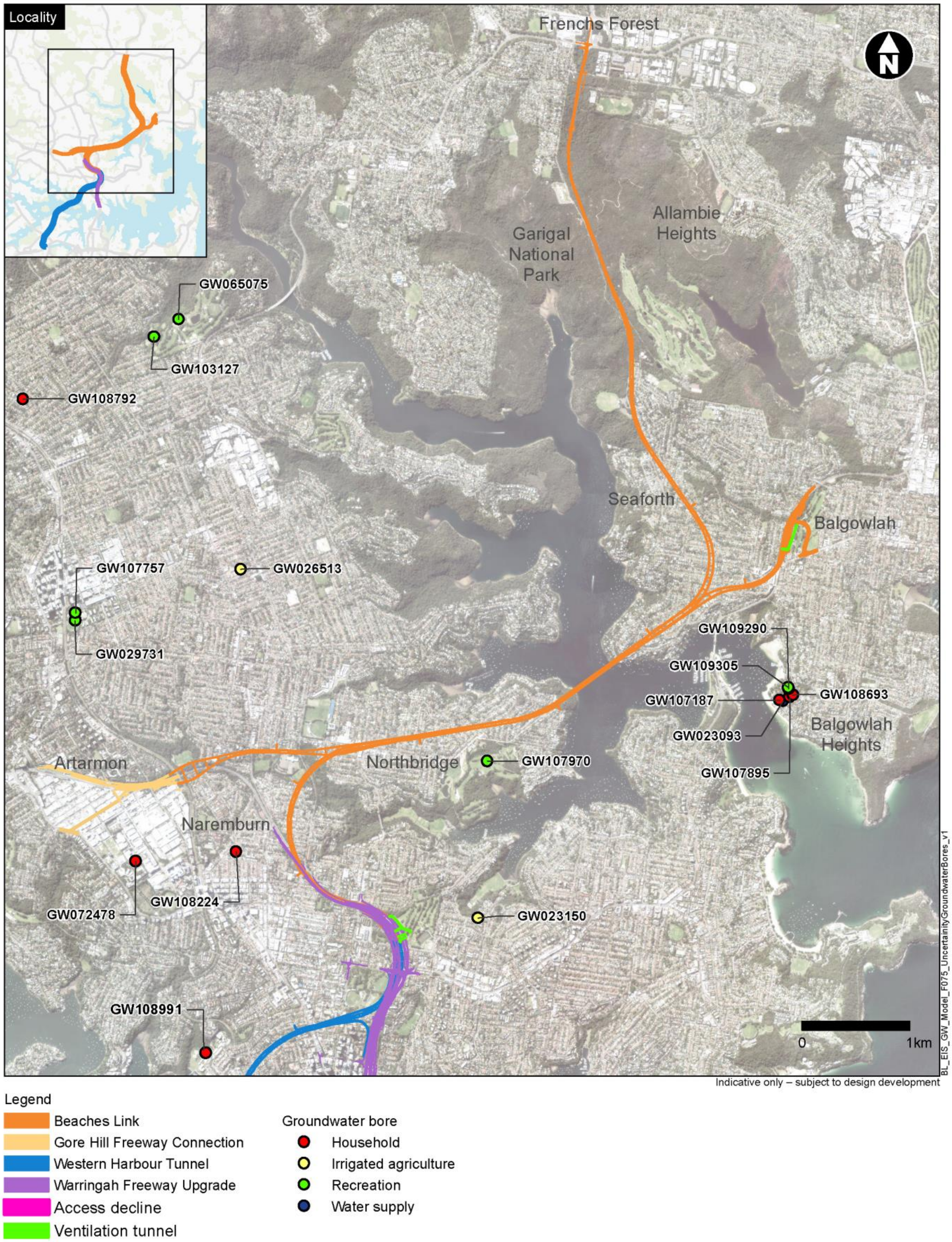

Figure 5-17 Registered groundwater bores

5.5.8 Existing and proposed tunnels

Numerous other existing and proposed tunnels either occur or 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 5-15. 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 5) they would be included as groundwater stresses for the purpose of assessing cumulative impacts.

Table 5-15 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*	Twin – three lane	-	5.5 each	1.5	17	GHD 2015a
New M5	2020*	Twin – three lane	14.1-20.6	9	0.63 to 0.67	12.9	AECOM 2015
Sydney Metro Chatswood to Sydenham	2020*	Twin rail – Tanked	-	15.5	negligible	negligible	Jacobs 2016

* - Assumed completion of tunnelling.

5.5.9 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 Department of Planning, Industry and Environment Water Risk Assessment Guidelines for Groundwater Dependent Ecosystems (Serov et al., 2012) adopts the definition of a groundwater dependent ecosystem as:

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

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

Appendix S (Biodiversity development assessment report) 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 the following locations with potential for groundwater dependent ecosystems:

- Upper reaches of Flat Rock Creek at Munro Park and upper reaches of Quarry Creek located south east of the project alignment. Identified as 'moderate to high potential' for terrestrial groundwater dependent ecosystem (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest)
- Bates Creek, about 550 metres west of the project alignment. Identified as 'moderate to high' potential for terrestrial groundwater dependent ecosystem (Estuarine Mangrove Forest, Seagrass Meadow and Coastal Sandstone Gully Forest)
- Manly Dam Reserve, about 650 metres east of the project alignment. Identified as 'moderate' potential for terrestrial groundwater dependent ecosystem (Coastal Sandstone Gully Forest and Coastal Sandstone Plateau Heath)
- Coastal Upland Swamp next to Wakehurst Parkway. Coastal Upland Swamps primarily occur on impermeable sandstone plateau with shallow groundwater aquifers, in the headwaters and impeded drainage lines of streams, and on sandstone benches with abundant seepage moisture.

The location of the potential groundwater dependent ecosystems is shown in Figure 5-1.

High priority groundwater dependent ecosystems 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 groundwater dependent ecosystems are identified in the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources in the vicinity of the proposed alignment.

5.5.10 Wetlands of international importance

A search of the Department of Agriculture, Water and the Environment Protected Matters Search Tool found one Wetland of international importance 24 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 Ramsar site (ie a Wetlands of International Importance) in 1984. This reserve lies at significant distance from the predicted groundwater level drawdown associated with the Beaches Link tunnels.

5.5.11 Groundwater surface water interaction

Groundwater surface water interaction along the project alignment is expected to be limited due to the typically large depth to groundwater over most 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.

Flat Rock Creek, Quarry Creek and Willoughby Creek

Groundwater levels measured in piezometers B134A-a, B134A-b and B134A-c, located next to Flat Rock Creek above the project alignment, indicate that the current groundwater table is about 20 metres below the base of the creek. It is expected that Flat Rock Creek is connected to the water table in the lower reaches to the east of Flat Rock Drive where the groundwater dependent ecosystem exists. However, it is known that as the creek enters Tunks Park it is diverted into an underground box culvert where groundwater interaction is unlikely to occur.

As with Flat Rock Creek, there is potential for Quarry Creek and Willoughby Creek to interact with groundwater in their lower reaches.

Burnt Bridge Creek

From review of observed groundwater elevations, the upper reaches of Burnt Bridge Creek are not considered to be in connectivity with the groundwater table. In the vicinity of Balgowlah Golf Club observed groundwater levels at Bore B128 are around two to three metres below ground level, which indicates there is potential for interaction between the creek and the groundwater in this location where the creek is unlined.

5.5.12 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 NSW Office of Environment and Heritage (OEH) 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 Appendix K (Technical working paper: Aboriginal Cultural Heritage Assessment Report) and Appendix J (Technical working paper: Non-Aboriginal Heritage). No Aboriginal sites have been identified in the project area.

5.5.13 Sensitive receiving environments

Appendix O (Technical working paper: Surface water quality and hydrology) identifies Flat Rock Creek, Trefoil Creek, and Manly Dam as sensitive receiving environments relevant to the project in areas downstream of the project alignment. Apart from parts of Flat Rock Creek, these environments are not considered to be groundwater dependent.

5.6 Areas of environmental interest for contamination

Areas of environmental interest for contamination along, or within 500 metres of the alignment are discussed in detail in Appendix M (Technical working paper: Contamination). Each of the areas was given a risk ranking from low to high with respect to potential for contamination. A further assessment has been made as to whether the contamination is likely to be present near the surface or at depth. The sites that are considered to have potentially contaminated groundwater are those where there is a moderate or high contamination risk, with potential contamination at depth. Consideration is also given to the potential depth of the groundwater table since the project is unlikely to cause migration of shallow contamination where the water table lies below the contaminated zone.

A point of interest from a contamination point of view is the fill material between Flat Rock Drive and Willoughby Road at Willoughby, around the Willoughby Leisure Centre, and Bicentennial Reserve. 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 box culvert and up to 30 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 up until 1985, industrial and domestic waste were tipped and burnt in the area on both sides of Flat Rock Drive and into Flat Rock Gully Reserve.

The marine sediments around the Middle Harbour crossing are also of interest regarding potential sources of contamination and are described as high risk of contamination. However, from a groundwater perspective, given the immersed tube construction, the harbour sediments are not considered to pose a risk to groundwater or to tunnel inflows.

Unsealed areas next to Wakehurst Parkway were identified as having the potential for deposition of vehicle particulates, but these would not be expected to affect groundwater quality.

Areas of interest with moderate or high risk ranking and potential contamination at depth are listed in Table 5-16. The table also provides an assessment of the potential for contaminated groundwater at the listed site. The sites with a moderate or high risk of contaminated groundwater are shown in Figure 5-18. The site W8, associated with the Western Harbour Tunnel project, is also listed because it lies within the predicted zone of groundwater level drawdown due to the Beach Link project. Note that AEI W8 is included because due to the potential for cumulative impacts to occur due to the Western Harbour Tunnel project. No land disturbance at AEI W8 is expected due to the Beaches Link project. Appendix M (Technical working paper: Contamination) identifies seven regulated/notified sites registered with the NSW Environmental Protection Agency and located within 500 metres of the project. All these sites have a small footprint and groundwater is estimated to be greater than ten metres below ground level at them. Therefore, the risk of the project impacting potential groundwater contamination at these sites is considered unlikely. These sites are also shown in Figure 5-18.

Table 5-16 Areas of environmental interest for contamination

Figure 5-2 reference	Area of environmental interest	Potential contamination source	Potential contamination distribution	Potential contaminant	Contamination risk ranking (see Appendix M (Technical working paper: Contamination)	Contaminated groundwater risk ranking
B1	Unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray	Filling with material of unknown quality during construction of the Warringah Freeway	Surface and depth (depth distribution associated with depth of filling) (potentially 0–2.0 metres)	Heavy metals, hydrocarbons, pesticides, PCB, asbestos	**Moderate** • Possible contamination • Excavation activities within site footprint • Excavation activities within potential contamination distribution range (surface work only).	**Moderate** –groundwater quality data at B348 and B343 indicate potentially elevated heavy metals, ammonia and hydrocarbons at depth
B7	Punch Street at Artarmon	Historical hazardous building materials (bridge) and filling	Surface and depth (depth distribution associated with depth of filling) (potentially 0–2.0 metres)	Heavy metals, hydrocarbons, pesticides, PCB, nutrients, cyanide, VOC, asbestos	**Moderate** • Possible contamination • Excavation activities within site footprint • Excavation activities within potential contamination distribution range (surface work only).	**Moderate** –groundwater quality data at B114A indicate potentially elevated heavy metals and ammonia at depth
		Commercial/industrial use of site and surrounding areas (ie manufacturing, chemical use and storage etc)	Surface and depth (potentially 0–4.0 metres)	Heavy metals, hydrocarbons, VOC	**Moderate** • Possible contamination • Excavation activities within site footprint • Excavation activities within potential contamination distribution range (surface work only).	**Moderate** –groundwater quality data at B114A indicate potentially elevated heavy metals and ammonia at depth

Figure 5-2 reference	Area of environmental interest	Potential contamination source	Potential contamination distribution	Potential contaminant	Contamination risk ranking (see Appendix M (Technical working paper: Contamination)	Contaminated groundwater risk ranking
B8	Freeway Hotel, Reserve Road at Artarmon	Commercial/industrial use of site and surrounding areas (ie manufacturing, chemical use and storage etc)	Surface and depth (potentially 0–4.0 metres)	Heavy metals, hydrocarbons, VOC	**Moderate** • Possible contamination • Excavation activities within site footprint • Excavation activities within potential contamination distribution range (surface work only).	**Low –** depth to groundwater is estimated to be greater than 10 m and groundwater quality data do not indicate the presence of contamination
B9	Flat Rock Gully Reserve at Northbridge	Infilling	Surface and depth (depth distribution associated with depth of infilling). Infilling materials could comprise putrescible materials	Heavy metals, hydrocarbons, pesticides, PCB, nutrients, cyanide, VOC, asbestos, landfill gas	**Moderate** • Known contamination adjacent to site/possible contamination beneath site • Excavation activities within compound and access portal • Excavation activities within potential contamination distribution range (laterally and vertically).	**Moderate –** depth to groundwater is estimated to be greater than 10 m, groundwater quality data indicate the presence of contamination

Figure 5-2 reference	Area of environmental interest	Potential contamination source	Potential contamination distribution	Potential contaminant	Contamination risk ranking (see Appendix M (Technical working paper: Contamination)	Contaminated groundwater risk ranking
B10	Willoughby Leisure Centre and Bicentennial Reserve at Willoughby	Infilling	Surface and depth (depth distribution associated with depth of infilling). Infilling materials could comprise historical residential, industrial and furnace waste from the on-site incinerator) (potentially 0 to > 30 metres in depth)	Heavy metals, hydrocarbons, pesticides, PCB, nutrients, cyanide, VOC, asbestos, landfill gas	**High** • Known contamination beneath site • Excavation activities within site footprint • Excavation activities within potential contamination distribution range (vertically).	**High** – water quality monitoring data from B134A-a indicates relatively high EC, heavy metals, ammonia and hydrocarbons at depth
B11	Reclamation of land – Spit West Reserve at Mosman	Reclamation of land with material of unknown quality	Surface and depth (distribution associated with depth of infilling) (potentially > 2.0 metres)	Heavy metals, hydrocarbon, pesticides, PCB, nutrients, cyanide, VOC, organotins, asbestos	**Moderate** • Possible contamination • Excavation activities within site footprint • Excavation activities within potential contamination distribution range (surface work only).	**Low –** due to the coastal location of this site, any mobilised contamination is expected to leach directly to Middle Harbour

Figure 5-2 reference	Area of environmental interest	Potential contamination source	Potential contamination distribution	Potential contaminant	Contamination risk ranking (see Appendix M (Technical working paper: Contamination)	Contaminated groundwater risk ranking
B13	Balgowlah Golf Course at Balgowlah	Filling with material of unknown quality during construction of the Burnt Bridge Creek Deviation	Surface and depth (depth distribution associated with depth of filling) (potentially 0–2.0 metres)	Heavy metals, hydrocarbon, pesticides, PCB, asbestos	**Moderate** • Possible contamination • Excavation activities within site footprint • Excavation activities within potential contamination distribution range (surface work only).	**Moderate –** depth to groundwater is estimated to be less than 2m across a portion of this site, groundwater quality monitoring data at B128 indicates low pH and the presence of heavy metals at depth
W8[a]	Waverton Park – Woolcott Road, Waverton	Infill/reclamation next to shoreline	Surface and depth (potentially 0 m to > 20 m). (Depth distribution associated with depth of infilling)	Heavy metals, hydrocarbon, pesticides, PCB, nutrients, cyanide, VOC, asbestos	**High** • Known contamination (which could impact upon groundwater) • Tunnel below site footprint.	**High –** depth to groundwater is estimated to be less than 4 m across this site

Table notes: [a]See *Appendix M (Technical working paper: Contamination)*

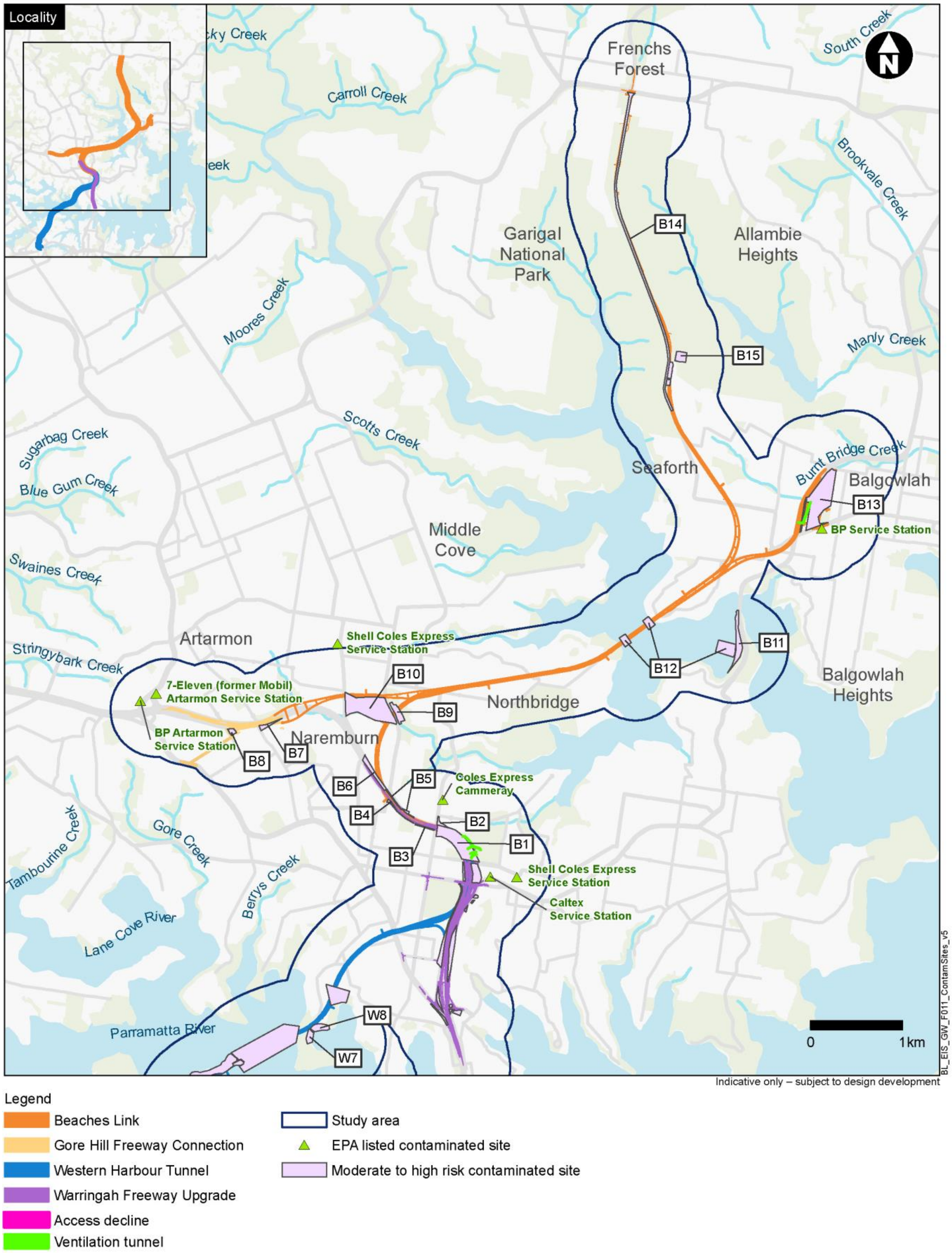

Figure 5-18 Area of environmental interest for contamination within 500 metres of the project

6. Impact assessment

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

The potential changes to groundwater conditions and potential receivers are as follows:

- Groundwater users (both Water Access Licences and Stock and Domestic use)
- Groundwater dependent ecosystems 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 that reduces the beneficial uses of the aquifer.

No groundwater dependent culturally significant sites were identified in the project area.

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

The groundwater modelling completed for this environmental impact statement is conservative as it does not include design measures to reduce groundwater inflows to the project design requirement of one litre per second per kilometre. The groundwater modelling described in Section 4.4 and Annexure F predicts drawdown at the water table and in the intermediate model layers. As most potential receivers are associated with the water table, drawdown at the water table is the key issue when assessing potential impacts on receivers.

6.1 Assessment of construction impacts

Subject to planning approval, construction of the project is planned to commence in early 2023, with completion of tunnel construction in 2026, and project completion in 2028. The tunnel construction is scheduled to take place from 2023 to 2027 as follows:

- 2023 – early works, site establishment and construction of tunnel access declines
- 2024 to 2027 – tunnel construction and fitout.

Project excavation and tunnel construction would occur in close sequence. Where required, structures to manage inflows (such as waterproof linings) would be installed at the time of, or soon after excavation. Tanking or full concrete lining of the tunnel either side of Middle Harbour crossing would occur in 2025 with tanking to take place progressively as the tunnel is constructed.

6.1.1 Tunnel inflows

In general, maximum inflow rates would occur when tunnel excavation is complete and measures to mitigate inflows (such as fully concrete lined sections) have not yet been installed. The greatest inflow rates are predicted to occur around the harbour crossing before the tunnel has been fully concrete lined in 2025.

Average inflows are presented for each year of the construction phase, as shown in Table 6-1. Peak inflows of 1.39 litres per second per kilometre averaged over the whole project would occur in 2025, which is marginally above the design criteria of one litre per second per kilometre. Inflows for each tunnel component are included in Table 6-1, and show that elevated inflows occur in several locations in 2025. The largest of these inflows are associated with the caverns under Northbridge due to inflows from the palaeovalley, and the interface structures connecting to the immersed tube tunnels in Middle Harbour.

Total inflows over the construction period are 2817 megalitres, with annual inflows during construction peaking at 899 megalitres per year in 2024. The long term average annual extraction limit 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 seven per cent of the water unassigned under the long term average annual extraction limit.

As shown in Table 6-1, average inflows for each year of construction are generally above the design criteria of one litre per second per kilometre that has been adopted as an acceptable level of inflow for the project. It is expected that criteria would be based on average values for the tunnel length, which the current design satisfies in every year except 2025. Planned measures to reduce, collect and dispose of tunnel inflows during construction are summarised in Section 7.1.

The modelled groundwater inflows to the tunnels were controlled by the formation permeability, which in some cases causes inflows to the tunnels greater than one litre per second per kilometre. However, a construction requirement for the project is that the tunnel inflows do not exceed one litre per second per kilometre on average, and the tunnels would be treated with appropriately designed linings during construction to ensure that this is the case. Therefore, the predicted tunnel inflows would be less than predicted by the modelling.

Table 6-1 Summary of modelled average tunnel inflows during construction (cumulative scenario)

Year	Cammeray to Middle Harbour	Middle Harbour to Wakehurst Parkway	Whole project		Total annual inflows
	L/s/km	L/s/km	L/s/km	ML/day	ML/year
2023	0.70	0.12	0.41	0.753	275
2024	1.14	0.33	0.73	1.337	488
2025	1.54	1.23	1.39	2.462	899
2026	1.01	0.84	0.93	1.638	598
2027	0.90	0.83	0.87	1.527	557

Tunnel inflows during construction would be collected at the wastewater treatment plants and disposed as described in Section 2.1.6. Appendix O (Technical working paper: Surface water quality and hydrology) provides an assessment of potential impacts of treated wastewater discharges into receiving waters.

6.1.2 Drawdown

Water table drawdown would occur because groundwater would flow into the tunnels and lower pressure (and groundwater levels) in the surrounding aquifer. This section assesses the predicted drawdown caused by the tunnel components during the construction phase, assuming that measures to achieve the one litre per second per kilometre inflow design requirement have not been installed, as well as drawdown associated with other construction projects. The Western Harbour Tunnel and Warringah Freeway Upgrade project, which is expected to proceed to construction ahead of the Beaches Link and Gore Hill Freeway Connection project, is likely to contribute to drawdown between the beginning of its construction and the completion of this project. The Sydney Metro Chatswood to Sydenham tunnel construction commenced in 2018 and was completed in 2020. This project comprises a fully lined tunnel, therefore the contribution to cumulative impacts in respect to drawdown is considered to be relatively small. The proposed Victoria Cross Station, located at North Sydney, will be a drained station, and the effects of this can be seen in the cumulative drawdown (see Section 6.1.2.2). Where the drawdown zones of each of these projects overlap, impacts to affected receivers would be cumulative.

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

- Beaches Link and Gore Hill Freeway Connection project only (this represents the incremental additional impact due to the project if the Western Harbour Tunnel and Warringah Freeway Upgrade and Sydney Metro Chatswood to Sydenham projects would go ahead)

- Cumulative scenario. This represents the Beaches Link and Gore Hill Freeway Connection project together with the Sydney Metro Chatswood to Sydenham project and Western Harbour Tunnel and Warringah Freeway Upgrade project. This represents the cumulative or total impact due to all three projects.

The modelled groundwater inflows to the tunnels were controlled by the formation permeability, which in some cases causes inflows to the tunnels greater than one litre per second per kilometre. However, a construction requirement for the project is that the tunnel inflows do not exceed one litre per second per kilometre on average, and the tunnels would be treated during construction to ensure that this is the case. Therefore, the predicted tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling. The results presented here therefore represent a conservative scenario for estimated drawdown and associated impacts.

6.1.2.1 Beaches Link and Gore Hill Freeway Connection only

Figure 6-1 and Figure 6-2 indicate water table drawdown at the end of tunnel construction could be up to a maximum of around 28 metres immediately overlying the tunnel centreline in the Northbridge area. Predicted drawdown propagates away from the tunnels, with the drawdown extending up to around 0.5 kilometres northwards in the Willoughby/Chatswood area, and extending southwards up to around 0.4 kilometres in the Crows Nest area.

North of Middle Harbour, the drawdown would be slightly lower, with maximum predicted drawdown of 16 metres between Seaforth and Balgowlah. The drawdown is predicted to reach the harbour on both sides of Middle Harbour as well as at Berrys Bay and Balls Head Bay.

Receivers that may be impacted by these drawdown levels are discussed in Section 6.1.3.

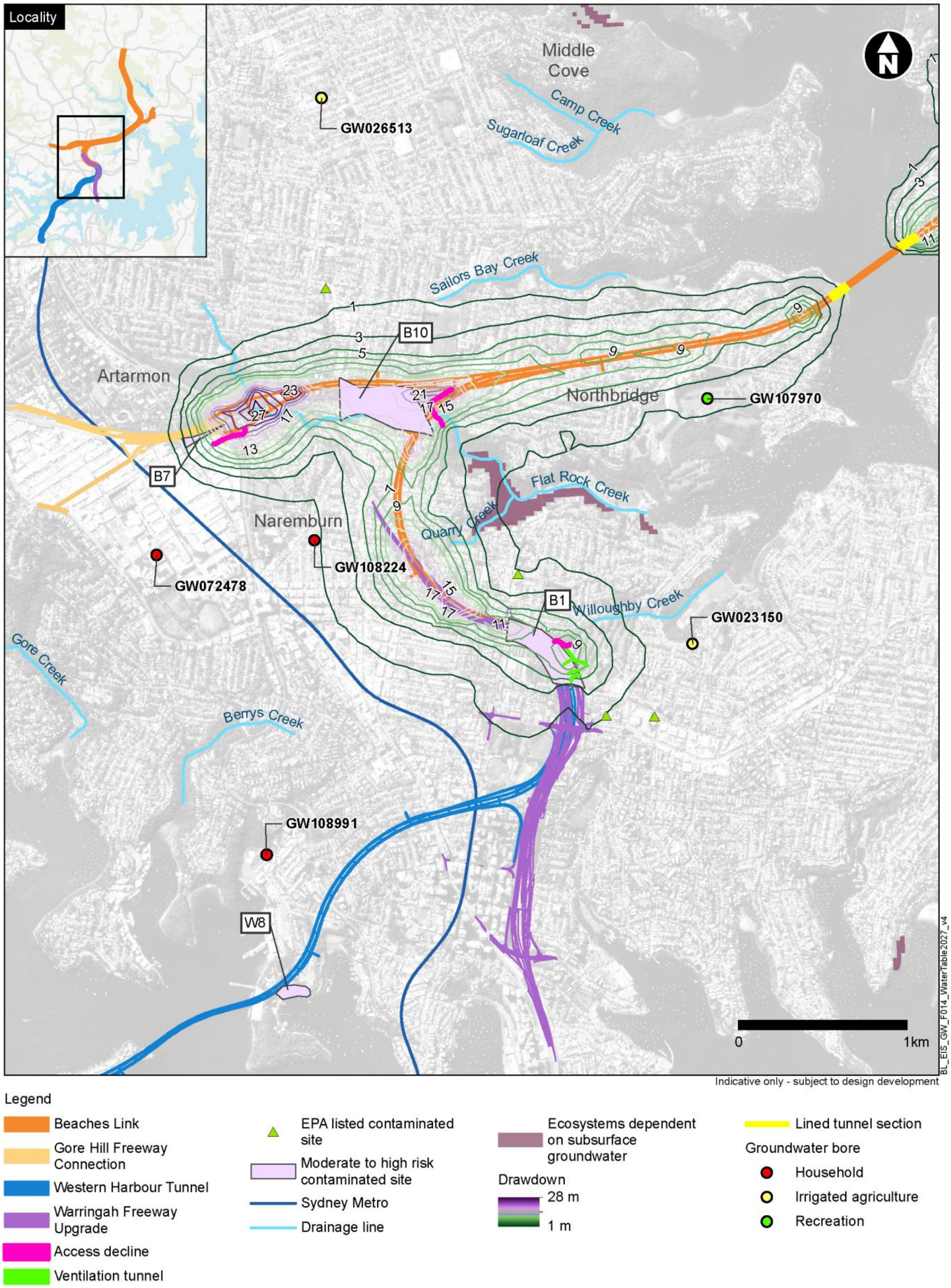

Figure 6-1 Predicted drawdown in the water table at the end of tunnel construction (south), June 2028 (project only)

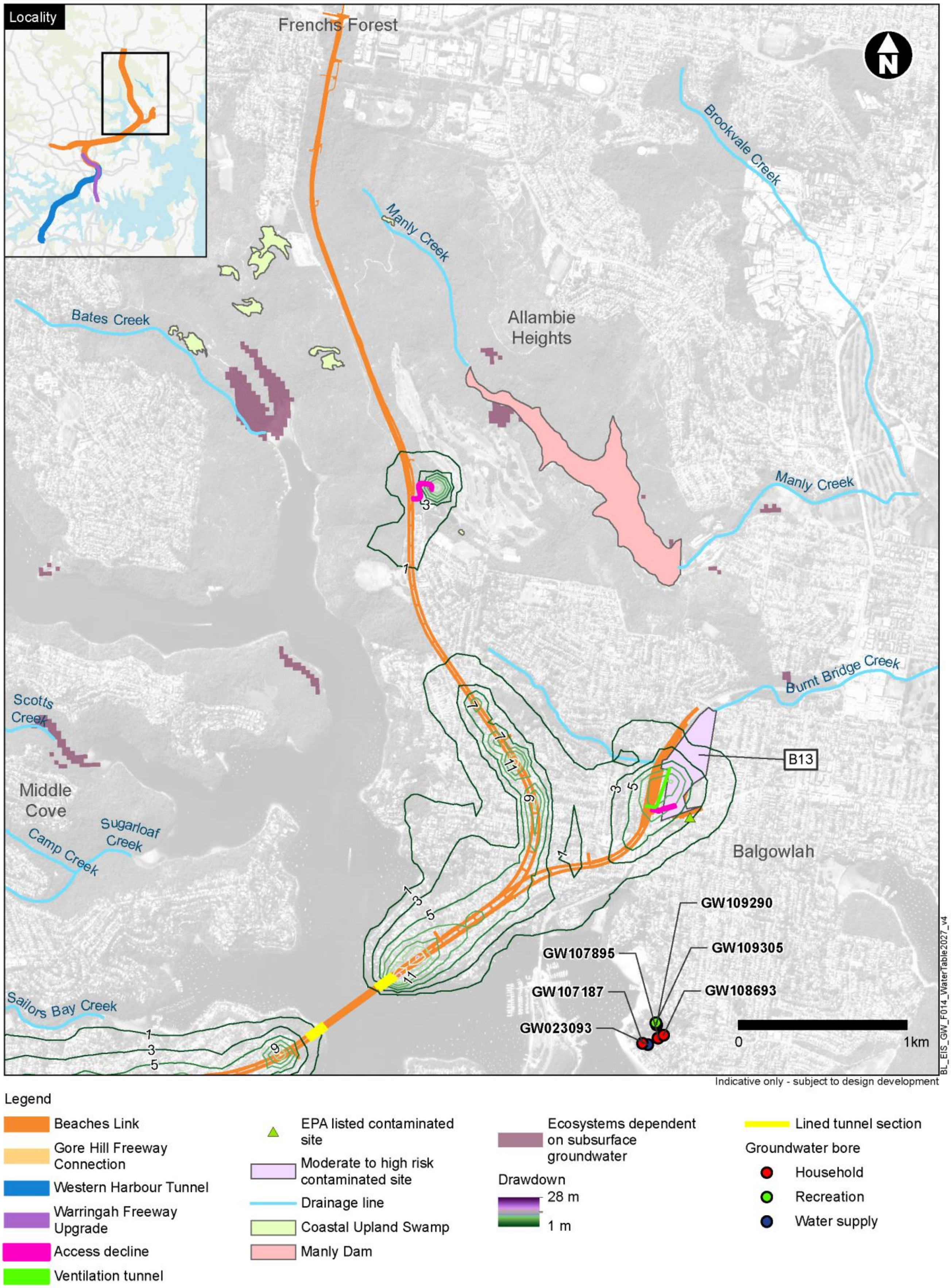

Figure 6-2 Predicted drawdown in the water table at the end of tunnel construction (north), June 2028 (project only)

6.1.2.2 Cumulative drawdown

Predicted cumulative drawdown in the water table at the end of tunnel construction would be only marginally greater than in the project only case, as shown in Figure 6-3 and Figure 6-4, as the Sydney Metro City and Southwest tunnel would be lined before the commencement of construction of the tunnels.

Victoria Cross Station, located at North Sydney, will be a drained station. Cumulative drawdown associated with this station and the project can be seen in Figure 6-3.

Maximum drawdown is predicted to be around 28 metres, which is the same as the project only case. The extent of drawdown in the cumulative scenario is also like that in the project only scenario. Potential impacts on receivers in that area are discussed in Section 6.1.3.

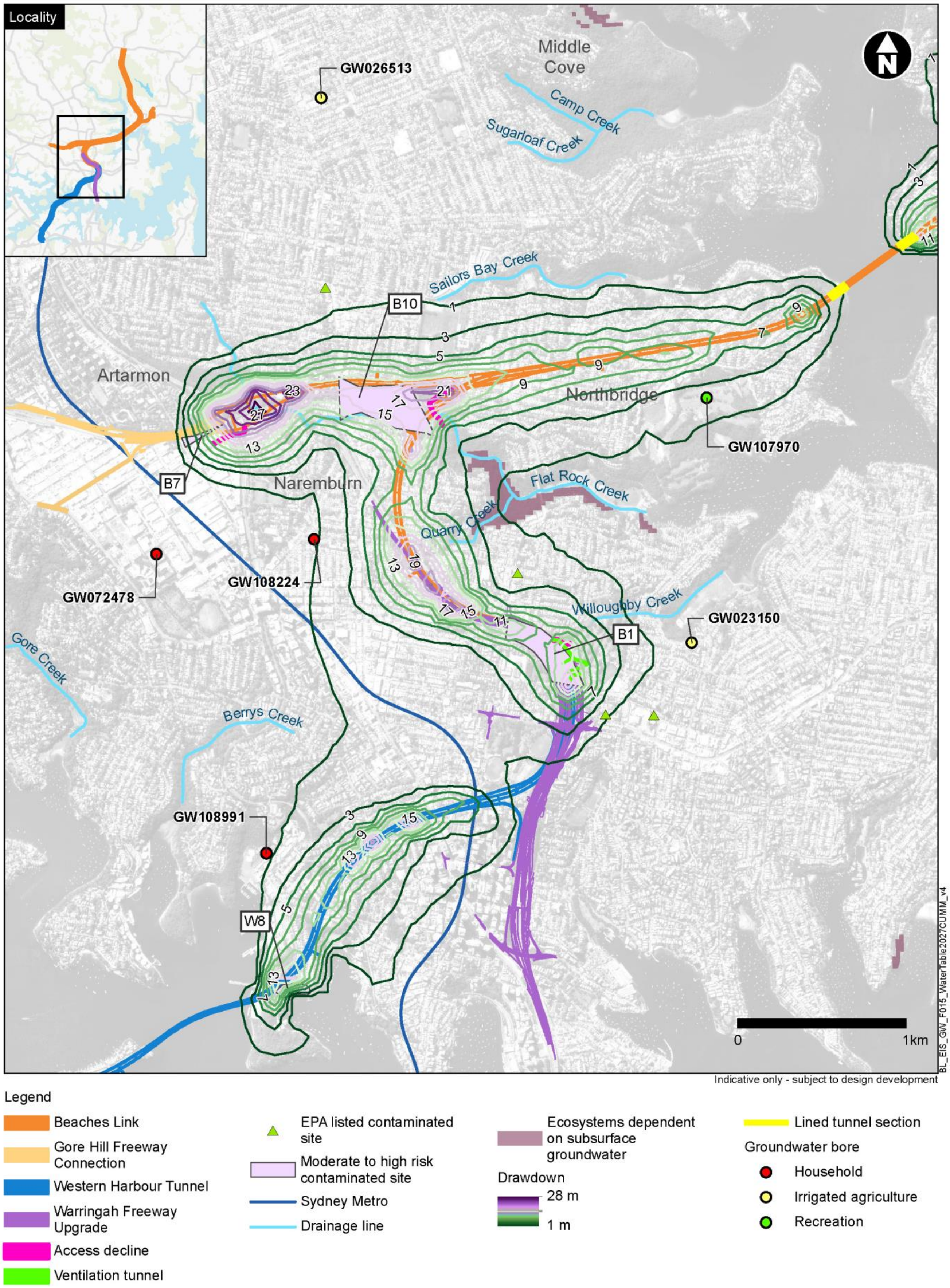

Figure 6-3 Predicted drawdown in the water table at the end of tunnel construction (south), June 2028 (cumulative)

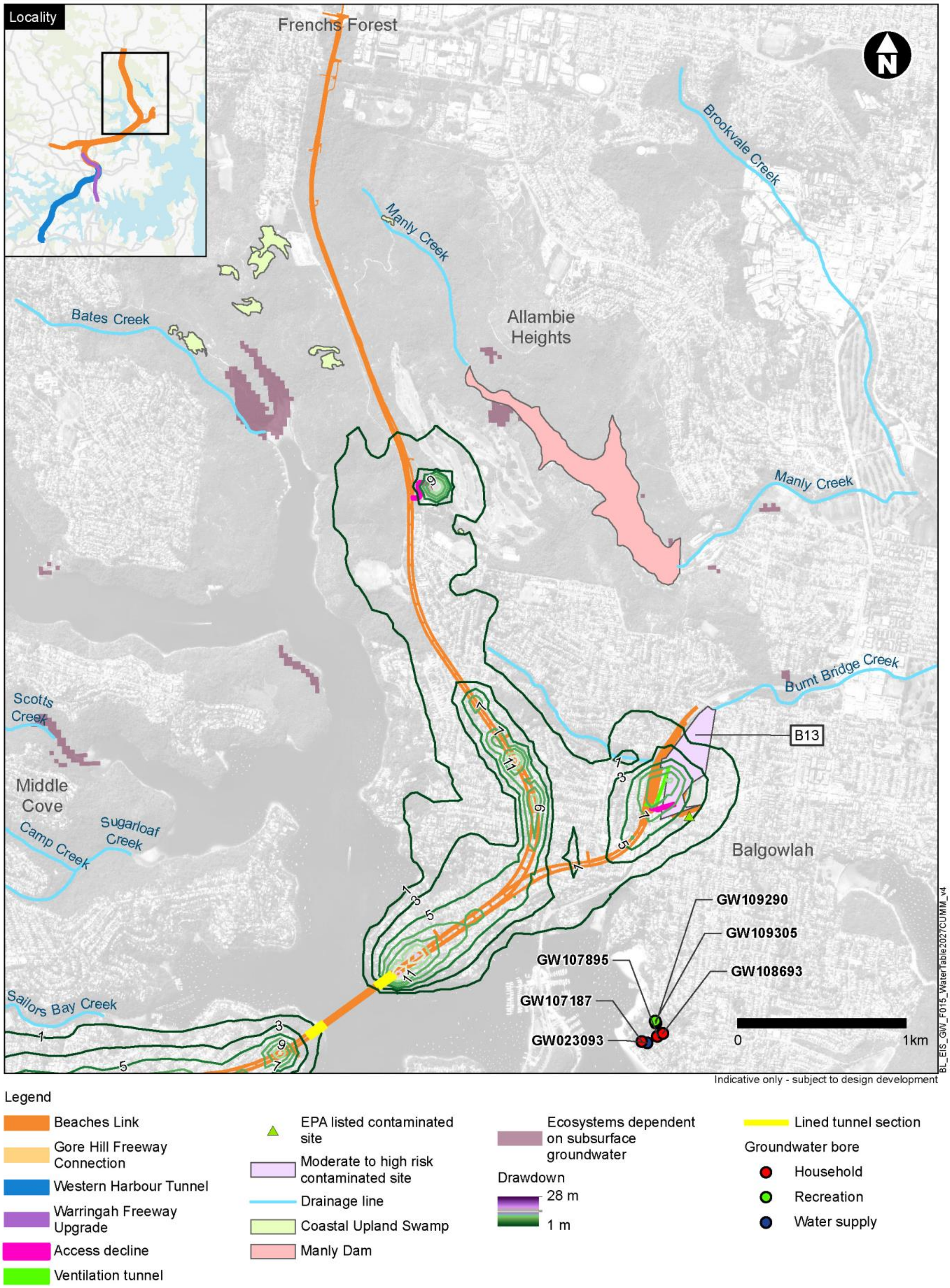

Figure 6-4 Predicted drawdown in the water table at the end of tunnel construction (north), June 2028 (cumulative)

6.1.3 Predicted impacts

Potential impacts resulting from the predicted drawdown of the water table aquifer are discussed in the following sections. Drawdown for each receiver is rounded up to the nearest metre and assessed against the NSW Aquifer Interference Policy (AIP) requirements. There are no Water Access Licence bores or groundwater dependent culturally sensitive sites within the predicted drawdown extents, therefore drawdown from the project would not affect these receivers.

Culturally sensitive sites that are not groundwater dependent do exist in the area of drawdown and are therefore not assessed in relation to groundwater impacts. Potential settlement of the groundwater surface may affect their integrity, and as such they are considered in Section 6.1.3.8.

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 sea water to intrude into fresh aquifers. The intrusion of saline water can reduce the beneficial uses of the aquifer, and potentially impact existing groundwater users and groundwater dependent ecosystems. 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 Middle 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 Annexure F) predicts that the onset of saline intrusion would be very slow within the Hawkesbury Sandstone due to the low hydraulic conductivity of the formation. Both the lateral and upward movement of the saline interface along the modelled cross-section through the deepest part of the proposed tunnel alignment is predicted to be negligible over the project construction period.

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. Where bores are targeting deeper horizons, a conservative approach has been adopted to assess the impacts by considering the maximum drawdown across all model layers.

Table 6-2 provides the project only and cumulative drawdown predicted by the modelling at each of the 17 groundwater bores identified in Section 5.5.7.

Drawdown at these bores is shown in Figure 6-1.

Of the 17 groundwater users identified in Section 5.5.7, all bores except GW107970, GW108224 and GW108991 are predicted to experience less than one metre of drawdown during construction and would therefore not be impacted by the project. Impacts to the three bores are predicted to be as follows:

- Bore GW107970 is recorded in the Department of Planning, Industry and Environment (Water) database as being 199 metres deep with a water level of 110 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at the bore would be up to seven metres in 2028, which equates to about eight per cent of available drawdown and is therefore not anticipated to cause significant impact to the groundwater supply

- Bore GW108224 is recorded in the Department of Planning, Industry and Environment (Water) database as being 132 metres deep with a water level of 35 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at the bore would be up to five metres in 2028, which equates to about five per cent of available drawdown and is therefore anticipated to cause negligible impact to the groundwater supply
- Bore GW108991 is recorded in the Department of Planning, Industry and Environment (Water) database as being 168 metres deep with a water level about 13 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at this bore would be up to three metres in 2028, which equates to less than two per cent of available drawdown and is therefore anticipated to cause negligible impact to the groundwater supply.

Given the relatively small predicted change in total water head within bores GW107970, GW108224 and GW108991, and the fact that these bores lie upgradient of direction of potential contaminant migration towards the tunnels from AEIs, the groundwater quality at these bores is not expected to be modified due to the project.

Measures to manage impacts on bores GW107970, GW108224 and GW108991 are discussed in Section 7.

Table 6-2 Predicted drawdown and impact at receivers at the end of construction (2028)

Bore ID	Bore depth (m BGL)	Drawdown – project only (m)	Drawdown - cumulative (m)
GW023093	2.4	Less than 1	Less than 1
GW023150	1.8	Less than 1	Less than 1
GW026513	64	Less than 1	Less than 1
GW029731	21.6	Less than 1	Less than 1
GW065075	150	Less than 1	Less than 1
GW072478	180.5	Less than 1	Less than 1
GW103127	138	Less than 1	Less than 1
GW107187	8	Less than 1	Less than 1
GW107757	162.6	Less than 1	Less than 1
GW107895	4	Less than 1	Less than 1
GW107970	199	Up to 6	Up to 7
GW108224	132.4	Up to 5	Up to 5
GW108693	4	Less than 1	Less than 1
GW108792	174	Less than 1	Less than 1
GW108991	168	Less than 1	Up to 3
GW109290	6.1	Less than 1	Less than 1
GW109305	6.1	Less than 1	Less than 1

Table notes: BGL means below ground level

6.1.3.3 Areas of environmental interest for contamination

The following potential impacts may 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 also 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 (modelled without tunnel linings) at areas of environmental interest for contamination within 500 metres of the project alignment with moderate or high risk are summarised in Table 6-3.

Table 6-3 Predicted drawdown at areas of environmental interest for contamination at the end of construction (2028)

Figure 5-2 reference	Area of environmental interest	Contaminated groundwater risk ranking	Drawdown – project only (m)	Drawdown – cumulative (m)
B1	Unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray	Moderate	Up to 13	Up to 17
B7	Punch Street at Artarmon	Moderate	Up to 19	Up to 19
B9	Flat Rock Gully Reserve at Northbridge	Moderate	Up to 21	Up to 21
B10	Willoughby Leisure Centre and Bicentennial Reserve at Willoughby	High	Up to 22	Up to 22
B13	Balgowlah Golf Course at Balgowlah	Moderate	Up to 11	Up to 11
W8	Waverton Park – Woolcott Road, Waverton	High	Less than 1	Up to 12

Significant drawdown is predicted at the unsealed areas next to Warringah Freeway (eastern side by Cammeray Golf Course) at Cammeray; the Willoughby Leisure Centre and Bicentennial Reserve; Punch Street, Artarmon; Flat Rock Gully Reserve at Northbridge; and Balgowlah Golf Course at Balgowlah.

The levels of drawdown at Waverton Park during construction would be minor for the project only scenario and would not be expected to cause significant migration of contaminants or to cause migration of contaminants into areas of relatively good quality groundwater. Under the cumulative scenario, drawdown at Waverton Park would be largely due to the effect of the Western Harbour Tunnel and Warringah Freeway Upgrade project. The movement of groundwater would be towards the Western Harbour Tunnel and would be collected and treated at the water treatment plants established for that project. If contaminants are mobilised from unsealed areas next to Warringah Freeway (eastern side by Cammeray Golf Course) at Cammeray; the Willoughby Leisure Centre and Bicentennial Reserve; Punch Street, Artarmon; or Balgowlah Golf Course at Balgowlah, they would travel towards the tunnel during construction.

The rate of contaminant migration would depend predominantly on the hydraulic conductivity at the area of environmental interest for contamination, contaminant viscosity and the hydraulic gradient at the site, but over the construction period a drawdown of this magnitude would cause migration of contaminants.

The quality of groundwater inflows could pose a potential human health risk (due to the potential migration of potential volatile contaminants into the tunnel system from B7, B10 and W8). This risk should be managed through the ongoing monitoring of the quality of groundwater inflows to the tunnels, as well as the groundwater quality and groundwater levels at groundwater monitoring sites B348, B343, B114A, B134A-a to B134A-cm and B128 as discussed in Section 7.1. All groundwater inflows would be collected and treated at the construction wastewater treatment plant.

Contaminant migration caused by drawdown from the tunnel has the potential to degrade water quality more than 40 metres from the tunnel. The only groundwater dependent ecosystem in the vicinity of these areas of environmental interest is that which is present at the upper reaches of Flat Rock Creek and Quarry Creek in the vicinity of the Willoughby Leisure Centre and Bicentennial Reserve (ie Terrestrial GDE - Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest). This groundwater dependent ecosystem is not expected to be impacted by contaminant migration since the potentially contaminated fill area at this area of environmental interest is immediately overlying the tunnels and would therefore drain towards the tunnels and away from the groundwater dependent ecosystem, which would satisfy the requirements of the AIP.

Groundwater supply bores with the potential to be impacted by the project (see Section 6.1.3.2) lie upgradient of the hydraulic gradient predicted to be induced by the tunnels. Therefore, contamination from these areas of environmental interest is not expected to impact groundwater quality within these supply bores.

6.1.3.4 Groundwater dependent ecosystems and sensitive environments

As outlined in section 5.5.9 and shown in Figure 5-1, there are four areas of vegetation considered to be groundwater dependent ecosystems or sensitive environments within the area of predicted drawdown.

Drawdown at the following ecosystems is predicted to be less than one metre over the construction period: Vegetation at Bates Creek, Vegetation at Manly Dam Reserve, and the Coastal Upland Swamp south of Frenchs Forest. Drawdown is predicted to be up to five metres at the Vegetation at Flat Rock Creek and Quarry Creek.

The potential significance of these impacts is discussed in Appendix S (Technical working paper: Biodiversity development assessment report). Management measures are discussed in Section 7. The other groundwater dependent ecosystems in the project area are outside the predicted drawdown extents.

Table 6-4 Predicted drawdown and impact at groundwater dependent ecosystem and sensitive environments at the end of construction (2028)

Receiver	Location	Drawdown – project only (m)	Drawdown – cumulative (m)
Vegetation at Flat Rock and Quarry Creek	Northbridge	Up to 4	Up to 5
Vegetation at Bates	Bates Reserve/Garigal	Less than 1	Less than 1
Manly Dam Reserve	Manly Dam Reserve	Less than 1	Less than 1
Coastal Upland Swamp	Bates Reserve/Garigal	Less than 1	Less than 1

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 (refer to Annexure F).

The predicted impacts are based on a comparison of model predicted baseflow for the scenario without either the projector the Western Harbour Tunnel and Warringah Freeway Upgrade projects (the null scenario) and the scenario that includes the simulation of both projects (the cumulative scenario).

The baseflow impacts have been compared against the indicative flow measurements to determine the potential impact to total flow. The nature of the watercourse substrate has been ascertained during ground truthing (refer to Section 5.2). The method used to estimate baseflow from the groundwater models is described in Annexure F.

Due to the assessment being based on limited gauging data and modelled baseflows, monitoring has been listed as a management measure in Section 7 to confirm modelled results.

The predicted volumetric reduction and percentage reduction in baseflow to various watercourses and water bodies at the end of construction (2028) are provided in Table 6-5.

Baseflow reduction of five per cent or less is not considered to be significant. The model, however, indicates that baseflow reduction above five per cent has the potential to occur during construction stage to Flat Rock Creek, Quarry Creek and Burnt Bridge Creek. The predicted baseflow reduction at Burnt Bridge Creek is 79 per cent during construction. As discussed below, it is expected that the additional creek flows from treated water from the construction wastewater treatment plants could partially feed the surrounding groundwater system.

The reduction in baseflow to Flat Rock Creek and Quarry Creek has the potential to also impact the groundwater dependent ecosystem at those locations (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest) and ecosystems reliant on surface water.

It should be noted that the assessment of baseflow reduction is conservative and is likely to overestimate actual baseflow reduction for the following reasons:

- The modelled groundwater inflows to the tunnels were controlled by the formation permeability, which in some cases causes inflows to the tunnels greater than one litre per second per kilometre. However, a design requirement for the project is that the tunnel inflows do not exceed an average of one litre per second per kilometre, and the tunnels would be treated during construction as they are excavated to ensure that this is the case. Therefore, the predicted tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling. Potential baseflow reduction to watercourses and waterbodies would therefore be less than predicted and discussed here

- It is assumed that there is continuous saturation between the tunnel horizon and the shallow water table at the location of watercourses (i.e. there is a single connected groundwater system beneath the creek and the proposed underlying tunnel. In reality, the system will be stratified, possibly with disconnected aquifer horizons. The predicted maximum drawdowns beneath the creek are therefore unlikely to be realised and the predicted reduction in baseflows are therefore conservative

- For watercourses and waterbodies other than Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, the whole length or area at the base of the creek or dam is considered to be unlined. At the time of modelling there was no information on the nature of creek bed conditions for Willoughby Creek and Sailors Bay Creek. Should any of these watercourses be lined, the reduction baseflow would be less than that predicted

- Groundwater inflows to the tunnels would be collected, treated and discharged to local waterways (Willoughby Creek, Flat Rock Creek and Burnt Bridge Creek). This is expected to offset baseflow reduction to these waters, as the additional creek flows could partially feed the surrounding groundwater system

- The Water Sharing Plan requires that the source of the impact (ie the tunnels) be more than 30 metres deep and located in underlying parent material. The tunnels satisfy these requirements. However due to the potential impact, mitigation measures are outlined in Section 7.

While the potential impacts to groundwater dependent ecosystems and baseflow reductions are likely to be overestimated, it is recommended that additional monitoring of surface water flows and groundwater levels in the vicinity of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek be undertaken to support refined assessment and develop suitable design mitigation measures during further design development. This should be supported by a focussed study, with appropriate ecological input, to assess how the health of the affected aquatic ecosystems and the groundwater dependent ecosystem associated with Burnt Bridge Creek, Flat Rock Creek and Quarry Creek, might be impacted by the predicted groundwater drawdown and associated reductions in baseflow. The study should consider how existing site features affect the interaction between surface water and groundwater along the affected reaches of these watercourses, and the hydraulic connectivity in the underlying geology. Where unacceptable ecological impacts are predicted, feasible and reasonable mitigation measures to address the impacts should be identified, incorporated into the detailed design, and implemented during construction. The mitigation measures considered should include tunnel linings. Refer to Section 7 for further detail.

Table 6-5 Predicted drawdown impacts at watercourses at the end of construction (2028)

Watercourse	Location	Drawdown – project only (m)	Drawdown – cumulative (m)	Maximum baseflow reduction – cumulative (kL/day)	Maximum total flow reduction – cumulative (%)
Flat Rock Creek	Northbridge	Up to 28	Up to 28	43.6	20
Quarry Creek	Cammeray	Up to 8	Up to 9	4.1	23
Willoughby Creek	Cammeray	Up to 3	Up to 4	Negligible	Negligible
Burnt Bridge Creek	North Balgowlah	Up to 5	Up to 5	16.7	79
Sailors Bay Creek	Castlecrag	Less than 1	Less than 1	Negligible	Negligible
Manly Dam	Manly Vale/Allambie Heights	Less than 1	Less than 1	1.9	2
Gore Creek	Longueville	Less than 1	Less than 1	Negligible	Negligible
Tambourine Creek	Lane Cove	Less than 1	Less than 1	Negligible	Negligible
Tannery Creek	Lane Cove	Less than 1	Less than 1	Negligible	Negligible
Stringybark Creek	Lane Cove	Less than 1	Less than 1	Negligible	Negligible
Swaines Creek	Lane Cove	Less than 1	Less than 1	Negligible	Negligible
Blue Gum Creek	Lane Cove	Less than 1	Less than 1	Negligible	Negligible
Scotts Creek	Castlecrag	Less than 1	Less than 1	Negligible	Negligible

Watercourse	Location	Drawdown – project only (m)	Drawdown – cumulative (m)	Maximum baseflow reduction – cumulative (kL/day)	Maximum total flow reduction – cumulative (%)
Camp Creek and Sugarloaf Creek	Castlecrag	Less than 1	Less than 1	Negligible	Negligible

6.1.3.6 Risk of activation of acid sulfate soils

Areas at high risk of acid sulfate soils 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 Acid sulfate soils have the potential to alter groundwater quality by lowering pH, which can in turn cause increased dissolution and migration of heavy metals. The Hawkesbury Sandstone would not pose a high risk of acid generation.

Outside of the harbour areas, potential areas of acid sulfate soils risk may be associated with low lying and estuarine sediments such as the lower reaches of Flat Rock Creek. Activation of acid sulfate soils has the potential to alter groundwater quality by lowering pH and elevating heavy metal content, which could then impact groundwater dependent ecosystems or groundwater users.

The modelling (without designed tunnel linings) indicates that water table drawdown could occur within sediments immediately adjacent to these waters. However, these sediments are expected to remain saturated (due to constant recharge from harbour waters) and are not expected to experience oxidation due to the project beyond historical levels. Therefore, impacts to groundwater dependent ecosystems, sensitive sites and groundwater users from oxidation of acid sulfate soils due to groundwater drawdown during the construction phase is considered unlikely.

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 structure 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 low risk because all water within the tunnels would be collected and treated. 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 tunnels acts as a drain and groundwater flows towards them, rather than away from them. 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).

6.1.3.8 Potential for settlement

Settlement of the ground surface and ground movement may occur due to:

- Removal of subsurface material during tunnel excavation causing the redistribution of stresses in the rock mass

- Tunnel inflows causing groundwater drawdown and depressurisation of aquifers.

Settlement assessment was undertaken by Arup and WSP (2020). Assessment of ground movement-induced damage to infrastructure considered the maximum predicted settlement and surface angular distortion at infrastructure locations based on:

- Excavation
- Groundwater drawdown modelled using a conservative approach, with designed tunnel linings only present at 125 metre long sections either side of Middle Harbour.

All project components are expected to experience ground surface settlement impacts of over 10 millimetres. The maximum long-term total surface settlement of 85 millimetres is predicted at Flat Rock Reserve. The maximum long-term surface settlement of over 30 millimetres is predicted around the Warringah Freeway portal, Balgowlah Connection, Burnt Bridge Creek portal, Wakehurst Parkway portal/tunnel access decline and the Balgowlah ventilation tunnel/tunnel access decline. All other project components are predicted to be subject to total settlement of 30 millimetres or less.

Arup and WSP (2020) identified 61 buildings across the alignment where the predicted potential degree of severity for damage was very slight (refer to Table 4-1). This equates to potential aesthetic damage such as fine cracks to decorations, internal wall finishes and external brickwork or masonry. No buildings were assessed to be in the slight, moderate, severe or very severe categories.

Arup and WSP (2020) identified the following services where the predicted potential degree of severity for damage was slight (refer to Table 4-1):

- Two existing DN300 sewers (at two metres depth) at Cammeray
- Two separate 132 kV transmission cables (depth unknown) at Artarmon
- An existing DN375 sewer (at approximately 2.7 metres to 4.3 metres depth) at Seaforth.

This equates to potential aesthetic damage such as cracks that require redecoration, repointing for weather-tightness, and door/windows sticking slightly.

No utilities were assessed to be in the moderate, severe or very severe categories. It should be noted that the risk categories are relevant to buildings and may not be suitable for application to utilities. The potential for predicted ground movement to impact utilities would have to be confirmed with the respective utility service provider/asset owner.

Arup & WSP (2020) identified a number of Aboriginal heritage items where the potential degree of severity for damage was slight (refer to Table 4-1). Refer to Appendix L (Technical working paper: Aboriginal heritage) for potential impacts to Aboriginal heritage sites from settlement.

Arup and WSP (2020) identified a number of non-Aboriginal heritage items where the potential degree of severity for damage was slight (refer to Table 4-1). Refer to Appendix J (Technical working paper: Non-Aboriginal heritage) for potential impacts to non-Aboriginal heritage items from settlement.

No heritage structures were assessed to be in the moderate, severe or very severe categories.

Refer to Section 7 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 5.2.3.9.

6.2 Assessment of operational impacts

Subject to project approval, the operation of the project is planned to start following completion in 2028. The assessment of operational impacts considers potential impacts from the commencement of operation to around 100 years into the operational lifetime of the project. The modelling assumes that the tunnels are not lined (except for a 125 metre section on either side of Middle Harbour) and therefore provides a relatively conservative estimate of groundwater inflows to the tunnels and associated groundwater level drawdown.

6.2.1 Tunnel inflows

Inflows to the completed drained sections of the tunnels were calculated for two time periods during the operational phase, as shown in Table 6-6. Inflows would diminish over time as the hydraulic gradient towards the tunnels flattens and the system approaches equilibrium.

At the beginning of operation, inflows of 0.86 litres per second per kilometre (averaged over the whole project) are predicted to occur. After 100 years of operation, inflows are predicted to decline to 0.69 litres per second per kilometre. Planned measures to collect, treat and dispose of tunnel inflows are summarised in Section 7.

Annual inflows are predicted to be 551 megalitres per year in the first year of operation (2028) and decline to 436 megalitres per year after 100 years. The long term average annual extraction limit 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 ML of unassigned water. The predicted peak annual tunnel inflows would be less than two per cent of the water unassigned under the long term average annual extraction limit.

The modelled groundwater inflows to the tunnels were controlled by the formation permeability, which in some cases causes inflows to the tunnels greater than one litre per second per kilometre. However, a construction requirement for the project is that the tunnel inflows do not exceed one litre per second per kilometre on average, and the tunnels would be treated during construction to ensure that this is the case. Therefore, the predicted tunnel inflows would likely be less than predicted by the modelling.

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

Year	Cammeray to Middle Harbour	Middle Harbour to Seaforth	Whole project		Total annual inflows
	L/s/km	L/s/km	L/s/km	ML/day	ML/ year
2028	0.88	0.83	0.86	1.51	551
2128	0.58	0.80	0.69	1.20	436

During operation, tunnel inflows would be collected, treated at the Punch Street wastewater treatment plant and discharged into the local stormwater system and ultimately Flat Rock Creek. Refer to Appendix O (Technical working paper: Surface water quality and hydrology) for an assessment of potential impacts from treated tunnel inflow discharges from the Punch Street wastewater treatment plant into Flat Rock Creek.

6.2.2 Drawdown

This section assesses the drawdown of the water table due to the tunnel components and considers the cumulative impacts of the project together with the Sydney Metro and Western Harbour Tunnel and Warringah Freeway Upgrade projects. Drawdown is reported for 2128, 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 Annexure F:

- Beaches Link and Gore Hill Freeway Connection project only (this represents the incremental additional impact due to the project with the Sydney Metro City and Southwest project which has been approved)

- Beaches Link and Gore Hill Freeway Connection project together with the Sydney Metro City and Southwest project and the Western Harbour Tunnel and Warringah Freeway Upgrade projects (this represents the cumulative or total impact due to all three projects).

The modelled groundwater inflows to the tunnels were controlled by the formation permeability, which in some cases causes inflows to the tunnels greater than one litre per second per kilometre. However, a construction requirement for the project is that the tunnel inflows do not exceed one litre per second per kilometre on average, and the tunnels would be treated during construction to ensure that this is the case. Therefore, the predicted tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling. The results presented here therefore represent a conservative scenario for estimated drawdown and associated impacts.

6.2.2.1 Beaches Link and Gore Hill Freeway Connection only

Figure 6-5 and Figure 6-6 shows predicted drawdown of the water table after 100 years of operation (2128) (project only).

After 100 years of operation, drawdown in the Northbridge area would be up to 36 metres and up to 16 metres at Seaforth and Balgowlah.

Predicted drawdown propagates away from the tunnels, with the drawdown extending up to around 1.7 kilometres northwards in the Willoughby/Chatswood area, extending westwards up to around 0.5 kilometres in the Lane Cove area and extending southwards up to around 1.7 kilometres in the North Sydney/Waverton area.

The drawdown is predicted to reach both sides of Middle Harbour as well as Berrys Bay and Balls Head Bay.

Receivers that may be impacted by these drawdown levels are discussed in Section 6.2.3.

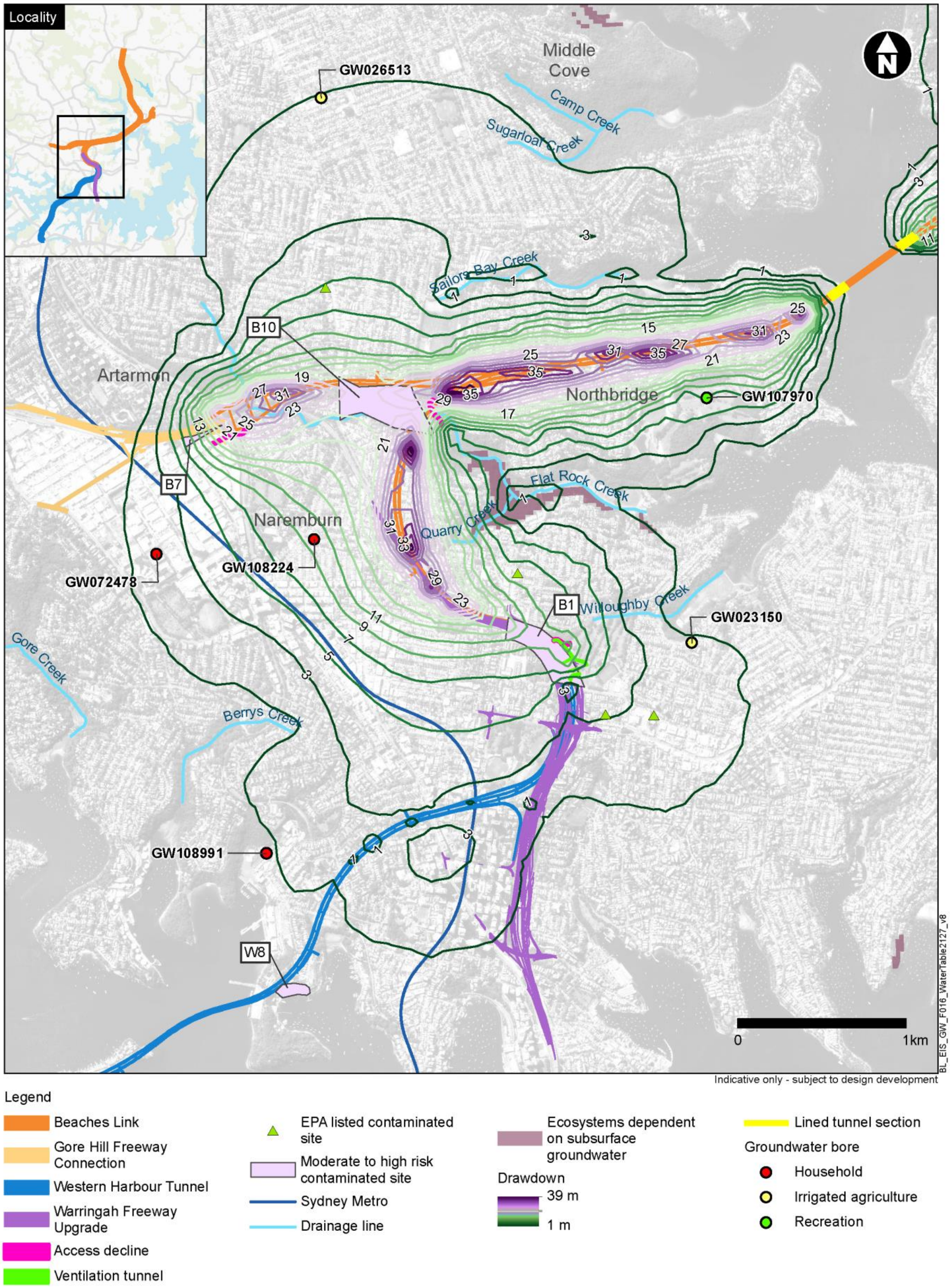

Figure 6-5 Predicted drawdown in the water table after 100 years of operation (south), 2128 (project only)

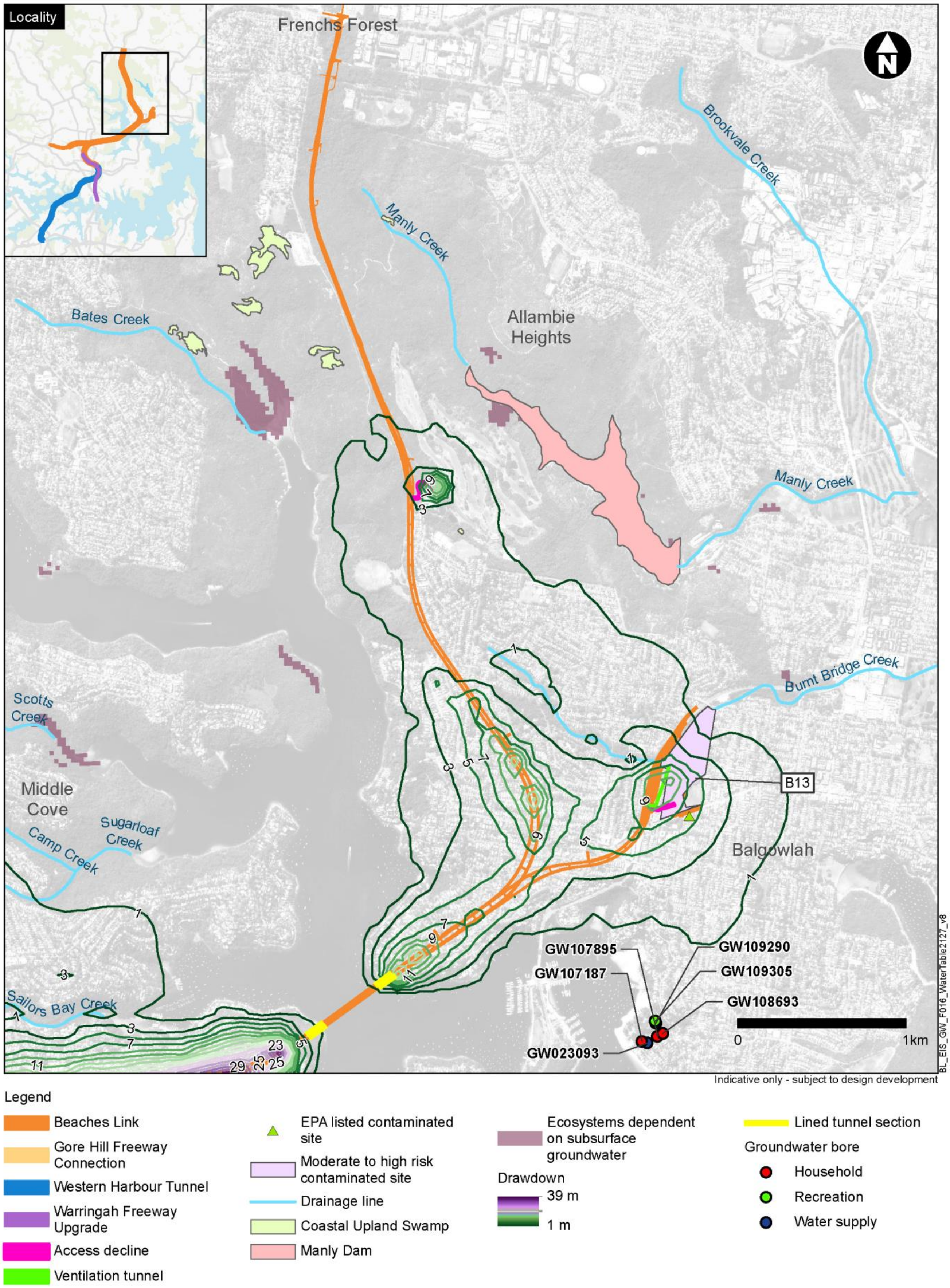

Figure 6-6 Predicted drawdown in the water table after 100 years of operation (north), 2128 (project only)

6.2.2.2 Cumulative drawdown

At the beginning of operation in 2028, the predicted cumulative drawdown of the water table is generally consistent with that for the Beaches Link only case. No additional drawdown is predicted to be generated by the Sydney Metro project, since the Sydney Metro tunnels would be tanked to prevent inflow and drawdown. Victoria Cross Station, located at North Sydney, will be a drained station. Cumulative drawdown associated with the Sydney Metro project and the Beaches Link project has been estimated.

After around 100 years of operation, cumulative drawdown 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 tunnels interacts with drawdown from the northern part of the Western Harbour Tunnel, as shown in Figure 6-7 and Figure 6-8.

It should be noted that due to the conceptualisation of the Hawkesbury Sandstone as a single aquifer, drawdowns predicted in the model are likely to be over-estimated. Potential impacts on receivers in the areas of drawdown are discussed in Section 6.2.3.

6.2.2.3 Flat Rock Gully Reserve lined tunnel scenario

An additional modelling scenario was undertaken to assess the potential groundwater level drawdown after 100 years of operation for a scenario in which the section of tunnels beneath the Flat Rock Gully Reserve are lined. The modelling assumes that tunnel inflow to an approximately 300-metre section of tunnels beneath Flat Rock Gully Reserve is zero. The modelled lined tunnel section is located in bedrock underneath highly permeable fill material deposited within the Flat Rock Creek valley.

Figure 6-9 shows the predicted water table drawdown after approximately 100 years of operation, for the Flat Rock Gully Reserve lined tunnel scenario. The predicted water table drawdown at Flat Rock Gully Reserve for the lined option is up to eight metres less than the drawdown predicted for the model with no lining (compare to Figure 6-5).

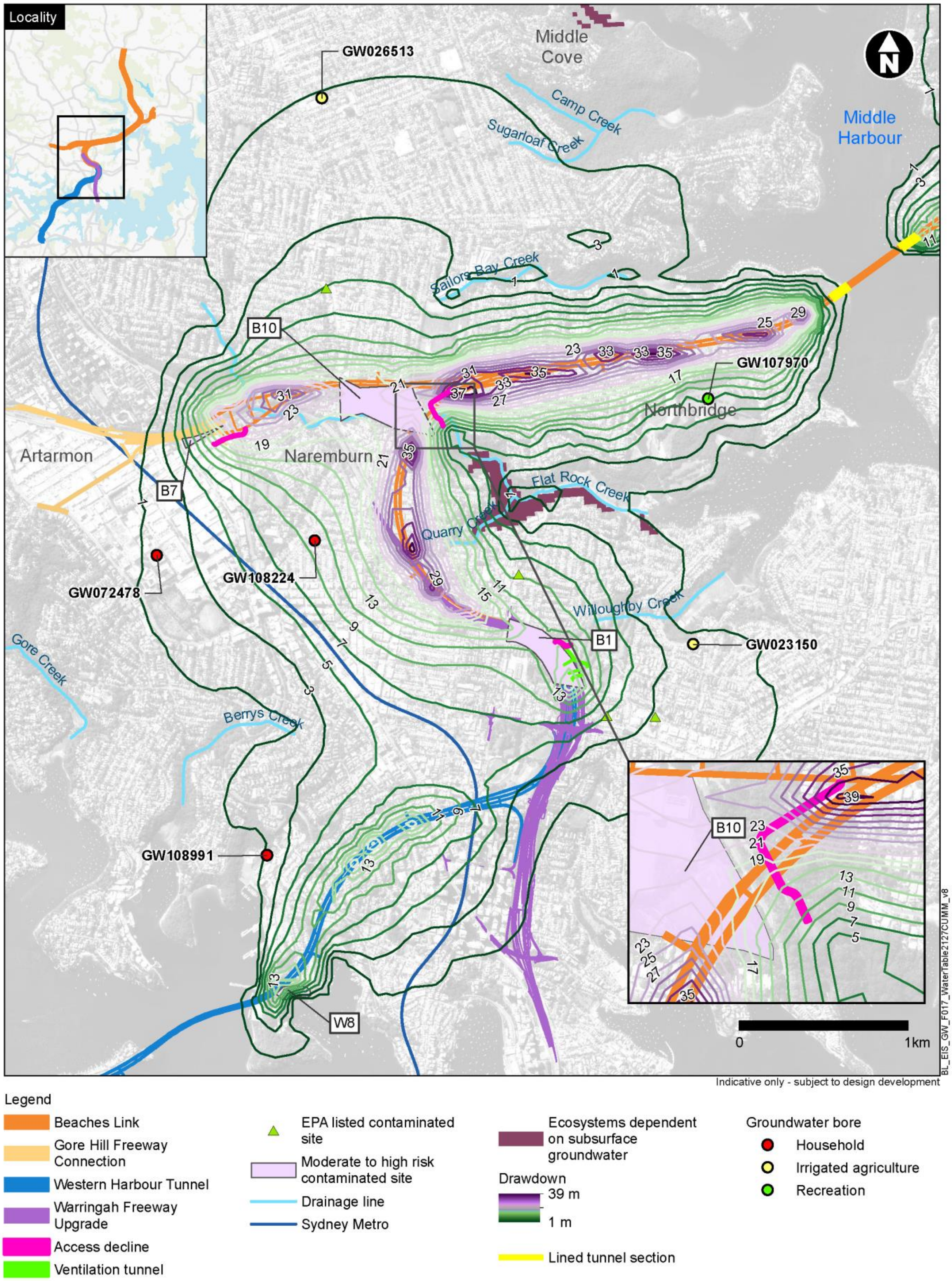

Figure 6-7 Predicted drawdown in the water table after 100 years of operation (south), 2128 (cumulative)

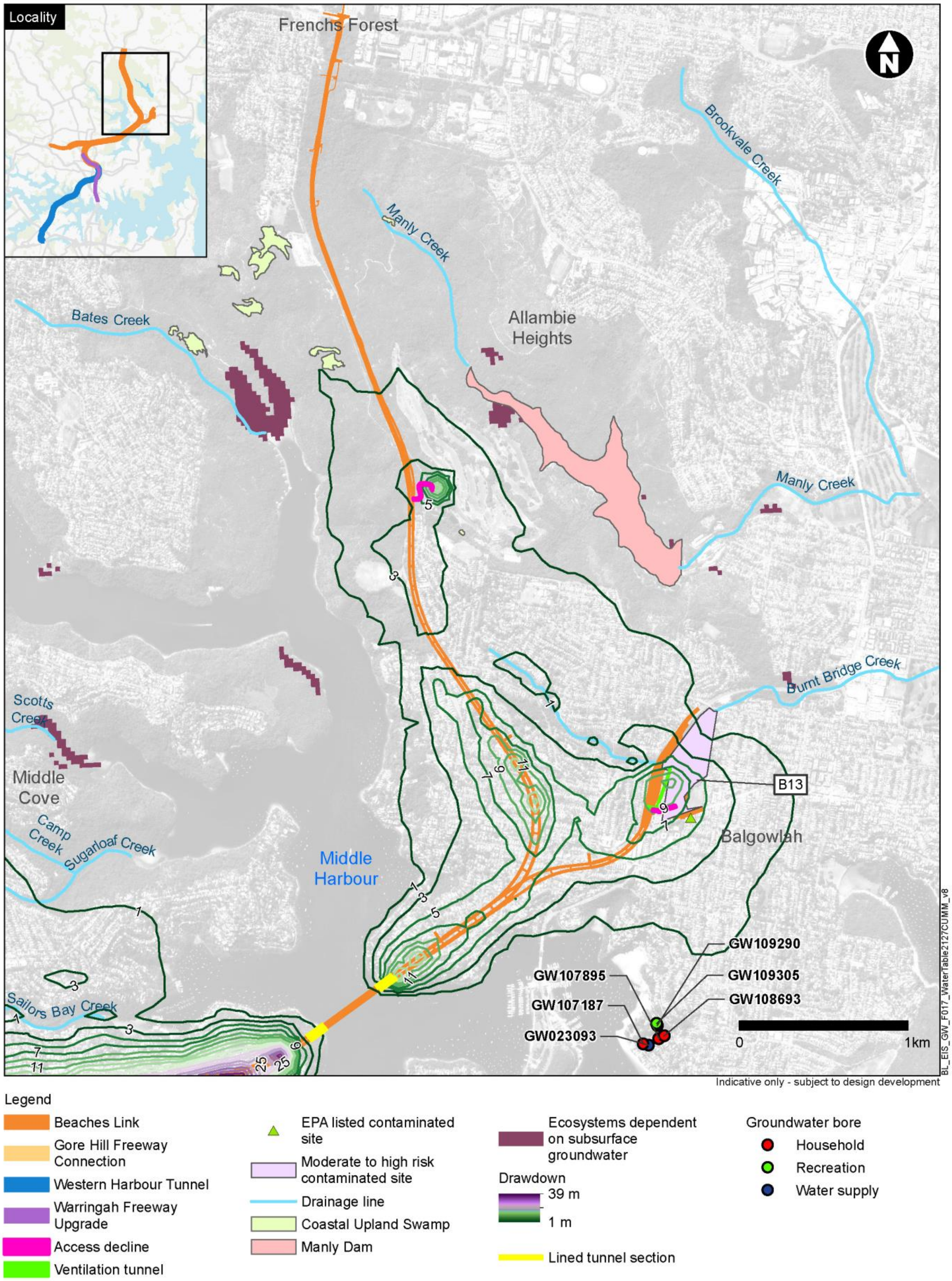

Figure 6-8 Predicted drawdown in the water table after 100 years of operation (north), 2128 (cumulative)

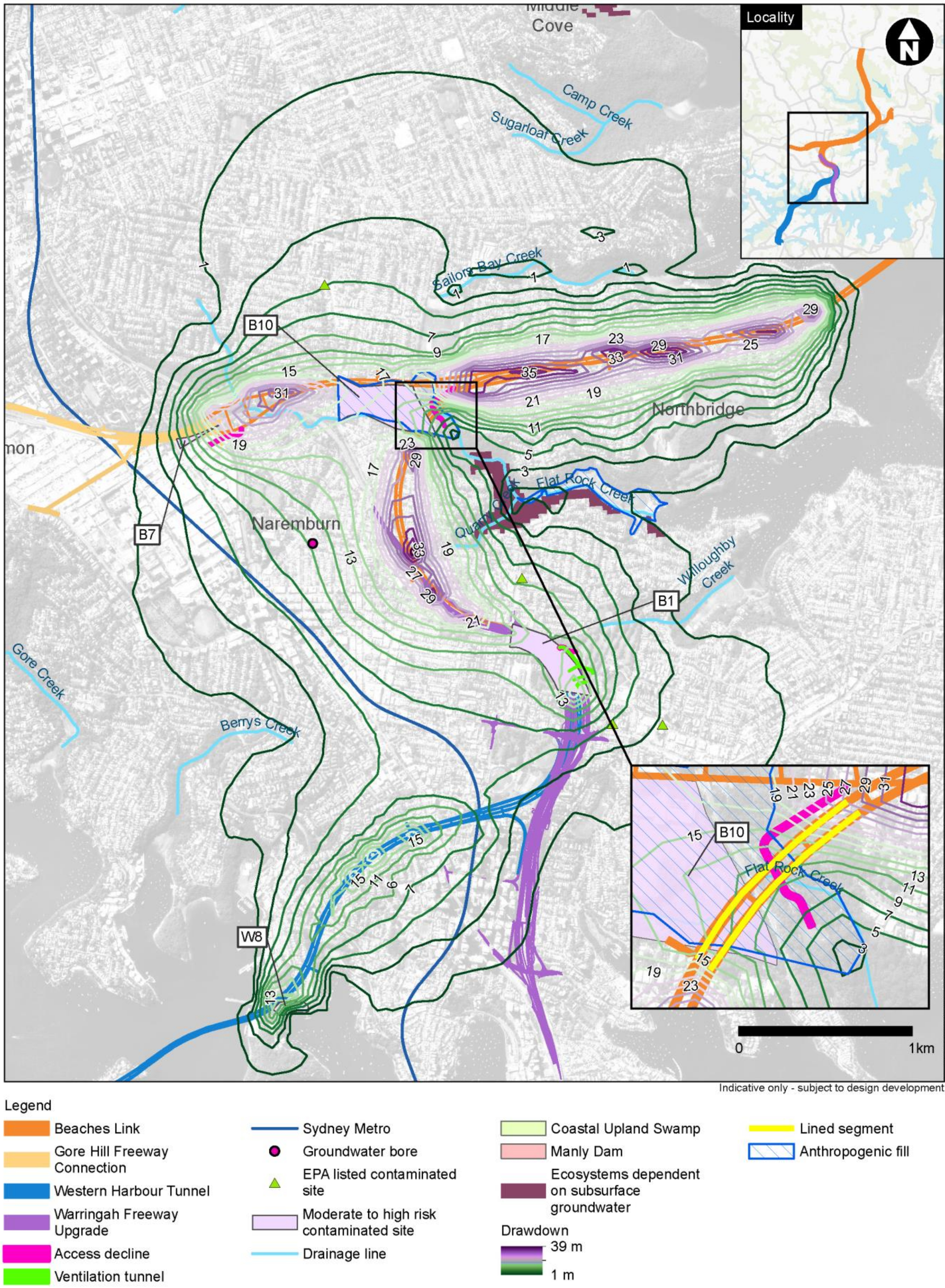

Figure 6-9 Predicted drawdown in the water table after 100 years of operation for the Flat Rock Gully Reserve lined tunnel scenario (south), 2128 (cumulative)

6.2.3 Predicted impacts

Potential impacts of the predicted drawdown in the water table during the operational phase are discussed in the following sections. Drawdown for each receiver is rounded up to the nearest metre and assessed against the AIP requirements. There are no Water Access Licence bores or groundwater dependent culturally sensitive sites within the predicted drawdown extents, therefore drawdown from the project would not affect these receivers.

The receivers 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 Annexure F) predicts that the onset of saline intrusion would very slow within the Hawkesbury Sandstone due to the low hydraulic conductivity of the formation. Both the lateral and upward movement of the saline interface along the modelled cross-section through the deepest part of the tunnel alignment is predicted to be negligible after 100 years of project operation. Therefore, impacts to groundwater users, groundwater dependent ecosystems and 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, a conservative approach has been adopted to assess the impacts by considering the maximum drawdown across all model layers.

Of the 17 groundwater users identified in Section 5.5.7, all bores except GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991 are predicted to experience less than one metre of drawdown during operation and would therefore not be impacted by the project.

Table 6-7 provides the project only and cumulative drawdown predicted by the modelling at each of the 17 groundwater bores identified in Section 5.5.7.

Drawdown at these bores is shown in Figure 6-5.

Bore GW023150 is recorded in the Department of Planning, Industry and Environment (Water) database as being less than two metres deep. Modelling predicts that the cumulative water table drawdown at this bore would be up to three metres in 2128. If this bore were to rely on shallow groundwater, water availability at this bore could be impacted.

Bore GW026513 is recorded in the Department of Planning, Industry and Environment (Water) database as being 64 metres deep, with a water level of about 6 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at this bore would be up to two metres in 2128, which equates to about three per cent of available drawdown (water head) within the bore and is therefore anticipated to cause negligible impact to the groundwater supply.

Bore GW072478 is recorded in the Department of Planning, Industry and Environment (Water) database as being 180.5 metres deep with a water level of about 48 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at this bore would be up to two metres in 2128, which equates to about five per cent of available drawdown (water head) within the bore and is therefore anticipated to cause negligible impact to the groundwater supply.

Bore GW107970 is recorded in the Department of Planning, Industry and Environment (Water) database as being 199 metres deep with a water level of 110 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at the bore would be up to 13 metres in 2128, which equates to about 15 per cent of available drawdown and is therefore not anticipated to cause significant impact to the groundwater supply.

Bore GW108224 is recorded in the Department of Planning, Industry and Environment (Water) database as being 132 metres deep with a water level of 35 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at the bore would be up to 11 metres in 2128, which equates to about 11 per cent of available drawdown and is therefore anticipated to cause negligible impact to the groundwater supply.

Bore GW108991 is recorded in the Department of Planning, Industry and Environment (Water) database as being 168 metres deep with a water level about 13 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at this bore would be up to four metres in 2128 (cumulative case), which equates to less than three per cent of available drawdown and is therefore anticipated to cause negligible impact to the groundwater supply.

Although these impacts are minor, the minimal impact considerations in the AIP specifies that a drawdown greater than two metres at any water supply works is unacceptable and would require make good provisions to be implemented. Further assessment has been carried out to assess the potential for this drawdown to affect the long term viability of these bores. It is considered unlikely that the predicted drawdown at bores GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991 would detrimentally affect the operation of the bores. Given the relatively small predicted change in total water head within bores GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991, and the fact that these bores lie upgradient of direction of potential contaminant migration towards the tunnels from AEIs, the groundwater quality at these bores is not expected to be modified due to the project.

Measures to manage impacts on bores are discussed in Section 7.

Table 6-7 Predicted drawdown and impact at receivers during operation (2028 and 2128)

Bore ID	Bore depth (m BGL)	Drawdown – project only (m)	Drawdown - cumulative (m)
GW023093	2.4	Less than 1	Less than 1
GW023150	1.8	Up to 2	Up to 2
GW026513	64	Up to 2	Up to 2
GW029731	21.6	Less than 1	Less than 1
GW065075	150	Less than 1	Less than 1
GW072478	180.5	Up to 3	Up to 2
GW103127	138	Less than 1	Less than 1
GW107187	8	Less than 1	Less than 1
GW107757	162.6	Less than 1	Less than 1
GW107895	4	Less than 1	Less than 1
GW107970	199	Up to 13	Up to 13
GW108224	132.4	Up to 11	Up to 11
GW108693	4	Less than 1	Less than 1
GW108792	174	Less than 1	Less than 1
GW108991	168	Up to 3	Up to 4
GW109290	6.1	Less than 1	Less than 1
GW109305	6.1	Less than 1	Less than 1

Table notes: BGL means below ground level

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 6-8.

Table 6-8 Predicted drawdown at areas of environmental interest for contamination during operation (2028 and 2128)

Figure 5-2 reference	Area of environmental interest	Contaminated groundwater risk ranking	Drawdown – project only 2028 (m)	Drawdown – project only 2128 (m)	Drawdown – cumulative 2028 (m)	Drawdown – cumulative 2128 (m)
B1	Unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray	Moderate	Up to 13	Up to 13	Up to 17	Up to 19
B7	Punch Street at Artarmon	Moderate	Up to 19	Up to 21	Up to 19	Up to 21
B9	Flat Rock Gully Reserve at Northbridge	Moderate	Up to 21	Up to 25	Up to 21	Up to 25
B10	Willoughby Leisure Centre and Bicentennial Reserve at Willoughby	High	Up to 22	Up to 27	Up to 22	Up to 27
B13	Balgowlah Golf Course at Balgowlah	Moderate	Up to 11	Up to 11	Up to 11	Up to 11
W8	Waverton Park – Woolcott Road, Waverton	High	Less than 1	Less than 1	Up to 12	Up to 13

Significant drawdown is predicted at the unsealed areas next to Warringah Freeway (eastern side by Cammeray Golf Course) at Cammeray; the Willoughby Leisure Centre and Bicentennial Reserve; Punch Street, Artarmon; Flat Rock Gully Reserve at Northbridge; Balgowlah Golf Course at Balgowlah; and Waverton Park at Woolcott Road, Waverton. Drawdown modelling results are conservative as the modelling excluded designed tunnel linings (except on either side of Middle Harbour) or other measures designed to limit tunnel inflows and hence drawdown impacts.

Drawdown at the Willoughby Leisure Centre and Bicentennial Reserve is predicted to be up to about 22 metres at the start of operation and up to about 27 metres after 100 years of operation, as parts of this site are located immediately above the tunnel centrelines. It is noted, however, that these predictions are based on an unlined tunnel and unconstrained groundwater inflows (ie groundwater inflows may be greater than the one litre per second per kilometre design requirement). The provision of tunnel linings would reduce groundwater drawdown in the vicinity.

The levels of drawdown at Waverton Park during construction would be minor for the project only scenario and would not be expected to cause significant migration of contaminants or to cause migration of contaminants into areas of relatively good quality groundwater. Under the cumulative scenario, drawdown at Waverton Park would be largely due to the effect of the Western Harbour Tunnel and Warringah Freeway Upgrade project. The movement of groundwater would be towards the Western Harbour Tunnel and would be collected and treated at the water treatment plants established for that project.

The rate of migration of potential contaminants would depend predominantly on the hydraulic conductivity at the contaminant location, contaminant viscosity and the hydraulic gradient at the site.

Contaminant migration caused by drawdown from the tunnel has the potential to degrade water quality more than 40 metres from the tunnel. There are no groundwater users or groundwater dependent ecosystems in the vicinity of these areas of environmental interest, with the exception that a groundwater dependent ecosystem is present at the upper reaches of Flat Rock Creek and Quarry Creek in the vicinity of the Willoughby Leisure Centre and Bicentennial Reserve. This is not expected to be impacted by contaminant migration since the potentially contaminated fill area at this areas of environmental interest is immediately overlying the tunnels and would therefore drain towards the tunnels and away from the groundwater dependent ecosystem, which would satisfy the requirements of the AIP.

If contaminants are mobilised from the unsealed areas next to Warringah Freeway (eastern side by Cammeray Golf Course) at Cammeray; the Willoughby Leisure Centre and Bicentennial Reserve; Punch Street, Artarmon; Balgowlah Golf Course at Balgowlah; or Waverton Park, they would travel towards the tunnels during operation. The quality of groundwater inflows to the tunnels could pose a potential human health risk and could impact the integrity of the construction materials. This risk would be managed through monitoring of the quality of groundwater inflows to the tunnels, as well as the groundwater quality and groundwater levels at groundwater monitoring sites B110, B114A, B128, B134A-a to B134A-c, B343 and B348, as discussed in Section 7.2. All groundwater inflows would be collected and treated at the Gore Hill Freeway wastewater treatment plant.

Groundwater supply bores with the potential to be impacted by the project (see Section 6.1.3.2) lie upgradient of the hydraulic gradient predicted to be induced by the tunnels. Therefore, contamination from these areas of environmental interest is not expected to impact groundwater quality within these supply bores.

6.2.3.4 Groundwater dependent ecosystems and sensitive environments

Groundwater dependent ecosystems or sensitive environments within the area of predicted drawdown are shown in Figure 5-1.

Drawdown is predicted to be up less than one metre at the Coastal Upland Swampland, the terrestrial groundwater dependent ecosystems at Flat Rock Creek and Quarry Creek, and the groundwater dependent ecosystem at Manly Dam Reserve. The potential significance of these impacts is discussed in Appendix S (Technical working paper: Biodiversity development assessment report). Management measures are discussed in Section 7.2.

The other groundwater dependent ecosystems in the project area are outside the predicted drawdown extents.

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 and would not be impacted by the project.

Table 6-9 Predicted drawdown and impact at groundwater dependent ecosystems and sensitive environments during operation (2028 and 2128)

Receiver	Location	Drawdown – project only 2028 (m)	Drawdown – project only 2128 (m)	Drawdown – cumulative 2028 (m)	Drawdown – cumulative 2128 (m)
Vegetation at Flat Rock and Quarry Creek	Northbridge	Up to 4	Up to 11	Up to 4	Up to 12
Vegetation at Bates Creek	Bates Reserve/Garigal National Park	Less than 1	Less than 1	Less than 1	Less than 1
Manly Dam Reserve	Manly Dam Reserve	Less than 1	Less than 1	Less than 1	Less than 1
Coastal Upland Swamp	Bates Reserve/Garigal National Park	Less than 1	Less than 1	Less than 1	Less than 1

6.2.3.5 Surface water systems

The maximum predicted drawdown and groundwater baseflow impacts are discussed below. The predicted impacts are based on a comparison of model predicted baseflow for the scenario without either the Beaches Link and Gore Hill Freeway Connection or the Western Harbour Tunnel and Warringah Freeway Upgrade projects (the null scenario) and the scenario that includes the simulation of both projects (the cumulative scenario). The baseflow impacts have been compared against the indicative flow measurements described in Section 4.3.5 to assess the potential impact to total flow. The nature of the watercourse substrate has been ascertained during ground truthing (refer to Section 5.2).

The method used to estimate baseflow from the groundwater models is described in Annexure F. The results are summarised in Table 6-10 and indicate that the baseflow reduction would result in a loss in total flows in the watercourses.

Due to the assessment being based on limited gauging data and modelled baseflows, monitoring has been listed in Section 7 to confirm modelled results.

The model indicates that baseflow reduction greater than five per cent has the potential to occur during operation to Flat Rock Creek (39 per cent), Quarry Creek (69 per cent) and Burnt Bridge Creek (96 per cent). While these reductions could be considered significant, in particular for Burnt Bridge Creek and Quarry Creek, they are unlikely to result in a complete loss of aquatic habitat. Pools would be retained and there would still be high flows within the waterways immediately after rainfall events. Between rainfall events there would still be some (low) flow along the waterways. Further consideration to the potential impacts of baseflow reduction on aquatic ecosystems is provided in Appendix S (Technical working paper: Biodiversity development assessment report).

The reduction in baseflow to Flat Rock Creek and Quarry Creek also has the potential to impact the groundwater dependent ecosystem at those locations (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest) and ecosystems reliant on surface water.

It should be noted that the assessment of baseflow reduction is conservative and is likely to overestimate actual baseflow reduction for the following reasons:

- The modelled groundwater inflows to the tunnels were controlled by the formation permeability, which in some cases causes inflows to the tunnels greater than one litre per second per kilometre. However, a design requirement for the project is that the tunnel inflows do not exceed an average of one litre per second per kilometre, and the tunnels would be treated during construction as they are excavated to ensure that this is the case. Therefore, the predicted tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling. Potential baseflow reduction to watercourses and waterbodies would therefore be less than predicted and discussed here
- It is assumed that there is continuous saturation between the tunnel horizon and the shallow water table at the location of watercourses (i.e. there is a single connected groundwater system beneath the creek and the proposed underlying tunnel. In reality, the system will be stratified, possibly with disconnected aquifer horizons. The predicted maximum drawdowns beneath the creek are therefore unlikely to be realised and the predicted reduction in baseflows are therefore conservative
- For watercourses and waterbodies other than Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, the whole length or area at the base of the creek or dam is considered to be unlined. At the time of modelling there was no information on the nature of creek bed conditions for Willoughby Creek and Sailors Bay Creek. Should any of these watercourses be lined, the reduction baseflow would be less than that predicted
- Groundwater inflows to the tunnels would be collected and discharged to local waterways (Willoughby Creek, Flat Rock Creek, Burnt Bridge Creek and Manly Creek/Manly Dam). This is expected to offset baseflow reduction to these waters, as the additional creek flows could partially feed the surrounding groundwater system.

The Water Sharing Plan requires that the source of the impact (ie the tunnel) be more than 30 metres deep and located in underlying parent material. The Beaches Link tunnels satisfy these requirements. However, mitigation measures are presented in Section 7.

As discussed in Section 6.1.3.5, further groundwater monitoring and a focussed study on the potentially affected aquatic ecosystems and the groundwater dependent ecosystem associated with Burnt Bridge Creek, Flat Rock Creek and Quarry Creek should be carried out to support refined assessment and develop suitable design mitigation measures during further design development.

Table 6-10 Predicted drawdown impacts at watercourses after 100 years operation

Watercourse	Location	Drawdown – project only (m)	Drawdown – cumulative (m)	Maximum baseflow reduction (kL/day)	Maximum total flow reduction (%)
Flat Rock Creek	Northbridge	Up to 29	Up to 29	84.7	39
Quarry Creek	Cammeray	Up to 18	Up to 18	11.4	69
Willoughby Creek	Cammeray	Up to 6	Up to 7	Negligible	Negligible
Burnt Bridge Creek	North Balgowlah	Up to 6	Up to 6	16.8	96
Sailors Bay Creek	Castlecrag	Up to 5	Up to 5	Negligible	Negligible

Watercourse	Location	Drawdown – project only (m)	Drawdown – cumulative (m)	Maximum baseflow reduction (kL/day)	Maximum total flow reduction (%)
Manly Dam	Manly Vale/ Allambie Heights	Less than 1	Less than 1	1.2	2
Berrys Creek	Longueville	Negligible	Up to 2	Negligible	Negligible
Gore Creek	Longueville	Less than 1	Less than 1	Negligible	Negligible
Tambourine Creek	Lane Cove	Less than 1	Less than 1	Negligible	Negligible
Tannery Creek	Lane Cove	Less than 1	Less than 1	Negligible	Negligible
Stringybark Creek	Lane Cove	Less than 1	Less than 1	Negligible	Negligible
Swaines Creek	Lane Cove	Less than 1	Less than 1	Negligible	Negligible
Blue Gum Creek	Lane Cove	Less than 1	Less than 1	Negligible	Negligible
Scotts Creek	Castlecrag	Less than 1	Less than 1	Negligible	Negligible
Camp Creek and Sugarloaf Creek	Castlecrag	Up to 2	Up to 2	0.2	4

6.2.3.6 Risk of activation of acid sulfate soils

Areas at high risk of acid sulfate soils activation are where drawdown causes soil and rock with high concentrations of sulphide minerals (predominantly pyrite and pyrrhotite) to be exposed to oxygen.

The modelling indicates that water table drawdown could occur within sediments immediately adjacent to the lower reaches of Flat Rock Creek, Sailors Bay Creek, Willoughby Creek, and the waters of Middle Harbour, Balls Head Bay, Berrys Bay and Clontarf Beach.

However, these sediments are expected to remain saturated (due to constant recharge from harbour waters) and are not expected to experience oxidation due to the project beyond historical levels. Therefore, impacts to groundwater dependent ecosystems, sensitive sites and groundwater users from oxidation of acid sulfate soils due to groundwater drawdown is considered unlikely.

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 tunnels would be collected and treated at the Punch Street wastewater treatment plant. If contamination was to occur, the likelihood of the contaminated groundwater migrating away from the tunnels is very low, since the tunnels would act as a drain and groundwater would flow towards rather than away from them.

6.2.3.8 Potential for settlement

Settlement of the ground surface may occur due to:

- Removal of subsurface material during tunnel excavation causing the redistribution of stresses in the rock mass
- Tunnel inflows causing groundwater drawdown and depressurisation of aquifers. Modelling for groundwater drawdown is conservative for the operational phase with measures to reduce tunnel inflows to one litre per second per kilometre, such as designed tunnel linings, excluded from the modelling.

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 significantly exceed that experienced during the construction phase because the majority of settlement (excavation and groundwater drawdown induced) would be realised during the construction phase.

Ground settlement impacts and are outlined in Section 6.1.3.8.

As described in Section 6.2.2.3, an assessment of potential settlement was also undertaken for a scenario in which the section of tunnel beneath Flat Rock Gully Reserve is lined. Potential settlement was estimated based on the potential groundwater level drawdown after 100 years of operation for this lined scenario. Figure 6-9 shows the predicted water table drawdown after approximately 100 years of operation for the Flat Rock Gully Reserve lined tunnel scenario. The predicted water table drawdown at Flat Rock Gully Reserve for the lined option (Figure 6-9) is up to eight metres less than the drawdown predicted for the model with no lining (compared to Figure 6-7).

The settlement assessment was undertaken by Arup and WSP (2020) for this scenario and found that the predicted settlement at Flat Rock Gully Reserve is reduced from 85 mm without the lined tunnels to 35 mm with the lined tunnels. Arup and WSP (2020) assessed that there were no buildings in the area and that impacts to roads in the area (Eastern Valley Way) are expected to be limited.

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 Gore Hill, Balgowlah and Wakehurst Parkway 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, and the Hawkesbury Sandstone recharge rate of three per cent that has been applied in the groundwater modelling.

The results are displayed as percentage reduction in annual recharge to the modelled zone bound 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 6-11 indicate that the reduction in groundwater recharge would be negligible.

Table 6-11 Estimated groundwater recharge reduction

Location	Existing impervious area (ha)	Increase in impervious area (ha)	Groundwater recharge reduction (kL/yr)	Groundwater recharge reduction %
Gore Hill Freeway	9.1	0.47	173	0.004%
Balgowlah Connection	4.1	3.40	1,255	0.04%
Wakehurst Parkway	5.1	6.63	2,446	0.08%

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 operational infrastructure such as the Punch Street wastewater treatment plants, utility adjustments and ventilation facilities would not penetrate to sufficient depths to interact with the water table and are therefore 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 proposed tunnel design for the project is predominantly drained, where groundwater would enter the tunnels and, as such, the tunnels 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 tunnels. 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 Middle Harbour crossing and are therefore localised. Given the naturally enhanced permeability in this area and the proximity to the coast, groundwater would be able 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. The majority of settlement due to the project is expected to occur during construction. In most locations (outside of fill areas), the settlement due to the removal of rock during tunnelling is predicted to cause the majority of settlement (compared to groundwater drawdown induced settlement), and this settlement would occur at the time of excavation. Tunnelling activities are generally undertaken prior to above ground works associated with the final landform, impacts on the final landform due to settlement are therefore expected to be negligible.

Other impacts to landform can occur due to baseflow reduction to watercourses leading to geomorphological changes. Potential impacts to geomorphology are discussed in Appendix O (Technical working paper: Surface water quality and hydrology).

7. Environmental management measures

This section presents recommended 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 should address potential impacts such as those outlined in Table 7-1.

As noted previously above, there are no groundwater dependent culturally significant sites within the project area, reduced recharge as a result of creation of impervious surface during construction is considered negligible and the potential for impacts associated with saline intrusion, acid sulfate soils and contamination of groundwater by tunnel infrastructure are also unlikely during the construction period. As such, these risks are not considered to require management during construction and are therefore not included in Table 7-1.

Table 7-1 Environmental management measures during construction

Impact	Mitigation and management measure
Groundwater modelling update	As more information becomes available through ongoing groundwater monitoring, groundwater modelling should be updated to refine the predictions documented in this technical working paper. Inflow predictions should be updated prior to finalising detailed design and the detailed design should be updated based on the updated operational inflow and impact predictions. If refined predictions indicate that impacts would be greater than the impacts documented in this technical working paper, feasible and reasonable mitigation measures should be incorporated into the detailed design and implemented. Groundwater modelling should be conducted considering *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012), including sensitivity analysis and consideration of future climate change, as required.

Groundwater inflows and water table drawdown	Groundwater inflows are predicted conservatively to result in water table drawdown of up to 28 metres during construction. Where feasible and reasonable, groundwater drawdown should be managed by reducing inflows through the following measures:
	• Where inflows exceed 1 L/s/km, particularly at excavated tunnel sections in proximity to Middle Harbour, appropriate waterproofing measures should be implemented. Measures could include spray-on membranes 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 should be implemented. Procedures to be considered should 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 should be monitored during construction and compared to predictions from the updated groundwater model. If required, the groundwater model should be updated based on the results of the monitoring and the proposed feasible and reasonable management and mitigation measures adjusted and implemented to minimise groundwater inflows to ensure that groundwater inflow performance criteria are met.

Impact	Mitigation and management measure
Drawdown impact on existing groundwater users	Three bores lie within the predicted zone of drawdown influence (GW107970, GW108224, GW108991). While the project is assessed to cause negligible impact to the groundwater supply at these bores, the predicted drawdown at these bores is greater than two metres, which does not satisfy the minimal impact considerations of the *NSW Aquifer Interference Policy* (DPI Water, 2012). Site inspections should be carried out to confirm the current viability of these bores. If viable, additional studies should be carried out to confirm how the bore might be affected, and appropriate make good provisions implemented (if required) to maintain viability. Identified make good provisions should be implemented as appropriate. The bores should be monitored throughout construction to confirm that impacts are as expected. Additional make good provisions should be implemented as required to maintain the viability of the bores. If loss of yield results from tunnel dewatering, make good measures to be considered should include deepening the bore or connection to an alternative water supply.
Reduced groundwater baseflow to creeks and groundwater level drawdown at groundwater dependent ecosystems	Significant baseflow loss is predicted due to the project at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek. Groundwater inflows to the tunnels, however, would be collected, treated and discharged to Flat Rock Creek and Burnt Bridge Creek, which would partially offset baseflow reduction to these waterways. The predicted groundwater drawdown in the vicinity of Flat Rock Creek and Quarry Creek has the potential to impact the groundwater dependent ecosystems (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest) at that location. The modelling, however, is based on limited data, and assumes full hydraulic connection in the hydrogeological layers between the identified groundwater dependent ecosystems and the underlying rock through which the tunnels pass, which might not be the case. To support refined assessment and develop suitable design mitigation measures during detailed design, it is recommended that additional monitoring of surface water flows and groundwater levels in the vicinity of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek be undertaken; as well as installation of one groundwater monitoring bore immediately adjacent to the Flat Rock Creek/Quarry Creek groundwater dependent ecosystems, and one groundwater monitoring bore between the groundwater dependent ecosystems and the tunnel alignment, to assess for connectivity to the water table and to provide early identification and quantification of impacts. A focussed study, with appropriate ecological input, should be carried out to assess how the health of the affected surface water dependent ecosystems, and the groundwater dependent ecosystem associated with Burnt Bridge Creek, Flat Rock Creek and Quarry creek, might be impacted by the predicted groundwater drawdown and associated reductions in baseflow. The study should consider how existing site features affect the interaction between surface water and groundwater along the affected reaches of these watercourses, and the hydraulic connectivity in the underlying geology. Where unacceptable ecological impacts are predicted, feasible and reasonable mitigation measures to address the impacts should be identified, incorporated into the detailed design, and implemented during construction. The mitigation measures considered should include tunnel linings.

<table>
<tr><th>Impact</th><th>Mitigation and management measure</th></tr>
<tr><td>Drawdown causing migration of contaminant plumes and reduction in beneficial uses of the aquifer</td><td>To further quantify the risk from groundwater contamination to construction of the project (including dewatering), further investigations should occur at the unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray (AEI B1), Punch Street at Artarmon (AEI B7), Flat Rock Gully Reserve at Northbridge (AEI B9), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10), Balgowlah Golf Course at Balgowlah (AEI B13), and Waverton Park – Woolcott Road, Waverton (AEI B8).

If unacceptable contamination risks are established, appropriate design (eg tanking) and/or management (eg treatment) measures should be implemented to remove or suitably reduce the associated risk.

The following groundwater contamination management measures should be implemented as required at the sites listed above:
• Monitoring of groundwater levels and quality prior to and during construction
• Confirmation/characterisation of the contamination risk at this site
• 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 groundwater levels and quality at groundwater monitoring bores B110, B114A, B128, B134A-a to B134A-c, B343 and B348 during construction
- Monitoring of the quality and quantity of groundwater inflows to tunnels for comparison against modelled predictions and human health risk trigger levels
- Suitable tunnel design measures (such as waterproof linings) should be implemented at detailed design to reduce the risk of contamination migration during the construction phase of the project.</td></tr>
<tr><td>Contamination due to leakage or spills</td><td>Emergency Spill measures should 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.</td></tr>
<tr><td>Ground surface settlement</td><td>The following measures should be implemented to manage settlement impacts:
• Develop detailed predictive settlement models for areas of concern to guide tunnel design and construction methodology, including the selection of appropriate tunnel lining options to minimise settlement where required.
• Prepare building/structure condition surveys for properties (and heritage assets) within the zone of influence of tunnel settlement prior to the commencement of construction activities.

Agreements with utility and infrastructure owners should be reached before tunnel construction starts identifying acceptable limits of settlement, settlement monitoring and actions in the event that settlement limits are exceeded.</td></tr>
</table>

7.2 Management of operational impacts

A management plan should be developed for the project's operation which includes measures to manage potential impacts, including those outlined in Table 7-2.

As noted previously, there are no groundwater dependent culturally significant sites within the project area, reduced recharge as a result of creation of impervious surface is considered negligible, and the potential for activation of acid sulfate soils is also unlikely during the operational period. Ground surface settlement during operation is not expected to exceed that during construction and is therefore managed during the construction phase of the project. Therefore, these risks do not require management during operation and are not included in Table 7-2.

Table 7-2 Environmental management measures during operation

Impact	Management measure
Groundwater inflows causing water table drawdown	The operational groundwater inflows and water table drawdown monitoring requirements should be established based on updated groundwater modelling informed by groundwater monitoring data collected during further design development and construction stages. Operational groundwater monitoring requirements should be developed in consultation with the Environmental Protection Agency and Department of Planning, Industry and Environment (Water).
Drawdown impact on existing groundwater users	Six bores lie within the predicted zone of drawdown influence (GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991). While the project is assessed to cause negligible impact to the groundwater supply at these bores, the predicted drawdown at these bores is greater than two metres, which does not satisfy the minimal impact considerations of the *NSW Aquifer Interference Policy* (DPI Water, 2012). Site inspections should be carried out to confirm the current viability of these bores. If viable, additional studies should be carried out to confirm the likely impacts of drawdown associated with the project on the bores and implement appropriate make good provisions (if required) to maintain viability. Impacts to the bores should be monitored during the operational phase to confirm that predicted impacts are as expected, and any implemented make good provisions are appropriate. If loss of yield results from tunnel dewatering, make good measures to be considered should include deepening the bore or connection to an alternative water supply. Given the relatively small predicted change in total water head within bores GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991, and the fact that these bores lie upgradient of direction of potential contaminant migration towards the tunnels from AEIs, the groundwater quality at these bores is not expected to be modified due to the project.

Impact	Management measure
Reduced groundwater baseflow to creeks	Significant baseflow loss is predicted due to the project during operation at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek. Groundwater inflows to the tunnels, however, would be collected, treated and discharged to Flat Rock Creek and Burnt Bridge Creek, which would partially offset baseflow reduction to these waterways. The predicted groundwater drawdown in the vicinity of Flat Rock Creek and Quarry Creek has the potential to impact the groundwater dependent ecosystems (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest) at that location. The modelling, however, is based on limited data, and assumes full hydraulic connection in the hydrogeological layers between the identified groundwater dependent ecosystems and the underlying rock through which the tunnels pass, which might not be the case. To support refined assessment and develop suitable design mitigation measures during detailed design, it is recommended that additional monitoring of surface water flows and groundwater levels in the vicinity of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek be undertaken; as well as installation of one groundwater monitoring bore immediately adjacent to the Flat Rock Creek/Quarry Creek groundwater dependent ecosystems, and one groundwater monitoring bore between the groundwater dependent ecosystems and the tunnel alignment, to assess for connectivity to the water table and to provide early identification and quantification of impacts. A focussed study, with appropriate ecological input, should be carried out to assess how the health of the affected surface water dependent ecosystems, and the groundwater dependent ecosystem associated with Burnt Bridge Creek, Flat Rock Creek and Quarry creek, might be impacted by the predicted groundwater drawdown and associated reductions in baseflow. The study should consider how existing site features affect the interaction between surface water and groundwater along the affected reaches of these watercourses, and the hydraulic connectivity in the underlying geology. Where unacceptable ecological impacts are predicted, feasible and reasonable mitigation measures to address the impacts should be identified, incorporated into the detailed design, and implemented during construction. The mitigation measures considered should include tunnel linings.
Drawdown causing migration of contaminant plumes and reduction in beneficial uses of the aquifer	To further quantify the risk from groundwater contamination to operation of the project, further investigations are required at the unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray (AEI B1), Punch Street at Artarmon (AEI B7), Flat Rock Gully Reserve at Northbridge (AEI B9), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10), Balgowlah Golf Course at Balgowlah (AEI B13), and Waverton Park – Woolcott Road, Waverton (AEI B8). If contamination risks are established, appropriate design measures should be implemented at the construction phase, reducing the operational management requirements. Should potential impacts be expected during operation, feasible and reasonable management and mitigation measures (eg groundwater treatment) be should be identified and implemented to remove or suitably reduce the associated risk.

Impact	Management measure
Drawdown impact on groundwater dependent ecosystems	If potential impacts to groundwater dependent ecosystems are confirmed based on the additional site investigations and the focussed study undertaken for the construction phase, appropriate design measures should be implemented at the construction phase, reducing the operational management requirements. Should potential impacts be expected during operation, appropriate feasible and reasonable management and mitigation measures (eg groundwater treatment or make-good measures) should be identified and implemented to remove or suitably reduce the associated risk.

7.3 Groundwater monitoring program

7.3.1 Construction

A groundwater monitoring regime for the construction phase should be developed and implemented, taking into consideration the groundwater monitoring being carried out for the Western Harbour Tunnel and Warringah Freeway Upgrade project. The monitoring regime should include:

- Continuation of groundwater levels and groundwater quality monitoring within the currently installed project monitoring network during the construction period to inform the update and refinement of the groundwater model
- If bores GW107970, GW108224 and GW108991 are found to be viable, installation of water level logger and electrical conductivity logger and/or periodic manual measurements (subject to agreement by the well owner) to obtain a baseline for assessing potential drawdown impacts with respect to static and pumping water levels
- Monitoring of the water quality and volume of inflows to the tunnels in the vicinity of the unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray (AEI B1), Punch Street at Artarmon (AEI B7), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10), Balgowlah Golf Course at Balgowlah (AEI B13), and Waverton Park – Woolcott Road, Waverton (AEI B8)
- Monitoring of surface water flows within, and groundwater levels in the vicinity of, Flat Rock Creek and Quarry Creek, both prior to and during construction to confirm potential baseflow loss to these surface waters
- Settlement monitoring.

7.3.2 Operation

As noted in Table 7-2, operational monitoring of groundwater inflows and water table drawdown should be developed in consultation with the Environmental Protection Agency and Department of Planning, Industry and Environment (Water).

The operational monitoring regime should include:

- Monitoring the quality and quantity of groundwater inflows into tunnels next to the unsealed areas of the Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray (AEI B1), Punch Street at Artarmon (AEI B7), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10), Balgowlah Golf Course at Balgowlah (AEI B13), and Waverton Park – Woolcott Road, Waverton (AEI B8).
- While the project is assessed to cause negligible impact to identified groundwater supply bores, site inspections should be carried out to confirm the current viability of these bores. If viable, make good measures should be implemented as required
- Monitoring of the quality and quantity of the treated wastewater discharges from the wastewater treatment plant
- Ongoing settlement monitoring, as per the independent property impact assessment requirements.

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 Beaches Link 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 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 rock aquifer'

Minimal impact considerations	Response
Water table **1.** 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.	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 5.5.9) b) No listed high priority culturally significant sites (refer to Section 5.5.12). Groundwater modelling has predicted that drawdown could exceed two metres at bores GW107970, GW108224 and GW108991 during both construction and operation. (refer to sections 6.1.3.2 and 6.2.3.2). Impact minimisation measures are discussed below.

Minimal impact considerations	Response
2. If more than 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 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 2m decline cumulatively at any water supply work then make good provisions should apply.	The approach to 'make good' the predicted impacts should 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 should be discussed with the bore owner. Make good provisions to be considered should include provision of alternative water supply (such as mains water), replacing the bore with a deeper bore, or compensation for additional pumping costs.
Water pressure **1.** A cumulative pressure head decline of not more than a 2m decline, at any water supply work.	Management mitigation measures to address long-term operational impacts at bores GW107970, GW108224 and GW108991 should be carried out.
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 should be carried out. 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 supply, or compensation.
Water quality **1.** Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m 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 tunnels rather than away from it. Contaminants associated with the project would therefore remain within 40 m of the tunnel. Drawdown caused by the project may cause mobilisation of contaminated groundwater more than 40 m away from the tunnels 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.

Minimal impact considerations	Response
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.	Intrusion of saline water from the coast into fresher groundwater, and migration of already contaminated groundwater, are not likely to impact the long-term viability of dependent ecosystems or significant sites.
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.	The level of predicted drawdown does not present a substantial risk of 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 additional areas of ASS are identified, measures to mitigate impacts will be needed. There is no risk of water logging or water table rise since the tunnels would be drained during both construction and operation. The only tanked structures would be short distances either side of the harbour or as otherwise determined by further design development. Waterlogging or damming of groundwater flow is not expected to occur, since the hydraulic gradient by that time would cause flow towards the drained sections of the tunnel.

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, treated 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 Transport for NSW 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, Transport for NSW 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 Section 3 to Section 6 of this report.

The total inflow to the project during construction is predicted to be 2817 megalitres, which peaks at 899 megalitres per year in 2024. The peak annual inflow during operation is 551 megalitres per year in the first year of operation, which declines to 436 megalitres per year by 2128.

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 around 43,323 megalitres per year that is unassigned under the long term average annual extraction limit. Annual inflows for the Beaches Link and Gore Hill Freeway Connection would be less than about two per cent of the unassigned water.

8.3 Water Sharing Plan

All groundwater and surface water in the project area are 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 groundwater dependent ecosystems, 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 long term average annual extraction limit. Transport for NSW is exempt from the requirement to hold a water access licence for the project, under Schedule 5, 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	Transport for NSW are exempt from the requirement to hold a licence for the take of water during construction and operation of major projects under Schedule 5, 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 899 ML/year during construction, and up to 551 ML/year during operation would need to be assigned under the long term average annual extraction limit.
Part 8 – Rules for managing access licences	Refer to 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 six bores (GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991) that may be impacted by drawdown. Viability of water access at these bores is not expected to be impacted, with the potential exception of bore GW023150 (during operation) if it is found to be viable and rely on shallow groundwater.
Distance restriction from the property boundary is 50 metres	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.
Distance restriction from an approved water supply work is 100 metres	There are no approved water supply works within 100 metres of the project. Supply bores GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991 are within the area of drawdown, but make good provisions would apply, as discussed above.

WSP rule	Response
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 metres	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 metres	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 Appendix M (Technical working paper: Contamination), Environmental Protection Agency notified contaminated sites have been identified as relevant to the project 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 metres to 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. 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.
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 4.3). The project is within 40 metres of a first/second order stream (Flat Rock Creek/Quarry Creek) but, as the tunnels are more than 30 m 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.

WSP rule	Response
Part 9 – 44 Rules for water supply works located within distance restrictions	As the potential supply bores (GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991) and the areas of environmental interest for contamination may be within restricted distances, the proponent must not take more water than specified in the water access licence. Although Transport for NSW 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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Annexure A. Borehole 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

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	

DRILLING

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

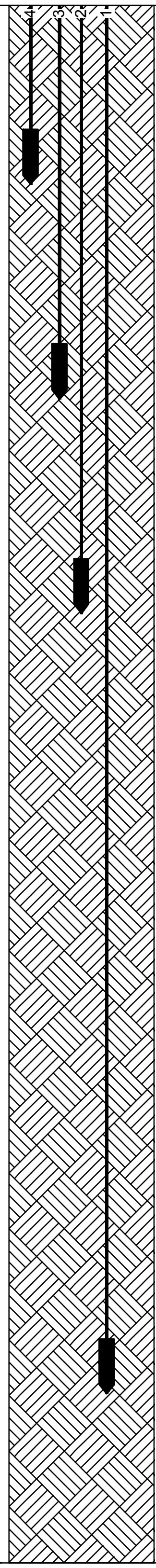
- DRILLING & CASING: ADT/TA; HW Casing; HQ3
- WATER: (GWNO); 0% LOSS; 10% LOSS; 0% LOSS; 10% LOSS; 100% LOSS; 40% LOSS; 100% LOSS

MATERIAL

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

Depth	Material Description
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



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

RMS LIB 40.3.1.GLB Log RTA PIEZOMETER INSTALLATION LOG 1 B106A_W.GPJ <<DrawingFile>> 01/Nov/2017 11:10 8.30.004 Datgel Tools

Engineering Log

PIEZOMETER No. B112

Sheet: 1 of 3

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

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

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

Method	Core Run	TCR (%)	RQD (%)	Ground Water	Reduced Level (m)	Depth (m)	Summary Geology (refer to geological log for full descriptions)
HQ3	R7	100	100		16.0	32.0	SANDSTONE, medium, pale grey *continued*
	R8	100	99		18.0	34.0	
	R9	100	100		20.0	36.0	BRECCIA
					22.0	38.0	SANDSTONE, fine to medium, pale grey to grey
	R10	100	100		24.0	40.0	SANDSTONE, fine, grey
					26.0	42.0	SANDSTONE, medium, grey to pale grey
	R11	100	100		28.0	44.0	SANDSTONE, fine to medium, grey
							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
	R14	100	100		36.0	52.0	SANDSTONE, fine, pale grey
					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

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

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 —

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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

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	~61–63	SANDSTONE, medium, grey
HQ3	R18	100	100	~63	SANDSTONE, fine, grey
HQ3	R19	100	100	~63–66	SANDSTONE, medium, pale grey; SANDSTONE, fine to medium, pale grey
HQ3	R20	100	100	~66–69	SANDSTONE, medium, pale grey
HQ3	R21	100	100	~69–71	
HQ3	R22	100	100	~71–73	
HQ3	R23	100	100	~73–75.5	SANDSTONE, medium to coarse, pale grey to brown-grey; SANDSTONE, fine to medium, pale grey
HQ3	R24	100	100	~76	

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

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 (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

Interval	Piezometer Details
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.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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	**Easting:**	333230.4 m	**RL:**	15.94 m
Drill Rig:	Comacchio 450P	**Northing:**	6254078.3 m	**Ver. Datum:**	AHD
Hole Diameter:	99 mm	**Hor. Proj/Dat:**	MGA94/GDA94-56H	**Surface:**	Grass
Inclination:	-90°				
Bearing:	N/A				

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: HA (0.0–1.5 m); ADT (1.5–15.6 m); RT (15.6–16.4 m); WB (16.4–30.0 m)

Summary Geology:
- SANDSTONE, medium, pale grey
- MUDSTONE
- SANDSTONE
- SANDSTONE, fine to medium, pale grey to grey
- SANDSTONE, medium, pale grey
- SANDSTONE, fine to medium, grey
- SANDSTONE, medium, pale grey

Piezometer construction:
- 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

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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	**Easting:**	333230.4 m	**RL:**	15.94 m
Drill Rig:	Comacchio 450P	**Northing:**	6254078.3 m	**Ver. Datum:**	AHD
Hole Diameter:	99 mm	**Hor. Proj/Dat:**	MGA94/GDA94-56H	**Surface:**	Grass
Inclination:	-90°				
Bearing:	N/A				

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

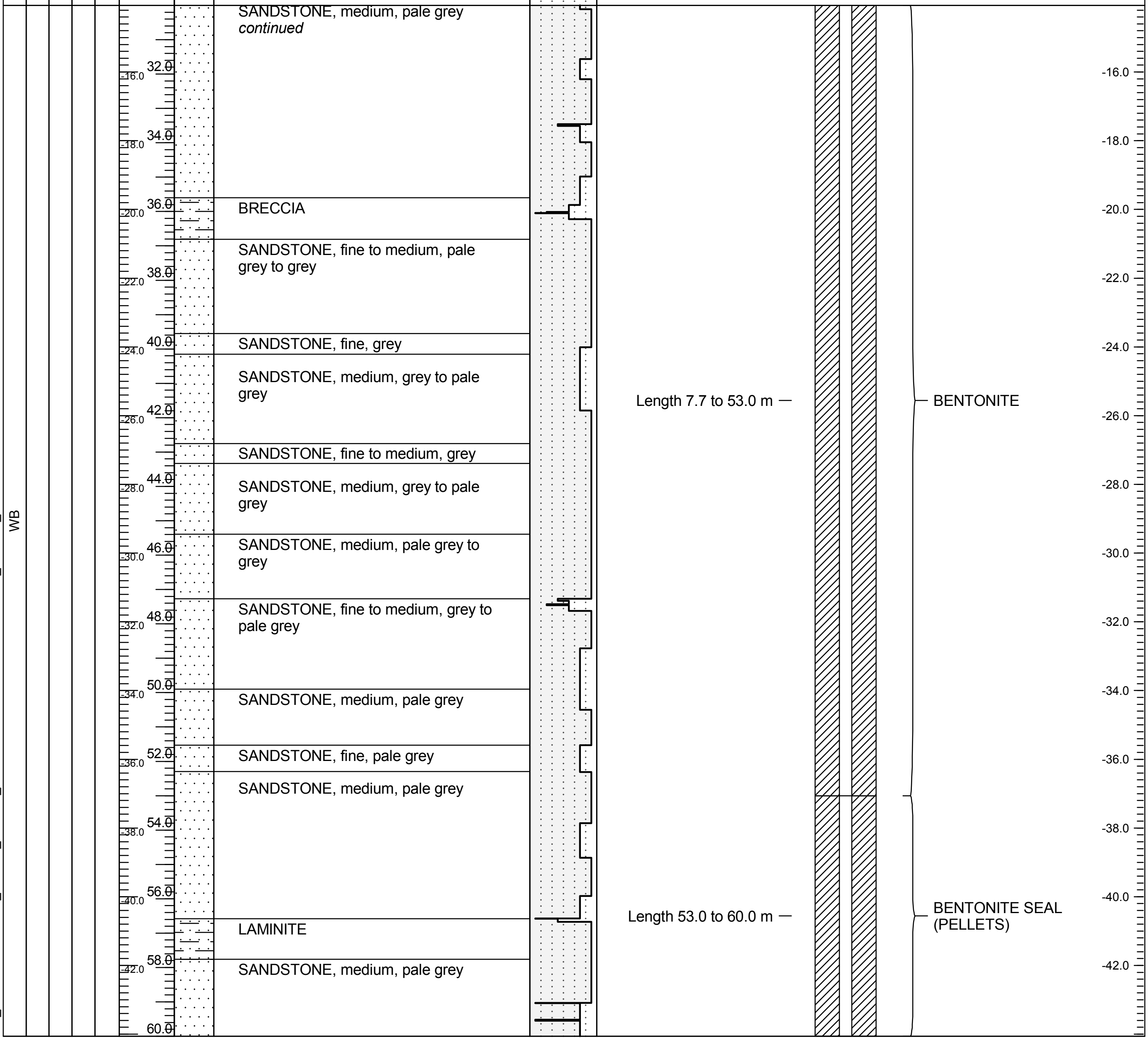
Response Zone Top RL: -46.56 m AHD
Response Zone Base RL: -49.56 m AHD
Length of Response Zone: 3.00 m

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

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

Method: WB

Depth (m)	Summary Geology (refer to geological log for full descriptions)
30.0–36.0	SANDSTONE, medium, pale grey *continued*
36.0–37.2	BRECCIA
37.2–40.0	SANDSTONE, fine to medium, pale grey to grey
40.0–40.6	SANDSTONE, fine, grey
40.6–43.2	SANDSTONE, medium, grey to pale grey
43.2–43.8	SANDSTONE, fine to medium, grey
43.8–45.9	SANDSTONE, medium, grey to pale grey
45.9–47.8	SANDSTONE, medium, pale grey to grey
47.8–50.4	SANDSTONE, fine to medium, grey to pale grey
50.4–52.0	SANDSTONE, fine, pale grey (50.4 medium, pale grey)
52.0–52.8	SANDSTONE, fine, pale grey
52.8–57.0	SANDSTONE, medium, pale grey
57.0–58.0	LAMINITE
58.0–60.0	SANDSTONE, medium, pale grey



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**

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 ~61.5	(continued)
~61.5 – 62.6	SANDSTONE, medium, grey
62.6 – 62.8	SANDSTONE, fine, grey
62.8 – 64.6	SANDSTONE, medium, pale grey
64.6 – 67.2	SANDSTONE, fine to medium, pale grey
67.2 – 70.0	SANDSTONE, medium, pale grey

Installation	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 (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

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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

Summary Geology (refer to geological log for full descriptions)

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

Ground Water: 25/08/2017

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

Length	Piezometer detail
Length 0.0 to 0.0 m	GATIC COVER
Length 0.0 to 10.5 m	CEMENT/BENTONITE GROUT (mass ratio 5 Water / 4 Cement / 0.3 Bentonite)
Length 10.5 to 13.0 m	BENTONITE SEAL (PELLETS)
Length 13.0 to 15.0 m	2mm FILTER SAND
Length 15.0 to 18.0 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 18.0 to 19.0 m	2mm FILTER SAND (SUMP/PVC CAP)

B128 terminated at 19.00 m.

Reduced Level (m): 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, 2.0

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

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

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: -

Summary Geology (refer to geological log for full descriptions)

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

Method	Core Run	TCR (%)	RQD (%)	Depth (m)	Summary Geology
HA				0.0–1.4	ASPHALTIC CONCRETE, black
HA					Fill, yellow-brown
HQ3	R1	100	81		SANDSTONE, fine to coarse grained, grey and orange-brown
HQ3	R2	100	100		SANDSTONE, fine to coarse grained, yellow and orange-brown
HQ3					SANDSTONE
HQ3					SANDSTONE, fine to coarse grained, yellow, orange-brown and pale grey
HQ3	R3	100	98		SANDSTONE, pale grey
HQ3					SANDSTONE, fine to coarse grained, red and yellow-brown
HQ3	R4	100	94		SANDSTONE, fine to coarse grained, yellow-brown and purple
HQ3					SANDSTONE, fine to coarse grained, pale grey
HQ3	R5	100	94		SANDSTONE, fine to coarse grained, red-brown, yellow-brown and purple-brown
HQ3					SANDSTONE, fine to coarse grained, pale grey and pale yellow
HQ3	R6	100	99		SANDSTONE, fine to coarse grained, pale grey and purple
HQ3					SANDSTONE, pale orange-brown
HQ3	R7	100	100		SANDSTONE, fine to medium grained, pale grey
HQ3					SANDSTONE, fine to medium grained, grey
HQ3	R8	100	100		SANDSTONE, fine to coarse grained, pale grey
HQ3					SANDSTONE, fine to coarse grained, grey
HQ3	R9	100	96		SANDSTONE, fine to coarse grained, pale grey and grey
HQ3					SANDSTONE, fine to coarse grained, yellow-brown and red-brown
HQ3	R10	100	97		SANDSTONE, fine to coarse grained, pale grey

Ground Water: 28/09/2017 (at approx. 20.3 m depth); 28/09/2017

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): 20.0, 18.0, 16.0, 14.0, 12.0, 10.0, 8.0, 6.0, 4.0, 2.0, 0.0, -2.0, -4.0

Piezometer construction:

- 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

Reduced Level RL (m): 20.0, 18.0, 16.0, 14.0, 12.0, 10.0, 8.0, 6.0, 4.0, 2.0, 0.0, -2.0, -4.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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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

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: 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

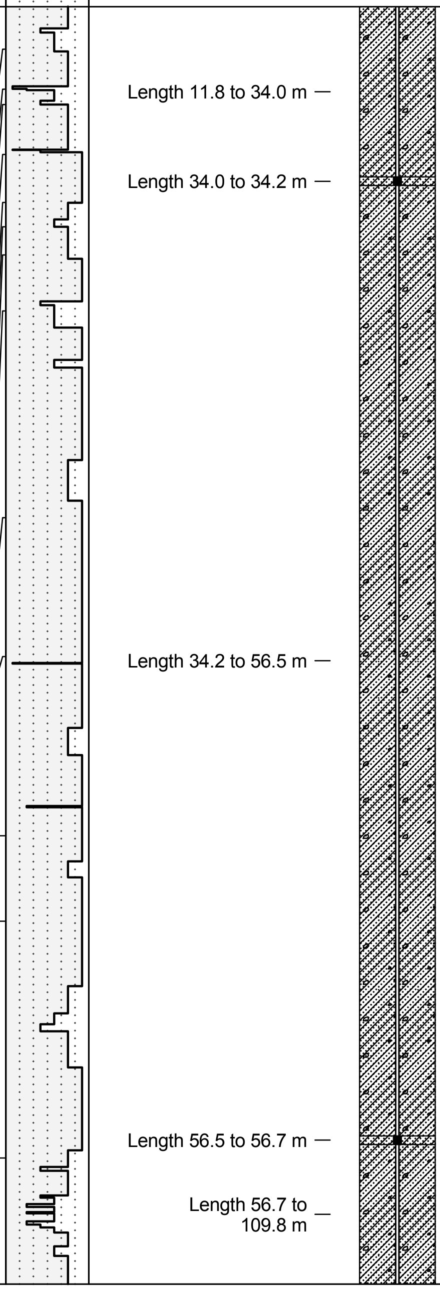
Reduced Level (m): -6.0, -8.0, -10.0, -12.0, -14.0, -16.0, -18.0, -20.0, -22.0, -24.0, -26.0, -28.0, -30.0

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):

- 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



Piezometer 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

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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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

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: -

Summary Geology (refer to geological log for full descriptions)

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

Method	Core Run	TCR (%)	RQD (%)
HQ3	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

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 (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

Rock Description:

- 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:

Length 56.7 to 109.8 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	**Easting:**	332923.5 m	**RL:**	20.56 m
Drill Rig:	Comacchio 405	**Northing:**	6253603.3 m	**Ver. Datum:**	AHD
Hole Diameter:	96 mm	**Hor. Proj/Dat:**	MGA94/GDA94-56	**Surface:**	Road surface
Inclination:	-59°				
Bearing:	340°				

Field Data / Rock Description / 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: HQ3

Core Run	TCR (%)	RQD (%)	Depth (m)	Summary Geology (refer to geological log for full descriptions)
R35	100	99	to 92.0	SANDSTONE, fine to coarse grained, pale grey to grey *continued*
R36	100	100	92.0 – 95.3	SANDSTONE, fine to coarse grained, pale grey and pale yellow-brown
R37	100	100	95.3 – 104.6	SANDSTONE, fine to coarse grained, pale grey
R38	100	100		
R39	100	100		
R40	100	100		
R41	100	100	104.6 – 105.0	SHALE BRECCIA
			105.0 – 106.6	SANDSTONE, fine to medium grained, dark grey
R42	100	100	106.6 – 110.0	SANDSTONE, fine to coarse grained, pale grey
R43	100	99	110.0 – 111.3	SANDSTONE, fine to medium grained, grey
			111.3 – 112.6	SANDSTONE, fine to medium grained, pale grey
R44	100	100	112.6 – 116.9	SANDSTONE, fine to coarse grained, pale grey and grey
R45	100	100	116.9 – 120.0	SANDSTONE, medium to coarse grained, pale grey
R46	100	98		

Reduced Level (m): -58.0 (92.0 m) to -82.0 (120.0 m)

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

Piezometer details:
- Length 56.7 to 109.8 m — CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE
- Length 109.8 to 110.0 m — VIBRATING WIRE SENSOR + SLOTTED PVC PIPE
- Length 110.0 to 120.3 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

Reduced Level RL (m): -58.0, -60.0, -62.0, -64.0, -66.0, -68.0, -70.0, -72.0, -74.0, -76.0, -78.0, -80.0, -82.0

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**

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

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: -

SANDSTONE, fine to coarse grained, pale grey *continued*

B132 terminated at 120.27 m.

Depth (m) scale: 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) scale: -84.0, -86.0, -88.0, -90.0, -92.0, -94.0, -96.0, -98.0, -100.0, -102.0, -104.0, -106.0

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

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

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

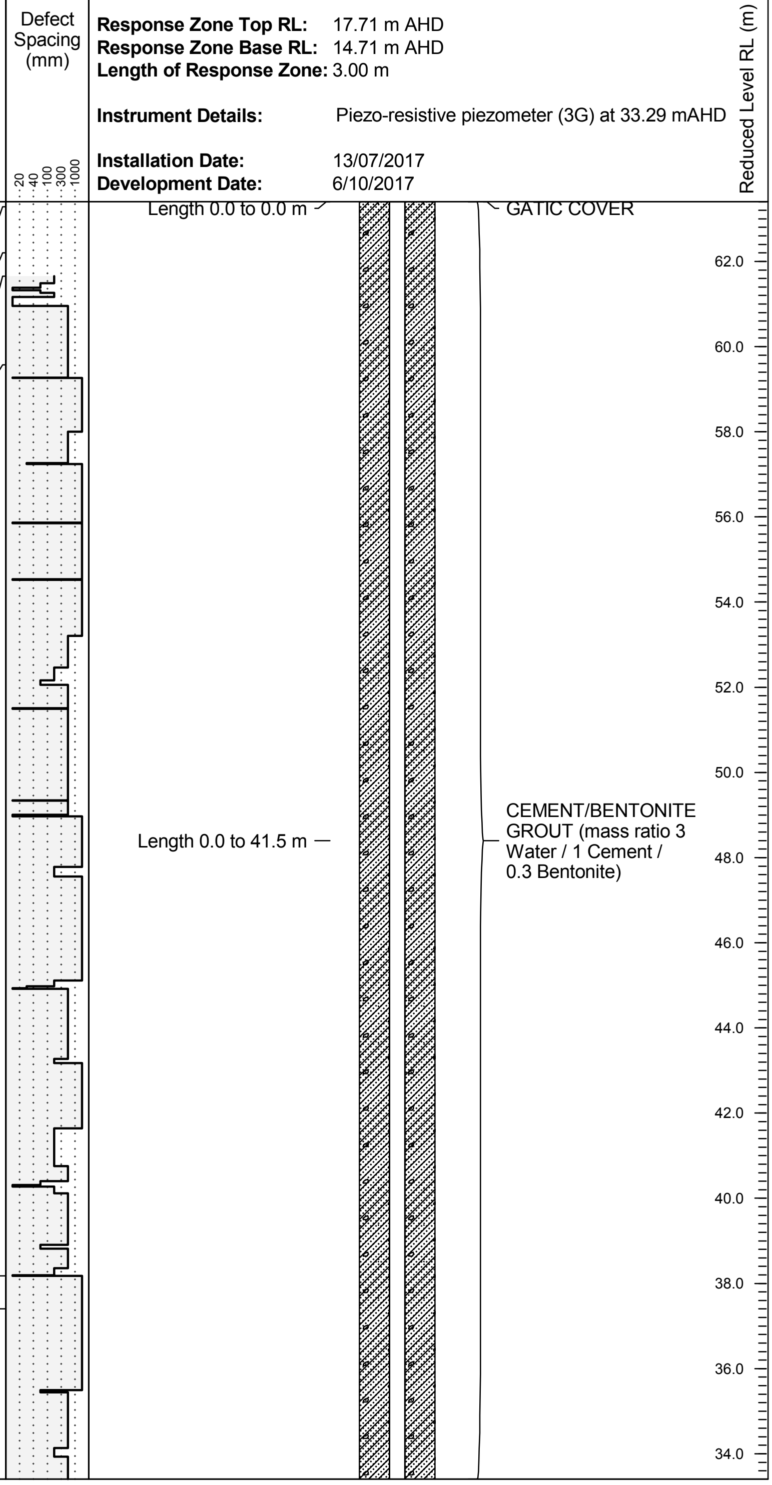
Instrument Details: Piezo-resistive piezometer (3G) at 33.29 mAHD

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

Field Data / Rock Description

Summary Geology (refer to geological log for full descriptions)

Method	Core Run TCR (%)	RQD (%)	Ground Water	Depth (m)	Rock Description
ADT NDD				0.0–0.5	ASPHALTIC CONCRETE, black
					Clayey SAND, fine to coarse, brown
HQ3	100	66			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			
	100	96			
	100	98			
	100	100			
	100	97			
	100	96			
	100	96		25.8	SANDSTONE, fine to coarse, grey
				26.6	SANDSTONE, fine to coarse, pale grey
	100	98	29/09/2017		



GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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

Method	Core Run	TCR (%)	RQD (%)	Reduced Level (m)	Depth (m)	Summary Geology (refer to geological log for full descriptions)
HQ3		100	100	32.0	32.0	SANDSTONE, fine to coarse, pale grey *continued*
		100	100	30.0	34.0	SANDSTONE, medium to coarse, pale grey
		100	99	28.0	36.0	SANDSTONE, fine to coarse, pale brown to pale grey
				26.0	38.0	SANDSTONE, fine to coarse, pale grey
		100	100	24.0	40.0	
		100	100	22.0	42.0	
		100	100	20.0	44.0	SANDSTONE, medium to coarse, pale grey
				18.0	46.0	SANDSTONE, fine to coarse, pale grey
		100	97	16.0	48.0	SANDSTONE, fine to medium, pale grey
		100	100	14.0	50.0	SANDSTONE, fine to coarse, pale grey and grey
				12.0	52.0	SANDSTONE, medium to coarse, pale grey
		100	98	10.0	54.0	SANDSTONE, fine to coarse, pale grey
		100	100	8.0	56.0	SANDSTONE, medium to coarse, pale grey
				6.0	58.0	SANDSTONE, fine to coarse, dark grey to pale grey
		100	100	4.0	60.0	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

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	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.

Reduced Level RL (m): 2.0, 0.0, -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

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B135

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** AS	**Checked by:** RPW
Location: Minnamurra Road - Northbridge		**Start Date:** 5/06/2017	**End Date:** 27/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 335435.1 m	**RL:** 53.93 m
Drill Rig: Comacchio 450P	**Inclination:** -58°	**Northing:** 6257598.9 m	**Ver. Datum:** AHD
	Bearing: 232°	**Hor. Proj/Dat:** MGA94/GDA94-56M	**Surface:** Road Surface

Field Data / Rock Description / 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 -71.05 mAHD, VWP2 at -29.86 mAHD, VWP3 at 7.05 mAHD
Installation Date: 9/08/2017
Development Date: -

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	Core Run	TCR (%)	RQD (%)
NDD			
HQ3	R1	88	87
	R2	100	100
	R3	100	97
	R4	100	97
	R5	100	100
	R6	100	99
	R7	100	100
	R8	100	100
	R9	100	100
	R10	100	98
	R11	100	100

Reduced Level (m): 52.0, 50.0, 48.0, 46.0, 44.0, 42.0, 40.0, 38.0, 36.0, 34.0, 32.0, 30.0

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

Summary Geology:
- CONCRETE, grey
- Silty CLAY, brown
- Silty SAND, fine to medium grained, orange-brown
- SANDSTONE, fine to medium grained, orange-brown
- NO CORE
- SANDSTONE, fine to medium grained, orange-brown and pale grey
- SANDSTONE, medium to coarse grained, red-brown and purple
- SANDSTONE, fine to medium grained, pale grey
- SHALE BRECCIA
- SANDSTONE, fine to medium grained, pale grey
- SANDSTONE, fine to medium grained, pale grey and grey
- SANDSTONE, fine to medium grained, pale grey
- SHALE BRECCIA
- SANDSTONE, fine to medium grained, pale grey
- SANDSTONE, fine grained, pale grey and grey
- SANDSTONE, medium to coarse grained, pale grey

Piezometer details:
- Length 0.0 to 0.1 m — GATIC COVER
- Length 0.1 to 55.2 m — CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE

Reduced Level RL (m): 52.0, 50.0, 48.0, 46.0, 44.0, 42.0, 40.0, 38.0, 36.0, 34.0, 32.0, 30.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B135

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** AS	**Checked by:** RPW
Location: Minnamurra Road - Northbridge		**Start Date:** 5/06/2017	**End Date:** 27/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 335435.1 m	**RL:** 53.93 m
Drill Rig: Comacchio 450P	**Inclination:** -58°	**Northing:** 6257598.9 m	**Ver. Datum:** AHD
	Bearing: 232°	**Hor. Proj/Dat:** MGA94/GDA94-56M	**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 -71.05 mAHD, VWP2 at -29.86 mAHD, VWP3 at 7.05 mAHD
Installation Date: 9/08/2017
Development Date: -

Field Data / Rock Description

Method: HQ3

Core Run	TCR (%)	RQD (%)	Ground Water	Summary Geology (refer to geological log for full descriptions)
R12	100	100		SANDSTONE, fine grained, grey; SANDSTONE, fine grained, pale grey *continued*; SANDSTONE, medium to coarse grained, pale grey
R13	100	100		SANDSTONE, fine to medium grained, pale grey and grey
R14	100	100		
R15	100	100	29/09/2017	SHALE BRECCIA (42.0)
R16	100	100		SANDSTONE, fine to medium grained, pale grey; SANDSTONE, medium grained, pale grey
R17	100	100		SANDSTONE, fine to medium grained, pale grey; SANDSTONE, medium to coarse grained, pale grey
R18	100	100		
R19	100	100		SANDSTONE, fine to medium grained, pale grey; SANDSTONE, fine to medium grained, pale grey and grey
R20	100	100	29/09/2017	SANDSTONE, medium to coarse grained, pale grey
R21	100	100	29/09/2017	SANDSTONE, fine grained, grey

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): 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

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

Installation

Length 0.1 to 55.2 m — CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE

Length 55.2 to 55.4 m — VIBRATING WIRE SENSOR + SLOTTED PVC PIPE

Length 55.4 to 99.0 m — CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE

Reduced Level RL (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

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. **B135**

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** AS	**Checked by:** RPW
Location: Minnamurra Road - Northbridge		**Start Date:** 5/06/2017	**End Date:** 27/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 335435.1 m	**RL:** 53.93 m
Drill Rig: Comacchio 450P	**Inclination:** -58°	**Northing:** 6257598.9 m	**Ver. Datum:** AHD
	Bearing: 232°	**Hor. Proj/Dat:** MGA94/GDA94-56M	**Surface:** Road Surface

Field Data | **Rock Description** | **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 -71.05 mAHD, VWP2 at -29.86 mAHD, VWP3 at 7.05 mAHD
Installation Date: 9/08/2017
Development Date: -

Method: HQ3

Core Run	TCR (%)	RQD (%)	Reduced Level (m)	Depth (m)	Summary Geology (refer to geological log for full descriptions)
					SANDSTONE, fine to medium grained, pale grey and grey *continued*
R22	100	100	2.0	62.0	
R23	100	100	0.0	64.0	SANDSTONE, fine grained, grey
					SANDSTONE, fine to medium grained, pale grey
			-2.0	66.0	LAMINITE
R24	100	100			SANDSTONE, fine to medium grained, pale grey and grey
			-4.0	68.0	SANDSTONE, medium grained, pale grey
R25	100	100		70.0	SANDSTONE, medium to coarse grained, pale grey
			-6.0		SHALE BRECCIA
				72.0	SANDSTONE, fine to medium grained, pale grey
R26	100	100	-8.0	74.0	SANDSTONE, fine grained, grey
					SANDSTONE, fine to medium grained, pale grey
R27	100	100	-10.0	76.0	SANDSTONE, fine to medium grained, pale grey and grey
R28	100	100	-12.0	78.0	
R29	100	100	-14.0	80.0	SANDSTONE, medium grained, pale grey
R30	100	100	-16.0	82.0	
				84.0	
R31	100	100	-18.0		
R32	100	100		86.0	
			-20.0	88.0	
R33	100	100	-22.0	90.0	SANDSTONE, fine grained, pale grey and grey

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

Piezometer: Length 55.4 to 99.0 m — CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE

Reduced Level RL (m): 2.0, 0.0, -2.0, -4.0, -6.0, -8.0, -10.0, -12.0, -14.0, -16.0, -18.0, -20.0, -22.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

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PIEZOMETER No. B135

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	AS	**Checked by:**	RPW
Location:	Minnamurra Road - Northbridge	**Start Date:**	5/06/2017	**End Date:**	27/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:**	335435.1 m	**RL:**	53.93 m
Drill Rig: Comacchio 450P	**Inclination:** -58°	**Northing:**	6257598.9 m	**Ver. Datum:**	AHD
	Bearing: 232°	**Hor. Proj/Dat:**	MGA94/GDA94-56M	**Surface:**	Road Surface

Field Data | **Rock Description** | **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 -71.05 mAHD, VWP2 at -29.86 mAHD, VWP3 at 7.05 mAHD
Installation Date: 9/08/2017
Development Date: -

Method: HQ3

Core Run	TCR (%)	RQD (%)
R34	100	100
R35	100	100
R36	100	100
R37	100	100
R38	100	100
R39	100	100
R40	100	100
R41	100	100
R42	100	100
R43	100	100
R44	100	100
R45	100	98

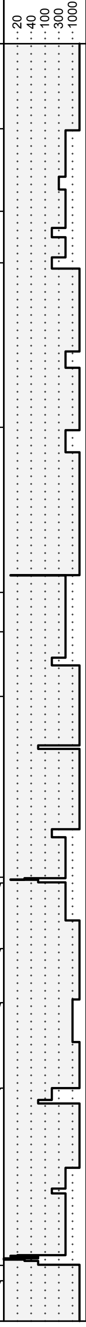
Depth (m): 92.0, 94.0, 96.0, 98.0, 100.0, 102.0, 104.0, 106.0, 108.0, 110.0, 112.0, 114.0, 116.0, 118.0, 120.0

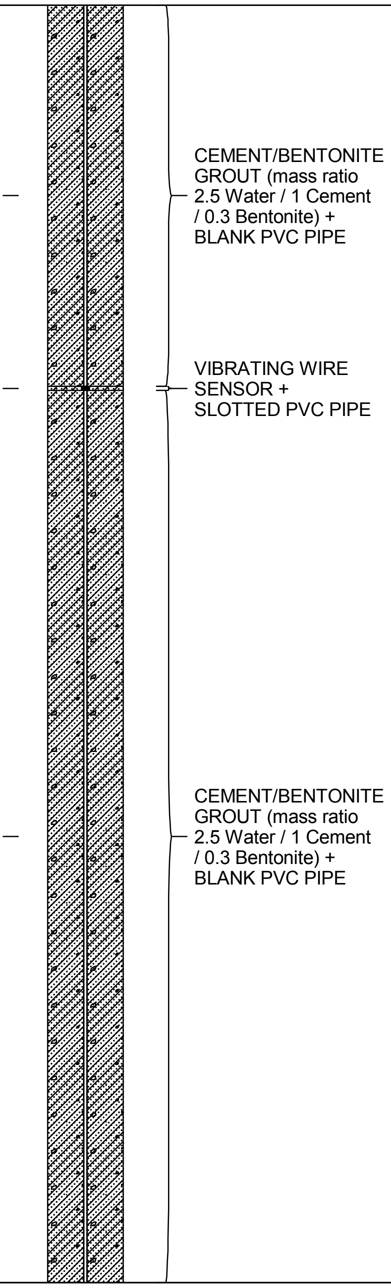
Reduced Level (m): -24.0, -26.0, -28.0, -30.0, -32.0, -34.0, -36.0, -38.0, -40.0, -42.0, -44.0, -46.0

Summary Geology (refer to geological log for full descriptions)

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

Defect Spacing (mm)





GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	AS	**Checked by:**	RPW
Location:	Minnamurra Road - Northbridge	**Start Date:**	5/06/2017	**End Date:**	27/06/2017
Driller:	Terratest	**Hole Diameter:** 96 mm	**Easting:** 335435.1 m	**RL:**	53.93 m
Drill Rig:	Comacchio 450P	**Inclination:** -58°	**Northing:** 6257598.9 m	**Ver. Datum:**	AHD
		Bearing: 232°	**Hor. Proj/Dat:** MGA94/GDA94-56M	**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 -71.05 mAHD, VWP2 at -29.86 mAHD, VWP3 at 7.05 mAHD
Installation Date: 9/08/2017
Development Date: -

Method: HQ3

Core Run	TCR (%)	RQD (%)
R46	100	100
R47	100	99
R48	100	99
R49	100	100
R50	100	100
R51	100	100
R52	100	100
R53	100	100
R54	100	100
R55	100	100
R56	100	100
R57	100	100

Rock Description — Summary Geology (refer to geological log for full descriptions)

Approx. Depth (m)	Description
121.0	SANDSTONE, medium grained, pale grey *continued*
122.0	SANDSTONE, medium grained, pale grey
128.0	SANDSTONE, coarse grained, pale grey
	SANDSTONE, medium to coarse grained, pale grey
	SANDSTONE, fine to medium grained, grey
	LAMINITE
	SANDSTONE, fine grained, grey
	LAMINITE
	SANDSTONE, medium to coarse grained, pale grey and grey
139.0	SANDSTONE, medium grained, pale grey
143.8	SANDSTONE, fine to medium grained, pale grey and brown
	SANDSTONE, medium to coarse grained, pale grey
	SANDSTONE, fine to medium grained, pale grey
148.0	SANDSTONE, medium to coarse grained, pale grey

Depth scale: 122.0 – 150.0 m; Reduced Level scale: -48.0 to -72.0 m. Defect Spacing (mm): 20, 40, 100, 300, 1000.

Piezometer installation

Interval	Details
Length 99.1 to 147.6 m	CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE
Length 147.6 to 147.8 m	VIBRATING WIRE SENSOR + SLOTTED PVC PIPE
Length 147.8 to 160.0 m	

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Client: RMS		**Project No:**	60537922		
Project: Western Harbour Tunnel and Beaches Link		**Logged by:**	AS	**Checked by:**	RPW
Location: Minnamurra Road - Northbridge		**Start Date:**	5/06/2017	**End Date:**	27/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:**	335435.1 m	**RL:**	53.93 m
Drill Rig: Comacchio 450P	**Inclination:** -58°	**Northing:**	6257598.9 m	**Ver. Datum:**	AHD
	Bearing: 232°	**Hor. Proj/Dat:**	MGA94/GDA94-56M	**Surface:**	Road Surface

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

Summary Geology (refer to geological log for full descriptions)

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 -71.05 mAHD, VWP2 at -29.86 mAHD, VWP3 at 7.05 mAHD
Installation Date: 9/08/2017
Development Date: -

Method	Core Run	TCR (%)	RQD (%)	Depth (m)	Summary Geology
HQ3	R58	100	100	152.0	SANDSTONE, medium grained, pale grey
HQ3	R59	100	100		SANDSTONE, medium to coarse grained, pale grey
HQ3	R60	100	99		SANDSTONE, fine to medium grained, pale grey and brown
HQ3					SANDSTONE, medium to coarse grained, pale grey
HQ3	R61	100	100	160.0	SANDSTONE, fine grained, grey
					MUDSTONE, dark grey
					SANDSTONE, fine grained, pale grey

Depth scale (m): 152.0, 154.0, 156.0, 158.0, 160.0, 162.0, 164.0, 166.0, 168.0, 170.0, 172.0, 174.0, 176.0, 178.0, 180.0

Reduced Level (m): -74.0, -76.0, -78.0, -80.0, -82.0, -84.0, -86.0, -88.0, -90.0, -92.0, -94.0, -96.0, -98.0

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

Length 147.8 to 160.0 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

B135 terminated at 160.00 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B138

Sheet: 1 of 5

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** LH	**Checked by:** RPW
Location: Edgecliffe Esplanade - Seaforth		**Start Date:** 22/05/2017	**End Date:** 1/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 337118.7 m	**RL:** 56.99 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:** 6258391.8 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56M	**Surface:** Road Surface

Field Data

Method	Core Run	TCR (%)	RQD (%)
NDD			
HQ3	R1	90	88
HQ3	R2	100	100
HQ3	R3	100	100
HQ3	R4	92	87
HQ3	R5	100	100
HQ3	R6	100	100
HQ3	R7	100	100
HQ3	R8	100	97
HQ3	R9	100	100
HQ3	R10	100	100

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

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): 56.0, 54.0, 52.0, 50.0, 48.0, 46.0, 44.0, 42.0, 40.0, 38.0, 36.0, 34.0, 32.0, 30.0, 28.0

Rock Description

Summary Geology (refer to geological log for full descriptions)

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

- ASPHALTIC CONCRETE
- GRAVEL, medium, dark grey
- SAND, medium, pale brown and pink
- NO CORE
- SANDSTONE, medium, pale grey to pale orange and red-brown
- SANDSTONE, medium to coarse, pale grey to orange
- SANDSTONE, medium, pale grey
- SANDSTONE, medium to coarse, pale red to pink
- INTERBEDDED MUDSTONE/SANDSTONE
- NO CORE
- INTERBEDDED MUDSTONE/SANDSTONE
- NO CORE
- INTERBEDDED MUDSTONE/SANDSTONE
- LAMINITE
- SANDSTONE, medium, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium, pale grey
- SANDSTONE, fine, grey
- SANDSTONE, medium, pale grey
- SANDSTONE, fine to medium, grey
- SANDSTONE, medium, pale grey

Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 56.90 m AHD
Casing Top: 0.1 mBGL
Casing Base: 126.5 mBGL

Response Zone Top RL: -66.51 m AHD
Response Zone Base RL: -69.51 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -8.70 mAHD

Installation Date: 1/06/2017
Development Date: 16/10/2017

Reduced Level RL (m): 56.0, 54.0, 52.0, 50.0, 48.0, 46.0, 44.0, 42.0, 40.0, 38.0, 36.0, 34.0, 32.0, 30.0, 28.0

Length 0.0 to 0.1 m — GATIC COVER

Length 0.1 to 120.5 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** LH	**Checked by:** RPW
Location: Edgecliffe Esplanade - Seaforth		**Start Date:** 22/05/2017	**End Date:** 1/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 337118.7 m	**RL:** 56.99 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:** 6258391.8 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56M	**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: 56.90 m AHD
Casing Top: 0.1 mBGL
Casing Base: 126.5 mBGL

Response Zone Top RL: -66.51 m AHD
Response Zone Base RL: -69.51 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -8.70 mAHD

Installation Date: 1/06/2017
Development Date: 16/10/2017

Summary Geology (refer to geological log for full descriptions)

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

Method	Core Run	TCR (%)	RQD (%)	Ground Water
HQ3	R11	100	100	
HQ3	R12	98	97	
HQ3	R13	100	100	
HQ3	R14	100	100	
HQ3	R15	100	98	
HQ3	R16	100	100	
HQ3	R17	100	100	
HQ3	R18	100	98	
HQ3	R19	100	100	
HQ3	R20	100	98	29/09/2017

Reduced Level (m): 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, -2.0

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

Rock Description:

- SANDSTONE, medium, pale grey *continued*
- SANDSTONE, medium, grey
- SANDSTONE, medium, pale grey
- SHALE BRECCIA
- NO CORE
- SHALE BRECCIA
- SANDSTONE, medium, pale grey
- SHALE BRECCIA
- SANDSTONE, medium, pale grey
- MUDSTONE, dark grey
- LAMINITE
- MUDSTONE, dark grey
- LAMINITE
- SANDSTONE, fine to medium
- LAMINITE
- SHALE BRECCIA
- LAMINITE
- SHALE BRECCIA

Piezometer: Length 0.1 to 120.5 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

Reduced Level RL (m): 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, -2.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	LH	**Checked by:**	RPW
Location:	Edgecliffe Esplanade - Seaforth	**Start Date:**	22/05/2017	**End Date:**	1/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:**	337118.7 m	**RL:**	56.99 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:**	6258391.8 m	**Ver. Datum:**	AHD
	Bearing: N/A	**Hor. Proj/Dat:**	MGA94/GDA94-56M	**Surface:**	Road Surface

Piezometer Details

Construction details:	Standpipe Piezometer, 3 m slotted screen, sump
Remarks:	Class 18 PVC 50 mm ID
Casing Top RL:	56.90 m AHD
Casing Top:	0.1 mBGL
Casing Base:	126.5 mBGL
Response Zone Top RL:	-66.51 m AHD
Response Zone Base RL:	-69.51 m AHD
Length of Response Zone:	3.00 m
Instrument Details:	Piezo-resistive piezometer (3G) at -8.70 mAHD
Installation Date:	1/06/2017
Development Date:	16/10/2017

Field Data / Rock Description (Summary Geology (refer to geological log for full descriptions)); Method: HQ3

Core Run	TCR (%)	RQD (%)	Depth (m)	Summary Geology
R21	100	100	to 62.0	SANDSTONE, medium, pale grey *continued*
			62.0	SHALE BRECCIA
R22	100	100		SANDSTONE, medium, pale grey
			64.0	LAMINITE
				SHALE BRECCIA
R23	100	90	66.0	SANDSTONE, medium, pale grey
R24	100	95	68.0	
R25	100	100	70.0	
R26	100	96	72.0	SANDSTONE, medium, pale grey and brown-grey
				SANDSTONE, fine to medium, grey
R27	100	100	74.0	SANDSTONE, fine, grey
R28	100	100	76.0	SANDSTONE, fine to medium, pale grey
				LAMINITE
R29	100	100	78.0	SANDSTONE, medium to coarse, pale grey
				SANDSTONE, medium, pale grey
R30	100	100	80.0	SANDSTONE, fine to medium, grey to pale grey
			82.0	SANDSTONE, medium to coarse, pale grey
R31	100	89	84.0	SANDSTONE, medium to coarse, brown
				SANDSTONE, fine to medium, pale grey to grey
R32	97	78	86.0	SANDSTONE, fine
				SANDSTONE, fine to medium, pale grey to grey
R33	100	100	88.0	SANDSTONE, fine, grey
			90.0	SANDSTONE, medium, pale grey

Reduced Level (m): -4.0 to -32.0

Length 0.1 to 120.5 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B138

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** LH	**Checked by:** RPW
Location: Edgecliffe Esplanade - Seaforth		**Start Date:** 22/05/2017	**End Date:** 1/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 337118.7 m	**RL:** 56.99 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:** 6258391.8 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56M	**Surface:** Road Surface

Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 56.90 m AHD
Casing Top: 0.1 mBGL
Casing Base: 126.5 mBGL

Response Zone Top RL: -66.51 m AHD
Response Zone Base RL: -69.51 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -8.70 mAHD

Installation Date: 1/06/2017
Development Date: 16/10/2017

Field Data / Rock Description (Summary Geology (refer to geological log for full descriptions))

Method: HQ3

Core Run	TCR (%)	RQD (%)	Summary Geology
R33	100	100	SANDSTONE, medium to coarse, pale grey
R34	100	100	NO CORE
			SANDSTONE, medium to coarse, pale grey
R35	100	100	NO CORE
			SANDSTONE, medium to coarse, pale grey
R36	100	100	SANDSTONE, coarse, pale grey
			SANDSTONE, medium to coarse, pale grey *continued*
R37	100	100	SANDSTONE, fine to medium, pale grey
			SANDSTONE, medium, pale grey
R38	100	100	SANDSTONE, medium to coarse, pale grey and brown-grey
R39	100	100	SANDSTONE, medium, pale grey
			SANDSTONE, medium, grey
			SANDSTONE, medium, pale grey
R40	100	100	SANDSTONE, coarse, pale brown
			SANDSTONE, medium, pale grey
R41	100	100	SANDSTONE, coarse, pale grey to pale brown
			SANDSTONE, medium, pale grey
R42	100	100	SANDSTONE, coarse, pale grey
			SANDSTONE, medium, pale grey
			SANDSTONE, medium, grey
R43	100	100	SANDSTONE, medium, pale grey
R44	100	100	SANDSTONE, medium to coarse, pale grey
			SANDSTONE, coarse, pale grey

Depth (m): 92.0, 94.0, 96.0, 98.0, 100.0, 102.0, 104.0, 106.0, 108.0, 110.0, 112.0, 114.0, 116.0, 118.0, 120.0

Reduced Level (m): -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, -62.0

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

Length 0.1 to 120.5 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B138

Client: RMS		**Project No:** 60537922			
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** LH		**Checked by:** RPW	
Location: Edgecliffe Esplanade - Seaforth		**Start Date:** 22/05/2017		**End Date:** 1/06/2017	
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 337118.7 m		**RL:** 56.99 m	
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:** 6258391.8 m		**Ver. Datum:** AHD	
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56M		**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: 56.90 m AHD
Casing Top: 0.1 mBGL
Casing Base: 126.5 mBGL

Response Zone Top RL: -66.51 m AHD
Response Zone Base RL: -69.51 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -8.70 mAHD

Installation Date: 1/06/2017
Development Date: 16/10/2017

Summary Geology (refer to geological log for full descriptions)

Method	Core Run	TCR (%)	RQD (%)	Depth (m)	Rock Description
HQ3	R45	100	100	120.5–122.7	SANDSTONE, medium to coarse, pale grey
HQ3				122.7–123.8	SANDSTONE, fine to medium, pale grey
HQ3	R46	100	99	123.8–128.8	SANDSTONE, medium to coarse, pale grey
HQ3	R47	100	100		
HQ3	R48	100	100	128.8–129.2	SHALE BRECCIA
HQ3				129.2–130.6	SANDSTONE, medium, pale grey
HQ3	R49	100	98	130.6–131.4	SANDSTONE, medium, pale brown
HQ3				131.4–136.8	SANDSTONE, medium to coarse, pale grey
HQ3	R50	100	98		
HQ3	R51	100	100	136.8–137.0	SANDSTONE, fine, grey

Depth scale (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): -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, -92.0

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

Piezometer construction:
- Length 0.1 to 120.5 m; Length 120.5 to 121.0 m — BENTONITE SEAL (PELLETS)
- Length 121.0 to 123.5 m — 2mm FILTER SAND
- Length 123.5 to 126.5 m — SLOTTED SCREEN with 2mm FILTER SAND
- Length 126.5 to 127.3 m — 2mm FILTER SAND
- Length 127.3 to 137.0 m — BENTONITE SEAL (PELLETS)

B138 terminated at 137.00 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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Engineering Log

PIEZOMETER No. B138P

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** MC/AM	**Checked by:** -
Location: Edgecliffe Esplanade - Seaforth		**Start Date:** 13/12/2017	**End Date:** 21/12/2017
Driller: Terratest	**Hole Diameter:** 99 mm	**Easting:** 337152.9 m	**RL:** 57.54 m
Drill Rig: Hydrapower Scout	**Inclination:** -90°	**Northing:** 625405.9 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H	**Surface:** Road Surface

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: 57.47 m AHD
Casing Top: 0.0 mBGL
Casing Base: 129.1 mBGL

Response Zone Top RL: -65.99 m AHD
Response Zone Base RL: -68.99 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -8.13 mAHD

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

Method: ADT (0.0–1.3 m), WB (below)

Summary Geology:
- ASPHALTIC CONCRETE
- GRAVEL, medium, dark grey
- SAND, medium, pale brown and pink
- NO CORE
- SANDSTONE, medium, pale grey to pale orange and red-brown
- SANDSTONE, medium to coarse, pale grey to orange
- SANDSTONE, medium, pale grey
- SANDSTONE, medium to coarse, pale red to pink
- INTERBEDDED MUDSTONE/SANDSTONE
- NO CORE
- INTERBEDDED MUDSTONE/SANDSTONE
- NO CORE
- INTERBEDDED MUDSTONE/SANDSTONE
- LAMINITE
- SANDSTONE, medium, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium, pale grey
- SANDSTONE, fine, grey
- SANDSTONE, medium, pale grey
- SANDSTONE, fine to medium, grey
- SANDSTONE, medium, pale grey

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): 56.0, 54.0, 52.0, 50.0, 48.0, 46.0, 44.0, 42.0, 40.0, 38.0, 36.0, 34.0, 32.0, 30.0, 28.0

Piezometer construction:
- Length 0.0 to 0.0 m — GATIC COVER
- Length 0.0 to 0.4 m — CONCRETE ROAD BOX
- Length 0.4 to 60.0 m — BENTONITE

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B138P

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	MC/AM	**Checked by:**	-
Location:	Edgecliffe Esplanade - Seaforth	**Start Date:**	13/12/2017	**End Date:**	21/12/2017
Driller:	Terratest	**Easting:**	337152.9 m	**RL:**	57.54 m
Drill Rig:	Hydrapower Scout	**Northing:**	625405.9 m	**Ver. Datum:**	AHD
Hole Diameter:	99 mm	**Hor. Proj/Dat:**	MGA94/GDA94-56H	**Surface:**	Road Surface
Inclination:	-90°				
Bearing:	N/A				

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: 57.47 m AHD
Casing Top: 0.0 mBGL
Casing Base: 129.1 mBGL

Response Zone Top RL: -65.99 m AHD
Response Zone Base RL: -68.99 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -8.13 mAHD

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

Reduced Level RL (m)

Method: WB

Reduced Level (m)	Depth (m)	Summary Geology
		SANDSTONE, medium, pale grey *continued*
26.0	32.0	
24.0	34.0	SANDSTONE, medium, grey
		SANDSTONE, medium, pale grey
22.0	36.0	SHALE BRECCIA
		NO CORE
20.0	38.0	SHALE BRECCIA
		SANDSTONE, medium, pale grey
18.0	40.0	SHALE BRECCIA
		SANDSTONE, medium, pale grey
16.0	42.0	
14.0	44.0	
12.0	46.0	
10.0	48.0	
8.0	50.0	
6.0	52.0	MUDSTONE, dark grey
		LAMINITE
4.0	54.0	MUDSTONE, dark grey
		LAMINITE
2.0	56.0	SANDSTONE, fine to medium
		LAMINITE
0.0	58.0	SHALE BRECCIA
		LAMINITE
-2.0	60.0	SHALE BRECCIA

Length 0.4 to 60.0 m — BENTONITE

Reduced Level RL (m): 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, -2.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. **B138P**

Client: RMS		**Project No:**	60537922		
Project: Western Harbour Tunnel and Beaches Link		**Logged by:**	MC/AM	**Checked by:**	-
Location: Edgecliffe Esplanade - Seaforth		**Start Date:**	13/12/2017	**End Date:**	21/12/2017
Driller: Terratest	**Hole Diameter:** 99 mm	**Easting:**	337152.9 m	**RL:**	57.54 m
Drill Rig: Hydrapower Scout	**Inclination:** -90°	**Northing:**	625405.9 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:	57.47 m AHD
Casing Top:	0.0 mBGL
Casing Base:	129.1 mBGL
Response Zone Top RL:	-65.99 m AHD
Response Zone Base RL:	-68.99 m AHD
Length of Response Zone:	3.00 m
Instrument Details:	Piezo-resistive piezometer (3G) at -8.13 mAHD
Installation Date:	22/12/2017
Development Date:	25/01/2018

Method: WB

Reduced Level (m)	Depth (m)	Summary Geology
		SANDSTONE, medium, pale grey *continued*
-4.0	62.0	SHALE BRECCIA
		SANDSTONE, medium, pale grey
-6.0	64.0	LAMINITE
		SHALE BRECCIA
-8.0	66.0	SANDSTONE, medium, pale grey
-10.0	68.0	
-12.0	70.0	
-14.0	72.0	SANDSTONE, medium, pale grey and brown-grey
-16.0	74.0	SANDSTONE, fine to medium, grey
		SANDSTONE, fine, grey
-18.0	76.0	SANDSTONE, fine to medium, pale grey
		LAMINITE
-20.0	78.0	SANDSTONE, medium to coarse, pale grey
-22.0	80.0	SANDSTONE, medium, pale grey
		SANDSTONE, fine to medium, grey to pale grey
-24.0	82.0	SANDSTONE, medium to coarse, pale grey
-26.0	84.0	SANDSTONE, medium to coarse, brown
		SANDSTONE, fine to medium, pale grey to grey
-28.0	86.0	SANDSTONE, fine
		SANDSTONE, fine to medium, pale grey to grey
-30.0	88.0	SANDSTONE, fine, grey
-32.0	90.0	SANDSTONE, medium, pale grey

Piezometer: Length 60.0 to 90.0 m — BENTONITE

Reduced Level RL (m): -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, -32.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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Engineering Log

PIEZOMETER No. B138P

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** MC/AM	**Checked by:** -
Location: Edgecliffe Esplanade - Seaforth		**Start Date:** 13/12/2017	**End Date:** 21/12/2017
Driller: Terratest	**Hole Diameter:** 99 mm	**Easting:** 337152.9 m	**RL:** 57.54 m
Drill Rig: Hydrapower Scout	**Inclination:** -90°	**Northing:** 625405.9 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H	**Surface:** Road Surface

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: 57.47 m AHD
Casing Top: 0.0 mBGL
Casing Base: 129.1 mBGL

Response Zone Top RL: -65.99 m AHD
Response Zone Base RL: -68.99 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -8.13 mAHD

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

Method: WB

Reduced Level (m)	Depth (m)	Summary Geology
		SANDSTONE, medium to coarse, pale grey
-34.0	92.0	NO CORE
		SANDSTONE, medium to coarse, pale grey
-36.0	94.0	NO CORE
-38.0	96.0	SANDSTONE, medium to coarse, pale grey
		SANDSTONE, coarse, pale grey
-40.0	98.0	SANDSTONE, medium to coarse, pale grey *continued*
-42.0	100.0	SANDSTONE, fine to medium, pale grey
		SANDSTONE, medium, pale grey
-44.0	102.0	SANDSTONE, medium to coarse, pale grey and brown-grey
-46.0	104.0	SANDSTONE, medium, pale grey
		SANDSTONE, medium, grey
-48.0	106.0	SANDSTONE, medium, pale grey
		SANDSTONE, coarse, pale brown
-50.0	108.0	SANDSTONE, medium, pale grey
-52.0	110.0	SANDSTONE, coarse, pale grey to pale brown
		SANDSTONE, medium, pale grey
-54.0	112.0	SANDSTONE, coarse, pale grey
		SANDSTONE, medium, pale grey
-56.0	114.0	SANDSTONE, medium, grey
-58.0	116.0	SANDSTONE, medium, pale grey
-60.0	118.0	SANDSTONE, medium to coarse, pale grey
-62.0	120.0	SANDSTONE, coarse, pale grey

Piezometer: Length 90.0 to 120.0 m — BENTONITE SEAL (PELLETS)

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B138P

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** MC/AM	**Checked by:** -
Location: Edgecliffe Esplanade - Seaforth		**Start Date:** 13/12/2017	**End Date:** 21/12/2017
Driller: Terratest	**Hole Diameter:** 99 mm	**Easting:** 337152.9 m	**RL:** 57.54 m
Drill Rig: Hydrapower Scout	**Inclination:** -90°	**Northing:** 625405.9 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H	**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: 57.47 m AHD
Casing Top: 0.0 mBGL
Casing Base: 129.1 mBGL

Response Zone Top RL: -65.99 m AHD
Response Zone Base RL: -68.99 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -8.13 mAHD

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
120.0–122.7		SANDSTONE, medium to coarse, pale grey
122.7–123.5		SANDSTONE, fine to medium, pale grey
123.5–128.6		SANDSTONE, medium to coarse, pale grey
128.6–129.0		SHALE BRECCIA
129.0–129.1		SANDSTONE, medium, pale grey

Depth scale: 122.0 (-64.0), 124.0 (-66.0), 126.0 (-68.0), 128.0 (-70.0), 130.0 (-72.0), 132.0 (-74.0), 134.0 (-76.0), 136.0 (-78.0), 138.0 (-80.0), 140.0 (-82.0), 142.0 (-84.0), 144.0 (-86.0), 146.0 (-88.0), 148.0 (-90.0), 150.0 (-92.0)

Interval	Installation
Length 120.0 to 123.5 m	2mm FILTER SAND
Length 123.5 to 126.5 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 126.5 to 129.1 m	2mm FILTER SAND (SUMP/PVC CAP)

B138P terminated at 129.10 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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Engineering Log

PIEZOMETER No. B140

Sheet: 1 of 4

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** DK/LB	**Checked by:** RR
Location: Ponsonby Parade - Seaforth		**Start Date:** 16/05/2017	**End Date:** 5/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 337517.1 m	**RL:** 65.67 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:** 6258806.8 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: 65.60 m AHD
Casing Top: 0.1 mBGL
Casing Base: 103.5 mBGL

Response Zone Top RL: -33.83 m AHD
Response Zone Base RL: -36.83 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -3.50 mAHD

Installation Date: 5/06/2017
Development Date: 24/08/2017

Method: NDD (0.0–0.4 m), HQ3

Core Run	TCR (%)	RQD (%)
R1	88	0
R2	100	85
R3	60 60	55 52
R4	100	100
R5	100	89
R6	100	86
R7	100	79
R8	100	74
R9	100	99
R10	100	91
R11	100 100	47 47
R12	100	95
R13	84	61

Reduced Level (m)	Depth (m)
64.0	2.0
62.0	4.0
60.0	6.0
58.0	8.0
56.0	10.0
54.0	12.0
52.0	14.0
50.0	16.0
48.0	18.0
46.0	20.0
44.0	22.0
42.0	24.0
40.0	26.0
38.0	28.0
36.0	30.0

Summary Geology (refer to geological log for full descriptions)

- CONCRETE
- Gravelly SAND, mediumt to coarse
- SANDSTONE, medium to coarse, pale yellow-brown and pale grey
- SANDSTONE, medium to coarse, orange-brown and pale grey
- NO CORE
- SANDSTONE, medium to coarse, orange-brown and pale grey
- SANDSTONE, fine to medium, pale grey and pale red
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE
- NO CORE
- SANDSTONE
- SANDSTONE, medium to coarse, pale grey
- MUDSTONE, dark grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, fine to medium, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, fine to medium, pale grey
- SANDSTONE, medium to coarse, pale grey

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

Piezometer installation:

- Length 0.0 to 0.0 m — GATIC COVER
- Length 0.0 to 97.0 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

Reduced Level RL (m): 64.0, 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

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	DK/LB	**Checked by:**	RR
Location:	Ponsonby Parade - Seaforth	**Start Date:**	16/05/2017	**End Date:**	5/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:**	337517.1 m	**RL:**	65.67 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:**	6258806.8 m	**Ver. Datum:**	AHD
	Bearing: N/A	**Hor. Proj/Dat:**	MGA94/GDA94-56	**Surface:**	Road surface

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 65.60 m AHD
Casing Top: 0.1 mBGL
Casing Base: 103.5 mBGL

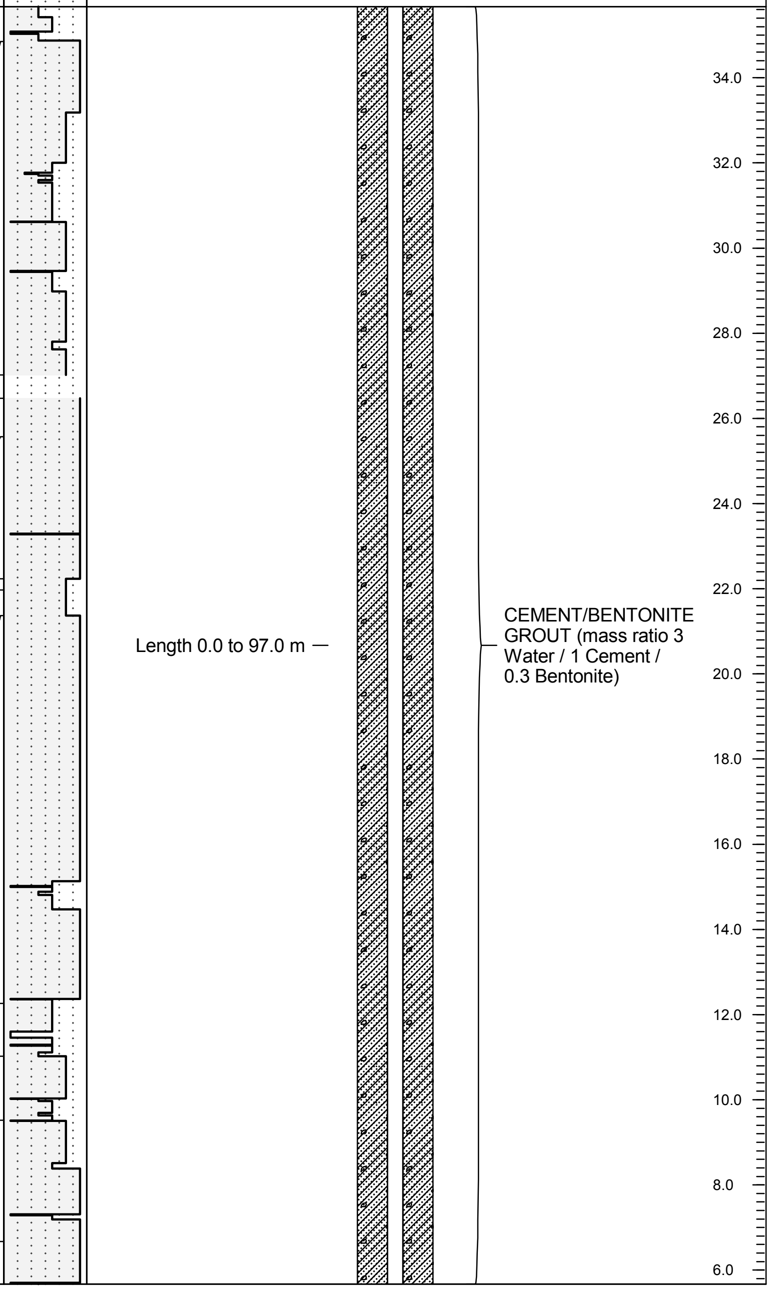
Response Zone Top RL: -33.83 m AHD
Response Zone Base RL: -36.83 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -3.50 mAHD

Installation Date: 5/06/2017
Development Date: 24/08/2017

Method: HQ3

Core Run	TCR (%)	RQD (%)	Reduced Level (m)	Depth (m)	Summary Geology (refer to geological log for full descriptions)
					NO CORE
R14	100	86	34.0	32.0	SANDSTONE, medium to coarse, pale grey *continued*
R15	100	100			SANDSTONE, fine to medium, pale grey
R16	100	95	32.0 / 30.0	34.0 / 36.0	
R17	82	81	28.0	38.0	
					NO CORE
R18	100	100	26.0	40.0	SANDSTONE, fine to medium, pale grey
R19	100	100	24.0	42.0	SANDSTONE, fine to medium, grey
R20	100	100			
R21	100	100	22.0	44.0	~~SANDSTONE, fine, pale grey to grey~~
					SANDSTONE, fine to medium, pale grey
R22	100	100	20.0 / 18.0	46.0 / 48.0	SANDSTONE
R23	100	97	16.0	50.0	
R24	100	100	14.0	52.0	
R25	100	93	12.0	54.0	SANDSTONE, medium to coarse, pale grey
R26	100	93	10.0	56.0	SANDSTONE, medium, pale grey
					SANDSTONE, fine to medium, pale grey
R27	100	98	8.0 / 6.0	58.0 / 60.0	SANDSTONE, medium, pale grey



GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. **B140**

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** DK/LB	**Checked by:** RR
Location: Ponsonby Parade - Seaforth		**Start Date:** 16/05/2017	**End Date:** 5/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 337517.1 m	**RL:** 65.67 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:** 6258806.8 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Road surface

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: 65.60 m AHD
Casing Top: 0.1 mBGL
Casing Base: 103.5 mBGL

Response Zone Top RL: -33.83 m AHD
Response Zone Base RL: -36.83 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -3.50 mAHD

Installation Date: 5/06/2017
Development Date: 24/08/2017

Method: HQ3
Ground Water: 29/09/2017

Core Run	TCR (%)	RQD (%)
R28	100	73
R29	100	94
R30	100	100
R31	100	100
R32	100	100
R33	100	99
R34	100	98
R35	100	98
R36	100	100
R37	100	100
R38	99 / 100	100 / 100
R39 / R40 / R41	100 / 100 / 100	100 / 100 / 100
R42	100	100
R43	100	100
R44		

Reduced Level (m)	Depth (m)
4.0	62.0
2.0	64.0
0.0	66.0
-2.0	68.0
-4.0	70.0
-6.0	72.0
-8.0	74.0
-10.0	76.0
-12.0	78.0
-14.0	80.0
-16.0	82.0
-18.0	84.0
-20.0	86.0
-22.0	88.0
-24.0	90.0

Summary Geology:

- MUDSTONE, dark grey
- SANDSTONE, fine to medium, pale grey
- SANDSTONE, fine to medium, grey
- SHALE BRECCIA
- SANDSTONE, medium, pale grey
- LAMINITE
- SANDSTONE, medium, pale grey
- LAMINITE
- SANDSTONE, medium, pale grey to grey
- SANDSTONE, fine to coarse, pale grey
- SANDSTONE, medium, pale grey
- SANDSTONE, fine to medium, pale grey
- SANDSTONE, medium to coarse, pale grey
- MUDSTONE, dark grey
- SANDSTONE, coarse, pale grey
- SANDSTONE, fine, pale grey
- SANDSTONE, medium, pale grey

Piezometer: Length 0.0 to 97.0 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:**	DK/LB	**Checked by:**	RR
Location: Ponsonby Parade - Seaforth		**Start Date:**	16/05/2017	**End Date:**	5/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:**	337517.1 m	**RL:**	65.67 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:**	6258806.8 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 (%)	Reduced Level (m)	Depth (m)	Summary Geology (refer to geological log for full descriptions)
	100	100			SANDSTONE, medium, pale grey *continued*
R45	100	94	-26.0	92.0	
R46	100	56	-28.0	94.0	MUDSTONE
					SANDSTONE, medium, pale grey
R47	96	60	-30.0	96.0	NO CORE
R48	100	100			SANDSTONE, medium, pale grey
R49	100	100	-32.0	98.0	
R50	100	95	-34.0	100.0	
			-36.0	102.0	
R51	100	94	-38.0	104.0	SANDSTONE, fine to medium, pale grey
R52	100	35			
R53	100	98	-40.0	106.0	
R54	100	100			
R55	100	100			
R56	100	98	-42.0	108.0	
			-44.0	110.0	SANDSTONE, medium, grey
R57	100	96	-46.0	112.0	SANDSTONE, fine to medium, pale grey
R58	100	100			SANDSTONE, medium to coarse, pale grey
			-48.0	114.0	
			-50.0	116.0	
			-52.0	118.0	
			-54.0	120.0	

Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 65.60 m AHD
Casing Top: 0.1 mBGL
Casing Base: 103.5 mBGL

Response Zone Top RL: -33.83 m AHD
Response Zone Base RL: -36.83 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -3.50 mAHD

Installation Date: 5/06/2017
Development Date: 24/08/2017

Interval	Material
Length 0.0 to 97.0 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)
Length 97.0 to 97.5 m	BENTONITE SEAL (PELLETS)
Length 97.5 to 99.5 m	2mm FILTER SAND
Length 99.5 to 102.5 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 102.5 to 103.5 m	2mm FILTER SAND (SUMP/PVC CAP)
Length 103.5 to 113.0 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

B140 terminated at 113.39 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

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PIEZOMETER No. B141

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** LB	**Checked by:** RR
Location: McMillan Street - Seaforth		**Start Date:** 6/06/2017	**End Date:** 20/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 337437.8 m	**RL:** 92.37 m
Drill Rig: Comacchio 405	**Inclination:** -90°	**Northing:** 6259374.0 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Grass

Field Data

Method	Core Run	TCR (%)	RQD (%)
ADT/NDD			
HQ3	R1	100	100
	R2	100	95
	R3	100	95
	R4	100	98
	R5	100	99
	R6	100	96
	R7	100	99
	R8	100	99
	R9	100	97
	R10	100	95
	R11	100	100
	R12	100	100

Columns: Ground Water, Reduced Level (m), Depth (m), Graphic Log, Defect Spacing (mm) (20, 40, 100, 300, 1000)

Rock Description

Summary Geology (refer to geological log for full descriptions)

Depth (m)	Description
0.0 – ~0.9	Clayey SAND
~0.9 – 2.2	SANDSTONE
2.2 – 3.6	SANDSTONE, medium, red and pale grey
3.6 – 10.9	SANDSTONE, fine to medium, pale grey and pale orange
10.9 – 15.2	SANDSTONE, medium, pale grey
15.2 – 15.7	SHALE BRECCIA
15.7 – 22.4	SANDSTONE, medium, pale grey
22.4 – 23.4	SANDSTONE, medium to coarse, pale grey
23.4 – 24.8	SANDSTONE, fine to medium, pale grey
24.8 – 26.2	SANDSTONE, medium to coarse, pale grey
26.2 – 30.0	SANDSTONE, medium, pale grey

Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 92.30 m AHD
Casing Top: 0.1 mBGL
Casing Base: 52.2 mBGL

Response Zone Top RL: 44.21 m AHD
Response Zone Base RL: 41.21 m AHD
Length of Response Zone: 3.00 m

Instrument Details: TD-Diver (Manual) at 53.80 mAHD

Installation Date: 20/06/2017
Development Date: 24/08/2017

Length 0.0 to 0.0 m — GATIC COVER

Length 0.0 to 45.2 m — CEMENT/BENTONITE GROUT (mass ratio 4 Water / 1 Cement / 0.3 Bentonite)

Reduced Level RL (m): 92.0, 90.0, 88.0, 86.0, 84.0, 82.0, 80.0, 78.0, 76.0, 74.0, 72.0, 70.0, 68.0, 66.0, 64.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. **B141**

Client: RMS			**Project No:** 60537922		
Project: Western Harbour Tunnel and Beaches Link			**Logged by:** LB	**Checked by:** RR	
Location: McMillan Street - Seaforth			**Start Date:** 6/06/2017	**End Date:** 20/06/2017	
Driller: Terratest	**Hole Diameter:** 96 mm		**Easting:** 337437.8 m	**RL:** 92.37 m	
Drill Rig: Comacchio 405	**Inclination:** -90°		**Northing:** 6259374.0 m	**Ver. Datum:** AHD	
	Bearing: N/A		**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Grass	

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 92.30 m AHD
Casing Top: 0.1 mBGL
Casing Base: 52.2 mBGL

Response Zone Top RL: 44.21 m AHD
Response Zone Base RL: 41.21 m AHD
Length of Response Zone: 3.00 m

Instrument Details: TD-Diver (Manual) at 53.80 mAHD

Installation Date: 20/06/2017
Development Date: 24/08/2017

Field Data / Rock Description

Method: HQ3

Core Run	TCR (%)	RQD (%)
R13	100	100
R14	100	99
R15	100	80
R16	100	100
R17	100	98
R18	100	98
R19	100	90
R20	100	95
R21	100	100
R22	100	100
R23	100	100
R24	100	100
R25	100	100
R26	100	99
R27	100	89
R28	100	100

Summary Geology (refer to geological log for full descriptions)

Depth (m) approx.	Description
30.0 – 36.4	SANDSTONE, medium, pale grey *continued*
36.4 – 37.9	SANDSTONE, fine, pale grey
37.9 – 40.5	SANDSTONE, medium, pale grey
40.5 – 40.8	SHALE BRECCIA
40.8 – 43.4	SANDSTONE, medium, pale grey
43.4 – 44.4	SANDSTONE, fine to medium, pale grey
44.4 – 47.6	SANDSTONE, medium, pale grey
47.6 – 51.7	SANDSTONE, fine to medium, pale grey
51.7 – 55.2	SANDSTONE, medium, pale grey
55.2 – 58.5	SANDSTONE, fine to medium, pale grey
58.5 – 59.2	SHALE BRECCIA
59.2 – 60.0	—

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

Piezometer Details

Length	Installation
Length 0.0 to 45.2 m	CEMENT/BENTONITE GROUT (mass ratio 4 Water / 1 Cement / 0.3 Bentonite)
Length 45.2 to 46.2 m	BENTONITE SEAL (PELLETS)
Length 46.2 to 48.2 m	2mm FILTER SAND
Length 48.2 to 51.2 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 51.2 to 52.2 m	2mm FILTER SAND (SUMP/PVC CAP)
Length 52.2 to 100.2 m	CEMENT/BENTONITE GROUT (mass ratio 4 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

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Engineering Log

PIEZOMETER No. B141

Client:	RMS		**Project No:**	60537922	
Project:	Western Harbour Tunnel and Beaches Link		**Logged by:**	LB	**Checked by:** RR
Location:	McMillan Street - Seaforth		**Start Date:**	6/06/2017	**End Date:** 20/06/2017
Driller:	Terratest	**Hole Diameter:** 96 mm	**Easting:**	337437.8 m	**RL:** 92.37 m
Drill Rig:	Comacchio 405	**Inclination:** -90°	**Northing:**	6259374.0 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: 92.30 m AHD
Casing Top: 0.1 mBGL
Casing Base: 52.2 mBGL

Response Zone Top RL: 44.21 m AHD
Response Zone Base RL: 41.21 m AHD
Length of Response Zone: 3.00 m

Instrument Details: TD-Diver (Manual) at 53.80 mAHD

Installation Date: 20/06/2017
Development Date: 24/08/2017

Method	Core Run	TCR (%)	RQD (%)	Ground Water	Reduced Level (m)	Depth (m)	Summary Geology (refer to geological log for full descriptions)
HQ3	R29	100	100	24/08/2017	32.0 – 30.0	62.0	SANDSTONE, fine to medium, pale grey *continued*
	R30	100	95		28.0	64.0 – 66.0	
	R31	100	100		26.0 – 24.0	68.0	
	R32	100	100		22.0	70.0 – 72.0	
	R33	100	100		20.0	74.0	
	R34	100	100		18.0		
	R35	100	100		16.0	76.0	SANDSTONE, fine to medium, grey
							SANDSTONE, fine to medium, pale grey to grey
	R36	100	100		14.0	78.0	
	R37	100	98		12.0	80.0	
	R38	100	100			82.0	MUDSTONE, dark grey
	R39	100	100		10.0		SANDSTONE, medium, grey
							LAMINITE
	R40	100	100		8.0	84.0	SANDSTONE, medium, pale grey
	R41	100	100		6.0	86.0	
	R42	100	100		4.0	88.0 – 90.0	

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

Length 52.2 to 100.2 m — CEMENT/BENTONITE GROUT (mass ratio 4 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

PIEZOMETER No. B141

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	LB	**Checked by:**	RR
Location:	McMillan Street - Seaforth	**Start Date:**	6/06/2017	**End Date:**	20/06/2017
Driller:	Terratest	**Hole Diameter:** 96 mm	**Easting:** 337437.8 m	**RL:**	92.37 m
Drill Rig:	Comacchio 405	**Inclination:** -90°	**Northing:** 6259374.0 m	**Ver. Datum:**	AHD
		Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:**	Grass

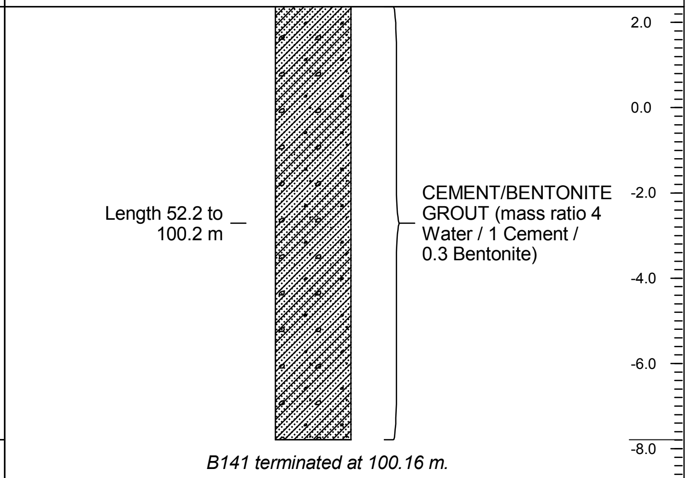
Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 92.30 m AHD
Casing Top: 0.1 mBGL
Casing Base: 52.2 mBGL

Response Zone Top RL: 44.21 m AHD
Response Zone Base RL: 41.21 m AHD
Length of Response Zone: 3.00 m

Instrument Details: TD-Diver (Manual) at 53.80 mAHD

Installation Date: 20/06/2017
Development Date: 24/08/2017

Method	Core Run	TCR (%)	RQD (%)	Reduced Level (m)	Depth (m)	Summary Geology (refer to geological log for full descriptions)
HQ3	R43	100 / 100	100 / 100	2.0		SANDSTONE, medium, pale grey *continued*
HQ3	R44	100	100	0.0	92.0	SANDSTONE, fine to medium, pale grey
HQ3	R45	100	97	-2.0	94.0–96.0	
HQ3	R46	100	100	-4.0 to -6.0	98.0	LAMINITE
HQ3	R47	100	93		100.0	SANDSTONE, fine to medium, pale grey



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	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 (at approx. 9.0 m depth)

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

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

Length 0.0 to 0.0 m — GATIC COVER

Length 0.0 to 54.9 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. **B149**

Sheet: 2 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

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

Method	Core Run	TCR (%)	RQD (%)	Depth (m)	Summary Geology
HQ3					grey
	R12	100	100	32.0	SANDSTONE, coarse, pale grey *continued*
					SANDSTONE, medium to coarse, pale grey
	R13	100	100	34.0–36.0	
	R14	100	100	38.0	
	R15	100	100	40.0	MUDSTONE, fine, dark grey and pale grey
	R16	100	100	42.0	LAMINITE
	R17	100	100	44.0	SANDSTONE, medium to coarse, pale grey
	R18	100	96	46.0–48.0	SANDSTONE, fine, grey
	R19	100	99	50.0	SANDSTONE, medium to coarse, pale grey
	R20	100	100	52.0	SANDSTONE, medium to coarse, pale grey and pale brown
	R21	100	100	54.0	SANDSTONE, medium to coarse, pale grey
	R22	100	100	56.0–58.0	
	R23	100	100	60.0	

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

Reduced Level RL (m): -2.0 to -30.0

Interval	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

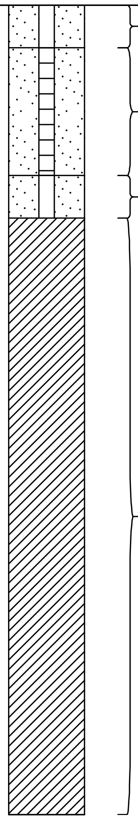
Field Data | **Rock Description** | **Piezometer Details**

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

Summary Geology (refer to geological log for full descriptions)

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

Method	Core Run	TCR (%)	RQD (%)	Ground Water	Reduced Level (m)	Depth (m)	Summary Geology
HQ3	R24	100	100		-32.0	62.0	SANDSTONE, medium to coarse, pale grey *continued*
	R25	33	100		-34.0 / -36.0	64.0	
	R26	100	100		-38.0	66.0	SANDSTONE, coarse, pale grey
						68.0	MUDSTONE, dark grey
	R27	100	95		-40.0 / -42.0	70.0	SANDSTONE, fine to medium, pale grey to grey
	R28	100	98		-44.0	72.0	SANDSTONE, fine to coarse, pale grey
							MUDSTONE, dark grey
						74.0	SANDSTONE, fine to medium, pale grey
	R29	100	100		-46.0 / -48.0	76.0	SANDSTONE, medium to coarse, pale grey
	R30	100	72		-50.0	78.0	SANDSTONE, fine to medium, pale grey
					-52.0	80.0	
					-54.0	82.0	
					-56.0	84.0	
					-58.0	86.0	
					-60.0	88.0	
						90.0	



Length	Piezometer detail
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)

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, -58.0, -60.0

B149 terminated at 79.00 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

AECOM coffey

Engineering Log

PIEZOMETER No. B150

Sheet: 1 of 2

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

Method	Core Run	TCR (%)	RQD (%)	Summary Geology (refer to geological log for full descriptions)
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. RL 67.7 m)

Piezometer installation

Length	Detail
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

AECOM coffey

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)	Rock Description
HQ3	R11	100	100	30.0–32.0	SANDSTONE, medium, pale grey *continued*
	R12	100	100	34.0–36.0	
	R13	100	100	38.0	SHALE BRECCIA
	R14	100	100	40.0	SANDSTONE, medium to coarse, pale grey
				42.0	SANDSTONE, fine, grey
	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

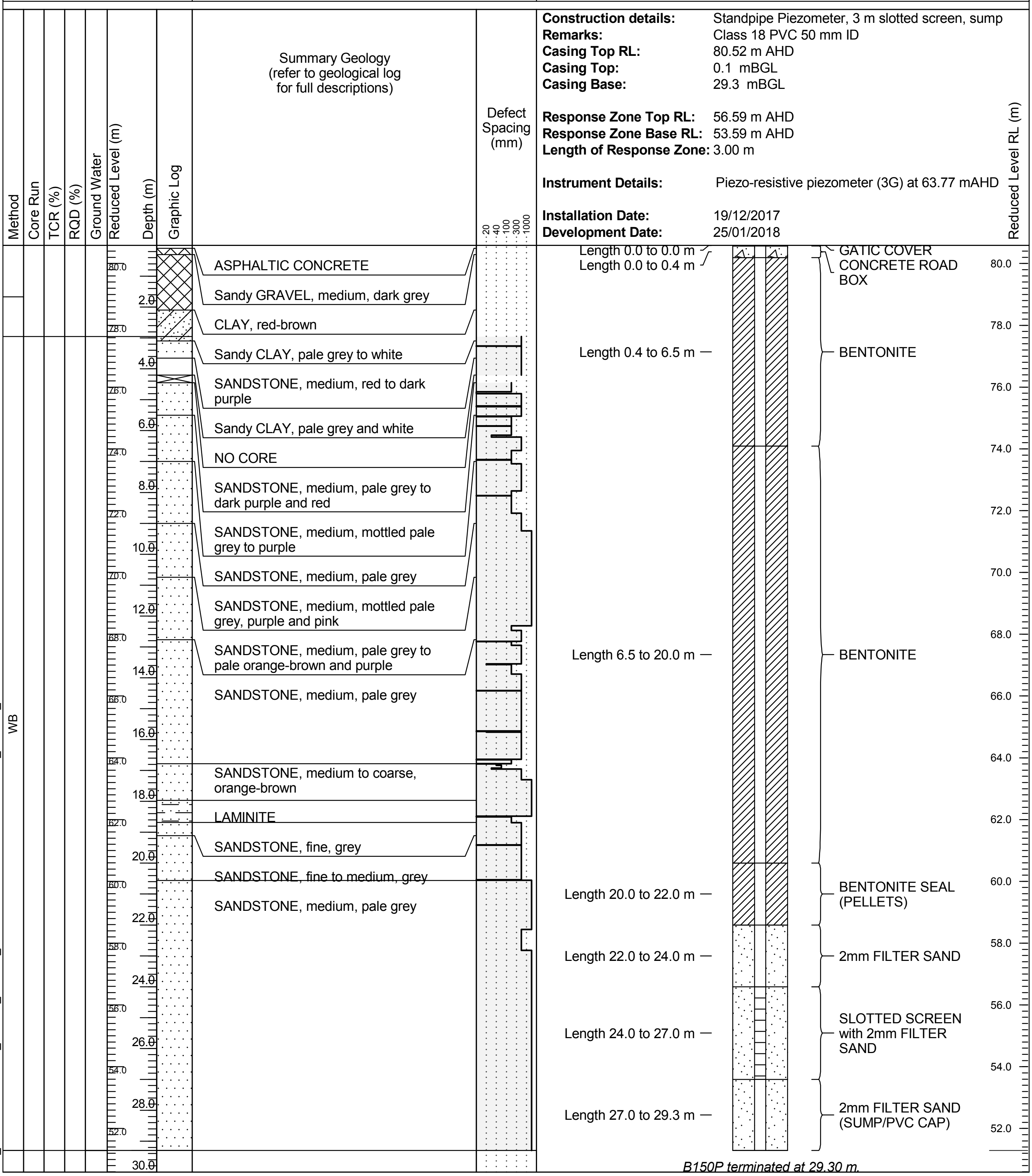
Field Data | **Rock Description** | **Piezometer Details**

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)

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



B150P terminated at 29.30 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

AECOM coffey

PIEZOMETER No. B154

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** LH	**Checked by:** RPW
Location: Small Street - Willoughby		**Start Date:** 18/06/2017	**End Date:** 26/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 333821.6 m	**RL:** 56.29 m
Drill Rig: Comacchio 305	**Inclination:** -90°	**Northing:** 6257311.2 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56	**Surface:** Road Surface

Field Data

Method	Core Run	TCR (%)	RQD (%)
HAND			
HQ3	R1	100	100
HQ3	R2	100	96
HQ3	R3	100	97
HQ3	R4	100	100
HQ3	R5	98	93
HQ3	R6	100	100
HQ3	R7	100	100
HQ3	R8	100	90
HQ3	R9	100	88
HQ3	R10	100	90
HQ3	R11	100	88
HQ3	R12	100	100

Columns: Ground Water, Reduced Level (m), Depth (m), Graphic Log. Reduced Level marks 56.0 to 28.0; Depth marks 2.0 to 30.0.

Rock Description

Summary Geology (refer to geological log for full descriptions)

- ASPHALTIC CONCRETE
- Clayey Gravelly SAND
- Sandy, Gravelly CLAY, fine to coarse, brown-grey
- Clayey SAND, fine to medium, pale brown to grey
- SANDSTONE, medium, pale grey and mottled pale brown
- SANDSTONE, medium, pink to pale pink
- SANDSTONE, medium, orange-brown
- SANDSTONE, medium to coarse, pale pink to dark pink
- SANDSTONE, medium, dark pink to pale orange
- SANDSTONE, medium, pale grey
- SHALE BRECCIA
- SANDSTONE, medium, pale grey
- NO CORE
- SANDSTONE, medium, pale grey
- SANDSTONE, fine to medium, grey
- SANDSTONE, medium, pale grey
- SANDSTONE, medium to coarse, grey and pale grey
- SANDSTONE, medium, pale grey
- SANDSTONE, medium, pale brown
- SANDSTONE, medium, pale grey to pale brown
- SANDSTONE, fine to medium, grey to 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:	56.19 m AHD
Casing Top:	0.1 mBGL
Casing Base:	54.0 mBGL
Response Zone Top RL:	6.29 m AHD
Response Zone Base RL:	3.29 m AHD
Length of Response Zone:	3.00 m
Instrument Details:	Piezo-resistive piezometer (3G) at 20.89 mAHD
Installation Date:	29/06/2017
Development Date:	28/08/2017

Length 0.0 to 0.1 m — GATIC COVER

Length 0.0 to 46.0 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

Reduced Level RL (m): 56.0, 54.0, 52.0, 50.0, 48.0, 46.0, 44.0, 42.0, 40.0, 38.0, 36.0, 34.0, 32.0, 30.0, 28.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

2017_ANZ_PIEZO_WHT_AECOM 60537922_WHTBL_AECOM_MASTER FOR PIEZO.GPJ WHTBL_AECOM_2-06.LIBRARY.GLB 11.4.2018

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** LH	**Checked by:** RPW
Location: Small Street - Willoughby		**Start Date:** 18/06/2017	**End Date:** 26/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 333821.6 m	**RL:** 56.29 m
Drill Rig: Comacchio 305	**Inclination:** -90°	**Northing:** 6257311.2 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: 56.19 m AHD
Casing Top: 0.1 mBGL
Casing Base: 54.0 mBGL

Response Zone Top RL: 6.29 m AHD
Response Zone Base RL: 3.29 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at 20.89 mAHD

Installation Date: 29/06/2017
Development Date: 28/08/2017

Summary Geology (refer to geological log for full descriptions)

Method: HQ3. Ground water: 29/09/2017 (water level at approx. 31.0 m depth).

Core Run	TCR (%)	RQD (%)	Depth (m)	Rock Description
R13	100	97	to 32.0	SANDSTONE, fine to medium, grey and pale grey *continued*
R14	100	85	to 34.0	SANDSTONE, fine to medium, pale grey to grey
R15	100	92	to 36.0	SANDSTONE, medium, pale grey
R16	100	85	to 39.0	
R17	100	67	to 42.0	
R18	100	100	to 44.0	
R19	100	97	to 47.0	SANDSTONE, fine to coarse, pale grey (from 46.0)
R20	100	90	to 49.0	SANDSTONE, medium, pale grey (from 49.0)
R21	100	95	to 51.0	SANDSTONE, medium, pale grey and dark grey
R22	100	43	to 54.5	SANDSTONE, medium, pale grey to grey; SANDSTONE, medium, pale grey
R23	90	0	to 55.5	NO CORE
R24	100	45	to 57.0	SANDSTONE, coarse, pale grey and brown; SANDSTONE, fine, grey
R25	100	70	to 60.0	SHALE BRECCIA; SANDSTONE, fine, grey and dark grey

Length	Piezometer Details
Length 0.0 to 46.0 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)
Length 46.0 to 48.0 m	BENTONITE SEAL (PELLETS)
Length 48.0 to 50.0 m	2mm FILTER SAND
Length 50.0 to 53.0 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 53.0 to 54.0 m	2mm FILTER SAND (SUMP/PVC CAP)
Length 54.0 to 68.0 m	BENTONITE SEAL (PELLETS)

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** LH	**Checked by:** RPW
Location: Small Street - Willoughby		**Start Date:** 18/06/2017	**End Date:** 26/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 333821.6 m	**RL:** 56.29 m
Drill Rig: Comacchio 305	**Inclination:** -90°	**Northing:** 6257311.2 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: 56.19 m AHD
Casing Top: 0.1 mBGL
Casing Base: 54.0 mBGL

Response Zone Top RL: 6.29 m AHD
Response Zone Base RL: 3.29 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at 20.89 mAHD

Installation Date: 29/06/2017
Development Date: 28/08/2017

Method	Core Run	TCR (%)	RQD (%)	Ground Water	Reduced Level (m)	Depth (m)	Graphic Log	Summary Geology
HQ3	R26	100	70		-4.0			SHALE BRECCIA *continued*
						62.0		SANDSTONE, fine to medium, pale grey and grey
	R27	100	100		-6.0			SANDSTONE, coarse, pale grey
						64.0		SANDSTONE, fine, grey
					-8.0			SANDSTONE, medium, pale grey
	R28	100	97		-10.0	66.0		
						68.0		

Length 54.0 to 68.0 m — BENTONITE SEAL (PELLETS)

B154 terminated at 68.00 m.

Reduced Level RL (m): -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, -32.0

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

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

AECOM coffey

PIEZOMETER No. B155

Client: RMS
Project: Western Harbour Tunnel and Beaches Link
Location: Bega Road - Northbridge
Driller: Terratest
Drill Rig: Comacchio 305
Hole Diameter: 96 mm
Inclination: -90°
Bearing: N/A
Project No: 60537922
Logged by: LH
Start Date: 5/06/2017
Easting: 335052.9 m
Northing: 6257485.8 m
Hor. Proj/Dat: MGA94/GDA94-56M
Checked by: RPW
End Date: 15/06/2017
RL: 80.11 m
Ver. Datum: AHD
Surface: Road Surface

Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 79.95 m AHD
Casing Top: 0.2 mBGL
Casing Base: 139.0 mBGL

Response Zone Top RL: -54.89 m AHD
Response Zone Base RL: -57.89 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -10.95 mAHD

Installation Date: 15/06/2017
Development Date: 28/08/2017

Field Data

Method: NDD (0.0–1.5 m); HQ3 (1.5–30.0 m)

Core Run	TCR (%)	RQD (%)
R1	100	90
R2	100	98
R3	100	100
R4	100	97
R5	100	100
R6	100	100
R7	100	99
R8	100	100
R9	100	100
R10	100	100
R11	100	100

Rock Description

Summary Geology (refer to geological log for full descriptions)

- ASPHALTIC CONCRETE
- CONCRETE
- Clayey SAND, fine to medium, brown-grey
- Clayey SAND, fine to medium, pale orange-brown
- SANDSTONE, medium, pale grey
- SANDSTONE, medium to coarse, dark purple
- SANDSTONE, medium, pale grey
- SANDSTONE, medium to coarse, pale grey to purple
- SANDSTONE, medium, pale grey
- SANDSTONE, medium to coarse, pale grey
- SHALE BRECCIA
- SANDSTONE, medium, pale grey
- SANDSTONE, medium, grey to pale grey

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

Installation

- Length 0.0 to 0.1 m — GATIC COVER
- Length 0.0 to 132.0 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

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 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

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B155

Sheet: 2 of 5

Client: RMS		**Project No:**	60537922		
Project: Western Harbour Tunnel and Beaches Link		**Logged by:**	LH	**Checked by:**	RPW
Location: Bega Road - Northbridge		**Start Date:**	5/06/2017	**End Date:**	15/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:**	335052.9 m	**RL:**	80.11 m
Drill Rig: Comacchio 305	**Inclination:** -90°	**Northing:**	6257485.8 m	**Ver. Datum:**	AHD
	Bearing: N/A	**Hor. Proj/Dat:**	MGA94/GDA94-56M	**Surface:**	Road Surface

Piezometer Details

- **Construction details:** Standpipe Piezometer, 3 m slotted screen, sump
- **Remarks:** Class 18 PVC 50 mm ID
- **Casing Top RL:** 79.95 m AHD
- **Casing Top:** 0.2 mBGL
- **Casing Base:** 139.0 mBGL
- **Response Zone Top RL:** -54.89 m AHD
- **Response Zone Base RL:** -57.89 m AHD
- **Length of Response Zone:** 3.00 m
- **Instrument Details:** Piezo-resistive piezometer (3G) at -10.95 mAHD
- **Installation Date:** 15/06/2017
- **Development Date:** 28/08/2017

Field Data / Rock Description (Method: HQ3)

Core Run	TCR (%)	RQD (%)	Depth (m)	Summary Geology (refer to geological log for full descriptions)
R12	100	100	30.0–32.0	SANDSTONE, medium to coarse, pale grey *continued*; SANDSTONE, fine, grey; SANDSTONE, medium to coarse, pale grey
R13	100	100	34.0	SANDSTONE, fine, grey; SANDSTONE, medium, pale grey
R14	100	100	38.0	SANDSTONE, medium to coarse, pale grey with pale purple speckling
R15	100	99	40.0	SANDSTONE, medium, pale grey
R16	100	99		
R17	100	100	44.0	
R18	100	100	46.0	
R19	100	100	50.0	SANDSTONE, medium to coarse, pale grey; SANDSTONE, medium, pale grey
R20	100	99	52.0	SANDSTONE, medium to coarse, pale grey, with speckled brown and purple
R21	100	100	54.0–56.0	SANDSTONE, medium, pale grey; SANDSTONE, fine to medium, grey and pale grey
R22	99	99	58.0–60.0	MUDSTONE, dark grey; SANDSTONE, medium, pale grey; SANDSTONE, fine to medium, pale

Length 0.0 to 132.0 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

Reduced Level RL (m): 48.0, 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

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B155

Client:	RMS		**Project No:**	60537922	
Project:	Western Harbour Tunnel and Beaches Link		**Logged by:**	LH	**Checked by:** RPW
Location:	Bega Road - Northbridge		**Start Date:**	5/06/2017	**End Date:** 15/06/2017
Driller:	Terratest	**Hole Diameter:** 96 mm	**Easting:**	335052.9 m	**RL:** 80.11 m
Drill Rig:	Comacchio 305	**Inclination:** -90°	**Northing:**	6257485.8 m	**Ver. Datum:** AHD
		Bearing: N/A	**Hor. Proj/Dat:**	MGA94/GDA94-56M	**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: 79.95 m AHD
Casing Top: 0.2 mBGL
Casing Base: 139.0 mBGL

Response Zone Top RL: -54.89 m AHD
Response Zone Base RL: -57.89 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -10.95 mAHD

Installation Date: 15/06/2017
Development Date: 28/08/2017

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) | Piezometer Details | Reduced Level RL (m)

Method: HQ3

Core Run	TCR (%)	RQD (%)
R23	100	100
R24	100	100
R25	100	100
R26	100	100
R27	100	100
R28	100	100
R29	100	100
R30	100	100
R31	100	100
R32	100	100
R33	100	100
R34	100	100

Ground Water: 29/[illegible]/2017

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 (m): 20.0, 18.0, 16.0, 14.0, 12.0, 10.0, 8.0, 6.0, 4.0, 2.0, 0.0, -2.0, -4.0, -6.0, -8.0

Summary Geology:
- grey to grey
- NO CORE
- SANDSTONE, medium, pale grey to grey *continued*
- SANDSTONE, medium, pale grey
- MUDSTONE, dark grey
- SANDSTONE, fine to medium, pale grey to grey
- SANDSTONE, medium, pale grey
- SANDSTONE, medium to coarse, pale grey
- LAMINITE
- SANDSTONE, pale grey
- LAMINITE
- SANDSTONE, medium, pale grey
- LAMINITE
- SANDSTONE, medium, pale grey
- SANDSTONE, fine to medium, grey
- SANDSTONE, medium, pale grey

Piezometer Details: Length 0.0 to 132.0 m — CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

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

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. **B155**

Client: RMS		**Project No:**	60537922		
Project: Western Harbour Tunnel and Beaches Link		**Logged by:**	LH	**Checked by:**	RPW
Location: Bega Road - Northbridge		**Start Date:**	5/06/2017	**End Date:**	15/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:**	335052.9 m	**RL:**	80.11 m
Drill Rig: Comacchio 305	**Inclination:** -90°	**Northing:**	6257485.8 m	**Ver. Datum:**	AHD
	Bearing: N/A	**Hor. Proj/Dat:**	MGA94/GDA94-56M	**Surface:**	Road Surface

Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 79.95 m AHD
Casing Top: 0.2 mBGL
Casing Base: 139.0 mBGL

Response Zone Top RL: -54.89 m AHD
Response Zone Base RL: -57.89 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -10.95 mAHD

Installation Date: 15/06/2017
Development Date: 28/08/2017

Field Data / Rock Description

Method: HQ3

Core Run	TCR (%)	RQD (%)	Depth (m)	Summary Geology (refer to geological log for full descriptions)
R34	100	100	90.0–92.0	SANDSTONE, medium, pale grey *continued*
R35	100	100	92.0–94.0	
R36	100	100	94.0–96.0	
R37	100	100	96.0–98.0	
R38	100	90	100.0–102.0	SHALE BRECCIA (~101.6 m)
			~102.0	SANDSTONE, medium, pale grey
R39	100	100		
			~105.5	LAMINITE
R40	100	100	~105.8	SANDSTONE, medium, pale grey
			~107.8	SANDSTONE, fine to medium, grey
R41	100	100	~109.8	SANDSTONE, medium to coarse, pale grey
R42	100	100	~110.9	SANDSTONE, medium, pale grey
			~113.2	SANDSTONE, fine to medium, grey to pale grey
R43	100	100	~114.6	SANDSTONE, medium, pale grey
			~115.5	SANDSTONE, medium to coarse, pale grey
R44	100	100		
R45	100	100	120.0	

Reduced Level (m): -10.0 to -40.0

Length 0.0 to 132.0 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:**	LH	**Checked by:**	RPW
Location:	Bega Road - Northbridge	**Start Date:**	5/06/2017	**End Date:**	15/06/2017
Driller:	Terratest	**Hole Diameter:**	96 mm	**Easting:**	335052.9 m
RL:	80.11 m	**Drill Rig:**	Comacchio 305	**Inclination:**	-90°
Northing:	6257485.8 m	**Ver. Datum:**	AHD	**Bearing:**	N/A
Hor. Proj/Dat:	MGA94/GDA94-56M	**Surface:**	Road Surface		

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 79.95 m AHD
Casing Top: 0.2 mBGL
Casing Base: 139.0 mBGL

Response Zone Top RL: -54.89 m AHD
Response Zone Base RL: -57.89 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -10.95 mAHD

Installation Date: 15/06/2017
Development Date: 28/08/2017

Field Data / Rock Description

Method: HQ3

Core Run	TCR (%)	RQD (%)
R45	100	100
R46	100	100
R47	100	100
R48	100	100
R49	100	100
R50	100	100
R51	100	100
R52	100	100
R53	100	100
R54	100	66
R55	100	100
R56	100	100

Summary Geology (refer to geological log for full descriptions)

Depth from (m)	Summary Geology
122.0	SANDSTONE, medium, pale grey
~122.6	SANDSTONE, medium to coarse, pale grey
~124.3	SANDSTONE, medium, pale grey
~126.2	SANDSTONE, medium to coarse, pale grey
~130.3	SANDSTONE, medium, pale grey
~135.4	SANDSTONE, medium to coarse, pale grey
~138.3	SANDSTONE, medium, pale grey
~141.6	SANDSTONE, medium to coarse, pale grey
~144.2	SANDSTONE, medium, pale grey
~145.3	SANDSTONE, medium to coarse, pale grey
~146.5	SANDSTONE, medium, pale grey

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

Piezometer Details

Length	Material	Reduced Level
Length 0.0 to 132.0 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)	
Length 132.0 to 133.0 m	BENTONITE SEAL (PELLETS)	
Length 133.0 to 135.0 m	2mm FILTER SAND	
Length 135.0 to 138.0 m	SLOTTED SCREEN with 2mm FILTER SAND	
Length 138.0 to 139.0 m	2mm FILTER SAND (SUMP/PVC CAP)	
Length 139.0 to 143.0 m	2mm FILTER SAND	
Length 143.0 to 149.0 m	BENTONITE SEAL (PELLETS)	

B155 terminated at 149.00 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B155P

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** MC/AM	**Checked by:** -
Location: Bega Road - Northbridge		**Start Date:** 12/12/2017	**End Date:** 15/12/2017
Driller: Terratest	**Hole Diameter:** 99 mm	**Easting:** 335052.9 m	**RL:** 80.06 m
Drill Rig: Comacchio 450P	**Inclination:** -90°	**Northing:** 6257486.1 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H	**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: 79.98 m AHD
Casing Top: 0.1 mBGL
Casing Base: 139.0 mBGL

Response Zone Top RL: -54.94 m AHD
Response Zone Base RL: -57.94 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -10.92 mAHD

Installation Date: 15/12/2017
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: ADT (0.0–~2.0 m); WB (below ~2.0 m)

Summary Geology
ASPHALTIC CONCRETE
CONCRETE
Clayey SAND, fine to medium, brown-grey
Clayey SAND, fine to medium, pale orange-brown
SANDSTONE, medium, pale grey
SANDSTONE, medium to coarse, dark purple
SANDSTONE, medium, pale grey
SANDSTONE, medium to coarse, pale grey to purple
SANDSTONE, medium, pale grey
SANDSTONE, medium to coarse, pale grey
SHALE BRECCIA
SANDSTONE, medium, pale grey
SANDSTONE, medium, grey to pale grey

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): 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

Piezometer installation:

Length	Item
Length 0.0 to 0.0 m	GATIC COVER
Length 0.0 to 0.4 m	CONCRETE ROAD BOX
Length 0.4 to 26.0 m	BENTONITE - bridged seal
Length 26.0 to 80.0 m	BENTONITE

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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Engineering Log

PIEZOMETER No. **B155P**

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	MC/AM	**Checked by:**	-
Location:	Bega Road - Northbridge	**Start Date:**	12/12/2017	**End Date:**	15/12/2017
Driller:	Terratest	**Hole Diameter:** 99 mm	**Easting:** 335052.9 m	**RL:**	80.06 m
Drill Rig:	Comacchio 450P	**Inclination:** -90°	**Northing:** 6257486.1 m	**Ver. Datum:**	AHD
		Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H	**Surface:**	Road surface

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

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 79.98 m AHD
Casing Top: 0.1 mBGL
Casing Base: 139.0 mBGL

Response Zone Top RL: -54.94 m AHD
Response Zone Base RL: -57.94 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -10.92 mAHD

Installation Date: 15/12/2017
Development Date: 25/01/2018

Method: WB

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

Piezometer: Length 26.0 to 80.0 m — BENTONITE

Reduced Level RL (m): 48.0, 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

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:	Bega Road - Northbridge		**Start Date:**	12/12/2017	**End Date:** 15/12/2017
Driller:	Terratest	**Hole Diameter:** 99 mm	**Easting:**	335052.9 m	**RL:** 80.06 m
Drill Rig:	Comacchio 450P	**Inclination:** -90°	**Northing:**	6257486.1 m	**Ver. Datum:** AHD
		Bearing: N/A	**Hor. Proj/Dat:**	MGA94/GDA94-56H	**Surface:** Road surface

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:	79.98 m AHD
Casing Top:	0.1 mBGL
Casing Base:	139.0 mBGL
Response Zone Top RL:	-54.94 m AHD
Response Zone Base RL:	-57.94 m AHD
Length of Response Zone:	3.00 m
Instrument Details:	Piezo-resistive piezometer (3G) at -10.92 mAHD
Installation Date:	15/12/2017
Development Date:	25/01/2018

Method: WB

Depth (m)	Summary Geology
60.0	grey to grey
	NO CORE
	SANDSTONE, medium, pale grey to grey *continued*
64.4	SANDSTONE, medium, pale grey
65.9	MUDSTONE, dark grey
67.3	SANDSTONE, fine to medium, pale grey to grey
74.2	SANDSTONE, medium, pale grey
78.5	SANDSTONE, medium to coarse, pale grey
	LAMINITE
	SANDSTONE, pale grey
	LAMINITE
	SANDSTONE, medium, pale grey
	LAMINITE
	SANDSTONE, medium, pale grey
	SANDSTONE, fine to medium, grey
87.4	SANDSTONE, medium, pale grey

Depth scale: 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 scale: 20.0, 18.0, 16.0, 14.0, 12.0, 10.0, 8.0, 6.0, 4.0, 2.0, 0.0, -2.0, -4.0, -6.0, -8.0

Piezometer details:

- Length 26.0 to 80.0 m — BENTONITE
- Length 80.0 to 129.0 m — BENTONITE - confirmed seal

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. **B155P**

Client:	RMS		**Project No:**	60537922	
Project:	Western Harbour Tunnel and Beaches Link		**Logged by:**	MC/AM	**Checked by:** -
Location:	Bega Road - Northbridge		**Start Date:**	12/12/2017	**End Date:** 15/12/2017
Driller:	Terratest	**Hole Diameter:** 99 mm	**Easting:**	335052.9 m	**RL:** 80.06 m
Drill Rig:	Comacchio 450P	**Inclination:** -90°	**Northing:**	6257486.1 m	**Ver. Datum:** AHD
		Bearing: N/A	**Hor. Proj/Dat:**	MGA94/GDA94-56H	**Surface:** Road surface

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: 79.98 m AHD
Casing Top: 0.1 mBGL
Casing Base: 139.0 mBGL

Response Zone Top RL: -54.94 m AHD
Response Zone Base RL: -57.94 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -10.92 mAHD

Installation Date: 15/12/2017
Development Date: 25/01/2018

Method: WB

Depth (m)	Reduced Level (m)	Summary Geology
90.0	-10.0	SANDSTONE, medium, pale grey *continued*
102.0	-22.0	SHALE BRECCIA
		SANDSTONE, medium, pale grey
106.0	-26.0	LAMINITE
		SANDSTONE, medium, pale grey
108.0	-28.0	SANDSTONE, fine to medium, grey
110.0	-30.0	SANDSTONE, medium to coarse, pale grey
		SANDSTONE, medium, pale grey
		SANDSTONE, fine to medium, grey to pale grey
		SANDSTONE, medium, pale grey
		SANDSTONE, medium to coarse, pale grey

Depth scale: 92.0, 94.0, 96.0, 98.0, 100.0, 102.0, 104.0, 106.0, 108.0, 110.0, 112.0, 114.0, 116.0, 118.0, 120.0

Reduced Level scale: -10.0, -12.0, -14.0, -16.0, -18.0, -20.0, -22.0, -24.0, -26.0, -28.0, -30.0, -32.0, -34.0, -36.0, -38.0

Piezometer: Length 80.0 to 129.0 m — BENTONITE - confirmed seal

Reduced Level RL (m): -12.0, -14.0, -16.0, -18.0, -20.0, -22.0, -24.0, -26.0, -28.0, -30.0, -32.0, -34.0, -36.0, -38.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B155P

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** MC/AM	**Checked by:** -
Location: Bega Road - Northbridge		**Start Date:** 12/12/2017	**End Date:** 15/12/2017
Driller: Terratest	**Hole Diameter:** 99 mm	**Easting:** 335052.9 m	**RL:** 80.06 m
Drill Rig: Comacchio 450P	**Inclination:** -90°	**Northing:** 6257486.1 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H	**Surface:** Road surface

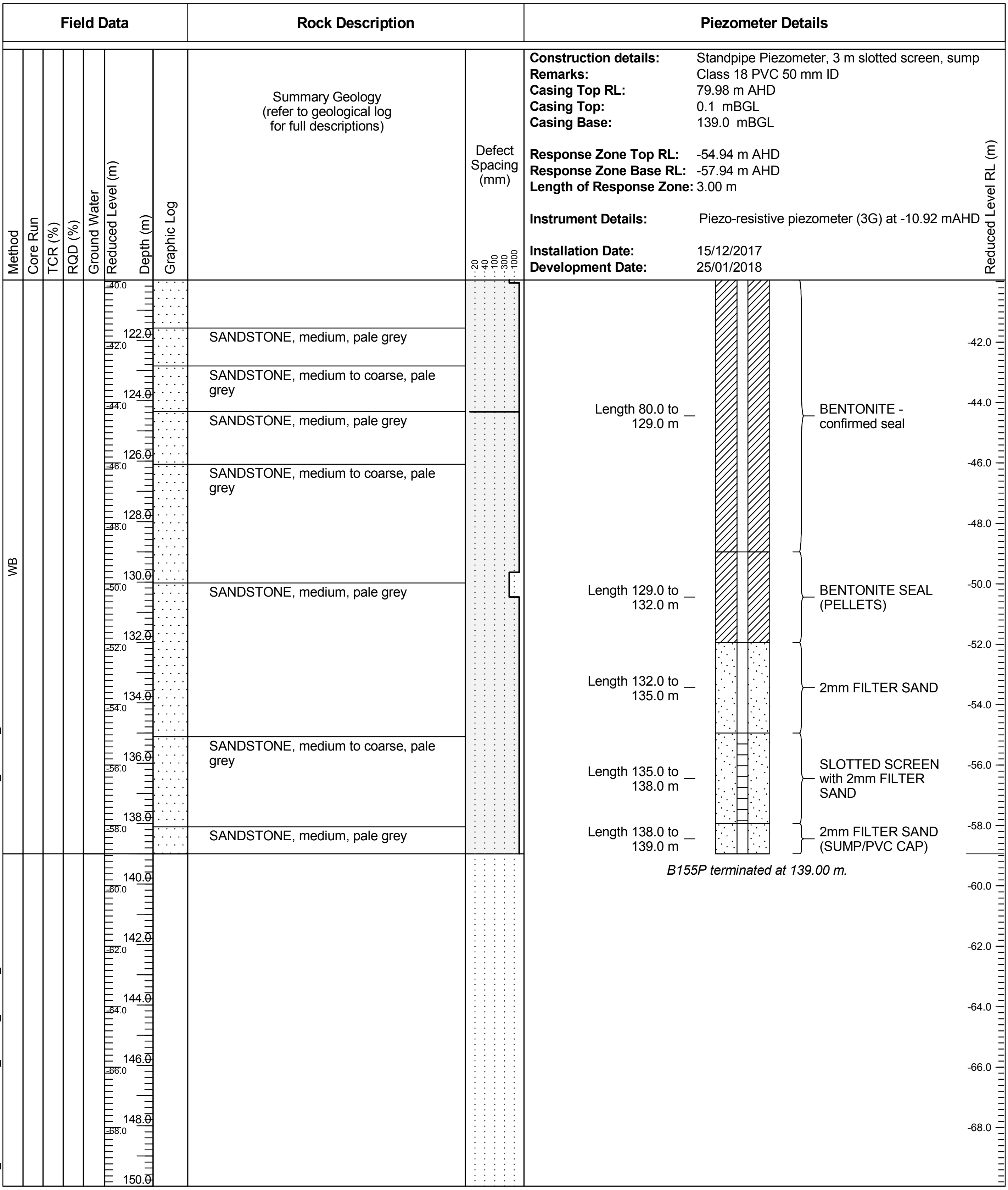
Piezometer Details

Construction details: Standpipe Piezometer, 3 m slotted screen, sump
Remarks: Class 18 PVC 50 mm ID
Casing Top RL: 79.98 m AHD
Casing Top: 0.1 mBGL
Casing Base: 139.0 mBGL

Response Zone Top RL: -54.94 m AHD
Response Zone Base RL: -57.94 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at -10.92 mAHD

Installation Date: 15/12/2017
Development Date: 25/01/2018



GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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Engineering Log

PIEZOMETER No. B156

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	DK/KW	**Checked by:**	RR
Location:	Harwood Place - Seaforth	**Start Date:**	7/06/2017	**End Date:**	16/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:**	337236.0 m	**RL:**	79.93 m
Drill Rig: Comacchio 405	**Inclination:** -60°	**Northing:**	6259873.6 m	**Ver. Datum:**	AHD
	Bearing: 271°	**Hor. Proj/Dat:**	MGA94/GDA94-56	**Surface:**	Road surface

Field Data

Method	Core Run	TCR (%)	RQD (%)
AD/T			
HQ3	R1	100	95
HQ3	R2	100	73
HQ3	R3	100	40
HQ3	R4	100	86
HQ3	R5	100	68
HQ3	R6	100	22
HQ3	R7	100	100
HQ3	R8	100	98
HQ3	R9	100	93
HQ3	R10	100	74
HQ3	R11	100	100
HQ3	R12	100	97
HQ3	R13	100	100

Ground Water: 27/09/2017

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

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): 78.0, 76.0, 74.0, 72.0, 70.0, 68.0, 66.0, 64.0, 62.0, 60.0, 58.0, 56.0

Rock Description

Summary Geology (refer to geological log for full descriptions)

- ASPHALTIC CONCRETE, black
- Silty CLAY, grey-brown
- SANDSTONE, fine to coarse grained, yellow-brown
- SANDSTONE, fine to coarse grained, pale yellow
- SANDSTONE, fine to coarse grained, pale grey
- SANDSTONE, fine to medium grained, pale grey
- SANDSTONE, fine to coarse grained, red-brown, orange-brown and pale grey
- SANDSTONE, fine to coarse grained, pale grey
- SANDSTONE, medium to coarse grained, pale grey
- SANDSTONE, fine to coarse grained, pale grey
- LAMINITE
- SANDSTONE, fine to medium grained, pale grey
- LAMINITE
- SANDSTONE, fine to coarse grained, pale grey
- SHALE BRECCIA, fine grained, pale grey
- MUDSTONE

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

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 29.68 mAHD, VWP2 at 43.54 mAHD, VWP3 at 53.94 mAHD
Installation Date:	3/08/2017
Development Date:	-

Length 0.0 to 0.1 m — GATIC COVER

Length 0.1 to 29.8 m — CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE

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

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

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PIEZOMETER No. B156

Client: RMS		**Project No:**	60537922		
Project: Western Harbour Tunnel and Beaches Link		**Logged by:**	DK/KW	**Checked by:**	RR
Location: Harwood Place - Seaforth		**Start Date:**	7/06/2017	**End Date:**	16/06/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:**	337236.0 m	**RL:**	79.93 m
Drill Rig: Comacchio 405	**Inclination:** -60°	**Northing:**	6259873.6 m	**Ver. Datum:**	AHD
	Bearing: 271°	**Hor. Proj/Dat:**	MGA94/GDA94-56	**Surface:**	Road surface

Field Data / Rock Description / 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 29.68 mAHD, VWP2 at 43.54 mAHD, VWP3 at 53.94 mAHD
Installation Date: 3/08/2017
Development Date: -

Method: HQ3

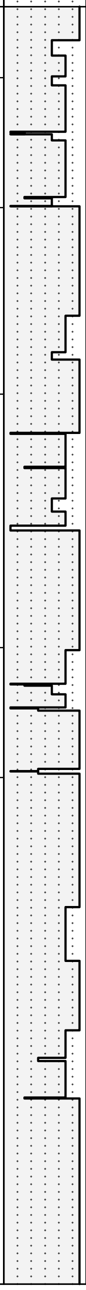
Ground Water: 27/09/2017; 27/09/2017

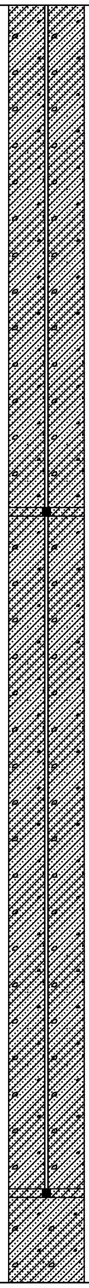
Core Run	TCR (%)	RQD (%)	Summary Geology (refer to geological log for full descriptions)
R14	100 / 100	81 / 81	MUDSTONE *continued*
R15	100	97	SANDSTONE, fine to medium grained, pale grey (from 32.0 m)
R16	100	97	SANDSTONE, fine to coarse grained, pale grey (from 35.0 m)
R17	100	100	
R18	100	94	SANDSTONE, fine to medium grained, grey (from 39.4 m)
R19	100	100	
R20	100	94	SANDSTONE, fine to medium grained, pale grey (from 45.4 m)
R21	100	94	SANDSTONE, fine to coarse grained, pale grey (from 48.4 m)
R22	100	97	
R23	100	100	
R24	100	97	
R25	100	100	

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): 52.0, 50.0, 48.0, 46.0, 44.0, 42.0, 40.0, 38.0, 36.0, 34.0, 32.0, 30.0

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





Length	Piezometer detail
Length 29.8 to 30.0 m	VIBRATING WIRE SENSOR + SLOTTED PVC PIPE
Length 30.0 to 41.8 m	CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE
Length 41.8 to 42.0 m	VIBRATING WIRE SENSOR + SLOTTED PVC PIPE
Length 42.0 to 57.8 m	CEMENT/BENTONITE GROUT (mass ratio 2.5 Water / 1 Cement / 0.3 Bentonite) + BLANK PVC PIPE
Length 57.8 to 58.0 m	VIBRATING WIRE SENSOR + SLOTTED PVC PIPE
Length 58.0 to 60.5 m	CEMENT/BENTONITE

Reduced Level RL (m): 52.0, 50.0, 48.0, 46.0, 44.0, 42.0, 40.0, 38.0, 36.0, 34.0, 32.0, 30.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. **B156**

Client:	RMS		**Project No:**	60537922	
Project:	Western Harbour Tunnel and Beaches Link		**Logged by:**	DK/KW	**Checked by:** RR
Location:	Harwood Place - Seaforth		**Start Date:**	7/06/2017	**End Date:** 16/06/2017
Driller:	Terratest	**Hole Diameter:** 96 mm	**Easting:**	337236.0 m	**RL:** 79.93 m
Drill Rig:	Comacchio 405	**Inclination:** -60°	**Northing:**	6259873.6 m	**Ver. Datum:** AHD
		Bearing: 271°	**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 29.68 mAHD, VWP2 at 43.54 mAHD, VWP3 at 53.94 mAHD
Installation Date: 3/08/2017
Development Date: -

Reduced Level RL (m)

Length 58.0 to 60.5 m — GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)

B156 terminated at 60.51 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 (m): 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

PIEZOMETER No. B173

Sheet: 1 of 1

Client:	RMS	**Project No:**	60537922		
Project:	Western Harbour Tunnel and Beaches Link	**Logged by:**	NB	**Checked by:**	RPW
Location:	Wakehurst Parkway - Seaforth	**Start Date:**	27/07/2017	**End Date:**	1/08/2017
Driller:	Terratest	**Hole Diameter:**	96 mm	**Easting:**	336682.6 m
RL:	113.58 m	**Inclination:**	-90°	**Northing:**	6261689.2 m
Ver. Datum:	AHD	**Drill Rig:**	Hydrapower Scout	**Bearing:**	N/A
Hor. Proj/Dat:	MGA94/GDA94-56H	**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: 113.50 m AHD
Casing Top: 0.1 mBGL
Casing Base: 7.0 mBGL

Response Zone Top RL: 110.58 m AHD
Response Zone Base RL: 107.58 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at 106.70 mAHD

Installation Date: 31/07/2017
Development Date: 3/10/2017

Method	Core Run	TCR (%)	RQD (%)	Ground Water	Depth (m)	Summary Geology (refer to geological log for full descriptions)
ADT/NDD					0.0–1.3	ASPHALTIC CONCRETE, fine to medium, dark grey
HQ3	R1	100	96			SANDY CLAY, yellow-brown and pale red-brown
HQ3	R2	98	95	▼ 27/09/2017		SANDSTONE, fine to coarse, red-brown and yellow-brown
						SANDSTONE, fine to medium, pale grey and yellow-brown
HQ3	R3	100	76			SANDSTONE, medium, purple and pale grey
HQ3	R4	100	78			SANDSTONE, medium to coarse, pale grey, streaked purple and yellow-brown
						SANDSTONE, medium, pale grey and purple
						NO CORE
						SANDSTONE, medium, pale grey
						SANDSTONE, coarse, pale grey

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

Length	Installation
Length 0.0 to 0.0 m	GATIC COVER
Length 0.0 to 1.3 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)
Length 1.3 to 2.0 m	BENTONITE SEAL (PELLETS)
Length 2.0 to 3.0 m	2mm FILTER SAND
Length 3.0 to 6.0 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 6.0 to 7.0 m	2mm FILTER SAND (SUMP/PVC CAP)
Length 7.0 to 10.0 m	BENTONITE SEAL (PELLETS)

B173 terminated at 9.95 m.

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): 112.0, 110.0, 108.0, 106.0, 104.0, 102.0, 100.0, 98.0, 96.0, 94.0, 92.0, 90.0, 88.0, 86.0, 84.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

AECOM coffey

Engineering Log

PIEZOMETER No. B174

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** SG/NB	**Checked by:** RPW
Location: Wakehurst Parkway - Seaforth		**Start Date:** 31/07/2017	**End Date:** 1/08/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 336546.3 m	**RL:** 121.94 m
Drill Rig: Hydrapower Scout	**Inclination:** -90°	**Northing:** 6262050.2 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56H	**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: 121.87 m AHD
Casing Top: 0.1 mBGL
Casing Base: 7.0 mBGL

Response Zone Top RL: 118.96 m AHD
Response Zone Base RL: 115.96 m AHD
Length of Response Zone: 3.00 m

Instrument Details: Piezo-resistive piezometer (3G) at 115.27 mAHD

Installation Date: 1/08/2017
Development Date: 3/10/2017

Summary Geology (refer to geological log for full descriptions)

Method	Core Run	TCR (%)	RQD (%)	Depth (m)	Summary Geology
ADT / DD				0.0	ASPHALTIC CONCRETE
ADT / DD					GRAVELLY SANDY CLAY, pale grey mottled yellow-brown
HQ3	R1	100	96	2.0	SANDSTONE, fine, pale grey and brown
HQ3	R2	100	100	4.0	SANDSTONE, fine to medium, orange and yellow-brown
HQ3	R2			6.0	SANDSTONE, medium to coarse, pale grey and orange
HQ3	R3	100	100	7.0	SANDSTONE, fine to coarse, pale grey
HQ3	R3			8.0	SANDSTONE, fine to medium, pale grey
HQ3	R3			10.0	SANDSTONE, coarse, pale grey

Ground Water: 27/09/2017

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

Interval	Installation
Length 0.0 to 0.0 m	GATIC COVER
Length 0.0 to 1.4 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)
Length 1.4 to 2.0 m	BENTONITE SEAL (PELLETS)
Length 2.0 to 3.0 m	2mm FILTER SAND
Length 3.0 to 6.0 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 6.0 to 6.9 m	2mm FILTER SAND (SUMP/PVC CAP)
Length 6.9 to 10.0 m	BENTONITE SEAL (PELLETS)

B174 terminated at 10.05 m.

Reduced Level (m): 120.0, 118.0, 116.0, 114.0, 112.0, 110.0, 108.0, 106.0, 104.0, 102.0, 100.0, 98.0, 96.0, 94.0

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

Engineering Log

AECOM coffey

PIEZOMETER No. B175

Client: RMS		**Project No:** 60537922	
Project: Western Harbour Tunnel and Beaches Link		**Logged by:** NB	**Checked by:** RPW
Location: Wakehurst Parkway - Seaforth		**Start Date:** 2/08/2017	**End Date:** 2/08/2017
Driller: Terratest	**Hole Diameter:** 96 mm	**Easting:** 336335.0 m	**RL:** 121.05 m
Drill Rig: Hydrapower Scout	**Inclination:** -90°	**Northing:** 6263122.7 m	**Ver. Datum:** AHD
	Bearing: N/A	**Hor. Proj/Dat:** MGA94/GDA94-56M	**Surface:** Road Surface

Field Data

Method	Core Run	TCR (%)	RQD (%)	Depth (m)
NDD				0.0–1.5
ADT				1.5–4.8
HQ3	R1	100	100	4.8–7.0
HQ3	R2	100	93	7.0–10.0

Rock Description

Summary Geology (refer to geological log for full descriptions)

- ASPHALTIC CONCRETE
- GRAVEL, fine to medium, dark grey
- SANDSTONE, fine to coarse, red-brown
- SANDY CLAY, pale grey mottled red-brown
- SANDSTONE, fine to coarse, red-brown
- CLAY, dark brown-grey
- Clayey SAND, fine to medium, pale grey and white
- SAND, fine to coarse, red-brown
- SANDSTONE, fine to coarse, purple and red-brown
- SANDSTONE, coarse, purple and pale grey
- SANDSTONE, fine to coarse, yellow-brown and pale grey
- SANDSTONE, coarse, pale grey and brown

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:	120.97 m AHD
Casing Top:	0.1 mBGL
Casing Base:	7.0 mBGL
Response Zone Top RL:	118.05 m AHD
Response Zone Base RL:	115.05 m AHD
Length of Response Zone:	3.00 m
Instrument Details:	Piezo-resistive piezometer (3G) at 114.07 mAHD
Installation Date:	2/08/2017
Development Date:	3/10/2017

Interval	Construction
Length 0.0 to 0.0 m	GATIC COVER
Length 0.0 to 1.5 m	CEMENT/BENTONITE GROUT (mass ratio 3 Water / 1 Cement / 0.3 Bentonite)
Length 1.5 to 2.0 m	BENTONITE SEAL (PELLETS)
Length 2.0 to 3.0 m	2mm FILTER SAND
Length 3.0 to 6.0 m	SLOTTED SCREEN with 2mm FILTER SAND
Length 6.0 to 7.0 m	2mm FILTER SAND (SUMP/PVC CAP)
Length 7.0 to 10.0 m	BENTONITE SEAL (PELLETS)

B175 terminated at 10.00 m.

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

AECOM coffey

PIEZOMETER No. B343

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

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

Summary Geology (refer to geological log for full descriptions)

Method	Core Run	TCR (%)	RQD (%)	Depth (m)	Summary Geology
DT					CONCRETE
HQ3	R1	100	44		SANDSTONE, fine to medium, pale grey
	R2	100	90	2.0	SANDSTONE, medium to coarse
	R3	100	100	4.0	SANDSTONE, medium to coarse, pale grey
	R4	100	94	6.0	SANDSTONE, medium to coarse, yellow and brown stained pale brown
				8.0	SANDSTONE, medium to coarse, yellow and brown stained pale brown
	R5	100	100	10.0	SANDSTONE, coarse, pale yellow brown
					SANDSTONE, medium to coarse, yellow and brown
	R6	100	98	12.0	SANDSTONE, medium to coarse, pale grey
	R7	100	93	14.0	SANDSTONE, medium to coarse, pale grey
	R8	100	90	16.0	SANDSTONE, medium to coarse, yellow, brown and red brown stained pale grey
				18.0	SANDSTONE, medium to coarse, red and brown stained pale grey
	R9	100	97	20.0	SANDSTONE, medium to coarse, pale grey
					SANDSTONE, medium to coarse, red-brown stained pale grey
	R10	100	100	22.0	SANDSTONE, medium to coarse, pale grey
				24.0	SANDSTONE, medium to coarse, pale grey
	R11	100	100	26.0	SANDSTONE, medium to coarse, pale grey
					SANDSTONE, medium to coarse, pale grey
	R12	100	100	28.0	SANDSTONE, medium to coarse, pale grey
				30.0	SANDSTONE, medium to coarse, pale grey

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

Piezometer construction:
- 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)

Reduced Level RL (m): 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, 50.0, 48.0

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

Engineering Log

PIEZOMETER No. B343

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**

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: 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 (%)
HQ3	R13	100	93
HQ3	R14	100	95
HQ3	R15	100	100
HQ3	R16	100	100
HQ3	R17	100	100
HQ3	R18	100	100

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): 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

Summary Geology:
- SANDSTONE, medium to coarse, pale grey
- MUDSTONE, dark grey *continued*
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium to coarse, pale grey
- SANDSTONE, medium to coarse, 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, medium to coarse, pale grey
- SANDSTONE, fine to medium, grey

Piezometer Details:

Length	Detail
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

AECOM coffey

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	Core Run	TCR (%)	RQD (%)
ADT / NDD			
HQ3	R1	100	91
HQ3	R2	100	98
HQ3	R3	100	100
HQ3	R4	100	97
HQ3	R5	100	96
HQ3	R6	100	100
HQ3	R7	100	98
HQ3	R8	100	92
HQ3	R9	100	96
HQ3	R10	100	100

Ground Water: 20/09/2017; 21/08/2017

Reduced Level (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

Graphic Log

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	Material
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

GROUNDWATER MONITORING NOTES: refer to Groundwater Monitoring Report

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**

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: 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

Summary Geology:

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

B390 terminated at 30.16 m.

Reduced Level (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

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

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

DRILLING

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

Depth (m)	Drilling & Casing	Water	Ground Water Levels
0.0 – 1.60	AD/T, NADIT, HW Casing		
1.60 – 58.11	HQ3		
~3.0			▽ [illegible]
1.60 – 44.50		0% LOSS	
44.50 – 58.11		5% LOSS	

MATERIAL

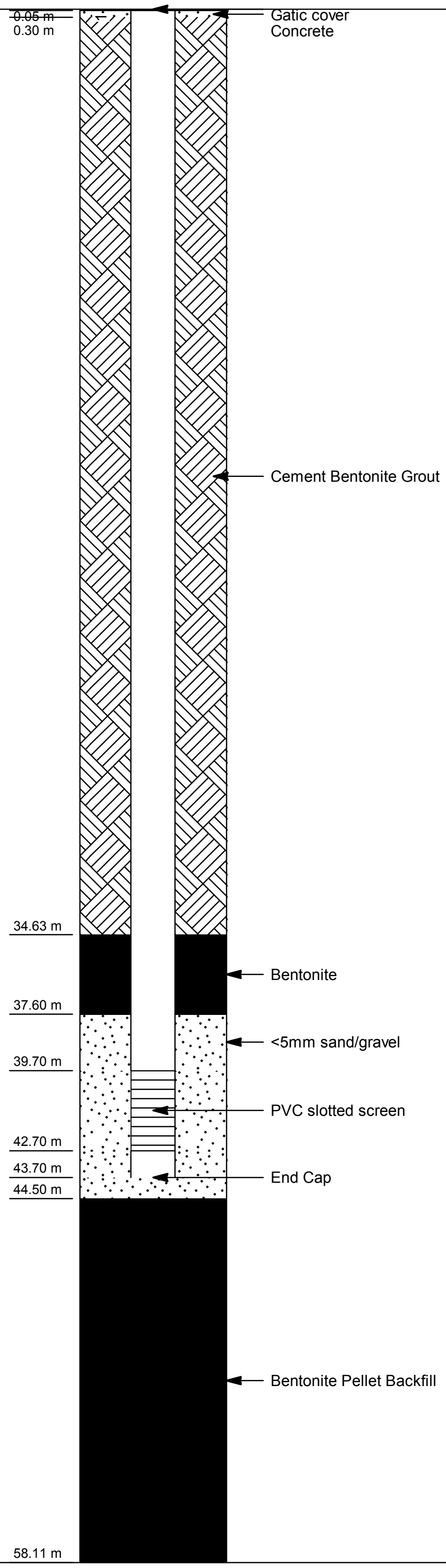
GRAPHIC LOG | CLASSIFICATION SYMBOL | MATERIAL DESCRIPTION: Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components

Depth	Material Description
0.0 – 0.40m	FILL
0.40m – 1.60m	CLAYEY SAND
1.60m – 49.31m	SANDSTONE
~34.0	- siltstone band
49.31m – 52.00m	SILTSTONE AND SANDSTONE
52.00m – 58.11m	SANDSTONE

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

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	



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

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

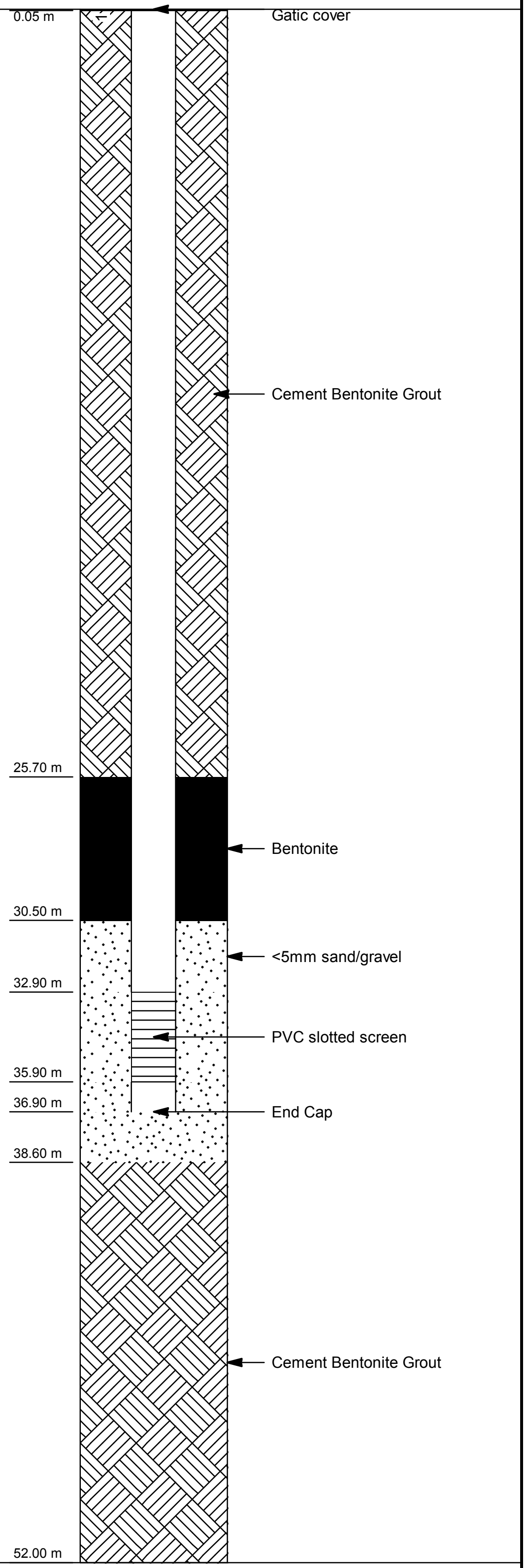
Drilling & Casing	Water (Progress)	Ground Water Levels
RA (0.0–0.5)	0% LOSS	07/09/17 08:15
HQ3 (0.5–4.0)	0% LOSS / 100% LOSS (to 6.3)	
WB (4.0–6.3)	0% LOSS (6.3–7.5)	
HQ3 (6.3–52.0)	50% LOSS (7.5–15.0)	
	80-95% LOSS (15.0–52.0)	

MATERIAL

Depth (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
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)
8.38m	SANDSTONE
18.27m–18.31m	CORE LOSS 0.04m (18.27-18.31)
18.31m	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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PIEZOMETER CONSTRUCTION

HOLE NO : B114A_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Artarmon - Lambs Road

POSITION : E: 332643.3, N: 6257061.7 (56 MGA94) SURFACE ELEVATION : 59.36 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Hanjin DB8 MOUNTING : Track CONTRACTOR : Macquarie Geotech
DATE STARTED : 17/7/17 DATE COMPLETED : 19/7/17 DATE LOGGED : 17/7/17 LOGGED BY : TZ CHECKED BY : GM

DRILLING

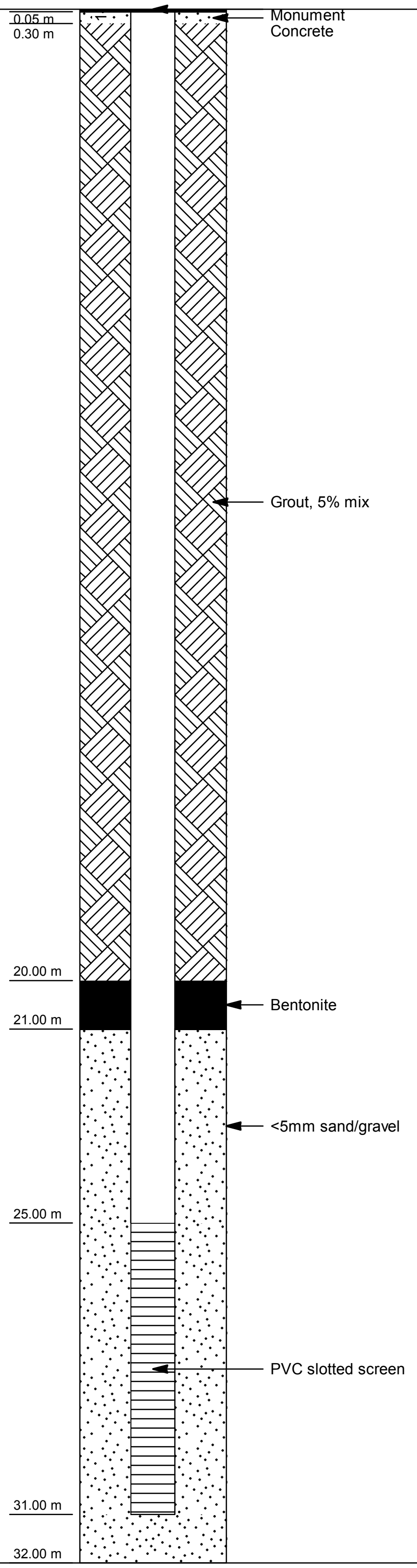
PROGRESS – DRILLING & CASING	PROGRESS – WATER	GROUND WATER LEVELS	DEPTH (m)
NDD (0.0–1.5); AD/T, HW Casing (to 5.5)	Water (Not Observed) (0.0–5.5)	19/07/17 08:00 (at about 5.0)	0.0
HQ3 (5.5–32.0)	0% Water LOSS (5.5–20.0)		5.0
	5% Water LOSS (20.0–32.0)		10.0 – 30.0

MATERIAL

DEPTH (m)	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.00–3.00m		FILL
3.00–8.45m	CI	CLAY/SILTY CLAY
8.45–32.00m		SANDSTONE
32.00m		B114A_w TERMINATED AT 32.00 m Target depth

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe Piezometer	0.56 m 58.80 m AHD	31.00 m 28.36 m AHD	19/07/2017	



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PIEZOMETER CONSTRUCTION

HOLE NO : B127A_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : North Balgowlah - Bangaroo Street

POSITION : E: 338070.3, N: 6259609.2 (56 MGA94) SURFACE ELEVATION : 49.46 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Comacchio 305 MOUNTING : Track CONTRACTOR : Ground test
DATE STARTED : 23/5/17 DATE COMPLETED : 26/5/17 DATE LOGGED : 23/5/17 LOGGED BY : TZ CHECKED BY : FM

DRILLING

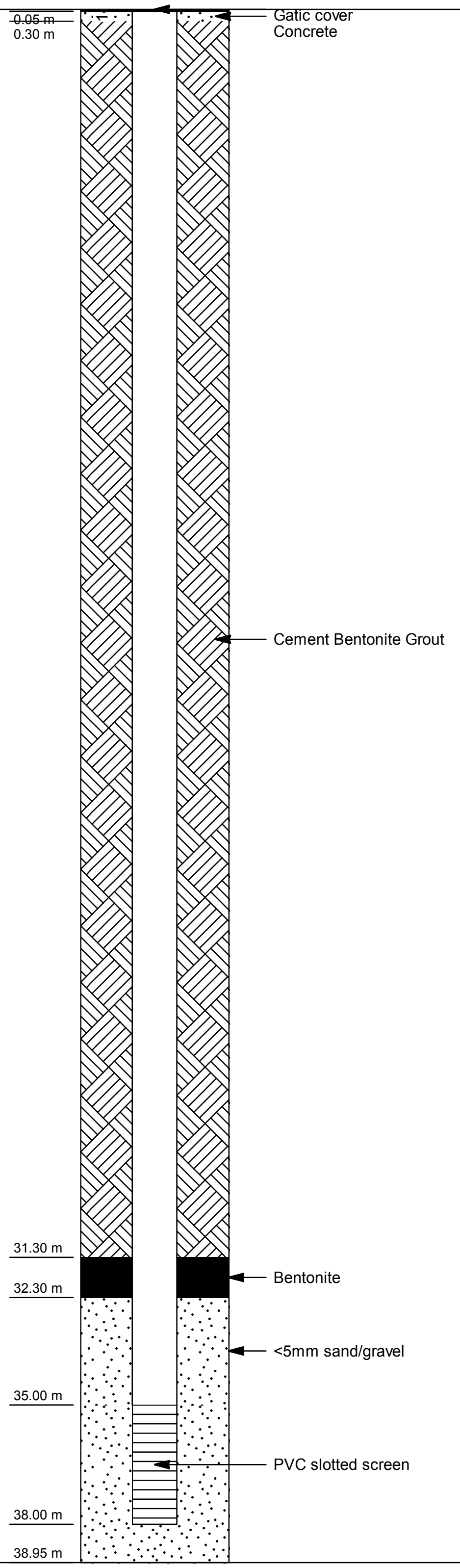
PROGRESS: DRILLING & CASING	PROGRESS: WATER	GROUND WATER LEVELS
NDD 0.0–0.3 m; HW Casing; HQ3 to 38.95 m	0% LOSS (0.7–5.0 m); 80% LOSS (5.0–38.95 m)	26/05/17 08:15 (approx. 7.5 m)

MATERIAL

DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic; Secondary and Minor Components)
0.0		ML	SILT
0.70m			SANDSTONE
34.97m			SILTSTONE
36.63m			SANDSTONE
38.95m			B127A_w TERMINATED AT 38.95 m

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe	0.00 m 49.46 m AHD	38.00 m 11.46 m AHD	29/05/2017	



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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

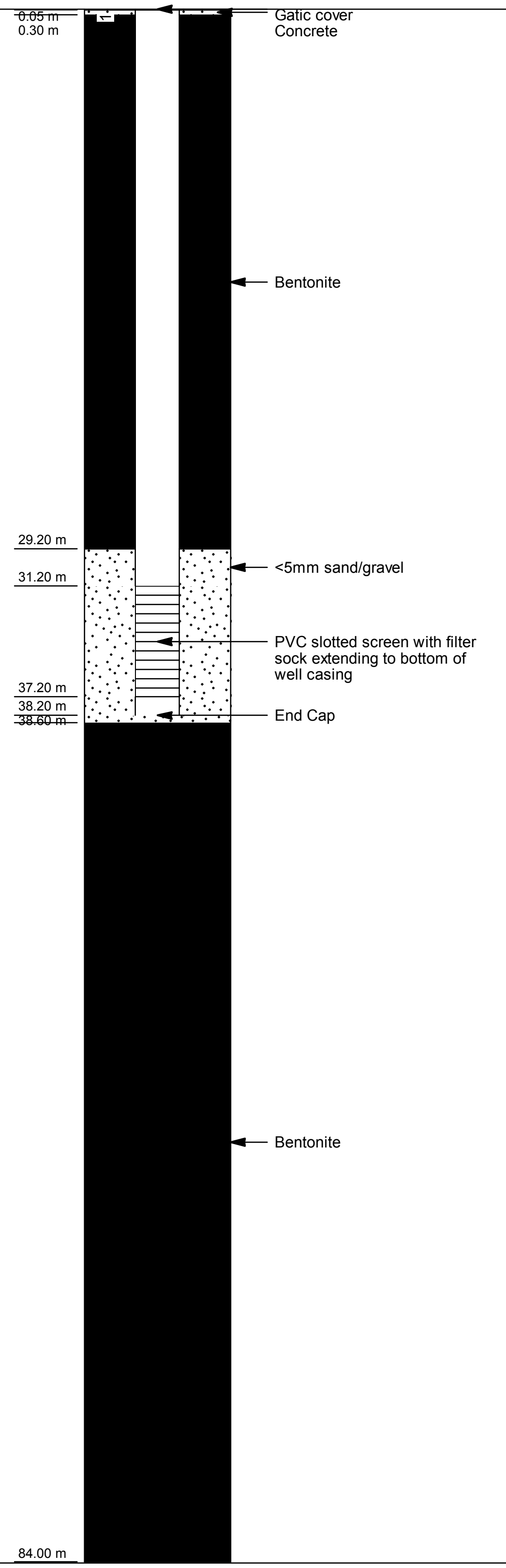
Depth (m)	Drilling & Casing	Water
0.0–3.0	AD/T	(GWNE)
3.0–21.0	HQ3	0% LOSS
21.0–57.6	HQ3	10-20% LOSS
57.6–68.3	HQ3	80-95% LOSS
68.3–84.06	HQ3	90-100% LOSS

MATERIAL

Depth	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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RMS LIB 40.3.1.GLB Log RTA PIEZOMETER INSTALLATION LOG 1 B131A_W.GPJ <<DrawingFile>> 28/Sep/2017 11:01 8.30.004 Datgel Tools

PIEZOMETER CONSTRUCTION

HOLE NO : B134A-a
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Naremburn - Flat Rock Creek

POSITION : E: 333870.9, N: 6257107.5 (56 MGA94) SURFACE ELEVATION : 45.67 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Sonic (Geoprobe) MOUNTING : Track CONTRACTOR : Numac
DATE STARTED : 21/7/17 DATE COMPLETED : 24/7/17 DATE LOGGED : 21/7/17 LOGGED BY : JS CHECKED BY : GM

DRILLING

Progress – Drilling & Casing: Sonic (0.0 – 27.00 m)
Ground Water Levels: Not Observed

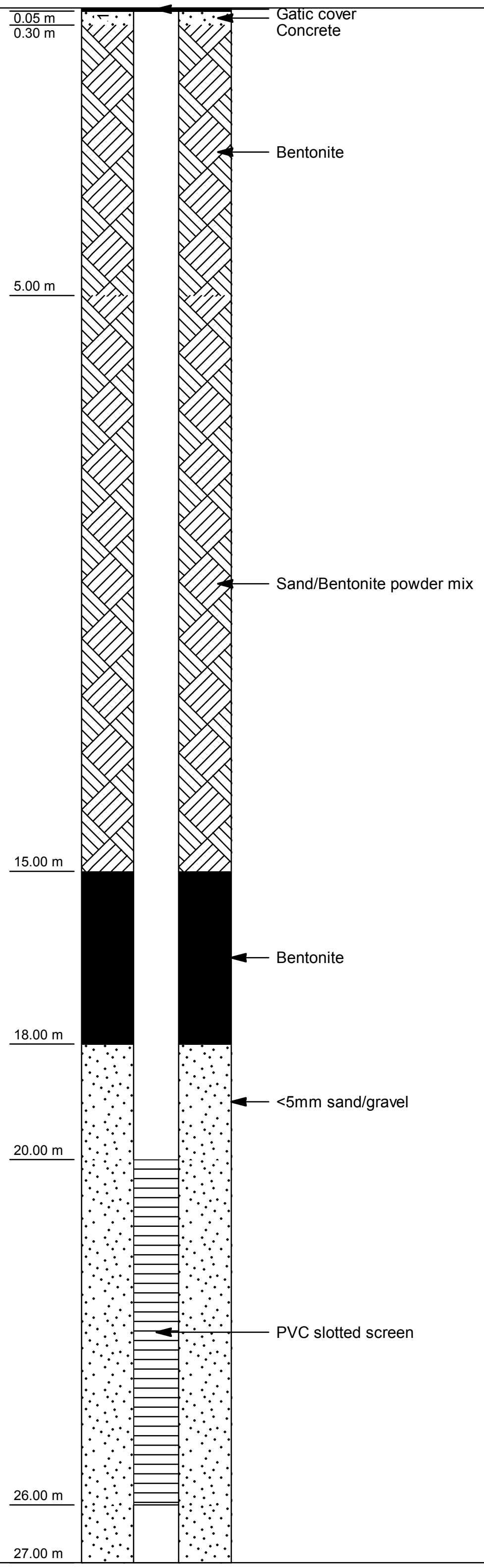
MATERIAL

Depth	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.0 – 0.15m	CLAY: Brown, filling with some medium grained sand and some rootles (with grass cover)
0.15 – 1.50m	CLAY: Brown and grey, filling with some sand, sandstone and shale gravel and cobbles and some building rubble (bricks, concrete and steel reinforcment)
1.50 – 3.00m	SAND: Brown, medium grained sand, filling with some brown and grey silty clay, brick (fragments and whole), shale gravel and cobbles, timber and some igneous rock cobbles (railway ballast)
3.00 – 27.00m	SILTY CLAY: Brown and grey, filling with some sandstone and shale gravel, cobbles and boulders, timber, igneous rock gravel (roadbase) and cobbles (railway ballast), silty sand, timber, concrete and brick rubble silt

B134A-a TERMINATED AT 27.00 m
Target depth

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe Piezometer	0.00 m 45.67 m AHD	26.00 m 19.67 m AHD	24/07/2017	



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PIEZOMETER CONSTRUCTION

HOLE NO : B134A-b
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Naremburn - Flat Rock Creek

POSITION : E: 333870.9, N: 6257107.5 (56 MGA94) SURFACE ELEVATION : 45.67 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Sonic Geoprobe MOUNTING : Track CONTRACTOR : Numac
DATE STARTED : 20/7/17 DATE COMPLETED : 20/7/17 DATE LOGGED : 20/7/17 LOGGED BY : JS CHECKED BY : GM

DRILLING

PROGRESS: DRILLING & CASING: Sonic (0.0 m to 32.50 m); WATER; GROUND WATER LEVELS: 20/07/17 14:00 (at approximately 25.0 m)

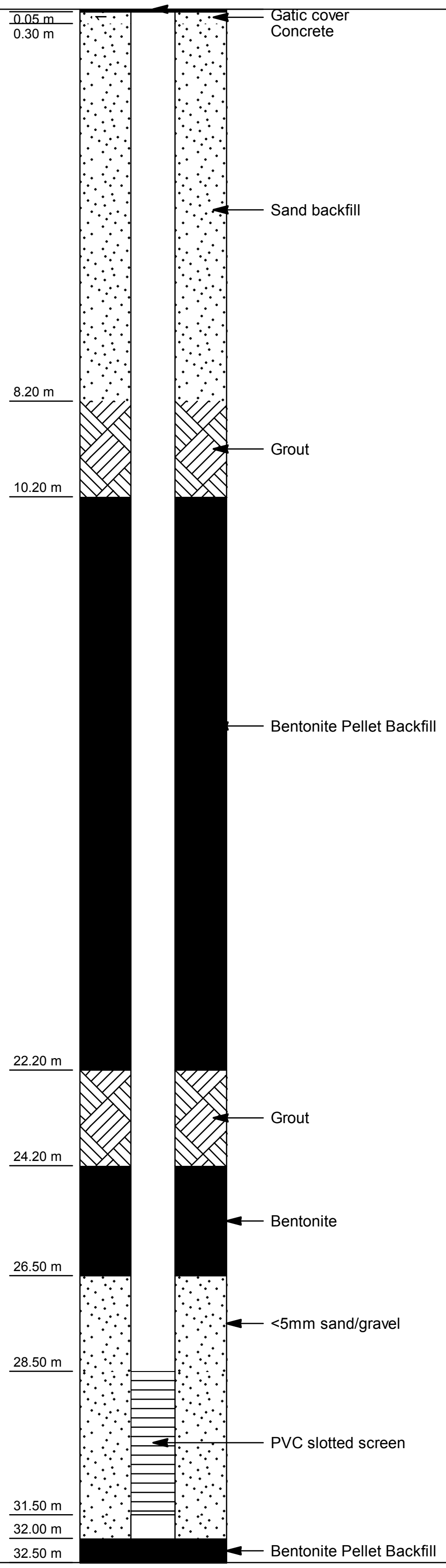
MATERIAL

Depth	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.15m	CLAY: brown, filling (topsoil) with some medium grained sand and some rootlets (with grass cover)
1.50m	CLAY: brown and grey, filling with some sand, sandstone and shale gravel/cobbles trace building rubble (bricks, concrete and steel reinforcment)
3.00m	SAND: brown, medium grained sand, filling with some brown and grey silty clay, brick (fragments and whole), shale gravel and cobbles, timber and some igneous rock cobbles (railway ballast)
19.00m	SILTY CLAY: brown and grey, filling with some sandstone and shale gravel, cobbles and boulders, timber, igneous rock gravel (roadbase) and cobbles (railway ballast), silty sand, timber, concrete and brick rubble
20.00m	CONCRETE
31.00m	SANDY CLAY: grey, brown and red-brown, and sandstone filling with a trace of ironstone and igneous rock gravel and some concrete rubble
31.50m	SANDSTONE: brown, medium grained, boulder
32.00m	SANDY CLAY: brown, (possibly filling)
32.50m	SANDSTONE: grey, medium grained

B134A-b TERMINATED AT 32.50 m
Target depth

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe Piezometer		31.50 m 14.17 m AHD	20/07/2017	



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PIEZOMETER CONSTRUCTION

HOLE NO : B134A-c_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Naremburn - Flat Rock Creek

POSITION : E: 333868.9, N: 6257112.1 (56 MGA94) SURFACE ELEVATION : 45.63 (AHD) ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Sonic MOUNTING : Track CONTRACTOR : Terra Test
DATE STARTED : 16/6/17 DATE COMPLETED : 30/6/17 DATE LOGGED : 16/6/17 LOGGED BY : JS CHECKED BY : GM

DRILLING

Depth (m)	Drilling & Casing	Water
0.0 – 34.7	Sonic — CASING (NDD at top)	(NFGWO during sonic drilling)
34.7 – 42.8	HQ3	100% Water LOSS
42.8 – 54.2	HQ3	10-50% Water LOSS
54.2 – 76.35	HQ3	100% Water LOSS

Ground water levels: 20/06/17 (~19 m); 28/06/17 (~29 m); further readings near 25 m (overlapping, illegible)

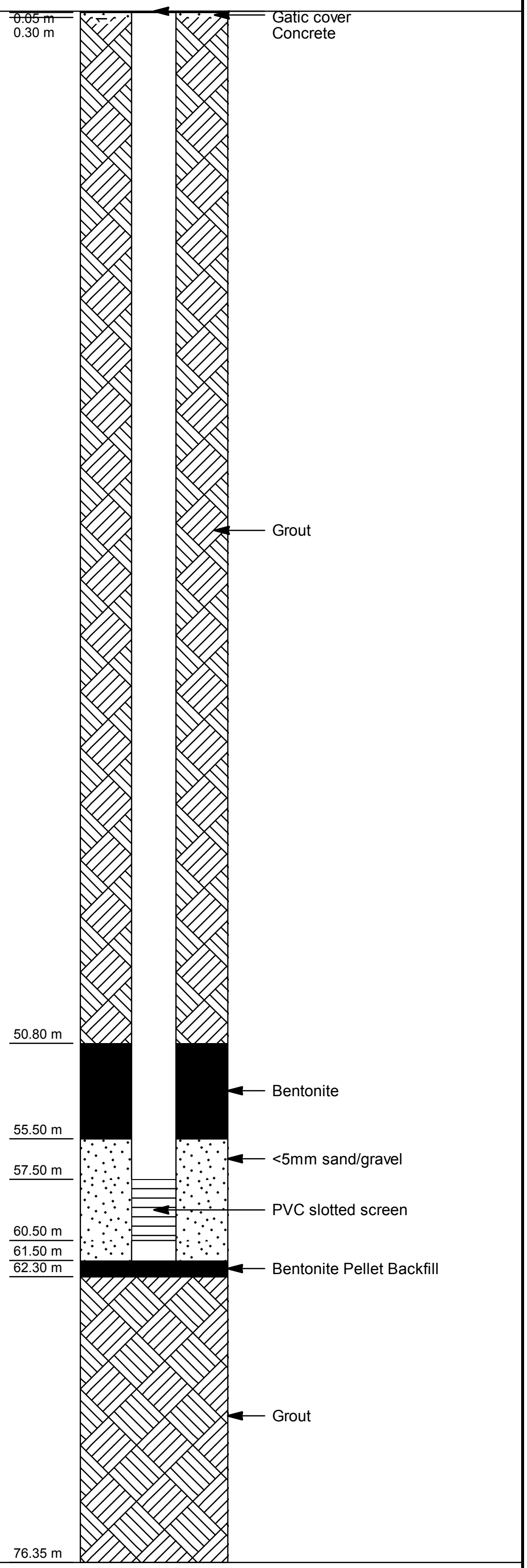
MATERIAL

Depth (m)	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.00 – 33.30	Fill
33.30 – 64.58	Sandstone
64.58 – 65.13	Siltstone
65.13 – 76.35	Sandstone

B134A-c_w TERMINATED AT 76.35 m
Target depth

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe Piezometer	0.00 m 45.63 m AHD	60.50 m -14.87 m AHD	25/07/2017	



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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

PIEZOMETER CONSTRUCTION DETAILS

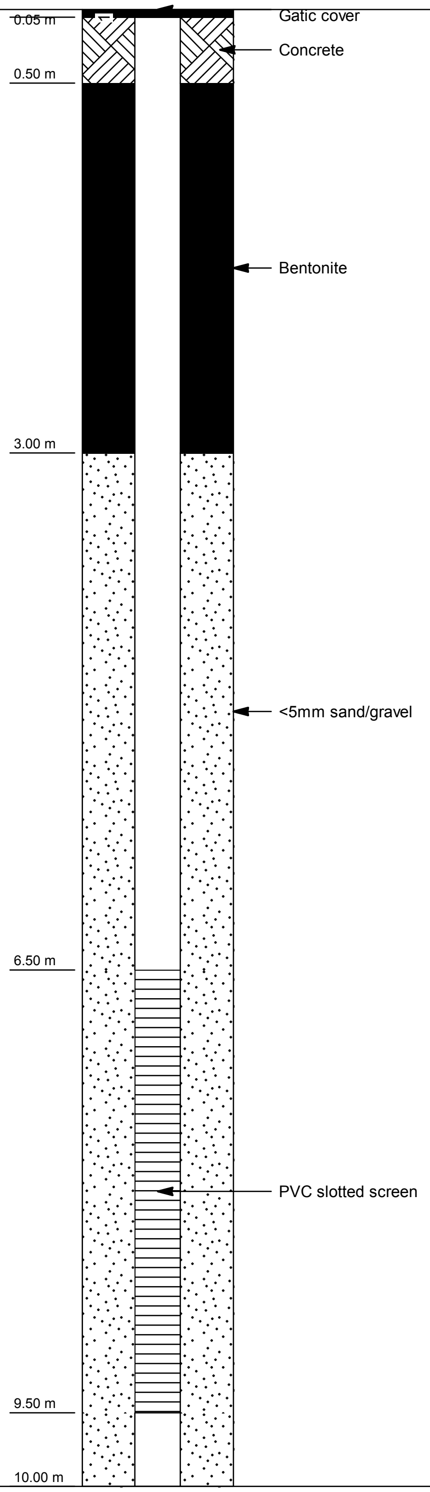
ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe Piezometer		9.50 m 20.74 m AHD	12/10/2017	

DRILLING / MATERIAL

Depth (m)	Drilling & Casing	Water	Material Description
0.00–0.50	NDD / AD/T / HW Casing	(GWNO)	FILL
0.50–10.00	WB (1.4–2.0), HQ3 (2.0–10.0)	0% LOSS	SANDSTONE

B181A_w TERMINATED AT 10.00 m
Target depth
Standpipe Installed

Installation



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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

DRILLING

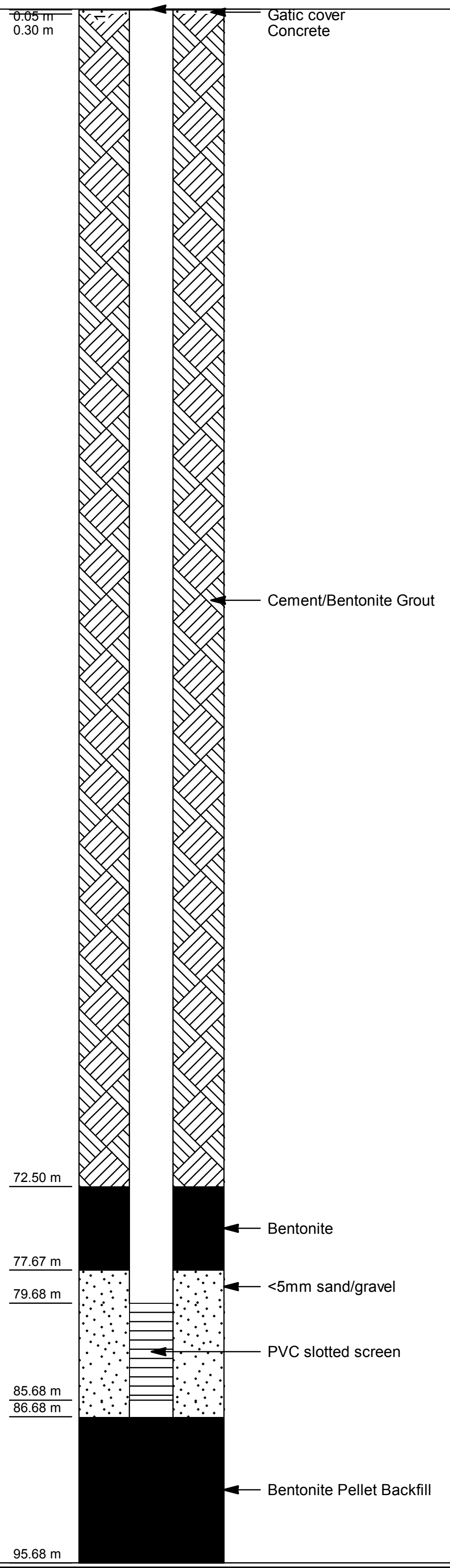
PROGRESS: DRILLING & CASING — ADVD / HW Casing (0.0–~2.5 m); HQ3 (to 95.68 m)
WATER: GWNE; 0% LOSS; 5% LOSS; 0% LOSS
GROUND WATER LEVELS: 26/09/17 08:08

MATERIAL

DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION Soil Type, Colour, Plasticity or Particle Characteristic Secondary and Minor Components
0.0			FILL
0.60m			SANDSTONE
~60.5			- conglomeratic sandstone band (0.08m thick)
~70.5			- brecciated sandstone layer (0.84m thick)
95.68m			B208_w TERMINATED AT 95.68 m Target depth Verticality survey completed Piezometer installed

PIEZOMETER CONSTRUCTION DETAILS

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

DRILLING

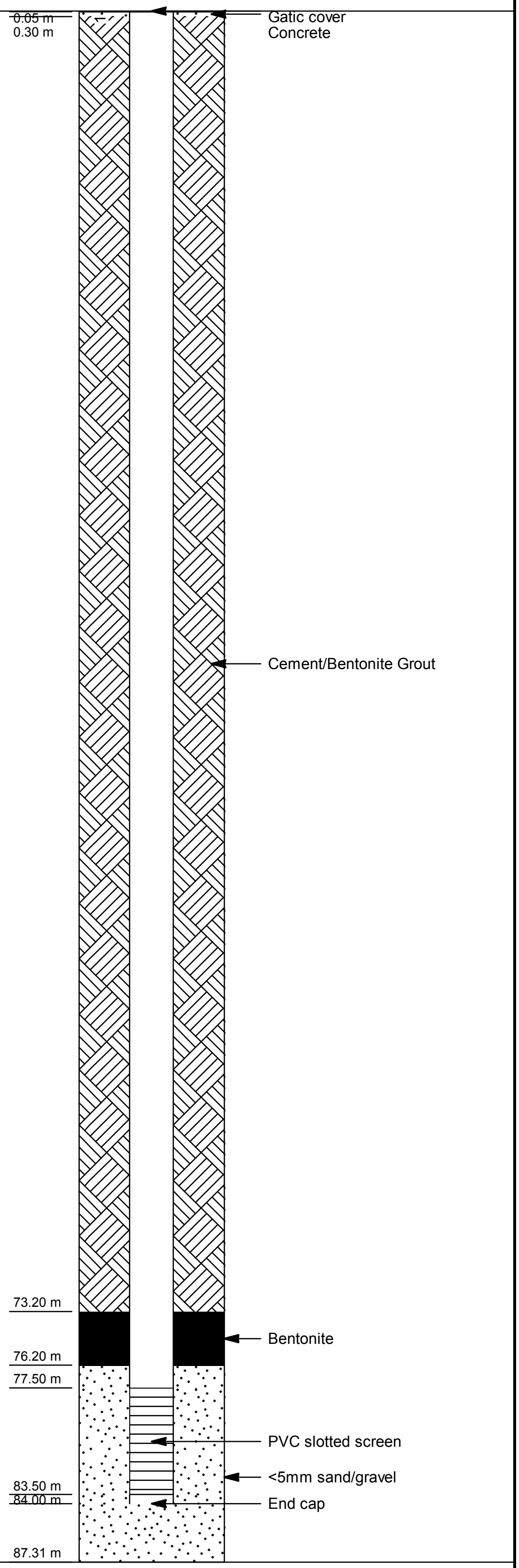
PROGRESS: DRILLING & CASING — ADT (to 0.3 m); HW Casing; HQ3 (to 87.31 m)
WATER: 0% LOSS; 10% LOSS (approx. 48–49 m); 0% LOSS
GROUND WATER LEVELS: 15/08/17; [illegible] (overlapping labels, approx. 12–13 m); 17/08/17

MATERIAL

Depth (m)	Material Description (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.0 – 0.20m	FILL
0.20m	SANDSTONE: highly weathered to fresh
	- siltstone band (0.95m)
	- siltstone band (0.37m)
	- siltstone band (0.12m)
	- siltstone band (0.32m)
	- siltstone band (0.13m)
	- siltstone band (0.23m)
	- siltstone band (0.08m)
	- siltstone band (0.09m)
	- siltstone band (0.24m)
87.31m	B209_w TERMINATED AT 87.31 m Target depth ATV IMAGING COMPLETED GROUTED

PIEZOMETER CONSTRUCTION DETAILS

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 : B238_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Northbridge - Sailors Bay Road

POSITION : E: 336173.8, N: 6257785.9 (56 MGA94) | SURFACE ELEVATION : 38.91 (AHD) | ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Explora 140 | MOUNTING : Truck | CONTRACTOR : Ground test
DATE STARTED : 5/6/17 | DATE COMPLETED : 22/6/17 | DATE LOGGED : 5/6/17 | LOGGED BY : FDS/TZ | CHECKED BY : GS

DRILLING

PROGRESS: DRILLING & CASING; WATER

- DRILLING & CASING: HW Casing (top); HQ3 (0.0 m to approx. 123 m); HQ3 (approx. 123 m to 144.00 m)
- WATER: 5% LOSS; 10% LOSS; 15% LOSS; 15% LOSS
- GROUND WATER LEVELS: Not Observed; 23/06/17

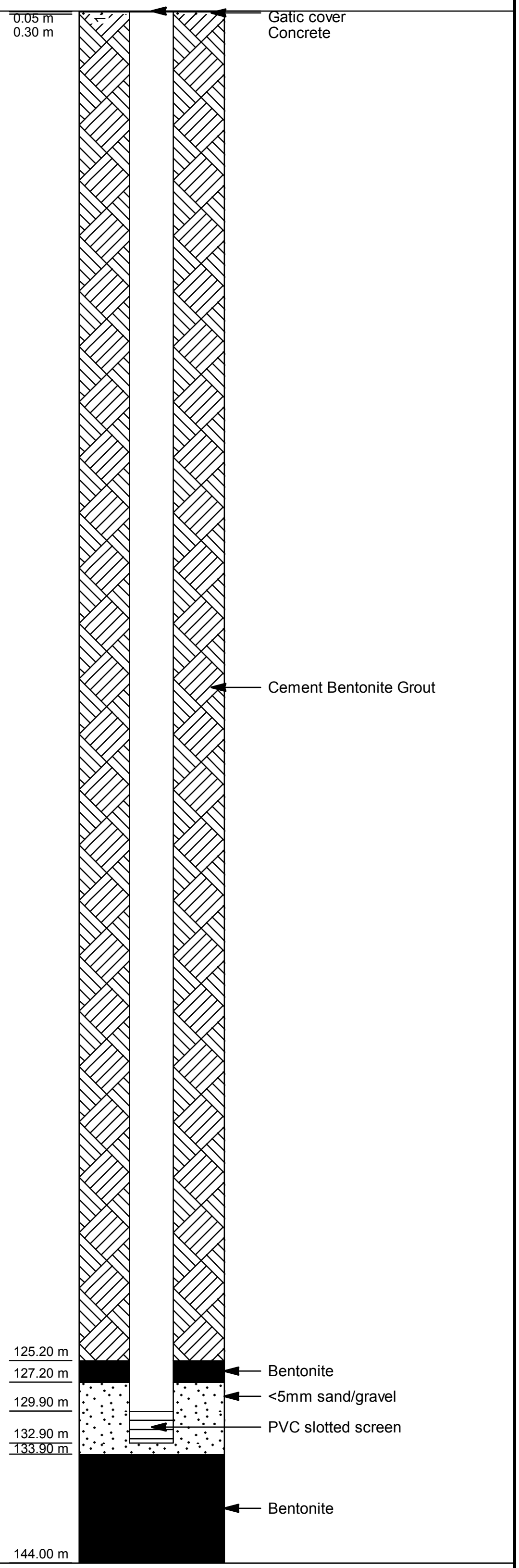
MATERIAL

DEPTH (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.0 – 0.82m	FILL
0.82m – 87.05m	SANDSTONE
87.05m – 90.32m	SILTSTONE
90.32m – 144.00m	SANDSTONE - siltstone layer - conglomerate layer

B238_w TERMINATED AT 144.00 m
Target depth
ATV Imaging Completed
Grouted

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Standpipe	0.00 m 38.91 m AHD	133.90 m -94.99 m AHD	26/06/2017	



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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

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	

DRILLING

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

Drilling & casing: ADH / HW Casing; HQ3

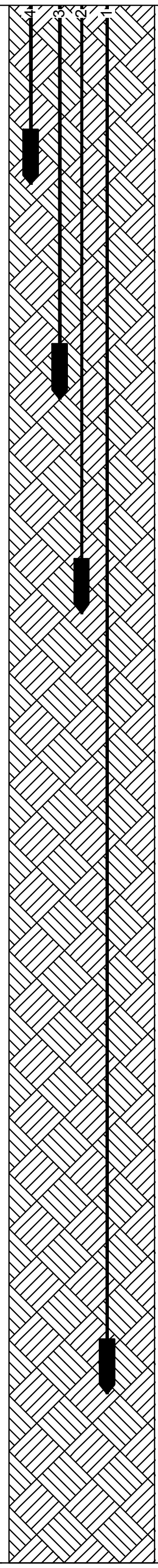
Water: (GWNO); 0% LOSS; 0% LOSS; 10% LOSS; 10% LOSS; 40% LOSS; 100% LOSS

MATERIAL

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

Depth (m)	Material Description
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



95.80 m

VWPs installed in full cement/bentonite grout mix

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Golder Associates
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Geotechnics / Environment / Groundwater

PIEZOMETER CONSTRUCTION

HOLE NO : B176A_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Naremburn - Flat Rock Drive

POSITION : E: 333856.1, N: 6257072.3 (56 MGA94) SURFACE ELEVATION : 45.13 (AHD) ANGLE FROM HORIZONTAL : 60° AT 062°
RIG TYPE : LS250 MOUNTING : Track CONTRACTOR : Groundwave Drilling
DATE STARTED : 7/8/17 DATE COMPLETED : 15/8/17 DATE LOGGED : 7/8/17 LOGGED BY : PGH CHECKED BY : GS

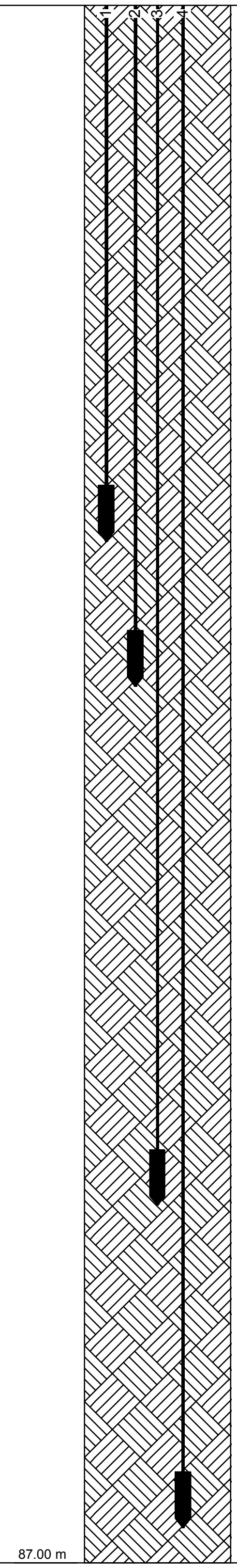
PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Vibrating Wire Piezometer		29.90 m 19.24 m AHD	18/08/2017	
2	Vibrating Wire Piezometer		38.00 m 12.22 m AHD	18/08/2017	
3	Vibrating Wire Piezometer		67.00 m -12.89 m AHD	18/08/2017	
4	Vibrating Wire Piezometer		85.00 m -28.48 m AHD	18/08/2017	

DRILLING / MATERIAL

Depth (m)	Drilling & Casing	Water	Material Description
0.00 – 30.60	NDD (to ~1 m); Sonic – HW Casing	100% Water LOSS (water lost down hole due to sonic drilling)	FILL
30.60 – 31.60	HQ3	0% Water LOSS (30.6–39.0)	SANDSTONE
31.60 – 31.90	HQ3		CORE LOSS 0.30m (31.60-31.90)
31.90 – 87.00	HQ3	100% Water LOSS (39.0–87.0)	SANDSTONE -siltstone band (0.15m) - siltstone breccia band (0.45m) - siltstone band (0.22m) - siltstone breccia/siltstone band (0.98m)

B176A_w TERMINATED AT 87.00 m
Target depth
ATV Imaging Completed
Installed Vibrating Wire Piezometers at four levels



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

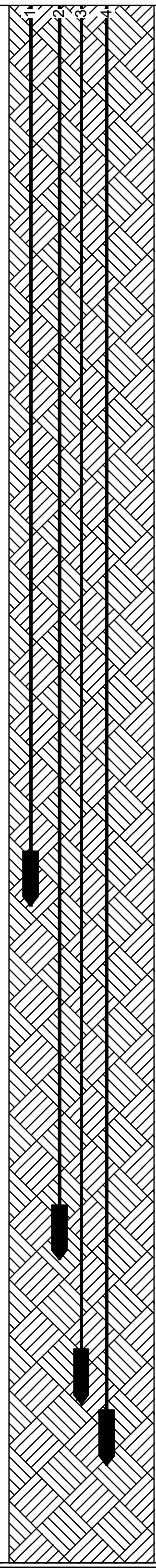
ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
1	Vibrating Wire Piezometer		58.77 m -16.82 m AHD	05/09/2017	
2	Vibrating Wire Piezometer		81.87 m -36.82 m AHD	05/09/2017	
3	Vibrating Wire Piezometer		91.30 m -44.99 m AHD	05/09/2017	
4	Vibrating Wire Piezometer		95.26 m -48.42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

MATERIAL

Depth (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.0 – 0.35m	FILL
0.35m – 6.92m	SANDSTONE
6.92m – 7.02m	CORE LOSS 0.10m (6.92-7.02)
7.02m – 86.49m	SANDSTONE - Interlaminated siltstone and sandstone band (0.56m) - Interlaminated siltstone and sandstone band (0.28m) - Siltstone band (0.06m)
86.49m – 86.74m	CORE LOSS 0.25m (86.49-86.74)
86.74m – 92.50m	SANDSTONE
92.50m – 95.15m	DOLERITE
95.15m – 101.65m	SANDSTONE

B202_w TERMINATED AT 101.65 m
Target depth
ATV imaging completed
VWPs installed

DRILLING: PROGRESS — ADT DRILLING HW Casing & CASING; HQ3; WATER (OWNE); 0% Water LOSS



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RMS LIB 40.3.1.GLB Log RTA PIEZOMETER INSTALLATION LOG 1 B202_W.GPJ <<DrawingFile>> 14/Sep/2017 08:54 8.30.004 Datgel Tools

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	

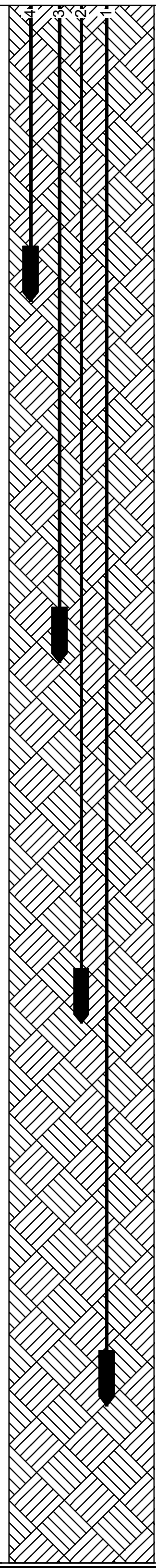
DRILLING / MATERIAL

DRILLING: AD/T 0.0–3.5 m (HW Casing); HQ3 3.5–65.81 m

WATER (PROGRESS): 0.0–3.5 m (GWNE); 3.5–6.2 m 2% Water LOSS; 6.2–18.1 m 2% Water LOSS; 18.1–21.1 m 50% Water LOSS; 21.1–24.1 m 50% Water LOSS; 24.1–30.4 m 50% Water LOSS; 30.4–36.0 m 50% Water LOSS; 36.0–46.9 m 50% Water LOSS; 46.9–57.1 m 50% Water LOSS; 57.1–65.81 m 50% Water LOSS

Depth (m)	MATERIAL DESCRIPTION (Soil Type, Colour, Plasticity or Particle Characteristic, Secondary and Minor Components)
0.00–2.95m	FILL
2.95–12.86m	SANDSTONE
12.86–12.95m	CORE LOSS 0.09m (12.86-12.95)
12.95–17.39m	SANDSTONE
17.39–17.44m	CORE LOSS 0.05m (17.39-17.44)
17.44–18.09m	SANDSTONE
18.09–20.41m	SILTSTONE/SANDSTONE
20.41–57.08m	SANDSTONE
57.08–62.30m	SILTSTONE/SANDSTONE
62.30–65.81m	SANDSTONE

B211_w TERMINATED AT 65.81 m
Target depth
ATV completed
VWP installed



VWPs installed in full cement/bentonite grout mix

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PIEZOMETER CONSTRUCTION

HOLE NO : B1013_w
FILE / JOB NO : 16.0000302526.2138
SHEET : 1 OF 1

PROJECT : WHTBL
LOCATION : Northbridge - Clive Park

POSITION : E: 336306.4, N: 6257879.0 (56 MGA94) | SURFACE ELEVATION : 14.71 (AHD) | ANGLE FROM HORIZONTAL : 60° AT 120°

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

DATE STARTED : 4/9/17 | DATE COMPLETED : 25/9/17 | DATE LOGGED : 4/9/17 | LOGGED BY : MB | CHECKED BY : GS

PIEZOMETER CONSTRUCTION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL	Installation Date	Static Water Level
4	Vibrating Wire Piezometer		40.10 m -20.02 m AHD	26/09/2017	
3	Vibrating Wire Piezometer		54.40 m -32.40 m AHD	26/09/2017	
2	Vibrating Wire Piezometer		91.00 m -64.10 m AHD	26/09/2017	
1	Vibrating Wire Piezometer		127.80 m -95.97 m AHD	26/09/2017	

DRILLING

PROGRESS: AD/T DRILLING; HW Casing & CASING; HQ3 (to ~87 m); HQ3 (to 132.50 m)

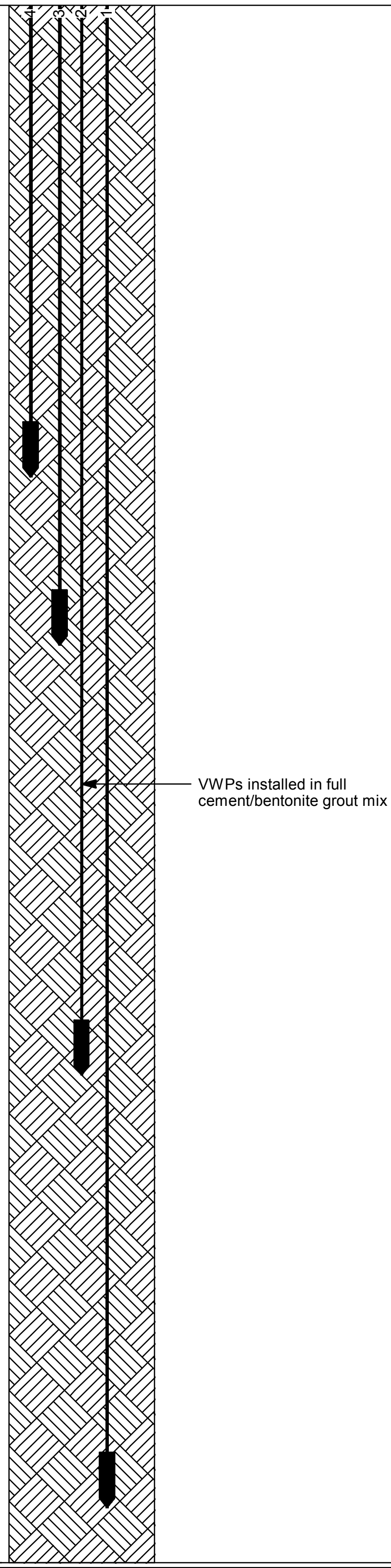
WATER: (GWNO); 0% LOSS; 10% LOSS; 80% LOSS; 100% LOSS; 95% LOSS; 75% LOSS; 60% LOSS

MATERIAL

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

Depth (m)	Description
0.0–0.50	FILL
0.50–0.80	CLAYEY SAND
0.80–3.25	SANDSTONE
3.25–3.55	CORE LOSS 0.30m (3.25-3.55)
3.55–21.10	SANDSTONE
21.10–21.20	CORE LOSS 0.10m (21.10-21.20)
21.20–84.78	SANDSTONE - interlaminated siltstone and sandstone
84.78–89.20	SILTSTONE AND INTERLAMINATED SANDSTONE/SILTSTONE
89.20–106.40	SANDSTONE
106.40–106.62	SILTSTONE
106.62–132.50	SANDSTONE

B1013_w TERMINATED AT 132.50 m
Target depth
ATV imaging complete
VWPs installed



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RMS LIB 40.3.1.GLB Log RTA PIEZOMETER INSTALLATION LOG 1 B1013_W.GPJ <<DrawingFile>> 04/Oct/2017 10:16 8.30.004 Datgel Tools

Annexure 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
B138	Edgecliffe Esplanade - Seaforth	337119.04	6258390.56	60.97	137.00	76.03	96	1/06/2017	15/08/2017	19/11/2017	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	-60.03 to -66.33	Sandstone
B138P	Edgecliffe Esplanade - Seaforth	337152.9	625405.9	57.54	129.10	-71.56	99	21/12/2017	22/12/2017	6/04/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	-62.49 to -71.59	Sandstone
B140	Ponsonby Parade - Seaforth	337517.11	6258806.84	65.67	113.39	-47.72	96	5/06/2017	10/08/2017	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	-29.83 to -37.83	Sandstone
B141	McMillian Street - Seaforth	337437.81	6259373.99	92.37	100.16	-7.79	96	20/06/2017	10/08/2017	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	46.37 to 40.37	Sandstone

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
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
B154	Small Street - Willoughby	333821.60	6257311.21	56.29	68.00	-11.71	96	26/06/2017	9/08/2017	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	8.29 to 2.29	Sandstone
B155	Bega Road - Northbridge	335052.9	6257485.8	80.11	149.00	-68.89	96	15/06/2017	15/08/2017	23/11/2017	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	-52.89 to -62.89	Sandstone
B155P	Bega Road - Northbridge	335052.9	6257486.1	80.06	139.00	-58.94	99	15/12/2017	22/12/2017	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	-51.94 to -58.94	Sandstone
B173	Wakehurst Parkway - Seaforth	336683.95	6261686.85	114.00	9.95	104.05	96	1/08/2017	4/10/2017	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	112.00 to 107.00	Sandstone
B174	Wakehurst Parkway - Seaforth	336546.34	6262050.23	121.94	10.05	111.89	96	1/08/2017	3/10/2017	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	119.94 to 115.01	Sandstone
B175	Wakehurst Parkway - Seaforth	336334.98	6263122.67	121.05	10.00	111.05	96	2/08/2017	4/10/2017	15/03/2018	Standpipe Piezometer, 3 m slotted screen, sump Class 18 PVC 50 mm ID	119.05 to 114.05	Sandstone

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
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

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
B114A	Artarmon - Lambs Road	332643.3	6257061.7	59.36	32.00	27.36		19/07/2017	04/08/2017	28/08/2017	Standpipe Piezometer	34.36 to 28.36	Sandstone
B127A	North Balgowlah - Bangaroo Street	338070.3	6259609.2	49.46	38.95	10.51		26/05/2017	03/08/2017	28/08/2017	Standpipe Piezometer	14.46 to 11.46	Siltstone / 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
B134A-a	Naremburn - Flat Rock Creek	333870.9	6257107.5	45.67	27.00	18.67		24/072017	03/08/2017	28/08/2017	Standpipe Piezometer	25.67 to 19.67	Silty Clay
B134A-b	Naremburn - Flat Rock Creek	333870.0	6257109.6	45.66	32.50	13.16		20/07/2017	03/08/2017	28/08/2017	Standpipe Piezometer	17.16 to 14.16	Sandy Clay

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
B134A-c	Naremburn - Flat Rock Drive	333868.9	6257112.1	45.63	76.35	-30.72		16/06/2017	04/08/2017	28/08/2017	Standpipe Piezometer	-11.87 to -14.87	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
B238	Northbridge - Sailors Bay Road	336173.8	6257785.9	38.91	144.00	-105.09		05/06/2017	17/08/2017	28/08/2017	Standpipe Piezometer	-90.99 to -93.99	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	
B135	Minnamurra Road - Northbridge	335435.10	6257598.94	53.93	160.00	-81.42	96	27/06/2017	21/08/2017	15/03/2018	Vibrating Wire Piezometer	VWP1 = -71.05 VWP2 = -29.86 VWP3 = 7.05	

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
B156	Harwood Place - Seaforth	337236.04	6259873.57	79.93	60.51	27.50	96	16/06/2017	11/08/2017	15/03/2018	Vibrating Wire Piezometer	VWP1 = 29.68 VWP2 = 43.54 VWP3 = 53.94	

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	
B176A	Naremburn – Flat Rock Drive	333856.1	625707.3	45.13	87.00	-41.87		15/08/2018	18/08/2017	1/03/2018	Vibrating Wire Piezometer	VWP1 = 19.24 VWP2 = 12.22 VWP3 = -12.89 VWP4 = -28.48	
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	

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
												VWP2 = -31.81 VWP3 = -18.60 VWP4 = -5.40	
B1013	Northbridge – Clive Park	336306.4	6257879.0	14.71	132.50	-117.79		25/09/2017	17/10/2017	NRD*	Vibrating Wire Piezometer	VWP1 = -95.97 VWP2 = -64.10 VWP3 = -32.40 VWP4 = -20.02	

*Data was not received

Annexure C. Packer test intervals and interpretation

Borehole	Inclination (°)	Length to Top (m)	Length to Bottom (m)	Test Number	Reading Method	Fixed Volume (L)	Packer Inflation Pressure (kPa)	Packer Seal Condition	Pressure Gauge Height (m)	Initial Groundwater Length (m)	Initial Groundwater Depth (m)	Depth to Top (m)	Depth to Bottom (m)	Depth to Centre (m)	Section Length (m)	Correction Gauge Pressure (kPa)	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	Interpreted Lugeon Value (Houlsby) (uL)	Remark
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	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	<1	Flow rate too low to define flow type.
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	2	90.0	3615	3615	3615	3615	0	0	0				156.5	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	3	135.0	3624	3624	3624	3624	0	0	0				201.5	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	4	90.0	3518	3518	3518	3518	0	0	0				156.5	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	5	45.0	3525	3525	3525	3525	0	0	0				111.5	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	1.53	None.
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	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	1.64	None.
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	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	1.63	None.
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	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	1.68	None.
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	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	1.72	None.
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	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	4.24	None.
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	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	5.36	None.
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	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	5.03	None.
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	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	4.26	None.
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	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	3.66	None.
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	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	8.17	None.
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	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	7.88	None.
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	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	7.24	None.
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	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	7.93	None.
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	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	7.72	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	1	75.0	606	606	606	606	0	0	0				176.6	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	1	135.0	645	645	645	645	0	0	0				253.3	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	1	135.0	32511	32511	32511	32511	0	0	0				512.7	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	1.19	Test terminated early due to high water loss (>40L/5min). Packer re-seated at 96.5 m and test started (see test 5).
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	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	1.06	Test terminated early due to high water loss (>45L/5min). Packer test successfully repeated 10/07/2017 at same depth interval.
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	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	1.25	Test terminated early due to high water loss (>45L/5min). Packer test successfully repeated 10/07/2017 at same depth interval.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type. Slight leakage of seal observed in stage 1 only, however stabilised and seal remained good for duration of test. Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
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	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	<1	Flow rate too low to define flow type. Slight leakage of seal observed in stage 1 only, however stabilised and seal remained good for duration of test. Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
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	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	<1	Flow rate too low to define flow type. Slight leakage of seal observed in stage 1 only, however stabilised and seal remained good for duration of test. Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
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	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	<1	Flow rate too low to define flow type. Slight leakage of seal observed in stage 1 only, however stabilised and seal remained good for duration of test. Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
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	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	<1	Flow rate too low to define flow type. Slight leakage of seal observed in stage 1 only, however stabilised and seal remained good for duration of test. Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
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	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	<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.
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	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	<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.
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	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	<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.
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	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	<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.
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	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	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.
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	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	<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.
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	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	<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.
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	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	<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.
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	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	<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.
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	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	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.
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	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	<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.
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	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	<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.
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	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	<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.
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	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	<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.

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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	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.
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	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	<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.
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	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	<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.
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	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	<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.
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	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	<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.
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	5	135.0	804	804	804	804	0	0	0				243.3	0.00	0.00	0.00	0.0	other - see comments	<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.
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	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	<1	Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
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	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	<1	Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
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	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	<1	Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
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	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	<1	Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
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	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	Flow meter not reading correctly - change in water volume measurements have been corrected based on measurements of change in water volume in the drum.
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	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	<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.
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	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	<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.
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	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	<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.
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	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	<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.
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	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	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.
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	1	130.0	14865	14942	15030	15117	77	88	87				463.8	84.00	16.80	1.96	4.2	other - see comments	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.
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	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	<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.
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	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	<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.
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	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	<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.
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	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	<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.
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	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	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.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	None.
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	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	<1	None.
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	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	1.11	None.
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	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	<1	None.
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	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	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	1.46	None.
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	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	1.45	None.
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	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	1.40	None.
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	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	1.45	None.
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	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	1.59	None.
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	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	1.64	None.
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	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	1.76	None.
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	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	1.68	None.
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	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	1.52	None.
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	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	1.78	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	1.18	Flow rate too low to define flow type.
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	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	1.98	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	1.14	Flow rate too low to define flow type.
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	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	1.71	Pump pressure fluctuating during final stage of test, disregard stage 5 result.
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	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	1.41	Pump pressure fluctuating during final stage of test, disregard stage 5 result.
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	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	1.82	Pump pressure fluctuating during final stage of test, disregard stage 5 result.
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	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	<1	Pump pressure fluctuating during final stage of test, disregard stage 5 result.
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	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	Pump pressure fluctuating during final stage of test, disregard stage 5 result.
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	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	<1	Changed pump valve after previous test, pressure is stable.
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	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	<1	Changed pump valve after previous test, pressure is stable.
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	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	<1	Changed pump valve after previous test, pressure is stable.
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	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	<1	Changed pump valve after previous test, pressure is stable.
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	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	Changed pump valve after previous test, pressure is stable.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	2.54	None.
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	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	2.97	None.
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	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	2.94	None.
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	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	2.39	None.
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	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	1.92	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	7.31	None.
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	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	7.03	None.
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	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	6.21	None.
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	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	5.67	None.
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	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	5.53	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	1.07	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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	1.07	None.
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	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	1.09	None.
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	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	<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	1.49	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	3.19	None.
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	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	3.68	None.
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	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	4.32	None.
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	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	3.60	None.
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	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	2.35	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
B132	-59.0	48.20	60.27	4	Fixed Volu	20.0	1600.0	Good	0.8	20.7	17.74	41.32	51.66	46.49	10.35	181.9	1	20.0								1:00	1:00	1:00	201.9	60.0	20.00	1.93	9.6	other - see comments	N/A	Could not hold pressure beyond 20 kPa due to high water loss, non standard method used.
B132	-59.0	57.00	60.27	5	Fixed Volu	300.0	1600.0	Good	0.8	20.7	17.74	48.86	51.66	50.26	2.80	181.9	2	30.0								3:30	3:29	3:28	211.9	100.0	31.58	11.27	53.2	other - see comments	N/A	Could not hold pressure beyond 40 kPa due to high water loss, non standard method used.
B132	-59.0	57.00	60.27	5	Fixed Volu	300.0	1600.0	Good	0.8	20.7	17.74	48.86	51.66	50.26	2.80	181.9	1	20.0								4:04	4:04	4:04	201.9	200.0	55.05	19.64	97.3	other - see comments	N/A	Could not hold pressure beyond 40 kPa due to high water loss, non standard method used.
B132	-59.0	78.90	84.01	10	Fixed Volu	250.0	1900.0	Good	0.8	22.4	19.19	67.63	72.01	69.82	4.38	196.1	2	150.0								4:08	5:24	6:19	346.1	300.0	22.12	5.05	14.6	other - see comments	N/A	Could not hold pressure beyond 150 kPa due to high water loss, non standard method used.
B132	-59.0	78.90	84.01	10	Fixed Volu	250.0	1900.0	Good	0.8	22.4	19.19	67.63	72.01	69.82	4.38	196.1	1	150.0								4:27	5:23	5:26	346.1	250.0	53.57	12.23	35.3	other - see comments	N/A	Could not hold pressure beyond 150 kPa due to high water loss, non standard method used.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	4	270.0	872	872	872	872	0	0	0				333.9	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	5	135.0	872	872	872	872	0	0	0				198.9	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	3	400.0	895	895	895	895	0	0	0				480.5	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	4	270.0	895	895	895	895	0	0	0				350.5	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	5	135.0	895	895	895	895	0	0	0				215.5	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	1	135.0	385	440	493	546	55	53	53				666.7	53.67	10.73	1.19	1.8	wash-out	1.79	None.
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	2	270.0	637	709	782	856	72	73	74				801.7	73.00	14.60	1.62	2.0	wash-out	2.02	None.
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	3	400.0	924	1037	1156	1270	113	119	114				931.7	115.33	23.07	2.56	2.8	wash-out	2.75	None.
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	4	270.0	1290	1393	1493	1593	103	100	100				801.7	101.00	20.20	2.24	2.8	wash-out	2.80	None.
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	5	135.0	1610	1695	1783	1869	85	88	86				666.7	86.33	17.27	1.92	2.9	wash-out	2.88	None.
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	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	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.
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	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	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.
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	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	1.14	None.
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	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	<1	None.
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	3	400.0	356	421	487.5	559	65	66.5	71.5				936.6	67.67	13.53	2.26	2.4	dilation	2.41	None.
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	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	<1	None.
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	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	None.
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	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	<1	None.
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	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	<1	None.
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	3	400.0	871	891.5	912	933	20.5	20.5	21				934.6	20.67	4.13	1.38	1.5	dilation	1.47	None.
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	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	<1	None.
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	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	None.
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	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	<1	None.
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	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	<1	None.
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	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	1.80	None.
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	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	<1	None.
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	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	None.
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	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	7.21	Could not hold pressure due to high water take, non standard method used.
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	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	7.81	Could not hold pressure due to high water take, non standard method used.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.

Borehole	Inclination (°)	Length to Top (m)	Length to Bottom (m)	Test Number	Reading Method	Fixed Volume (L)	Packer Inflation Pressure (kPa)	Packer Seal Condition	Pressure Gauge Height (m)	Initial Groundwater Length (m)	Initial Groundwater Depth (m)	Depth to Top (m)	Depth to Bottom (m)	Depth to Centre (m)	Section Length (m)	Correction Gauge Pressure (kPa)	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	Interpreted Lugeon Value (Houlsby) (uL)	Remark
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	1.40	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	None.
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	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	<1	None.
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	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	1.03	None.
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	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	<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	None.
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	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	<1	None.
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	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	2.15	None.
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	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	<1	None.
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	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	None.
B138	-90.0	82.00	88.00	7	Fixed Volu	100.0	1200.0	Good	1.2	53.0	53.00	82.00	88.00	85.00	6.00	531.7	1	50.0								1:42	1:40	1:42	581.7	750.0	49.54	8.26	14.2	other - see comments	N/A	Could not hold pressure beyond 50 kPa due to very high water take, non standard method used.
B138	-90.0	85.00	88.00	8	Fixed Volu	100.0	1200.0	Good	1.2	53.0	53.00	85.00	88.00	86.50	3.00	531.7	1	50.0								1:50	1:52	1:44	581.7	750.0	48.79	16.26	28.0	other - see comments	N/A	Could not hold pressure beyond 45 kPa due to very high water take, non standard method used.
B138	-90.0	85.00	91.00	9	Fixed Volu	100.0	1200.0	Good	1.2	58.0	58.00	85.00	91.00	88.00	6.00	580.8	1	50.0								1:50	1:52	1:44	630.8	300.0	59.22	9.87	15.6	other - see comments	N/A	Could not hold pressure beyond 50 kPa due to very high water take, non standard method used.
B138	-90.0	90.00	96.00	10	Fixed Volu	100.0	1200.0	Good	1.2	58.0	58.00	90.00	96.00	93.00	6.00	580.8	1	270.0								1:50	1:48		850.8	300.0	55.27	9.21	10.8	other - see comments	N/A	Could not build pressure beyond 270 kPa - reverted to fixed volume method.
B138	-90.0	85.00	88.00	8	Fixed Volu	100.0	1200.0	Good	1.2	53.0	53.00	85.00	88.00	86.50	3.00	531.7	2	25.0								3:10			556.7	100.0	31.58	10.53	18.9	other - see comments	N/A	Could not hold pressure beyond 45 kPa due to very high water take, non standard method used.
B138	-90.0	85.00	91.00	9	Fixed Volu	100.0	1200.0	Good	1.2	58.0	58.00	85.00	91.00	88.00	6.00	580.8	2	25.0								3:10			605.8	300.0	55.27	9.21	15.2	other - see comments	N/A	Could not hold pressure beyond 50 kPa due to very high water take, non standard method used.
B138	-90.0	93.00	96.00	12	Fixed Volu	100.0	1200.0	Good	1.2	58.0	58.00	93.00	96.00	94.50	3.00	580.8	1	400.0								4:30	4:35	4:29	980.8	250.0	48.39	16.13	16.5	other - see comments	N/A	Could not hold pressure due to high water take, non standard method used.
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	1	135.0	344	344	344	344	0	0	0				215.0	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	2	270.0	345	346	346	346	1	0	0				350.0	0.33	0.07	0.01	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	3	400.0	348	349	350	350	1	1	0				480.0	0.67	0.13	0.02	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	4	270.0	350	350	350	350	0	0	0				350.0	0.00	0.00	0.00	0.0	other - see comments	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	5	135.0	350	350	350	350	0	0	0				215.0	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	1	135.0	409.7	411	411	411	1.3	0	0				224.9	0.43	0.09	0.01	0.0	laminar flow	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	1	135.0	865	944	1023	1104	79	79	81				362.7	79.67	15.93	1.77	4.9	turbulent flow	4.88	None.
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	2	270.0	1320	1415	1501	1588	95	86	87				497.7	89.33	17.87	1.99	4.0	turbulent flow	3.99	None.
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	3	400.0	1668	1763	1858	1953	95	95	95				627.7	95.00	19.00	2.11	3.4	turbulent flow	3.36	None.
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	4	270.0	1989	2076	2160	2241	87	84	81				497.7	84.00	16.80	1.87	3.8	turbulent flow	3.75	None.
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	5	135.0	2280	2351	2423	2495	71	72	72				362.7	71.67	14.33	1.59	4.4	turbulent flow	4.39	None.
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	1	135.0	663	711	760	805	48	49	45				362.7	47.33	9.47	3.16	8.7	wash-out	8.70	None.
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	2	270.0	913	963	1022	1077	50	59	55				497.7	54.67	10.93	3.64	7.3	wash-out	7.32	None.
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	3	400.0	169	245	315	376	76	70	61				627.7	69.00	13.80	4.60	7.3	wash-out	7.33	None.
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	4	270.0	463	520	579	638	57	59	59				497.7	58.33	11.67	3.89	7.8	wash-out	7.81	None.
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	5	135.0	655	704	755	806	49	51	51				362.7	50.33	10.07	3.36	9.3	wash-out	9.25	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	1	135.0	218	218	218	218	0	0	0				574.1	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	Flow rate too low to define flow type.
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	1	135.0	134.5	183	232	283	48.5	49	51				714.4	49.50	9.90	2.20	3.1	dilation	3.08	None.
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	2	270.0	391	459	528	592	68	69	64				849.4	67.00	13.40	2.98	3.5	dilation	3.51	None.
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	3	400.0	628	717	799	882	89	82	83				979.4	84.67	16.93	3.76	3.8	dilation	3.84	None.
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	4	270.0	940	1017	1092	1162	77	75	70				849.4	74.00	14.80	3.29	3.9	dilation	3.87	None.
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	5	135.0	1173	1227	1277	1331	54	50	54				714.4	52.67	10.53	2.34	3.3	dilation	3.28	None.
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	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	<1	None.
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	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	<1	None.
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	3	400.0	131	205	287	374	74	82	87				968.6	81.00	16.20	3.06	3.2	dilation	3.16	None.
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	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	<1	None.
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	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	None.
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	1	135.0	538	627	723	822	89	96	99				704.6	94.67	18.93	3.44	4.9	wash-out	4.89	Test making water at highest pressure stage. Packer inflation increased from 1400 kPa to 1900 kPa and test resumed at 300 kPa.
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	2	200.0	1050	1220	1370	1544	170	150	174				769.6	164.67	32.93	5.99	7.8	wash-out	7.78	Test making water at highest pressure stage. Packer inflation increased from 1400 kPa to 1900 kPa and test resumed at 300 kPa.
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	3	300.0	390	610	839	1061	220	229	222				869.6	223.67	44.73	8.13	9.4	wash-out	9.35	Test making water at highest pressure stage. Packer inflation increased from 1400 kPa to 1900 kPa and test resumed at 300 kPa.
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	4	200.0	1230	1445	1655	1868	215	210	213				769.6	212.67	42.53	7.73	10.0	wash-out	10.05	Test making water at highest pressure stage. Packer inflation increased from 1400 kPa to 1900 kPa and test resumed at 300 kPa.
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	5	135.0	1910	2083	2282	2480	173	199	198				704.6	190.00	38.00	6.91	9.8	wash-out	9.81	Test making water at highest pressure stage. Packer inflation increased from 1400 kPa to 1900 kPa and test resumed at 300 kPa.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
B140	-90.0	87.20	93.20	9	Fixed Volu	250.0	1400.0	Good	0.8	58.3	58.30	87.20	93.20	90.20	6.00	579.4	1	135.0								4:40			714.4	500.0	29.59	4.93	6.9	other - see comments	N/A	Could not hold pressure beyond 200 kPa due to very high water take, non-standard method used.
B140	-90.0	87.20	93.20	9	Fixed Volu	250.0	1400.0	Good	0.8	58.3	58.30	87.20	93.20	90.20	6.00	579.4	2	200.0								5:10			779.4	300.0	65.22	10.87	13.9	other - see comments	N/A	Could not hold pressure beyond 200 kPa due to very high water take, non-standard method used.
B140	-90.0	92.20	95.20	10	Fixed Volu	250.0	1400.0	Good	0.8	58.3	58.30	92.20	95.20	93.70	3.00	579.4	1	400.0								8:10	8:45		979.4	300.0	75.32	25.11	25.6	other - see comments	N/A	Could not hold pressure beyond 200 kPa due to very high water take, non-standard method used.
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	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	1.74	None.
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	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	1.63	None.
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	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	1.53	None.
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	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	1.65	None.
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	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	1.90	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<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).
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	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	<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).
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	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	<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).
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	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	<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).
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	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	Flow rate too low to define flow type. Observed minor leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
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	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	<1	Flow rate too low to define flow type. Observed leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
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	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	<1	Flow rate too low to define flow type. Observed 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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Flow rate too low to define flow type. Observed leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
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	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	<1	Flow rate too low to define flow type. Observed leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
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	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	Flow rate too low to define flow type. Observed leakage in hose at 270kPa (0.2L/min) and at 400kPa (0.2L/min).
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	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	<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
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	2	270.0	426	426	426	426	0	0	0				439.3	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
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	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	<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
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	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	<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
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	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	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
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	1	135.0	446	446	446	446	0	0	0				304.3	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
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	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	<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
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	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	<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
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	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	<1	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
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	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	Flow rate too low to define flow type. Observed slight dripping from hose fitting.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	1.14	None.
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	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	1.65	None.
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	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	1.37	None.
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	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	1.51	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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	None.
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	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	1.08	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	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).
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	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	2.60	None.
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	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	2.18	None.
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	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	1.61	None.
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	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	1.16	None.
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	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	None.
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	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	1.30	None.
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	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	1.09	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	Mixture of dilation and turbulent flow types.
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	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	<1	Mixture of dilation and turbulent flow types.

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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Mixture of dilation and turbulent flow types.
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	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	<1	Mixture of dilation and turbulent flow types.
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	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	Mixture of dilation and turbulent flow types.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	None.
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	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	1.00	None.
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	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	5.03	None.
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	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	<1	None.
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	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	None.
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	1	65.0	536.6	536.6	536.6	536.6	0	0	0				82.2	0.00	0.00	0.00	0.0		<1	None.
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	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		<1	None.
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	3	190.0	536.8	536.8	536.8	536.8	0	0	0				207.2	0.00	0.00	0.00	0.0		<1	None.
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	4	125.0	539.8	539.8	539.8	539.8	0	0	0				142.2	0.00	0.00	0.00	0.0		<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
B156	-60.0	38.40	42.40	8	Fixed Volu	100.0	1400.0	Good	0.8	1.1	0.95	33.26	36.72	34.99	3.46	17.2	1	110.0								1:19	1:20	1:20	127.2	900.0	73.77	21.30	167.4	other - see comments	N/A	Test changed to non-standard method as could not hold pressure beyond 110 kPa - due to very high water take.
B156	-60.0	35.40	42.40	7	Fixed Volu	100.0	1400.0	Good	0.8	1.1	0.95	30.66	36.72	33.69	6.06	17.2	1	180.0								1:32	1:32	1:32	197.2	900.0	86.13	14.21	72.0	other - see comments	N/A	Test changed to non-standard method as could not hold pressure beyond 180 kPa - due to very high water take.
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	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	4.76	None.
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	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	4.64	None.
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	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	5.75	None.
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	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	6.71	None.
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	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	8.72	None.
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	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	11.30	None.
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	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	9.09	None.
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	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	8.18	None.
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	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	9.71	None.
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	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	12.01	None.
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	1	80.0	862	902			40						154.2	40.00	8.00	1.57	10.2	other - see comments	10.20	Test terminated due to high loss of water (>100L/min at 170 kPa).
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	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	30.83	None.
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	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	32.93	None.
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	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	36.69	None.
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	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	39.25	None.
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	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	40.28	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	1.27	None.
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	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	1.63	None.
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	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	1.67	None.
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	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	1.40	None.
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	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	1.19	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	None.
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	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	<1	None.
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	3	400.0	67945	67954	67963	67972	9	9	9				657.2	9.00	1.80	0.24	0.4	laminar flow	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	2.26	None.
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	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	5.76	None.
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	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	8.61	None.
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	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	4.45	None.
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	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	4.43	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	4	145.0	310	310	311	311	0	1	0				250.0	0.33	0.07	0.01	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	5	75.0	321	321	321	321	0	0	0				180.0	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	4	195.0	349	349	349	349	0	0	0				305.0	0.00	0.00	0.00	0.0	other - see comments	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.

Borehole	Inclination (°)	Length to Top (m)	Length to Bottom (m)	Test Number	Reading Method	Fixed Volume (L)	Packer Inflation Pressure (kPa)	Packer Seal Condition	Pressure Gauge Height (m)	Initial Groundwater Length (m)	Initial Groundwater Depth (m)	Depth to Top (m)	Depth to Bottom (m)	Depth to Centre (m)	Section Length (m)	Correction Gauge Pressure (kPa)	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	Interpreted Lugeon Value (Houlsby) (uL)	Remark
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	1.02	Small leak observed after 3rd stage, was able to maintain pressure and continue test.
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	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	1.22	Small leak observed after 3rd stage, was able to maintain pressure and continue test.
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	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	1.25	Small leak observed after 3rd stage, was able to maintain pressure and continue test.
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	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	<1	Small leak observed after 3rd stage, was able to maintain pressure and continue test.
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	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	1.32	Small leak observed after 3rd stage, was able to maintain pressure and continue test.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<1	None.
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	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	<1	None.
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	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	1.19	None.
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	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	<1	None.
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	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	None.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	<1	Flow rate too low to define flow type.
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	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	Flow rate too low to define flow type.
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	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	<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.
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	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	<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.
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	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	<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.
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	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	<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.
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	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	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.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	<1	None.
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	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	None.
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	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	<1	None.
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	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	<1	None.
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	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	<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	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	Interpreted Lugeon Value (Houlsby)	Remark
	(°)	(m)	(m)			(L)	(kPa)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(kPa)		(kPa)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(mm:ss)	(mm:ss)	(mm:ss)	(kPa)	(L)	(L/min)	(L/min/m)	(uL)		(uL)	
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	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	<1	None.
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	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	None.
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	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	<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
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	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	<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
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	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	<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
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	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	<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
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	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	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
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	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	<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
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	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	<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
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	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	<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
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	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	<1	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
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	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	Flow meter readings have been corrected based on measurement of change in water volume in the drum.
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	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	5.39	None.
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	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	4.58	None.
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	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	6.25	None.
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	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	6.42	None.
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	5	135.0	478.1	545	613	681	66.9	68	68				348.2	67.63	13.53	2.25	6.5	wash-out	6.48	None.

Annexure D. Groundwater quality results

Water Quality - Beaches Link

Chem_Group	ChemName	output unit	EQL	ANZECC 2000 FW 95%	ANZECC 2000 MW 95%	ADWG 2015 Health	NHMRC 2008 Recreational Water Quality/ Aesthetics	B114A	B114A	B114A	B114A	B114A	B114A	B127A	B127A	B127A	B127A	B127A	B127A	B128	B128	B128	B128	B128
	Monitoring_Zone							Artarmon Punch Street	Artarmon Punch Street	Artarmon Punch Street	Artarmon Punch Street	Artarmon Punch Street	Artarmon Punch Street	Balgowlah Connection	Balgowlah Connection	Balgowlah Connection	Balgowlah Connection	Balgowlah Connection	Balgowlah Connection	Balgowlah Connection	Balgowlah Connection	Balgowlah Connection	Balgowlah Connection	Balgowlah Connection
	Sampled_Date_Time							28/08/2017	15/11/2017	7/12/2017	10/01/2018	6/02/2018	7/03/2018	28/08/2017	16/11/2017	7/12/2017	11/01/2018	7/02/2018	8/03/2018	27/10/2017	8/12/2017	18/01/2018	9/02/2018	15/03/2018
EPA 621 Classification of Wastes	PAHs (EPA VIC Total)	µg/L	0.5					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5
Redox Potential	pH Redox	pH Units	0.01					-	-	-	-	-	-	-	-	-	-	-	-	5.54	-	-	-	-
	Redox Potential	mV	0.1					-	-	-	-	-	-	-	-	-	-	-	-	226	-	-	-	-
Resistivity (Saturated Paste)	Resistivity at 25°C	ohm cm	1					-	-	-	-	-	-	-	-	-	-	-	-	3220	3100	2670	3050	3340
Metals	Arsenic	µg/L	1			10	100	-	-	-	-	-	-	-	-	-	4	-	-	-	<1	-	-	-
	Arsenic (Filtered)	µg/L	1			10	100	<1	<1	<1	<1	<1	<1	<1	<1	<1	-	<1	<1	<1	-	<1	1	<1
	Barium	µg/L	1			2000	20000	-	-	-	-	-	-	-	-	-	822	-	-	-	60	-	-	-
	Barium (Filtered)	µg/L	1			2000	20000	48	103	95	90	94	76	80	25	3	-	60	43	60	-	52	23	28
	Boron	µg/L	50	370		4000	40000	-	-	-	-	-	-	-	-	-	<50	-	-	-	<50	-	-	-
	Boron (Filtered)	µg/L	50	370		4000	40000	<50	70	60	70	60	50	<50	<50	<50	-	<50	<50	200	-	<50	<50	<50
	Cadmium	µg/L	0.1	0.2	5.5	2	20	-	-	-	-	-	-	-	-	-	0.2	-	-	-	<0.1	-	-	-
	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
	Chromium (III+VI)	µg/L	1					-	-	-	-	-	-	-	-	-	148	-	-	-	2	-	-	-
	Chromium (III+VI) (Filtered)	µg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	-	<1	<1	<1	-	<1	<1	<1
	Cobalt	µg/L	1		1			-	-	-	-	-	-	-	-	-	18	-	-	-	<1	-	-	-
	Cobalt (Filtered)	µg/L	1		1			3	3	1	2	2	1	<1	<1	<1	-	<1	<1	<1	-	<1	<1	6
	Copper	µg/L	1	1.4	1.3	2000	20000	-	-	-	-	-	-	-	-	-	66	-	-	-	<1	-	-	-
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	<1	<1	<1	<1	<1	<1	<1	<1	<1	-	<1	<1	2	-	<1	<1	<1
	Iron	mg/L	0.05					-	-	-	-	-	-	-	-	-	122	-	-	-	20.9	-	-	-
	Iron (Filtered)	mg/L	0.05					0.19	23.4	24.4	24.2	27	21.2	0.06	10.3	11.6	-	11.1	-	25.9	-	21.2	17.4	9.04
	Lead	µg/L	1	3.4	4.4	10	100	-	-	-	-	-	-	-	-	-	19	-	-	-	1	-	-	-
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	<1	<1	<1	<1	<1	<1	<1	<1	<1	-	<1	<1	<1	-	<1	<1	<1
	Magnesium (Filtered)	mg/L	1					24	35	32	37	35	36	7	6	6	10	7	8	6	6	7	7	8
	Manganese	µg/L	1	1900		500	5000	-	-	-	-	-	-	-	-	-	1790	-	-	-	591	-	-	-
	Manganese (Filtered)	µg/L	1	1900		500	5000	623	840	816	904	856	771	348	322	358	-	374	363	629	-	586	413	217
	Mercury	µg/L	0.1	0.6	0.4	1	10	-	-	-	-	-	-	-	-	-	<0.1	-	-	-	<0.1	-	-	-
	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
	Nickel	µg/L	1	11	70	20	200	-	-	-	-	-	-	-	-	-	32	-	-	-	2	-	-	-
	Nickel (Filtered)	µg/L	1	11	70	20	200	<1	<1	<1	<1	<1	<1	1	<1	<1	-	<1	<1	4	-	4	<1	4
	Zinc	µg/L	5	8	15			-	-	-	-	-	-	-	-	-	318	-	-	-	30	-	-	-
	Zinc (Filtered)	µg/L	5	8	15			<5	8	8	<5	6	9	<5	<5	<5	-	6	5	35	-	19	6	17
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Alkalinity (total) as CaCO3	mg/L	1					128	250	195	187	203	193	110	149	71	180	156	175	<1	12	37	21	16
	Ammonia	mg/L	0.01	0.9	0.91		0.5	0.79	0.29	0.36	0.45	0.49	0.51	0.02	<0.01	<0.01	0.05	<0.01	0.02	0.15	0.2	0.13	0.04	0.08
	Ammonium as N	mg/L	0.01					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Anions Total	meq/L	0.01					13.6	21.1	21.4	21.2	21.8	22.1	4.3	5.24	3.34	5.91	5.64	5.64	-	2.4	3.3	2.59	3.1
	Bicarbonate Alkalinity as CaCO3	mg/L	1					128	250	195	187	203	193	110	149	71	180	156	175	<1	-	-	-	16
	Calcium (Filtered)	mg/L	1					24	32	31	36	36	35	38	40	14	51	32	54	2	2	2	2	6
	Cations Total	meq/L	0.01					13.2	18.6	18.7	19.8	19.6	19.9	4.66	5.21	3.47	5.86	5.11	5.69	-	2.38	3.69	2.5	2.86
	Chloride	mg/L	1					352	498	540	541	546	575	68	70	68	76	77	67	65	59	74	46	44
	pH (lab)	pH Units	0.01	7.0 - 8.5[#5]	8.0 - 8.4[#5]			6.86	7.03	7.04	6.97	6.68	6.49	7.25	7.88	6.69	7.76	7.06	7.67	4.82	6.68	6.53	5.9	5.71
	Electrical conductivity (lab)	uS/cm	1					1500	2100	2090	2170	2120	2240	490	647	433	618	575	630	311	322	374	328	299
	Fluoride	mg/L	0.1			1.5	15	0.5	0.8	0.4	0.5	0.5	0.5	0.2	0.2	0.1	0.2	1.3	0.2	<0.1	<0.1	<0.1	<0.1	<0.1
	Ionic Balance	%	0.01					1.6	6.49	6.71	3.29	5.45	5.1	4	0.37	1.95	0.38	5.01	0.49	-	-	5.54	-	4.03
	Kjeldahl Nitrogen Total	mg/L	0.1					1.6	0.6	0.4	1	0.6	0.7	0.4	0.1	0.2	<0.1	0.2	0.1	0.2	0.2	0.2	0.3	0.2
	Nitrate & Nitrite (as N)	mg/L	0.01					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.01
	Nitrate (as N)	mg/L	0.01	0.1581[#2]		11.29[#1]		0.02	0.02	0.06	0.09	0.07	0.16	0.02	<0.01	0.02	0.02	0.01	0.03	0.02	0.04	0.05	0.04	<0.01
	Nitrite (as N)	µg/L	10			910[#3]		<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	20	<10	20
	Nitrogen (Total Oxidised)	mg/L	0.01					0.02	0.02	0.06	0.09	0.07	0.16	0.02	<0.01	0.02	0.02	0.01	0.03	0.02	0.04	0.07	0.04	<0.01
	Nitrogen (Total)	mg/L	0.1					1.6	0.6	0.5	1.1	0.7	0.9	0.4	0.1	0.2	<0.1	0.2	0.1	0.2	0.2	0.3	0.3	0.2
	Phosphorus	mg/L	0.01					0.05	0.03	0.01	0.06	0.03	0.05	0.61	0.35	0.27	0.4	0.46	0.34	0.15	0.08	0.3	0.08	0.01
	Potassium (Filtered)	mg/L	1					12	6	6	7	6	5	4	3	4	4	3	3	1	<1	<1	<1	2
	Reactive Phosphorus as P	mg/L	0.01		0.01[#4]			<0.01	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.26	<0.01	<0.05	<0.01	<0.01	0.02	<0.01	<0.01	<0.01
	Sodium (Filtered)	mg/L	1					224	320	300	341	339	347	48	48	50	55	52	52	44	41	43	42	31
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					56	100	110	106	114	96	9	14	<1	8	17	12	28	24	23	42	74
	Total Dissolved Solids	mg/L	10					-	1170	1090	1080	1210	1110	-	373	287	345	889	354	-	233	206	170	201
	Total Dissolved Solids (Filtered)	mg/L	10					716	-	-	-	-	-	268	-	-	-	-	-	170	-	-	-	-
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					90	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
	TRH >C10 - C16	µg/L	100					190	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
	TRH >C16 - C34	µg/L	100					210	<100	<100	<100	<100	<100	<100	430	<100	<100	<100	<100	<100	<100	<100	<100	<100
	TRH >C34 - C40	µg/L	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					400	<100	<100	<100	<100	<100	<100	430	<100	<100	<100	<100	<100	<100	<100	<100	<100
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					0.03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
	TRH >C10 - C16 less Naphthalene (F2)	mg/L	0.1					0.19	<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
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					90	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
	TPH C10 - C14	µg/L	50					190	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
	TPH C15 - C28	µg/L	100					230	<100	<100	<100	<100	<100	<100	450	<100	<100	<100	<100	<100	<100	<100	<100	<100
	TPH C29-C36	µg/L	50					<50	<50	<50	<50	<50	<50	<50	130	<50	<50	<50	<50	<50	<50	<50	<50	<50
	TPH C10 - C36 (Sum of total)	µg/L	50					420	<50	<50	<50	<50	<50	<50	580	<50	<50	<50	<50	<50	<50	<50	<50	<50
BTEXN	Benzene	µg/L	1	950	700	1	10	<1	<1	<1	<1	<1	<1	<1	<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	<2	<2	<2	<2	<2	<2	<2
	Toluene	µg/L	2			800	8000	56	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Total BTEX	mg/L	0.001					0.058	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<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	<2	<2	<2	<2	<2
	Xylene (o)	µg/L	2	350				<2	<2	<2	<2	<2	<2	<2	<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	<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
	Acenaphthene	µg/L	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
	Anthracene	µg/L	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
	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
	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
	Benzo(a)pyrene TEQ (lower bound)*	µg/L	0.5					-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<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
	Benzo(k)fluoranthene	µg/L	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
	Dibenz(a,h)anthracene	µg/L	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
	Fluorene	µg/L	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
	Naphthalene	µg/L	1	16	70			<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
	Pyrene	µg/L	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	<0.5	<0.5
Field	Dissolved Oxygen	mg/L	0.1					-	-	-	-	-	-	-	-	-	-	-	-	4.8	-	-	-	-
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	-	-	-	-	-

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 - Beaches Link

Chem_Group	ChemName	output unit	EQL	ANZECC 2000 FW 95%	ANZECC 2000 MW 95%	ADWG 2015 Health	NHMRC 2008 Recreational Water Quality/ Aesthetics	B134A-A	B134A-A	B134A-A	B134A-A	B134A-A	B134A-A	B134A-B	B134A-B	B134A-B	B134A-B	B134A-B	B134A-B	B134A-C	B134A-C	B134A-C	B138P	B155P	B173	B173	B173	B173	B173	B174	B174	B174	B174
	Monitoring_Zone							Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Balgowlah Connection	Flat Rock Drive	Seaforth Oval	Seaforth Oval	Seaforth Oval	Seaforth Oval	Seaforth Oval	Seaforth Oval	Seaforth Oval	Seaforth Oval	Seaforth Oval
	Sampled_Date_Time							28/08/2017	16/11/2017	7/12/2017	11/01/2018	7/02/2018	8/03/2018	28/08/2017	16/11/2017	7/12/2017	11/01/2018	7/02/2018	8/03/2018	11/01/2018	7/02/2018	8/03/2018	6/04/2018	6/04/2018	2/11/2017	27/11/2017	12/01/2018	15/02/2018	28/03/2018	2/11/2017	27/11/2017	12/01/2018	15/02/2018
EPA 621 Classification of Wastes	PAHs (EPA VIC Total)	µg/L	0.5					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Redox Potential	pH Redox	pH Units	0.01					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Redox Potential	mV	0.1					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Resistivity (Saturated Paste)	Resistivity at 25°C	ohm cm	1					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Metals	Arsenic	µg/L	1			10	100	-	-	-	13	-	-	-	-	-	21	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Arsenic (Filtered)	µg/L	1			10	100	<1	2	4	-	3	3	1	3	2	-	2	3	-	<1	<1	<1	2	<1	<1	<1	<1	1	<1	<1	<1	<1
	Barium	µg/L	1			2000	20000	-	-	-	117	-	-	-	-	-	674	-	-	47	-	-	-	-	-	-	-	-	-	-	-	-	-
	Barium (Filtered)	µg/L	1			2000	20000	62	49	37	-	32	22	228	131	159	-	101	275	-	33	32	199	62	52	51	27	24	15	53	52	63	67
	Boron	µg/L	50	370		4000	40000	-	-	-	80	-	-	-	-	-	280	-	-	70	-	-	-	-	-	-	-	-	-	-	-	-	-
	Boron (Filtered)	µg/L	50	370		4000	40000	<50	80	80	-	100	80	170	280	290	-	290	350	-	80	60	120	120	<50	<50	90	50	70	170	150	260	330
	Cadmium	µg/L	0.1	0.2	5.5	2	20	-	-	-	0.6	-	-	-	-	-	0.4	-	-	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-
	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	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Chromium (III+VI)	µg/L	1					-	-	-	44	-	-	-	-	-	106	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-
	Chromium (III+VI) (Filtered)	µg/L	1					<1	<1	<1	-	<1	<1	<1	<1	<1	-	<1	1	-	<1	<1	<1	<1	1	2	4	3	5	<1	<1	<1	<1
	Cobalt	µg/L	1		1			-	-	-	26	-	-	-	-	-	23	-	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cobalt (Filtered)	µg/L	1		1			10	12	12	-	23	12	1	<1	<1	-	<1	<1	-	<1	<1	5	1	2	2	1	<1	<1	67	77	63	48
	Copper	µg/L	1	1.4	1.3	2000	20000	-	-	-	32	-	-	-	-	-	80	-	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	<1	<1	<1	-	<1	<1	<1	<1	<1	-	<1	<1	-	<1	<1	<1	<1	1	2	3	1	2	2	<1	<1	<1
	Iron	mg/L	0.05					-	-	-	128	-	-	-	-	-	85.8	-	-	0.85	-	-	-	-	-	-	-	-	-	-	-	-	-
	Iron (Filtered)	mg/L	0.05					0.08	82.4	101	-	101	-	0.07	12.3	14.6	-	4.39	-	-	0.05	-	21.1	<0.05	<0.05	<0.05	<0.05	0.08	0.05	4.82	8.52	18.7	32.3
	Lead	µg/L	1	3.4	4.4	10	100	-	-	-	121	-	-	-	-	-	216	-	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	<1	<1	<1	-	<1	<1	<1	<1	<1	-	<1	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Magnesium (Filtered)	mg/L	1					45	70	67	74	61	68	16	21	21	27	22	25	9	7	7	7	10	2	2	1	2	1	22	27	32	31
	Manganese	µg/L	1	1900		500	5000	-	-	-	2390	-	-	-	-	-	983	-	-	35	-	-	-	-	-	-	-	-	-	-	-	-	-
	Manganese (Filtered)	µg/L	1	1900		500	5000	1440	1890	1930	-	2470	2070	158	268	266	-	225	364	-	6	8	641	140	34	45	23	25	13	2090	2220	2350	2280
	Mercury	µg/L	0.1	0.6	0.4	1	10	-	-	-	<0.1	-	-	-	-	-	<0.1	-	-	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-
	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	<0.1	<0.1	<0.1
	Nickel	µg/L	1	11	70	20	200	-	-	-	19	-	-	-	-	-	32	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-
	Nickel (Filtered)	µg/L	1	11	70	20	200	2	7	7	-	12	4	3	<1	<1	-	<1	<1	-	2	2	1	3	2	2	1	<1	1	47	52	42	32
	Zinc	µg/L	5	8	15			-	-	-	342	-	-	-	-	-	467	-	-	39	-	-	-	-	-	-	-	-	-	-	-	-	-
	Zinc (Filtered)	µg/L	5	8	15			<5	8	<5	-	57	13	<5	<5	5	-	5	6	-	<5	<5	<5	<5	39	42	22	18	22	201	134	75	<5
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Alkalinity (total) as CaCO3	mg/L	1					324	256	217	172	265	291	387	386	410	420	430	468	99	73	82	90	147	11	4	29	<1	24	61	74	79	111
	Ammonia	mg/L	0.01	0.9	0.91		0.5	0.95	0.84	0.9	0.76	0.85	0.7	15.1	18.9	20.4	17	19.5	18.2	0.17	0.2	0.28	0.13	0.02	0.02	-	0.02	<0.01	0.03	0.02	-	<0.01	<0.01
	Ammonium as N	mg/L	0.01					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.01	-	-	-	-	<0.01	-	-
	Anions Total	meq/L	0.01					19.4	25.1	24.5	23.9	26.4	24.8	9.9	13.4	14.6	17	14.6	15.7	15.5	15.1	15.4	6.76	9.33	1.47	1.49	2.02	1.39	1.89	11	12.2	11.4	11.1
	Bicarbonate Alkalinity as CaCO3	mg/L	1					324	256	217	172	265	291	387	386	410	420	430	468	99	73	82	90	147	11	-	-	<1	24	61	-	-	111
	Calcium (Filtered)	mg/L	1					183	212	195	192	166	186	74	104	101	123	105	118	26	22	24	13	32	5	6	4	3	2	22	21	20	17
	Cations Total	meq/L	0.01					17.7	27	21.1	22.6	24.4	20.9	10.3	11.9	13.3	15	13.4	13.9	17.6	13.9	13.6	6.93	8.63	1.31	1.64	2.15	1.27	2.16	11	9.8	10.2	10.1
	Chloride	mg/L	1					169	212	216	226	220	223	74	115	120	136	111	128	421	407	418	108	104	31	25	20	25	28	246	287	282	258
	pH (lab)	pH Units	0.01	7.0 - 8.5#5	8.0 - 8.4#5			6.76	6.73	6.32	6.32	6.06	6.15	7.63	7.61	7.68	7.38	6.95	6.8	7.98	7.9	7.61	6.63	7.51	-	5.8	6.33	3.81	6.2	-	6.6	6.42	6.56
	Electrical conductivity (lab)	uS/cm	1					1800	2400	2060	2120	2050	2220	1100	1430	1320	1580	1260	1460	1660	1540	1700	677	978	-	207	242	237	211	-	1200	1140	1240
	Fluoride	mg/L	0.1			1.5	15	0.1	<0.1	<0.1	<0.1	0.1	<0.1	0.2	0.2	0.2	0.1	0.3	0.1	0.2	0.3	0.2	-	-	-	-	-	-	-	-	-	-	-
	Ionic Balance	%	0.01					4.64	3.57	7.51	2.95	3.95	8.58	2.05	6.19	4.62	1.82	4.44	6.12	6.38	3.96	6.1	1.25	3.88	-	-	-	-	-	5.65	8.91	2.76	4.99
	Kjeldahl Nitrogen Total	mg/L	0.1					2.8	2.3	2	2	1.9	2.5	15.8	19.9	23.1	16.6	20.2	20.4	0.2	0.4	0.6	0.2	1	<0.1	<0.1	0.2	0.1	0.3	0.2	<0.1	0.2	0.1
	Nitrate & Nitrite (as N)	mg/L	0.01					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	3.52	-	-	-	-	0.06	-	-	-	-
	Nitrate (as N)	mg/L	0.01	0.1581#2		11.29#1		0.04	0.02	<0.1	<0.01	<0.05	0.05	0.02	<0.01	0.02	<0.01	<0.01	0.04	0.02	<0.01	0.09	0.02	3.52	0.04	0.06	0.05	0.06	0.06	<0.01	0.04	<0.01	0.01
	Nitrite (as N)	µg/L	10			910#3		<10	<10	<100	<10	<50	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	10	10	<10	<10	<10	<10	<10	<10
	Nitrogen (Total Oxidised)	mg/L	0.01					0.04	0.02	<0.1	<0.01	<0.01	0.05	0.02	<0.01	0.02	<0.01	<0.01	0.04	0.02	<0.01	0.09	0.02	3.52	0.04	0.07	0.06	0.06	0.06	<0.01	0.04	<0.01	0.01
	Nitrogen (Total)	mg/L	0.1					2.8	2.3	2	2	1.9	2.6	15.8	19.9	23.1	16.6	20.2	20.4	0.2	0.4	0.7	0.2	4.5	<0.1	<0.1	0.3	0.2	0.4	0.2	<0.1	0.2	0.1
	Phosphorus	mg/L	0.01					0.26	0.03	0.24	0.15	0.08	0.36	0.12	0.18	0.18	0.49	0.05	0.05	<0.01	0.02	0.02	0.07	0.35	<0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01	0.04	<0.01
	Potassium (Filtered)	mg/L	1					9	7	7	9	7	7	29	19	19	25	22	19	12	10	8	2	3	1	<1	<1	<1	1	4	3	3	2
	Reactive Phosphorus as P	mg/L	0.01		0.01#4			<0.01	<0.01	<0.1	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	<0.05	<0.05	<0.01	<0.01	0.01	<0.01	<0.05	0.14	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Sodium (Filtered)	mg/L	1					107	138	130	153	126	134	105	88	88	109	96	95	351	276	268	104	141	20	27	43	22	45	156	158	162	152
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					394	672	676	678	715	610	4	120	148	230	139	130	79	103	95	92	166	18	34	42	33	30	135	127	88	78
	Total Dissolved Solids	mg/L	10					-	1570	1740	1620	1490	1330	-	762	943	1030	757	777	882	950	861	395	588	-	143	169	138	162	-	700	703	664
	Total Dissolved Solids (Filtered)	mg/L	10					1170	-	-	-	-	-	660	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					<20	<20	<20	<20	<20	<20	70	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
	TRH >C10 - C16	µg/L	100					<100	<100	<100	<100	<100	<100	230	380	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
	TRH >C16 - C34	µg/L	100					160	<100	<100	<100	<100	<100	530	220	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
	TRH >C34 - C40	µg/L	100					<100	<100	<100	<100	<100	<100	<100	<100	<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					160	<100	<100	<100	<100	<100	760	600	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.06	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<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	0.23	0.38	<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
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					<20	<20	<20	<20	<20	<20	70	<20	20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
	TPH C10 - C14	µg/L	50					80	<50	<50	<50	<50	<50	180	50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
	TPH C15 - C28	µg/L	100					200	<100	<100	<100	<100	<100	610	530	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
	TPH C29-C36	µg/L	50					<50	<50	<50	<50	<50	<50	<50	<50	<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					280	<50	<50	<50	<50	<50	790	580	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
BTEXN	Benzene	µg/L	1	950	700	1	10	2	<1	<1	<1	<1	<1	6	<1	<1	<1	<1	<1	<1	<1	<1	<1	<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	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Toluene	µg/L	2			800	8000	4	<2	<2	<2	<2	<2	7	<2	<2	<2	<2	<2	2	3	3	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Total BTEX	mg/L	0.001					0.006	<0.001	<0.001	<0.001	<0.001	<0.001	0.013	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.003	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<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	<2	<2	<2	<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	<2	<2	<2	<2	<2	<2	<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	<2	<2	<2	<2	<2	<2	<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	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Acenaphthene	µg/L	1					2.2	1.6	<1	<1	<1	<1	<1	1.6	<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	<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	<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	<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	<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	<0.5	-	-	<0.5
	Benzo(a)pyrene TEQ (lower bound)*	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
	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	<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	<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	<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	<1	<1	<1	<1	<1	<1
	Fluoranthene	µg/L	1					1.8	<1	<1	<1	<1	<1	1.4	1.2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Fluorene	µg/L	1					1.8	<1	<1	<1	<1	<1	<1	1.5	<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	<1	<1	<1	<1	<1	<1
	Naphthalene	µg/L	1	16	70			<5 - 1.2	<1	<1	<1	<1	<1	<5 - 1.8	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Phenanthrene	µg/L	1					3	2	<1	<1	<1	<1	1.2	1.6	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Pyrene	µg/L	1					1.6	<1	<1	<1	<1	<1	1.1	1.3	<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	11.6	3.6	-	-	-	-	5.5	7.2	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Field	Dissolved Oxygen	mg/L	0.1					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EPA 448 Classification of Wastes	Polycyclic 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 ecosystems

Water Quality - Beaches Link

Chem_Group	ChemName	output unit	EQL	ANZECC 2000 FW 95%	ANZECC 2000 MW 95%	ADWG 2015 Health	NHMRC 2008 Recreational Water Quality/ Aesthetics	B174	B175	B175	B175	B175	B175	B238	B238A	B238A	B238A	B238A	B238A	B343	B343
							Monitoring_Zone	Seaforth Oval	Seaforth Oval	Seaforth Oval	Seaforth Oval	Seaforth Oval	Seaforth Oval	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive	Flat Rock Drive
							Sampled_Date_Time	28/03/2018	26/10/2017	27/11/2017	12/01/2018	15/02/2018	28/03/2018	12/01/2018	28/08/2017	16/11/2017	7/12/2017	7/02/2018	8/03/2018	9/02/2018	15/03/2018
EPA 621 Classification of Wastes	PAHs (EPA VIC Total)	µg/L	0.5					-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5
Redox Potential	pH Redox	pH Units	0.01					-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Redox Potential	mV	0.1					-	-	-	-	-	-	-	-	-	-	-	-	-	-
Resistivity (Saturated Paste)	Resistivity at 25°C	ohm cm	1					-	-	-	-	-	-	-	-	-	-	-	-	1640	4670
Metals	Arsenic	µg/L	1			10	100	-	-	-	-	-	-	<1	-	-	-	-	-	-	-
	Arsenic (Filtered)	µg/L	1			10	100	2	<1	<1	<1	<1	<1	-	<1	<1	<1	<1	<1	<1	<1
	Barium	µg/L	1			2000	20000	-	-	-	-	-	-	1580	-	-	-	-	-	-	-
	Barium (Filtered)	µg/L	1			2000	20000	85	-	16	17	13	16	-	95	1420	1400	1230	1230	389	36
	Boron	µg/L	50	370		4000	40000	-	-	-	-	-	-	<50	-	-	-	-	-	-	-
	Boron (Filtered)	µg/L	50	370		4000	40000	470	-	<50	60	<50	<50	-	<50	<50	50	100	<50	220	<50
	Cadmium	µg/L	0.1	0.2	5.5	2	20	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-
	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
	Chromium (III+VI)	µg/L	1					-	-	-	-	-	-	2	-	-	-	-	-	-	-
	Chromium (III+VI) (Filtered)	µg/L	1					<1	<1	<1	<1	<1	<1	-	<1	<1	<1	<1	<1	<1	<1
	Cobalt	µg/L	1		1			-	-	-	-	-	-	<1	-	-	-	-	-	-	-
	Cobalt (Filtered)	µg/L	1		1			29	-	<1	<1	<1	<1	-	<1	<1	<1	<1	<1	<1	<1
	Copper	µg/L	1	1.4	1.3	2000	20000	-	-	-	-	-	-	<1	-	-	-	-	-	-	-
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	<1	2	3	4	<1	<1	-	<1	<1	<1	<1	<1	<1	2
	Iron	mg/L	0.05					-	-	-	-	-	-	0.15	-	-	-	-	-	-	-
	Iron (Filtered)	mg/L	0.05					35.2	-	<0.05	0.32	0.11	<0.05	-	<0.05	<0.05	<0.05	<0.05	-	15.7	1.16
	Lead	µg/L	1	3.4	4.4	10	100	-	-	-	-	-	-	320	-	-	-	-	-	-	-
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	<1	<1	<1	<1	<1	<1	-	<1	1	<1	<1	<1	<1	<1
	Magnesium (Filtered)	mg/L	1					30	8	8	7	6	6	<1	<1	<1	<1	<1	<1	8	3
	Manganese	µg/L	1	1900		500	5000	-	-	-	-	-	-	5	-	-	-	-	-	-	-
	Manganese (Filtered)	µg/L	1	1900		500	5000	2140	-	19	30	21	19	-	<1	<1	<1	<1	<1	497	72
	Mercury	µg/L	0.1	0.6	0.4	1	10	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-
	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
	Nickel	µg/L	1	11	70	20	200	-	-	-	-	-	-	3	-	-	-	-	-	-	-
	Nickel (Filtered)	µg/L	1	11	70	20	200	2	2	<1	1	<1	1	-	<1	<1	<1	<1	2	<1	<1
	Zinc	µg/L	5	8	15			-	-	-	-	-	-	12	-	-	-	-	-	-	-
	Zinc (Filtered)	µg/L	5	8	15			<5	7	9	27	6	7	-	<5	7	<5	8	7	6	8
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					<1	<1	<1	<1	<1	<1	66	43	59	35	63	63	<1	<1
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					<1	<1	<1	<1	<1	<1	968	319	925	924	1040	992	<1	<1
	Alkalinity (total) as CaCO3	mg/L	1					131	<1	<1	2	<1	<1	1030	362	985	959	1100	1050	114	48
	Ammonia	mg/L	0.01	0.9	0.91		0.5	0.28	<0.01	-	<0.01	<0.01	0.02	2.48	2.74	3.54	3.85	2.97	2.18	0.81	0.16
	Ammonium as N	mg/L	0.01					-	-	<0.01	-	-	-	-	-	-	-	-	-	-	-
	Anions Total	meq/L	0.01					12.3	4.08	4.04	3.52	3.47	3.83	22.7	10.1	21.7	21.5	23.8	22.9	5.24	2.47
	Bicarbonate Alkalinity as CaCO3	mg/L	1					131	<1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	-	48
	Calcium (Filtered)	mg/L	1					14	8	8	8	6	6	392	62	335	325	320	314	41	20
	Cations Total	meq/L	0.01					11.3	3.8	3.8	3.45	3.14	3.45	25.4	8.84	21.9	21.4	21.9	20.5	5.55	2.16
	Chloride	mg/L	1					305	121	121	102	103	113	57	67	53	63	47	52	100	30
	pH (lab)	pH Units	0.01	7.0 - 8.5[#5]	8.0 - 8.4[#5]			6.67	-	4.36	4.97	4.53	4.52	12.2	11.7	12.2	12	12	12.2	6.18	7.12
	Electrical conductivity (lab)	uS/cm	1					1240	-	490	405	453	463	4160	1650	4800	3740	4390	4380	609	214
	Fluoride	mg/L	0.1			1.5	15	-	<0.1	-	-	-	-	0.2	0.3	0.2	0.1	0.2	0.1	<0.1	<0.1
	Ionic Balance	%	0.01					4.16	3.57	3.06	0.95	4.92	5.31	5.66	6.58	0.5	0.2	4.09	5.34	2.87	8.02
	Kjeldahl Nitrogen Total	mg/L	0.1					<0.5	<0.1	<0.1	0.1	<0.1	0.3	2.4	2.8	3.9	5.5	3.2	2.4	11.6	0.8
	Nitrate & Nitrite (as N)	mg/L	0.01					<0.01	-	-	-	-	0.93	-	-	-	-	-	-	-	0.3
	Nitrate (as N)	mg/L	0.01	0.1581[#2]		11.29[#1]		<0.01	0.59	0.68	0.27	0.23	0.93	0.04	0.01	<0.01	0.04	0.02	<0.01	0.02	0.27
	Nitrite (as N)	µg/L	10			910[#3]		<10	<10	<10	<10	<10	<10	<10	10	20	<10	<10	30	<10	30
	Nitrogen (Total Oxidised)	mg/L	0.01					<0.01	0.59	0.68	0.27	0.23	0.93	0.04	0.02	<0.01	0.04	0.02	0.03	0.02	0.3
	Nitrogen (Total)	mg/L	0.1					<0.5	0.6	0.7	0.4	0.2	1.2	2.4	2.8	3.9	5.5	3.2	2.4	11.6	1.1
	Phosphorus	mg/L	0.01					0.02	0.05	<0.01	0.02	<0.01	0.04	0.01	0.05	<0.01	0.04	0.02	0.02	8.59	0.54
	Potassium (Filtered)	mg/L	1					2	<1	<1	<1	<1	<1	40	34	34	34	36	29	6	3
	Reactive Phosphorus as P	mg/L	0.01		0.01[#4]			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Sodium (Filtered)	mg/L	1					142	63	63	57	54	61	112	112	100	99	116	95	62	18
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					50	32	30	29	27	31	26	46	26	26	24	20	7	32
	Total Dissolved Solids	mg/L	10					627	-	290	226	229	258	1330	-	1340	1130	1340	1110	4940	181
	Total Dissolved Solids (Filtered)	mg/L	10					-	-	-	-	-	-	-	465	-	-	-	-	-	-
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					<20	<20	<20	<20	<20	<20	20	<20	<20	20	20	<20	60	<20
	TRH >C10 - C16	µg/L	100					<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	200
	TRH >C16 - C34	µg/L	100					<100	<100	<100	<100	<100	<100	<100	390	270	420	280	<100	1330	4440
	TRH >C34 - C40	µg/L	100					<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	400	1780
	TRH >C10 - C40 (Sum of total)	µg/L	100					<100	<100	<100	<100	<100	<100	<100	390	270	420	280	<100	1730	6420
	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	<0.02	0.06	<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	<0.1	<0.1	0.2
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					<20	<20	<20	<20	<20	<20	30	<20	<20	30	30	20	40	<20
	TPH C10 - C14	µg/L	50					<50	<50	<50	<50	<50	<50	<50	60	<50	<50	<50	<50	140	180
	TPH C15 - C28	µg/L	100					<100	<100	<100	<100	<100	<100	<100	430	290	360	200	<100	810	3120
	TPH C29-C36	µg/L	50					<50	<50	<50	<50	<50	<50	<50	<50	<50	100	<50	<50	600	2100
	TPH C10 - C36 (Sum of total)	µg/L	50					<50	<50	<50	<50	<50	<50	<50	490	290	460	200	<50	1550	5400
BTEXN	Benzene	µg/L	1	950	700	1	10	<1	<1	<1	<1	<1	<1	1	3	3	3	2	1	<1	<1
	Ethylbenzene	µg/L	2			300	3000	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Toluene	µg/L	2			800	8000	<2	<2	<2	<2	<2	<2	12	3	2	<2	13	11	<2	<2
	Total BTEX	mg/L	0.001					<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.013	0.006	0.005	0.003	0.015	0.012	0.003	<0.001
	Xylene (m & p)	µg/L	2					<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	3	<2
	Xylene (o)	µg/L	2	350				<2	<2	<2	<2	<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	<2	<2	3	<2
PAHs	Benzo[b+j]fluoranthene	µg/L	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
	Acenaphthylene	µg/L	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
	Benz(a)anthracene	µg/L	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
	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
	Benzo(a)pyrene TEQ (lower bound)*	µg/L	0.5					<0.5	<0.5	<0.5	<0.5	<0.5	<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
	Benzo(k)fluoranthene	µg/L	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
	Dibenz(a,h)anthracene	µg/L	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
	Fluorene	µg/L	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
	Naphthalene	µg/L	1	16	70			<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<5 - 2.8	<1
	Phenanthrene	µg/L	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
	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	<0.5	-	-	-	2.8	<0.5
Field	Dissolved Oxygen	mg/L	0.1					-	-	-	-	-	-	-	-	-	-	-	-	-	-
EPA 448 Classification of Wastes	Polycyclic aromatic hydrocarbons EPA448	µg/L	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 ecosystems

Water Quality - Beaches Link Artarmon 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	6	<1	0.5	0
	Barium (Filtered)	µg/L	1			2000	20000	6	103	92	0
	Boron (Filtered)	µg/L	50	370		4000	40000	6	70	60	0
	Cadmium (Filtered)	µg/L	0.1	0.2	5.5	2	20	6	<0.1	0.05	0
	Chromium (III+VI) (Filtered)	µg/L	1					6	<1	0.5	0
	Cobalt (Filtered)	µg/L	1		1			6	3	2	6
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	6	<1	0.5	0
	Iron (Filtered)	mg/L	0.05					6	27	23.8	6
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	6	<1	0.5	0
	Magnesium (Filtered)	mg/L	1					6	37	35	0
	Manganese (Filtered)	µg/L	1	1900		500	5000	6	904	828	6
	Mercury (Filtered)	µg/L	0.1	0.6	0.4	1	10	6	<0.1	0.05	0
	Nickel (Filtered)	µg/L	1	11	70	20	200	6	<1	0.5	0
	Zinc (Filtered)	µg/L	5	8	15			6	9	7	3
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					6	<1	0.5	0
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					6	<1	0.5	0
	Alkalinity (total) as CaCO3	mg/L	1					6	250	194	0
	Ammonia	mg/L	0.01	0.9	0.91		0.5	6	0.79	0.47	2
	Anions Total	meq/L	0.01					6	22.1	21.3	0
	Bicarbonate Alkalinity as CaCO3	mg/L	1					6	250	194	0
	Calcium (Filtered)	mg/L	1					6	36	33.5	0
	Cations Total	meq/L	0.01					6	19.9	19.15	0
	Chloride	mg/L	1					6	575	540.5	6
	pH (lab)	pH Units	0.01	7.0 - 8.5[#5]	8.0 - 8.4[#5]			6	7.04	6.915	6
	Electrical conductivity (lab)	uS/cm	1					6	2240	2110	0
	Fluoride	mg/L	0.1			1.5	15	6	0.8	0.5	0
	Ionic Balance	%	0.01					6	6.71	5.275	0
	Kjeldahl Nitrogen Total	mg/L	0.1					6	1.6	0.65	0
	Nitrate (as N)	mg/L	0.01	0.1581[#2]		11.29[#1]		6	0.16	0.065	1
	Nitrite (as N)	µg/L	10			910[#3]		6	<10	5	0
	Nitrogen (Total Oxidised)	mg/L	0.01					6	0.16	0.065	0
	Nitrogen (Total)	mg/L	0.1					6	1.6	0.8	0
	Phosphorus	mg/L	0.01					6	0.06	0.04	0
	Potassium (Filtered)	mg/L	1					6	12	6	0
	Reactive Phosphorus as P	mg/L	0.01		0.01 [#4]			6	<0.05	0.005	1
	Sodium (Filtered)	mg/L	1					6	347	329.5	6
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					6	114	103	0
	Total Dissolved Solids	mg/L	10					5	1210	1110	5
	Total Dissolved Solids (Filtered)	mg/L	10					1	716	716	1
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					6	90	10	0
	TRH >C10 - C16	µg/L	100					6	190	50	0
	TRH >C16 - C34	µg/L	100					6	210	50	0
	TRH >C34 - C40	µg/L	100					6	<100	50	0
	TRH >C10 - C40 (Sum of total)	µg/L	100					6	400	50	0
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					6	0.03	0.01	0
	TRH >C10 - C16 less Naphthalene (F2)	mg/L	0.1					6	0.19	0.05	0
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					6	90	10	0
	TPH C10 - C14	µg/L	50					6	190	25	0
	TPH C15 - C28	µg/L	100					6	230	50	0
	TPH C29-C36	µg/L	50					6	<50	25	0
	TPH C10 - C36 (Sum of total)	µg/L	50					6	420	25	0
BTEXN	Benzene	µg/L	1	950	700	1	10	6	<1	0.5	0
	Ethylbenzene	µg/L	2			300	3000	6	<2	1	0
	Toluene	µg/L	2			800	8000	6	56	1	0
	Total BTEX	mg/L	0.001					6	0.058	0.0005	0
	Xylene (m & p)	µg/L	2					6	2	1	0
	Xylene (o)	µg/L	2	350				6	<2	1	0
	Xylene Total	µg/L	2			600	6000	6	2	1	0
PAHs	Benzo[b+j]fluoranthene	µg/L	1					6	<1	0.5	0
	Acenaphthene	µg/L	1					6	<1	0.5	0
	Acenaphthylene	µg/L	1					6	<1	0.5	0
	Anthracene	µg/L	1					6	<1	0.5	0
	Benz(a)anthracene	µg/L	1					6	<1	0.5	0
	Benzo(a) pyrene	µg/L	0.5			0.01		6	<0.5	0.25	6
	Benzo(a)pyrene TEQ (zero)	µg/L	0.5					6	<0.5	0.25	0
	Benzo(g,h,i)perylene	µg/L	1					6	<1	0.5	0
	Benzo(k)fluoranthene	µg/L	1					6	<1	0.5	0
	Chrysene	µg/L	1					6	<1	0.5	0
	Dibenz(a,h)anthracene	µg/L	1					6	<1	0.5	0
	Fluoranthene	µg/L	1					6	<1	0.5	0
	Fluorene	µg/L	1					6	<1	0.5	0
	Indeno(1,2,3-c,d)pyrene	µg/L	1					6	<1	0.5	0
	Naphthalene	µg/L	1	16	70			6	<1	0.5	0
	Phenanthrene	µg/L	1					6	<1	0.5	0
	Pyrene	µg/L	1					6	<1	0.5	0
	PAHs (Sum of total)	µg/L	0.5			0.01	0.1	2	<0.5	0.25	2
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 - Beaches Link Balgowlah 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					2	<0.5	0.25	0
Redox Potential	pH Redox	pH Units	0.01					1	5.54	5.54	0
	Redox Potential	mV	0.1					1	226	226	0
Resistivity (Saturated Paste)	Resistivity at 25°C	ohm cm	1					7	3340	3100	0
Metals	Arsenic	µg/L	1			10	100	2	4	2.25	0
	Arsenic (Filtered)	µg/L	1			10	100	12	2	0.5	0
	Barium	µg/L	1			2000	20000	2	822	441	0
	Barium (Filtered)	µg/L	1			2000	20000	12	199	36	0
	Boron	µg/L	50	370		4000	40000	2	<50	25	0
	Boron (Filtered)	µg/L	50	370		4000	40000	12	200	25	0
	Cadmium	µg/L	0.1	0.2	5.5	2	20	2	0.2	0.125	1
	Cadmium (Filtered)	µg/L	0.1	0.2	5.5	2	20	12	<0.1	0.05	0
	Chromium (III+VI)	µg/L	1					2	148	75	0
	Chromium (III+VI) (Filtered)	µg/L	1					12	<1	0.5	0
	Cobalt	µg/L	1		1			2	18	9.25	1
	Cobalt (Filtered)	µg/L	1		1			12	6	0.5	3
	Copper	µg/L	1	1.4	1.3	2000	20000	2	66	33.25	1
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	12	2	0.5	1
	Iron	mg/L	0.05					2	122	71.45	2
	Iron (Filtered)	mg/L	0.05					11	25.9	11.6	11
	Lead	µg/L	1	3.4	4.4	10	100	2	19	10	1
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	12	<1	0.5	0
	Magnesium (Filtered)	mg/L	1					14	10	7	0
	Manganese	µg/L	1	1900		500	5000	2	1790	1190.5	2
	Manganese (Filtered)	µg/L	1	1900		500	5000	12	641	368.5	3
	Mercury	µg/L	0.1	0.6	0.4	1	10	2	<0.1	0.05	0
	Mercury (Filtered)	µg/L	0.1	0.6	0.4	1	10	12	<0.1	0.05	0
	Nickel	µg/L	1	11	70	20	200	2	32	17	1
	Nickel (Filtered)	µg/L	1	11	70	20	200	12	5	0.75	0
	Zinc	µg/L	5	8	15			2	318	174	2
	Zinc (Filtered)	µg/L	5	8	15			12	35	6	5
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					14	<1	0.5	0
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					14	<1	0.5	0
	Alkalinity (total) as CaCO3	mg/L	1					14	180	54	0
	Ammonia	mg/L	0.01	0.9	0.91		0.5	14	0.2	0.045	0
	Anions Total	meq/L	0.01					13	6.76	3.34	0
	Bicarbonate Alkalinity as CaCO3	mg/L	1					10	180	100	0
	Calcium (Filtered)	mg/L	1					14	54	9.5	0
	Cations Total	meq/L	0.01					13	6.93	3.69	0
	Chloride	mg/L	1					14	108	67.5	14
	pH (lab)	pH Units	0.01	7.0 - 8.5[#5]	8.0 - 8.4[#5]			14	7.88	6.655	14
	Electrical conductivity (lab)	uS/cm	1					14	677	403.5	0
	Fluoride	mg/L	0.1			1.5	15	13	1.3	0.1	0
	Ionic Balance	%	0.01					10	5.54	1.735	0
	Kjeldahl Nitrogen Total	mg/L	0.1					14	0.4	0.2	0
	Nitrate & Nitrite (as N)	mg/L	0.01					3	0.02	0.005	0
	Nitrate (as N)	mg/L	0.01	0.1581[#2]		11.29[#1]		14	0.05	0.02	0
	Nitrite (as N)	µg/L	10			910[#3]		14	20	5	0
	Nitrogen (Total Oxidised)	mg/L	0.01					14	0.07	0.02	0
	Nitrogen (Total)	mg/L	0.1					14	0.4	0.2	0
	Phosphorus	mg/L	0.01					14	0.61	0.21	0
	Potassium (Filtered)	mg/L	1					14	4	2	0
	Reactive Phosphorus as P	mg/L	0.01		0.01[#4]			14	0.26	0.005	4
	Sodium (Filtered)	mg/L	1					14	104	46	14
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					14	92	23.5	0
	Total Dissolved Solids	mg/L	10					12	889	260	12
	Total Dissolved Solids (Filtered)	mg/L	10					2	268	219	2
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					14	<20	10	0
	TRH >C10 - C16	µg/L	100					14	<100	50	0
	TRH >C16 - C34	µg/L	100					14	430	50	0
	TRH >C34 - C40	µg/L	100					14	<100	50	0
	TRH >C10 - C40 (Sum of total)	µg/L	100					14	430	50	0
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					14	<0.02	0.01	0
	TRH >C10 - C16 less Naphthalene (F2)	mg/L	0.1					14	<0.1	0.05	0
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					14	<20	10	0
	TPH C10 - C14	µg/L	50					14	<50	25	0
	TPH C15 - C28	µg/L	100					14	450	50	0
	TPH C29-C36	µg/L	50					14	130	25	0
	TPH C10 - C36 (Sum of total)	µg/L	50					14	580	25	0
BTEXN	Benzene	µg/L	1	950	700	1	10	14	<1	0.5	0
	Ethylbenzene	µg/L	2			300	3000	14	<2	1	0
	Toluene	µg/L	2			800	8000	14	<2	1	0
	Total BTEX	mg/L	0.001					14	<0.001	0.0005	0
	Xylene (m & p)	µg/L	2					14	<2	1	0
	Xylene (o)	µg/L	2	350				14	<2	1	0
	Xylene Total	µg/L	2			600	6000	14	<2	1	0
PAHs	Benzo[b+j]fluoranthene	µg/L	1					14	<1	0.5	0
	Acenaphthene	µg/L	1					14	<1	0.5	0
	Acenaphthylene	µg/L	1					14	<1	0.5	0
	Anthracene	µg/L	1					14	<1	0.5	0
	Benz(a)anthracene	µg/L	1					14	<1	0.5	0
	Benzo(a) pyrene	µg/L	0.5			0.01		14	<0.5	0.25	14
	Benzo(a)pyrene TEQ (zero)	µg/L	0.5					10	<0.5	0.25	0
	Benzo(a)pyrene TEQ (lower bound)*	µg/L	0.5					8	<0.5	0.25	0
	Benzo(g,h,i)perylene	µg/L	1					14	<1	0.5	0
	Benzo(k)fluoranthene	µg/L	1					14	<1	0.5	0
	Chrysene	µg/L	1					14	<1	0.5	0
	Dibenz(a,h)anthracene	µg/L	1					14	<1	0.5	0
	Fluoranthene	µg/L	1					14	<1	0.5	0
	Fluorene	µg/L	1					14	<1	0.5	0
	Indeno(1,2,3-c,d)pyrene	µg/L	1					14	<1	0.5	0
	Naphthalene	µg/L	1	16	70			14	<1	0.5	0
	Phenanthrene	µg/L	1					14	<1	0.5	0
	Pyrene	µg/L	1					14	<1	0.5	0
	PAHs (Sum of total)	µg/L	0.5			0.01	0.1	10	<0.5	0.25	10
Field	Dissolved Oxygen	mg/L	0.1					1	4.8	4.8	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 - Beaches Link Cammeray 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
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	4670	3155	0
Metals	Arsenic (Filtered)	µg/L	1			10	100	3	<1	0.5	0
	Barium (Filtered)	µg/L	1			2000	20000	3	389	118	0
	Boron (Filtered)	µg/L	50	370		4000	40000	3	220	160	0
	Cadmium (Filtered)	µg/L	0.1	0.2	5.5	2	20	3	<0.1	0.05	0
	Chromium (III+VI) (Filtered)	µg/L	1					3	<1	0.5	0
	Cobalt (Filtered)	µg/L	1		1			3	9	0.5	1
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	3	2	0.5	1
	Iron (Filtered)	mg/L	0.05					3	15.7	4.49	3
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	3	<1	0.5	0
	Magnesium (Filtered)	mg/L	1					3	8	4	0
	Manganese (Filtered)	µg/L	1	1900		500	5000	3	497	457	0
	Mercury (Filtered)	µg/L	0.1	0.6	0.4	1	10	3	<0.1	0.05	0
	Nickel (Filtered)	µg/L	1	11	70	20	200	3	24	0.5	1
	Zinc (Filtered)	µg/L	5	8	15			3	16	8	2
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					3	<1	0.5	0
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					3	<1	0.5	0
	Alkalinity (total) as CaCO3	mg/L	1					3	114	48	0
	Ammonia	mg/L	0.01	0.9	0.91		0.5	3	0.81	0.16	1
	Anions Total	meq/L	0.01					3	5.24	3.09	0
	Bicarbonate Alkalinity as CaCO3	mg/L	1					2	48	46	0
	Calcium (Filtered)	mg/L	1					3	41	20	0
	Cations Total	meq/L	0.01					3	5.55	3.42	0
	Chloride	mg/L	1					3	100	48	3
	pH (lab)	pH Units	0.01	7.0 - 8.5[#5]	8.0 - 8.4[#5]			3	7.12	6.9	3
	Electrical conductivity (lab)	uS/cm	1					3	609	392	0
	Fluoride	mg/L	0.1			1.5	15	2	<0.1	0.05	0
	Ionic Balance	%	0.01					3	8.02	5.12	0
	Kjeldahl Nitrogen Total	mg/L	0.1					3	11.6	0.8	0
	Nitrate & Nitrite (as N)	mg/L	0.01					2	0.3	0.16	0
	Nitrate (as N)	mg/L	0.01	0.1581[#2]		11.29[#1]		3	0.27	0.02	1
	Nitrite (as N)	µg/L	10			910[#3]		3	30	5	0
	Nitrogen (Total Oxidised)	mg/L	0.01					3	0.3	0.02	0
	Nitrogen (Total)	mg/L	0.1					3	11.6	1.1	0
	Phosphorus	mg/L	0.01					3	8.59	0.54	0
	Potassium (Filtered)	mg/L	1					3	6	3	0
	Reactive Phosphorus as P	mg/L	0.01		0.01[#4]			3	0.02	0.005	1
	Sodium (Filtered)	mg/L	1					3	63	62	3
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					3	41	32	0
	Total Dissolved Solids	mg/L	10					3	4940	200	3
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					3	60	10	0
	TRH >C10 - C16	µg/L	100					3	200	50	0
	TRH >C16 - C34	µg/L	100					3	4440	1330	0
	TRH >C34 - C40	µg/L	100					3	1780	400	0
	TRH >C10 - C40 (Sum of total)	µg/L	100					3	6420	1730	0
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					3	0.06	0.01	0
	TRH >C10 - C16 less Naphthalene (F2)	mg/L	0.1					3	0.2	0.05	0
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					3	40	10	0
	TPH C10 - C14	µg/L	50					3	180	140	0
	TPH C15 - C28	µg/L	100					3	3120	810	0
	TPH C29-C36	µg/L	50					3	2100	600	0
	TPH C10 - C36 (Sum of total)	µg/L	50					3	5400	1550	0
BTEXN	Benzene	µg/L	1	950	700	1	10	3	<1	0.5	0
	Ethylbenzene	µg/L	2			300	3000	3	<2	1	0
	Toluene	µg/L	2			800	8000	3	<2	1	0
	Total BTEX	mg/L	0.001					3	0.003	0.0005	0
	Xylene (m & p)	µg/L	2					3	3	1	0
	Xylene (o)	µg/L	2	350				3	<2	1	0
	Xylene Total	µg/L	2			600	6000	3	3	1	0
PAHs	Benzo[b+j]fluoranthene	µg/L	1					3	<1	0.5	0
	Acenaphthene	µg/L	1					3	<1	0.5	0
	Acenaphthylene	µg/L	1					3	<1	0.5	0
	Anthracene	µg/L	1					3	<1	0.5	0
	Benz(a)anthracene	µg/L	1					3	<1	0.5	0
	Benzo(a) pyrene	µg/L	0.5			0.01		3	<0.5	0.25	3
	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					3	<0.5	0.25	0
	Benzo(g,h,i)perylene	µg/L	1					3	<1	0.5	0
	Benzo(k)fluoranthene	µg/L	1					3	<1	0.5	0
	Chrysene	µg/L	1					3	<1	0.5	0
	Dibenz(a,h)anthracene	µg/L	1					3	<1	0.5	0
	Fluoranthene	µg/L	1					3	<1	0.5	0
	Fluorene	µg/L	1					3	<1	0.5	0
	Indeno(1,2,3-c,d)pyrene	µg/L	1					3	<1	0.5	0
	Naphthalene	µg/L	1	16	70			3	2.8	0.5	0
	Phenanthrene	µg/L	1					3	<1	0.5	0
	Pyrene	µg/L	1					3	<1	0.5	0
	PAHs (Sum of total)	µg/L	0.5			0.01	0.1	3	2.8	0.25	3

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 - Beaches Link Flat Rock 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	4670	3155	0
Metals	Arsenic	µg/L	1			10	100	4	21	7	2
	Arsenic (Filtered)	µg/L	1			10	100	20	4	0.75	0
	Barium	µg/L	1			2000	20000	4	1580	395.5	0
	Barium (Filtered)	µg/L	1			2000	20000	20	1420	98	0
	Boron	µg/L	50	370		4000	40000	4	280	75	0
	Boron (Filtered)	µg/L	50	370		4000	40000	20	350	80	0
	Cadmium	µg/L	0.1	0.2	5.5	2	20	4	0.6	0.225	2
	Cadmium (Filtered)	µg/L	0.1	0.2	5.5	2	20	20	<0.1	0.05	0
	Chromium (III+VI)	µg/L	1					4	106	25.5	0
	Chromium (III+VI) (Filtered)	µg/L	1					20	1	0.5	0
	Cobalt	µg/L	1		1			4	26	11.75	2
	Cobalt (Filtered)	µg/L	1		1			20	23	0.5	7
	Copper	µg/L	1	1.4	1.3	2000	20000	4	80	16.25	2
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	20	2	0.5	1
	Iron	mg/L	0.05					4	128	43.325	4
	Iron (Filtered)	mg/L	0.05					16	101	0.62	16
	Lead	µg/L	1	3.4	4.4	10	100	4	320	168.5	3
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	20	1	0.5	0
	Magnesium (Filtered)	mg/L	1					24	74	13	0
	Manganese	µg/L	1	1900		500	5000	4	2390	509	2
	Manganese (Filtered)	µg/L	1	1900		500	5000	20	2470	191.5	5
	Mercury	µg/L	0.1	0.6	0.4	1	10	4	<0.1	0.05	0
	Mercury (Filtered)	µg/L	0.1	0.6	0.4	1	10	20	<0.1	0.05	0
	Nickel	µg/L	1	11	70	20	200	4	32	13	2
	Nickel (Filtered)	µg/L	1	11	70	20	200	20	12	1.25	1
	Zinc	µg/L	5	8	15			4	467	190.5	4
	Zinc (Filtered)	µg/L	5	8	15			20	57	5	5
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					24	66	0.5	0
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					24	1040	0.5	0
	Alkalinity (total) as CaCO3	mg/L	1					24	1100	343	0
	Ammonia	mg/L	0.01	0.9	0.91		0.5	24	20.4	1.565	19
	Anions Total	meq/L	0.01					24	26.4	16.35	0
	Bicarbonate Alkalinity as CaCO3	mg/L	1					23	468	172	0
	Calcium (Filtered)	mg/L	1					24	392	120.5	0
	Cations Total	meq/L	0.01					24	27	16.3	0
	Chloride	mg/L	1					24	421	117.5	24
	pH (lab)	pH Units	0.01	7.0 - 8.5[#5]	8.0 - 8.4[#5]			24	12.2	7.56	24
	Electrical conductivity (lab)	uS/cm	1					24	4800	1680	0
	Fluoride	mg/L	0.1			1.5	15	23	0.3	0.1	0
	Ionic Balance	%	0.01					24	8.58	4.53	0
	Kjeldahl Nitrogen Total	mg/L	0.1					24	23.1	2.65	0
	Nitrate & Nitrite (as N)	mg/L	0.01					2	3.52	1.91	0
	Nitrate (as N)	mg/L	0.01	0.1581[#2]		11.29[#1]		24	3.52	0.02	2
	Nitrite (as N)	µg/L	10			910[#3]		24	<100	5	0
	Nitrogen (Total Oxidised)	mg/L	0.01					24	3.52	0.02	0
	Nitrogen (Total)	mg/L	0.1					24	23.1	2.8	0
	Phosphorus	mg/L	0.01					24	8.59	0.065	0
	Potassium (Filtered)	mg/L	1					24	40	15.5	0
	Reactive Phosphorus as P	mg/L	0.01		0.01[#4]			24	0.14	0.005	7
	Sodium (Filtered)	mg/L	1					24	351	110.5	24
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					24	715	111.5	0
	Total Dissolved Solids	mg/L	10					21	4940	1110	21
	Total Dissolved Solids (Filtered)	mg/L	10					3	1170	660	3
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					24	70	10	0
	TRH >C10 - C16	µg/L	100					24	380	50	0
	TRH >C16 - C34	µg/L	100					24	4440	50	0
	TRH >C34 - C40	µg/L	100					24	1780	50	0
	TRH >C10 - C40 (Sum of total)	µg/L	100					24	6420	50	0
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					24	0.06	0.01	0
	TRH >C10 - C16 less Naphthalene (F2)	mg/L	0.1					24	0.38	0.05	0
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					24	70	10	0
	TPH C10 - C14	µg/L	50					24	180	25	0
	TPH C15 - C28	µg/L	100					24	3120	50	0
	TPH C29-C36	µg/L	50					24	2100	25	0
	TPH C10 - C36 (Sum of total)	µg/L	50					24	5400	25	0
BTEXN	Benzene	µg/L	1	950	700	1	10	24	6	0.5	8
	Ethylbenzene	µg/L	2			300	3000	24	<2	1	0
	Toluene	µg/L	2			800	8000	24	13	1	0
	Total BTEX	mg/L	0.001					24	0.015	0.00125	0
	Xylene (m & p)	µg/L	2					24	3	1	0
	Xylene (o)	µg/L	2	350				24	<2	1	0
	Xylene Total	µg/L	2			600	6000	24	3	1	0
PAHs	Benzo[b+j]fluoranthene	µg/L	1					24	<1	0.5	0
	Acenaphthene	µg/L	1					24	2.2	0.5	0
	Acenaphthylene	µg/L	1					24	<1	0.5	0
	Anthracene	µg/L	1					24	<1	0.5	0
	Benz(a)anthracene	µg/L	1					24	<1	0.5	0
	Benzo(a) pyrene	µg/L	0.5			0.01		24	<0.5	0.25	24
	Benzo(a)pyrene TEQ (zero)	µg/L	0.5					23	<0.5	0.25	0
	Benzo(a)pyrene TEQ (lower bound)*	µg/L	0.5					3	<0.5	0.25	0
	Benzo(g,h,i)perylene	µg/L	1					24	<1	0.5	0
	Benzo(k)fluoranthene	µg/L	1					24	<1	0.5	0
	Chrysene	µg/L	1					24	<1	0.5	0
	Dibenz(a,h)anthracene	µg/L	1					24	<1	0.5	0
	Fluoranthene	µg/L	1					24	1.8	0.5	0
	Fluorene	µg/L	1					24	1.8	0.5	0
	Indeno(1,2,3-c,d)pyrene	µg/L	1					24	<1	0.5	0
	Naphthalene	µg/L	1	16	70			24	2.8	0.5	0
	Phenanthrene	µg/L	1					24	3	0.5	0
	Pyrene	µg/L	1					24	1.6	0.5	0
	PAHs (Sum of total)	µg/L	0.5			0.01	0.1	9	11.6	2.8	9
EPA 448 Classification of Wastes	Polycylic aromatic hydrocarbons EPA448	µg/L	0.5					15	<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 - Beaches Link Seaforth 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
Metals	Arsenic	µg/L	1			10	100	0	0		0
	Arsenic (Filtered)	µg/L	1			10	100	15	2	0.5	0
	Barium	µg/L	1			2000	20000	0	0		0
	Barium (Filtered)	µg/L	1			2000	20000	14	85	39	0
	Boron	µg/L	50	370		4000	40000	0	0		0
	Boron (Filtered)	µg/L	50	370		4000	40000	14	470	65	1
	Cadmium	µg/L	0.1	0.2	5.5	2	20	0	0		0
	Cadmium (Filtered)	µg/L	0.1	0.2	5.5	2	20	15	<0.1	0.05	0
	Chromium (III+VI)	µg/L	1					0	0		0
	Chromium (III+VI) (Filtered)	µg/L	1					15	5	0.5	0
	Cobalt	µg/L	1		1			0	0		0
	Cobalt (Filtered)	µg/L	1		1			14	77	1.5	8
	Copper	µg/L	1	1.4	1.3	2000	20000	0	0		0
	Copper (Filtered)	µg/L	1	1.4	1.3	2000	20000	15	4	1	7
	Iron	mg/L	0.05					0	0		0
	Iron (Filtered)	mg/L	0.05					14	35.2	0.095	14
	Lead	µg/L	1	3.4	4.4	10	100	0	0		0
	Lead (Filtered)	µg/L	1	3.4	4.4	10	100	15	<1	0.5	0
	Magnesium (Filtered)	mg/L	1					15	32	7	0
	Manganese	µg/L	1	1900		500	5000	0	0		0
	Manganese (Filtered)	µg/L	1	1900		500	5000	14	2350	32	5
	Mercury	µg/L	0.1	0.6	0.4	1	10	0	0		0
	Mercury (Filtered)	µg/L	0.1	0.6	0.4	1	10	15	<0.1	0.05	0
	Nickel	µg/L	1	11	70	20	200	0	0		0
	Nickel (Filtered)	µg/L	1	11	70	20	200	15	52	2	4
	Zinc	µg/L	5	8	15			0	0		0
	Zinc (Filtered)	µg/L	5	8	15			15	201	22	10
Inorganics	Carbonate Alkalinity as CaCO3	mg/L	1					15	<1	0.5	0
	Alkalinity (Hydroxide) as CaCO3	mg/L	1					15	<1	0.5	0
	Alkalinity (total) as CaCO3	mg/L	1					15	131	11	0
	Ammonia	mg/L	0.01	0.9	0.91		0.5	12	0.28	0.0125	0
	Ammonium as N	mg/L	0.01					3	<0.01	0.005	0
	Anions Total	meq/L	0.01					15	12.3	3.83	0
	Bicarbonate Alkalinity as CaCO3	mg/L	1					9	131	11	0
	Calcium (Filtered)	mg/L	1					15	22	8	0
	Cations Total	meq/L	0.01					15	11.3	3.45	0
	Chloride	mg/L	1					15	305	113	15
	pH (lab)	pH Units	0.01	7.0 - 8.5[#5]	8.0 - 8.4[#5]			12	6.67	6	12
	Electrical conductivity (lab)	uS/cm	1					12	1240	458	0
	Fluoride	mg/L	0.1			1.5	15	1	<0.1	0.05	0
	Ionic Balance	%	0.01					10	8.91	4.54	0
	Kjeldahl Nitrogen Total	mg/L	0.1					15	<0.5	0.1	0
	Nitrate & Nitrite (as N)	mg/L	0.01					3	0.93	0.06	0
	Nitrate (as N)	mg/L	0.01	0.1581[#2]		11.29[#1]		15	0.93	0.06	5
	Nitrite (as N)	µg/L	10			910[#3]		15	10	5	0
	Nitrogen (Total Oxidised)	mg/L	0.01					15	0.93	0.06	0
	Nitrogen (Total)	mg/L	0.1					15	1.2	0.2	0
	Phosphorus	mg/L	0.01					15	0.05	0.005	0
	Potassium (Filtered)	mg/L	1					15	4	0.5	0
	Reactive Phosphorus as P	mg/L	0.01		0.01[#4]			15	<0.01	0.005	0
	Sodium (Filtered)	mg/L	1					15	162	61	15
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1					15	135	33	0
	Total Dissolved Solids	mg/L	10					12	703	243.5	12
TRH - NEPM 2013 Fractions	TRH >C6 - C10	µg/L	20					15	<20	10	0
	TRH >C10 - C16	µg/L	100					15	<100	50	0
	TRH >C16 - C34	µg/L	100					15	<100	50	0
	TRH >C34 - C40	µg/L	100					15	<100	50	0
	TRH >C10 - C40 (Sum of total)	µg/L	100					15	<100	50	0
	TRH >C6 - C10 less BTEX (F1)	mg/L	0.02					15	<0.02	0.01	0
	TRH >C10 - C16 less Naphthalene (F2)	mg/L	0.1					15	<0.1	0.05	0
TPH - NEPM 1999 Fractions	TPH C6 - C9	µg/L	20					15	<20	10	0
	TPH C10 - C14	µg/L	50					15	<50	25	0
	TPH C15 - C28	µg/L	100					15	<100	50	0
	TPH C29-C36	µg/L	50					15	<50	25	0
	TPH C10 - C36 (Sum of total)	µg/L	50					15	<50	25	0
BTEXN	Benzene	µg/L	1	950	700	1	10	15	<1	0.5	0
	Ethylbenzene	µg/L	2			300	3000	15	<2	1	0
	Toluene	µg/L	2			800	8000	15	<2	1	0
	Total BTEX	mg/L	0.001					15	<0.001	0.0005	0
	Xylene (m & p)	µg/L	2					15	<2	1	0
	Xylene (o)	µg/L	2	350				15	<2	1	0
	Xylene Total	µg/L	2			600	6000	15	<2	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					9	<0.5	0.25	0
	Benzo(a)pyrene TEQ (lower bound)*	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	15	<0.5	0.25	15
EPA 448 Classification of Wastes	Polycylic aromatic hydrocarbons EPA448	µg/L	0.5					3	<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

Annexure E. Modelled inflows to tunnel components

Table E-1: North Model Tunnel Inflows – Cammeray to Middle Harbour Section of Beaches Link project (Main Tunnel)

Tunnel Sub-section	Length (m)	Tunnel Inflow (L/s)						
		2023	2024	2025	2026	2027	2028	2128
NB Main Line - Flat Rock Drive Site to North Bridge Cavern	545	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NB Northbridge Cavern	185	0.000	0.186	0.141	0.138	0.134	0.134	0.111
NB Main Line - North Bridge Cavern towards Clive Park	1,971	0.000	0.587	1.457	1.361	1.289	1.275	0.841
NB Main Line - Clive Park to Transition Structure (Undrained)	100	0.000	0.000	4.634	0.000	0.000	0.000	0.000
NB Main Line - Flat Rock Drive Site to Cammeray Cavern	1,467	0.417	1.220	1.173	1.080	0.957	0.936	0.484
NB Cammeray Cavern	183	0.000	0.000	0.109	0.077	0.053	0.049	0.007
EB Entry Ramp - Gore Hill Freeway to North Bridge Cavern	577	1.633	1.635	1.840	1.659	1.488	1.461	1.034
SB Main Line - Flat Rock Drive site to North Bridge Cavern	685	2.359	2.265	1.995	1.913	1.824	1.809	1.596
SB Northbridge Cavern	272	0.000	0.207	0.157	0.154	0.150	0.149	0.098
SB Main Line - North Bridge Cavern towards Clive Park	1,737	0.000	0.000	1.456	1.339	1.272	1.259	0.826
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
SB Main Line - Flat Rock Drive Site to Cammeray Cavern	1,450	0.414	1.293	1.132	1.035	0.900	0.876	0.440
SB Cammeray Cavern	136	0.000	0.000	0.088	0.071	0.058	0.056	0.020
WB Exit Ramp - Gore Hill Freeway to North Bridge Cavern	641	1.988	3.991	2.172	1.761	1.359	1.297	0.698
BL - Cammeray ventilation Tunnel	246	0.565	0.396	0.298	0.262	0.227	0.221	0.111
BL - Punch Street Access Decline	221	0.210	0.127	0.089	0.079	0.069	0.067	0.000
BL - Flat Rock Creek Access Decline	315	0.000	0.437	0.013	0.004	0.000	0.000	0.000
TOTAL TUNNEL INFLOW (L/s)		7.586	12.343	16.757	10.933	9.779	9.590	6.266
	Average Inflow (L/s/km)							
		2023	2024	2025	2026	2027	2028	2128
AVERAGE INFLOW (L/s/km)		0.699	1.138	1.545	1.008	0.902	0.884	0.578

Notes. (1) NB = North Bound, SB = South Bound, EB = East Bound & WB = West Bound.

Table E-2: North Model Tunnel Inflows - Middle Harbour to Wakehurst/North Balgowlah Section of Beaches Link project (Main Tunnel)

Tunnel Sub-section (1)	Length (m)	Tunnel Inflow (L/s)						
		2023	2024	2025	2026	2027	2028	2128
NB Main Line - Burnt Bridge Creek Deviation to Seaforth Ramp	1,364	0.076	0.056	0.037	0.029	0.022	0.021	0.005
NB Seaforth Cavern	157	0.000	0.038	0.005	0.003	0.002	0.001	0.000
NB Main Line - Seaforth Cavern towards Seaforth Bluff	1,150	0.000	0.000	1.925	2.459	2.466	2.466	2.461
NB Main Line - Seaforth Bluff to Transition Structure (Undrained)	90	0.000	0.000	1.692	0.000	0.000	0.000	0.000
NB Exit Ramp - Wakehurst Park towards Seaforth Cavern	1,657	0.000	0.135	0.160	0.126	0.098	0.094	0.038
NB Exit Ramp - Wakehurst Park towards Frenchs Forest	166	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SB Seaforth Cavern	298	0.000	0.396	0.186	0.160	0.149	0.147	0.126
SB Main Line - Seaforth Cavern towards Seaforth Bluff	975	0.000	1.267	4.121	4.380	4.367	4.364	4.333
SB Main Line - Seaforth Bluff to Transition Structure (Undrained)	125	0.000	0.000	2.662	0.000	0.000	0.000	0.000
SB Exit Ramp - Wakehurst Park towards Seaforth Cavern	1,719	0.000	0.290	0.288	0.247	0.214	0.209	0.127
SB Exit Ramp - Wakehurst Park towards Frenchs Forest	145	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SB Main Line - Burnt Bridge Creek Deviation to Seaforth Ramp	1,136	0.076	0.345	0.195	0.176	0.165	0.163	0.141
BL - Balgowlah Access Decline	300	0.914	0.576	0.443	0.411	0.380	0.374	0.307
BL - Wakehurst Parkway East	230	0.064	0.031	0.031	0.031	0.030	0.030	0.027
TOTAL TUNNEL INFLOW (L/s)		1.130	3.135	11.743	8.023	7.892	7.870	7.568
		Average Inflow (L/s/km)						
		2023	2024	2025	2026	2027	2028	2128
AVERAGE INFLOW (L/s/km)		0.119	0.330	1.235	0.844	0.830	0.827	0.796

Notes. (1) NB = North Bound, SB = South Bound, EB = East Bound & WB = West Bound.

Annexure F. Groundwater modelling report

Transport for NSW

Beaches Link and Gore Hill Freeway Connection

Groundwater modelling report

December 2020

Prepared for

Transport for NSW

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 is a NSW Government initiative to provide additional road network capacity across Sydney Harbour and to improve connectivity with Sydney's Northern Beaches. The Beaches Link and Gore Hill Freeway Connection component of the works (the project) includes 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.

Transport for NSW is seeking approval under Part 5, Division 5.2 of the *Environmental Planning and Assessment Act 1979* to construct and operate the project, which would comprise two main components:

- Twin motorway tunnels connecting the Warringah Freeway at Cammeray and the Gore Hill Freeway at Artarmon to the Burnt Bridge Creek Deviation at Balgowlah and Wakehurst Parkway at Killarney Heights, and an upgrade of Wakehurst Parkway (the Beaches Link)
- Connection and integration works along the existing Gore Hill Freeway at Artarmon (the Gore Hill Freeway Connection).

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 effects.

Available hydrogeological, geological, water level and hydraulic testing data were used to develop a conceptual groundwater model and to develop suitable numerical groundwater models.

Two three-dimensional (3D) groundwater models were developed to cover the whole proposed tunnel alignment for the program of works. The numerical groundwater models were used to estimate groundwater inflows, groundwater level drawdown, and changes in groundwater discharge to watercourses. More accurate and efficient modelling was undertaken by splitting the model area into these two models, separated along Sydney Harbour. The South Model covers the area south of Sydney Harbour and the North Model covers the area north of Sydney Harbour. The Beaches Link and Gore Hill Freeway Connection project area occurs entirely in the North Model domain. Therefore, the Beaches Link and Gore Hill Freeway Connection project groundwater modelling assessment was based on the North Model.

The North Model meets the Class 2 requirements of the Australian Groundwater Modelling Guidelines. The model was calibrated for steady state conditions against measured groundwater levels and stream flows, and for transient conditions against measured groundwater levels.

Predictive model scenarios considered the Beaches Link project only and the cumulative case. The cumulative scenario also considered the operation of the Western Harbour Tunnel and Warringah Freeway Upgrade project components located north of Sydney Harbour and the Sydney Metro Chatswood to Sydenham project. The predictive modelling considered a construction phase from the second quarter of 2023 to the second quarter of 2027, followed by an operational phase to December 2128.

In addition to the three-dimensional modelling, two-dimensional (2D) numerical groundwater models were developed to assess the rate of inland movement of saline water from saltwater bodies adjacent to the tunnels.

Project-wide tunnel groundwater inflows were predicted during the construction period and at 100 years of operation. Predicted inflows ranged between 0.75 ML/day and 1.53 ML/day for the project during construction and 1.20 ML/day after approximately 100 years of operation.

Predicted groundwater level drawdown results from the groundwater model were computed to provide predicted drawdown contours for the project only and the cumulative scenario. Groundwater level drawdown results are provided in this report for the period at the end of construction and at about 100 years of operation.

The potential change in groundwater baseflow contribution to surface waters was computed from the model for the cumulative scenario. Baseflow reduction was calculated at all creeks where more than one metre water table drawdown was predicted.

Uncertainty analysis modelling was conducted to assess potential groundwater-related impacts, identifying key factors of high and low range hydraulic parameter values. While some inconsistencies and localised model anomalies were observed, the uncertainty analysis provides a general indication of the potential magnitude of changes that might occur based on the assumed values and the hydrogeological features that are present across the alignment.

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), 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 Middle 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 the Gore Hill Freeway to Balgowlah and Killarney Heights and including the surface upgrade of the 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 areas 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 existing harbour crossings.

1.2 The project

Transport for NSW is seeking approval under Part 5, Division 5.2 of the *Environmental Planning and Assessment Act 1979* to construct and operate the Beaches Link and Gore Hill Freeway Connection project, which would comprise two components:

- Twin tolled motorway tunnels connecting the Warringah Freeway at Cammeray and the Gore Hill Freeway at Artarmon to the Burnt Bridge Creek Deviation at Balgowlah and the Wakehurst Parkway at Killarney Heights, and an upgrade of the Wakehurst Parkway (the Beaches Link)
- Connection and integration works along the existing Gore Hill Freeway and surrounding roads at Artarmon (the Gore Hill Freeway Connection).

A detailed description of these two components is provided in Section 1.4.

1.3 Project location

The project would be located within the North Sydney, Willoughby, Mosman and Northern Beaches local government areas, connecting Cammeray in the south with Killarney Heights, Frenchs Forest and Balgowlah in the north. The project would also connect to both the Gore Hill Freeway and Reserve Road in Artarmon in the west.

Commencing at the Warringah Freeway at Cammeray, the mainline tunnels would pass under Naremburn and Northbridge, then cross Middle Harbour between Northbridge and Seaforth. The mainline tunnels would then split under Seaforth into two ramp tunnels and continue north to the Wakehurst Parkway at Killarney Heights and north-east to Balgowlah, linking directly to the Burnt Bridge Creek Deviation to the south of the existing Kitchener Street bridge.

The mainline tunnels would also have on ramps and off ramps from under Northbridge connecting to the Gore Hill Freeway and Reserve Road east of the existing Lane Cove Tunnel. Surface works would also be carried out at the Gore Hill Freeway in Artarmon, Burnt Bridge Creek Deviation at Balgowlah and along the Wakehurst Parkway between Seaforth and Frenchs Forest to connect the project to the existing arterial and local road networks.

1.4 Key features of the project

Key features of the Beaches Link component of the project are shown in Figure A1-1 (Attachment 1) and would include:

- Twin mainline tunnels about 5.6 kilometres long and each accommodating three lanes of traffic in each direction, together with entry and exit ramp tunnels to connections at the surface. The crossing of Middle Harbour between Northbridge and Seaforth would involve three lane, twin immersed tube tunnels
- Connection to the stub tunnels constructed at Cammeray as part of the Western Harbour Tunnel and Warringah Freeway Upgrade project
- Twin two lane ramp tunnels:
  - Eastbound and westbound connections between the mainline tunnel under Seaforth and the surface at the Burnt Bridge Creek Deviation, Balgowlah (about 1.2 kilometres in length)
  - Northbound and southbound connections between the mainline tunnel under Seaforth and the surface at the Wakehurst Parkway, Killarney Heights (about 2.8 kilometres in length)
  - Eastbound and westbound connections between the mainline tunnel under Northbridge and the surface at the Gore Hill Freeway and Reserve Road, Artarmon (about 2.1 kilometres in length).
- An access road connection at Balgowlah between the Burnt Bridge Creek Deviation and Sydney Road including the modification of the intersection at Maretimo Street and Sydney Road, Balgowlah
- Upgrade and integration works along the Wakehurst Parkway, at Seaforth, Killarney Heights and Frenchs Forest, through to Frenchs Forest Road East
- New open space and recreation facilities at Balgowlah
- New and upgraded pedestrian and cyclist infrastructure
- Ventilation outlets and motorway facilities at the Warringah Freeway in Cammeray, the Gore Hill Freeway in Artarmon, the Burnt Bridge Creek Deviation in Balgowlah and the Wakehurst Parkway in Killarney Heights
- Operational facilities, including a motorway control centre at the Gore Hill Freeway in Artarmon, and tunnel support facilities at the Gore Hill Freeway in Artarmon and the Wakehurst Parkway in Frenchs Forest
- Other operational infrastructure including groundwater and tunnel drainage management and treatment systems, surface drainage, signage, tolling infrastructure, fire and life safety systems, roadside furniture, lighting, emergency evacuation and emergency smoke extraction infrastructure, Closed Circuit Television (CCTV) and other traffic management systems.

Key features of the Gore Hill Freeway Connection component of the project are shown in Figure A1-2 (Attachment 1) and would include:

- Upgrade and reconfiguration of the Gore Hill Freeway between the T1 North Shore & Western Line and T9 Northern Line and the Pacific Highway
- Modifications to the Reserve Road and Hampden Road bridges
- Widening of Reserve Road between the Gore Hill Freeway and Dickson Avenue
- Modification of the Dickson Avenue and Reserve Road intersection to allow for the Beaches Link off ramp
- Upgrades to existing roads around the Gore Hill Freeway to integrate the project with the surrounding road network
- Upgrade of the Dickson Avenue and Pacific Highway intersection

- New and upgraded pedestrian and cyclist infrastructure
- Other operational infrastructure, including surface drainage and utility infrastructure, signage and lighting, CCTV and other traffic management systems.

A detailed description of the project is provided in Chapter 5 (Project description) of the environmental impact statement.

Subject to obtaining planning approval, construction of the project is anticipated to commence in 2023 and is expected to take around five to six years to complete.

1.5 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 and ramp tunnels. However, surface areas would also be required to support tunnelling activities and to construct the tunnel connections, tunnel portals, surface road upgrades and operational 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), traffic management controls, vegetation clearing, earthworks, demolition of structures, building 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 and/or provision of alternative facilities (mooring or marina berth) within Middle Harbour
- Construction of the Beaches Link, with typical activities being excavation of tunnel construction access declines, construction of driven tunnels, cut and cover and trough structures, construction of surface upgrade works, construction of cofferdams, dredging and immersed tube tunnel piled support 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:
  - A motorway control centre at the Gore Hill Freeway in Artarmon
  - Tunnel support facilities at the Gore Hill Freeway in Artarmon and at the Wakehurst Parkway in Frenchs Forest
  - Motorway facilities and ventilation outlets at the Warringah Freeway in Cammeray (fitout only of the Beaches Link ventilation outlet at the Warringah Freeway (being constructed by the Western Harbour Tunnel and Warringah Freeway Upgrade project), the Gore Hill Freeway in Artarmon, the Burnt Bridge Creek Deviation in Balgowlah and the Wakehurst Parkway in Killarney Heights
  - A wastewater treatment plant at the Gore Hill Freeway in Artarmon
  - Installation of motorway tolling infrastructure
- Staged construction of the Gore Hill Freeway Connection at Artarmon and upgrade and integration works at Balgowlah and along the Wakehurst Parkway with typical activities being earthworks, bridgeworks, construction of retaining walls, stormwater drainage, pavement works and linemarking and the installation of roadside 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 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 would include:

- Cammeray Golf Course (BL1)
- Flat Rock Drive (BL2)
- Punch Street (BL3)
- Dickson Avenue (BL4)
- Barton Road (BL5)
- Gore Hill Freeway median (BL6)
- Middle Harbour south cofferdam (BL7)
- Middle Harbour north cofferdam (BL8)
- Spit West Reserve (BL9)
- Balgowlah Golf Course (BL10)
- Kitchener Street (BL11)
- Wakehurst Parkway south (BL12)
- Wakehurst Parkway east (BL13)
- Wakehurst Parkway north (BL14).

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

1.6 Specific aspects of the project relating to groundwater

The tunnelling strategy considered for the mined land tunnels is the use of a roadheader. The tunnelling strategy considered for the Middle 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.

1.6.1 Tunnel construction and lining methods

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

It is anticipated that the tunnel lining system would comprise the following three methods:

- Typical drained tunnel lining: Portions of the tunnel would be drained via a typical drained tunnel lining: a 125 millimetre thick layer of permanent shotcrete. This method is proposed to limit groundwater inflows to less than one litre per second per kilometre
- Drained tunnel with waterproof umbrella: Small portions of the tunnel would 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 watercourses and portals. The waterproof umbrella would comprise permanent shotcrete and a waterproof membrane over conduit drains that direct seepage to the floor drains (to prevent dripping onto trafficable parts of the roadway).
- Tanked or undrained tunnel lining: Some sections of the tunnel would be fully lined with a waterproof membrane to exclude inflows where the alignment is below sea level next to the immersed tube tunnel harbour crossing or to reduce groundwater drawdown and potential environmental impacts relative to a drained system.

For the purposes of this modelling report it was assumed that the tunnel was unlined, with the exception of a 125 metre section on either side of Middle Harbour, and that groundwater inflows to the tunnel were constrained by the formation permeability. Appropriate tunnel linings should be investigated during further design development and implemented to achieve the design requirements and mitigate unacceptable settlement due to groundwater drawdown associated with the tunnels.

1.6.2 Immersed tube tunnel design

The Middle Harbour crossing would utilise an immersed tube tunnel design from Northbridge to Seaforth. The required roadway grading across the harbour will be achieved with a constant 0.5 per cent slope, which would facilitate water drainage. Any water collected within the immersed tube tunnel will 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.

1.6.3 Cavern design

The project would include eight mined caverns, two at the Gore Hill entry and exit, two where the Gore Hill Freeway connection ramps merge with the main tunnels, two at the Warringah Freeway entry and exit, and two at the Wakehurst Parkway entry and exit. Caverns would be situated at diverging and merging areas as well as exit and entry points. The lengths of the caverns would vary from 108 metres to 208 metres and the widths will vary from 15 metres to 28 metres.

The caverns would be lined with a 50 millimetre thick layer of 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 50 millimetre thick shotcrete layer would be applied over the strip drains. For the purposes of this assessment, the caverns have been modelled as drained structures, given that the weep holes would allow drainage of groundwater from surrounding rocks.

1.6.4 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.

1.7 Scope of work

The scope of work for the groundwater modelling assessment included the following tasks:

1.7.1 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 three-dimensional (3D) conceptual model.

1.7.2 Task 2: Modelling

- Construct a 3D groundwater flow model using MODFLOW-USG utilising 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. Transport for NSW, as a transport authority, is exempt from the requirement to hold Water Access Licences, according to Schedule 5, 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 that the licensable take be calculated.

1.7.3 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 Appendix N (Technical working paper: Groundwater).

1.7.4 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 Murray -Darling Basin Authority (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 Bureau of Meteorology (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 Western Harbour Tunnel alignment has one harbour crossing at the Sydney Harbour. At the southern extent of the Western Harbour Tunnel project area is Whites Creek, which is a concrete lined artificial drainage that discharges to Rozelle Bay.

Topography and drainage features within the 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 elevated topography 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 ramps to the Gore Hill Freeway connection.

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 through a culvert 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 several 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 gullies and creeks contributing to the dam and the dam water body are 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 dry season, in September and October 2017, 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	
	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

Note 1: (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 recommends 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 recommends 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 Figure A11 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 (typically 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 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 and Figure A11). 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 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 and Figure A-11). 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 and Figure- A11).

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. Most excavations for the project 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 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 crossbed 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 and Figure A-11 show 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 Beaches Link project area. 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 Flat Rock Creek and Cammeray Golf Course, among others.

2.5.2 Hydrogeological cross sections

This section presents hydrogeological cross sections along the proposed project alignment. These hydrogeological cross sections are indicative and not intended for any purpose other than the groundwater impact assessment carried out as part of the environmental impact assessment.

The location of the cross-section line is shown on a map in Figure A2-1 in Attachment 2. In addition:

- Figure A2-2 to Figure A2-4 in Attachment 2 shows the hydrogeology along the proposed project alignment from Warringah Freeway to Middle Harbour
- Figure A2-5 in Attachment 2 shows the hydrogeology along the project alignment from the Gore Hill Freeway tunnel connection to the proposed Beaches Link mainline tunnel
- Figure A2-6 in Attachment 2 shows the hydrogeology along the project alignment from Seaforth to Balgowlah
- Figure A2-7 in Attachment 2 shows the hydrogeology along the project alignment from Seaforth to Wakehurst Parkway.

The cross-sections indicate that the Hawkesbury Sandstone is the dominant hydrogeological unit occurring along the project alignment.

The Mittagong Formation/Ashfield shale occurs along ridgelines at the following locations:

- Warringah Freeway to Middle Harbour Section: Between Merriburn Avenue and Market Street (Figure A2-2 in Attachment 2)
- Gore Hill Freeway tunnel connection to mainline tunnel section: Ashfield Shale/Mittagong Formation occurs along the ridgeline between Gore Hill Freeway and Willoughby Road (Figure A2-5 in Attachment 2).

Marine sediments occur at the bottom of Middle Harbour (Figure A2-2 and Figure A2-4).

Anthropogenic fill material occurs at the following locations:

- Flat Rock Creek (Figure A2-2 and Figure A2-3). There is a known history of dumping industrial and domestic waste at Flat Rock Creek in both whole and incinerated form. The site is known as a long running waste incineration and landfill site
- Cammeray Golf Course (Figure A2-2 in Attachment 2)
- Fill has been mapped beneath the North Shore rail line and in the depression between Willoughby Road and Small Street (Figure A2-5 in Attachment 2).

The cross sections show the locations and orientations of mapped and inferred fault zones. Packer testing was carried out on a few of the fault zones to estimate hydraulic conductivity (Figure A2-2 to Figure A2-7). Results of packer tests along faults zones at Flat Rock Creek (Figure A2-3) and Kameruka Road (Figure A2-2) do not show higher hydraulic conductivity values in the Hawkesbury Sandstone compared to the bulk rock. However, packer tests in the faulted Hawkesbury Sandstone at the Luna Park Fault zone (below Middle Harbour) indicated hydraulic conductivity values which are up to four orders higher than the bulk rock hydraulic conductivity (Figure A2-4).

A summary of the inferred groundwater table information shown on the cross-sections is as follows:

- Warringah Freeway to Middle Harbour Section: The inferred groundwater table elevation ranged from approximately 10 mBGL at Warringah Freeway to approximately 100 mBGL at Tunk Street (Figure A2-2)
- Gore Hill Freeway tunnel connection to mainline tunnel section: The groundwater table beneath Lambs Street, near the North Shore rail line, was measured at approximately 50 metres above Australian Height Datum (mAHD) or approximately 10 mBGL (Figure A2-5)
- Seaforth to Balgowlah section: The inferred groundwater table range along the section ranges from approximately 10 mBGL to 70 mBGL (Figure A2-6)
- Seaforth to Wakehurst Parkway: The inferred groundwater table range along the section ranges from approximately 2 mBGL to 70 mBGL (Figure A2-7).

Further information on groundwater levels is provided in Section 2.5.3.

2.5.3 Groundwater levels and flow

The regional water table across the project area typically mimics topography. Groundwater flow is typically from areas of high topographic relief to areas of low topographic relief, ultimately discharging at surface drainage features and to the harbours.

The water table elevation is highly variable and can range from close to ground surface and up to 100 metres below ground (Figure A2-2 to Figure A2-7). Localised perched water tables may also occur.

Figure A1-12 and Figure A1-13 show the groundwater table elevation contour map compiled from available water level monitoring data including monitoring for the Western Harbour Tunnel and Warringah Freeway Upgrade Project and Beaches Link and Gore Hill Freeway Project, 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 A1-12 and Figure A1-13, 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.

2.5.3.1 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 A1-14. The hydrographs are presented as elevations, in 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 about 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 several monitoring bores. B112 shows the most pronounced rainfall response with smaller responses observed at B154 and B209.

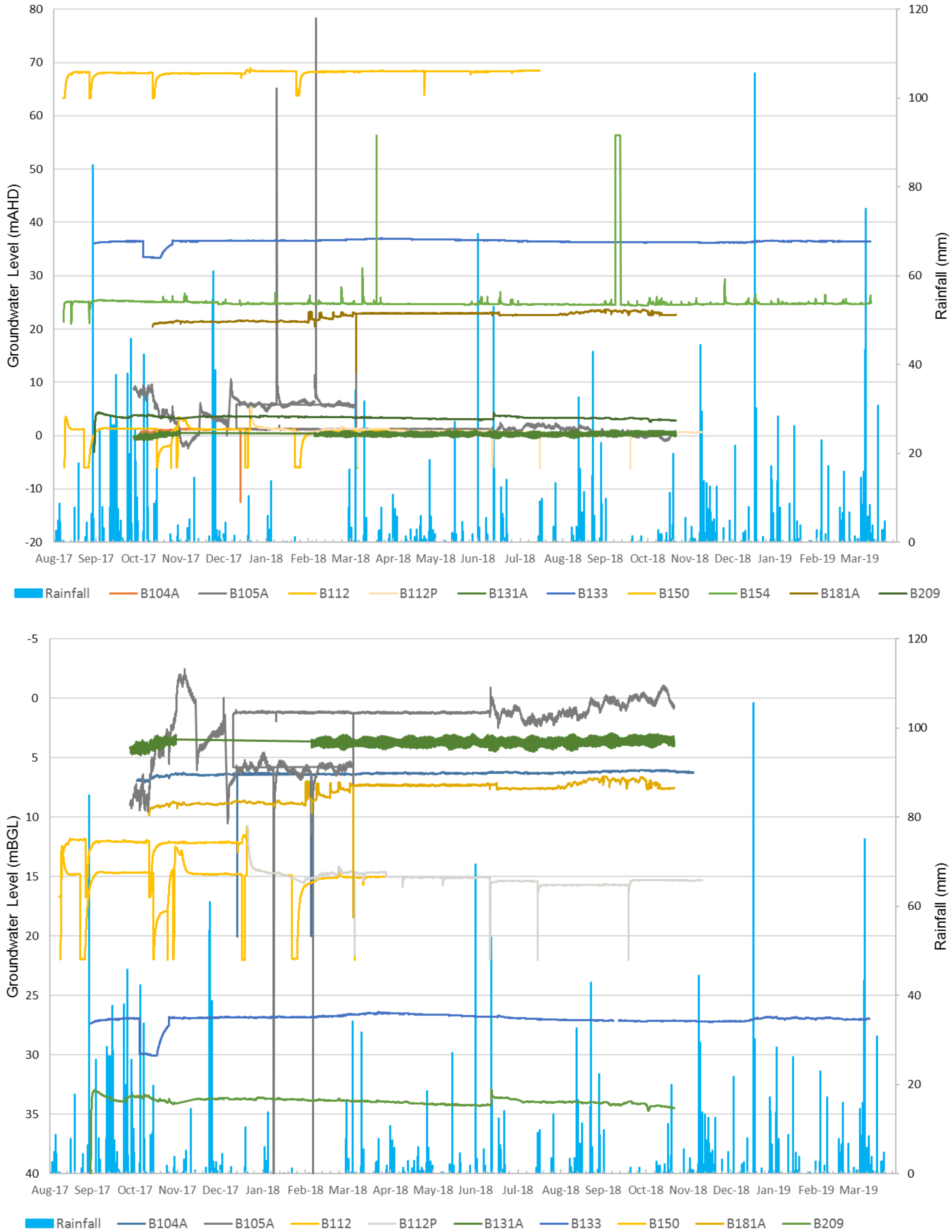


Figure 2-1: Monitoring bore hydrographs for WHT Project area

Three vibrating wire piezometer installations (VWP) have been installed along the project alignment at the locations shown in Figure A1-14.

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 near 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 about 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 m/day over this interval.

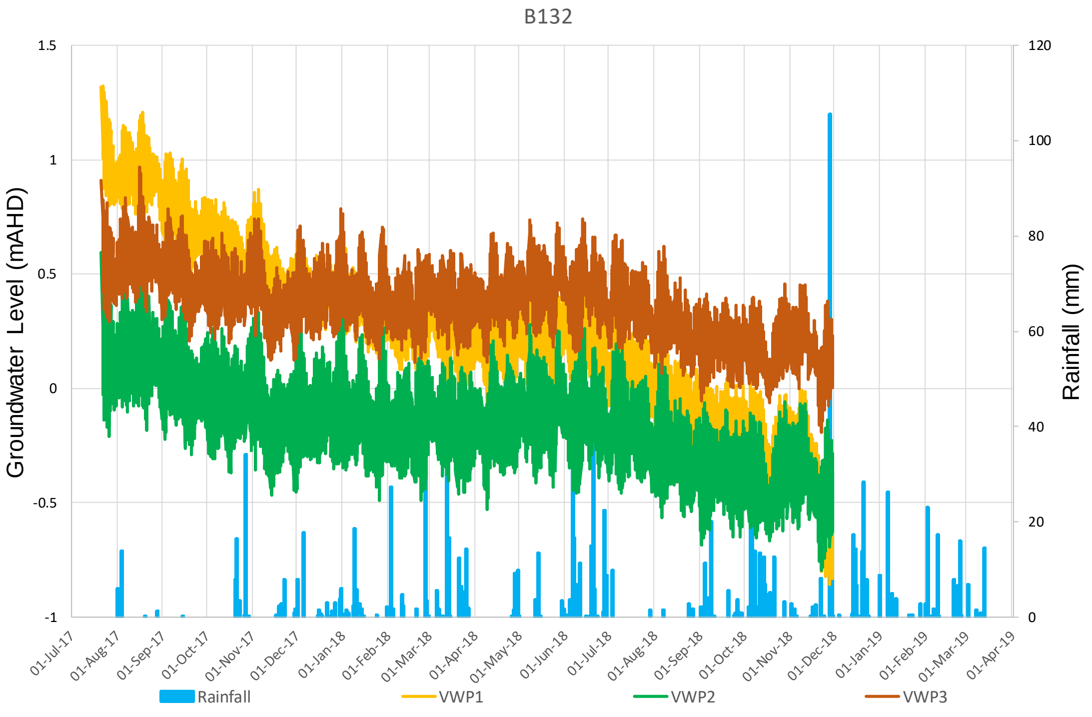


Figure 2-2: VWP hydrographs for Bore B132

2.5.3.2 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 A1-15. The hydrographs are presented as elevations and depths below ground level.

Groundwater elevations range from highs of about 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 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.

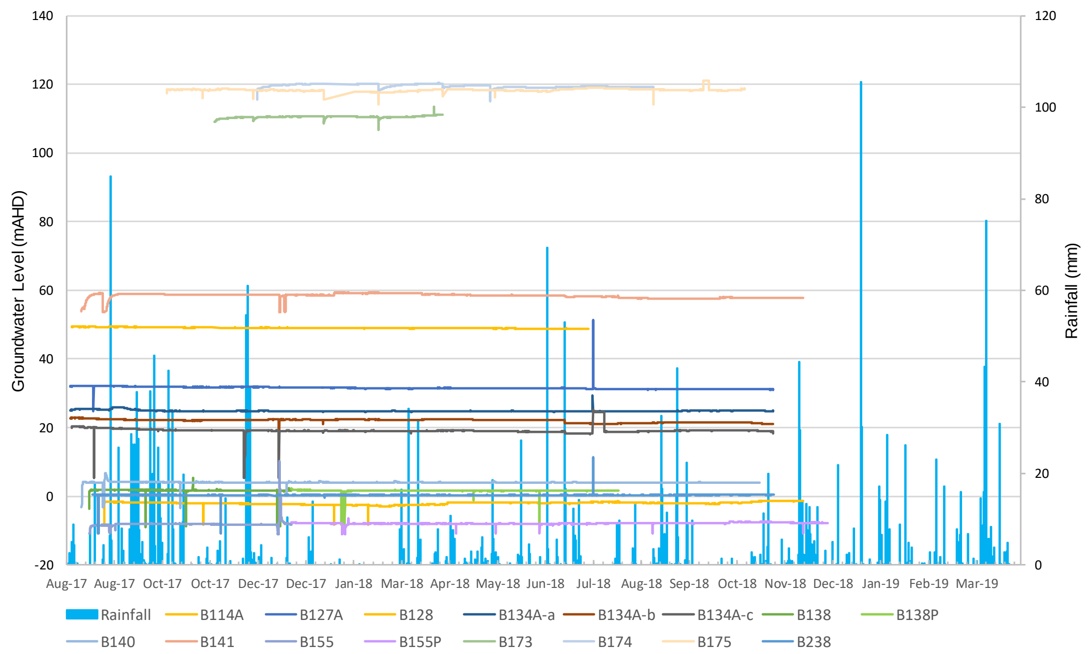
Monitoring bore B155, in North Bridge, shows a water level below sea level at about -8 mAHD, which is not considered to be representative of the local aquifer. This may be indicative of very low permeability and failure to recover post development, however, a number of small fluctuation in the monitoring 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 A1-15. 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 approximately sea level
- **VWP B156** is 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 m/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 metres below ground level (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.



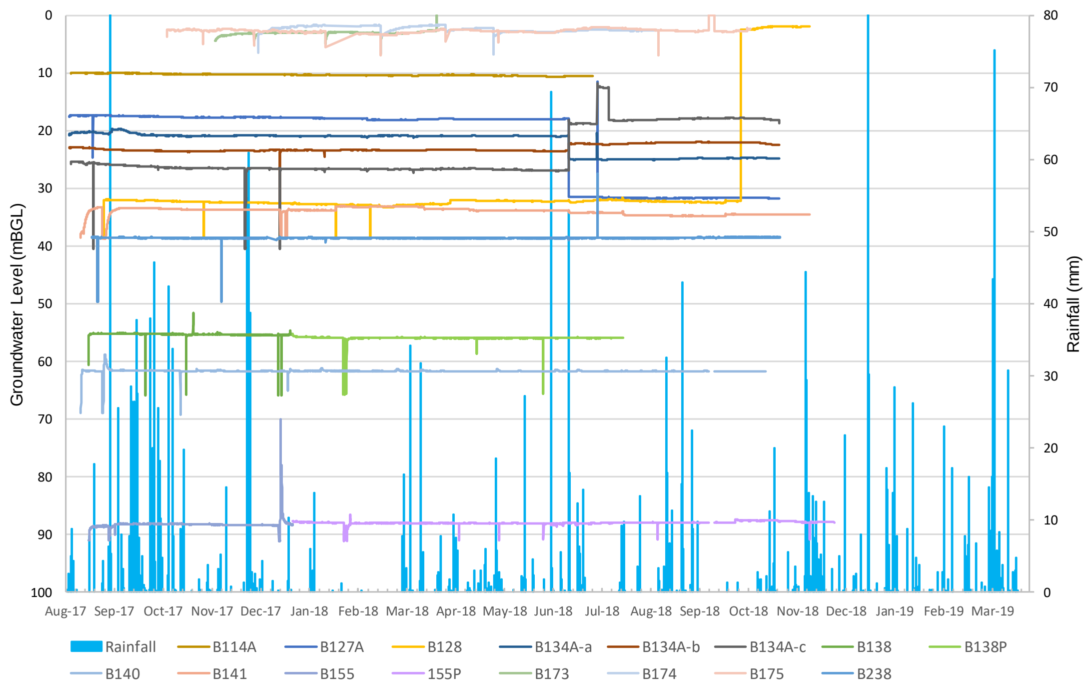


Figure 2-3: Monitoring bore hydrographs for Beaches Link project area.

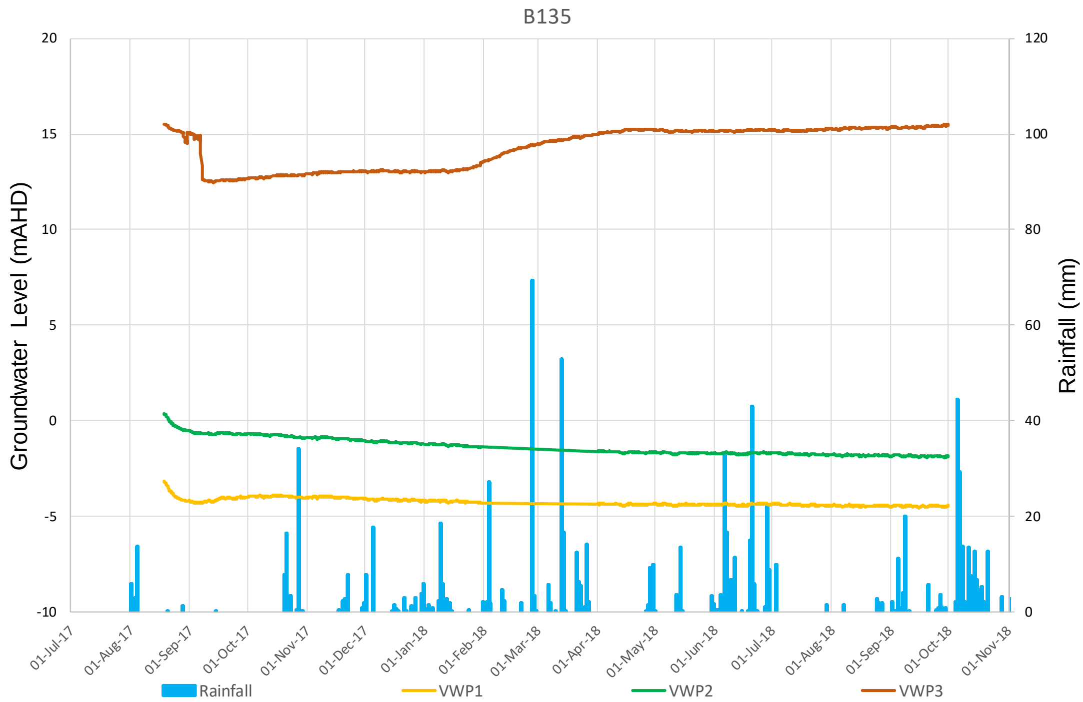


Figure 2-4: Hydrograph for VWP B135

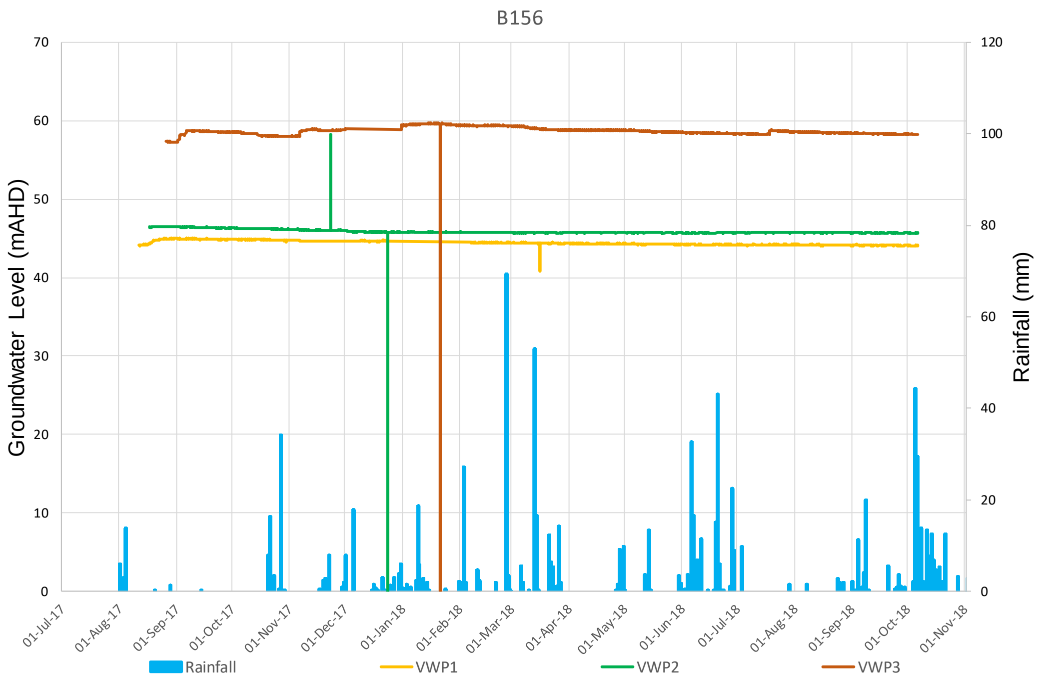


Figure 2-5: Hydrograph for VWP B156

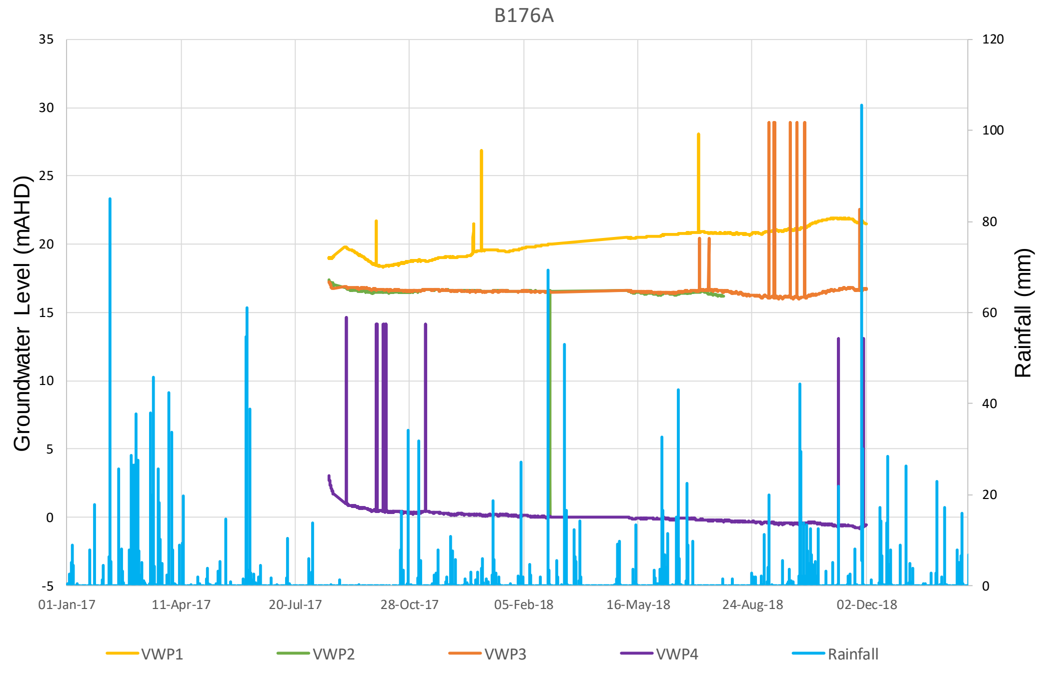


Figure 2-6: Hydrograph for VWP B176A.

2.5.4 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 using existing bores in the study area may also be considered a groundwater discharge mechanism. Existing groundwater use is minor (Appendix N (Technical working paper: Groundwater). Groundwater would also continuously drain into existing underground workings such as unlined tunnels and sewers.

2.5.5 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.

2.5.5.1 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 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.

Table 2-7: Hydraulic conductivity values derived from other investigations (m/day)

Source	Hydraulic conductivity (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, 2020)	No data	No data	Land based Mean = 0.015 Median = 0.001 Marine Mean = 0.454 Median = 0.026	Packer Tests (n = 191)
Beaches Link and Gore Hill Freeway Connection groundwater assessment	No data	No data	Land based Mean = 0.053 Median = 0.001 Marine Mean = 0.187 Median = 0.017	Packer Tests (n = 300)

Note 1: n = number of tests

2.5.5.1.1 Project specific packer testing

Overview

Packer testing was conducted to determine formation hydraulic conductivity at 74 drill holes across the Western Harbour Tunnel and Beaches Link project areas, 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.

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.

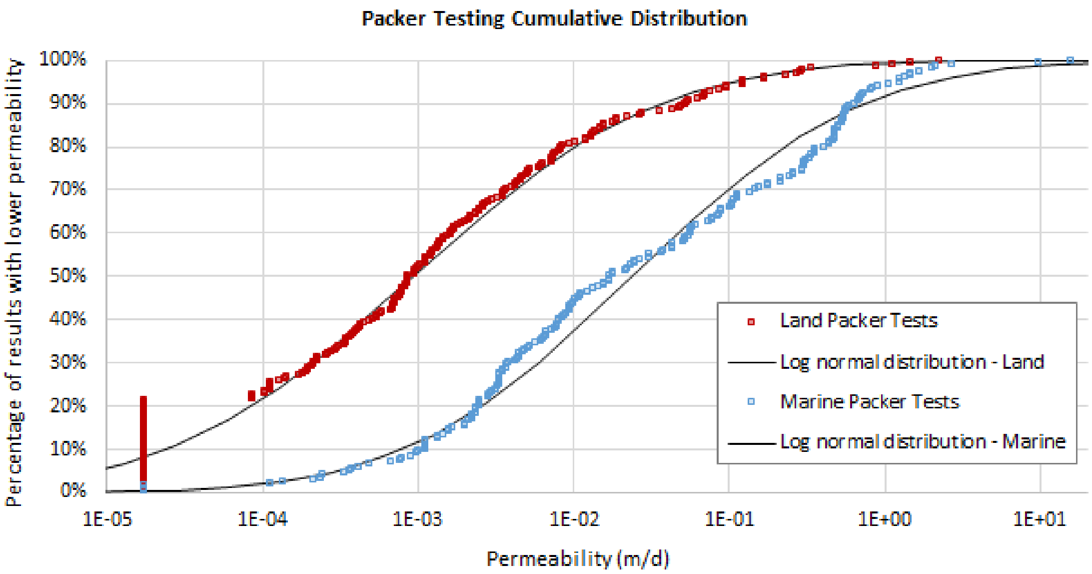


Figure 2-7: Packer testing cumulative distribution

Packer testing results for areas north of Sydney Harbour

Table 2-8 provides a summary of the packer testing carried out for the Beaches Link and Western Harbour Tunnel project areas located north of Sydney Harbour. All the packer tests except the tests at Western Harbour marine and Waverton are within the Beaches Link Project area. Testing comprised a total of 223 land-based packer tests and 250 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 0.054 m/d compared to the median values of 0.002 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: Project specific packer test 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	223	4.0×10^{-6}	2.25	0.054	0.002
Waverton	31	1.1×10^{-5}	0.17	0.021	0.001
Balgowlah to Seaforth	91	4.0×10^{-6}	1.47	0.045	0.003
Cremorne to Northbridge	59	4.0×10^{-6}	1.00	0.003	0.001
Flat Rock Creek	42	1.9×10^{-5}	2.25	0.146	0.005
Western Harbour marine	142	2.8×10^{-5}	15.72	0.454	0.026
Middle Harbour marine	108	1.4×10^{-4}	4.04	0.187	0.017

Note 1: for statistical analysis, all packer tests results recorded as less than 1×10^{-9} m/s (8.64×10^{-5} m/d) have been set as 2×10^{-10} m/s (1.73×10^{-5} m/d)

2.5.5.1.2 High permeability zones and structural influence

Known significant fracture zones occurring in the project are described in Section 2.4.7.2 and shown on cross sections presented in Section 2.5.2. 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.

Away from the harbours (Sydney Harbour and Middle Harbour) there was no evidence from the packer test results to suggest that the hydraulic conductivity for the fracture zones and dykes in the project areas was significantly different from the hydraulic conductivity of the surrounding bulk. It is important to note, however, that packer tests were not carried out at all the known and inferred fracture zones dykes and fracture zones within the project area.

High permeability zones were identified at the following locations:

- Middle Harbour
- Flat Rock Creek
- Sydney Harbour.

Areas of moderately high permeability were identified at the following locations:

- Near Grandview Grove at the locations of bores B140 and B124
- Near Waverton (north of Sydney Harbour in the Western Harbour Tunnel project area).

Middle Harbour high permeability zone

Zones of enhanced permeability occur immediately adjacent and underlying Middle Harbour. Table 2-9 provides summary statistics for Hawkesbury Sandstone hydraulic conductivity values estimated from packer tests carried out beneath the harbour and along the northern and southern flanks of the Harbour. The maximum hydraulic conductivity value of 3.1 m/day was estimated at the zone beneath the harbour. Hawkesbury Sandstone hydraulic conductivity values estimated along the northern and southern flanks of the harbour were about one order of magnitude lower than hydraulic conductivity values beneath the Harbour.

Table 2-9: Hawkesbury Sandstone hydraulic conductivity values for zones at Middle Harbour.

Packer test location	Mean hydraulic conductivity (m/d)	Maximum hydraulic conductivity (m/d)
North of harbour	0.10	0.54
South of harbour	0.03	0.24
Beneath harbour	0.53	3.10

Flat Rock Creek high permeability zone

Figure A2-3 in Attachment 2 shows that at the Flat Rock Creek, the relatively high hydraulic conductivity values obtained from packer testing at Bore B176A_w (0.26 to 0.6 m/d) were associated with tests within the basin fill material and the upper weathered/fractured zone of the underlying Hawkesbury Sandstone to 36 mBGL. Relatively high hydraulic conductivity of approximately 0.21 m/d was also obtained from testing in the weathered/fractured interval between 36 mBGL and 46 mBGL. No intervals of elevated permeability were encountered below 46 mBGL in Bore B176A_w.

Borehole B177, drilled to the north of Flat Rock Creek encountered fill and clay to 11.8 mBGL (Figure A2-3). Moderate permeability was returned from sandstone from 33 to 42 mBGL of 0.06 to 0.29 m/d, with no significant permeability returned below 42 mBGL.

Borehole B134A-C was drilled to intersect the central valley fill material and underlying sandstone and encountered fill to 41 mBGL. Elevated permeability (2.2 m/d) was encountered in the sandstone from 41 to 43 mBGL, with moderate permeability (0.017 to 0.027 m/d) to 54 mBGL. No significantly permeable intervals were encountered below 54mBGL.

Sydney Harbour high permeability zone

Structurally controlled high permeability zones occur immediately adjacent 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 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 (Jacobs, 2019). 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 (Jacobs, 2019).

Grandview Grove moderately high permeability zone

A zone of moderately high permeability in the vicinity of Grandview Grove, north of Middle Harbour, was identified from packer testing results at Bore 140 (Figure A2-6 in Attachment 2). The zone of moderately high permeability does not appear to be associated with a geological structure (fault or dyke). Intervals of moderately high hydraulic conductivity were identified in bore B140 from 65 mBGL to 75 mBGL (0.03 m/d to 0.08 m/d) and from 95 mBGL to 105 mBGL (0.03 m/d to 0.09 m/d). Moderate permeability zones in B140 are associated with sandstone units and some minor zones of brecciation and core loss.

Waverton Park moderate permeability zone

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 (Jacobs, 2019).

2.5.5.1.3 Permeability-depth relationship in Hawkesbury Sandstone

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.

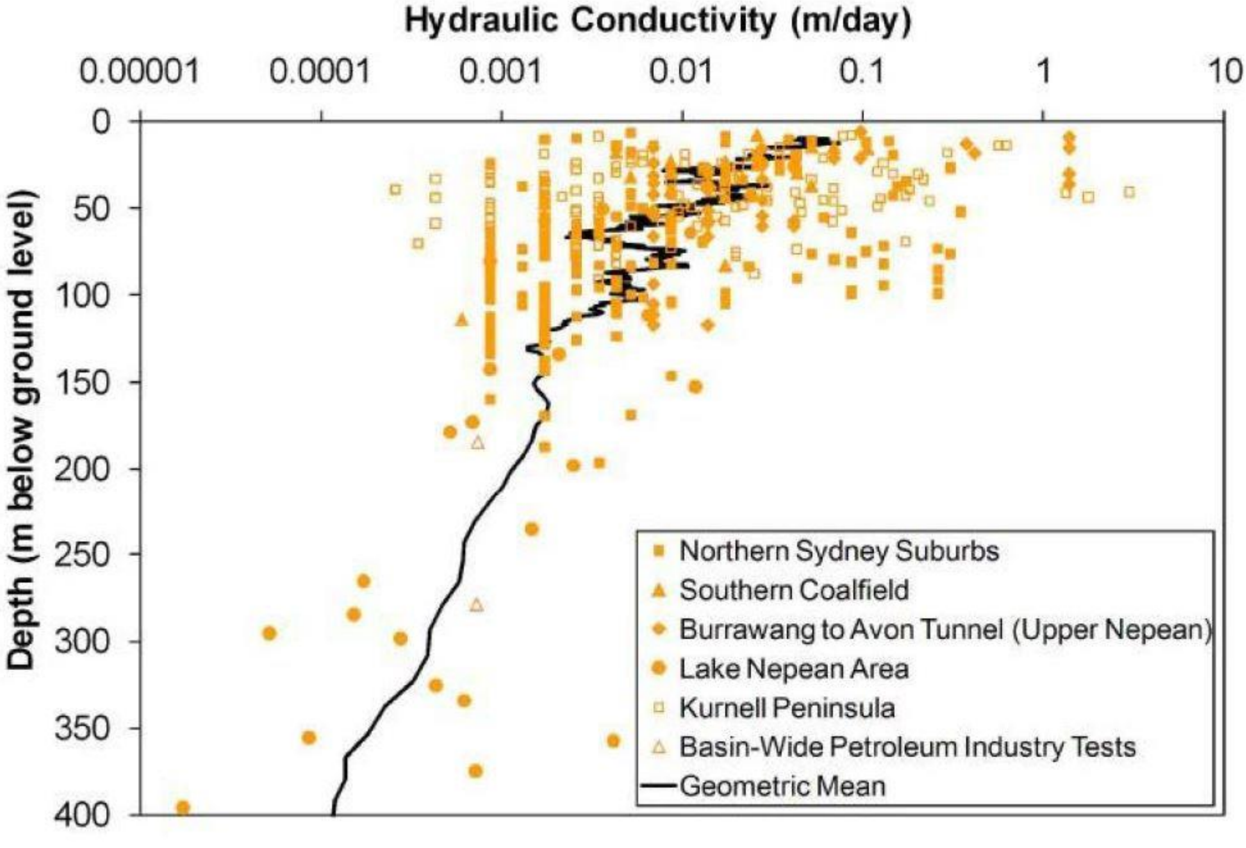


Figure 2-8: Tammetta and Hawkes (2009) hydraulic conductivity from packer testing in Sydney Basin

Figure 2-9 shows the Hawkesbury Sandstone hydraulic conductivity plotted against depth below ground level for results of land-based project specific packer tests carried out in the project area located north of Sydney Harbour. The project specific packer test results are highly variable but do indicate an upper limit to hydraulic conductivity that diminishes with depth. Figure 2-9 shows several 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 the lowest hydraulic conductivity value that can be reasonably derived with certainty using conventional packer testing equipment.

Figure 2-9 also shows the geometric mean values for Hawkesbury Sandstone hydraulic conductivity estimates from project specific packer tests and regional packer tests (Tammetta & Hawkes, 2009). The project specific packer testing results do not show a decreasing trend with depth in the geometric mean for hydraulic conductivity estimates which is observed in the regional packer testing results. However, as has already been indicated, the project specific data shows an upper limit to hydraulic conductivity that diminishes with depth.

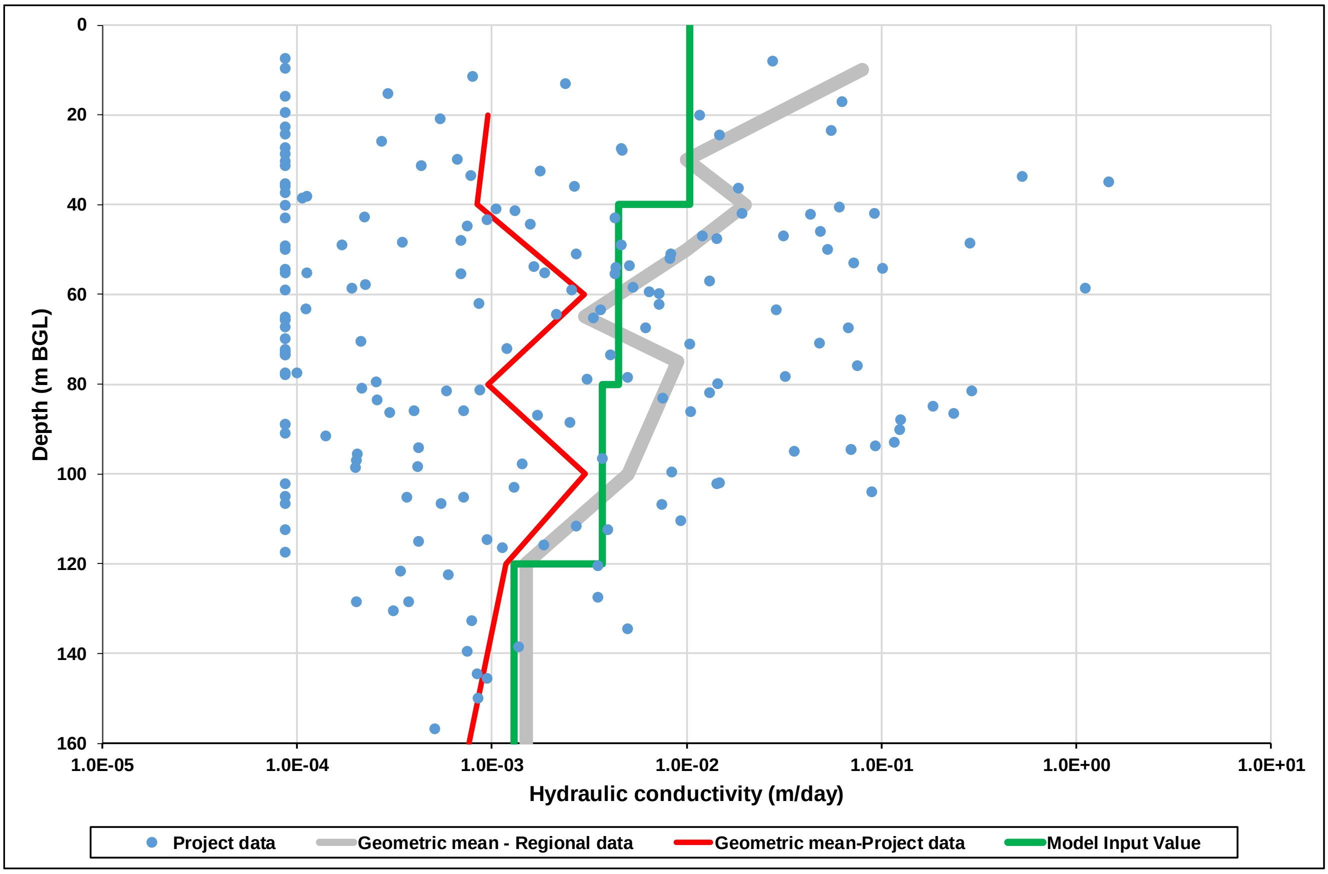


Figure 2-9: Hydraulic conductivity versus depth – north of Sydney Harbour

The decreasing hydraulic conductivity with depth relationship for the Hawkesbury Sandstone observed in the regional data has been adopted for the purposes of this assessment given that:

- The project specific packer test results indicate an upper limit to hydraulic conductivity that diminishes with depth
- Lithological observations from drill-core samples indicate that the sandstone is layered with variable in degree of weathering, grain size distribution and cementation observed with depth
- Structural observations from drill core samples indicate that the degree of fracturing (fracture density, and fracture aperture opening diameter) decrease with depth
- Geotechnical assessment results for drill-core samples indicate that the rock strength increases with depth, which suggests that hydraulic conductivity is likely to decrease with depth within the project area.

The green line in Figure 2-9 shows the hydraulic conductivity values assigned at 40 m depth intervals in the conceptual hydrogeological model. The hydraulic conductivity values assigned to each 40 m depth interval in the conceptual hydrogeological model is based on the arithmetic mean of the following, for the corresponding depth intervals:

- Geometric mean of hydraulic conductivity estimates from project specific packer testing
- Geometric mean of hydraulic conductivity estimates from regional packer testing (Tammetta & Hawkes, 2009).

Figure 2-9 indicates that the hydraulic conductivity values assigned to the conceptual hydrogeological model are higher than the geometric mean of project specific values, at corresponding depths.

2.5.5.1.4 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 x 10^{-2}	1:10 to 1:100
Ashfield Shale	1x 10^{-4} to 8.00 x 10^{-4}	-
Hawkesbury Sandstone	5.00 x 10^{-4} to 1.00 x 10^{-2}	1:10 to 1:100

2.5.5.2 Specific storage and specific yield

Review of previous studies in the Sydney Metropolitan area by Golder indicated the specific storage ranges from 5 x 10^{-6} to 5 x 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 x 10^{-6}	9.13 x 10^{-7}
Hawkesbury Sandstone - bedded	24	1.5-105	2.22 x 10^{-6}	9.85 x 10^{-7}
Basalt	1	82	5.53 x 10^{-7}	5.53 x 10^{-7}
Laminite	1	57	3.55 x 10^{-6}	3.55 x 10^{-6}
Shale breccia	1	7	2.35 x 10^{-6}	2.35 x 10^{-6}

Mean and median values for specific storage for the Hawkesbury Sandstone are in close agreement, indicating a uniform distribution of results with a mean specific storage for the Hawkesbury Sandstone overall of 1.9 x 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 x 10^{-6} to 1 x 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 Groundwater inflows to existing infrastructure

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 mainline tunnels 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
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	8	6.5 each	1 (2) 0.7 (3)	9 (2) 6 (3)	Jacobs 2019

Note 1: Assumed Completion of Tunnelling

Note 2: Maximum inflow during construction

Note 3: Long-term inflow

3. Numerical model design and construction

3.1 Modelling objectives

The objectives of the groundwater modelling are to:

- Estimate groundwater inflows to the proposed Beaches Link and Gore Hill Freeway Connection Project (the Project)
- Estimate groundwater drawdown due to the Project only and cumulative drawdown due to the project and other nearby projects
- Estimate changes in groundwater discharge to watercourses due to the project and other nearby 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 Warringah Freeway Upgrade project and the Beaches Link and Gore Hill Freeway Connection project. 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 by Sydney Harbour (Figure 3-1). The South Model includes components of the Western Harbour Tunnel project only. The North Model includes components of the Western Harbour Tunnel and Warringah Freeway Upgrade Project north of Sydney Harbour and all the components of the Beaches Link and Gore Hill Freeway Connection 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 and Warringah Freeway Upgrade Project and the Beaches Link and Gore Hill Freeway Connection Project located to the north of Sydney Harbour are unlikely to induce drawdown to the south of Sydney Harbour.

As shown in Figure 3-1, the Beaches Link and Gore Hill Freeway Connection project area is covered by the North Model. Therefore, the description of the groundwater modelling presented in this report is only for the North Model (the model).

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 Sparse Matrix Solver (SMS) was used in the numerical simulations. SMS solver options used are presented in Attachment 3.

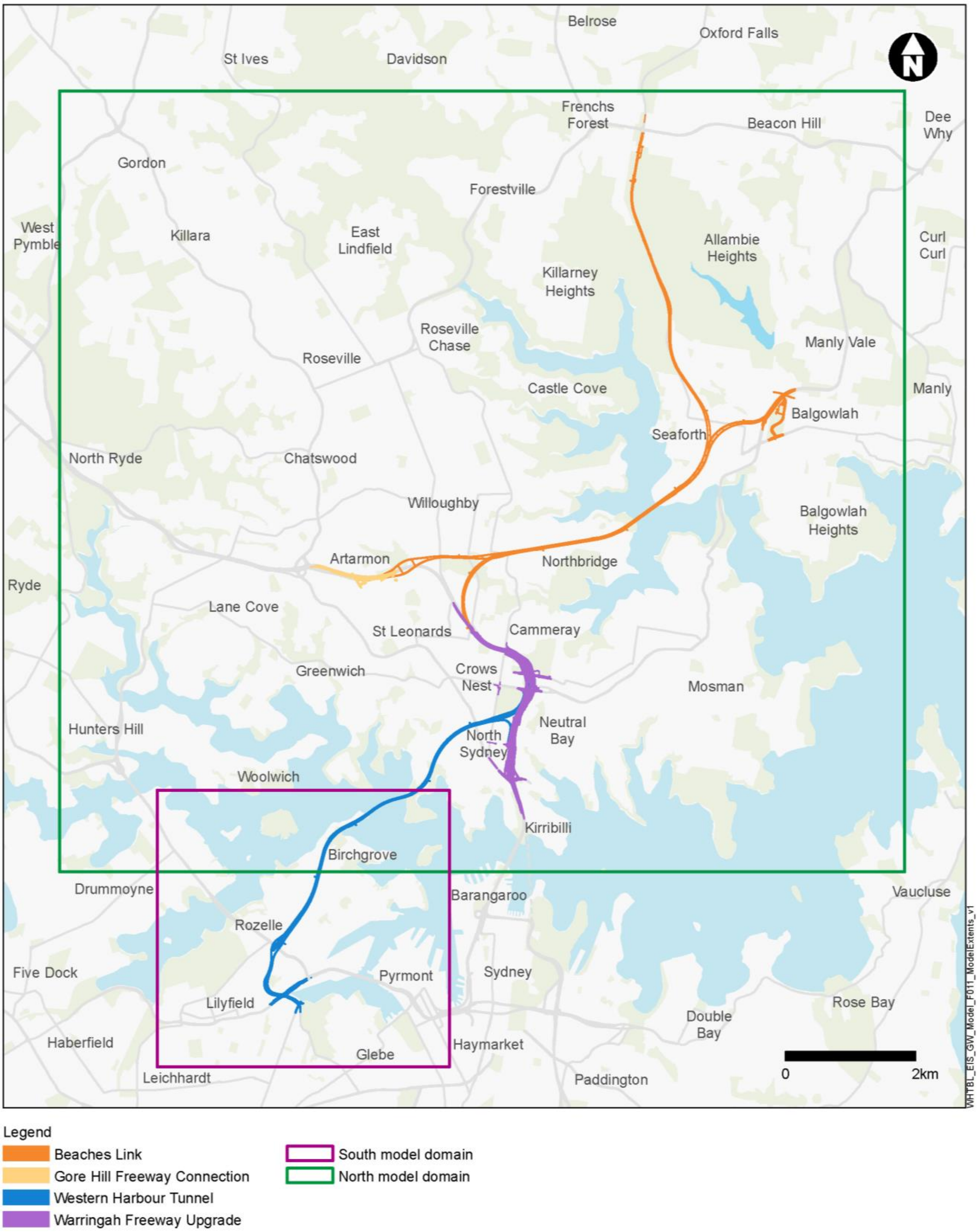


Figure 3-1: North and south model extents.

3.4 Model layers (vertical discretisation)

The model has been discretised (sub-divided) into seven vertical layers.

Figure 3-2 shows the model layer elevations along the project alignment. The location of the cross-section line is shown in Figure 3-3. The model layering is based on the permeability-depth analysis for the Hawkesbury Sandstone described in Section 2.5.5.1.3. Figure 2-9 shows that the project area was divided into 40 metre depth intervals to a depth of 160 mBGL based on the average hydraulic conductivity values estimated from packer tests. The 40 metre depth intervals shown in Figure 2-9 were further sub-divided into the following layers:

- The uppermost 40 metre interval in Figure 2-9 is represented as two layers (model layer 1 and model layer 2). The top layer (model layer 1) was assigned a uniform thickness of 10 metres and model layer 2 was assigned a thickness of 30 metres (Figure 3-2). A thickness of 10 metres was assigned to model layer 1 to allow more accurate representation of the thickness of surficial hydrogeological units such as fill/alluvium, Harbour sediments and weathered Hawkesbury sandstone. The thickness of these surficial units is less than 10 metres over much of the project area, except for basin fill sediments at Flat Rock Creek. The maximum thickness of model layer 1 at Flat Rock Creek at Flat Rock Creek was approximately 39 metres
- Each 40 metre depth interval between 40 mBGL and 120 mBGL (Figure 2-9) was divided into two layers of equal thickness (comprising model layers 3, 4, 5 and6). A uniform model layer thickness of 20 metres was a reasonable compromise considering the following competing requirements:
  - The need to have model cells at simulated tunnel locations that have sizes that are comparable with the dimensions of the proposed tunnels
  - The need to maintain model tractability by minimizing the number of numerical model cells in order to reduce the computational burden associated with solving the model
- The bottom elevation for model Layer 7 is -190 mAHD.

Table 3-1 summarises information of model layering. Layer 1 in the model comprises weathered Hawkesbury sandstone, Ashfield Shale/Mittagong Formation, Fill/Alluvium and Harbour Sediments. Layer 2 to Layer 7 represents Unweathered Hawkesbury Sandstone. Using multiple layers to represent the Unweathered Hawkesbury Sandstone also allows for the more accurate simulation of the steep vertical gradient induced by drainage of groundwater to the tunnels.

Table 3-1: Model layering summary

Model Layer	Layer thickness	Hydrostratigraphic Unit
1	10 metres, except at Flat Rock Creek where thickness is approximately 39 metres	Weathered Hawkesbury Sandstone, Harbour sediments, Ashfield Shale/Mittagong Formation & Fill/Alluvium.
2	30 metres , except at Flat Rock Creek where thickness is approximately one metre	Unweathered Hawkesbury Sandstone
3 -6	20 metres	Unweathered Hawkesbury Sandstone
7	Layer bottom elevation = -190 mAHD	Unweathered Hawkesbury Sandstone

All model layers 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.

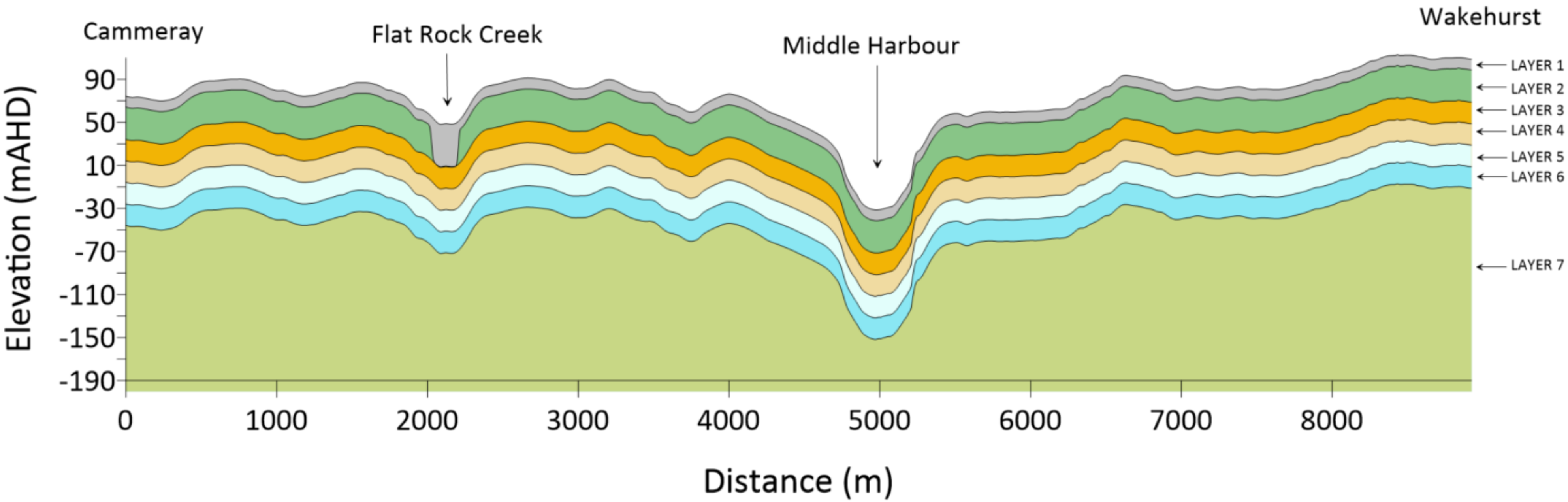


Figure 3-2: Model layer elevations along project alignment

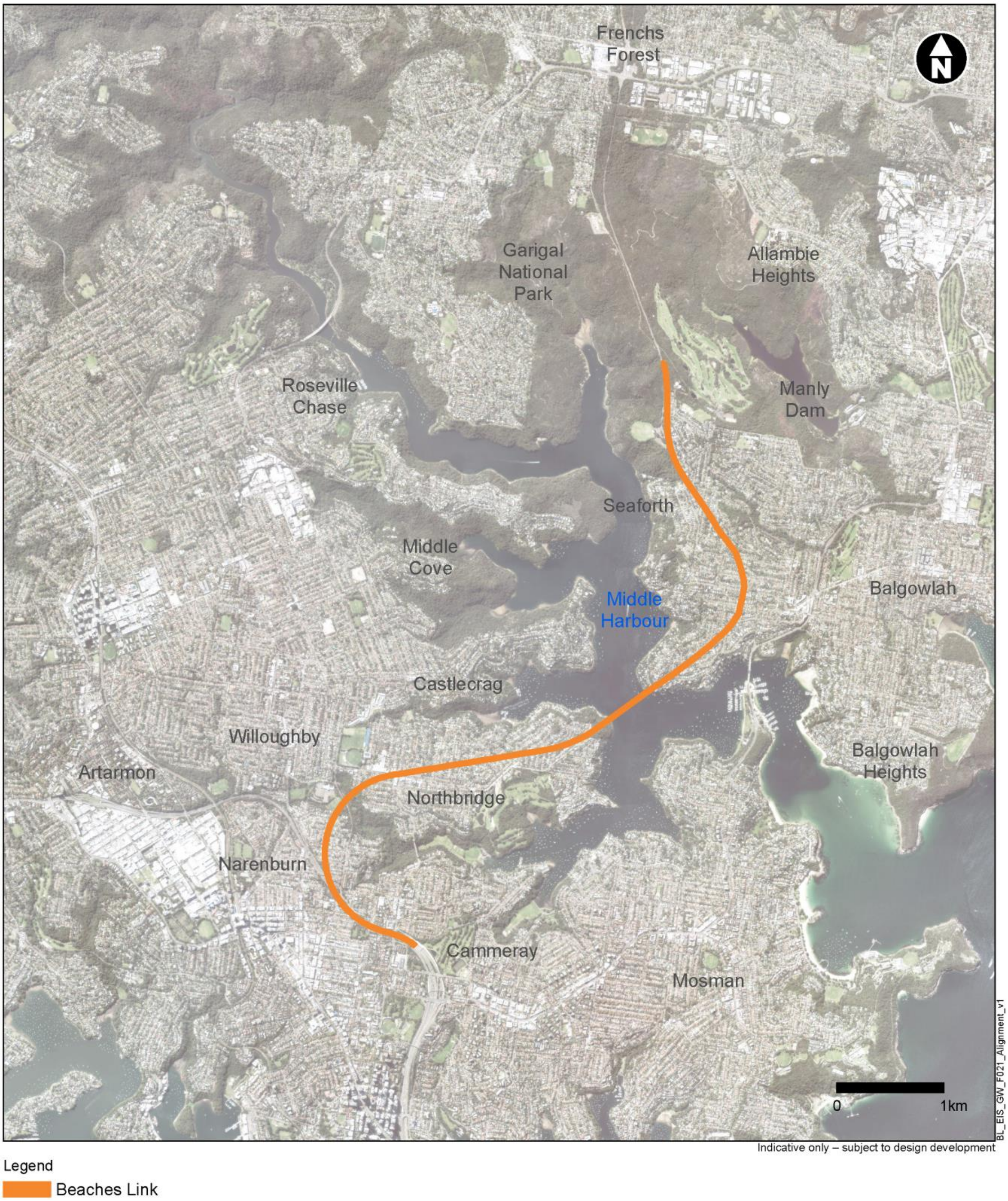


Figure 3-3: Location of model cross-section line (project alignment).

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 A1-16 in Attachment 1 shows the model grid. Table 3-2 summaries spatial discretisation information. The smallest model grid length used in the model was 16 metres. Approximately 88 per cent of the model domain is active in the model.

Table 3-2: Summary of spatial discretisation information

Parameter	Value
Minimum grid cell dimension (m)	16
Maximum grid cell dimension (m)	500
Number of layers	7
Total number of cells	570,801
Active cells	535,766
Total area (Hectares)	15,600
Active area (Hectares)	13,800

3.6 Model hydraulic conductivity zones

3.6.1 Layer 1 hydraulic conductivity zones

Figure A1-17 in Attachment 1 shows the spatial distribution of hydraulic conductivity zones in model layer 1 covering the outcrop areas of Weathered Hawkesbury sandstone (Zone 1), Hawkesbury Sandstone high hydraulic conductivity zone (Zone 7), Ashfield Shale/Mittagong Formation (Zone 2), Fill/Alluvium (Zone 4) and Harbour Sediments (Zone 3).

In model layer 1, the hydraulic conductivity model zone along Middle Harbour represents harbour sediments. The Hawkesbury Sandstone high hydraulic conductivity zone (Zone 7) has been assigned to the north and south of the harbour as described in Section 2.5.5.1.2.

The Hawkesbury Sandstone high hydraulic conductivity zone has been extended to the north of Middle Harbour to include the area of moderately high permeability in the vicinity of Grandview Grove, around Bore 140 (Section 2.5.5.1.2).

3.6.2 Layer 2 hydraulic conductivity zones

Figure A1-18 in Attachment 1 shows the spatial distribution of hydraulic conductivity zones in model layer 2. The Unweathered Hawkesbury Sandstone (Zone 9) covers most of model layer 2.

Two zones of high hydraulic conductivity (Zone 7 and Zone 22) were assigned at Middle Harbour Figure A1-18. Zone 22 represents the high permeability zone beneath the harbour and Zone 7 represents the high permeability zone along the flanks of the harbour (Section 2.5.5.1.2). Permeability testing results summarised in Table 2-9 indicate that the permeability beneath the harbour (Zone 22) is higher than permeability along the flanks (Zone 7).

High hydraulic conductivity zones were also assigned in model layer 2 at following locations:

- Fractured zone adjacent Sydney Harbour (Zone 20)
- Fractured zone at Flat Rock Creek (Zone 5).

3.6.3 Layer 3 hydraulic conductivity zones

Figure A1-19 in Attachment 1 shows the spatial distribution of hydraulic conductivity zones in model layer 3. The Unweathered Hawkesbury Sandstone (Zone 10) covers most of model layer 3. High permeability zones in within the Hawkesbury Sandstone were assigned in the model at Middle Harbour (Zone 7 and Zone 22), Flat Rock Creek (Zone 12) and Sydney Harbour (Zone 21).

3.6.4 Layer 4 hydraulic conductivity zones

Figure A1-20 in Attachment 1 shows the spatial distribution of hydraulic conductivity zones in model layer 4. The Unweathered Hawkesbury Sandstone (Zone 6) covers most of model layer 4. High permeability zones in within the Hawkesbury Sandstone were assigned in the model at Middle Harbour (Zone 7 and Zone 22) and Flat Rock Creek (Zone 13).

3.6.5 Layer 5 hydraulic conductivity zones

Figure A1-21 in Attachment 1 shows the spatial distribution of hydraulic conductivity zones in model layer 5. The Unweathered Hawkesbury Sandstone (Zone 17) covers most of model layer 5. High permeability zones in within the Hawkesbury Sandstone were assigned in the model at Middle Harbour (Zone 7 and Zone 22) and Flat Rock Creek (Zone 14).

3.6.6 Layer 6 hydraulic conductivity zones

Figure A1-22 in Attachment 1 shows the spatial distribution of hydraulic conductivity zones in model layer 6. The Unweathered Hawkesbury Sandstone (Zone 15) covers most of model layer 6. High permeability zones in within the Hawkesbury Sandstone were assigned in the model at Middle Harbour (Zone 7 and Zone 22) and Flat Rock Creek (Zone 18).

3.6.7 Layer 7 hydraulic conductivity zones

Figure A1-23 in Attachment 1 shows the spatial distribution of hydraulic conductivity zones in model layer 7 The Unweathered Hawkesbury Sandstone (Zone 8) covers most of model layer 7. High permeability zones in within the Hawkesbury Sandstone were assigned in the model at Middle Harbour (Zone 7 and Zone 22) and Flat Rock Creek (Zone 19).

3.7 Initial hydraulic conductivity values

Table 3-3 presents initial hydraulic conductivity values assigned to the hydraulic zones in the model. The initial hydraulic conductivity values were subsequently adjusted during the model calibration.

3.7.1 Bulk rock initial hydraulic conductivity values

Bulk rock horizontal hydraulic conductivity values assigned to Hawkesbury Sandstone zones in successive layers decreasing with depth based on the trend shown in Figure 2-9. For zones representing bulk rock permeability for the Hawkesbury Sandstone, the initial vertical hydraulic conductivity was assumed to be one order of magnitude lower than the horizontal hydraulic conductivity.

Due to the limited project specific permeability testing data, initial hydraulic conductivity values assigned to the Ashfield Shale/Mittagong Formation (Zone 2), Fill/Alluvium (Zone 4) and Harbour Sediments (Zone 3) were based on values assigned to the calibrated model for the M4-M5 Link project (HydroSimulations, 2017).

3.7.2 Middle Harbour high hydraulic conductivity zone initial values

The Hawkesbury Sandstone high permeability zone beneath the harbour (Zone 22) was assigned an initial horizontal hydraulic conductivity of 5.3 x 10^{-1} m/day based on the average hydraulic conductivity estimated from permeability testing (Table 2-9).

The initial horizontal hydraulic conductivity assigned to Hawkesbury Sandstone high permeability zone along the harbour flanks (Zone 7) of 6.5 x 10^{-2} m/day was based on the average hydraulic conductivity estimated from permeability testing along the northern and southern harbour flanks (Table 2-9).

The initial vertical hydraulic conductivity values assigned at the high permeability zones were assumed to be the same as the horizontal hydraulic conductivity values.

3.7.3 Flat Rock Creek high hydraulic conductivity zone initial values

The initial hydraulic conductivity values assigned at Flat Rock Creek to the Hawkesbury Sandstone high hydraulic conductivity zone in the model layers were as follows:

- Model layer 2: The initial horizontal hydraulic conductivity value of 2.0 x 10^{-2} m/day assigned to model layer 2 was based on the average value estimated from permeability testing. The initial vertical hydraulic conductivity was assumed to be the same as the horizontal hydraulic conductivity
- Model layer 3 to layer 7. The initial horizontal hydraulic conductivity values assigned to the fractured zone at Flat Rock Creek in layer 3 to 7 were twice as high as the bulk rock hydraulic conductivity values assigned to the Unweathered Hawkesbury Sandstone. This is a conservative assumption given that the results of permeability testing at Flat Rock Creek below depths of about 45 mBGL (Section 2.5.5.1.2) do not show a significant difference between the permeability of the fracture zone and the bulk rock permeability. The initial vertical hydraulic conductivity values were assumed to be the same as the horizontal hydraulic conductivity values.

3.7.4 Sydney Harbour high hydraulic conductivity zone initial values

The initial horizontal hydraulic conductivity values assigned at Sydney Harbour to high permeability zones in model layer 2 (Zone 20) and model layer 3 (Zone 21) were based on the average value estimated from permeability testing. The initial vertical hydraulic conductivity values were assumed to be the same as the horizontal hydraulic conductivity values.

Table 3-3: Initial hydraulic conductivity values assigned to model zones

Model Layer	Hydrogeological unit	Model Zone	Hydraulic conductivity (m/d)	
			Horizontal	Vertical
1	Harbour Sediments (1)	3	1.0 x 10^{-2}	5.0 x 10^{-3}
	Fill/Alluvium (1)	4	1	4.3 x 10^{-1}
	Ashfield Shale/Mittagong Formation (1)	2	6.0 x 10^{-2}	2.0 x 10^{-4}
	Middle Harbour High K Zone	7	6.5 x 10^{-2}	6.5 x 10^{-2}
	Weathered Hawkesbury Sandstone	1	1.0 x 10^{-2}	1.0 x 10^{-3}
2	Flat Rock Creek High K Zone	5	2.0 x 10^{-2}	2.0 x 10^{-2}
	Sydney Harbour High K Zone	20	2.1 x 10^{-1}	2.1 x 10^{-1}
	Middle Harbour High K Zone	22	5.3 x 10^{-1}	5.3 x 10^{-1}
	Middle Harbour High K Zone	7	6.5 x 10^{-2}	6.5 x 10^{-2}
	Unweathered Hawkesbury Sandstone	9	1.0 x 10^{-2}	1.0 x 10^{-3}

Model Layer	Hydrogeological unit	Model Zone	Hydraulic conductivity (m/d)	
			Horizontal	Vertical
3	Flat Rock Creek High K Zone	12	9.0×10^{-3}	9.0×10^{-3}
	Sydney Harbour High K Zone	21	2.9×10^{-1}	2.9×10^{-1}
	Middle Harbour High K Zone	22	5.3×10^{-1}	5.3×10^{-1}
	Middle Harbour High K Zone	7	6.5×10^{-2}	6.5×10^{-2}
	Unweathered Hawkesbury Sandstone	10	4.5×10^{-3}	4.5×10^{-4}
4	Flat Rock Creek High K Zone	13	9.0×10^{-3}	9.0×10^{-3}
	Middle Harbour High K Zone	22	5.3×10^{-1}	5.3×10^{-1}
	Middle Harbour High K Zone	7	6.5×10^{-2}	6.5×10^{-2}
	Unweathered Hawkesbury Sandstone	6	4.5×10^{-3}	4.5×10^{-4}
5	Flat Rock Creek High K Zone	14	7.4×10^{-3}	7.4×10^{-3}
	Middle Harbour High K Zone	22	5.3×10^{-1}	5.3×10^{-1}
	Middle Harbour High K Zone	7	6.5×10^{-2}	6.5×10^{-2}
	Unweathered Hawkesbury Sandstone	17	3.7×10^{-3}	3.7×10^{-4}
6	Flat Rock Creek High K Zone	18	7.4×10^{-3}	7.4×10^{-3}
	Middle Harbour High K Zone	22	5.3×10^{-1}	5.3×10^{-1}
	Middle Harbour High K Zone	7	6.5×10^{-2}	6.5×10^{-2}
	Unweathered Hawkesbury Sandstone	15	3.7×10^{-3}	3.7×10^{-4}
7	Flat Rock Creek High K Zone	19	2.6×10^{-3}	2.6×10^{-3}
	Middle Harbour High K Zone	22	5.3×10^{-1}	5.3×10^{-1}
	Middle Harbour High K Zone	7	6.5×10^{-2}	6.5×10^{-2}
	Unweathered Hawkesbury Sandstone	8	1.3×10^{-3}	1.3×10^{-4}

Note 1: Source: HydroSimulations (2017).

3.8 Initial storage parameter values

Table 3-4 presents the initial storage parameter values assigned to the model. The initial storage parameter values were based on the values assigned to the M4-M5 Link calibrated model HydroSimulations (2017) and were within the range of typical values for the Sydney basin (Section 2.5.5.2). The initial storage parameters were subsequently adjusted during the transient model calibration.

Table 3-4: Initial storage parameter values

Hydrostratigraphic Unit	Model layer	Specific storage (m-1)	Specific yield (dimensionless)
Harbour Sediments	1	1 x 10-5	0.2
Fill/Alluvium	1	1 x 10-5	0.1
Ashfield shale/Mittagong Formation	1	1 x 10-5	0.02
Weathered Hawkesbury Sandstone	1	1.9 x 10-6	0.02
Unweathered Hawkesbury Sandstone	2-7	1.9 x 10-6	0.02

3.9 Model boundaries

3.9.1 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 hydrogeological units based on the conceptualisation of groundwater recharge presented in Section 2.5.4.

Recharge rates applied to each hydrogeological 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 model are shown in Figure 3-4.

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.

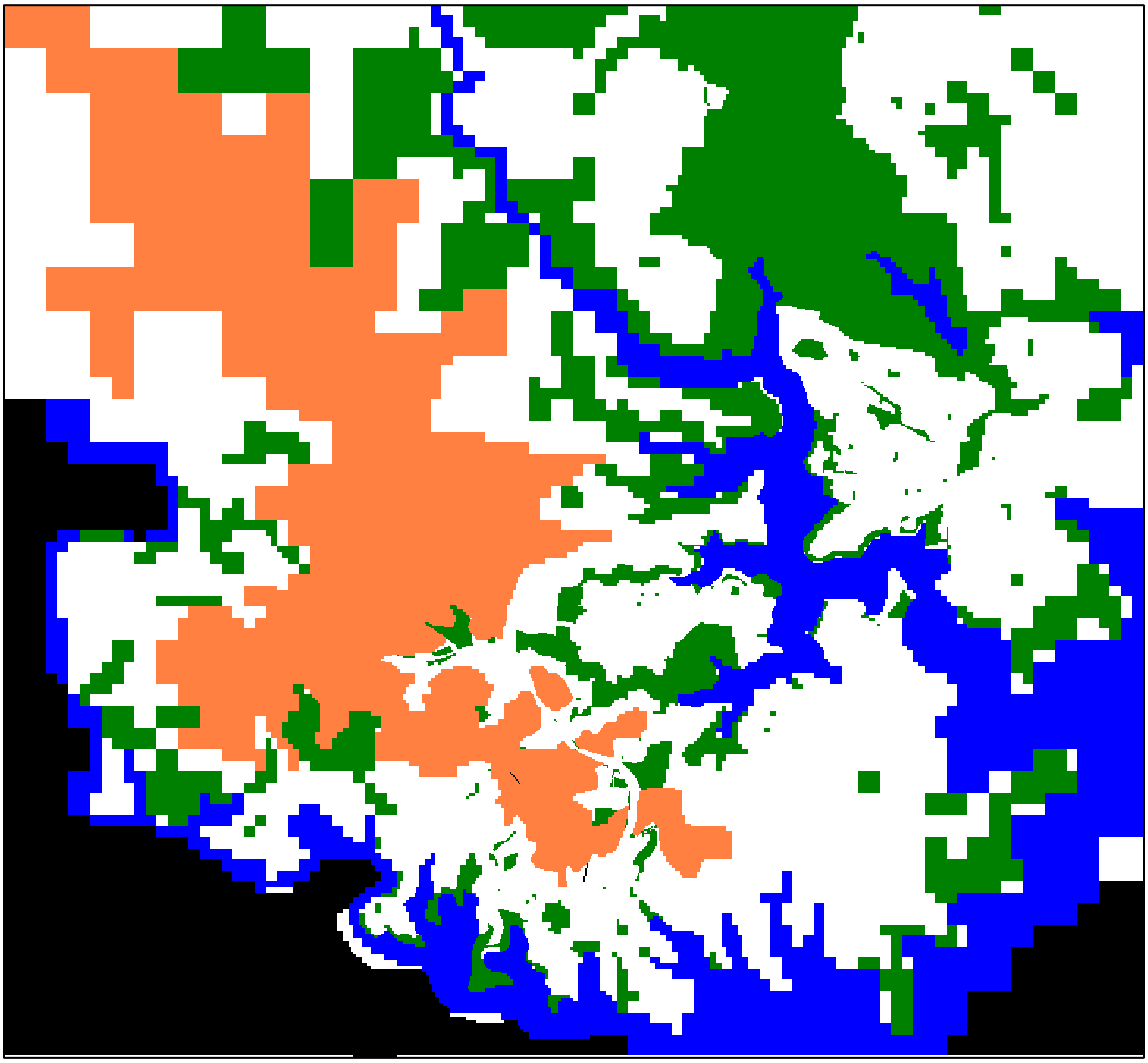


Figure 3-4: Model groundwater recharge zones

3.9.2 Evapotranspiration

Evapotranspiration (ET) is simulated using the MODFLOW Evapotranspiration Package (EVT). Maximum ET rates assigned to the different groundwater models are presented in Table 3-5. An extinction depth of 0.5 metres below the ground surface was applied to the models.

Table 3-5: 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).

Note 1: Reference evapotranspiration (FAO Penman-Monteith Method) for Observatory Hill station 066062

3.9.3 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 Beaches Link tunnel and Gore Hill Freeway Connection Project area were modelled using Drain (DRN) boundaries (Figure 3-5) 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 Flat Rock Creek, Quarry Creek, Willoughby Creek Bates Creek, Manly Creek and Burnt Bridge 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.

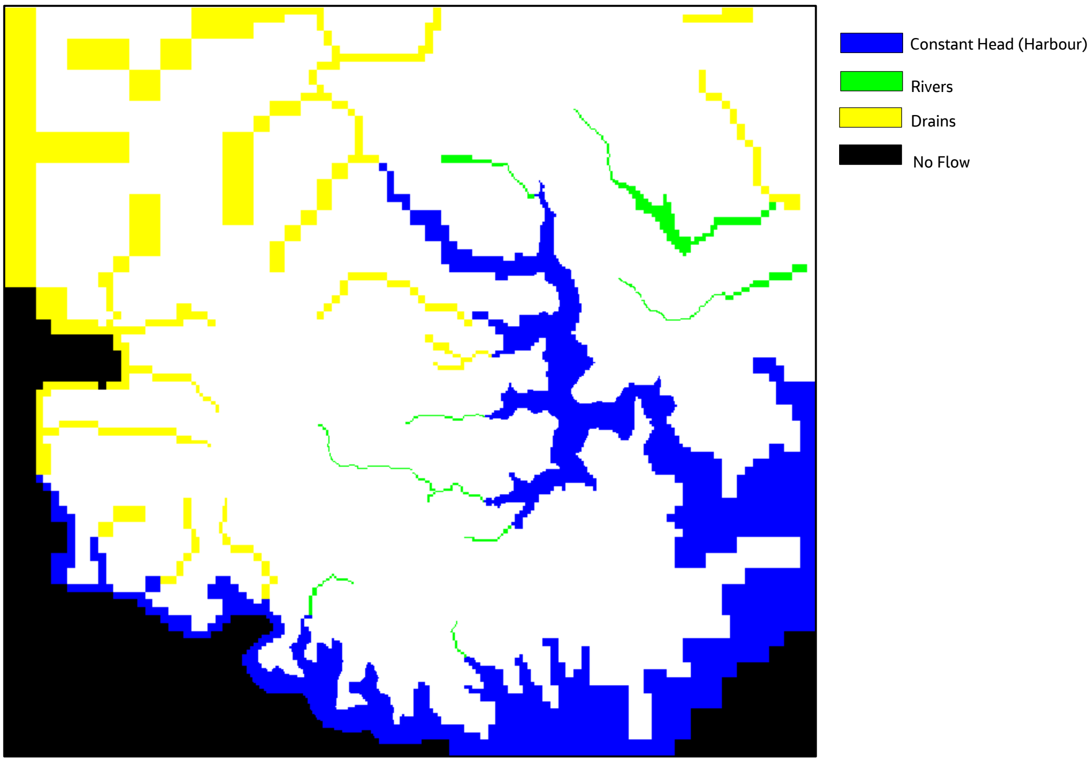


Figure 3-5: Model boundary conditions along watercourses.

The limited 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.

The conductance term assigned to the RIV or DRN boundaries was calculated as the product of the hydraulic conductivity and cell cross-section area divided by the assumed river-bed sediment thickness of one metre. The hydraulic conductivity used to calculate the RIV or DRN cell conductance for unlined water course sections was conservatively based on the horizontal hydraulic of the cell containing the RIV boundary. The RIV cell conductance terms were adjusted during the calibration and subjected to a sensitivity analysis.

Figure A1-15 shows the distribution of lined and unlined stream segments in the vicinity of the Beaches Link and Gore Freeway Connection Project and the Western Harbour Tunnel and Warringah Freeway Upgrade Project to the north of Sydney Harbour.

Manly Dam was simulated using River (RIV) boundary conditions. River stage elevations were set as static across the model due to the lack of transient surface water gauge level data. The river stage elevation of 35 mAHD applied to the model was based on the maximum operation level for the dam based on information obtained from the Sydney Water website (https://www.sydneywater.com.au/SW/water-the-environment/what-we-re-doing/Heritage-search/heritage-detail/index.htm?heritageid=4573702&FromPage=searchresults).

3.9.4 Harbours

Harbours are represented using the MODFLOW Constant Head Boundary Condition (CHD) with a specified head of 0 mAHD to represent sea level (Figure 3-6).

3.9.5 General head boundaries

MODFLOW General Head Boundary conditions (GHB) are used along the eastern boundary of the North model, around Manly Beach (Figure 3-7) 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.

3.9.6 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 projects. Parameters applied to the drain boundary conditions are described in Section 6.2 and 7.1.1.

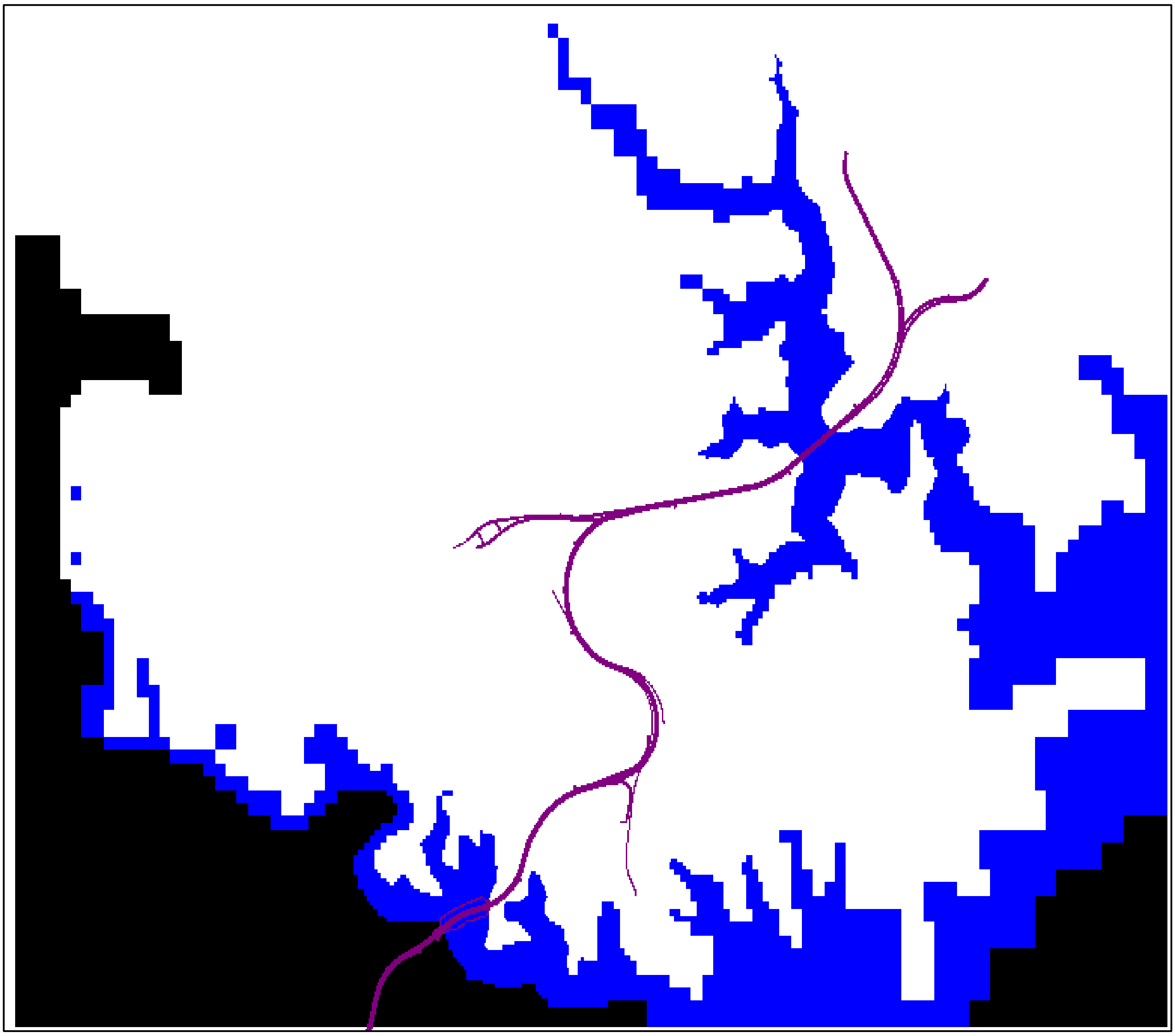


Figure 3-6: Constant Head Boundaries

Figure 3-7: General Head Boundaries.

4. Model calibration

The model was calibrated for steady state and transient conditions.

4.1 Steady state model calibration

4.1.1 Calibration for head targets – steady state model

4.1.1.1 Steady state model calibration procedure

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 61 head targets. The location of the bores used in calibrating the steady state model are presented in Figure A1-24. Information on bore construction, groundwater level monitoring dates and monitoring data suitability for calibration purposes is provided in Attachment 4. 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 model during calibration are presented in Table 2-6 and Table 3-3 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 achieved by qualitatively assessing the match between modelled and observed heads as well as assessing statistical calibration measures.

4.1.1.2 Steady state calibrated model parameter values

Table 4-1 presents both the calibrated and initial hydraulic conductivity values. The main changes to hydraulic conductivity values during the steady state model calibration were as follows:

- The horizontal hydraulic conductivity for the Weathered Hawkesbury Sandstone in layer 1 (Zone 1) was increased from 1.0×10^{-2} m/day to 2.0×10^{-2} m/day. The vertical hydraulic conductivity for Zone 1 was increased from 1.0×10^{-3} m/day to 2.0×10^{-3} m/day
- The horizontal hydraulic conductivity for the Unweathered Hawkesbury Sandstone in layer 2 (Zone 9) was increased from 1.0×10^{-2} m/day to 2.0×10^{-2} m/day. The vertical hydraulic conductivity for Zone 9 was increased from 1.0×10^{-3} m/day to 2.0×10^{-3} m/day
- The horizontal hydraulic conductivity for the Ashfield Shale/Mittagong Formation in layer 1 (Zone 2) was reduced from 6.0×10^{-2} m/day to 1.0×10^{-2} m/day. The vertical hydraulic conductivity for Zone 2 was increased from 2.0×10^{-4} m/day to 1.0×10^{-3} m/day
- The vertical hydraulic conductivity for the Fill/Alluvium in layer 1 (Zone 4) was reduced from 4.3×10^{-1} m/day to 1.0×10^{-1} m/day.

Table 4-1: Calibrated steady state model hydraulic conductivity values

Model layer	Hydrogeological unit	Model zone	Hydraulic conductivity (m/d)			
			Horizontal		Vertical	
			Initial	Calibrated	Initial	Calibrated
1	Harbour Sediments	3	1.0×10^{-2}	1.0×10^{-2}	5.0×10^{-3}	5.0×10^{-3}
	Fill/Alluvium	4	1	1	4.3×10^{-1}	1.0×10^{-1}
	Ashfield Shale/Mittagong	2	6.0×10^{-2}	1.0×10^{-2}	2.0×10^{-4}	1.0×10^{-3}
	Middle Harbour High K Zone	7	6.5×10^{-2}	6.6×10^{-2}	6.5×10^{-2}	6.6×10^{-2}
	Weathered Hawkesbury Sandstone	1	1.0×10^{-2}	2.0×10^{-2}	1.0×10^{-3}	2.0×10^{-3}
2	Flat Rock Creek High K Zone	5	2.0×10^{-2}	2.0×10^{-2}	2.0×10^{-2}	2.0×10^{-2}
	Sydney Harbour High K Zone	20	2.1×10^{-1}	2.1×10^{-1}	2.1×10^{-1}	2.1×10^{-1}
	Middle Harbour High K Zone	22	5.3×10^{-1}	5.0×10^{-1}	5.3×10^{-1}	5.0×10^{-1}
	Middle Harbour High K Zone	7	6.5×10^{-2}	6.6×10^{-2}	6.5×10^{-2}	6.6×10^{-2}
	Unweathered Hawkesbury Sandstone	9	1.0×10^{-2}	2.0×10^{-2}	1.0×10^{-3}	2.0×10^{-3}
3	Flat Rock Creek High K Zone	12	9.0×10^{-3}	9.0×10^{-3}	9.0×10^{-3}	9.0×10^{-3}
	Sydney Harbour High K Zone	21	2.9×10^{-1}	2.9×10^{-1}	2.9×10^{-1}	2.9×10^{-1}
	Middle Harbour High K Zone	22	5.3×10^{-1}	5.0×10^{-1}	5.3×10^{-1}	5.0×10^{-1}
	Middle Harbour High K Zone	7	6.5×10^{-2}	6.6×10^{-2}	6.5×10^{-2}	6.6×10^{-2}
	Unweathered Hawkesbury Sandstone	10	4.5×10^{-3}	4.5×10^{-3}	4.5×10^{-4}	4.5×10^{-4}
4	Flat Rock Creek High K Zone	13	9.0×10^{-3}	9.0×10^{-3}	9.0×10^{-3}	9.0×10^{-3}
	Middle Harbour High K Zone	22	5.3×10^{-1}	5.0×10^{-1}	5.3×10^{-1}	5.0×10^{-1}
	Middle Harbour High K Zone	7	6.5×10^{-2}	6.6×10^{-2}	6.5×10^{-2}	6.6×10^{-2}
	Unweathered Hawkesbury Sandstone	6	4.5×10^{-3}	4.5×10^{-3}	4.5×10^{-4}	4.5×10^{-4}
5	Flat Rock Creek High K Zone	14	7.4×10^{-3}	7.4×10^{-3}	7.4×10^{-3}	7.4×10^{-3}
	Middle Harbour High K Zone	22	5.3×10^{-1}	5.0×10^{-1}	5.3×10^{-1}	5.0×10^{-1}
	Middle Harbour High K Zone	7	6.5×10^{-2}	6.6×10^{-2}	6.5×10^{-2}	6.6×10^{-2}
	Unweathered Hawkesbury Sandstone	17	3.7×10^{-3}	3.7×10^{-3}	3.7×10^{-4}	3.7×10^{-4}
6	Flat Rock Creek High K Zone	18	7.4×10^{-3}	7.4×10^{-3}	7.4×10^{-3}	7.4×10^{-3}
	Middle Harbour High K Zone	22	5.3×10^{-1}	5.0×10^{-1}	5.3×10^{-1}	5.0×10^{-1}
	Middle Harbour High K Zone	7	6.5×10^{-2}	6.6×10^{-2}	6.5×10^{-2}	6.6×10^{-2}
	Unweathered Hawkesbury Sandstone	15	3.7×10^{-3}	3.7×10^{-3}	3.7×10^{-4}	3.7×10^{-4}
7	Flat Rock Creek High K Zone	19	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}
	Middle Harbour High K Zone	22	5.3×10^{-1}	5.0×10^{-1}	5.3×10^{-1}	5.0×10^{-1}
	Middle Harbour High K Zone	7	6.5×10^{-2}	6.6×10^{-2}	6.5×10^{-2}	6.6×10^{-2}
	Unweathered Hawkesbury Sandstone	8	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-4}	1.3×10^{-4}

Table 4-2 presents the recharge rates assigned to the calibrated steady state model. The calibrated model recharge rates are similar to initial recharge rates (Table 2-6)

Table 4-2: Summary of calibrated model recharge rates

Zone	Recharge (m/day)	Equivalent recharge (mm/yr)	% Mean annual rainfall
Ashfield Shale (paved)	3.20×10^{-5}	12	1
Ashfield Shale (unpaved)	3.20×10^{-5}	12	1
Hawkesbury Sandstone (paved)	3.20×10^{-5}	12	1
Hawkesbury Sandstone (unpaved)	9.60×10^{-5}	35	3

4.1.1.3 Steady state model calibration assessment

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.

Figure A1-25 in Attachment 1 shows the magnitudes of the residual errors for the calibration targets. The residual is the difference between the observed and modelled head. A positive residual indicates that the simulated head is less than observed head. A negative residual indicates that the simulated head is higher than the observed head.

Table 4-3 presents a summary of the calibration statistics for the steady state model. 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 two 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.

4.1.2 Calibration for measured stream-flows

As described in Section 2.3, preliminary flow gauging was undertaken at Flat Rock Creek, Quarry Creek (tributary to Flat Rock 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 A1-14. 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 m3/day)
- Quarry Creek – 2.1 L/s (178 m3/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. A conductance term of 0 m^2/day was assigned to lined creek segments.

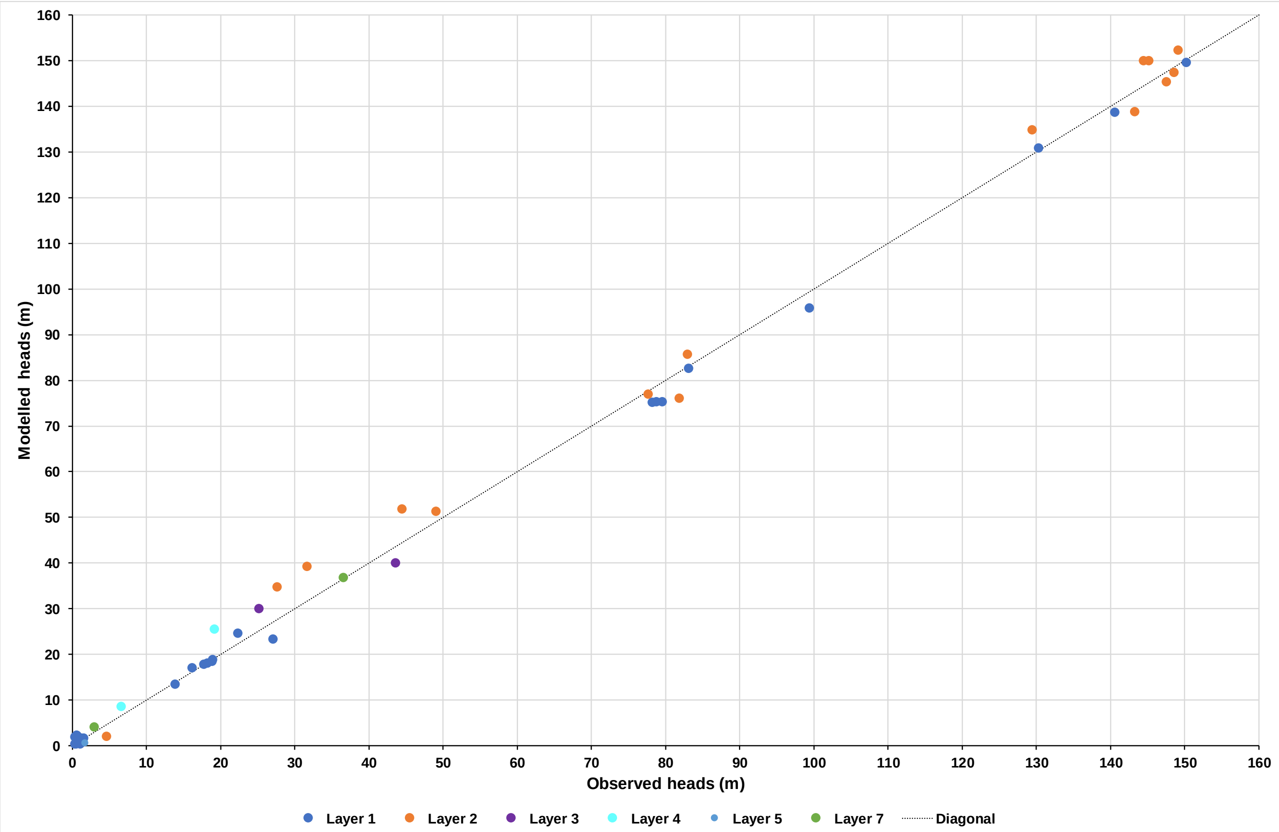


Figure 4-1: Comparison of modelled and observed heads – Steady State North Model

Table 4-3: Calibration statistics summary – Steady state model

Calibration statistic	Value
Residual Mean	0.43
Residual Standard Deviation	2.87
Absolute Residual Mean	1.99
Residual Sum of Squares	513
RMS Error	2.90
Minimum Residual	-7.59
Maximum Residual	5.72
Range of Observations	150.13
Scaled Residual Standard Deviation	0.019
Scaled Absolute Mean	0.013
Scaled RMS	0.019
Number of Observations	61

During the iterative manual calibration process, the conductance terms assigned to RIV boundary cells for unlined segments of the creek were adjusted in an attempt to achieve a reasonable match between modelled groundwater discharge to creeks (baseflow) and preliminary stream low-flow measurements at Flat Rock Creek and Quarry Creek. Table 4-4 shows the simulated stream-flows with varying conductance values assigned to RIV boundary cells for the unlined creek segments.

Table 4-4: Simulated baseflow

RIV boundary cell conductance m^2/day	Simulated baseflow (m^3/day)	
	Flat Rock Creek	Quarry Creek
10	145	14
100	157	14
500	158	14

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 the model calibration assessment represent only one round of field observations. It is recommended that continuous stream-flow monitoring is undertaken along the creeks located near the project 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 undertaken 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 Calibrated steady state model water balance

Table 4-5 presents the water balance for the steady state 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 model

	Inflow (m^3/day)	Outflow (m^3/day)
Rainfall-recharge	5,482	0
Constant head (tidal areas)	60	1,754
River boundaries	278	441
Evapotranspiration	0	3,360
General Head Boundaries	0	85
Drains	0	182
TOTAL	5,820	5,822
PERCENTAGE ERROR	< 0.1%	

4.2 Transient model calibration

4.2.1 Transient model calibration procedure

Transient model calibration was carried out for the period between January 2015 and September 2018 using monthly stress periods.

The recharge rates applied to each of the 45 monthly stress periods for each model recharge zone were varied based on the monthly rainfall recorded at Observatory Hill (BoM Station 66062) rainfall station. An equivalent daily rainfall rate (daily rainfall) was calculated for each month as follows:

$$Daily\ rainfall = \frac{total\ rainfall\ recorded\ for\ the\ month}{number\ of\ days\ in\ the\ month}$$

The daily recharge rate assigned to each model stress period was calculated as a percentage of the daily rainfall. Table 4-6 presents the percentages of daily rainfall applied as recharge to the transient model zones. The percentages of daily rainfall applied as daily recharge are based on results of the steady state model calibration (Table 4-2).

Table 4-6: Percentages of equivalent daily rainfall assigned as recharge.

Zone	Percentage of equivalent daily rainfall assigned as recharge
Ashfield Shale (paved)	1
Ashfield Shale (unpaved)	1
Hawkesbury Sandstone (paved)	1
Hawkesbury Sandstone (unpaved)	3

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 and GW10)- Groundwater level monitoring times-series data is available for the entire calibration period for most bores
- Sydney Metro project baseline monitoring bores (SRT_BH018 and SRT-BH019) - 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) presented in Table 3-4 were initially assigned to the model during calibration, Storage parameter values and, if necessary, hydraulic conductivity values were adjusted manually to obtain a suitable match between observed and simulated heads.

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.

4.2.2 Calibrated transient model parameter values

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).

Transient model calibration was also attained with no modification to the initial percentages of rainfall applied as recharge (Table 4-6).

Storage parameters assigned to the calibrated transient 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.

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/Mittagong Formation	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
Unweathered Hawkesbury Sandstone	2-7	1.9×10^{-6}	1.9×10^{-6}	0.02	0.02

4.2.3 Transient model calibration assessment

The scattergraph in Figure 4-2 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 less than 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.

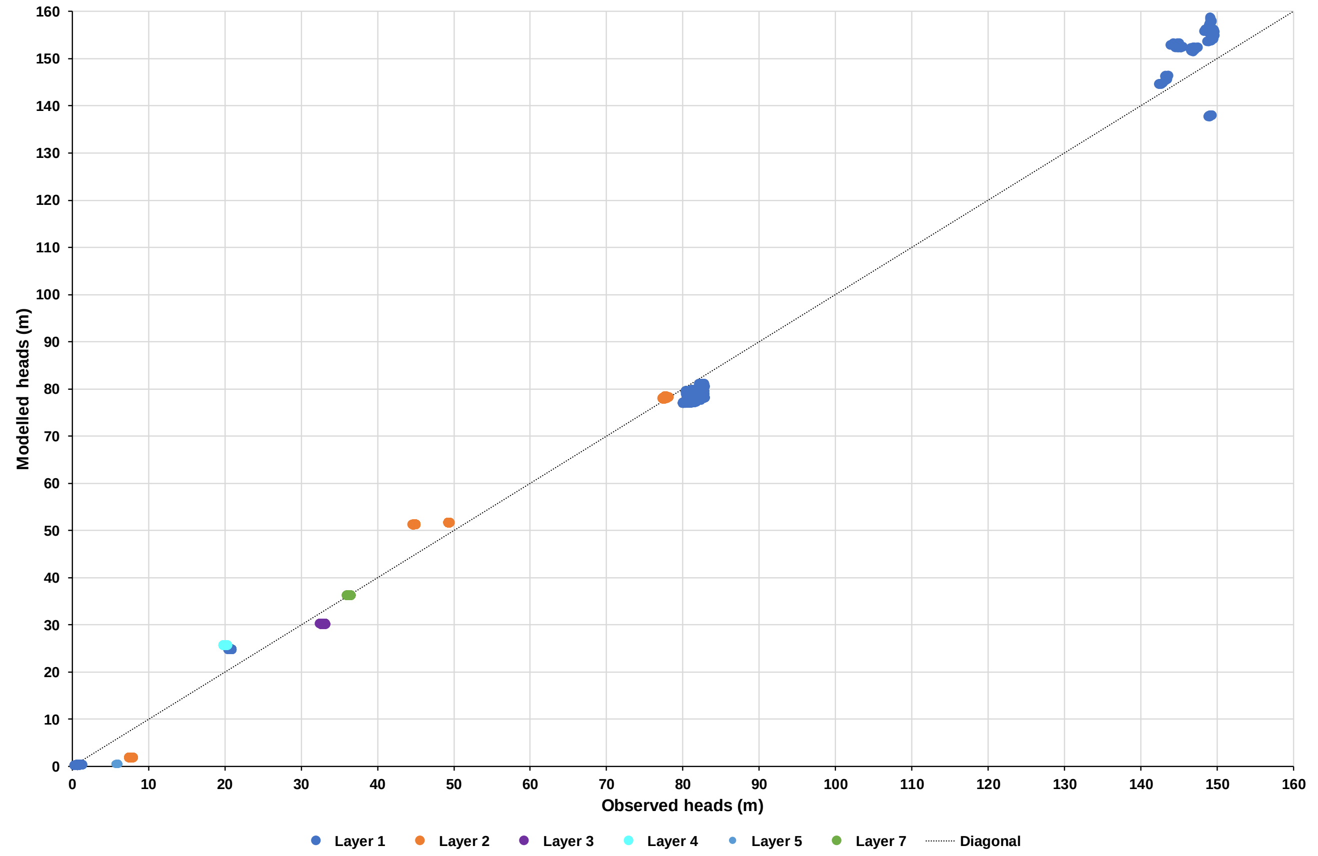


Figure 4-2: Comparison of modelled and observed heads – Transient North Model

Table 4-8: Calibration statistics summary – Transient North Model

Calibration target statistic	Value
Residual Mean	1.58
Residual Standard Deviation	3.36
Absolute Residual Mean	3.03
Residual Sum of Squares	2.57×10^5
RMS Error	3.72
Minimum Residual	-9.67
Maximum Residual	11.35
Range of Observations	149.47
Scaled Residual Standard Deviation	0.022
Scaled Absolute Mean	0.020
Scaled RMS	0.025
Number of Observations	18,591

Simulated and observed hydrographs for the monitoring bores are presented in Attachment 5. The simulated groundwater level peak elevations were slightly lower than observed peaks because the model is formulated with monthly stress periods (Attachment 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.

4.2.4 Calibrated transient model water balance

Table 4-9 presents the water balance for the transient 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: Calibrated transient model water balance

Parameter	Inflow (m^3/day)	Outflow (m^3/day)
Rainfall-recharge	3,180	
Constant head (tidal areas)	70	1,618
River boundaries	288	411
Evapotranspiration		3,331
General Head Boundaries		84
Drains		180
Storage	2,114	83
Total	5,652	5,707
Percentage error	≈ 0.96%	

5. Model confidence level classification

Under the confidence level classification system suggested by Barnett et al. (2012), the model would be classified as Confidence Level 2 groundwater models for the following reasons:

- Parameters assigned to the 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 model is approximately 16 metres which is comparable to the widths of the proposed tunnels
- Results of the model calibration presented in Section 4 indicate that the model can adequately represent historical and present-day groundwater conditions
- Mass balance closure error for the 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 Prediction model

6.1.1 Predictive model scenarios

The following model scenarios were run:

- **Scenario 1** ("Null" run) simulates existing groundwater conditions into the future. Scenario 1 does not include any components of the Beaches Link and Gorehill Freeway Connection project (Beaches Link project), Western Harbour Tunnel and Warringah Freeway Upgrade Project (WHTWFU) and Chatswood to Sydenham Sydney Metro project (Metro)
- **Scenario 2** ("Null + Metro + WHTWFU" run) assesses potential future groundwater impacts when groundwater stresses associated with Metro and WHTWFU projects are superimposed on Scenario 1. Components of the Beaches Link project are not included in Scenario 3 simulations
- **Scenario 3** ("Null + Metro + WHTWFU + Beaches Link" run) assesses potential future groundwater impacts when the cumulative groundwater stresses associated with Metro, WHTWFU 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

Project	Method for calculating impacts
Cumulative	Scenario 1 – Scenario 3
Beaches Link ONLY	Scenario 2 – Scenario 3

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 will 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 summarises 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

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 parameters 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 Tunnel inflow simulation

Attachment 6 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. For the Beaches Link project it was assumed that a 125 m section on either side of Middle Harbour would be tanked
- 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. For the Beaches Link project it was assumed that the mainline tunnels, with the exception of the 125 m section on either side of Middle Harbour, would be drained tunnels
- 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 (2018). Drain conductance values 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 will be "shotcreted" during construction (Hydrosimulations 2017).

A more conservative approach has been adopted for the Beaches Link project groundwater assessment 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 Model. 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 undertaken 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 conductance values assigned to simulate tunnel inflows in the model ranged from 0.13 m^2/day to 62 m^2/day.

7.1.2 Reporting of tunnel inflows

Predicted groundwater inflows are presented for each year of construction (2023 to 2027), the first year of operation (2028) and at the end of the model simulation period in 2128.

Section 7.2 presents groundwater inflows broken down into tunnel sections separated by harbours. The tunnel inflow reporting sections are shown in Figure A1-26. 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 7.2.3 presents project-wide groundwater inflows in megalitres per day (ML/day) and megalitres per year (ML/year).

7.2 Results – predicted tunnel inflows

7.2.1 Cammeray to Middle Harbour section - Beaches Link project tunnels

Table 7-1 presents predicted groundwater inflows for the Cammeray to Middle Harbour Section of the Beaches Link project (Figure A1-26). Groundwater inflows to the tunnel section are predicted to peak in 2025 at approximately 16.8 L/s (average inflow ≈ 1.5 L/s/km) and then gradually decrease to approximately 6.3 L/s (average inflow ≈ 0.6 L/s/km) by the end of the simulation period in 2128. 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.

7.2.2 Middle Harbour to Wakehurst/North Balgowlah - Beaches Link project tunnels

Table 7-2 presents results for the Middle Harbour to Wakehurst/North Balgowlah Section of the Beaches Link project (Figure A1-26). Groundwater inflows to the tunnel section are predicted to peak in 2025 at approximately 11.7 L/s (average inflow ≈ 1.2 L/s/km) and then gradually decrease to approximately 7.6 L/s (average inflow ≈ 0.8 L/s/km) by the end of the simulation period in 2128.

High inflow rates for the section, exceeding the 1 L/s/km threshold are associated with the 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.

Table 7-1: Modelled tunnel inflows – Cammeray to Middle Harbour section of Beaches Link project

Tunnel sub-section	Length (m)	Tunnel inflow (L/s)						
		2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2128**
NB Main Line - Flat Rock Drive Site to North Bridge Cavern	545	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NB Northbridge Cavern	185	0.000	0.186	0.141	0.138	0.134	0.134	0.111
NB Main Line - North Bridge Cavern towards Clive Park	1,971	0.000	0.587	1.457	1.361	1.289	1.275	0.841
NB Main Line - Clive Park to Transition Structure (Undrained)	100	0.000	0.000	4.634	0.000	0.000	0.000	0.000
NB Main Line - Flat Rock Drive Site to Cammeray Cavern	1,467	0.417	1.220	1.173	1.080	0.957	0.936	0.484
NB Cammeray Cavern	183	0.000	0.000	0.109	0.077	0.053	0.049	0.007
EB Entry Ramp - Gore Hill Freeway to North Bridge Cavern	577	1.633	1.635	1.840	1.659	1.488	1.461	1.034
SB Main Line - Flat Rock Drive site to North Bridge Cavern	685	2.359	2.265	1.995	1.913	1.824	1.809	1.596
SB Northbridge Cavern	272	0.000	0.207	0.157	0.154	0.150	0.149	0.098
SB Main Line - North Bridge Cavern towards Clive Park	1,737	0.000	0.000	1.456	1.339	1.272	1.259	0.826
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
SB Main Line - Flat Rock Drive Site to Cammeray Cavern	1,450	0.414	1.293	1.132	1.035	0.900	0.876	0.440
SB Cammeray Cavern	136	0.000	0.000	0.088	0.071	0.058	0.056	0.020
WB Exit Ramp - Gore Hill Freeway to North Bridge Cavern	641	1.988	3.991	2.172	1.761	1.359	1.297	0.698
BL - Cammeray ventilation Tunnel	246	0.565	0.396	0.298	0.262	0.227	0.221	0.111
BL - Punch Street Access Decline	221	0.210	0.127	0.089	0.079	0.069	0.067	0.000
BL - Flat Rock Creek Access Decline	315	0.000	0.437	0.013	0.004	0.000	0.000	0.000
TOTAL TUNNEL INFLOW (L/s)		**7.586**	**12.343**	**16.757**	**10.933**	**9.779**	**9.590**	**6.266**
	Average inflow (L/s/km)							
		2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2128**
AVERAGE INFLOW (L/s/km)		**0.699**	**1.138**	**1.545**	**1.008**	**0.902**	**0.884**	**0.578**

Note 1: NB = North Bound, SB = South Bound, EB = East Bound & WB = West Bound.

Table 7-2: Modelled tunnel inflows - Middle Harbour to Wakehurst/North Balgowlah Section of Beaches Link project

Tunnel Sub-section [1]	Length (m)	Tunnel inflow (L/s)						
		2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2128**
NB Main Line - Burnt Bridge Creek Deviation to Seaforth Ramp	1,364	0.076	0.056	0.037	0.029	0.022	0.021	0.005
NB Seaforth Cavern	157	0.000	0.038	0.005	0.003	0.002	0.001	0.000
NB Main Line - Seaforth Cavern towards Seaforth Bluff	1,150	0.000	0.000	1.925	2.459	2.466	2.466	2.461
NB Main Line - Seaforth Bluff to Transition Structure (Undrained)	90	0.000	0.000	1.692	0.000	0.000	0.000	0.000
NB Exit Ramp - Wakehurst Park towards Seaforth Cavern	1,657	0.000	0.135	0.160	0.126	0.098	0.094	0.038
NB Exit Ramp - Wakehurst Park towards Frenchs Forest	166	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SB Seaforth Cavern	298	0.000	0.396	0.186	0.160	0.149	0.147	0.126
SB Main Line - Seaforth Cavern towards Seaforth Bluff	975	0.000	1.267	4.121	4.380	4.367	4.364	4.333
SB Main Line - Seaforth Bluff to Transition Structure (Undrained)	125	0.000	0.000	2.662	0.000	0.000	0.000	0.000
SB Exit Ramp - Wakehurst Park towards Seaforth Cavern	1,719	0.000	0.290	0.288	0.247	0.214	0.209	0.127
SB Exit Ramp - Wakehurst Park towards Frenchs Forest	145	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SB Main Line - Burnt Bridge Creek Deviation to Seaforth Ramp	1,136	0.076	0.345	0.195	0.176	0.165	0.163	0.141
BL - Balgowlah Access Decline	300	0.914	0.576	0.443	0.411	0.380	0.374	0.307
BL - Wakehurst Parkway East	230	0.064	0.031	0.031	0.031	0.030	0.030	0.027
TOTAL TUNNEL INFLOW (L/s)		**1.130**	**3.135**	**11.743**	**8.023**	**7.892**	**7.870**	**7.568**
		Average Inflow (L/s/km)						
		2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2128**
AVERAGE INFLOW (L/s/km)		**0.119**	**0.330**	**1.235**	**0.844**	**0.830**	**0.827**	**0.796**

Note 1: NB = North Bound, SB = South Bound, EB = East Bound & WB = West Bound.

7.2.3 Project-wide tunnel groundwater inflows

Table 7-3 presents the total groundwater tunnel inflows for each year of construction (2023-2027), the first year of operation (2028) and the end of the simulation period (2128).

Table 7-3: Modelled project-wide groundwater tunnel inflows

Year	Cammeray to Middle Harbour	Middle Harbour to Wakehurst Parkway	Whole project		Total annual inflows
	L/s/km	L/s/km	L/s/km	ML/day	ML/ year
2023	0.70	0.12	0.41	0.753	275
2024	1.14	0.33	0.73	1.337	488
2025	1.54	1.23	1.39	2.462	899
2026	1.01	0.84	0.93	1.638	598
2027	0.90	0.83	0.87	1.527	557
2028	0.88	0.83	0.86	1.509	551
2128	0.58	0.80	0.69	1.195	436

8. Predicted drawdown

Predicted groundwater drawdown results from the model presented in this section are for:

- The Beaches Link project and
- The cumulative drawdown effects.

Cumulative drawdown is the sum of the predicted drawdown due to the Beaches Link project, WHTWFU Project, M4-M5 Link and Sydney Metro project.

Drawdown predictions are provided for the following:

- Water table
- Composite drawdown for the layer with the greatest amount of drawdown for each vertical column of model grid cells (i.e. the greatest drawdown for any layer at every x,y location in the model where drawdown is calculated). This composite drawdown represents the drawdown at the tunnel elevation.

Section 8.1 presents drawdown predictions for the Beaches Link Project only. Section 8.2 presents cumulative drawdown predictions.

This report only presents the predicted drawdown magnitudes. The impacts due to the drawdown are presented in the groundwater technical paper for the Beaches Link and Gore Hill Freeway Project (Appendix N (Technical working paper: Groundwater)).

8.1 Predicted drawdown – Beaches Link project

8.1.1 Drawdown at end of construction

Figure A1-27a indicates that water table drawdown at the end of tunnel construction in June 2027 is predicted to be up to a maximum of about 28 metres, in the area immediately overlying the Gorehill Freeway ramp tunnel. Predicted water table drawdown at the end of construction is predicted to propagate away from the tunnels, with the drawdown extending to Artarmon and Naremburn, to the west of the main Beaches Link tunnel (Figure A1-27a).

North of Middle Harbour, the maximum water table drawdown is predicted to be about 16 metres at Seaforth (Figure A1-27b). The water table drawdown is predicted to reach the harbour on both sides of Middle Harbour by the end of the Beaches Link Project construction.

Figure A1-28a indicates a maximum predicted drawdown at the tunnel level of up to about 61 metres at the end of tunnel construction, in the area immediately overlying the tunnel centreline in the Northbridge area.

The maximum drawdown at the tunnel level, north of Middle Harbour, at the end of construction, is predicted to be about 20 metres on the Seaforth area (Figure A1-28b). Drawdown is predicted to reach the harbour on both sides of Middle Harbour by the end of tunnel construction (Figure A1-28).

8.1.2 Long-term drawdown

Figure A1-29a indicates that the maximum predicted water table drawdown after approximately 100 years of operation of the Beaches Link Project is about 39 metres in the Northbridge area.

Figure A1-29b indicates that the maximum predicted water table drawdown north of Middle Harbour after 100 years of operation is about 16 metres at Seaforth. The maximum water table drawdown after approximately 100 years of operation (Figure A1-29b) is similar to the water table drawdown predicted in the same area at the end of construction (Figure A1-27b).

Figure A1-30a indicates that maximum drawdown at the tunnel level after approximately 100 years of operation is predicted to be up to a maximum of about 61 metres in the area immediately overlying the tunnel centreline in the Northbridge area. The maximum drawdown is predicted to have extended westwards to Greenwich after approximately 100 years of operation.

North of Middle Harbour, the maximum drawdown at the tunnel level after approximately 100 years of operation (Figure A1-30b) is predicted to be similar to the predicted drawdown at the water table within the same area.

8.2 Cumulative predicted drawdown

8.2.1 Cumulative drawdown at end of construction

Figure A1-31a and Figure A1-31b show the cumulative water table drawdown at the end of the Beaches Link project construction period for areas located south and north of Middle Harbour, respectively. Figure A1-32a and Figure A1-32b show the cumulative maximum drawdown at the tunnel level for the same period. Cumulative drawdown at the end of construction is predicted to be largely the same as the project only case. The only change would be in the south of the Beaches Link project area, where drawdown from the Beaches Link project interacts with drawdown from the Western Harbour Tunnel project and Sydney Metro project.

Figure A1-31a shows that the maximum cumulative water table drawdown at the end of construction over the Western Harbour Tunnel mainline between Sydney Harbour and North Sydney is predicted to be about 20 metres. Similar maximum cumulative drawdown of 20 metres is also predicted at the tunnel level for the Western Harbour Tunnel mainline tunnel (Figure A1-32a).

Cumulative drawdown at the water table and maximum drawdown are predicted to extend southwards to Balls Head by the end of the Beaches Link Project construction (Figure A1-31a and A1-32a).

8.2.2 Cumulative long-term drawdown

Figure A1-33a and Figure A1-33b show the cumulative water table drawdown after approximately 100 years of Beaches Link Project operation for areas located south and north of Middle Harbour, respectively. Figure A1-34a and Figure A1-34b show the maximum cumulative drawdown at the tunnel level for the same period. 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 and Metro Project.

Figure A1-33a shows that the maximum cumulative water table drawdown at the end of construction over the Western Harbour Tunnel mainline between Sydney Harbour and North Sydney is predicted to be about 20 metres. Similar maximum cumulative drawdown of about 20 metres is also predicted at the tunnel level for the Western Harbour Tunnel mainline (Figure A1-34a).

Cumulative drawdown at the water table and maximum drawdown are predicted to extend southwards to Balls Head by the end of the Beaches Link Project construction (Figure A1-33a and A1-34a).

8.3 Predicted drawdown at Flat Rock Reserve

The predictions of settlement due to groundwater drawdown indicated significant settlement in the vicinity of Flat Rock Creek. To test the potential for tunnel linings to reduce the predicted settlement at this lcoation, additional modelling was undertaken to assess the potential changes to modelled groundwater drawdown if groundwater inflows were restricted eg by a tunnel lining system for the section of tunnel beneath Flat Rock Reserve.

The predicted tunnel inflows presented in Section 7.2, and drawdown predictions presented in Section 8.1 and Section 8.2, are based on the conservative assumption that the tunnel inflow is unrestricted, except for the tunnel sections located immediately adjacent to the harbour. This conservative modelling approach, described in Section 7.1.1, assumes that unrestricted inflows to the tunnels occur.

8.3.1 Modelling assumptions

The modelling assumes that a length of tunnel approximately 300 metres long beneath Flat Rock Reserve (Figure A1-35 in Attachment 1) is constructed such that groundwater inflow is zero. This tunnel section is located in bedrock underneath highly permeable fill material deposited within the Flat Rock Creek valley.

8.3.2 Modelling results

Figure A1-35 shows the predicted water table drawdown after approximately 100 years of operation, for the Flat Rock Reserve restricted groundwater inflow scenario. The predicted water table drawdown at Flat Rock Reserve for this option (Figure A1-35) is approximately eight metres less than the drawdown predicted for the model with no inflow restriction (Figure A1-36).

Figure A1-37 shows the predicted maximum drawdown, after approximately 100 years of operation, for the Flat Rock Reserve restricted groundwater inflow scenario. The predicted maximum drawdown at Flat Rock Reserve for this option (Figure A1-37) is approximately 12 metres less than the drawdown predicted for the model with no inflow restriction (Figure A1-38).

Predicted long-term tunnel inflows for a one-kilometre length of tunnel (centred around the 300 metre segment in the Flat Rock Creek valley) under the restricted groundwater inflow scenario were as follows:

- 0.45 L/s/km for the northbound tunnel
- 0.47 L/s/km for the southbound tunnel.

The resulting settlement under the restricted groundwater inflow scenario and comparison with worst case predictions is provided in Appendix N (Technical working paper: Groundwater).

9. Predicted baseflow reduction

9.1 Introduction

This chapter reports on predicted reduction in baseflow to surface water features due to the cumulative impacts of the Beaches Link, Western Harbour Tunnel, and Sydney Metro projects. Baseflow is considered in this report to be the groundwater contribution to streamflow.

The predicted long-term cumulative water table drawdown contour map (Figure A1-24) indicates that water table drawdown greater than one metre is predicted to occur at Flat Rock Creek, Quarry Creek, Burnt Bridge Creek, Willoughby Creek, Berrys Creek, Camp Creek, Sugarloaf Creek and Sailors Bay Creek.

Predictions of baseflow reduction at the watercourses above are presented in this report. Baseflow reduction at Manly Dam (which has predicted drawdown of less than one metre) is also discussed in this report.

9.2 Stream baseflow reduction modelling assessment methodology

As described in Section 3.9.3, MODFLOW River (RIV) boundary conditions and Drain (DRN) boundary conditions are used in the model to simulate fluxes between streams and the groundwater system.

RIV boundaries simulate both groundwater discharge to streams (baseflow) 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 simulate discharge of groundwater to streams (baseflow) when groundwater levels are higher than stream stage.

Water bodies located close to the proposed Beaches Link tunnel project area including Flat Rock Creek, Burnt Bridge Creek, Quarry Creek, Willoughby Creek, Berrys Creek and Manly Dam were represented in the model using River (RIV) boundaries. RIV boundaries were assigned along these water bodies 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. Negative flows computed at RIV cells represent groundwater discharge to streams (baseflow) and positive flows represent leakage from streams to the groundwater system.

For river (RIV) boundaries, a stream segment (reach), representing a grouping of RIV cells, can have gaining sections (negative flows) and losing sections (positive flows). Therefore, the “net flux” for a reach represents the overall volume difference between groundwater inflows and leakage outflows for the reach. A negative net flux for the reach (stream segment) indicates that the stream segment is predominantly groundwater fed (i.e. gaining stream) and a positive net flux indicates that the stream segment is dominated by leakage (i.e. losing stream).

First and second order streams located further away from the proposed Beaches Link tunnel and Gore Hill Freeway Connection Project area were modelled using Drain (DRN) boundaries (Figure 3-5) to allow for the simulation of the draining effect of the water courses in highland areas. Only baseflow is computed at DRN boundaries.

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).

9.3 Stream baseflow reduction assessment results

This section presents the predicted cumulative stream baseflow reduction for the following periods:

- End of Beaches Link project construction (June 2027)
- Approximately 100 years post-construction (December 2126).

9.3.1 Flat Rock Creek, Quarry Creek, Willoughby Creek and Burnt Bridge Creek baseflow reduction assessment

The assessment of baseflow reduction for Flat Rock Creek, Quarry Creek, Willoughby Creek and Burnt Bridge Creek is based on the following assumptions:

- There is continuous saturation between the tunnel horizon and the shallow water table (ie there is a single connected groundwater system beneath the creek and the proposed underlying tunnel). In reality, the system will be stratified, possibly with disconnected aquifer horizons. The predicted maximum drawdowns beneath the creek are therefore unlikely to be realised and the predicted reduction in baseflows are therefore conservative
- Groundwater discharge (baseflow) to creeks does not occur along creek sections where the bottom surface is lined. Figure A1-14 and A1-15 show the condition of the creek bottom surfaces and Table 9-2 presents the lining assumptions applied to the model for the different bottom surface conditions. The unlined section of Flat Rock Creek is located to the south of the proposed mainline tunnel and extends to the Strathallen Avenue bridge. A review of Google Earth images indicates that the sections of Flat Rock Creek classified as "unknown" are mostly lined
- A RIV boundary conductance of 100 m^2/day was assigned to the unlined creek section based on the results of the calibration and sensitivity analysis described in Section 4.1.2. The applied conductance ensures that simulated groundwater inflow to the creek is controlled by the permeability of the underlying hydrogeological formation and not limited by the simulated resistance to flow imposed by the assumed conductance term applied to stream-bed sediments.

Table 9-1: Modelling assumptions for creek bottom surfaces

Description of creek bottom surface conditions	Model lining assumption
Above ground concrete lined storm-water channel	Lined
Alluvium	Unlined
Naturalised bedrock	Unlined
Naturalised bedrock and above ground concrete lined storm water channel	Unlined
Underground box culvert	Lined
Unknown	Lined

Table 9-2 presents the modelled baseflow reduction at Flat Rock Creek. There is a predicted baseflow reduction of approximately 20 per cent by the end of construction and approximately 39 per cent baseflow reduction after approximately 100 years of operation of the Beaches Link project.

Table 9-2: Predicted cumulative stream baseflow reduction at Flat Rock Creek

Stream baseflow predictions	End of construction (June 2027)	Long-term (December 2126)
Null model predicted baseflow (m^3/day)	215.7	215.4
Cumulative projects model predicted baseflow (m^3/day)	172.1	130.7
Predicted baseflow volume reduction (m^3/day)	43.6	84.7
Predicted baseflow percentage reduction (%)	20	39

Table 9-3 presents the modelled baseflow reduction at Quarry Creek. There is a predicted baseflow reduction of approximately 23 per cent by the end of construction and approximately 69 per cent baseflow reduction after approximately 100 years of operation of the Beaches Link Project.

Table 9-3: Predicted cumulative stream baseflow reduction at Quarry Creek

Stream baseflow predictions	June 2027	December 2126
Null model predicted baseflow (m^3/day)	17.5	16.5
Cumulative projects model predicted baseflow (m^3/day)	13.4	5.1
Predicted baseflow volume reduction (m^3/day)	4.1	11.4
Predicted baseflow percentage reduction (%)	23	69

Table 9-4 presents the modelled baseflow reduction at Burnt Bridge Creek. There is a predicted baseflow reduction of approximately 79 per cent by the end of construction and 96 per cent baseflow reduction after approximately 100 years of operation of the Beaches Link Project.

Table 9-4: Predicted cumulative stream baseflow reduction at Burnt Bridge Creek

Streamflow predictions	June 2027	December 2126
Null model predicted baseflow (m^3/day)	21.2	17.5
Cumulative projects model predicted baseflow (m^3/day)	4.4	0.7
Predicted baseflow volume reduction (m^3/day)	16.7	16.8
Predicted baseflow percentage reduction (%)	79	96

The models indicate that Willoughby Creek is a losing stream that does not receive groundwater inflows (baseflow). Therefore, there is no predicted baseflow reduction (Table 9-5).

Table 9-5: Predicted cumulative stream baseflow reduction at Willoughby Creek

Stream baseflow predictions	June 2027	December 2126
Null model predicted baseflow (m^3/day)	0	0
Cumulative projects model predicted baseflow (m^3/day)	0	0
Predicted baseflow volume reduction (m^3/day)	No predicted baseflow reduction	No predicted baseflow reduction
Predicted baseflow percentage reduction (%)	No predicted baseflow reduction	No predicted baseflow reduction

9.3.2 Sailors Bay Creek, Berrys Creek and Manly Dam baseflow reduction assessment

The assessment of baseflow reduction for Sailors Bay Creek, Berrys Creek and Manly Dam is based on the following assumptions:

- There is continuous saturation between the tunnel horizon and the shallow water table (i.e. there is a single connected groundwater system beneath the creek/dam and the proposed underlying tunnel. In reality, the system will be stratified, possibly with disconnected aquifer horizons. The predicted maximum drawdowns beneath the creek/dam are therefore unlikely to be realised and the predicted reduction in baseflows are therefore conservative
- The whole length or area at the base of the creek or dam is unlined. At the time of modelling there was no information on the nature of creek bottom surfaces for Sailors Bay Creek and Berrys Creek
- A RIV boundary conductance of 100 m^2/day was assigned to the unlined creek section and base of Manly dam based on the results of the calibration and sensitivity analysis described in Section 4.1.2. The applied conductance ensures that simulated groundwater inflow to the creek or dam is controlled by the permeability of the underlying hydrogeological formation and not limited by the simulated resistance to flow imposed by the assumed conductance term applied to stream-bed sediment or dam bottom sediments.

The models indicate that Sailors Bay Creek is a losing stream that does not receive groundwater inflows (baseflow). Therefore, there is no predicted baseflow reduction (Table 9-6).

Table 9-6: Predicted cumulative stream baseflow reduction at Sailors Bay Creek

Streamflow predictions	June 2027	December 2126
Null model predicted baseflow (m^3/day)	0	0
Cumulative projects model predicted baseflow (m^3/day)	0	0
Predicted baseflow volume reduction (m^3/day)	n/a	n/a
Predicted baseflow percentage reduction (%)	n/a	n/a

The models indicate that Berrys Creek is a losing stream that does not receive groundwater inflows (baseflow). Therefore, there is no predicted baseflow reduction (Table 9-7).

Table 9-7: Predicted cumulative stream baseflow reduction at Berrys Creek

Streamflow predictions	June 2027	December 2126
Null model predicted baseflow (m^3/day)	0	0
Cumulative projects model predicted baseflow (m^3/day)	0	0
Predicted baseflow volume reduction (m^3/day)	n/a	n/a
Predicted baseflow percentage reduction (%)	n/a	n/a

Table 9-8 presents the modelled baseflow reduction at Manly Dam. There is a predicted baseflow reduction of approximately two per cent by the end of construction and approximately two per cent baseflow reduction after 100 years of operation of the Beaches Link project.

Table 9-8: Predicted cumulative stream baseflow reduction at Manly Dam

Streamflow predictions	June 2027	December 2126
Null model predicted baseflow (m^3/day)	103.9	97.8
Cumulative projects model predicted baseflow (m^3/day)	102.0	96.6
Predicted baseflow volume reduction (m^3/day)	1.9	1.2
Predicted baseflow percentage reduction (%)	2	2

9.3.3 Baseflow reduction assessment for creeks represented by drain boundaries

The assessment of baseflow reduction for creeks represented by drain (DRN) boundary conditions is based on the following assumptions:

- There is continuous saturation between the tunnel horizon and the shallow water table (ie there is a single connected groundwater system beneath the creek and the proposed underlying tunnel). In reality, the system will be stratified, possibly with disconnected aquifer horizons. The predicted maximum drawdowns beneath the creek are therefore unlikely to be realised and the predicted reduction in baseflows are therefore conservative
- The whole length of the creek is unlined
- The conductance term assigned to the DRN boundaries was calculated as the product of the hydraulic conductivity and cell cross-section area divided by the assumed creek-bed sediment thickness of one metre. The applied conductance ensures that simulated groundwater inflow to the creek is controlled by the permeability of the underlying hydrogeological formation and not limited by the simulated resistance to flow imposed by the assumed conductance term applied to creek-bed sediment.

Table 9-9 presents the modelled combined baseflow reduction at Camp Creek and Sugar loaf Creek. There is negligible baseflow reduction predicted by the end of construction and approximately four per cent baseflow reduction after approximately 100 years of operation of the Beaches Link project.

Table 9-9: Predicted cumulative stream baseflow reduction at Camp Creek and Sugarloaf Creek.

Stream baseflow predictions	June 2027	December 2126
Null model predicted baseflow (m^3/day)	6.1	5.7
Cumulative projects model predicted baseflow (m^3/day)	6.1	5.5
Predicted baseflow volume reduction (m^3/day)	0	0.2
Predicted baseflow percentage reduction (%)	0	4

9.4 Baseflow reduction assessment summary and recommendations

Table 9-10 summarises the predicted baseflow reduction percentages for watercourses located in the vicinity of the Beaches Link Project due to the cumulative effects of construction and operation of the Beaches Link Project, Western Harbour Tunnel Project and Sydney Metro Project.

It is important to note that the groundwater modelling assumes continuous saturation between the tunnel horizon and the shallow water table. In reality, the system will be stratified, possibly with disconnected aquifer horizons and therefore the model will "over-simulate" the actual hydraulic connection. The predicted maximum drawdowns are therefore unlikely to be realised and the predicted reduction in base flows are therefore conservative.

In order to refine the baseflow reduction predictions, it is recommended that further investigations are carried out to assess the following:

- The degree of hydraulic connectivity between watercourses and the underlying groundwater system
- The presence/absence of a shallow perched groundwater system occurring above a regional groundwater flow system
- The occurrence of low permeability geological units that could be confining units between shallow and deeper groundwater systems.

Recommended investigations include the following:

- Drilling to characterise the geological layers and beds
- Installation of piezometers at different depths to monitor groundwater levels at different depths
- Preforming long-duration pumping tests in the deeper bores and monitoring groundwater levels at observations bores (piezometers) at multiple depths.

Table 9-10: Summary of predicted baseflow reduction percentages for watercourses.

Watercourse	Baseflow reduction (%)	
	End of Construction (June 2027)	Approx. 100 years post-operation (December 2126)
Flat Rock Creek	20	39
Quarry Creek	23	69
Burnt Bridge Creek	79	96
Willoughby Creek	n/a	n/a
Sailors Bay Creek	n/a	n/a
Berrys Creek	n/a	n/a
Manly Dam	2	2
Camp Creek and Sugarloaf Creek	0	4

10. Uncertainty analysis

An uncertainty analysis has been carried out to investigate the sensitivity of model predictions to parameter values assigned to the prediction model. The uncertainty analysis involved targeted sensitivity analyses to assess potential groundwater-related impacts, identifying key factors of high and low range hydraulic parameter values.

Hydraulic parameter values that were varied for the uncertainty analysis were selected based on results of preliminary uncertainty analyses carried out during modelling for previous concept designs of the Beaches Link Project. The most sensitive parameters identified from the previous modelling were:

- Hydraulic conductivity
- Rainfall recharge
- Storage parameters.

The uncertainty analysis assessed the effects of varying the values of these parameters in the model. The cumulative scenario was considered, which considers the cumulative impact of Beaches Link and Gore Hill Freeway Connection project, the Western Harbour Tunnel and Warringah Freeway Upgrade project and the Sydney Metro City and Southwest project. Together these projects could result in cumulative impacts on groundwater levels and flow, and therefore the cumulative impact case represents the most conservative assessment of potential impact.

The following modelling outcomes were used to assess groundwater-related impacts for the uncertainty impact assessment at the end of project construction and approximately 100 years into the future:

- Predicted groundwater drawdown
- Predicted baseflow reduction at watercourses.

Uncertainty analysis modelling compared the groundwater related impacts for the “Base case” modelling scenario to the “Scenario A” and “Scenario B” modelling scenarios (described below). The Base case modelling scenario refers to the prediction model with the same parameter values as the calibrated transient model, as reported earlier in this report.

The “Scenario A” modelling scenario provides a modelled groundwater-related impacts based on combinations of model input parameter values at the high and low end of the plausible range of the model parameters, with parameters adjusted to yield greater groundwater inflows to the project tunnels and greater associated groundwater level drawdown. The “Scenario A” model scenario does not necessarily consider the most severe groundwater-related impacts that could possibly occur.

The “Scenario B” model scenario provides a modelled groundwater-related impacts based on the selected high and low parameter ranges, with parameters adjusted to yield lesser groundwater inflows to the project tunnels and lesser associated groundwater level drawdown.

Table 10-1 provides summary information on the parameter values assigned to the “Scenario A” and “Scenario B” modelling scenarios. The maximum specific storage value assigned to any hydrogeological unit for Scenario B was 1.3×10^{-5} m^{-1}. Rau et al. (2018) considers this specific storage to be the physically plausible upper limit for unconsolidated materials. Given that the upper limit recommended by Rau et al. (2018) was partially 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 1.3×10^{-5} m^{-1}.

Table 10-1: Parameter values assigned to uncertainty analysis model scenarios

Parameter	Scenario A	Scenario B
Horizontal hydraulic conductivity	One order of magnitude higher than values applied to Base case	One order of magnitude lower than values applied to Base case
Vertical hydraulic conductivity	One order of magnitude higher than values applied to Base case	One order of magnitude lower than values applied to Base case
Recharge	50 per cent of the recharge rates assigned to the Base case	200 per cent of the recharge rates assigned to the Base case
Specific storage	50 per cent of the recharge rates assigned to the Base case	The lesser of: • 200 per cent of the recharge rates assigned to the Base case and • 1.3×10^{-5} m^{-1}
Specific yield	50 per cent of the value assigned to the Base case	200 per cent of the value assigned to the Base case

The model parameter values assigned to the uncertainty analysis model scenarios (Table 10-1) are at the high and low end of the plausible range of model parameters based on a literature review of hydrogeological information from the Sydney basin, including information from previous tunnelling projects. It is also important to note that the uncertainty analysis models have not been recalibrated to ensure that the particular combinations of the adopted parameter values produce realistic model predictions. This means that unrealistic groundwater levels, drawdown and flows will be predicted in some localised parts of the model. However, a preliminary review of the uncertainty analysis model predictions indicated that, overall, the model predictions are realistic with a few isolated anomalies, which are not necessarily reflective of likely impacts. Therefore, the uncertainty analysis is still considered appropriate, as it gives a general indication of the potential magnitude of changes that might occur based on the assumed values and the hydrogeological features that are present across the alignment.

10.1 Changes in water table drawdown

10.1.1 Construction

Water table drawdown would occur because groundwater would flow into the tunnels and reduce groundwater pressures (and groundwater levels) in the surrounding aquifer. Figure 10-1 and Figure 10-2 show the predicted water table drawdown at the end of tunnel construction for the Base case.

The predicted drawdown is up to a maximum of around 28 metres overlying the tunnel cross passages in the Artarmon area. Predicted drawdown propagates away from the tunnels, with the drawdown extending up to around 0.5 kilometres northwards in the Willoughby/Chatswood area, and extending southwards up to around 0.4 kilometres in the Crows Nest area.

North of Middle Harbour, the drawdown would be slightly lower, with maximum predicted drawdown of 16 metres between Seaforth and Balgowlah. The drawdown is predicted to reach the harbour on both sides of Middle Harbour as well as at Berrys Bay and Balls Head Bay.

Figure 10-3 and Figure 10-4 show the predicted water table drawdown at the end of tunnel construction for Scenario A.

For Scenario A, the maximum predicted drawdown and the extent of predicted drawdown is significantly greater than the Base case to the south of Middle Harbour, with a maximum of around 41 metres immediately overlying the tunnel centreline in the Northbridge area. Predicted drawdown propagates away from the tunnels, with the drawdown extending up to around 1.8 kilometres northwards in the Willoughby/Chatswood area, around

1.8 kilometres westwards across Artarmon, and around 3.4 kilometres southwards to North Sydney. North of Middle Harbour, the predicted drawdown is greater than the Base case, with maximum predicted drawdown of 35 metres between Seaforth and Balgowlah. The extent of predicted drawdown for Scenario A north of Middle Harbour is slightly larger than for the Base case.

Figure 10-5 and Figure 10-6 show the predicted water table drawdown at the end of tunnel construction for Scenario B.

For Scenario B, the predicted drawdown is generally less than the drawdown for the Base case, with the exception of some local anomalies due to the method of selection of model parameter values. The lateral extent of predicted drawdown is generally less than the lateral extent of predicted drawdown for the Base Case. North of Middle Harbour, significantly less drawdown (a maximum predicted drawdown of 11 metres between Seaforth and Balgowlah) and significantly less lateral extent of drawdown is predicted for Scenario B compared to the Base case.

As noted earlier, the method of choosing the model parameter values for the uncertainty analysis and the fact that the model is not then calibrated can lead to some local anomalies in terms of drawdown. In addition, some model parameters, and the magnitude of variation, have a greater influence over other parameters when assessing drawdown effects in certain areas of the model e.g. for Scenario A, high hydraulic conductivity can override the drawdown effects of low storage, resulting in broader but shallower drawdown in certain parts of the model. However, the likely impacts and the appropriateness of the recommended mitigation and management measures can, be considered based on the general observations from the additional uncertainty scenarios.

It should also be noted that the modelled groundwater inflows to the tunnels were controlled by the formation permeability, which in some cases causes inflows to the tunnels to be greater than 1 L/s/km. However, a design requirement for the project is that the tunnel inflows do not exceed 1 L/s/km on average, and the tunnels would be treated during construction to ensure that this is the case. Therefore, the predicted tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling for the Base case and Scenario A.

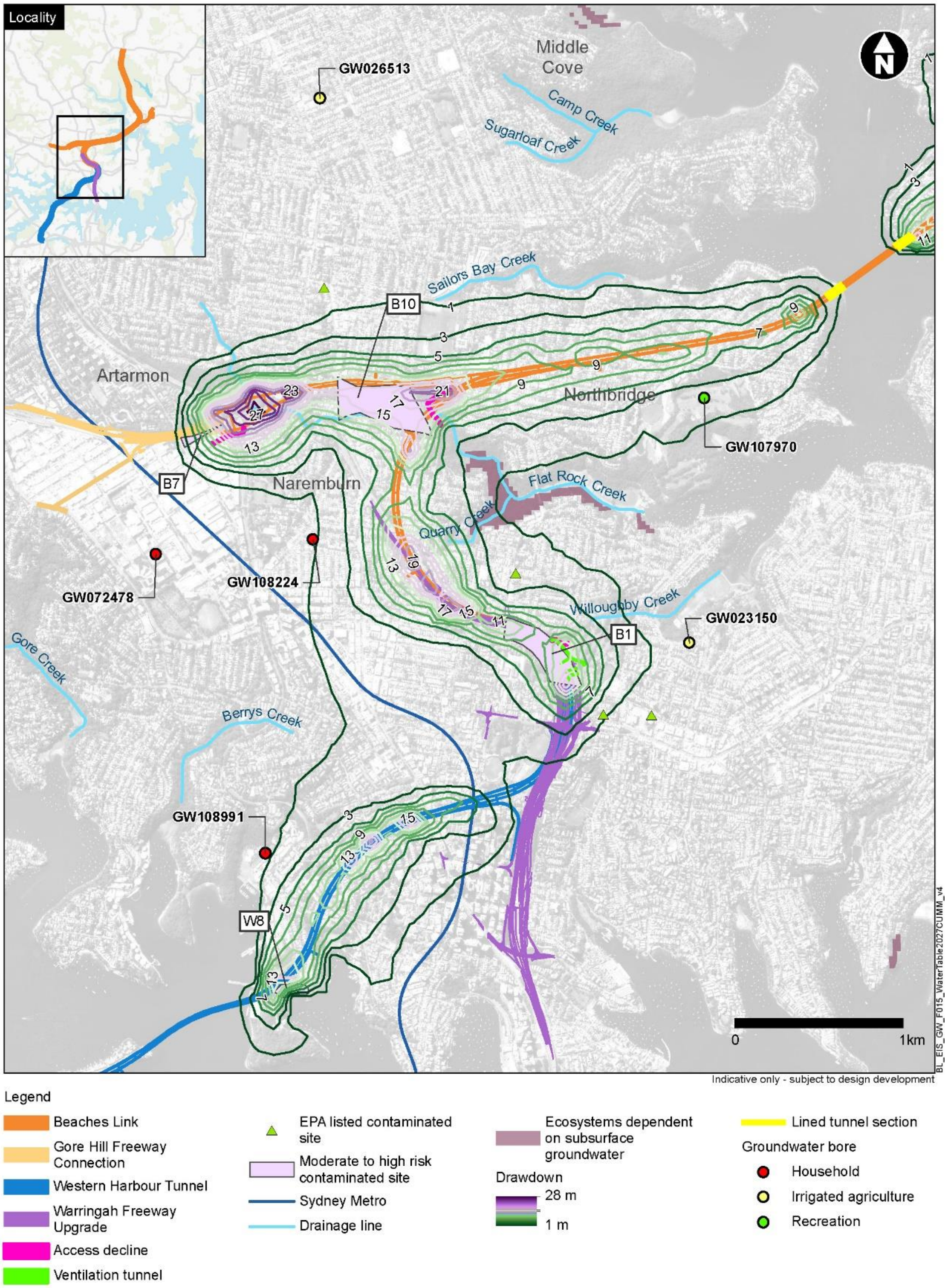


Figure 10-1: Predicted cumulative drawdown in the water table at the end of tunnel construction (south), June 2028, for the Base case

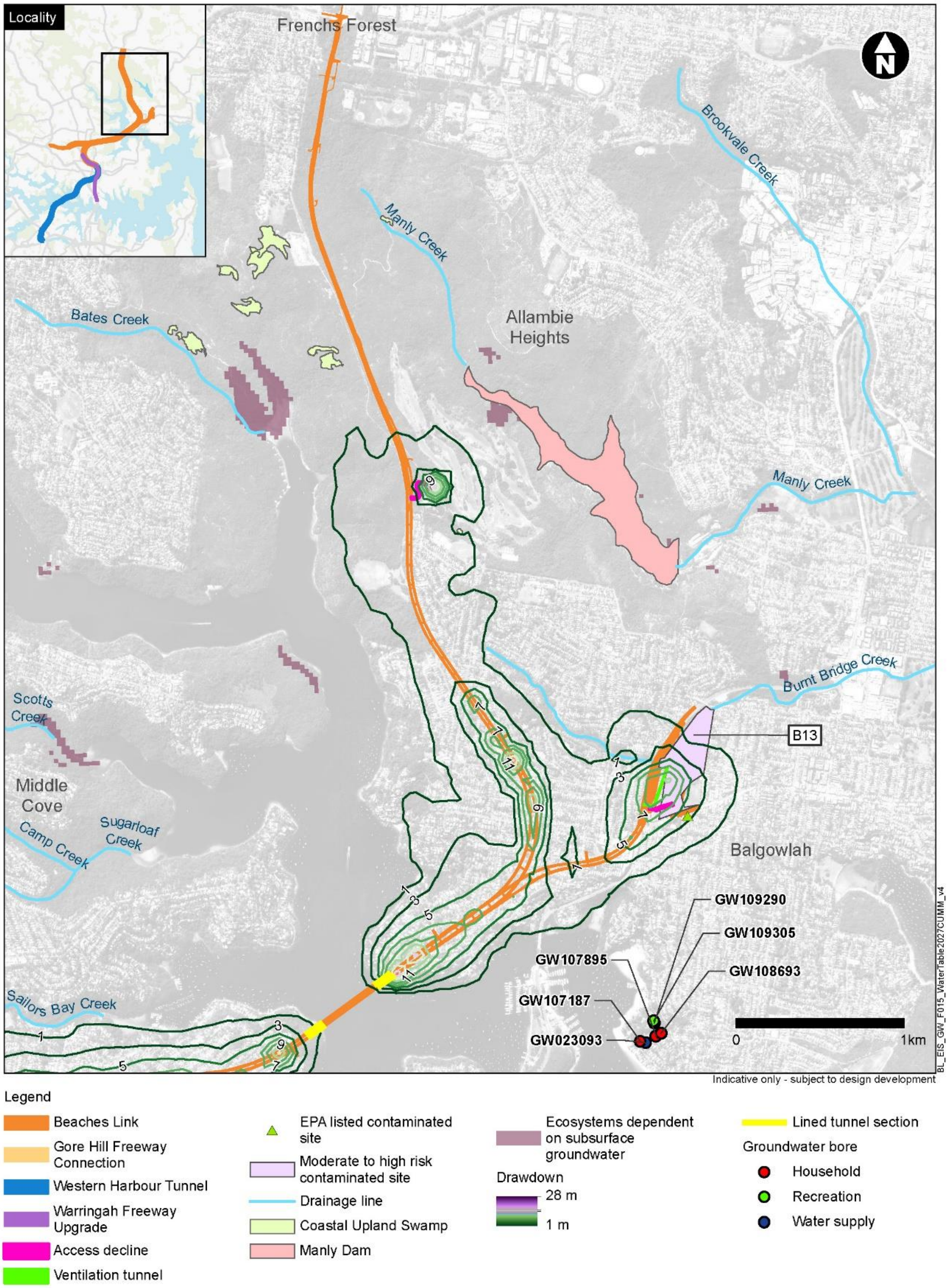


Figure 10-2: Predicted cumulative drawdown in the water table at the end of tunnel construction (north), June 2028, for the Base case

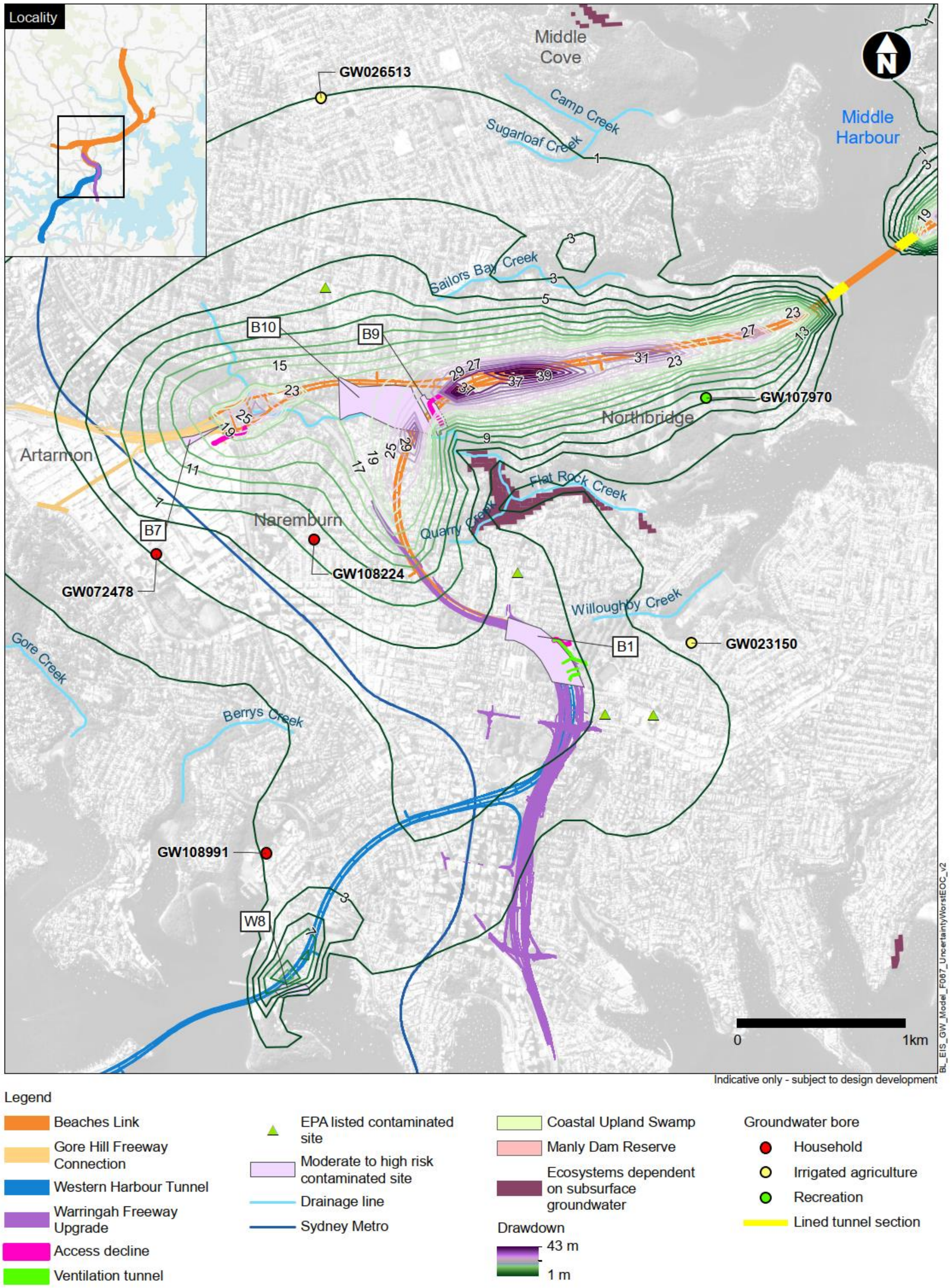


Figure 10-3: Predicted cumulative drawdown in the water table at the end of tunnel construction (south), June 2028, for Scenario A

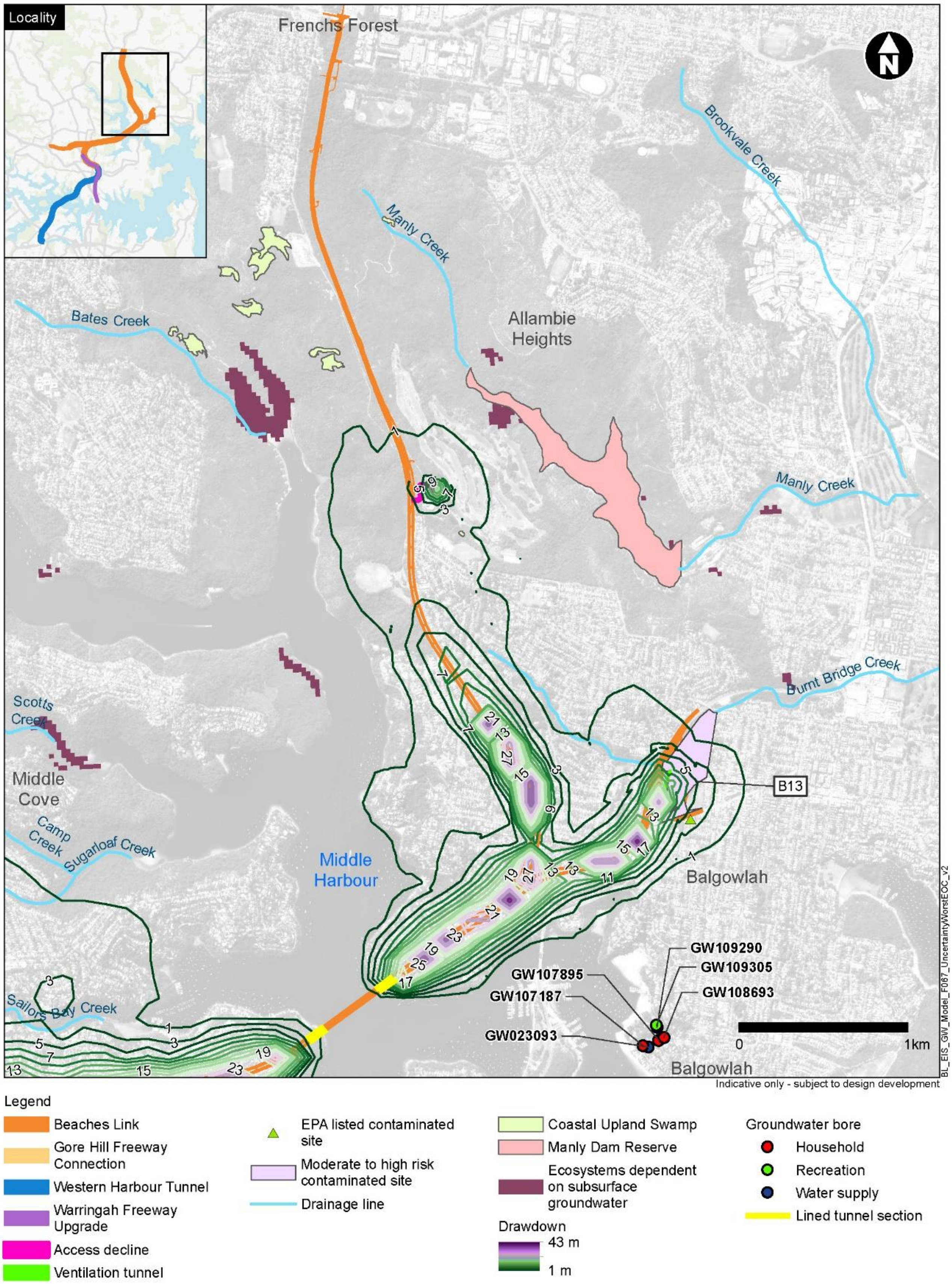


Figure 10-4: Predicted cumulative drawdown in the water table at the end of tunnel construction (north), June 2028, for Scenario A

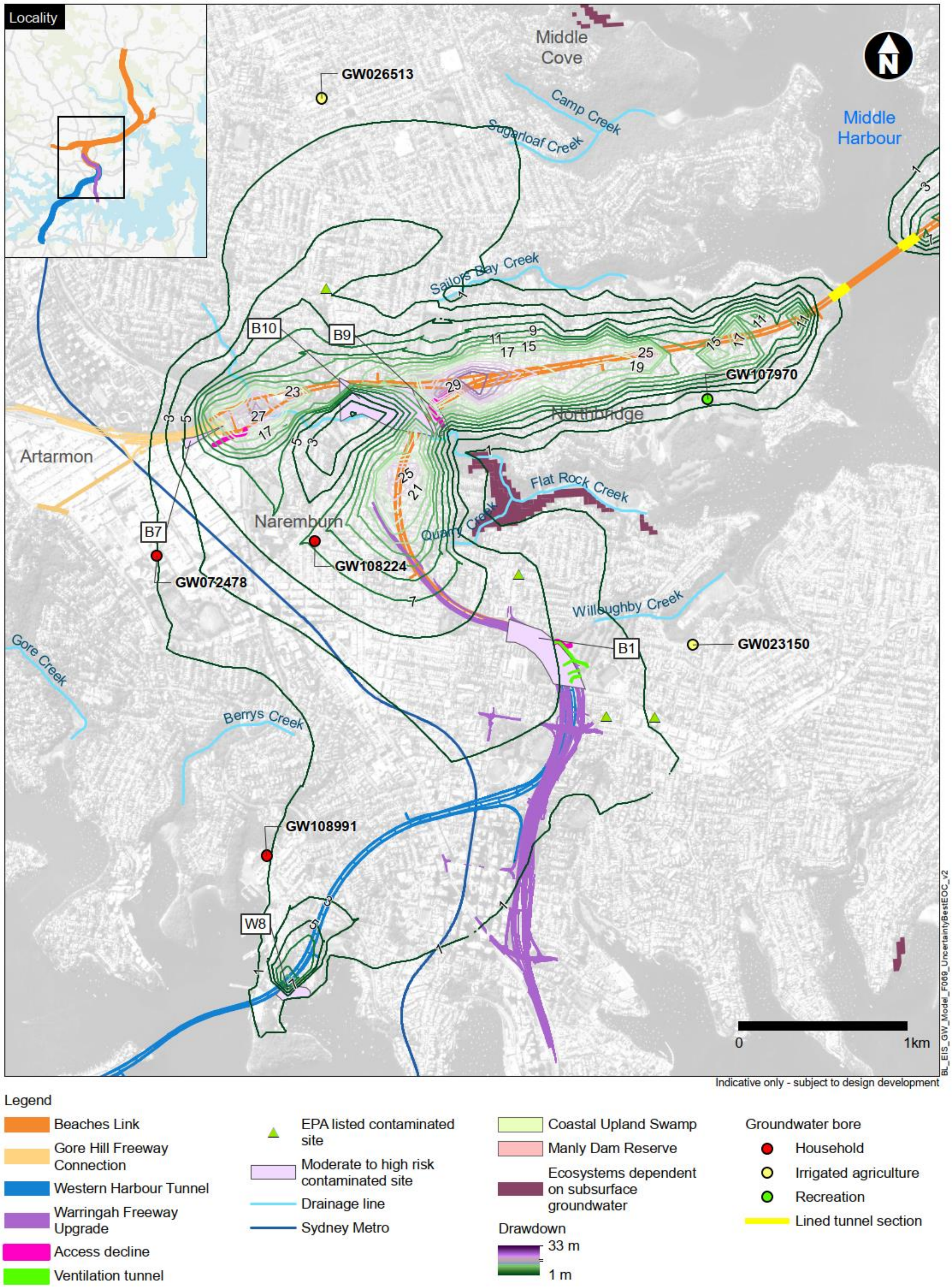


Figure 10-5: Predicted cumulative drawdown in the water table at the end of tunnel construction (south), June 2028, for Scenario B

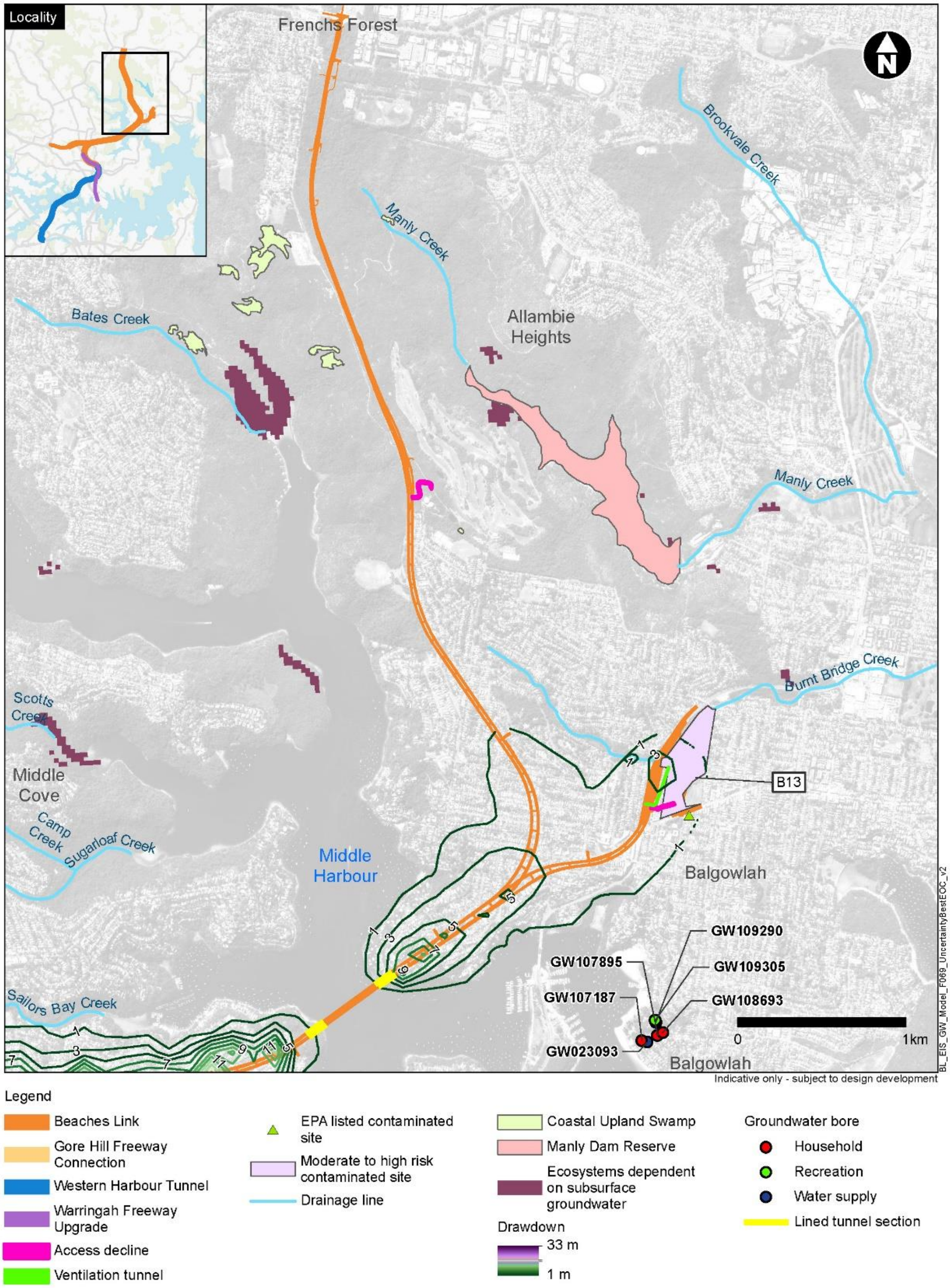


Figure 10-6: Predicted cumulative drawdown in the water table at the end of tunnel construction (north), June 2028, for Scenario B

10.1.2 Operation

Figure 10-7 and Figure 10-8 show the predicted water table drawdown after 100 years of operation for the Base case.

The predicted drawdown in the Base case is up to 39 metres in the Northbridge area, and up to 16 metres at Seaforth and Balgowlah. Predicted drawdown propagates away from the tunnels, with the drawdown extending up to around 1.7 kilometres northwards in the Willoughby/Chatswood area, extending westwards up to around 0.5 kilometres in the Lane Cove area and extending southwards up to around 1.7 kilometres in the North Sydney/Waverton area. The drawdown is predicted to reach both sides of Middle Harbour as well as Berrys Bay and Balls Head Bay.

Figure 10-9 and Figure 10-10 show the predicted water table drawdown after 100 years of operation for Scenario A.

For Scenario A, the maximum predicted drawdown is significantly greater than the Base case to the south of Middle Harbour, at around 45 metres immediately overlying the tunnel centreline in the Northbridge area. In general, however, drawdown is less than for the Base case across the entire alignment. This anomaly is due to the method of selecting model parameter values for the uncertainty analysis. For Scenario A, the predicted drawdown propagates away from the tunnels to the north and west significantly more than for the Base case (around 3.1 kilometres northwards into the Chatswood area, around two kilometres westwards into Lane Cove North). North of Middle Harbour, the predicted drawdown is greater in magnitude than for the Base case, with maximum predicted drawdown of 53 metres between Seaforth and Balgowlah. The extent of predicted drawdown for Scenario A is similar to the Base case.

Figure 10-11 and Figure 10-12 show the predicted water table drawdown after 100 years of operation for Scenario B.

For Scenario B, the magnitude predicted drawdown is less than the Base case scenario to the south of Middle Harbour, however, the drawdown distribution is different compared to the Base case, due to the localised interactions between the assumed model parameter values. The extent of predicted drawdown is generally less for Scenario B compared to the Base case. North of Middle Harbour, the predicted drawdown is significantly lesser in magnitude than the Base case, with maximum predicted drawdown of 11 metres between Seaforth and Balgowlah. The extent of predicted drawdown is also significantly less than for the base case.

It should be noted that the modelled groundwater inflows to the tunnels are controlled by the formation permeability, which in some cases causes inflows to the tunnels greater than 1 L/s/km. However, a construction requirement for the project is that the tunnel inflows do not exceed 1 L/s/km on average, and the tunnels would be treated during construction to ensure that this is the case. Therefore, the predicted tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling for the Base case and Scenario A.

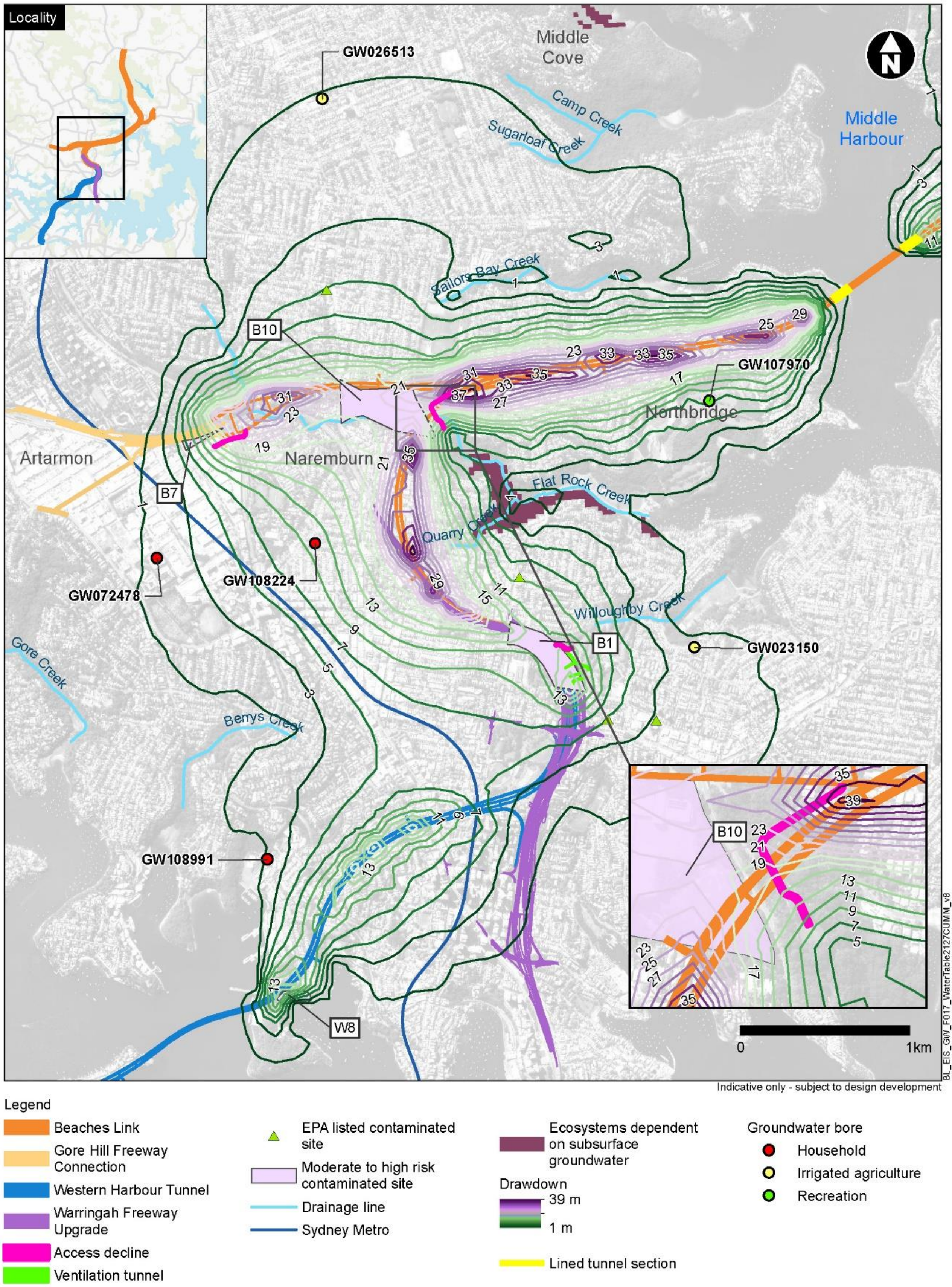


Figure 10-7: Predicted cumulative drawdown in the water table after 100 years of operation (south), 2128, for the Base case

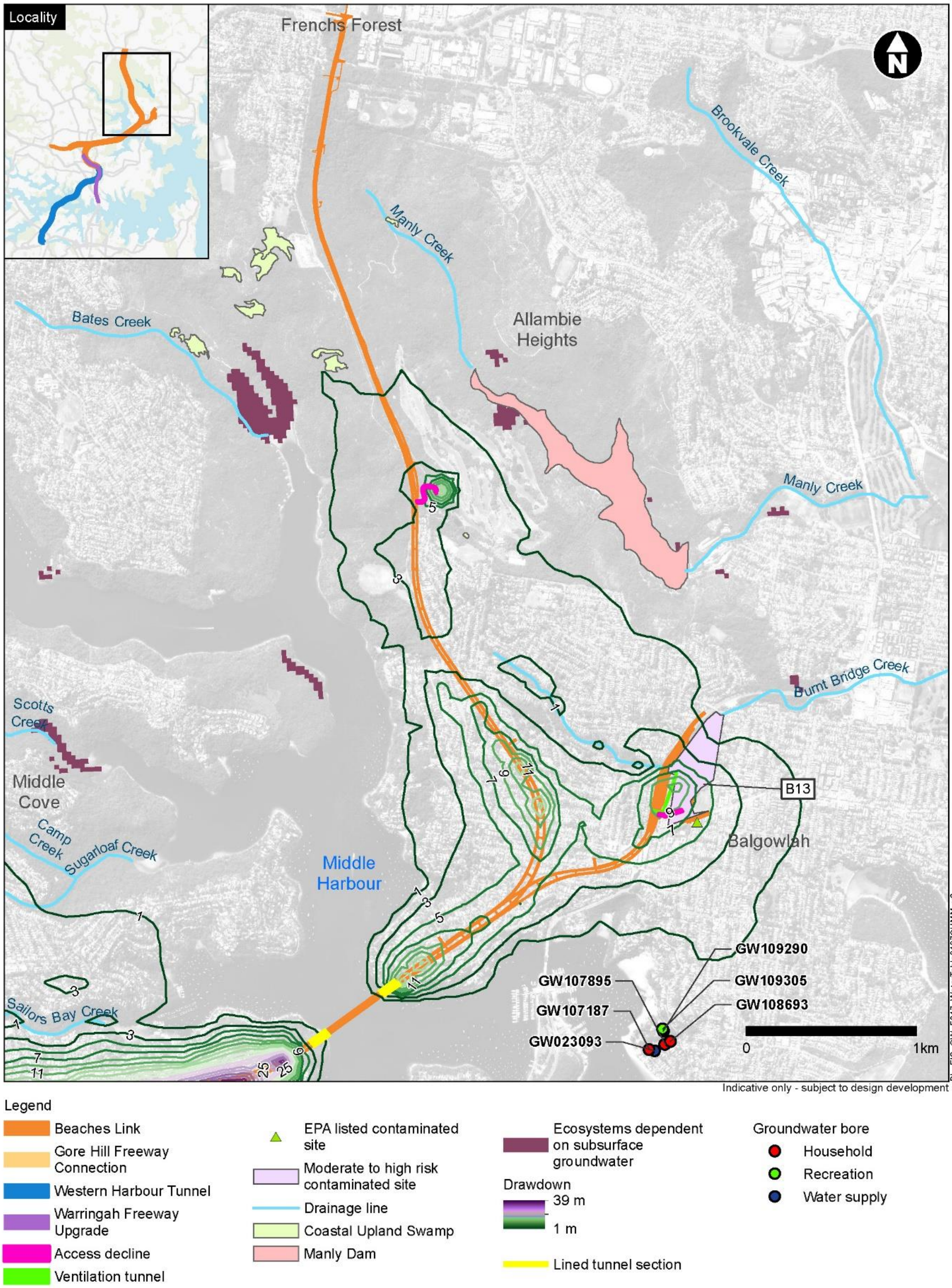


Figure 10-8: Predicted cumulative drawdown in the water table after 100 years of operation (north), 2128, for the Base case

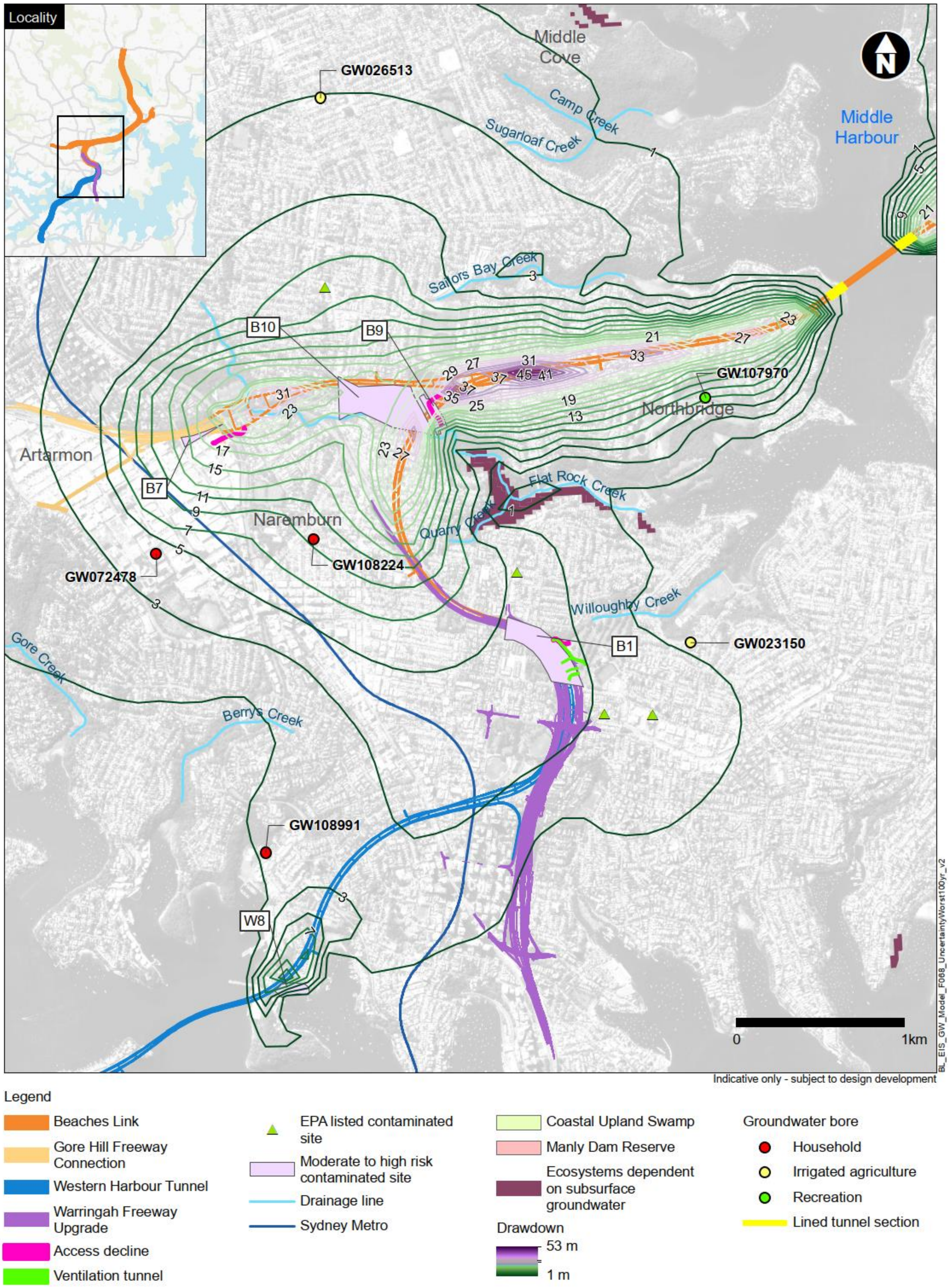


Figure 10-9: Predicted cumulative drawdown in the water table after 100 years of operation (south), 2128, for Scenario A

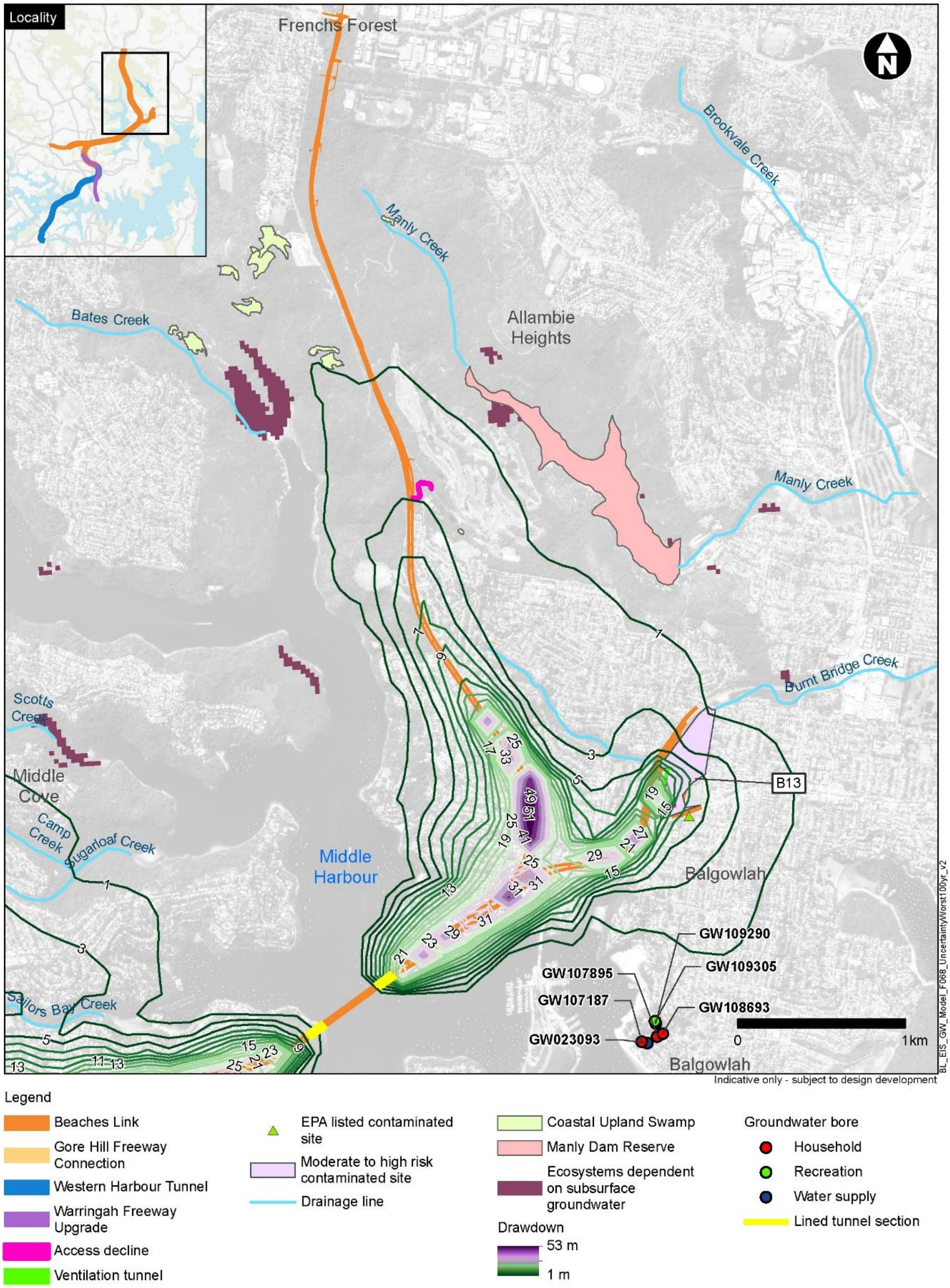


Figure 10-10: Predicted cumulative drawdown in the water table after 100 years of operation (north), 2128, for Scenario A

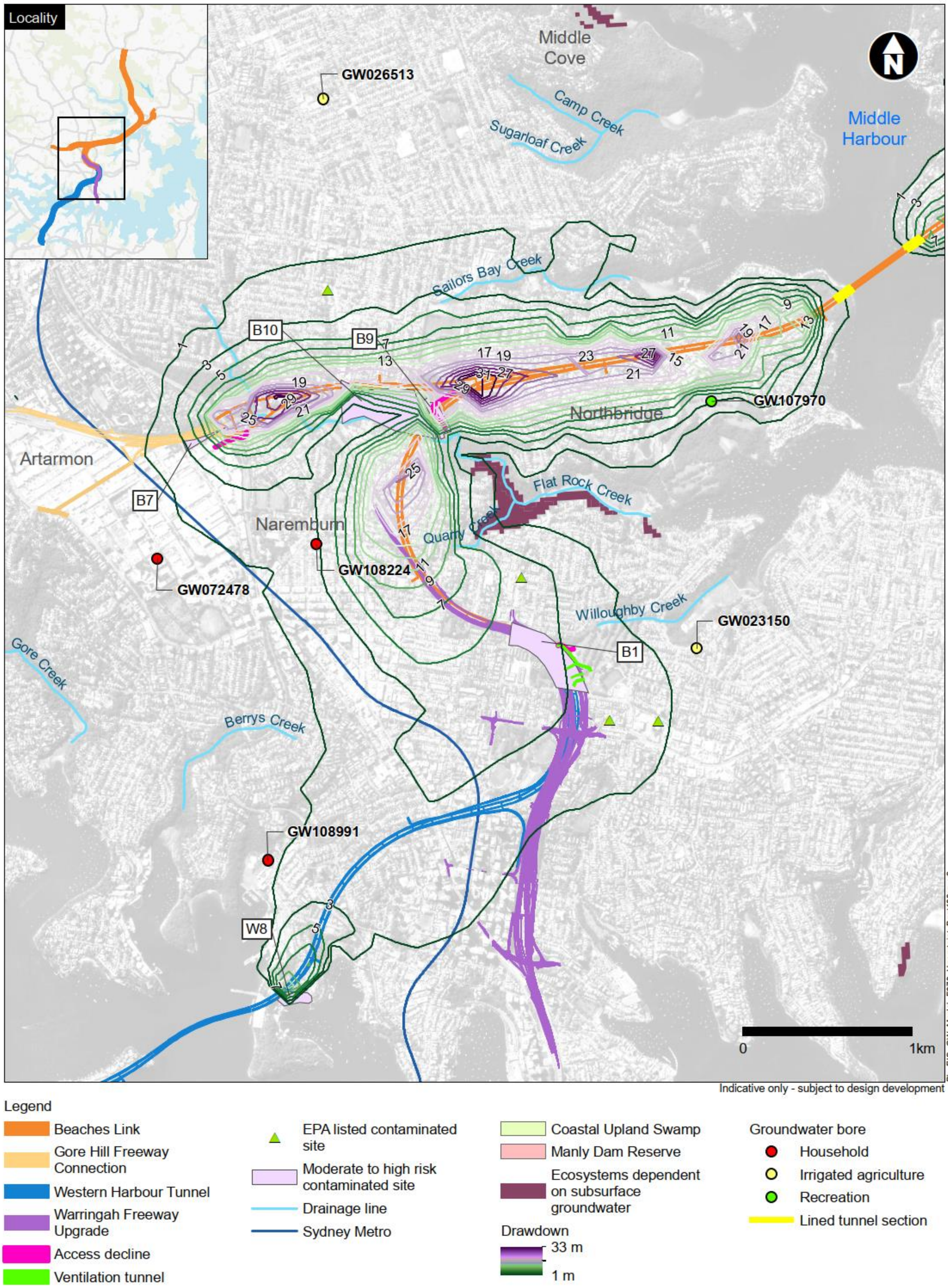


Figure 10-11: Predicted cumulative drawdown in the water table after 100 years of operation (south), 2128, for Scenario B

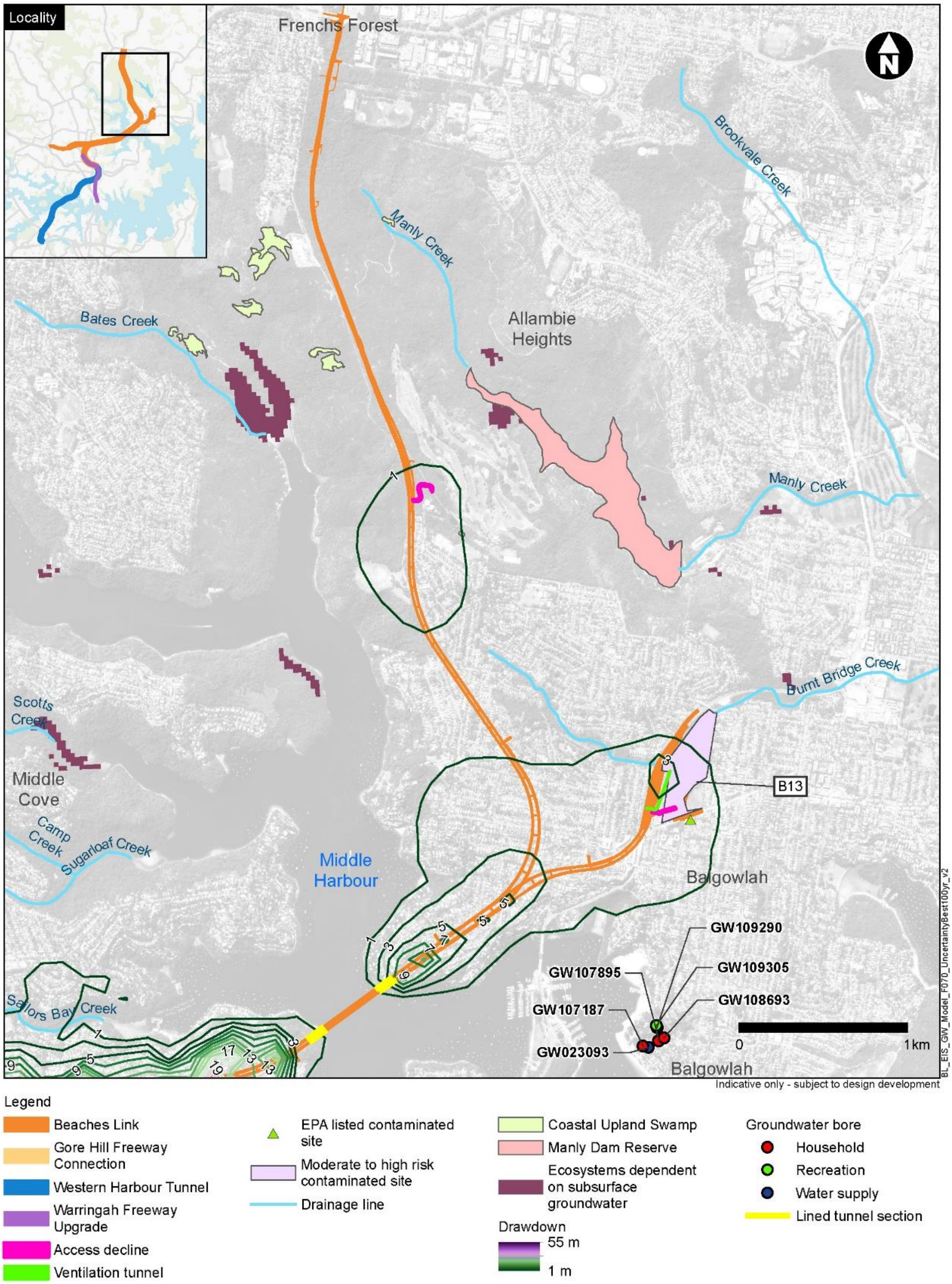


Figure 10-12: Predicted cumulative drawdown in the water table after 100 years of operation (north), 2128, for Scenario B

10.2 Environmental impacts of uncertainty scenarios

The groundwater technical working paper documents the assessment of predicted environmental impacts associated with the project based on the Base case prediction model. Model parameters assigned to the Base Case model are the same as parameters assigned to calibrated transient model (Section 4.2). This section of the report compares the environmental impacts based on the following models:

- Base Case model, and
- Uncertainty analysis models:
  - Scenario A
  - Scenario B

While it is noted that applying combinations of extreme parameter values to the uncertainty analysis model may result in unrealistic drawdown predictions in isolated parts of the model, the impact assessment of uncertainty analysis is still considered appropriate, as it gives a general indication of the potential magnitude of changes that might occur based on the assumed values and the hydrogeological features that are present across the alignment. The impacts associated with the uncertainty groundwater model predictions have been reviewed in the sections below and, except in particular locations, are considered consistent with the impacts assessed in the EIS. Generally therefore, the recommended mitigation and management measures in the EIS would also still be considered appropriate. Further groundwater modelling and uncertainty analysis would be undertaken as part of detailed design.

10.2.1 Construction

- **Groundwater (bore) users**: For the Base case scenario, three bores (GW107970, GW108224, GW108991) are predicted to experience more than one metre of drawdown during construction. However, the groundwater level drawdown predicted at each of these bores equates to less than eight per cent of available drawdown in each bore. Therefore, the project is not anticipated to impact the groundwater supply capacity at these bores.
- Under Scenario A and B, drawdown at identified groundwater supply bores is not expected to be significantly different to the drawdown predicted for Base case scenario conditions, and construction of the project is therefore anticipated to cause negligible impact to water availability at groundwater supply bores. The potential changes in the extent of predicted drawdown associated with Scenario A and B are unlikely to affect any additional bores
- **Areas of environmental interest for contamination**: For the Base case, significant drawdown was predicted at the unsealed areas next to Warringah Freeway (eastern side by Cammeray Golf Course) at Cammeray (AEI B1); Punch Street, Artarmon (AEI B7); Flat Rock Reserve at Northbridge (AEI B9); the Willoughby Leisure Centre and Bicentennial Reserve (AEI B10); and Balgowlah Golf Course at Balgowlah (AEI B13); and Waverton Park (AEI W8). If contaminants are mobilised from these sites, they are expected to travel towards the tunnels during construction. All groundwater inflows would be collected and treated at the construction wastewater treatment plant.
- Scenario A and B predict lesser drawdown than the Base case at these sites, with the exception of the predicted Scenario A drawdown at Flat Rock Gully Reserve at Northbridge (AEI B9), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10) and Balgowlah Golf Course at Balgowlah (AEI B13), and Scenario B at Flat Rock Gully Reserve at Northbridge (AEI B9). Predicted potential impacts associated with areas of environmental interest for contamination under Base case and Scenario A scenario conditions could exceed those reported in Appendix N of the EIS for Flat Rock Reserve at Northbridge (AEI B9), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10), and Balgowlah Golf Course at Balgowlah (AEI B13). However, if contaminants were mobilised from these sites, they would also be expected to travel towards the tunnels during construction. All groundwater inflows would be collected and treated at the construction wastewater treatment plant.

- The potential for lateral movement of any mobilised contaminants in groundwater near the surface would remain limited, as predicted for the Base case. Water quality at groundwater supply bores, and groundwater dependent ecosystems in the vicinity of these AEI's, are not expected to be impacted by the potential migration of contaminants at these AEI under any of the modelled scenarios.
- **Groundwater dependent ecosystems**: For the Base case, drawdown is predicted to be up to five metres at the Vegetation at Flat Rock Creek and Quarry Creek. The potential significance of these impacts is discussed in Appendix S (Technical working paper: Biodiversity development assessment report) of the EIS. For Scenario A, drawdown at the vegetation at Flat Rock Creek and Quarry Creek is predicted to be greater than for the Base case scenario. It is therefore possible that, under the hydrogeological conditions adopted for Scenario A, these groundwater dependent ecosystems could be impacted during construction to a greater extent than that discussed in the EIS. Under the hydrogeological conditions adopted for Scenario B, impacts to groundwater dependent ecosystems are only predicted for the vegetation at Flat Rock Creek and Quarry Creek.
- **Surface water systems**: A significant reduction (over 20%) in baseflow to Flat Rock Creek is predicted for the Base case, Scenario A and Scenario B. Based on this, it is likely that the baseflow to Flat Rock Creek would be reduced during construction. The reduction in baseflow to Flat Rock Creek has the potential to impact the groundwater dependent ecosystem at those locations (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest) and ecosystems reliant on surface water.

  However, it should be noted that the assessment of baseflow reduction is conservative and is likely to overestimate actual baseflow reduction for the following reasons:

  - The modelled groundwater inflows to the tunnels were controlled by the formation permeability, which in some cases causes inflows to the tunnels greater than 1 L/s/km. However, a construction requirement for the project is that the tunnel inflows do not exceed an average of 1 L/s/km, and the tunnels would be treated during construction to ensure that this is the case. Therefore, the predicted tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling. Potential baseflow reduction to watercourses and waterbodies would therefore be less than predicted and discussed here
  - It is assumed that there is continuous saturation between the tunnel horizon and the shallow water table at the location of watercourses (i.e. there is a single connected groundwater system beneath the creek and the proposed underlying tunnel. In reality, the system will be stratified, possibly with disconnected aquifer horizons. The predicted maximum drawdowns beneath the creek are therefore unlikely to be realised and the predicted reduction in baseflows are therefore conservative
  - For watercourses and waterbodies other than Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, the whole length or area at the base of the creek or dam is considered to be unlined. At the time of modelling there was no information on the nature of creek bed conditions for Willoughby Creek and Sailors Bay Creek. Should any of these watercourses be lined, the reduction baseflow would be less than that predicted
  - Groundwater inflows to the tunnels would be collected, treated and discharged to local waterways (Willoughby Creek, Flat Rock Creek and Burnt Bridge Creek). This is expected to offset baseflow reductions to these watercourses, and additional creek flows could partially feed the surrounding groundwater system.
- **Potential for ground settlement**: For the Base case, Arup and WSP (2020) identified 61 buildings across the alignment where the predicted potential degree of severity for damage was 'very slight'. This equates to potential aesthetic damage such as fine cracks to decorations, internal wall finishes and external brickwork or masonry. No buildings were assessed to be in the 'slight', 'moderate', 'severe' or 'very severe' categories, which equate to greater potential damage. Three services (two sewers and one transmission cable) and numerous non-Aboriginal and Aboriginal heritage items were identified where the predicted potential degree of severity for damage was slight.

- Settlement assessment has not been undertaken for Scenario A and B. However, Scenario A predicts a greater magnitude and extent of drawdown than the Base case. Therefore, under hydrogeological conditions consistent with Scenario A, greater potential severity of damage to buildings, services and heritage items in the suburbs of Naremburn and Northbridge, and potential for impacts in Lane Cove and Willoughby is possible. An updated settlement assessment should be undertaken during detailed design, based on a updated modelling that considers the proposed tunnel linings, to confirm predicted settlement and the proposed lining design is appropriate to minimise potential impacts.

10.2.2 Operation

- **Groundwater (bore) users**: For the Base case scenario, six bores (GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991) are predicted to experience more than one metre of drawdown during operation. With the exception of bore GW023150, the groundwater level drawdown predicted at each of these bores equates to less than 15 per cent of available drawdown in each bore, and the project is therefore anticipated to cause negligible impact to groundwater supply at these bores.
- Bore GW023150 is recorded in the Department of Planning, Industry and Environment (Water) database as being less than two metres deep. Modelling predicts that the cumulative water table drawdown at this bore would be up to three metres in 2128. If this bore were to rely on shallow groundwater, water availability at this bore could be impacted.
- Under Scenario B conditions, drawdown at identified groundwater supply bores is not expected to be significantly different to the drawdown predicted for Base case scenario conditions. Under Scenario A conditions, bores GW026513, GW029731, GW072478 and GW107757 are predicted to experience greater drawdown than the Base case. However, the greater predicted drawdown under Scenario A equates to less than an additional 3% reduction in the available groundwater drawdown (head) within these bores.
- Therefore, the predicted impacts under Scenarios A and B are not expected to be significantly different to those predicted for the Base case during operation. Operation of the project is therefore anticipated to cause negligible impact to water availability at groundwater supply bores, with the possible exception of bore GW023150, at which water availability could be impacted due to the project.
- **Areas of environmental interest for contamination**: For the Base case, significant drawdown was predicted at the unsealed areas next to Warringah Freeway (eastern side by Cammeray Golf Course) at Cammeray (AEI B1); Punch Street, Artarmon (AEI B7); Flat Rock Gully Reserve at Northbridge (AEI B9); the Willoughby Leisure Centre and Bicentennial Reserve (AEI B10); and Balgowlah Golf Course at Balgowlah (AEI B13); and Waverton Park (AEI W8). If contaminants are mobilised from these sites, they are expected to travel towards the tunnels during construction. All groundwater inflows would be collected and treated at the construction wastewater treatment plant.
- Scenario A and B predict lesser drawdown at these sites, with the exception of the predicted Scenario A drawdown at Flat Rock Gully Reserve at Northbridge (AEI B9), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10) and Balgowlah Golf Course at Balgowlah (AEI B13), and Scenario B at the unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray (AEI B1) and Punch Street at Artarmon (AEI B7).
- Predicted potential impacts associated with areas of environmental interest for contamination under Scenario A and B conditions could therefore exceed those reported in Appendix N of the EIS for the unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray (AEI B1), Punch Street at Artarmon (AEI B7), Flat Rock Gully Reserve at Northbridge (AEI B9), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10) and Balgowlah Golf Course at Balgowlah (AEI B13). However, if contaminants were mobilised from these sites, they would also be expected to travel towards the tunnels during construction. All groundwater inflows would be collected and treated at the construction wastewater treatment plant.
- The potential for lateral movement of any mobilised contaminants in groundwater near the surface would remain limited, as predicted for the Base case. Water quality at groundwater supply bores, and groundwater

dependent ecosystems in the vicinity of these AEI's, are not expected to be impacted by the potential migration of contaminants at these AEI's under any of the modelled scenarios

- **Groundwater dependent ecosystems**: For the Base case, drawdown is predicted to be less than one metre at the Coastal Upland Swamp, the vegetation at Quarry Creek, and the groundwater dependent ecosystem at Manly Dam Reserve. Cumulative water table drawdown up to 12 metres was predicted at the groundwater dependent ecosystems at Flat Rock Creek and Quarry Creek. The potential significance of these impacts is discussed in Appendix S (Technical working paper: Biodiversity development assessment report) of the EIS. The other groundwater dependent ecosystems in the project area are outside the predicted drawdown extents.
- For both Scenario A and B, drawdown at identified groundwater dependent ecosystems is predicted to be less than that predicted under the Base case. Based on this, the predicted drawdown under the Base case can be considered a conservative assessment
- **Surface water systems**: A significant reduction (over 20%) in baseflow to Flat Rock Creek is predicted for the Base case and Scenario A. Based on this, it is possible that the baseflow to Flat Rock Creek would be reduced during operation. The reduction in baseflow to Flat Rock Creek has the potential to impact the groundwater dependent ecosystem at those locations (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest) and ecosystems reliant on surface water.

  However, it should be noted that the assessment of baseflow reduction is conservative and is likely to overestimate actual baseflow reduction for the following reasons:

  - The modelled groundwater inflows to the tunnels were controlled by the formation permeability, which in some cases causes inflows to the tunnels greater than 1 L/s/km. However, a construction requirement for the project is that the tunnel inflows do not exceed an average of 1 L/s/km, and the tunnels would be treated during construction to ensure that this is the case. Therefore, the predicted tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling. Potential baseflow reduction to watercourses and waterbodies would therefore be less than predicted and discussed here
  - It is assumed that there is continuous saturation between the tunnel horizon and the shallow water table at the location of watercourses (i.e. there is a single connected groundwater system beneath the creek and the proposed underlying tunnel. In reality, the system will be stratified, possibly with disconnected aquifer horizons. The predicted maximum drawdowns beneath the creek are therefore unlikely to be realised and the predicted reduction in baseflows are therefore conservative
  - For watercourses and waterbodies other than Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, the whole length or area at the base of the creek or dam is considered to be unlined. At the time of modelling there was no information on the nature of creek bed conditions for Willoughby Creek and Sailors Bay Creek. Should any of these watercourses be lined, the reduction baseflow would be less than that predicted
  - Groundwater inflows to the tunnels would be collected, treated and discharged to local waterways (Willoughby Creek, Flat Rock Creek and Burnt Bridge Creek). This is expected to offset baseflow reduction to these waters, as the additional creek flows could partially feed the surrounding groundwater system.
- **Potential for ground settlement**: Areas of groundwater level drawdown assessed to induce ground settlement during operation are generally consistent with those predicted during construction. Ground settlement during operation is not expected to significantly exceed that experienced during the construction phase because the majority of settlement (excavation and groundwater drawdown induced) would be realised during the construction phase.

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 Beaches Link project.

Groundwater sampling indicates that saline water currently occurs along some areas of the proposed tunnel close to the harbours. The proposed tunnel design will 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 within the project area. Figure 11-1 shows the location of the cross-section line, which was selected to pass through the deepest part of the proposed project mainline tunnel. 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.

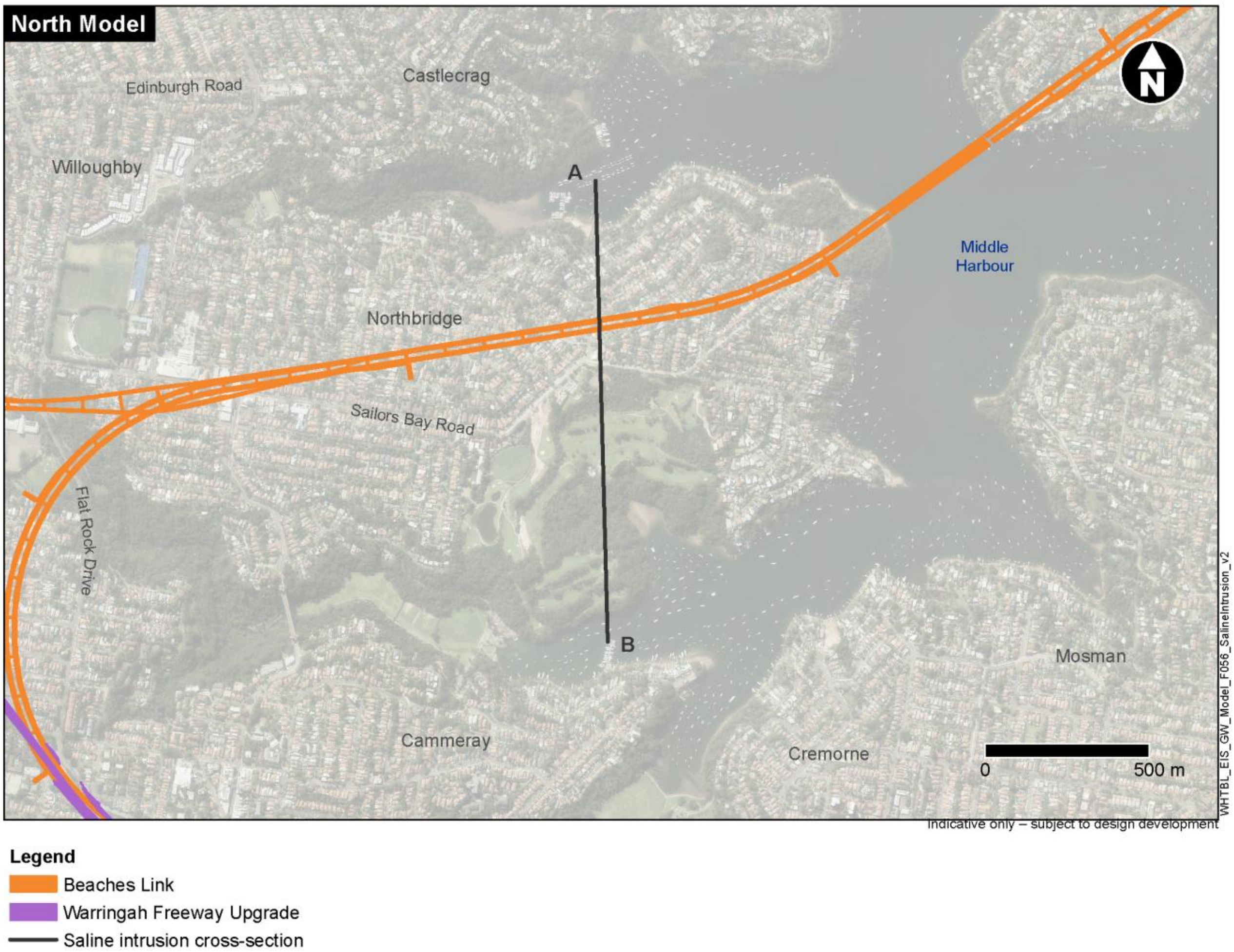


Figure 11-1: Location of model cross-section

11.2 Methodology – density dependent flow modelling

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.

The density of saline water is higher than the density of freshwater and therefore, the density contrast will 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 must 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 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.

11.2.1 Model structure and input parameters

The SEEP/W two-dimensional model has seven hydrogeological layers, corresponding to the three-dimensional MODFLOW-USG model (Figure 11-2). Layer 1 represents the unweathered Hawkesbury Sandstone and layer 2 to layer 7 represent the unweathered Hawkesbury Sandstone. The thickness of the layers in the SEEP/W two-dimensional model are slightly different from the layers in the three-dimensional MODFLOW-USG model because the SEEP/W two-dimensional model was developed before the project-wide conceptual hydrogeological model was finalised. The saturated hydraulic conductivity values assigned to the layers in the SEEP/W model were the same as the hydraulic conductivity values assigned to the three-dimensional MODFLOW-USG model (Table 4-1). 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.

11.2.1.1 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 Attachment 7. 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.

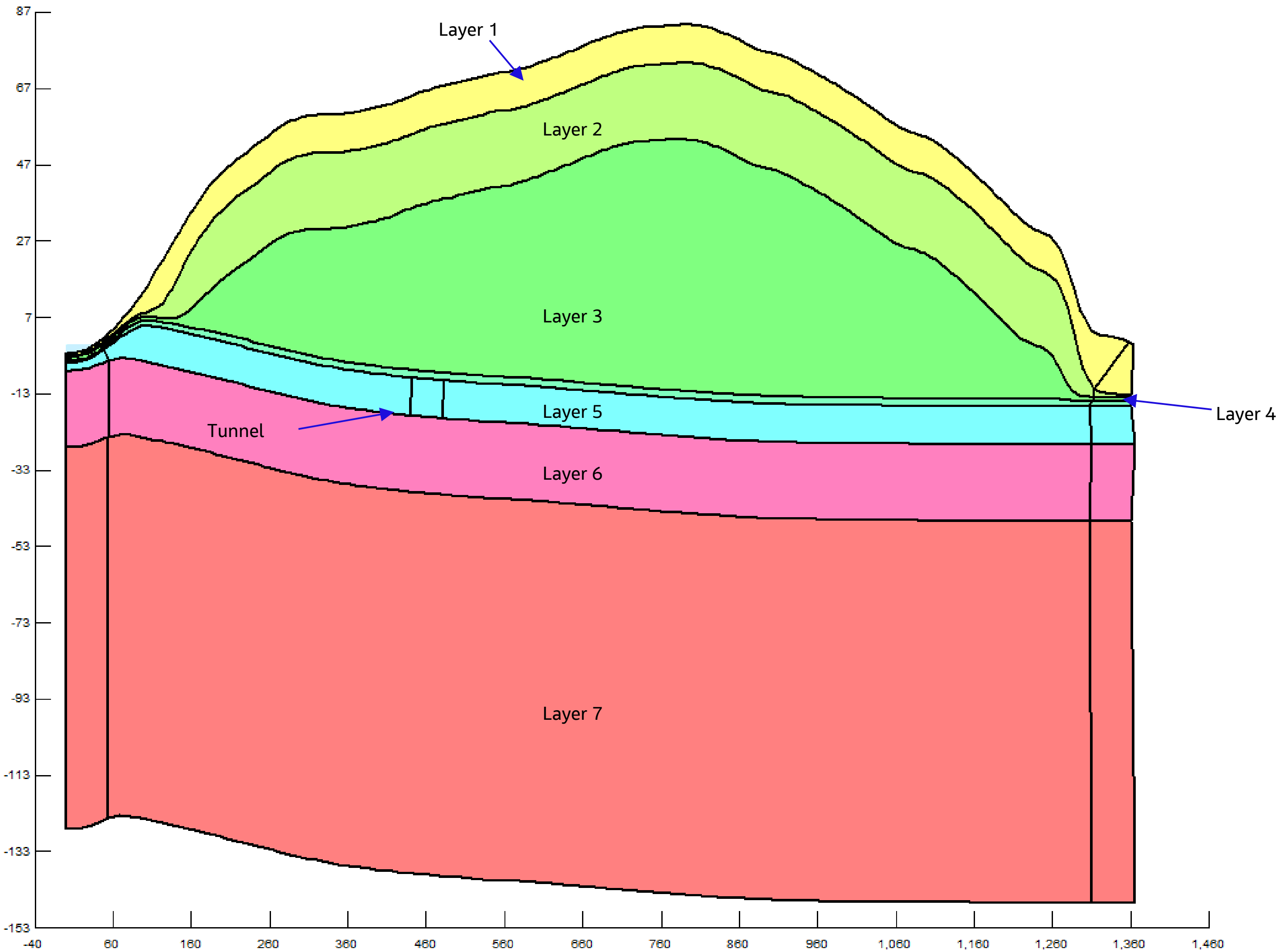


Figure 11-2: Hydrogeological layers in north cross section model.

11.2.1.2 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 10.1.

$$mv = \frac{Ss}{\rho g} \qquad \text{[Equation 10.1]}$$

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 compressibilty 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 x 10^{-5}	1,000	9.8	1.02 x 10^{-9}	1.02 x 10^{-6}
2- 7	1.9 x 10^{-6}	1,000	9.8	1.94 x 10^{-10}	1.94 x 10^{-7}

Note 1: Measured at 4ºC

11.2.1.3 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 Attachment 8. 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 Attachment 8. 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.

11.2.1.4 Head and flux boundary conditions (SEEP/W)

Head and flux boundary conditions assigned to the SEEP/W model are shown in Figure 11-3 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 North Model was approximately 2 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 -2 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.

11.2.1.5 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 11.2.2).

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 10.2 for estimating the longitudinal dispersivity:

$\alpha = c(L)^m$ [Equation 10.2]

Where,

α = longitudinal dispersivity (m).

c = parameter characteristic for the longitudinal dispersivity for a geological medium (m).

L= flow distance (m).

m = scaling exponenent.

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 North 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.

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 10.2 and the parameter values provided above.

The transverse dispersivity is commonly set to be equal to 30 per cent 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).

11.2.2 Results

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. Figure 11-6 shows the location of the sharp initial freshwater-saline water interfaces that have been simulated in the model.

Figure 11-7 shows the total head distribution and water table elevation along the cross section at the end of the Beaches Link 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 will be negligible over the construction period of the Beaches Link project.

Figure 11-9 and Figure 11-10 show the heads and relative seawater concentrations, respectively, after 100 years of Beaches Link project operation. Figure 11-10 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
- 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. At locations other than along the modelled cross-section, there may be locations where migration of saline waters into freshwater aquifers is more significant than predicted by the modelling, or where groundwater is already slightly saline and becomes more saline due to the project. This would apply to both construction and operation predictions.

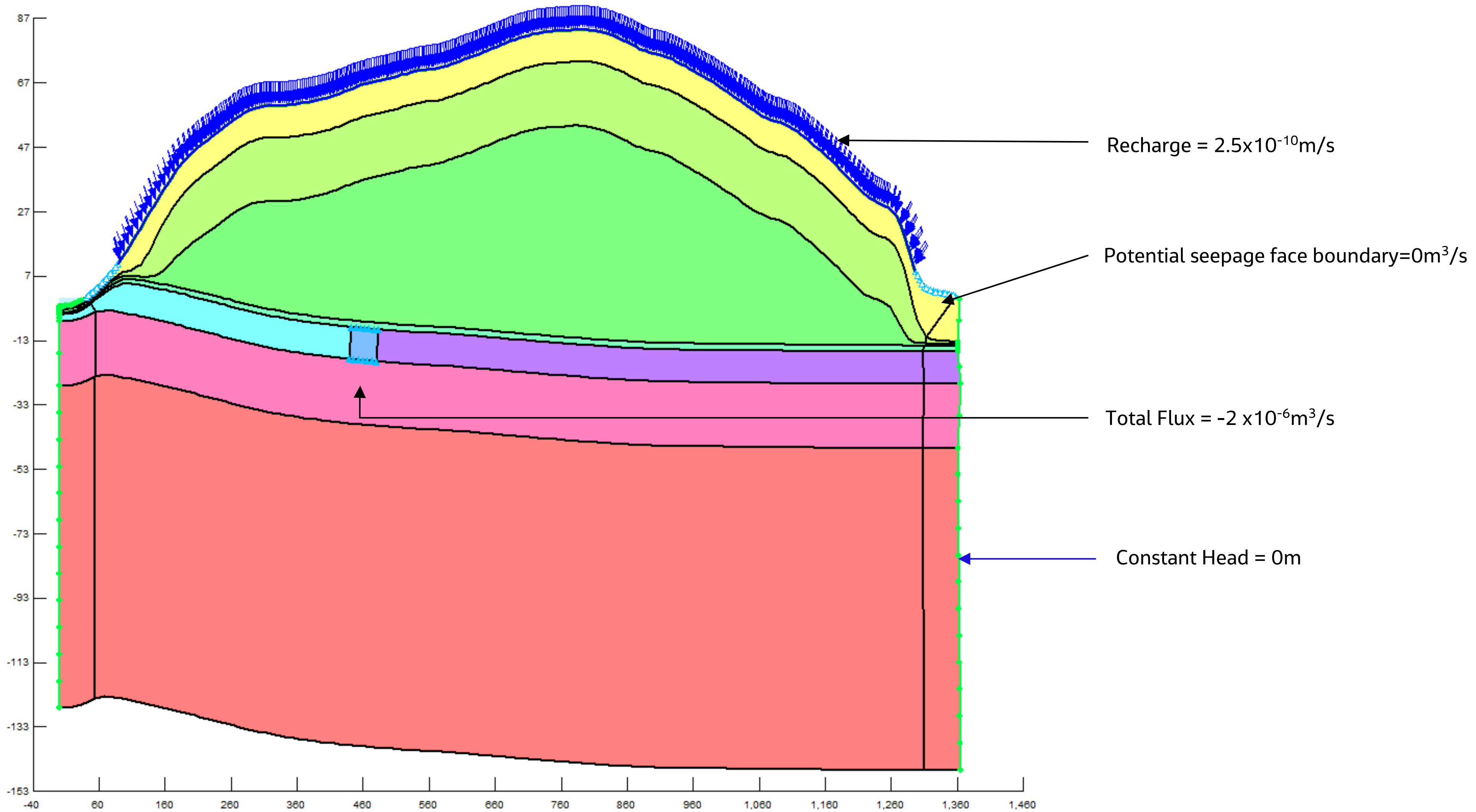


Figure 11-3: Head and Flux Boundary Conditions – North SEEP/W Model.

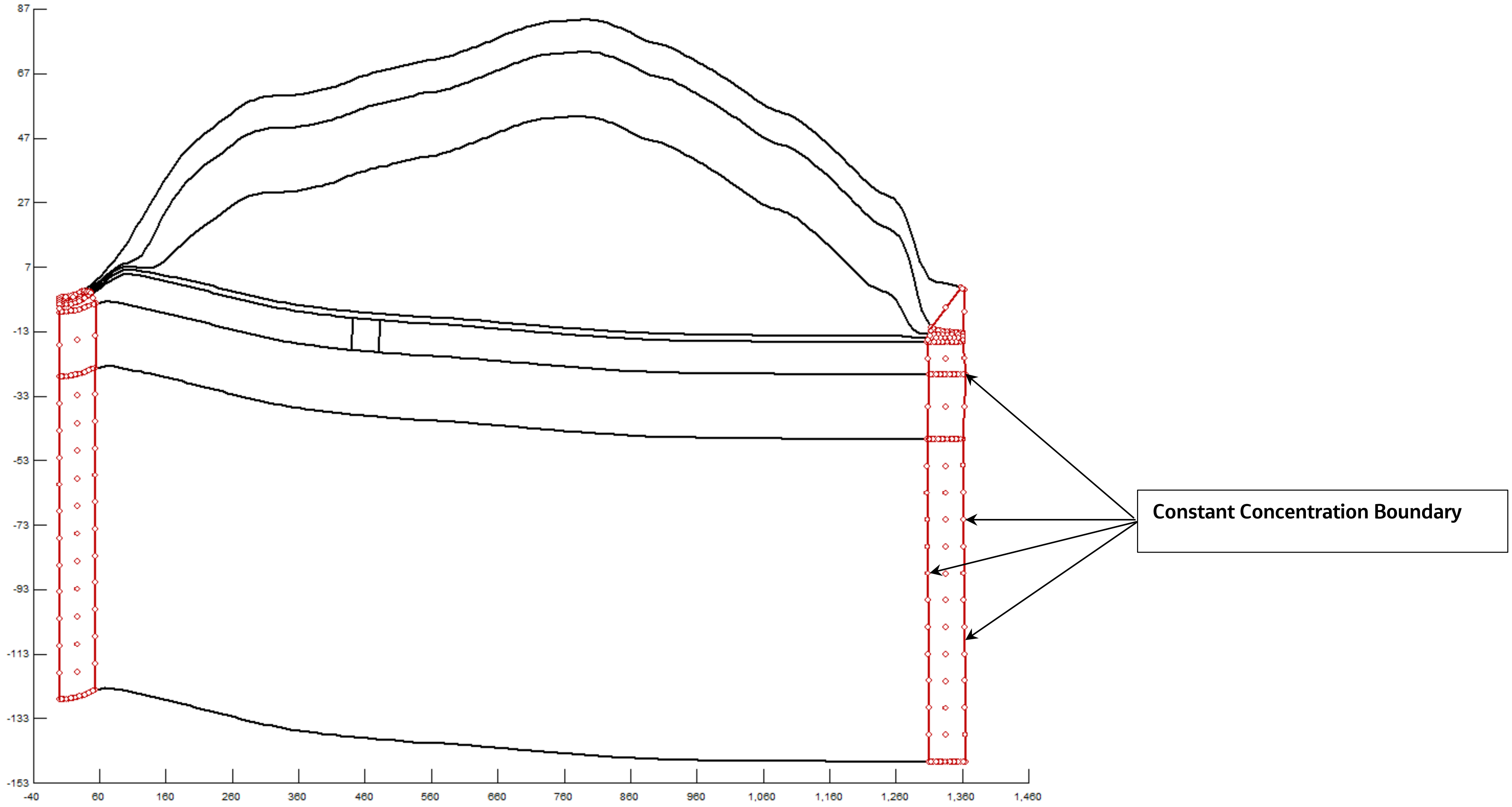


Figure 11-4: Constant unit relative seawater concentration boundary conditions – North CTRAN/W Model.

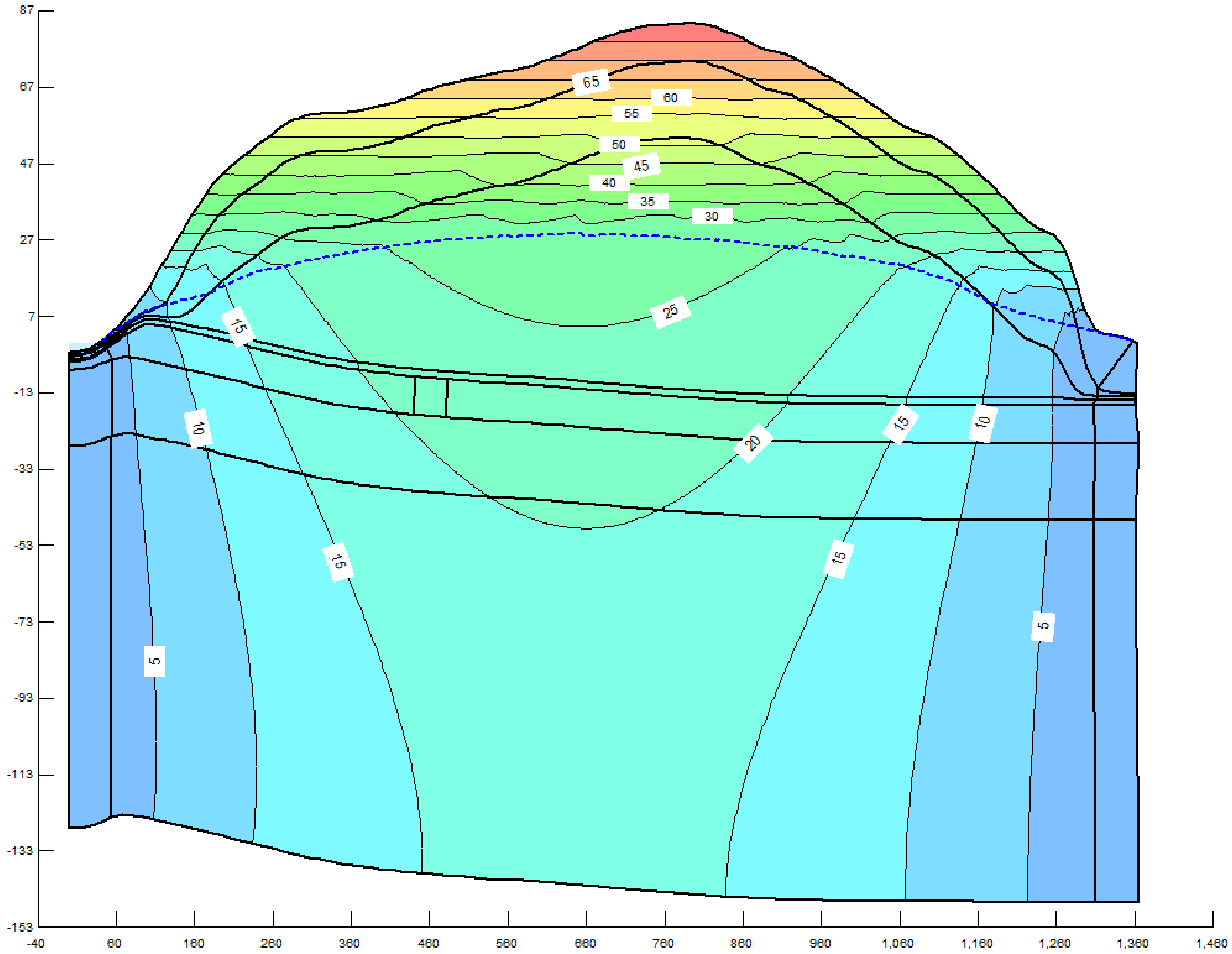


Figure 11-5: Predicted pre-construction heads - North Model

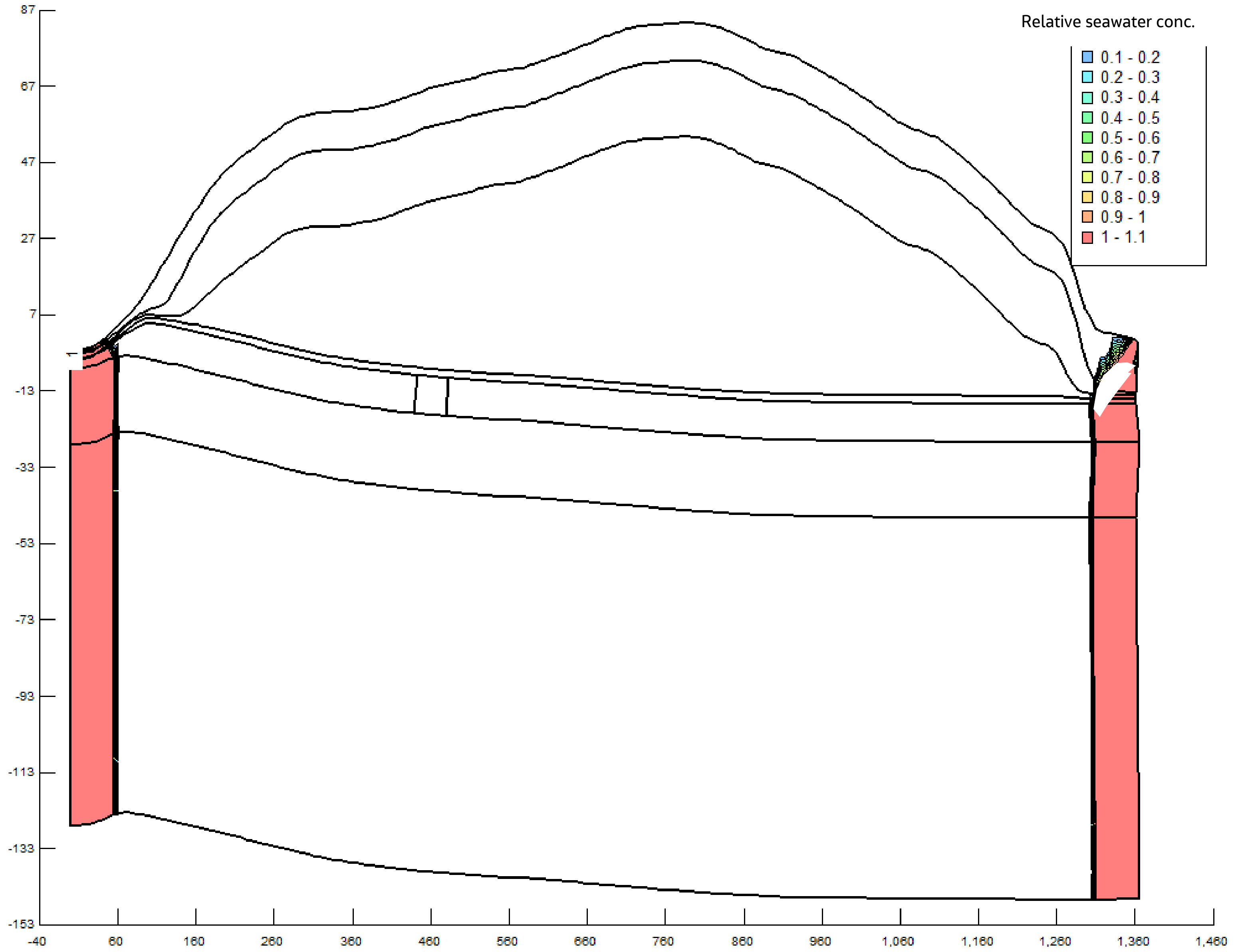


Figure 11-6: Predicted pre-construction relative seawater concentrations – North Model

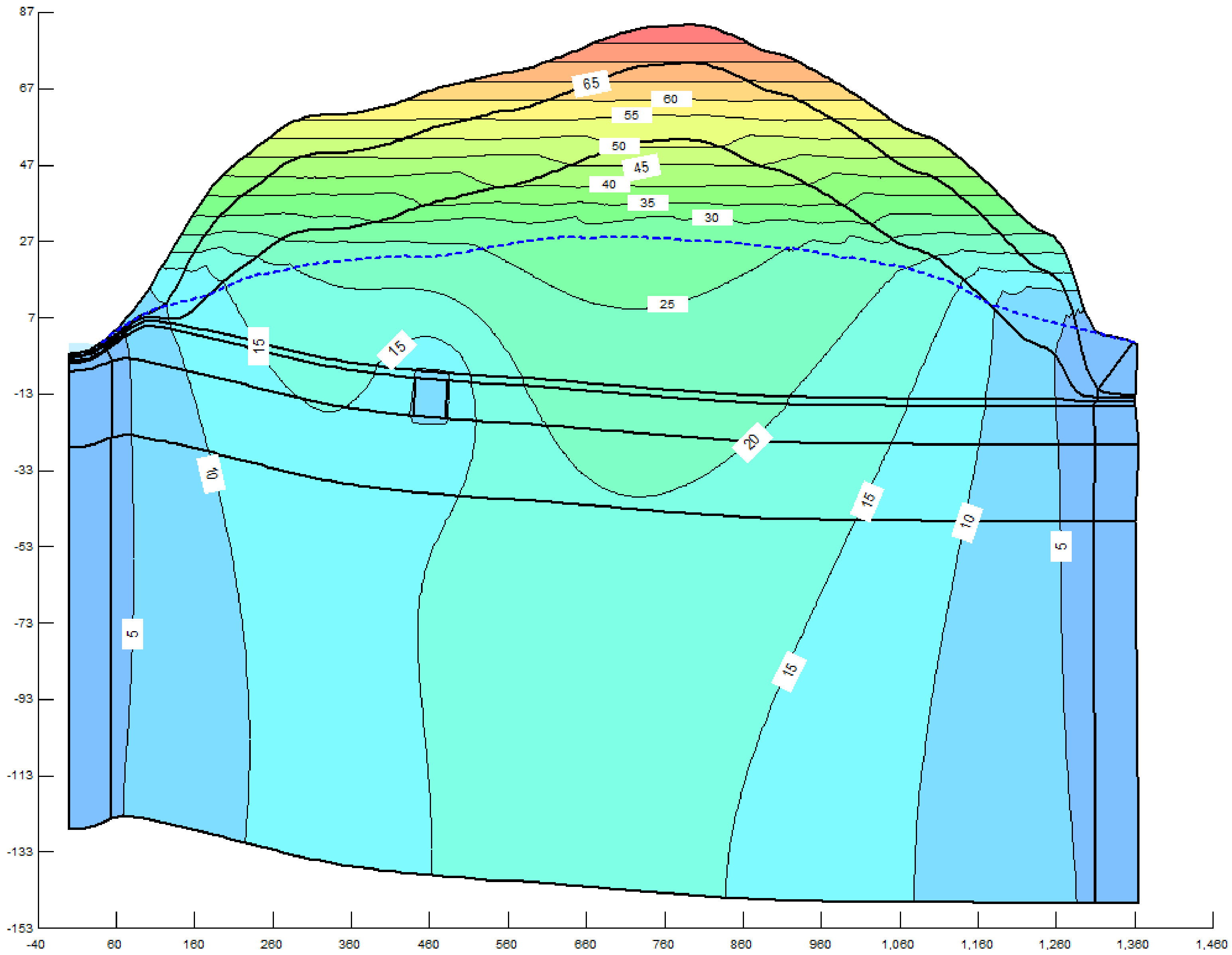


Figure 11-7: Predicted heads at end of construction - North Model

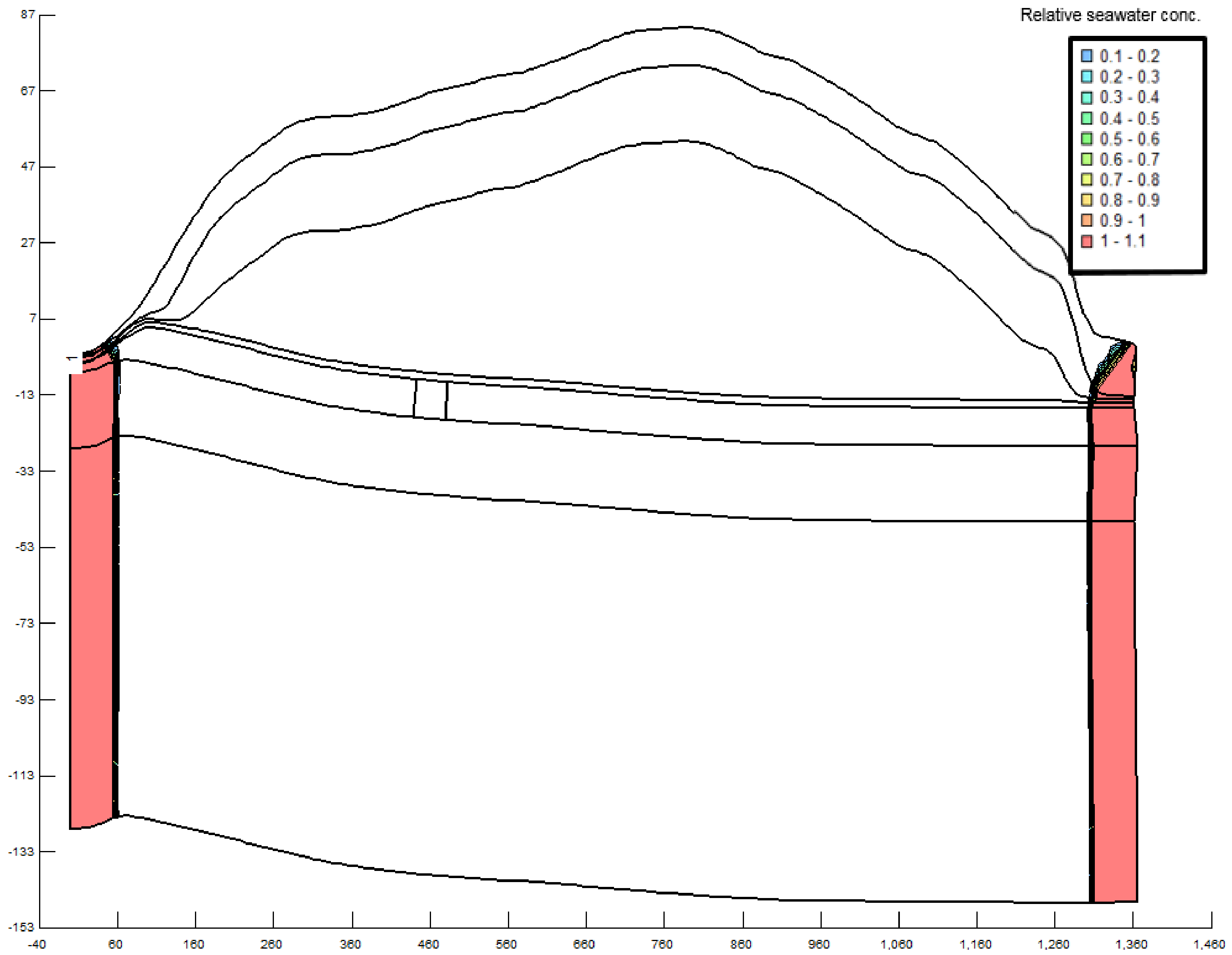


Figure 11-8: Predicted relative seawater concentrations at end of construction – North Model

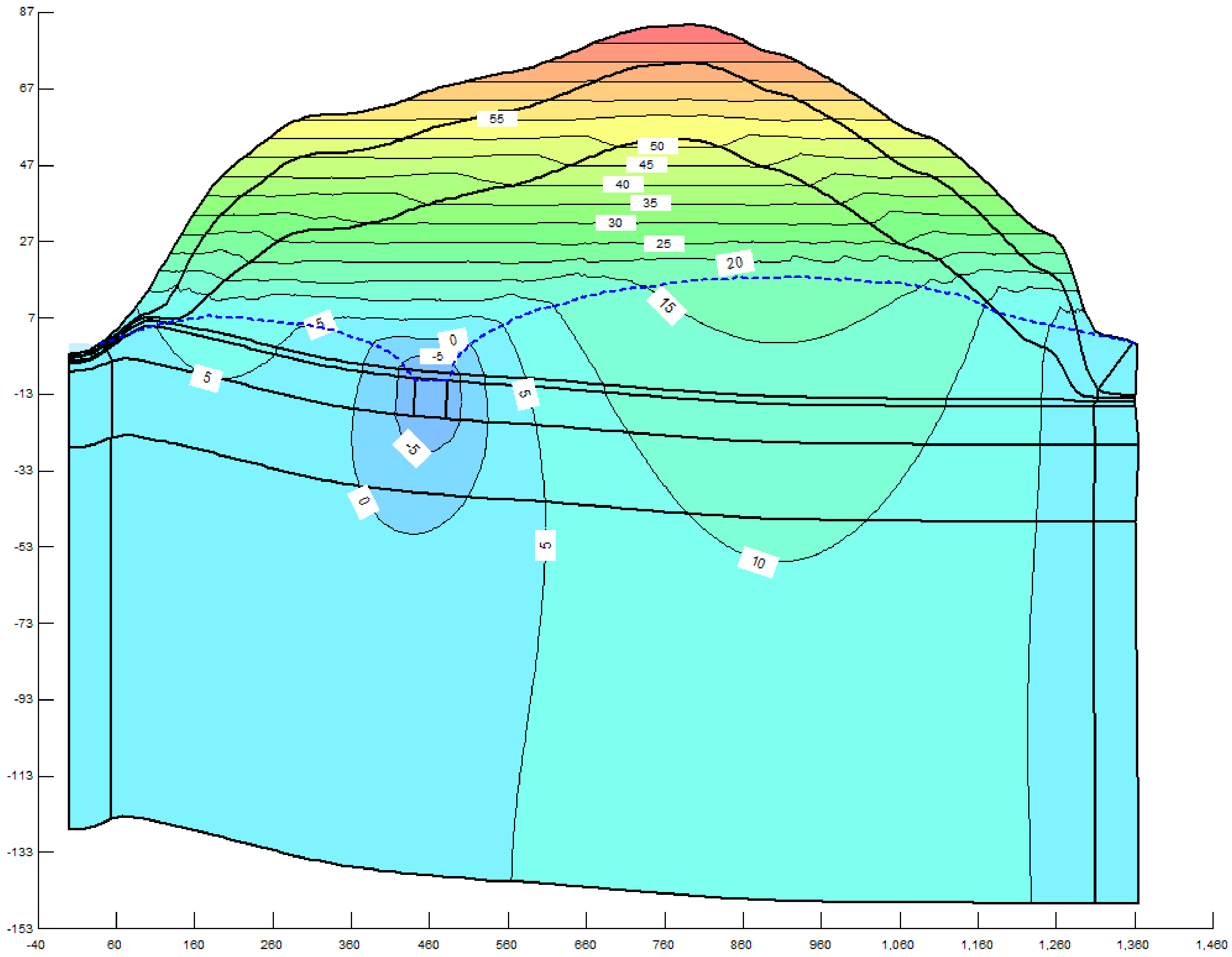


Figure 11-9: Predicted heads after 100 years of operation - North Model

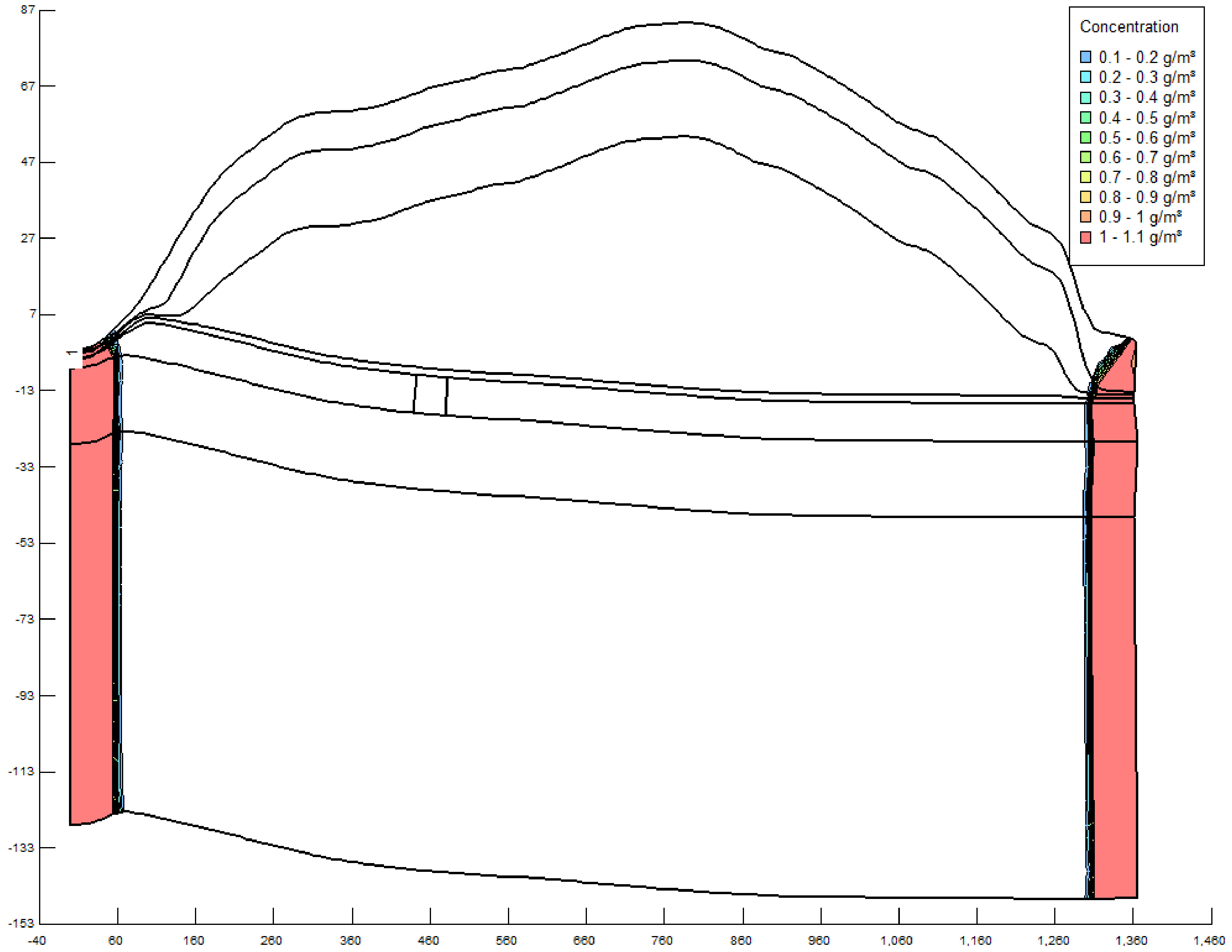


Figure 11-10: Predicted relative seawater concentrations after 100 years of operation - North Model

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 project design elements outlined in Section 1, which represent the 'gold' design version.

Field hydrogeological investigations carried out for this project were undertaken 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 project 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 storativity 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 will 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 project. The two other projects considered are the Western Harbour Tunnel and Warringah Freeway Upgrade project 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 project to provide indicative rates of the lateral and upward movement of the saline water interface due to the project. The results of the modelling assessment do not provide an assessment of the maximum (cumulative) saline water intrusion impacts due to the project.

13. References

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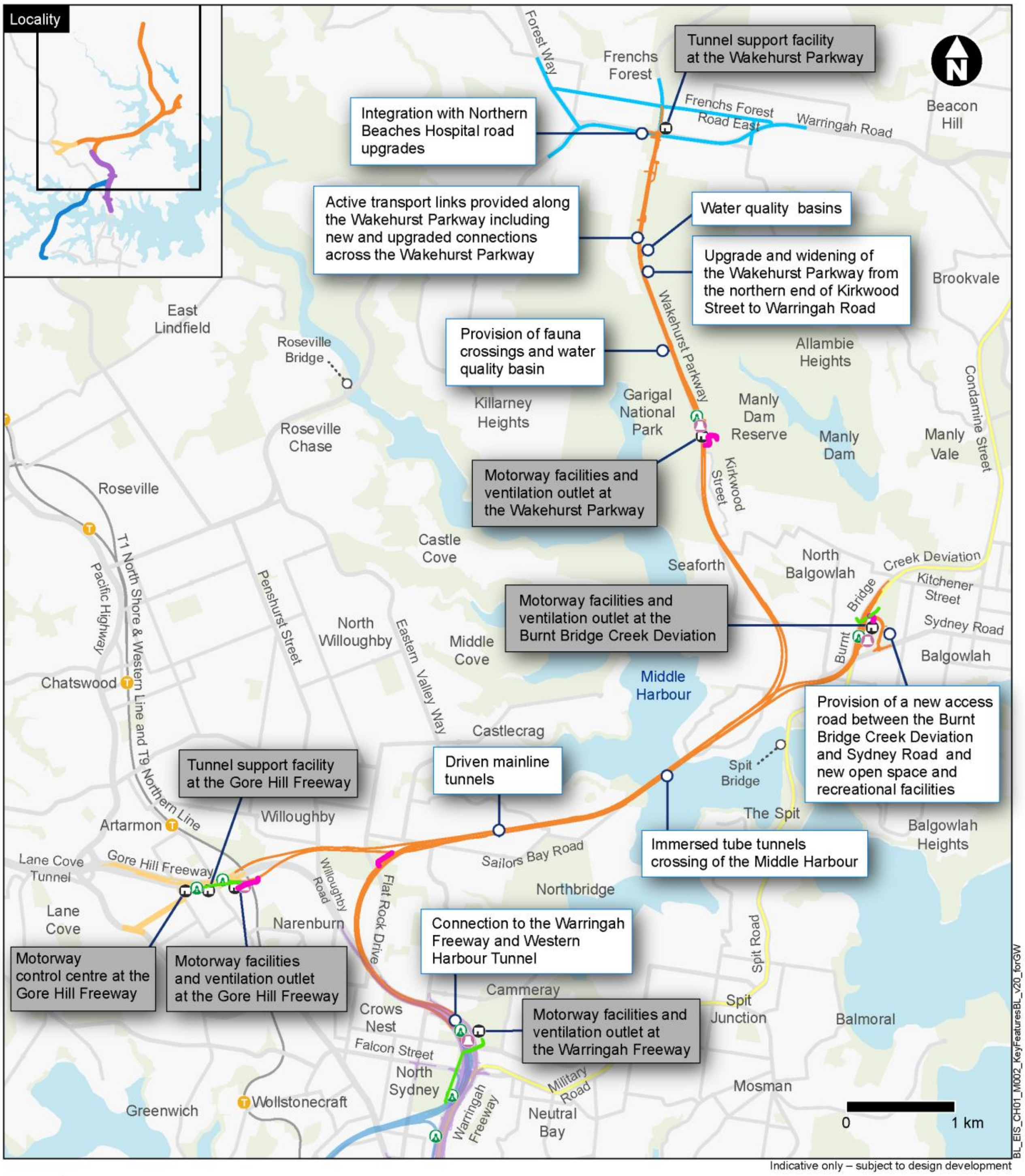
Attachment 1 Additional figures



Legend

Operational features
- Beaches Link
- Gore Hill Freeway Connection
- Ventilation tunnel
- Surface connection
- Permanent operational facility
- Ventilation outlet

Construction features
- Access decline

Connecting projects
- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Northern Beaches Hospital road upgrade

Existing rail network
- Heavy rail
- Northern Beache B-Line
- Train station

Figure A1-1: Key features of the Beaches Link component of the project

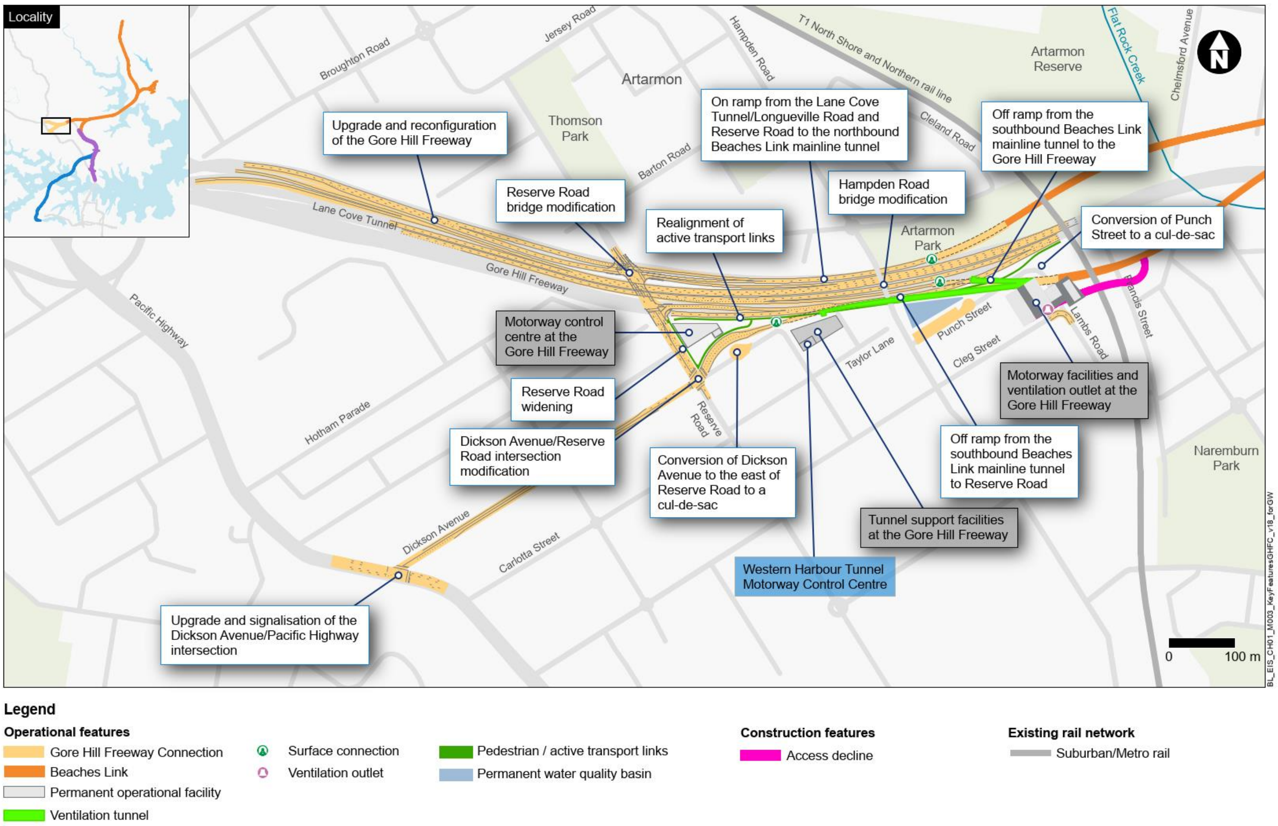
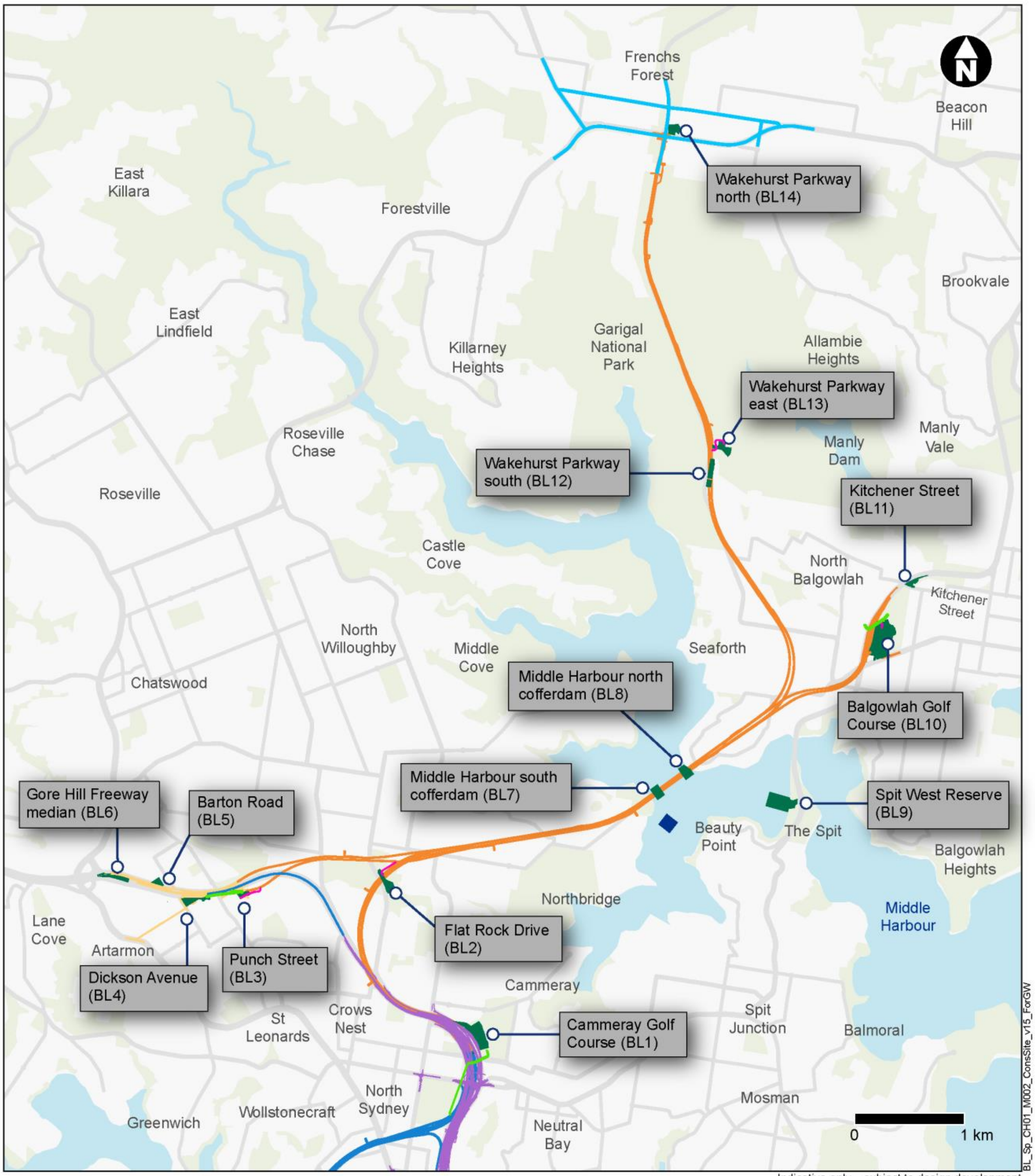


Figure A1-2: Key features of the Gore Hill Freeway Connection component of the project



Indicative only – subject to design development

Legend

Operational features
- Ventilation tunnel

Construction features
- Beaches Link
- Gore Hill Freeway Connection
- Construction support site
- Mooring site
- Access decline

Connecting projects
- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Northern Beaches Hospital road upgrades

Figure A1-3: Overview of the construction support sites for the Beaches Link and Gore Hill Freeway Connection project

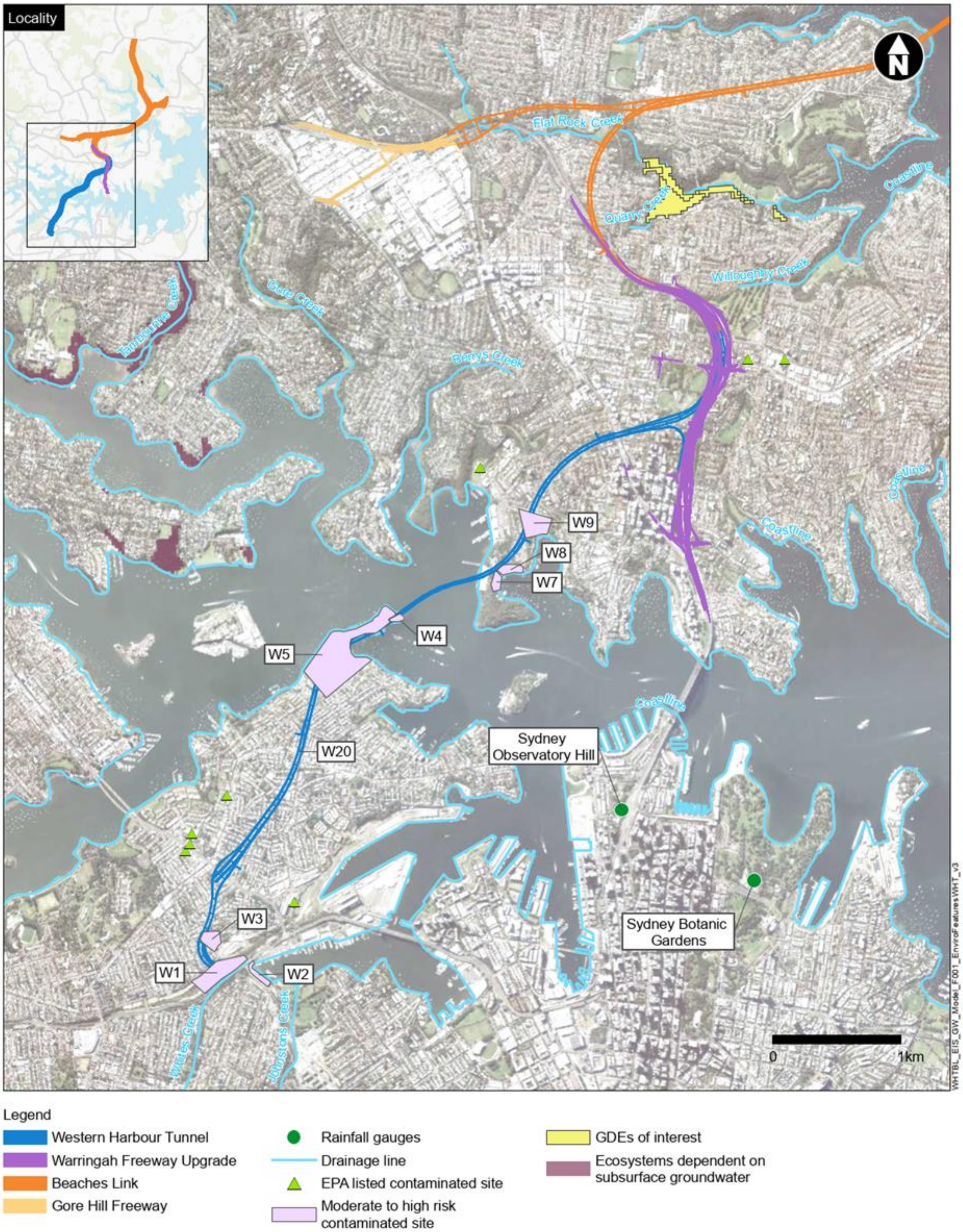


Figure A1-4: Location of rain gauge sites and other project and environmental features – Western Harbour Tunnel

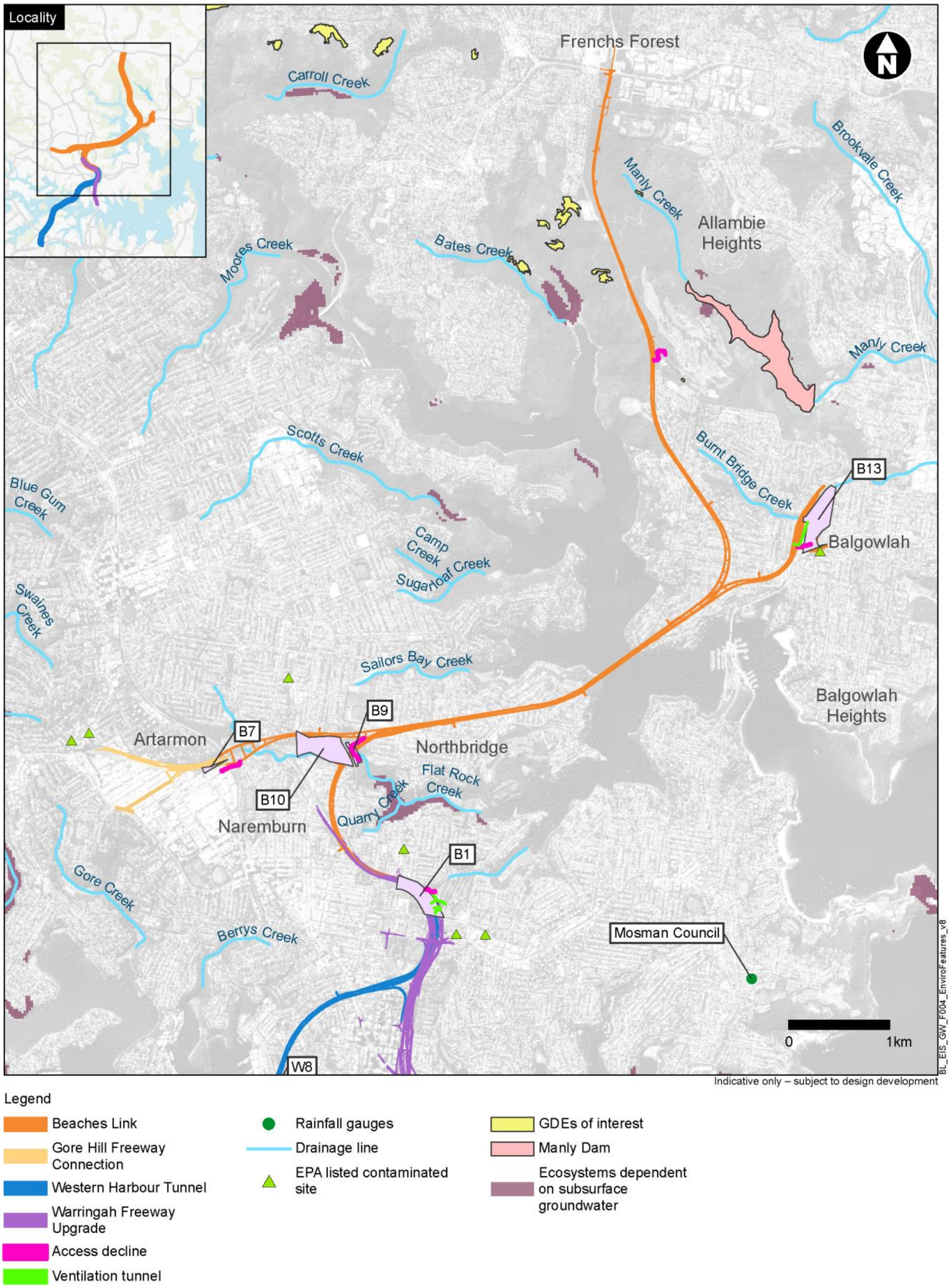


Figure A1-5: Location of rain gauge sites and other project and environmental features - Beaches Link project area

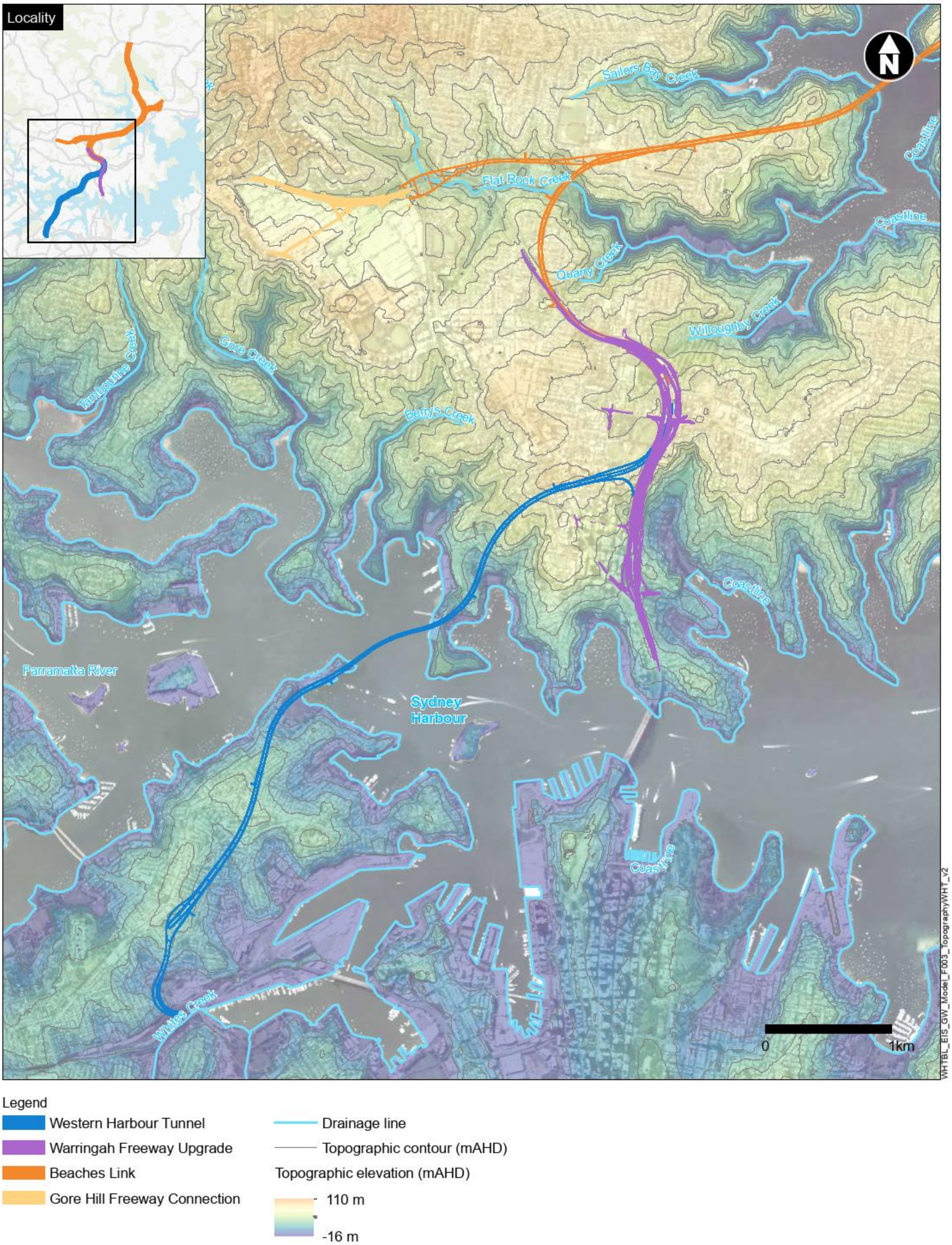


Figure A1-6: Topography and drainage – Western Harbour Tunnel project area

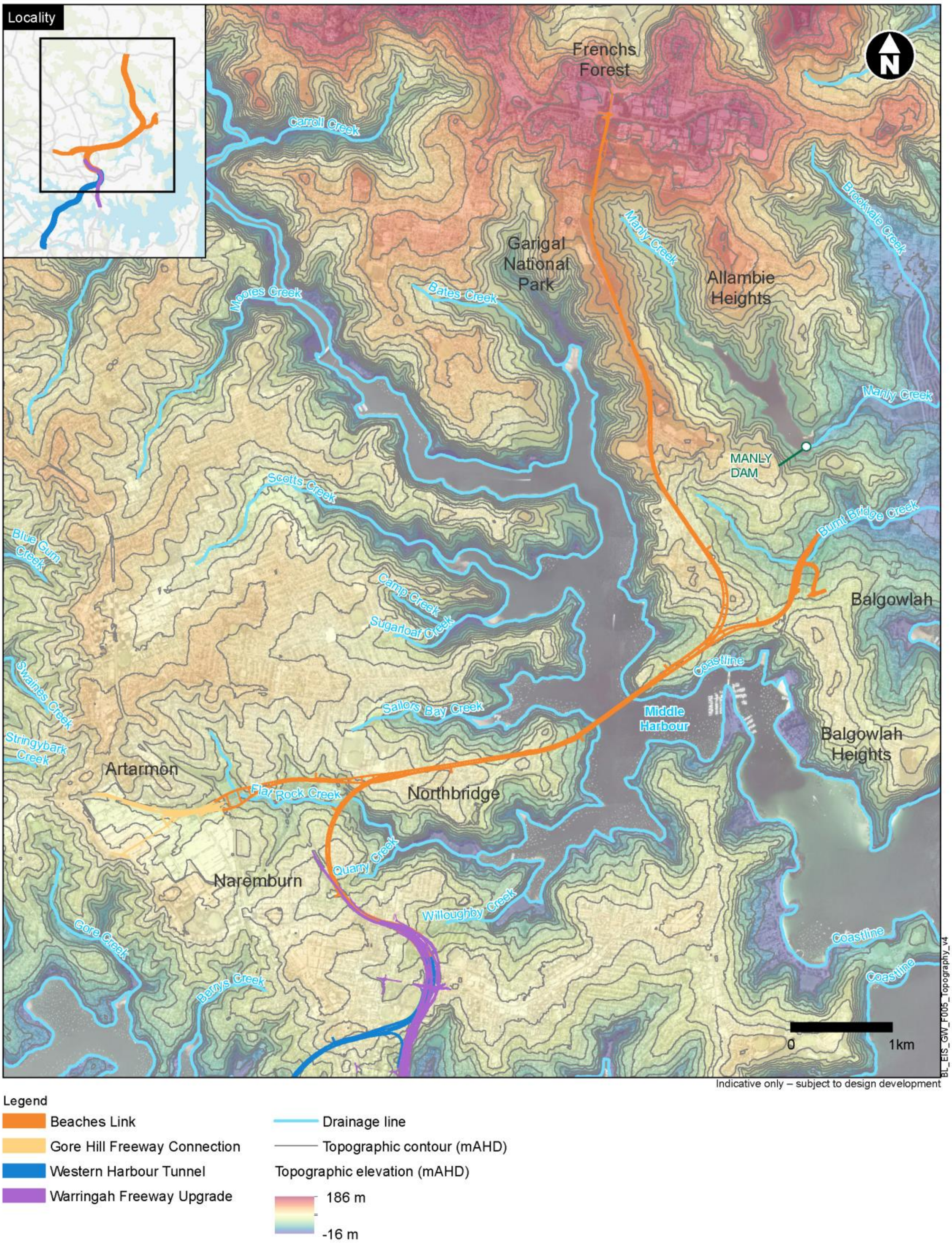


Figure A1-7: Topography and drainage – Beaches Link project area

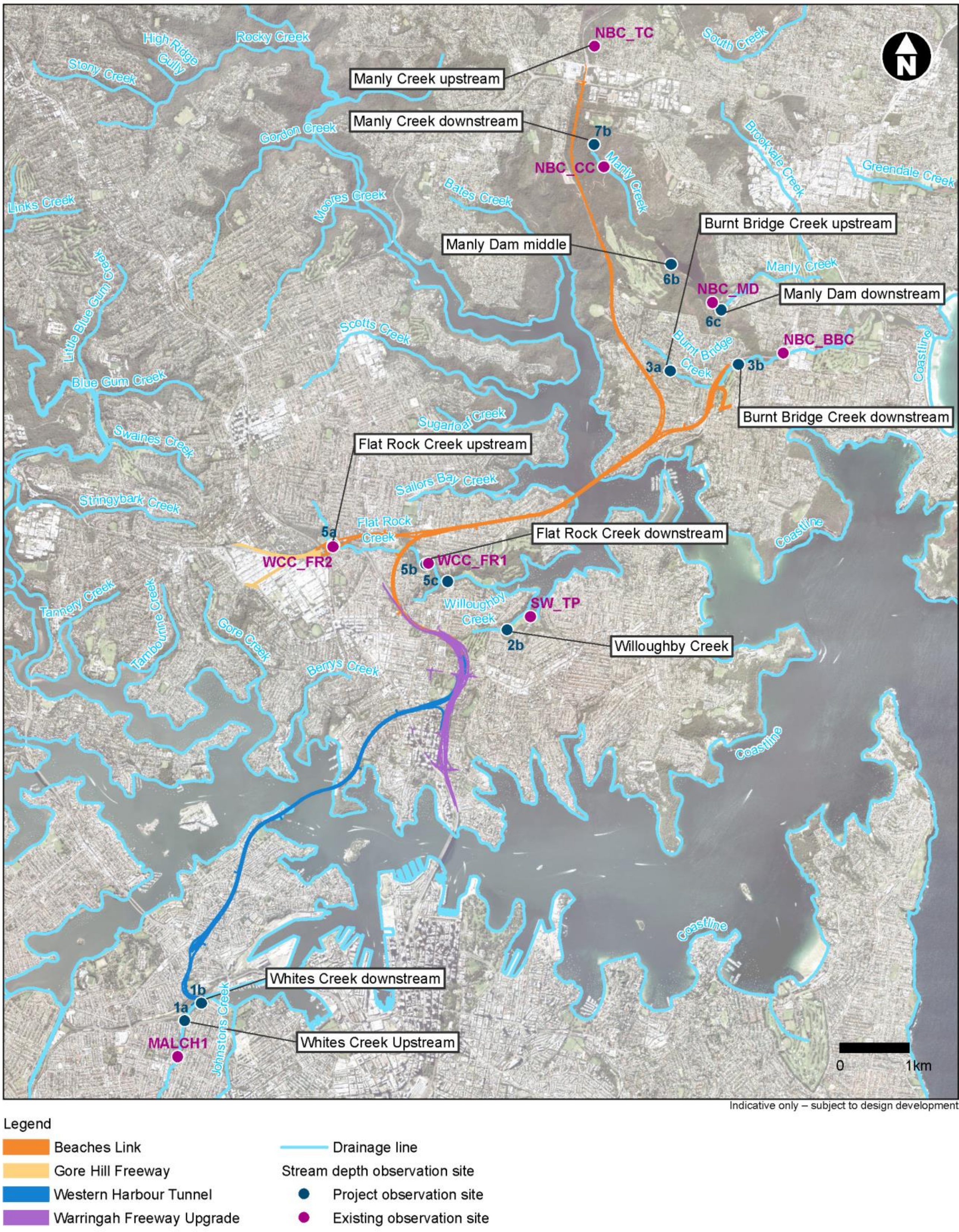


Figure A1-8: Location of stream depth observation sites

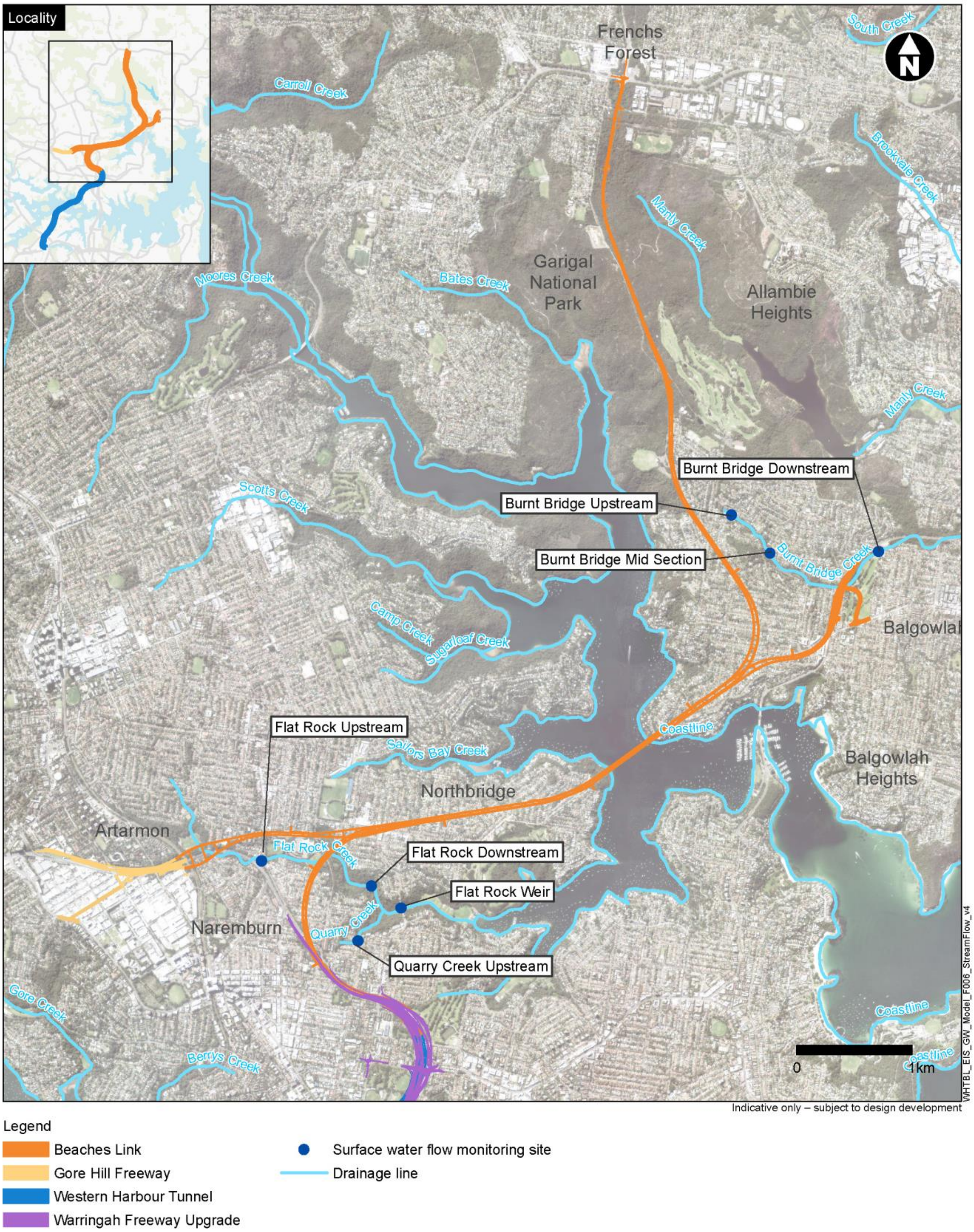


Figure A1-9: Location of stream flow measuring sites

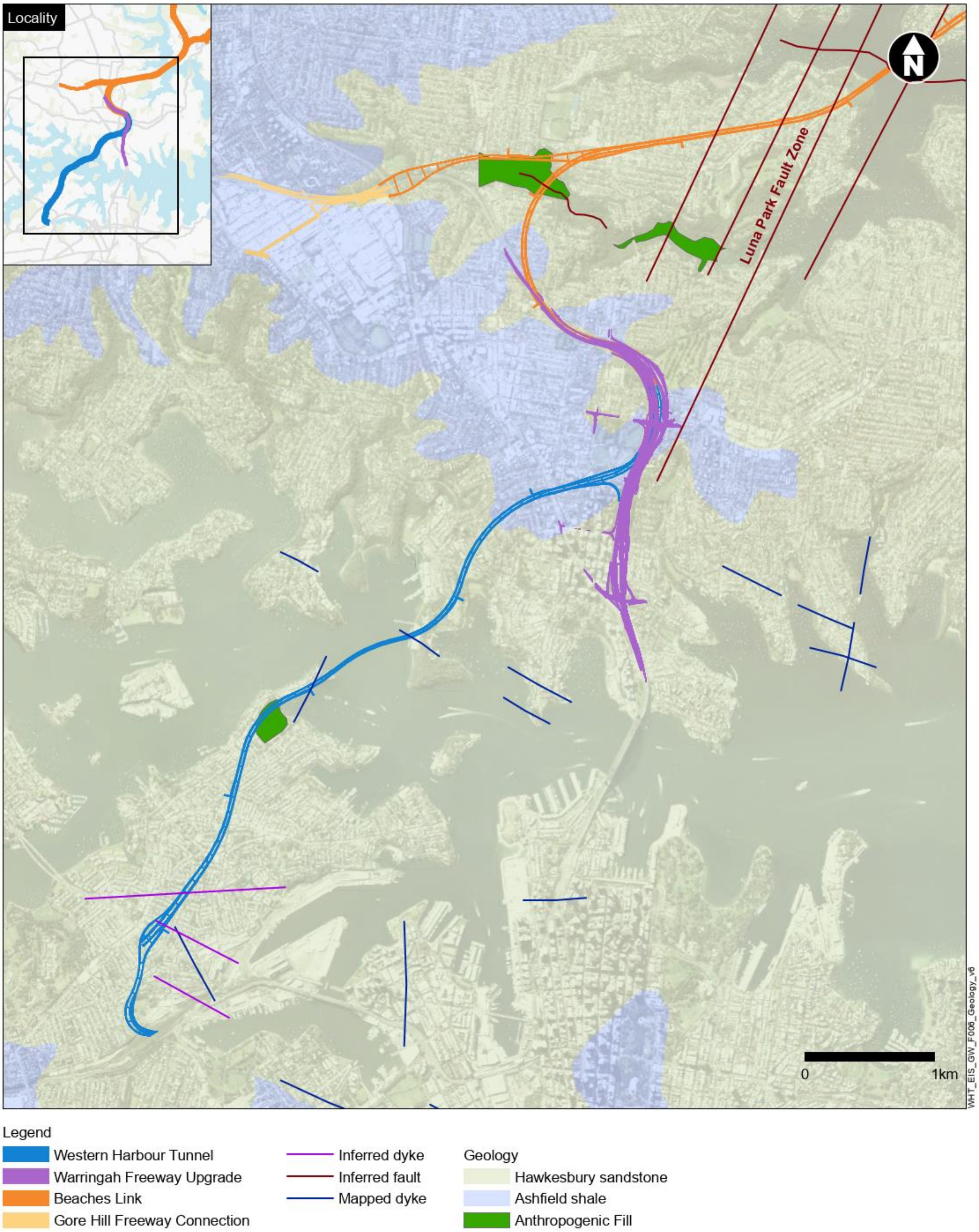


Figure A1-10: Geology of the area (South)

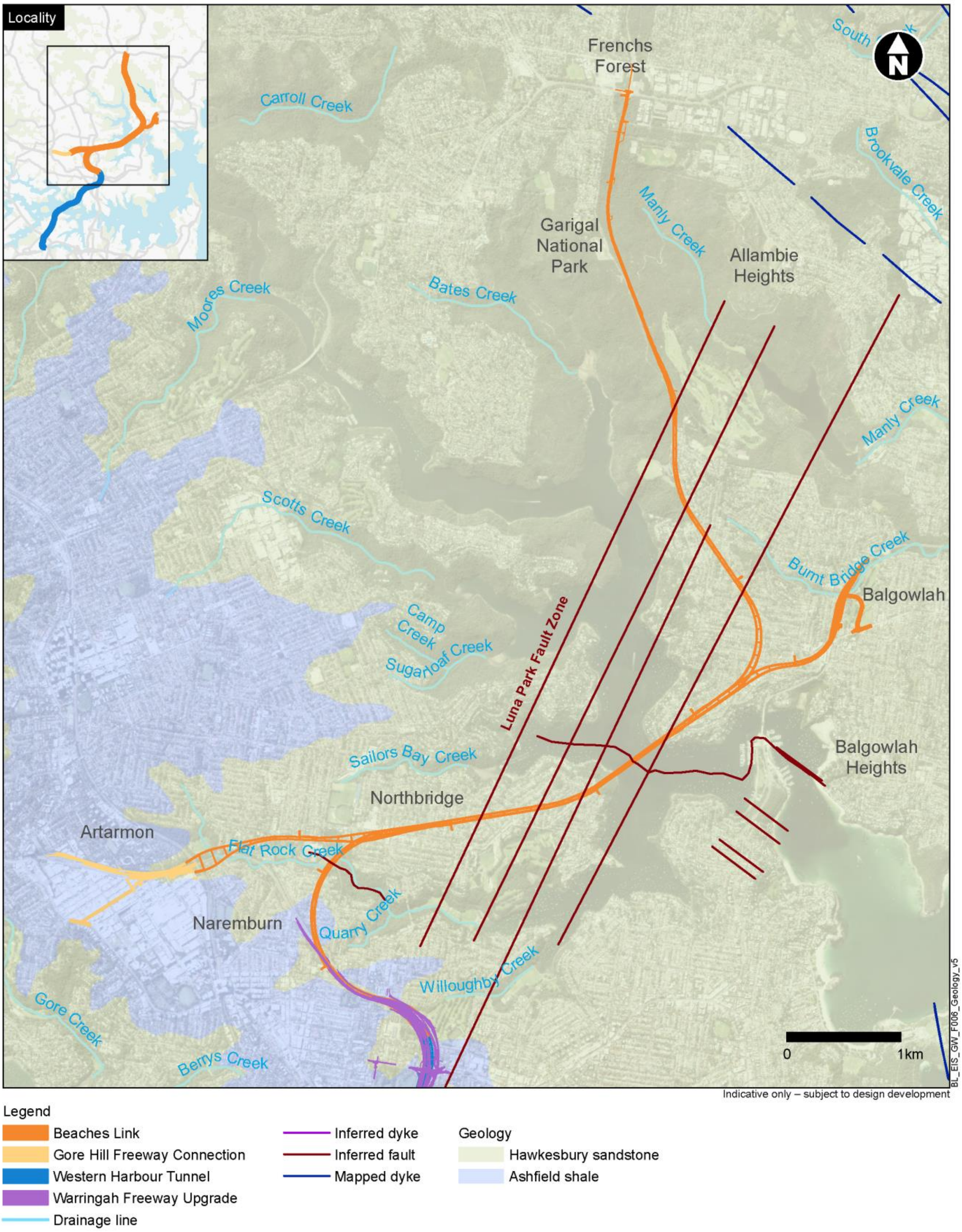


Figure A1-11: Geology of the area (North)

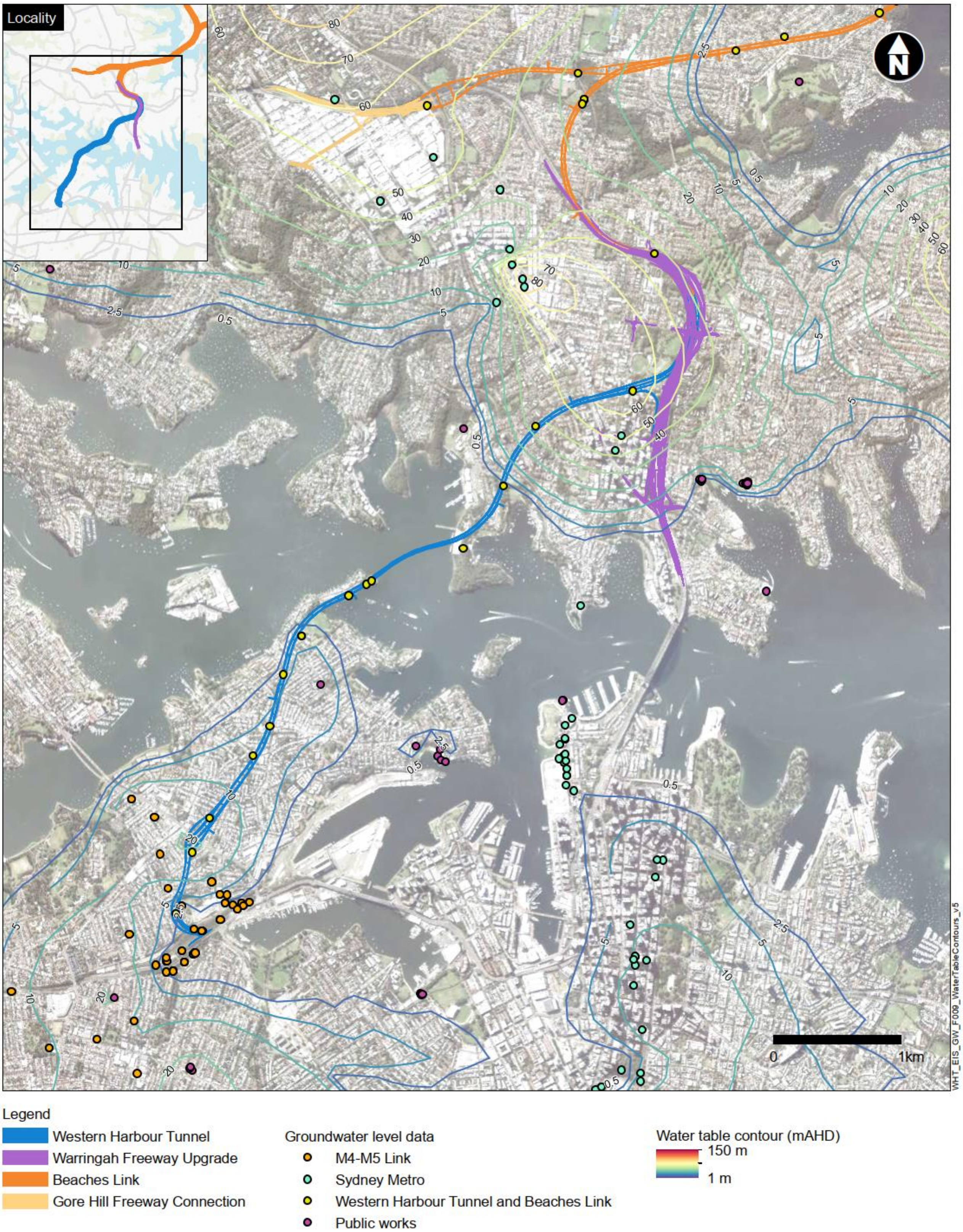


Figure A1-12: Groundwater table contour map (South)

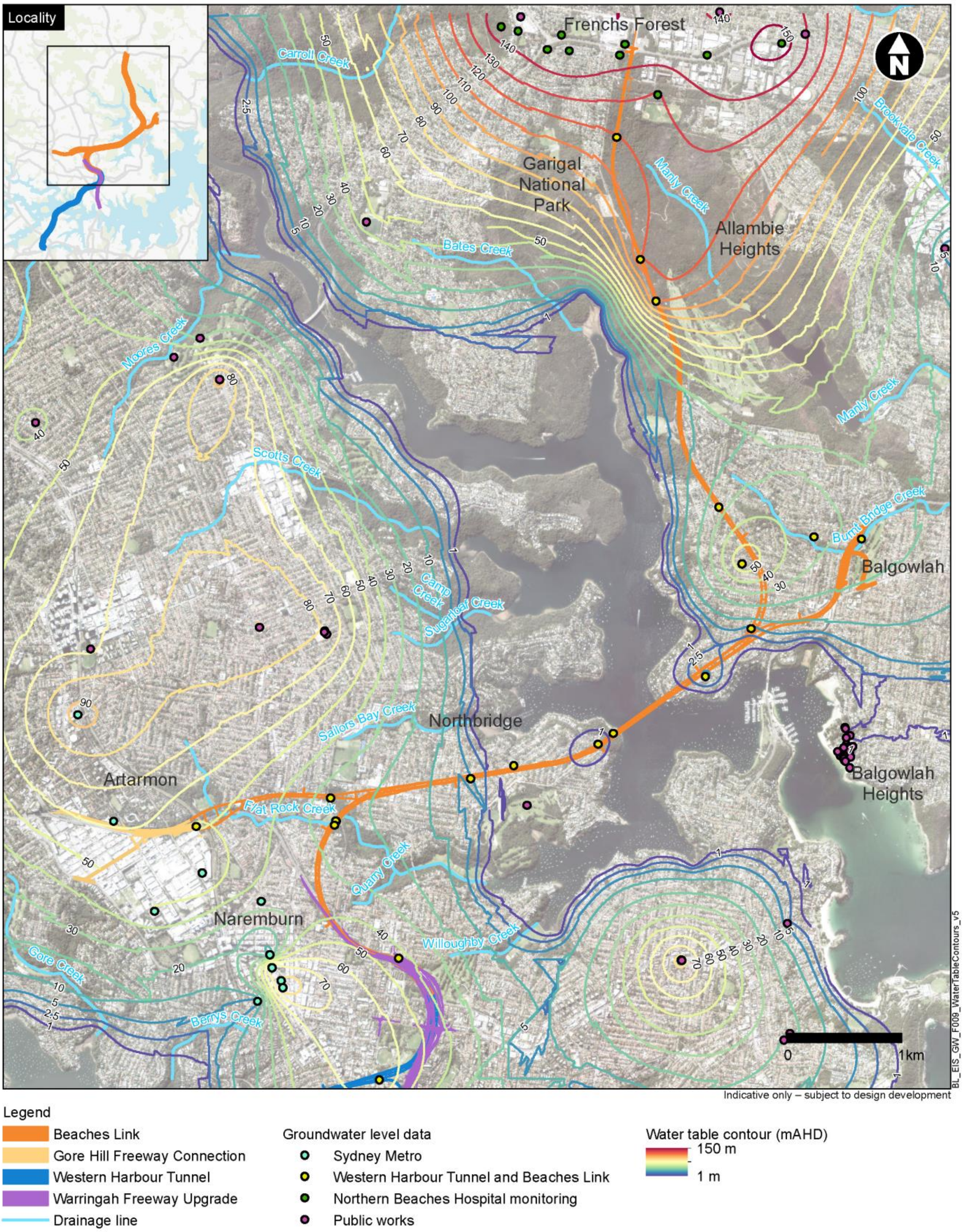


Figure A1-13: Groundwater table contour map (North)

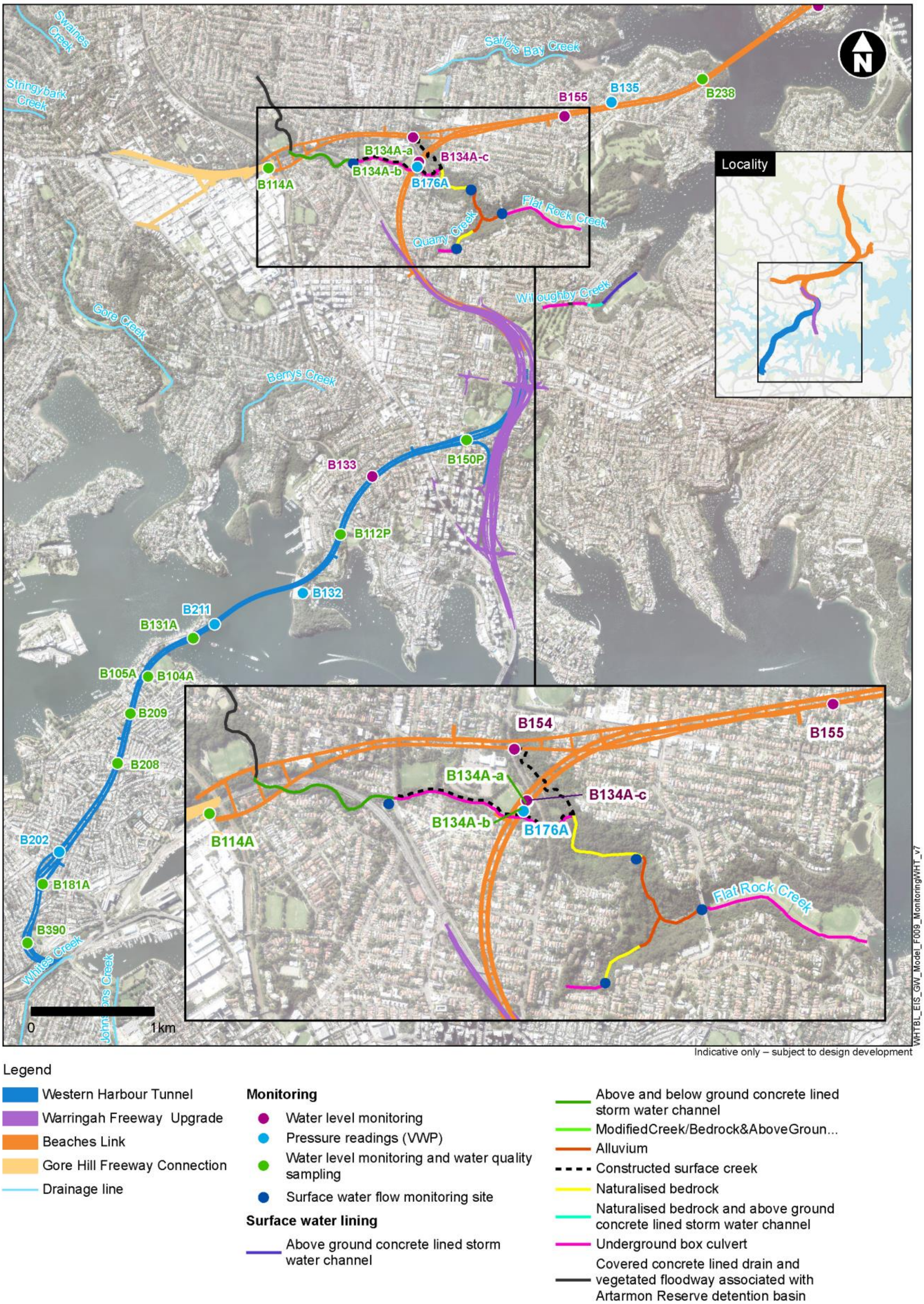


Figure A1-14: Groundwater level monitoring and packer test locations – Western Harbour Tunnel project area

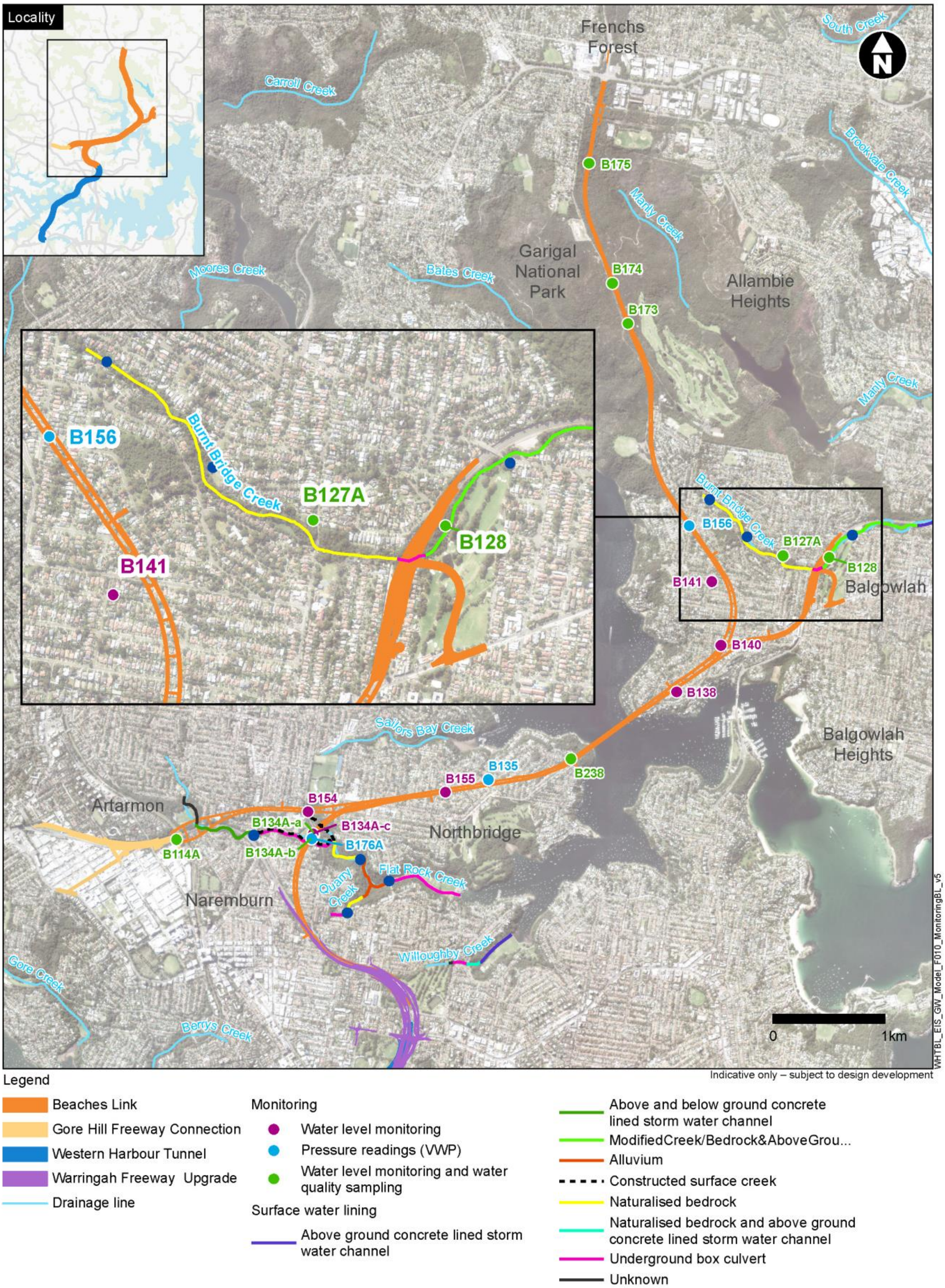


Figure A1-15: Groundwater level monitoring and packer test locations – Beaches Link project area

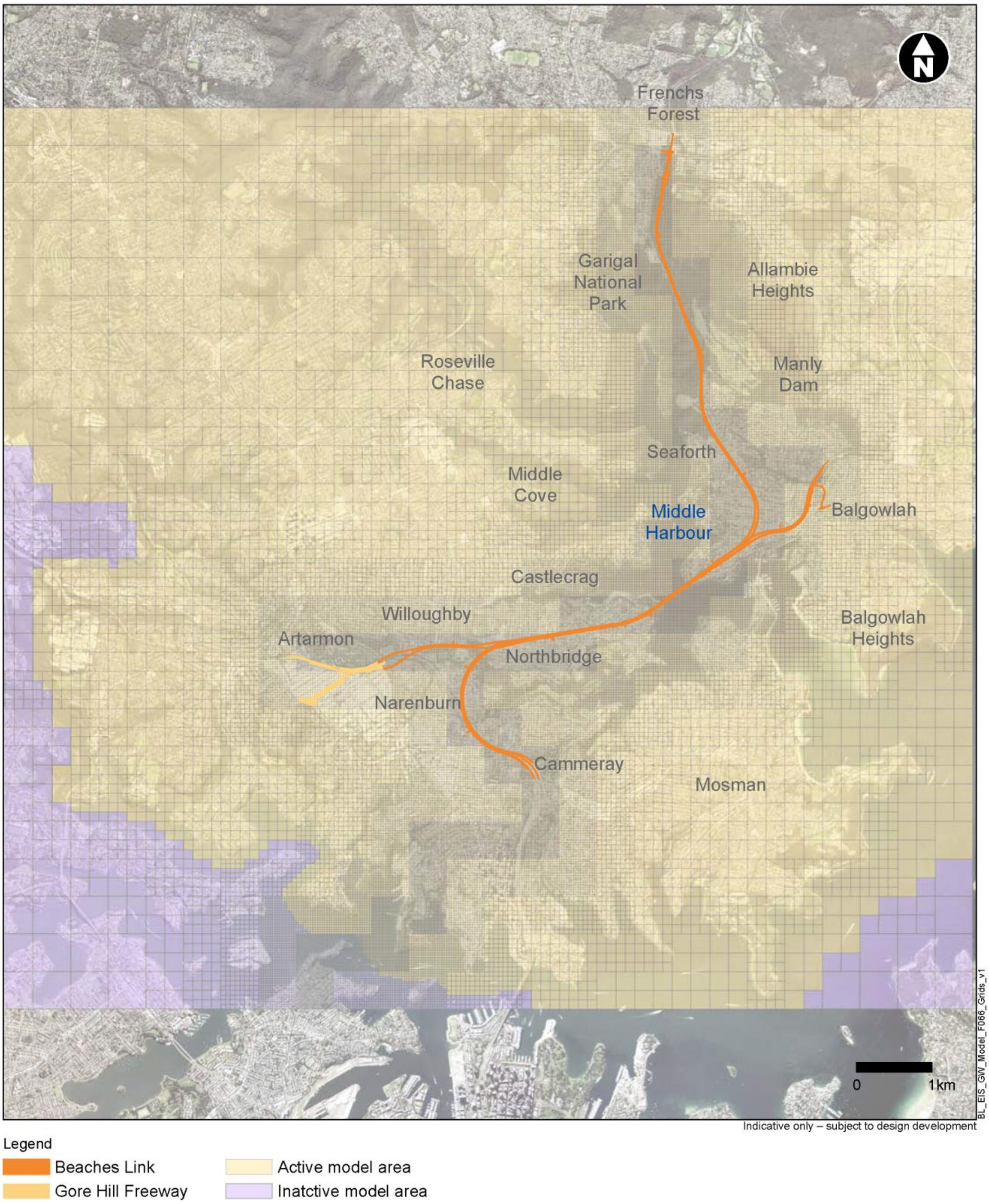


Figure A1-16: Model grid

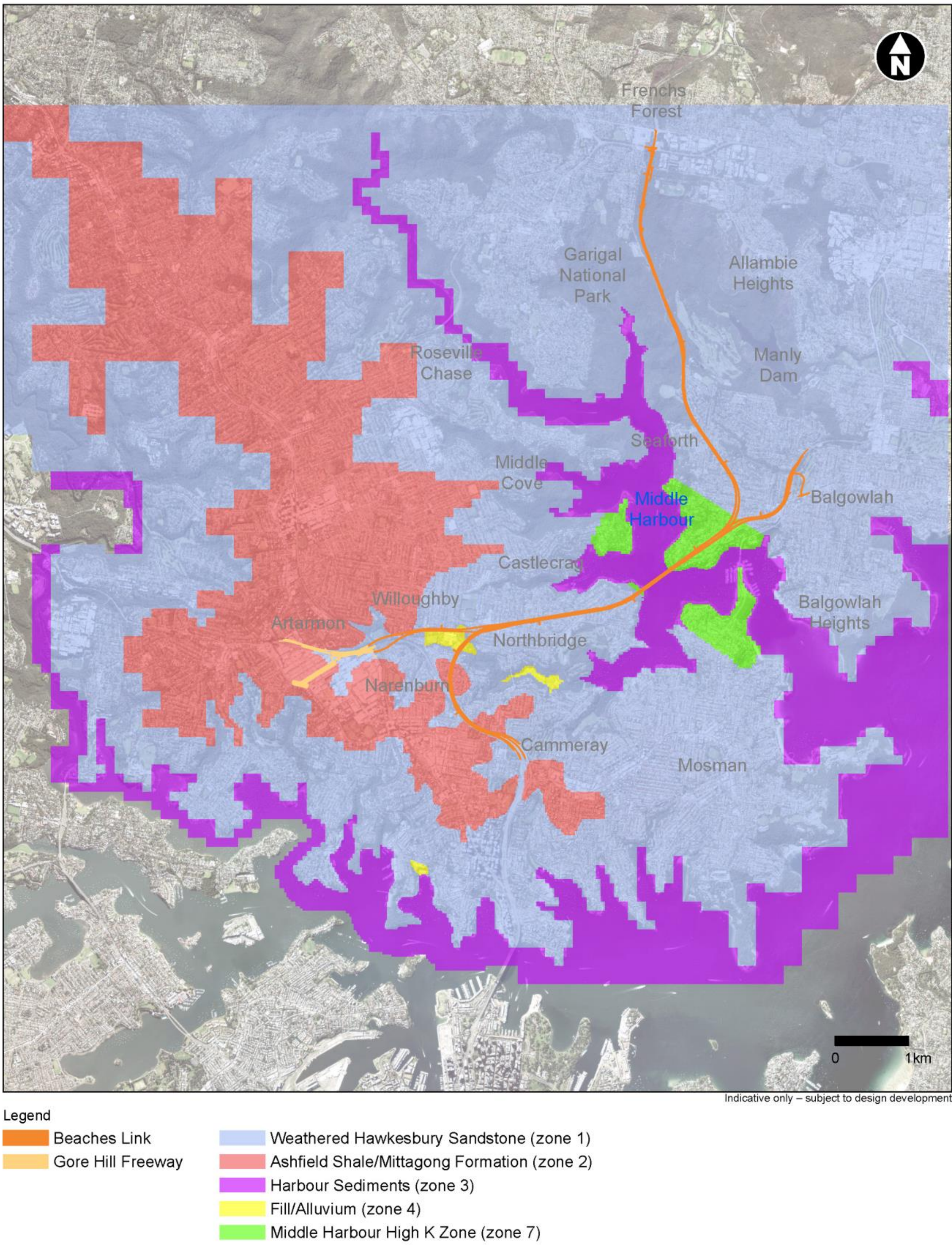


Figure A1-17: Hydraulic conductivity zones in model layer 1

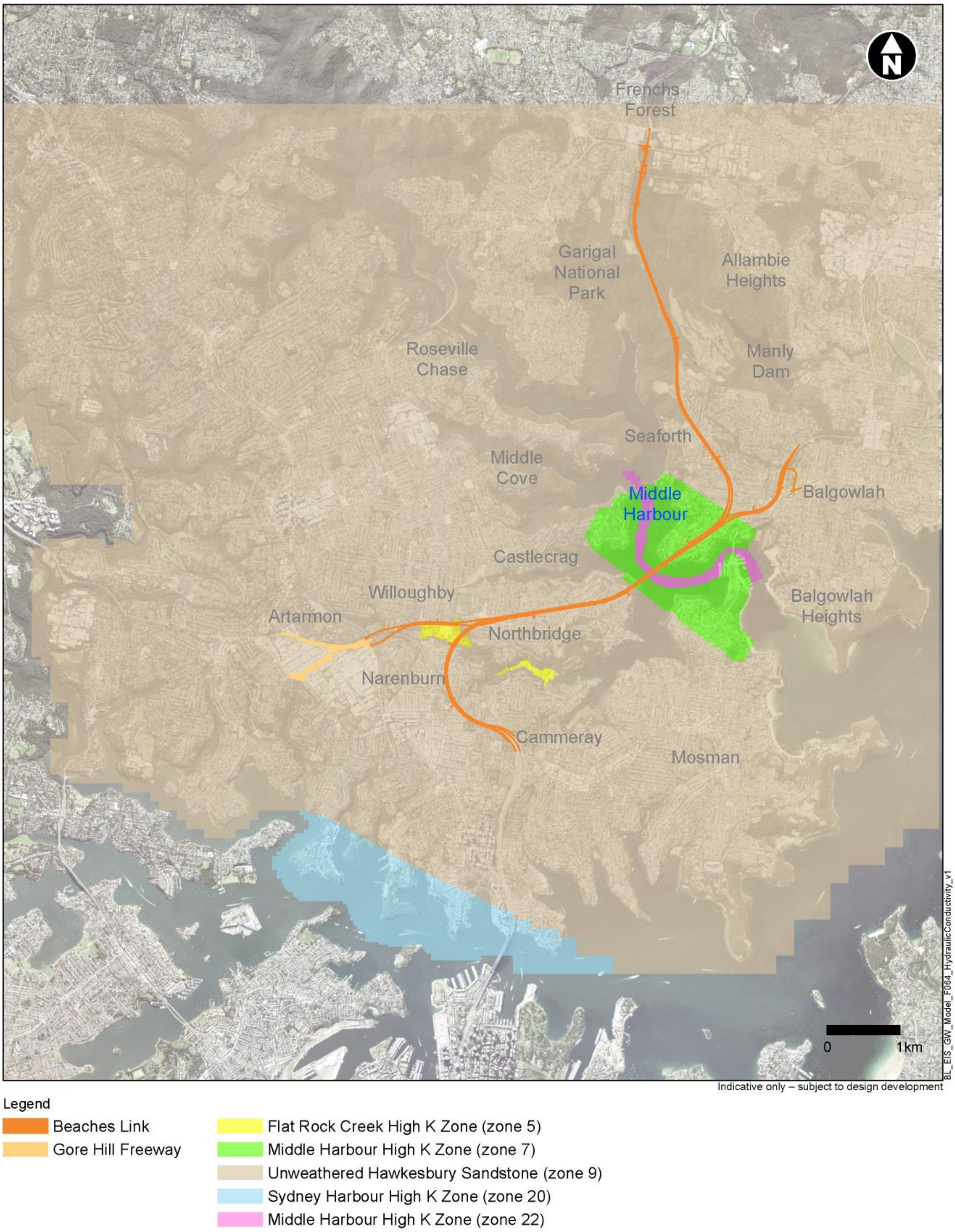
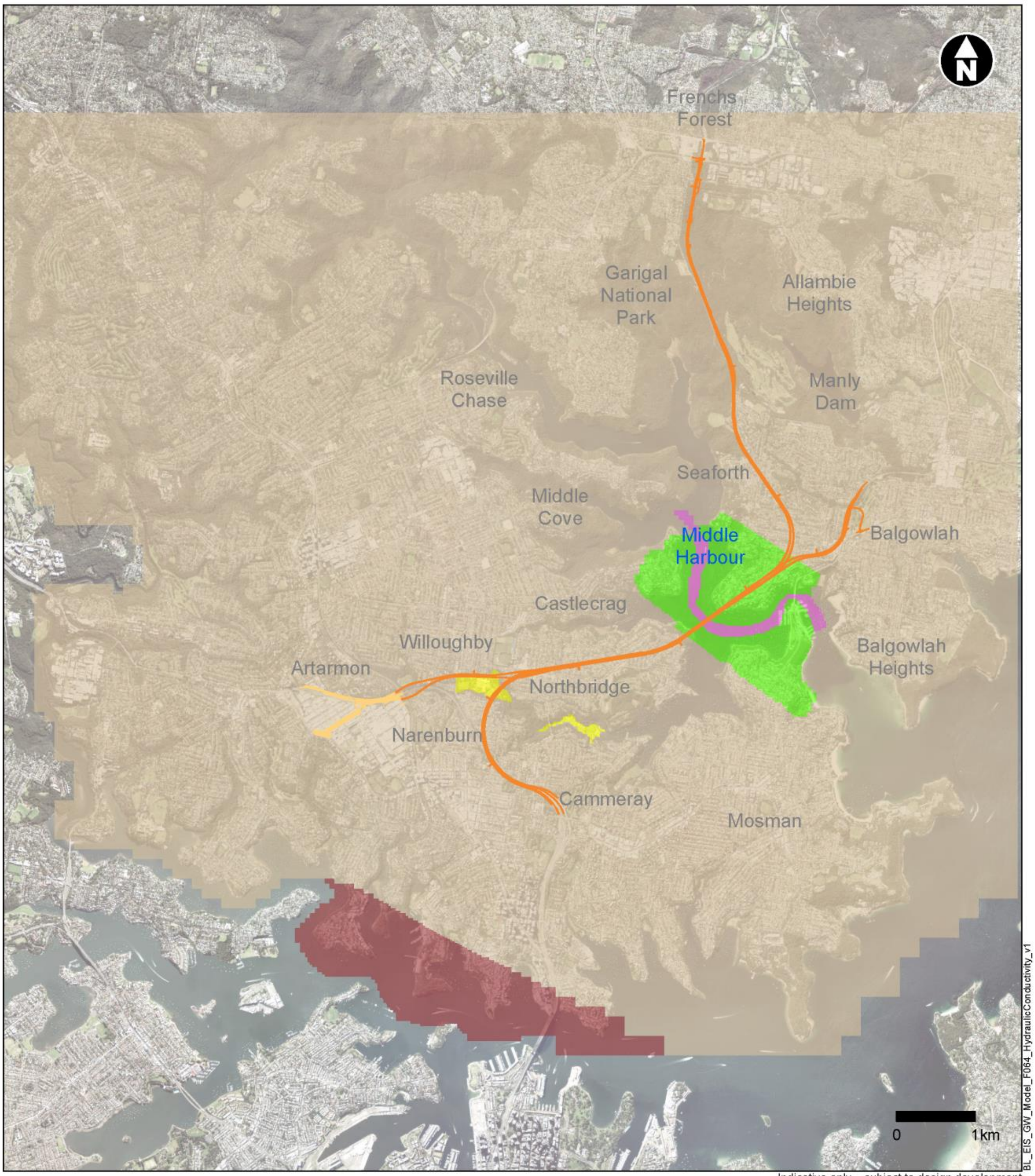


Figure A1-18: Hydraulic conductivity zones in model layer 2



Legend

- Beaches Link
- Gore Hill Freeway
- Middle Harbour High K Zone (zone 7)
- Unweathered Hawkesbury Sandstone (zone 10)
- Flat Rock Creek High K Zone (zone 12)
- Sydney Harbour High K Zone (zone 21)
- Middle Harbour High K Zone (zone 22)

Figure A1-19: Hydraulic conductivity zones in model layer 3

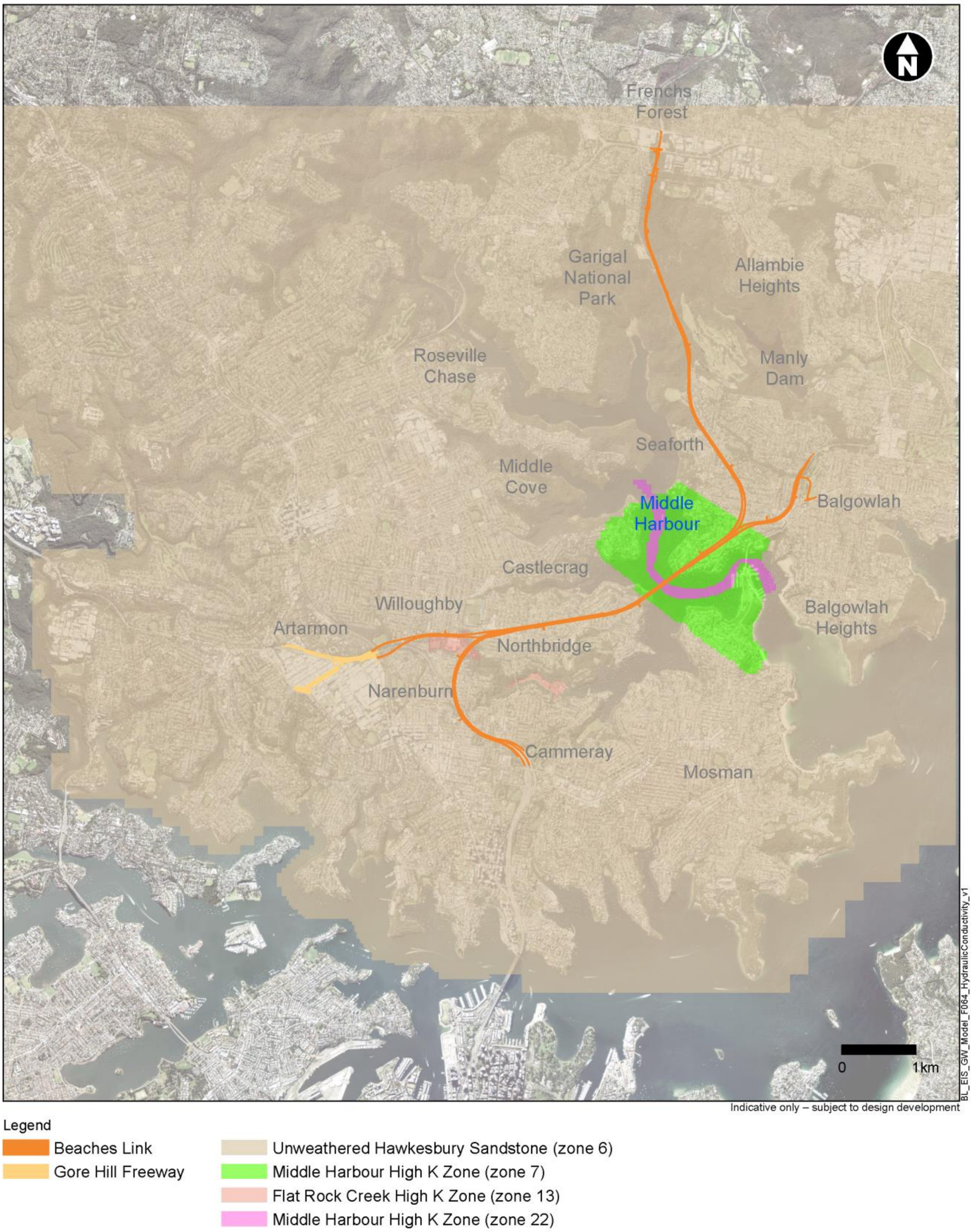


Figure A1-20: Hydraulic conductivity zones in model layer 4

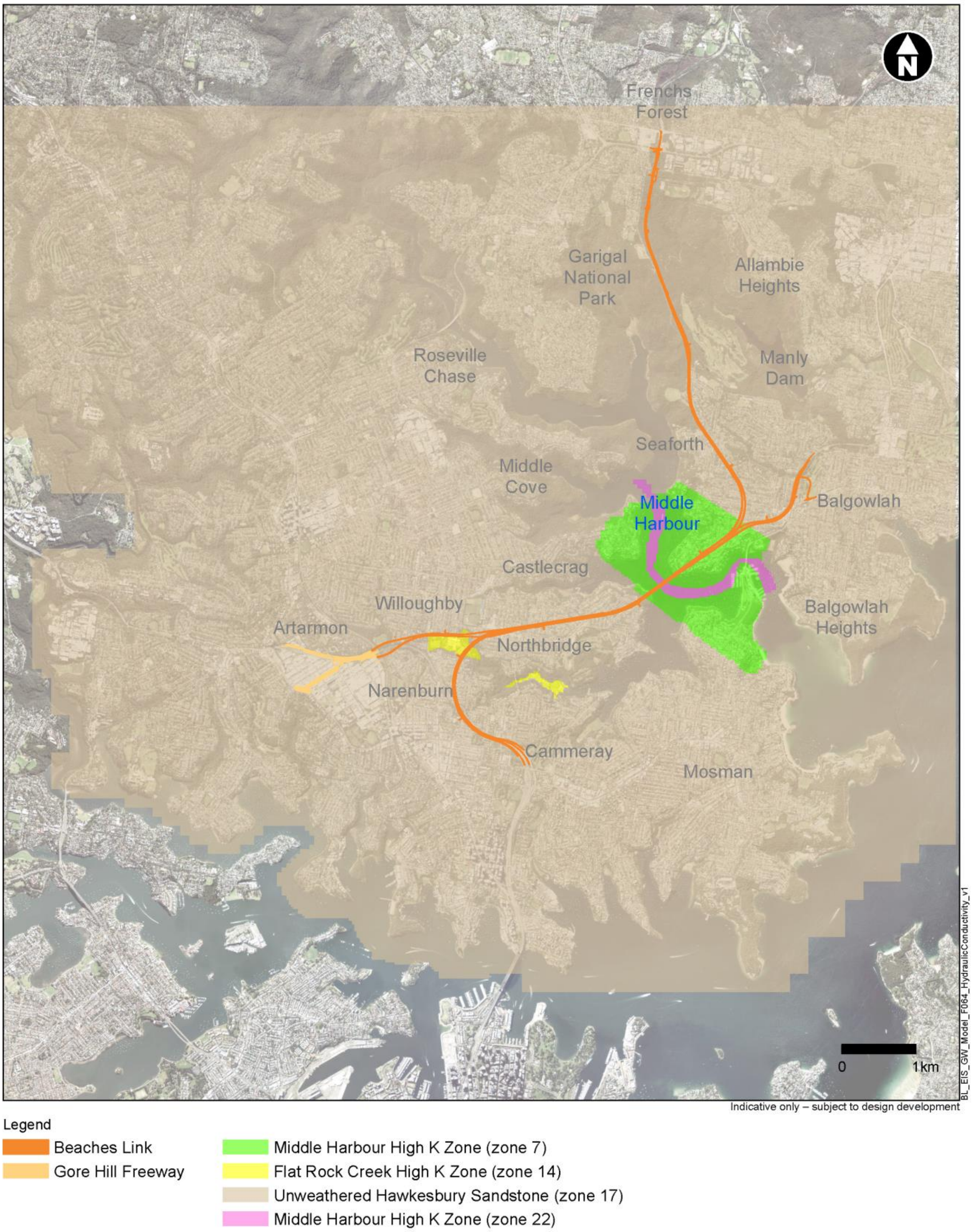


Figure A1-21: Hydraulic conductivity zones in model layer 5

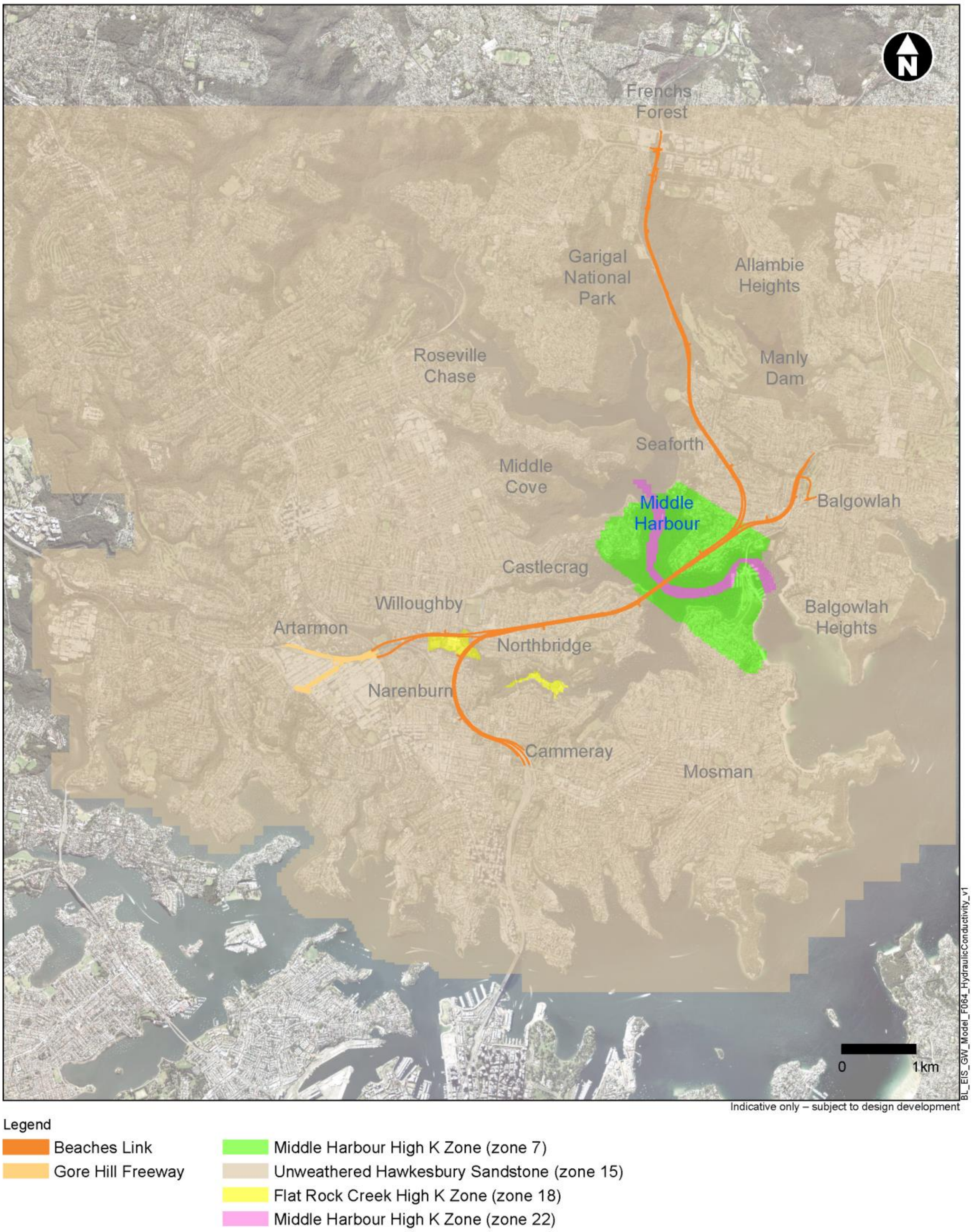


Figure A1-22: Hydraulic conductivity zones in model layer 6

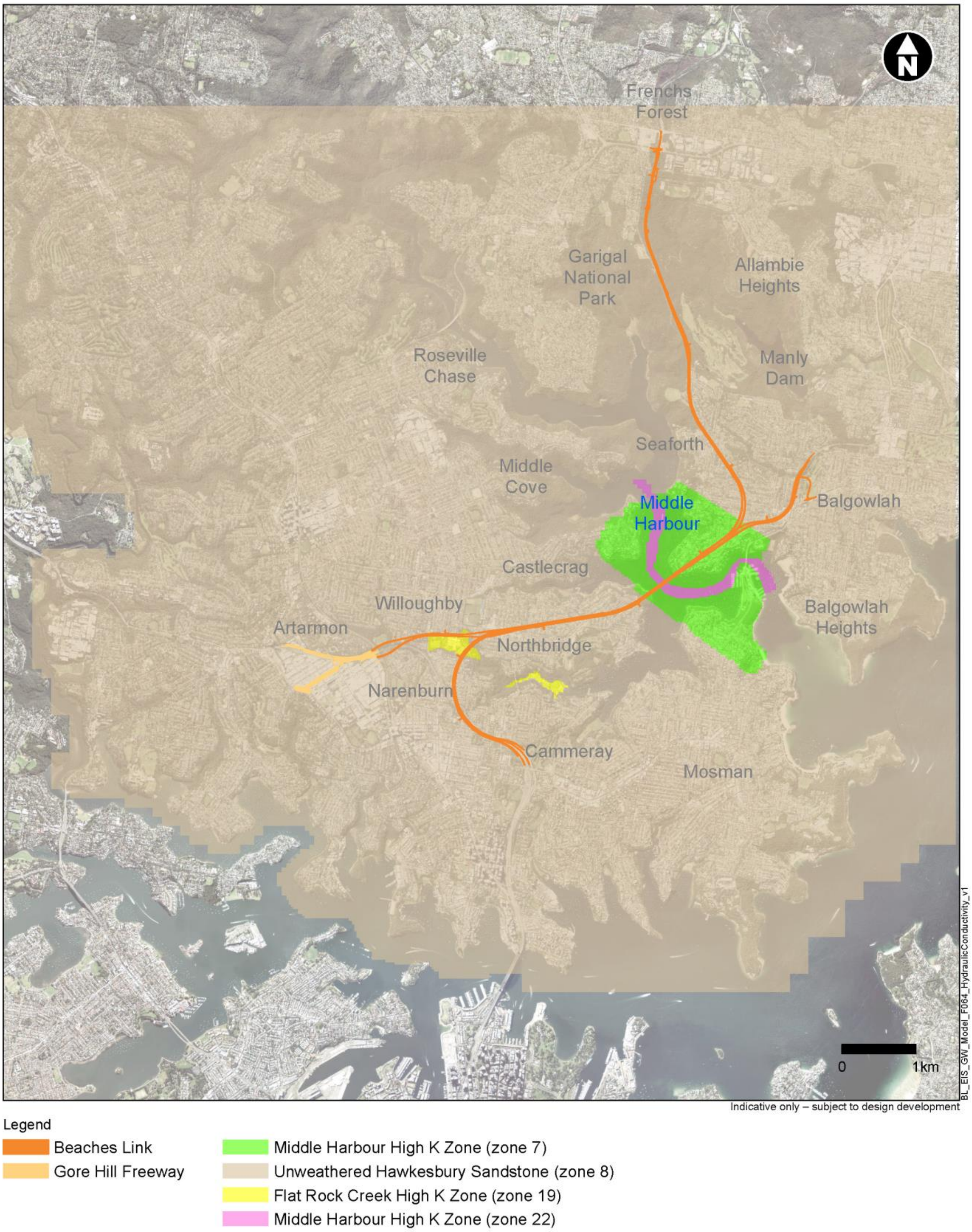


Figure A1-23: Hydraulic conductivity zones in model layer 7

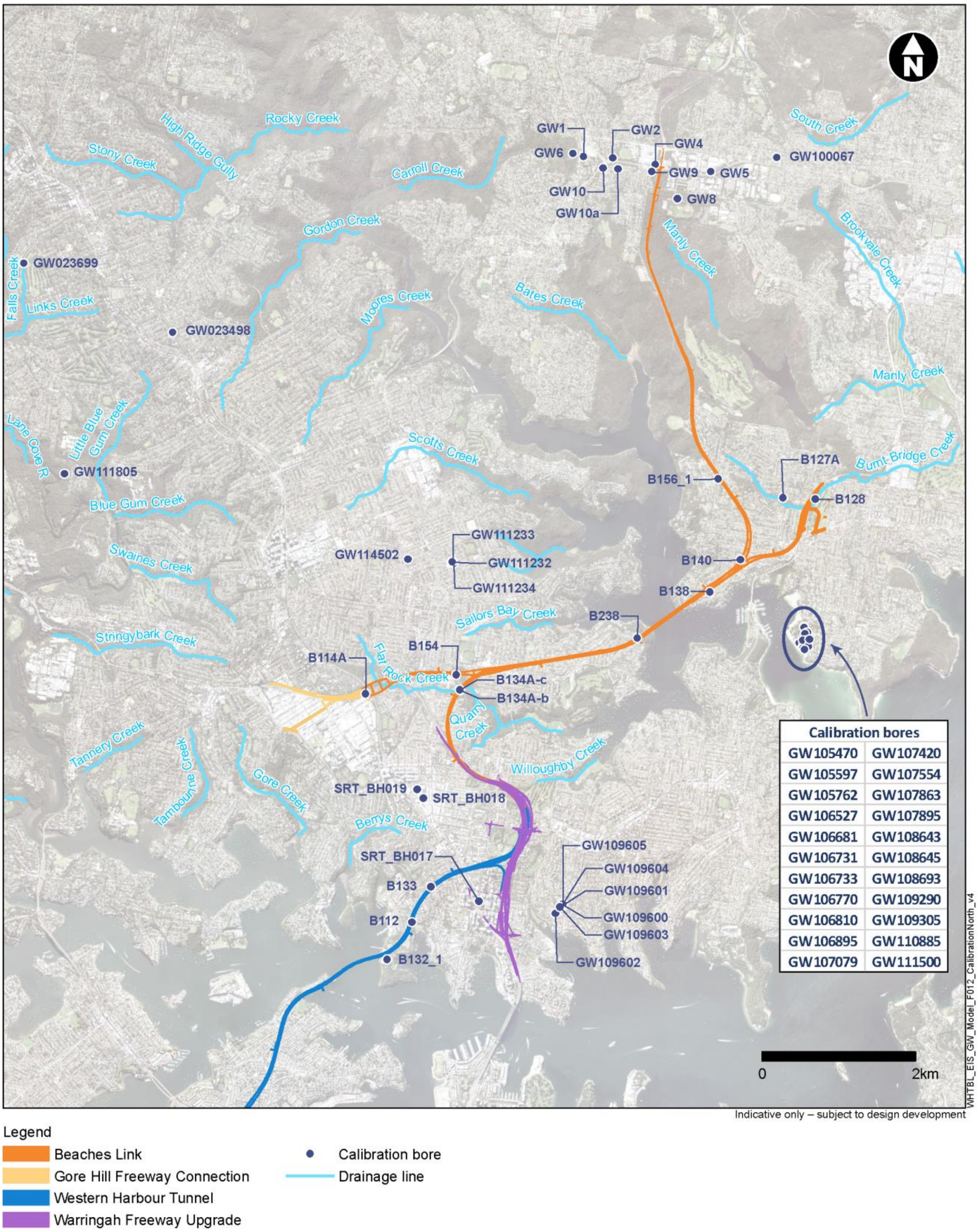


Figure A1-24: Bore locations –Steady state model calibration

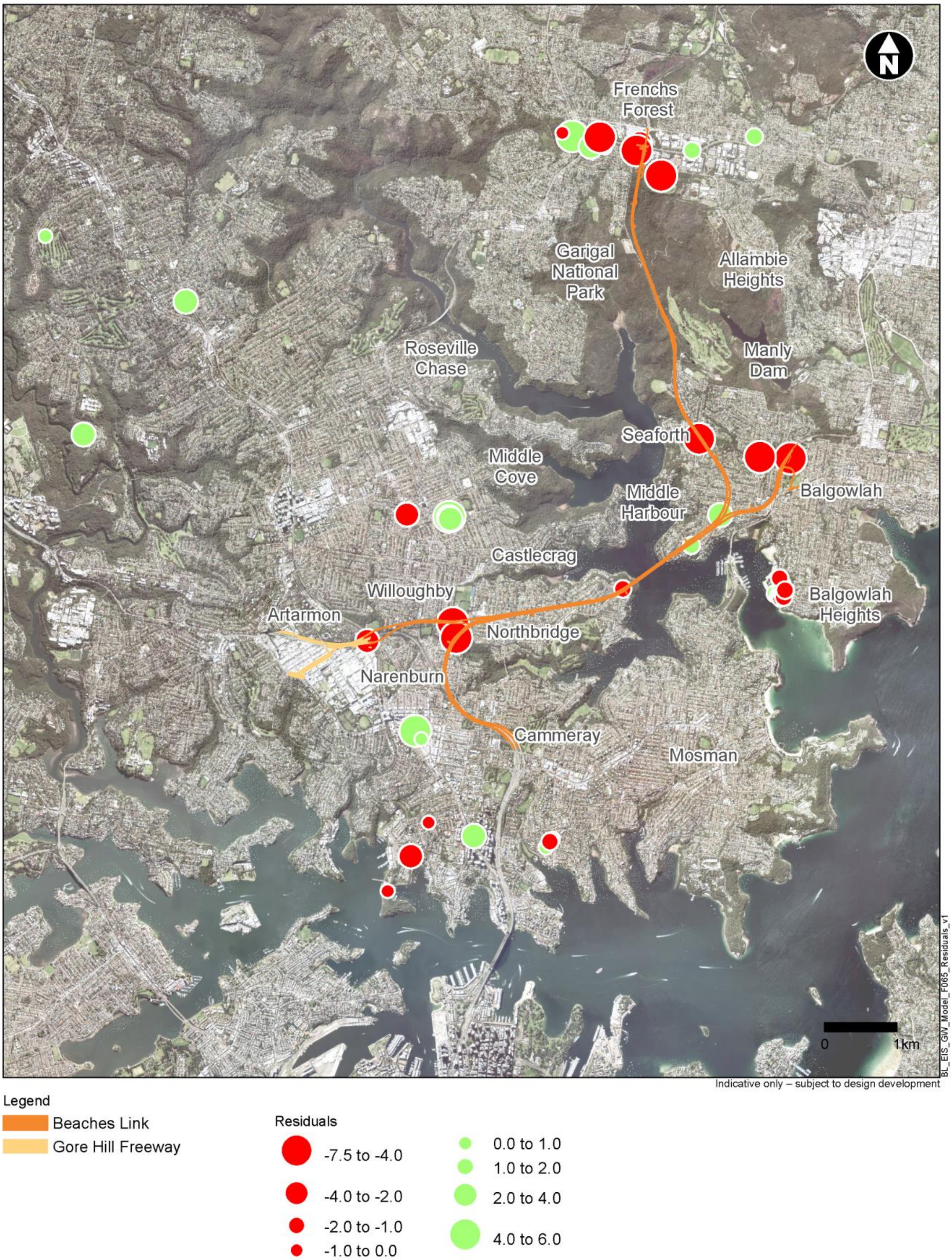


Figure A1-25: Calibration residuals for steady state model

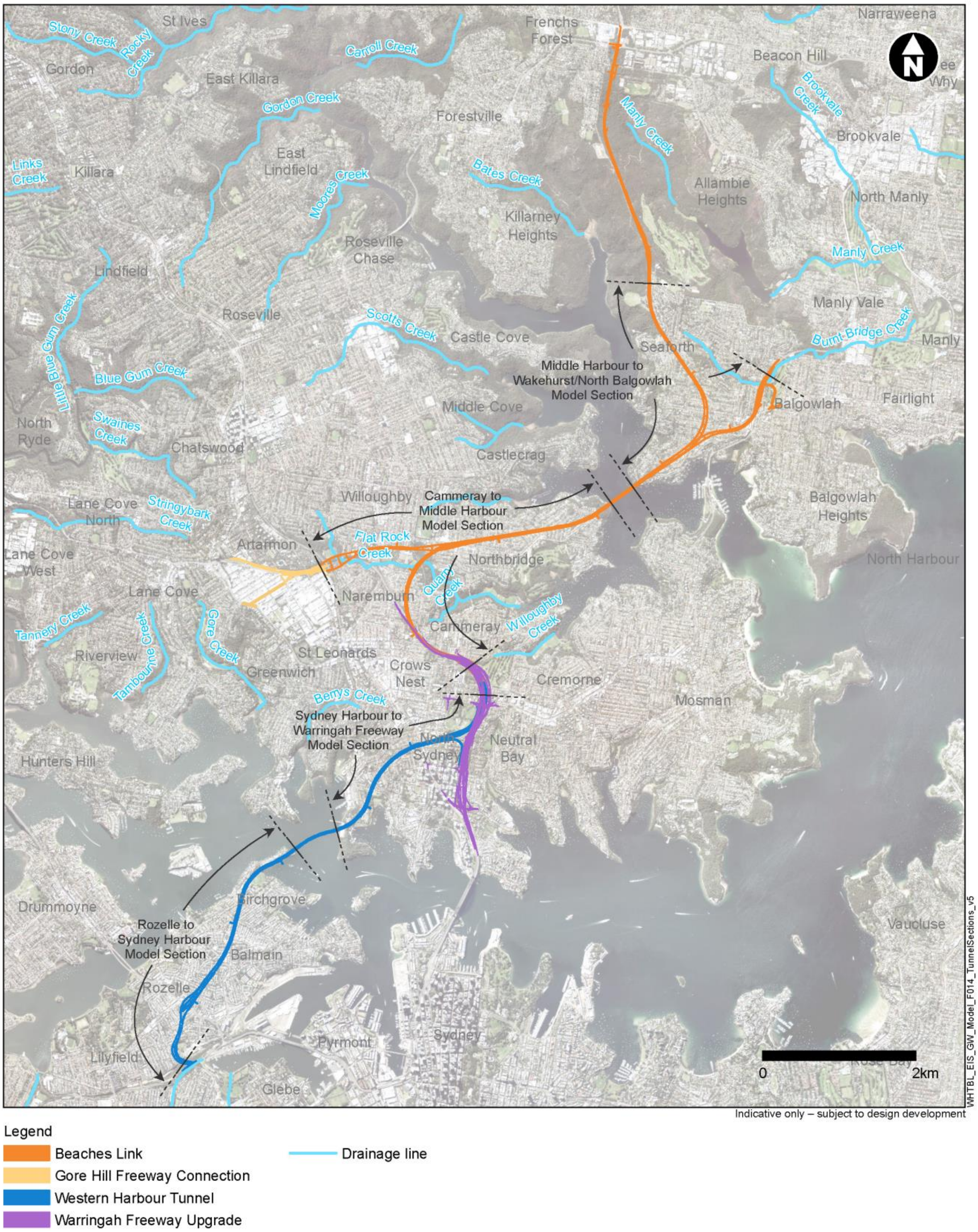


Figure A1-26: Tunnel sections used for reporting inflows

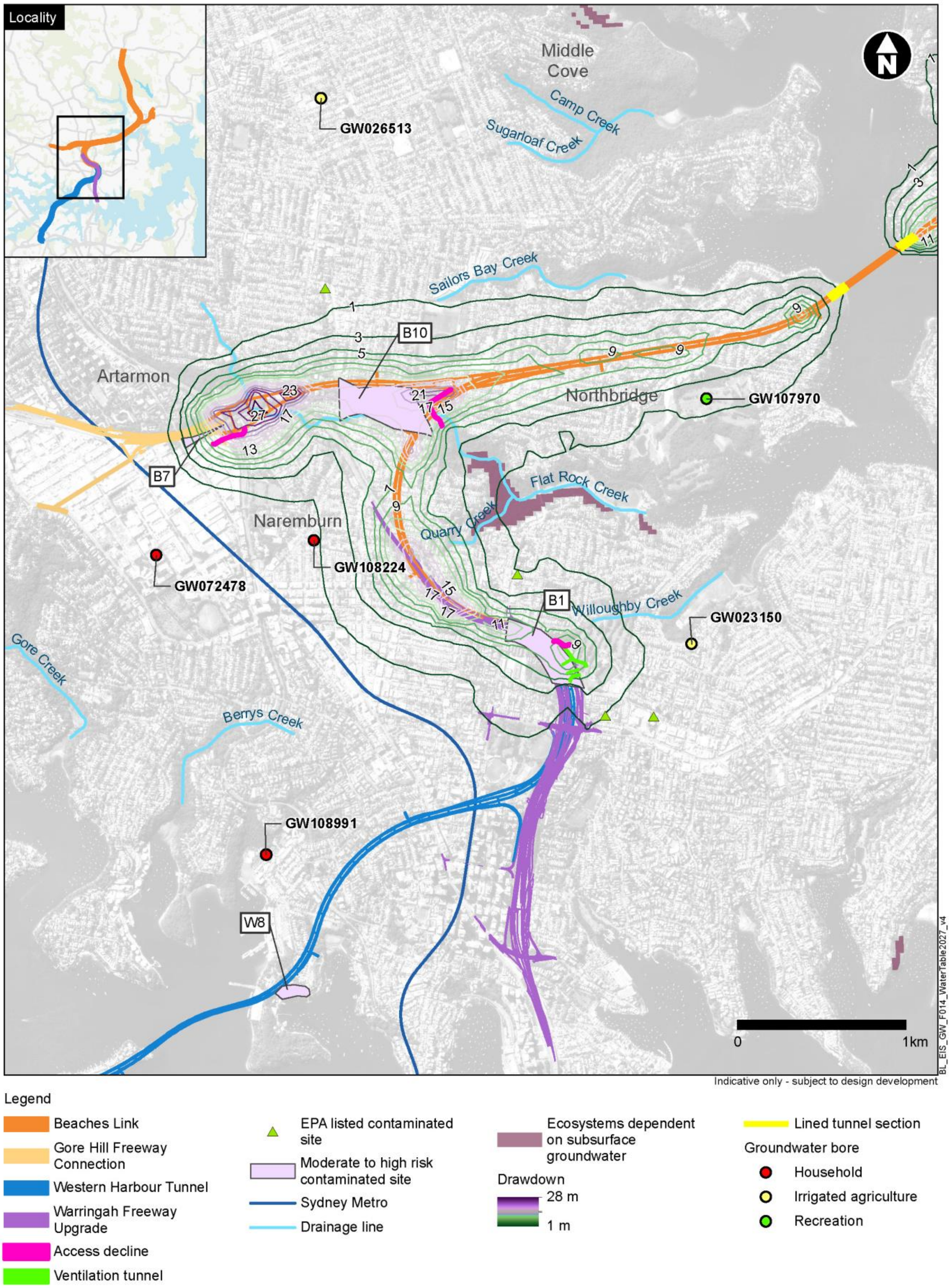


Figure A1-27a: Beaches Link project - Water table drawdown at the end of tunnel construction

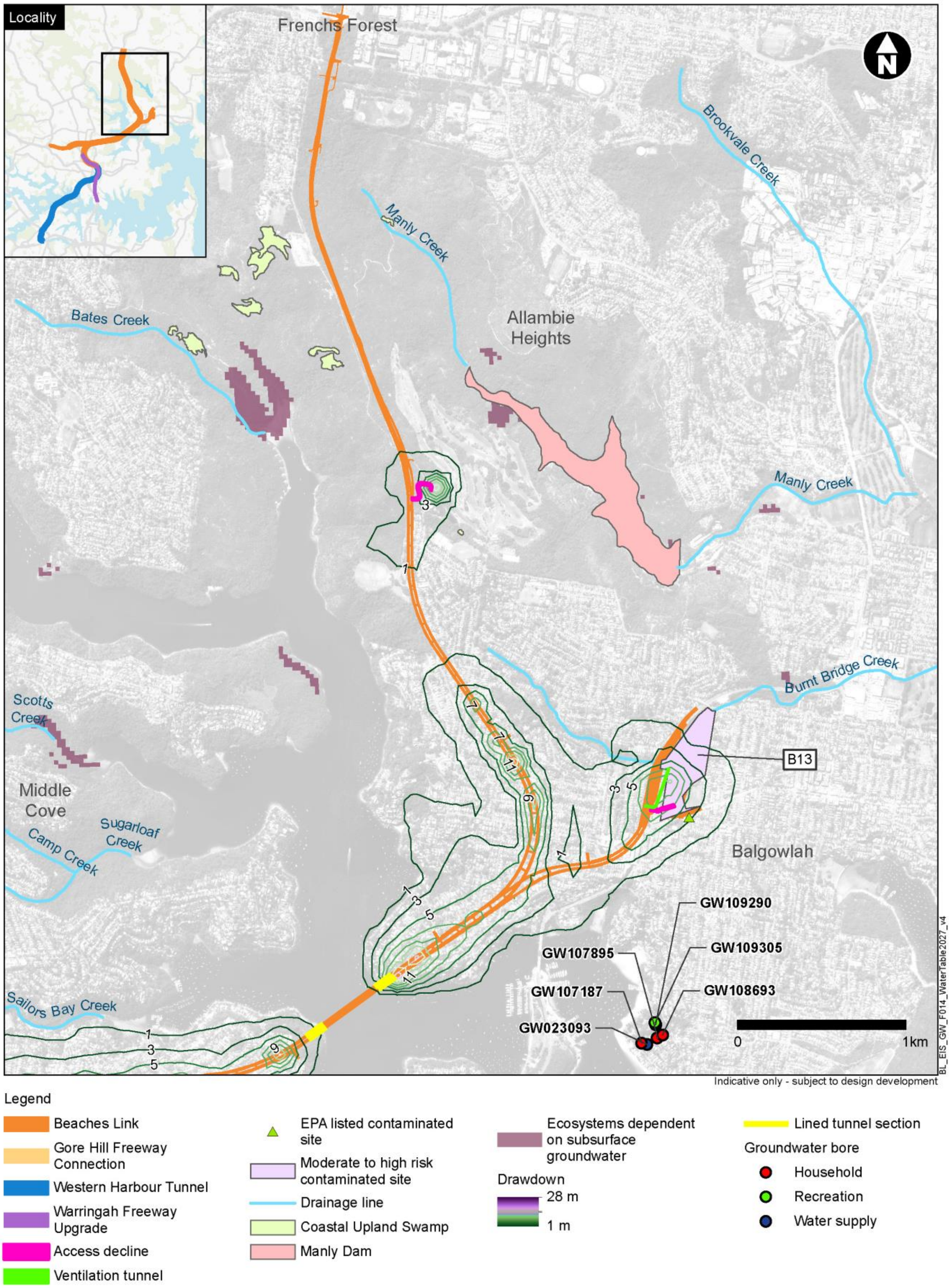


Figure A1-27b: Beaches Link project - Water table drawdown at the end of tunnel construction

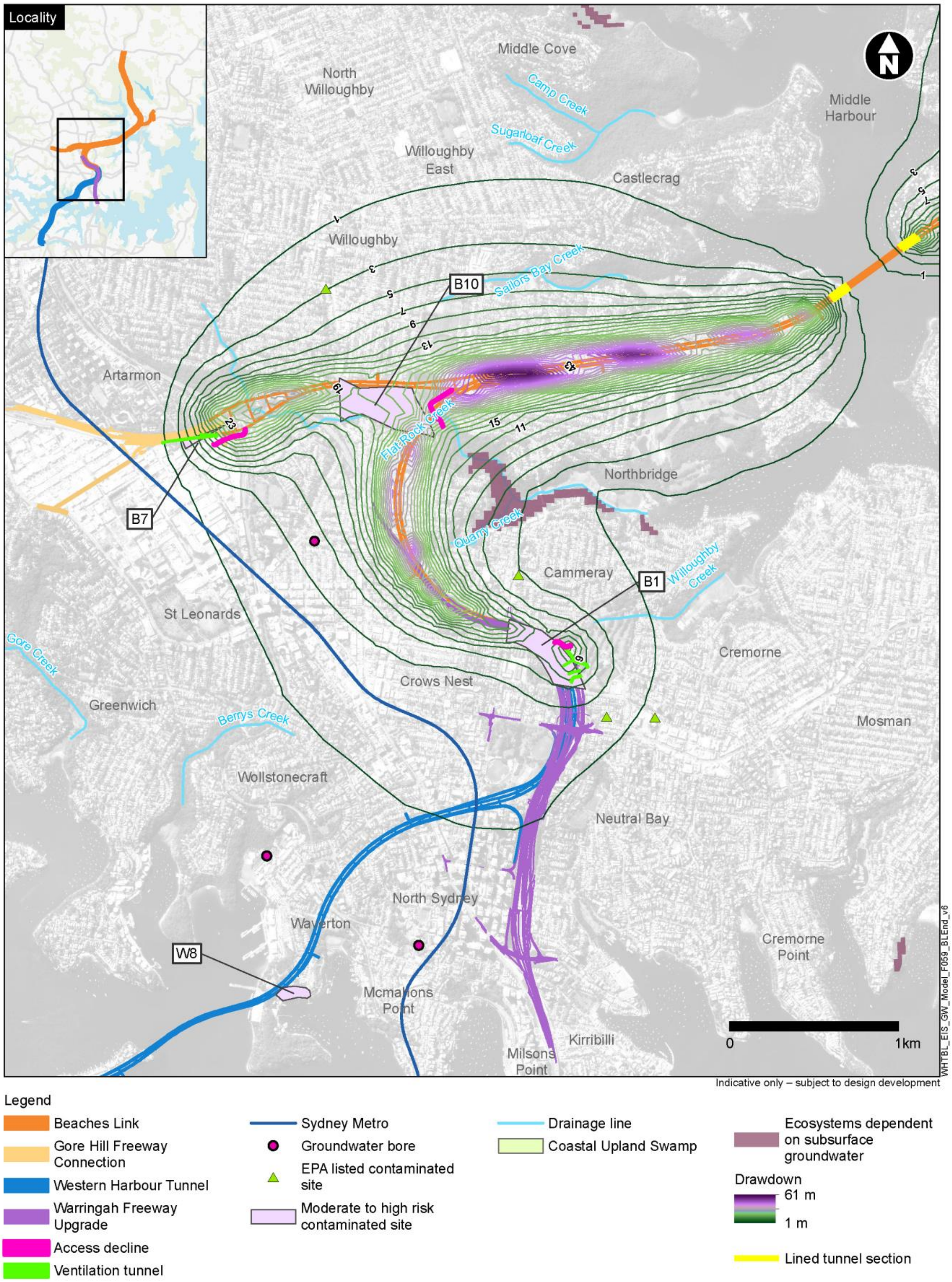


Figure A1-28a: Beaches Link project - Maximum drawdown at the end of tunnel construction

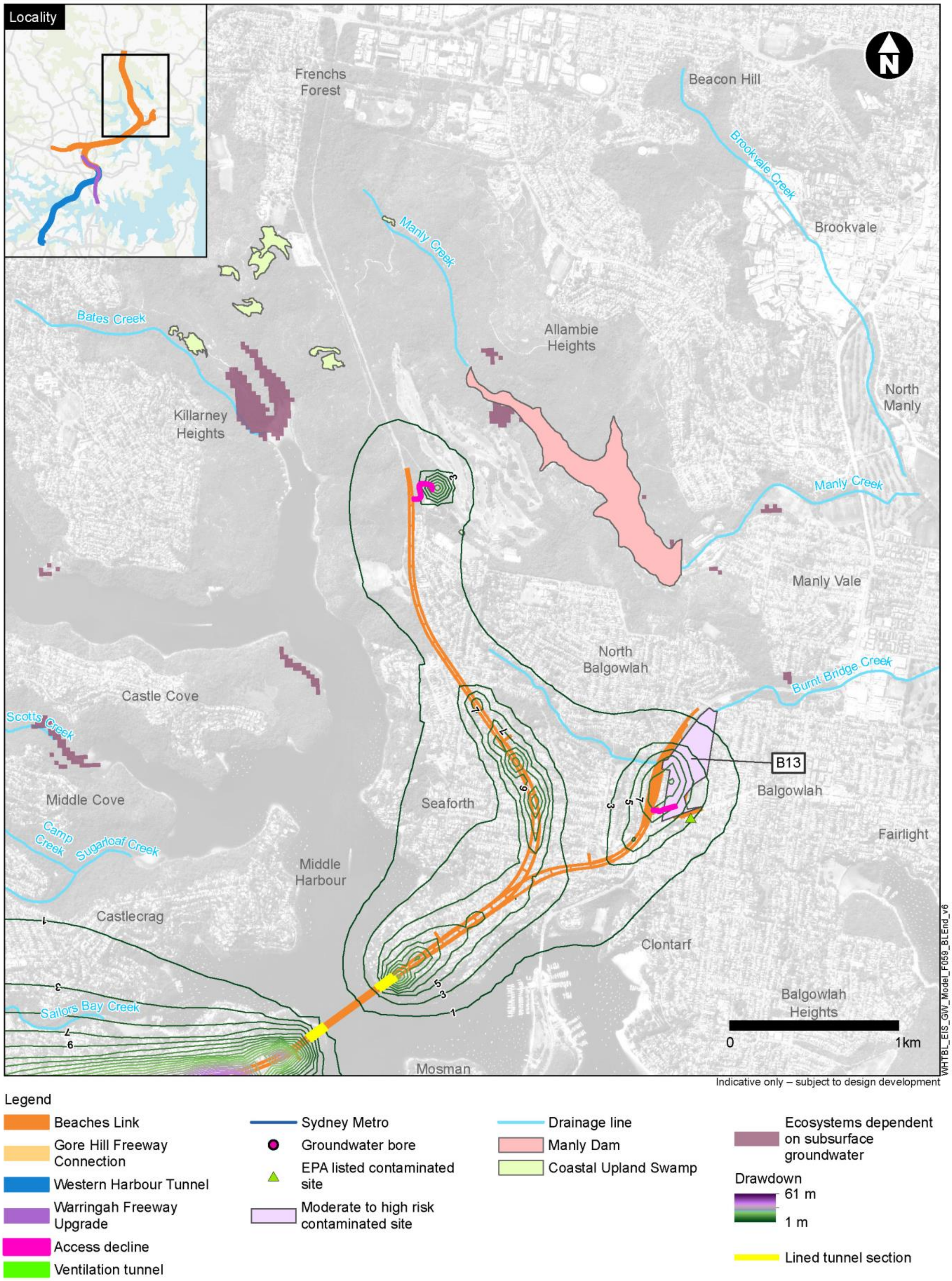


Figure A1-28b: Beaches Link project - Maximum drawdown at the end of tunnel construction

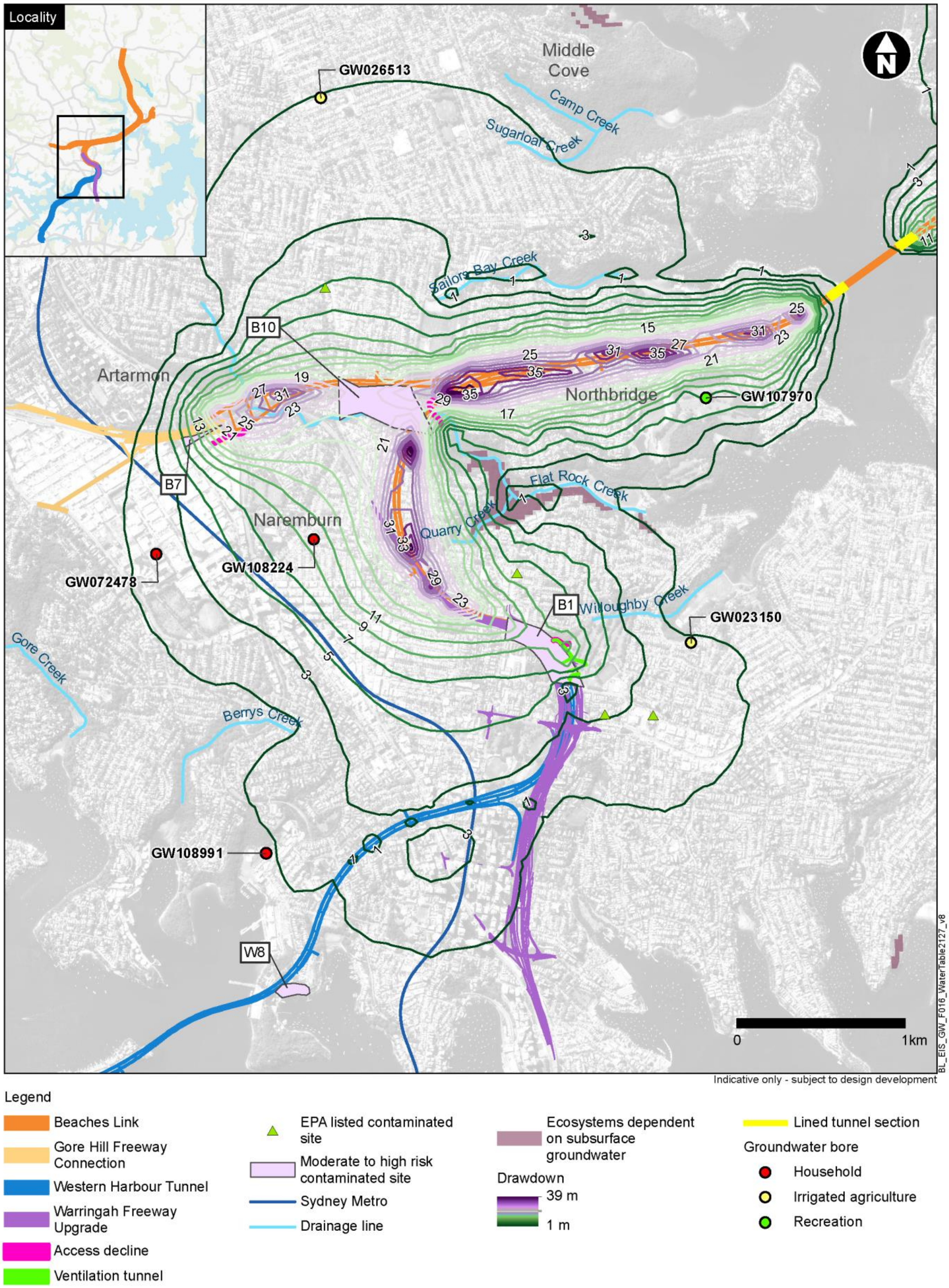


Figure A1-29a: Beaches Link project - Water table drawdown after approximately 100 years of operation

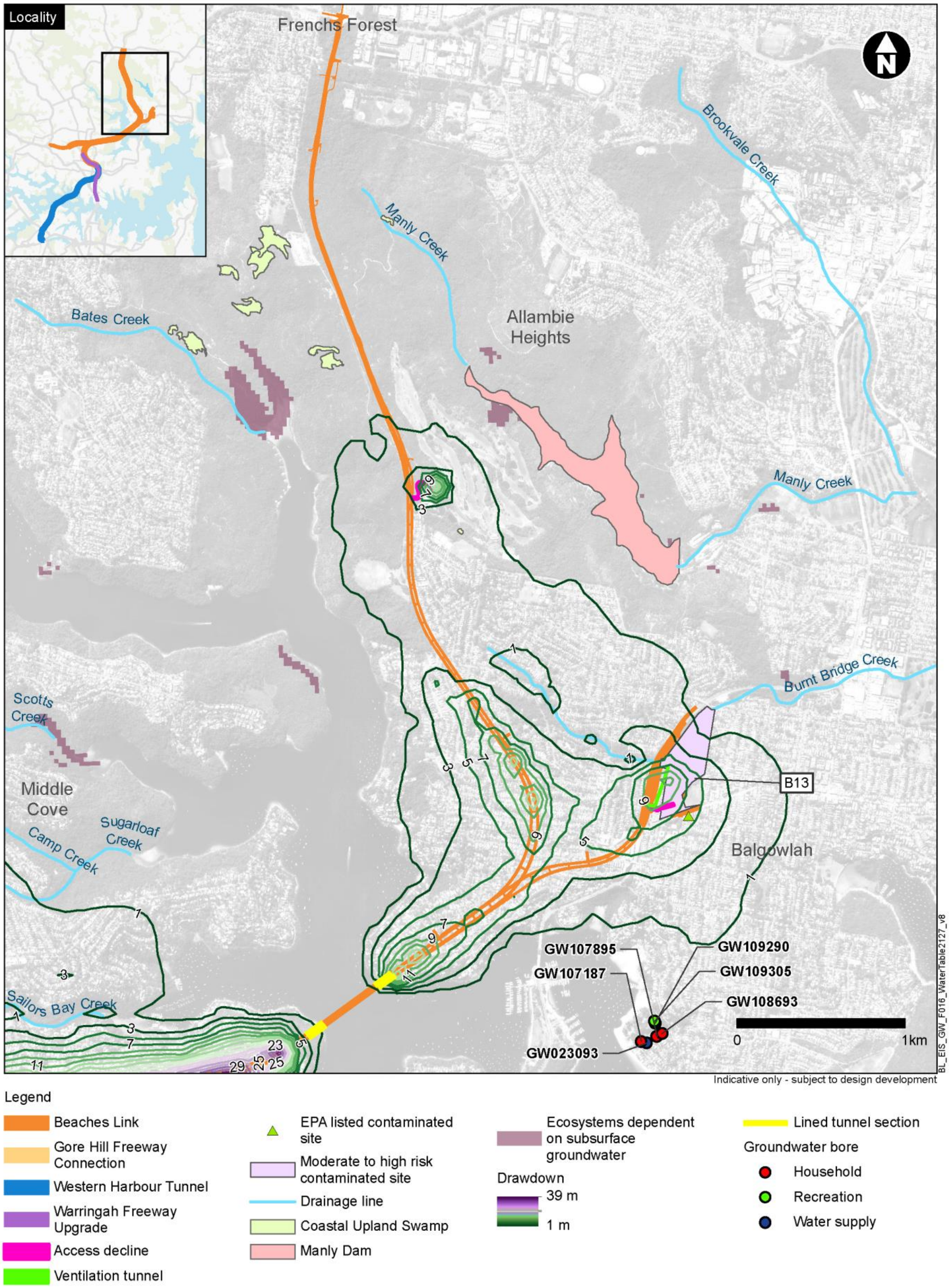


Figure A1-29b: Beaches Link project - Water table drawdown after approximately 100 years of operation

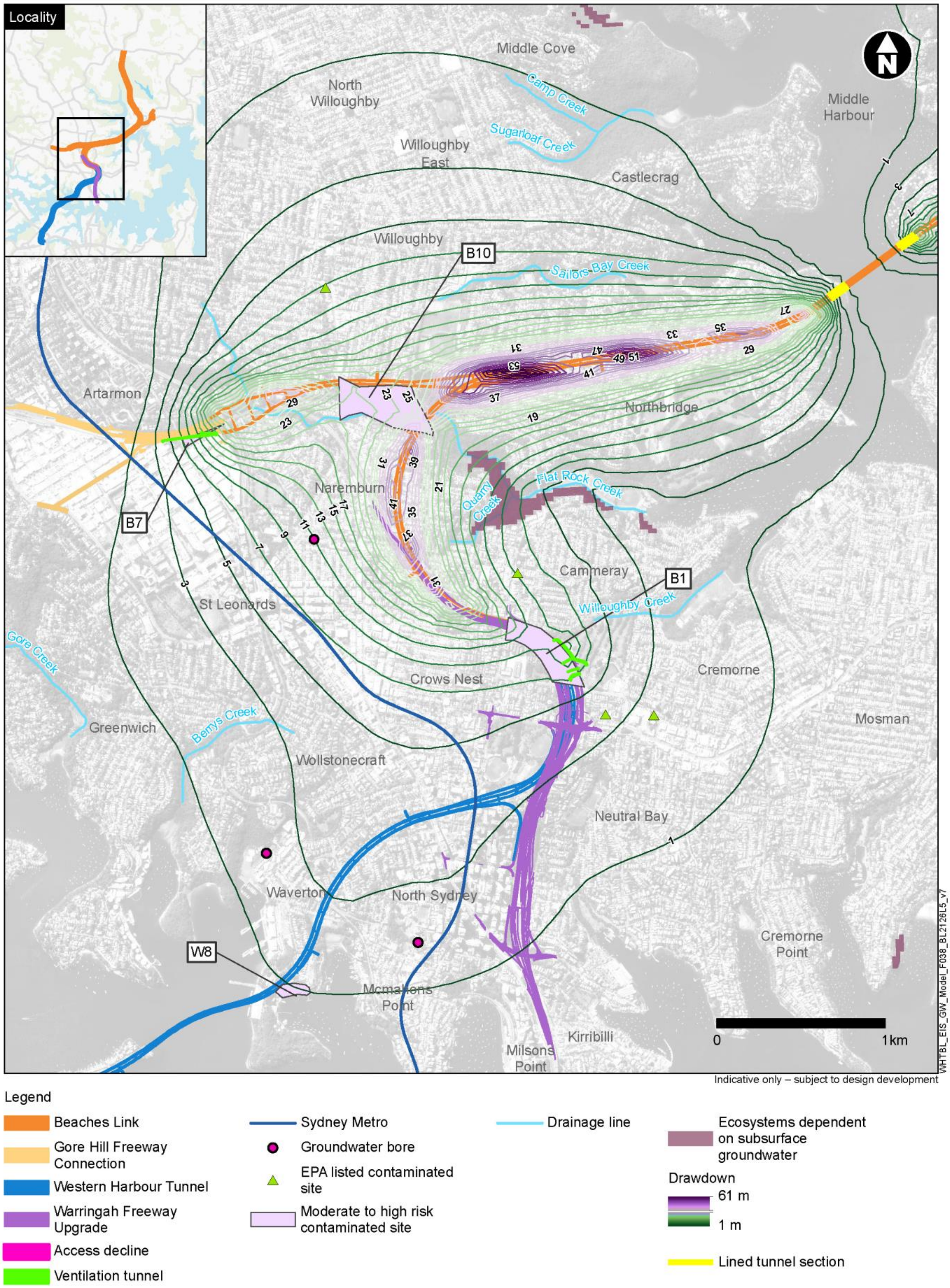


Figure A1-30a: Beaches Link project - Maximum drawdown after approximately 100 years of operation

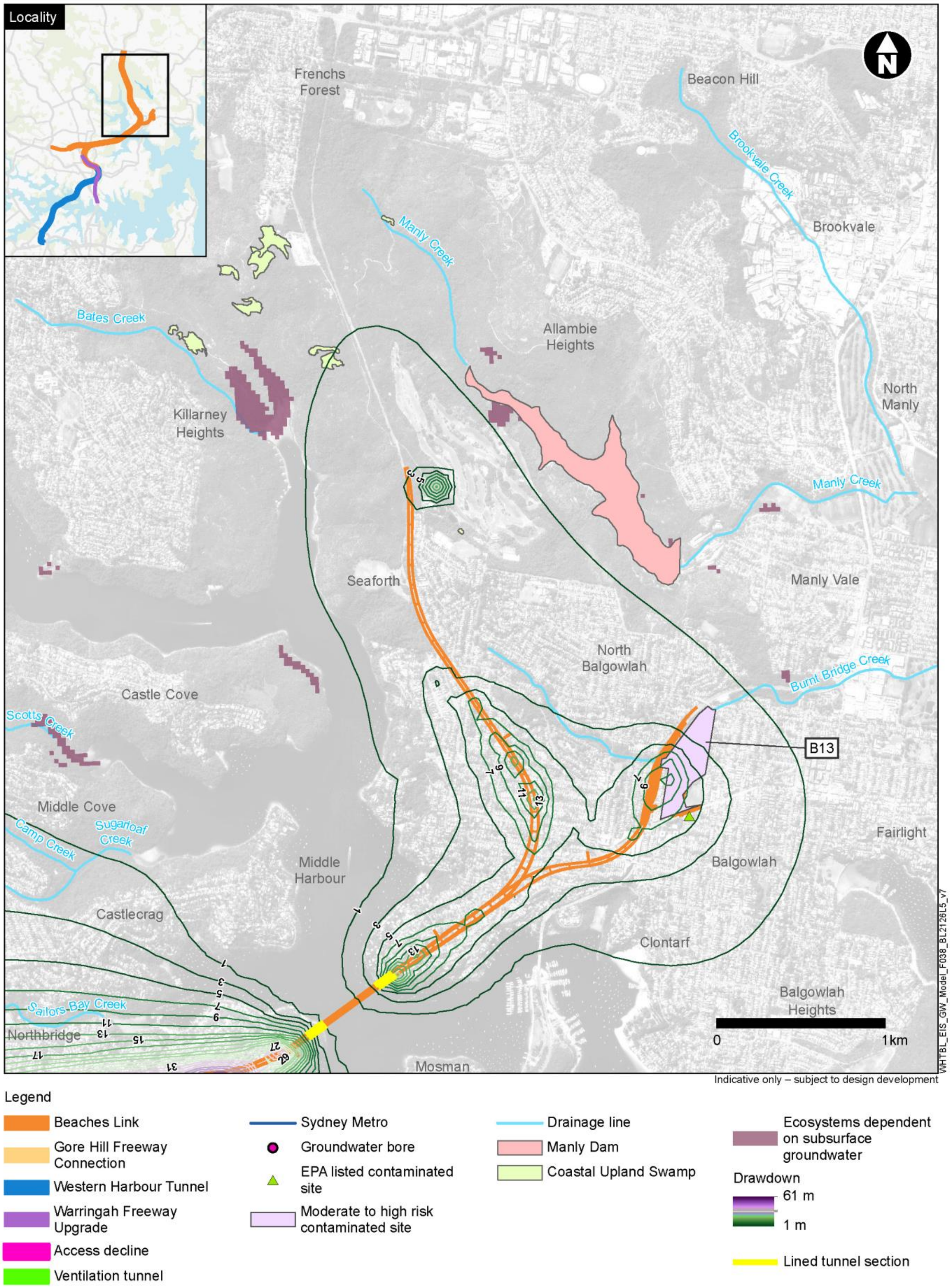


Figure A1-30b: Beaches Link project - Maximum drawdown after approximately 100 years of operation

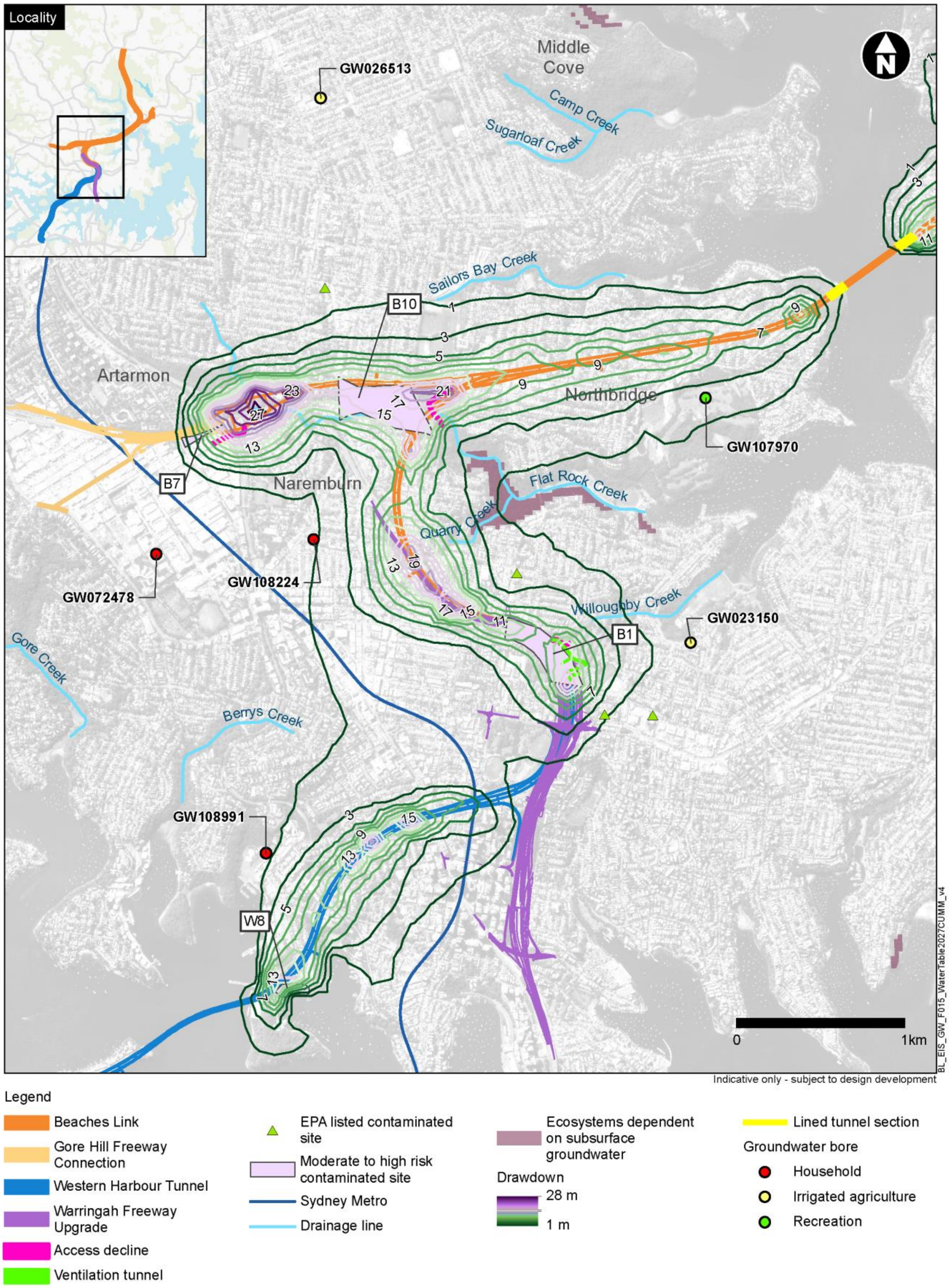


Figure A1-31a: Cumulative water table drawdown at the end of construction

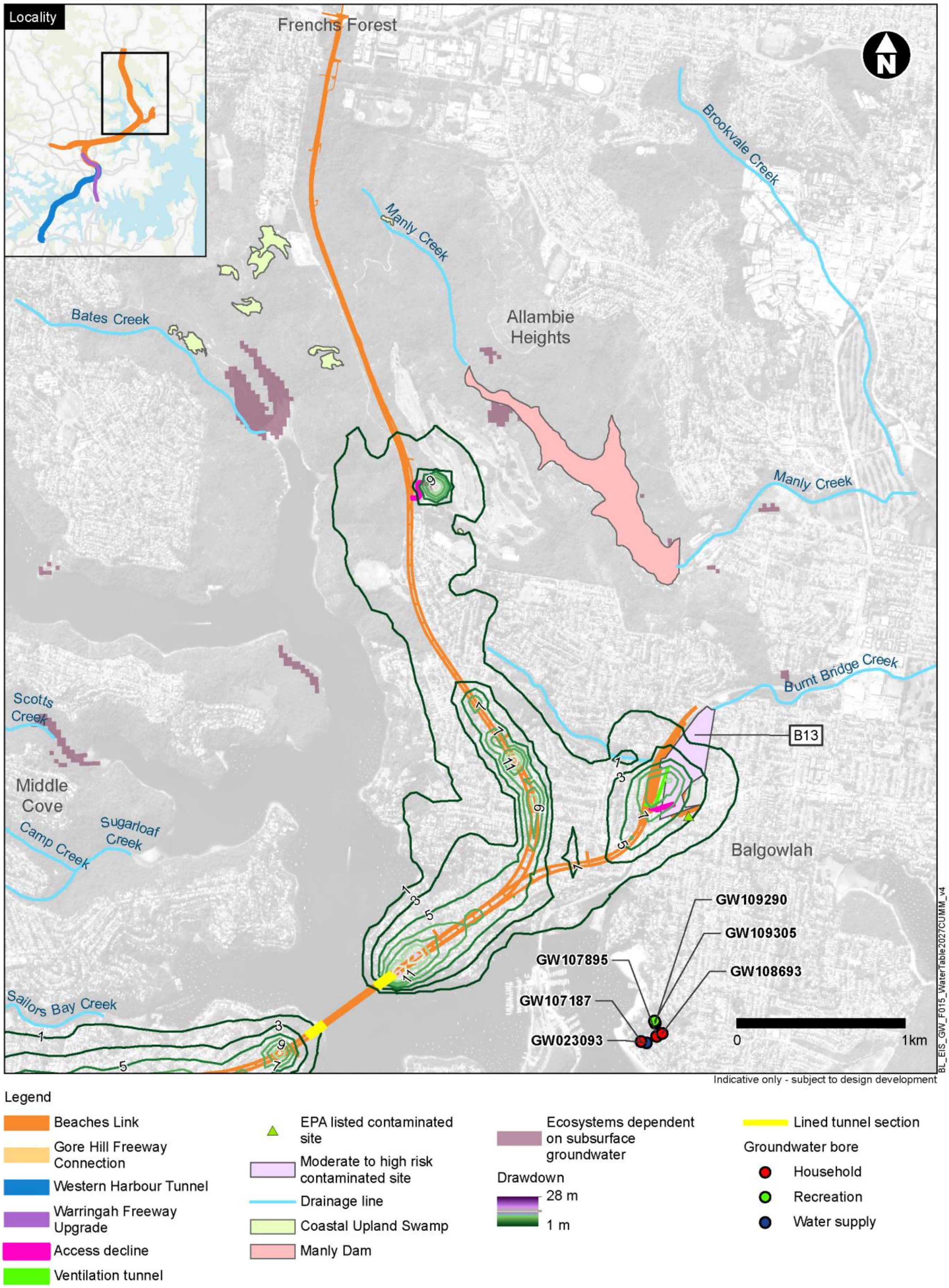


Figure A1-31b: Cumulative water table drawdown at the end of construction

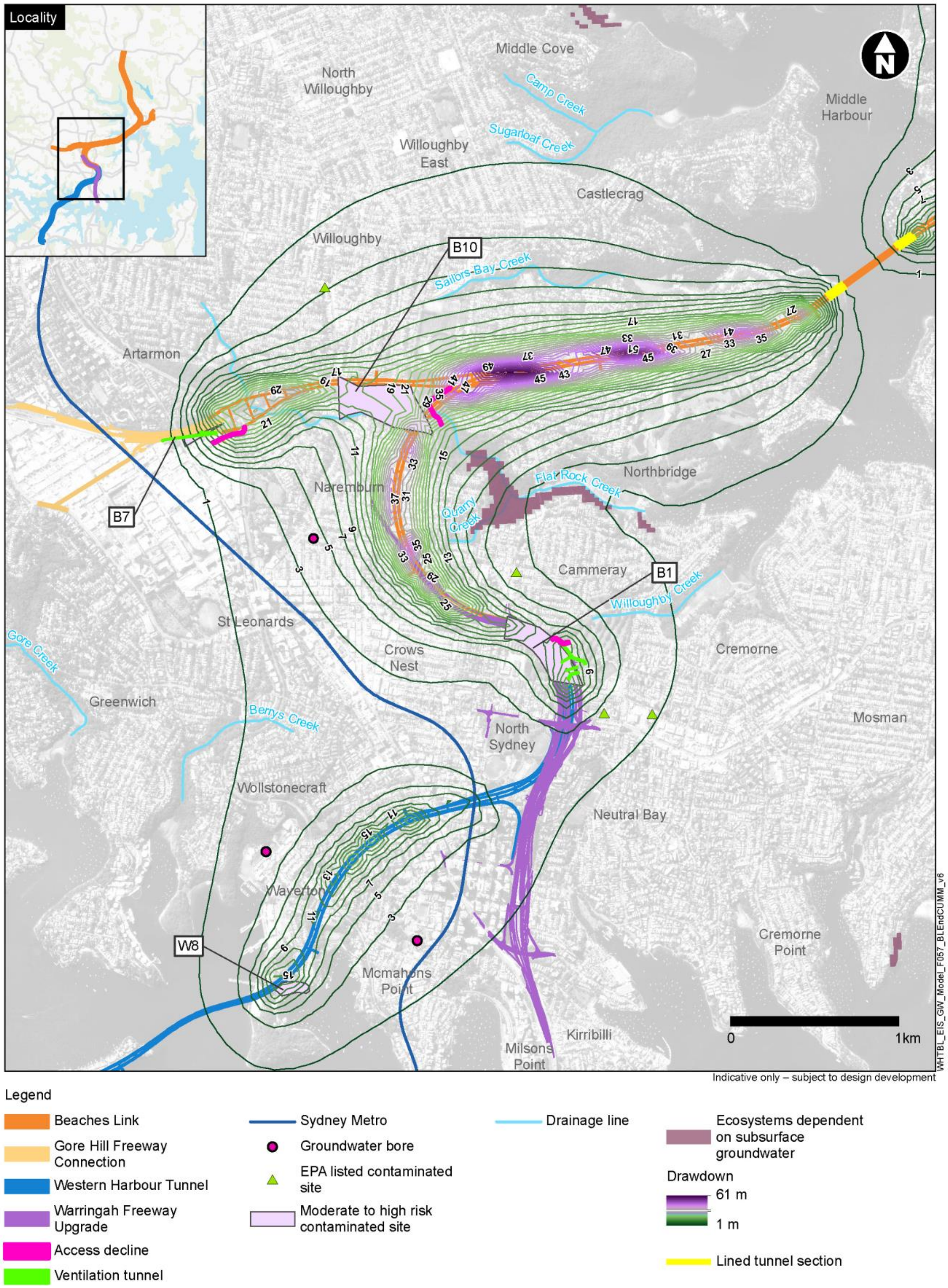


Figure A1-32a: Cumulative maximum drawdown at end of construction

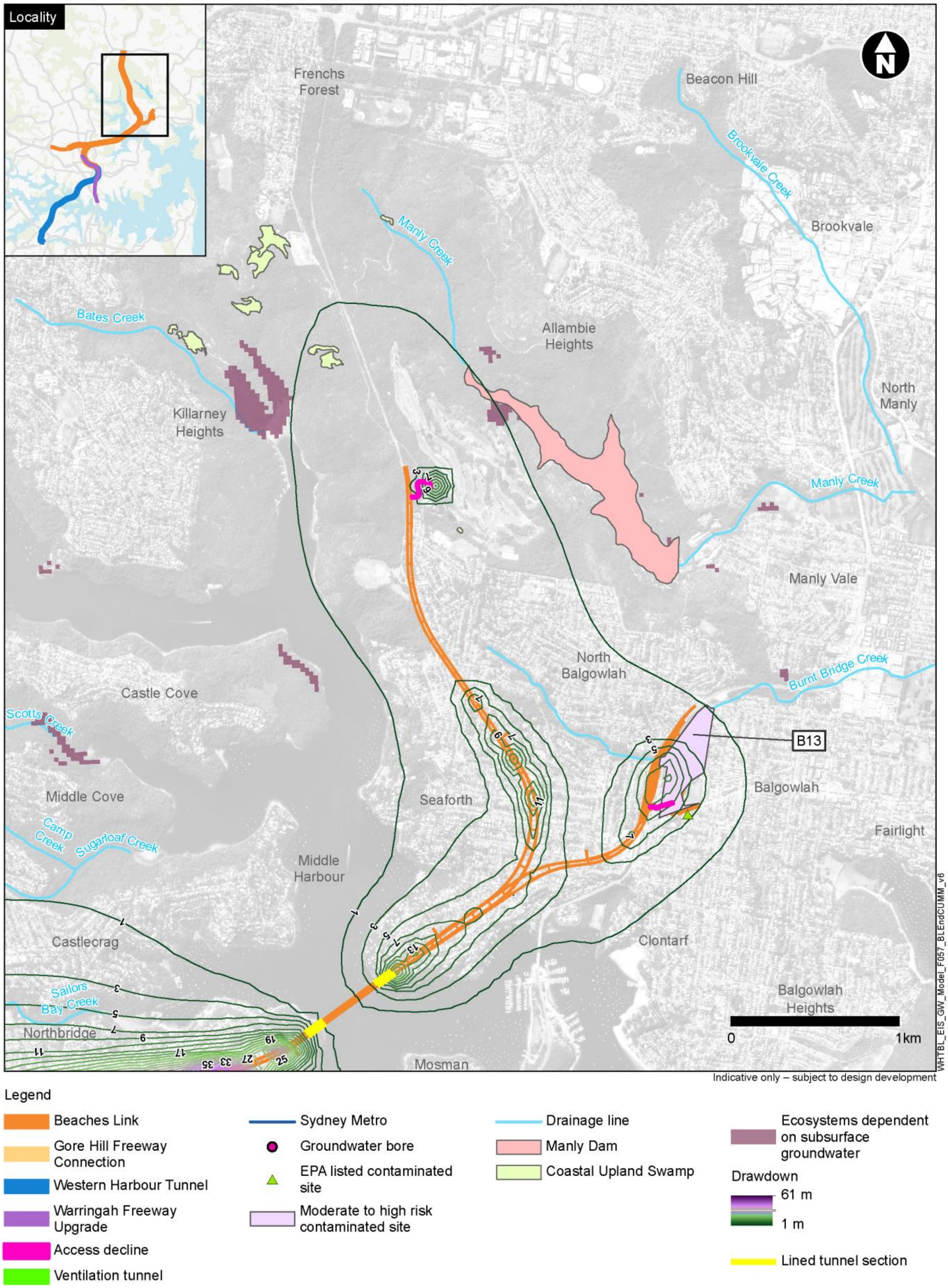


Figure A1-32b: Cumulative maximum drawdown at end of construction

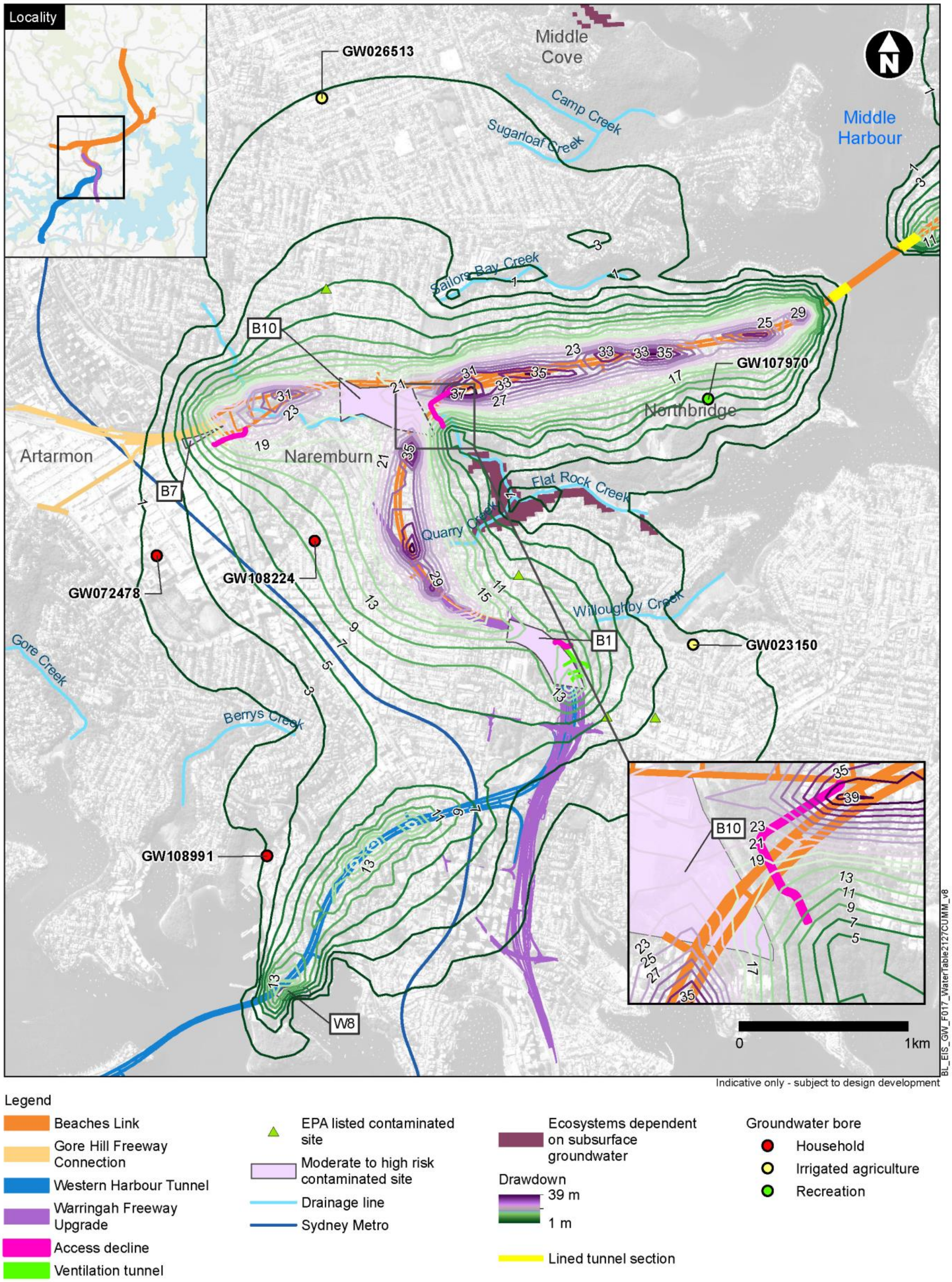


Figure A1-33a: Cumulative water table drawdown after approximately 100 years of operation

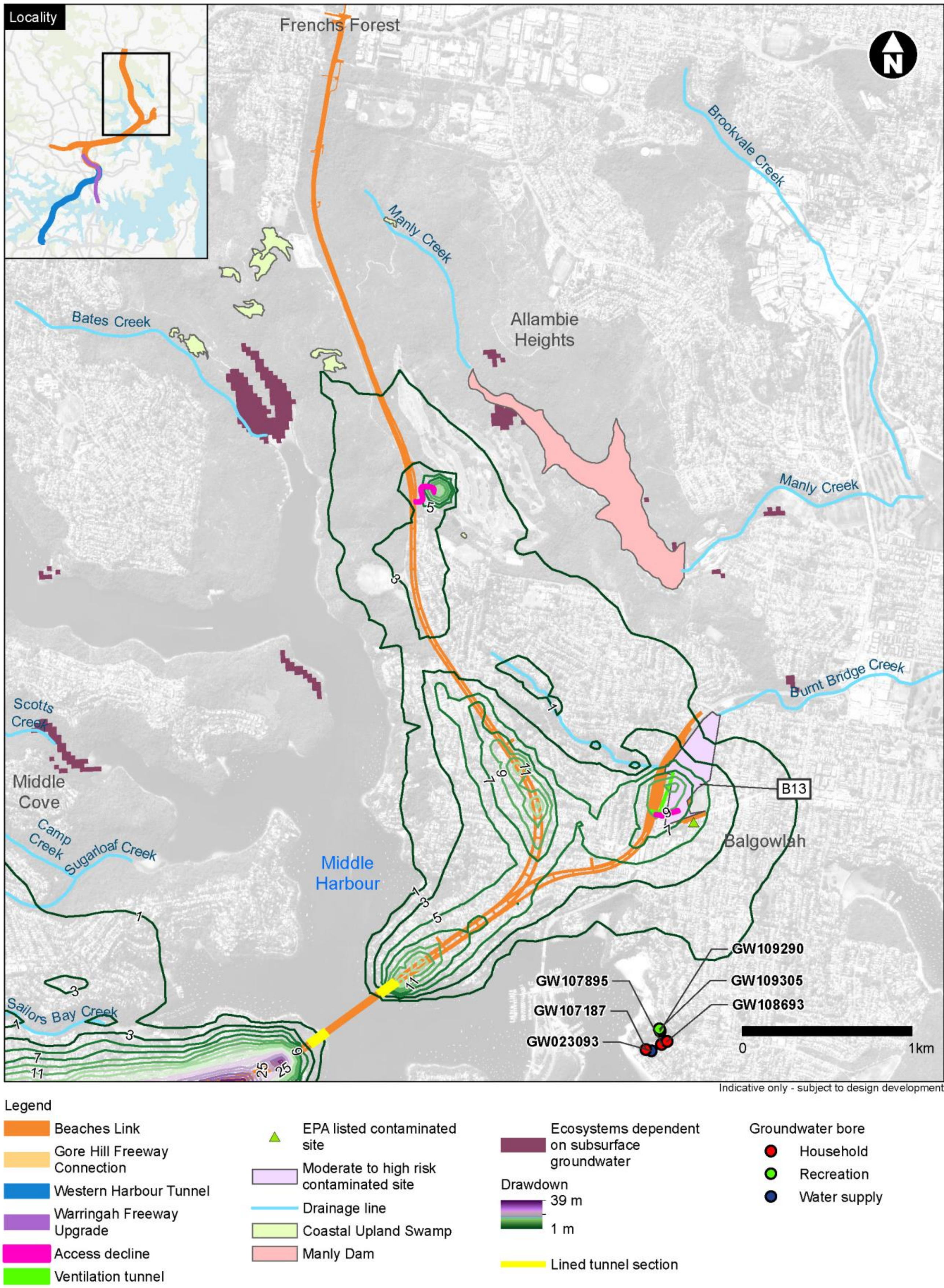


Figure A1-33b: Cumulative water table drawdown after approximately 100 years of operation

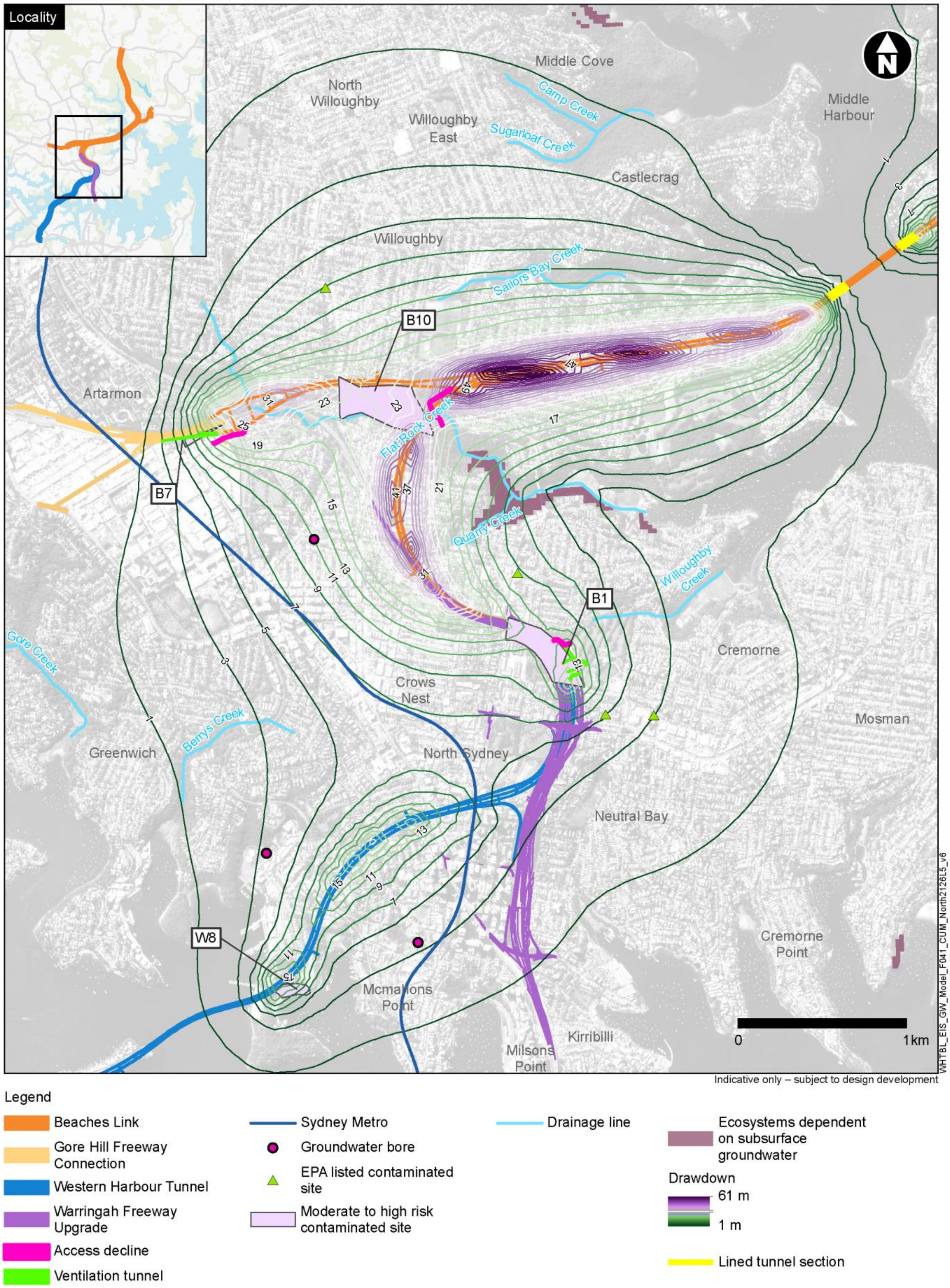


Figure A1-34a: Cumulative maximum drawdown after approximately 100 years of operation

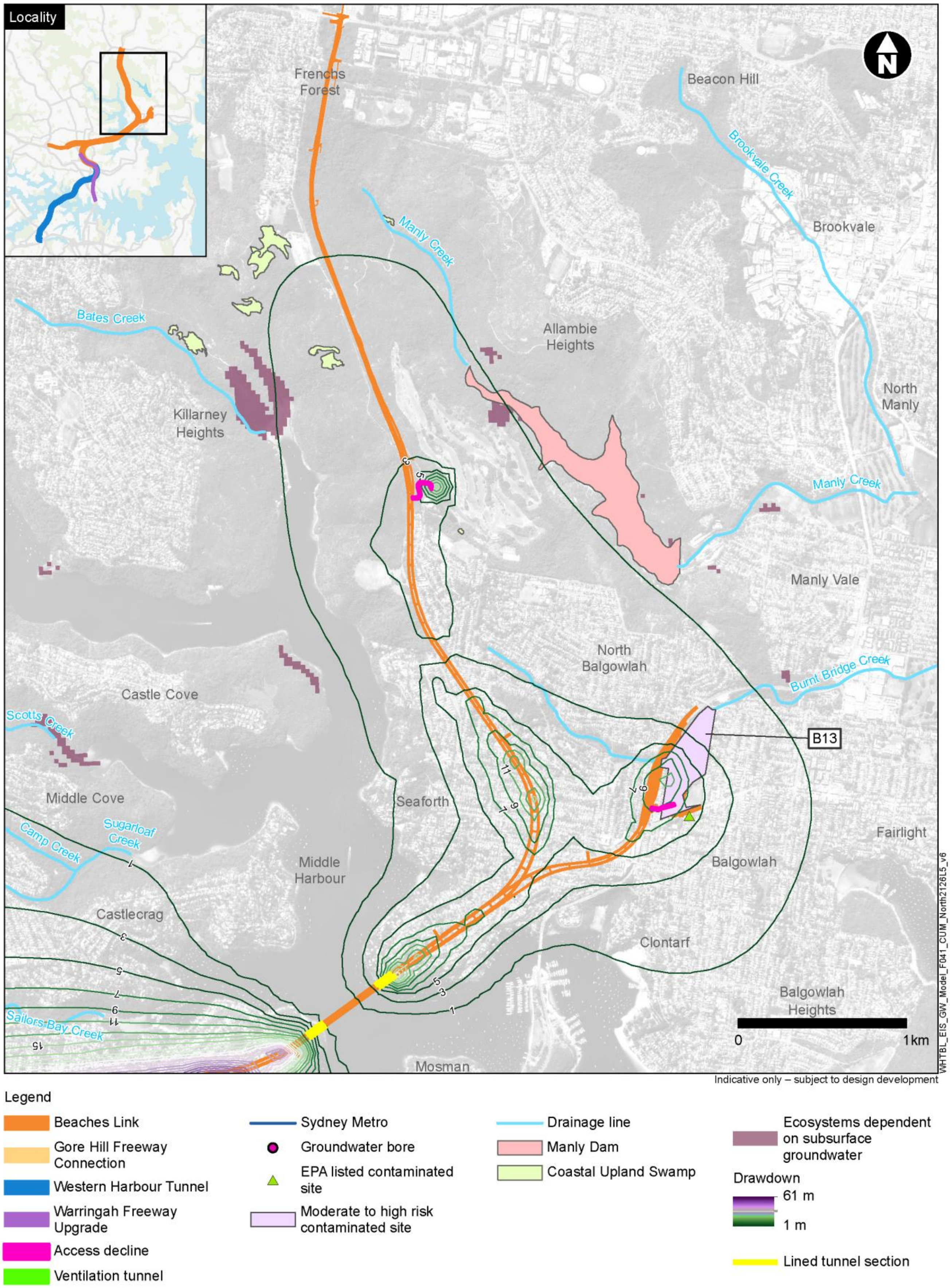


Figure A1-34b: Cumulative maximum drawdown after approximately 100 years of operation

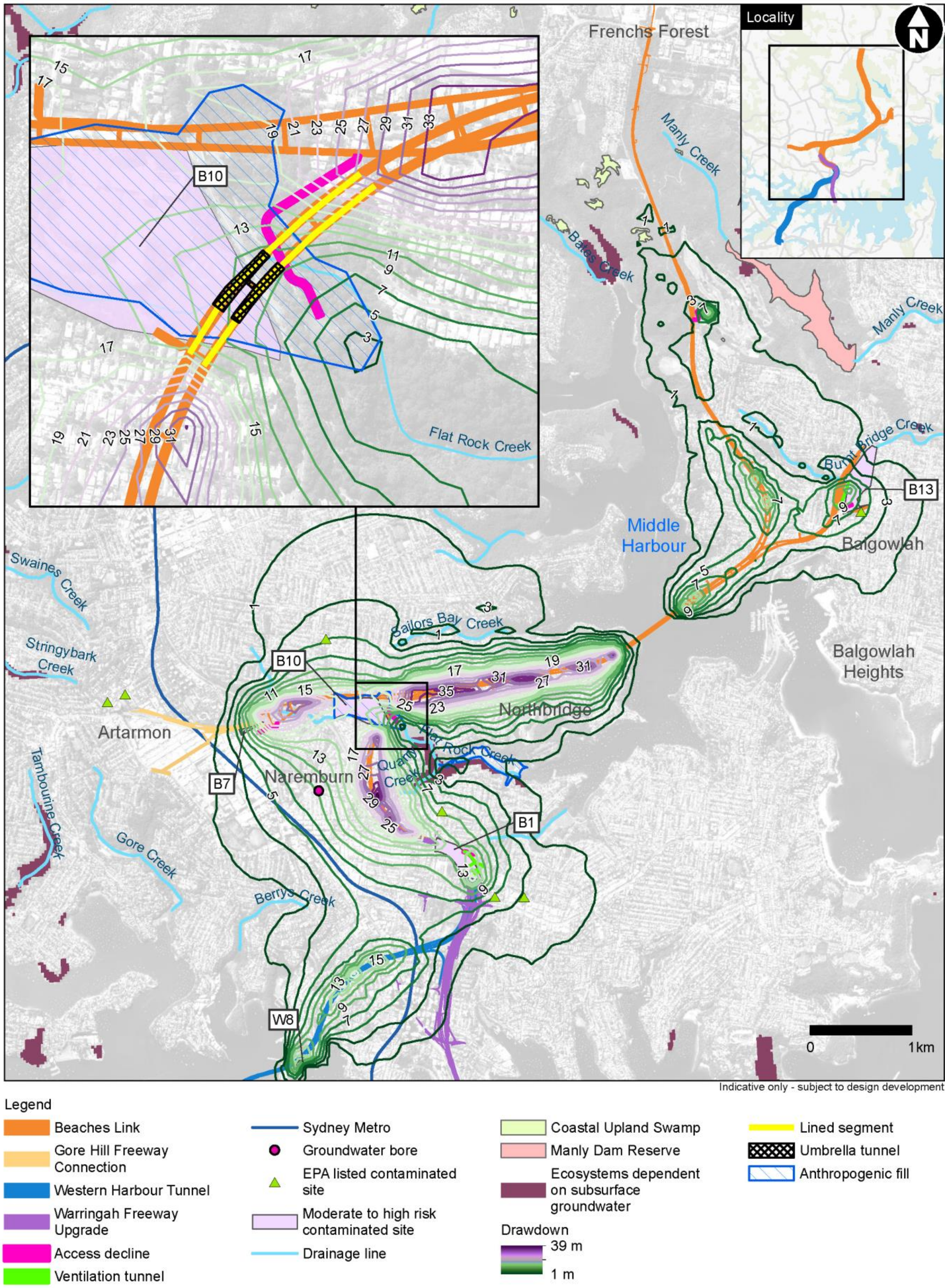


Figure A1-35: Predicted water table drawdown after about 100 years – Flat Rock Reserve lined tunnel scenario

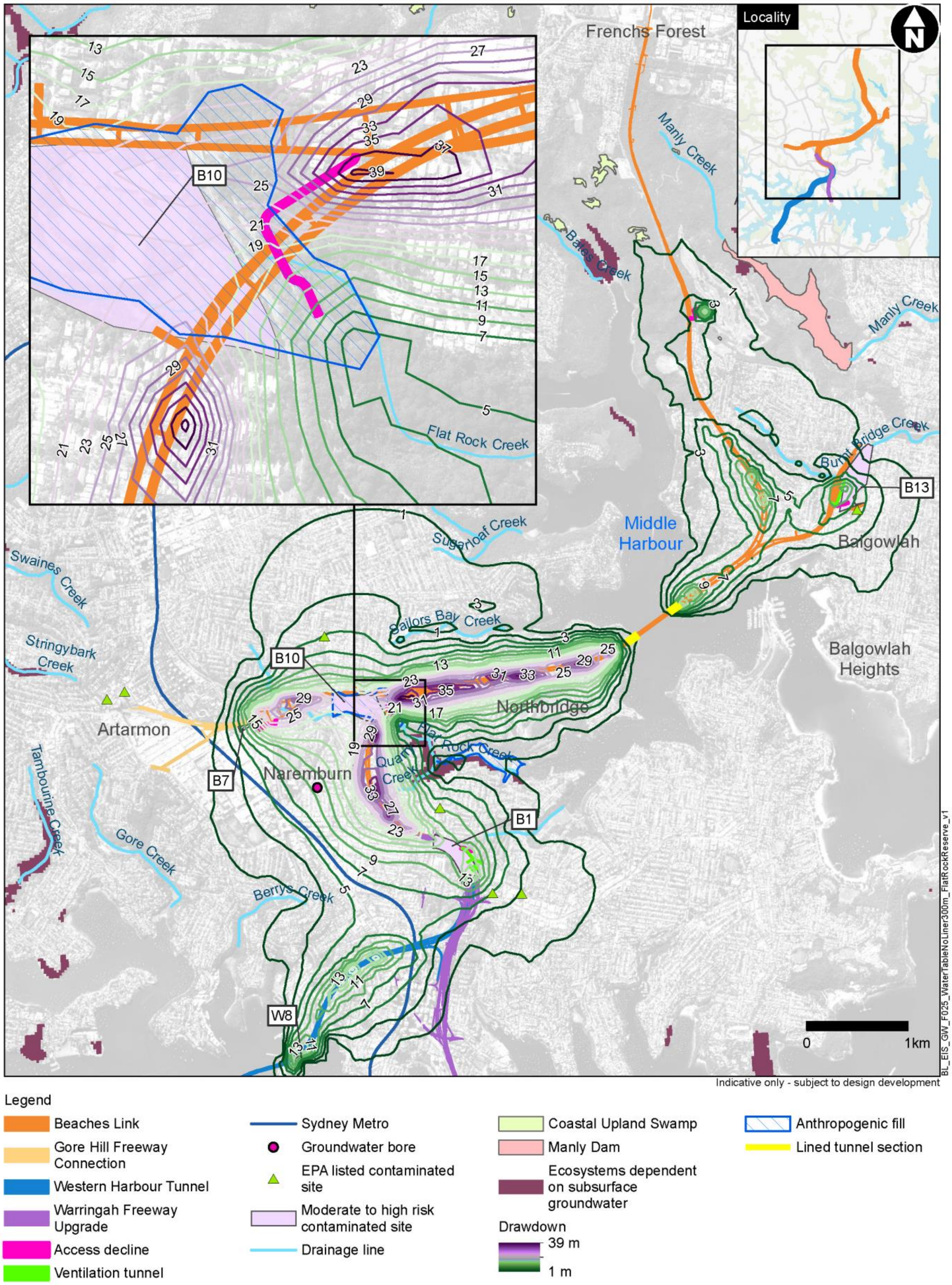


Figure A1-36: Predicted water table drawdown after about 100 years – Flat Rock Reserve unlined tunnel scenario

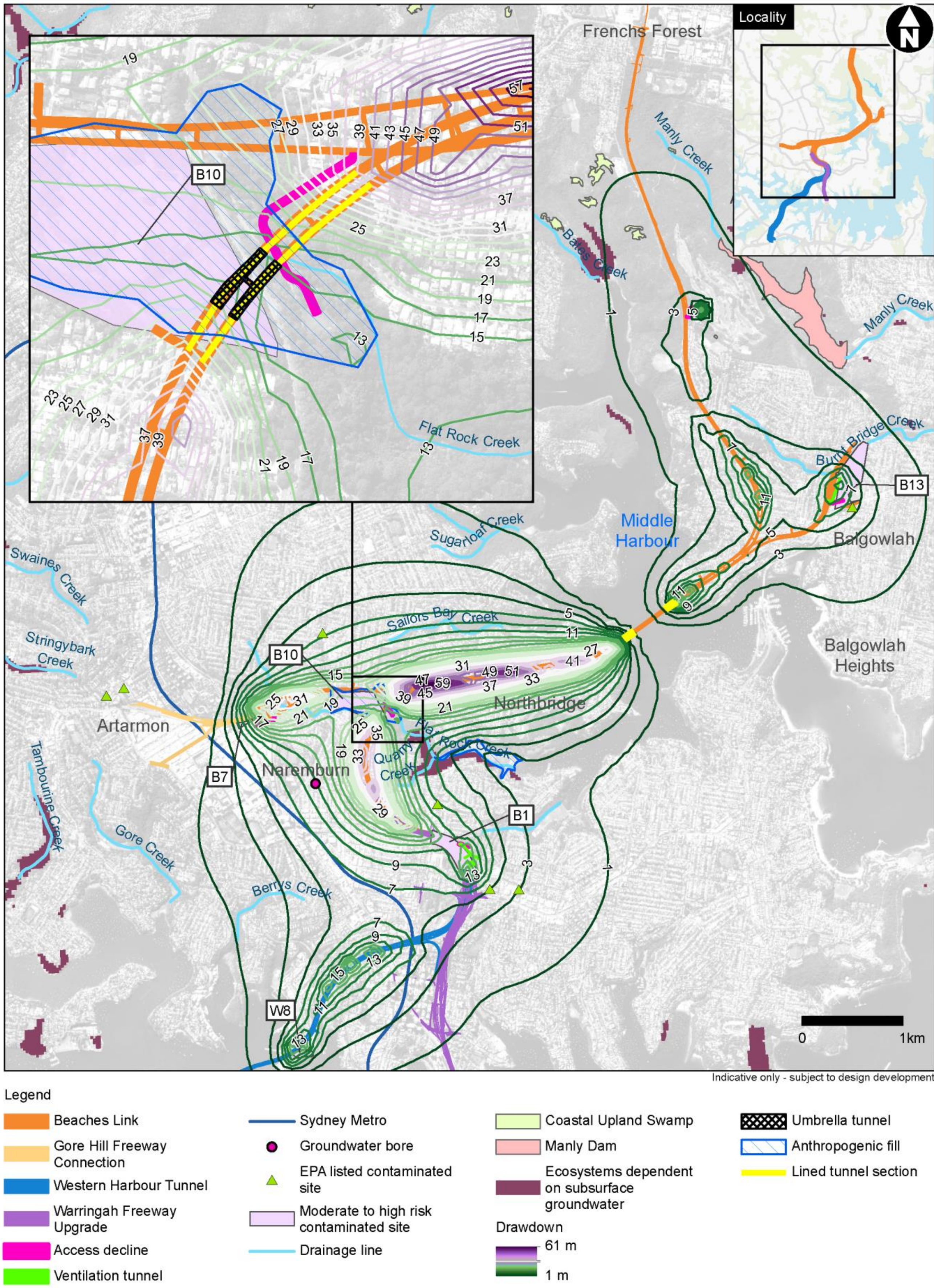


Figure A1-37: Predicted maximum drawdown after about 100 years – Flat Rock Reserve lined tunnel scenario

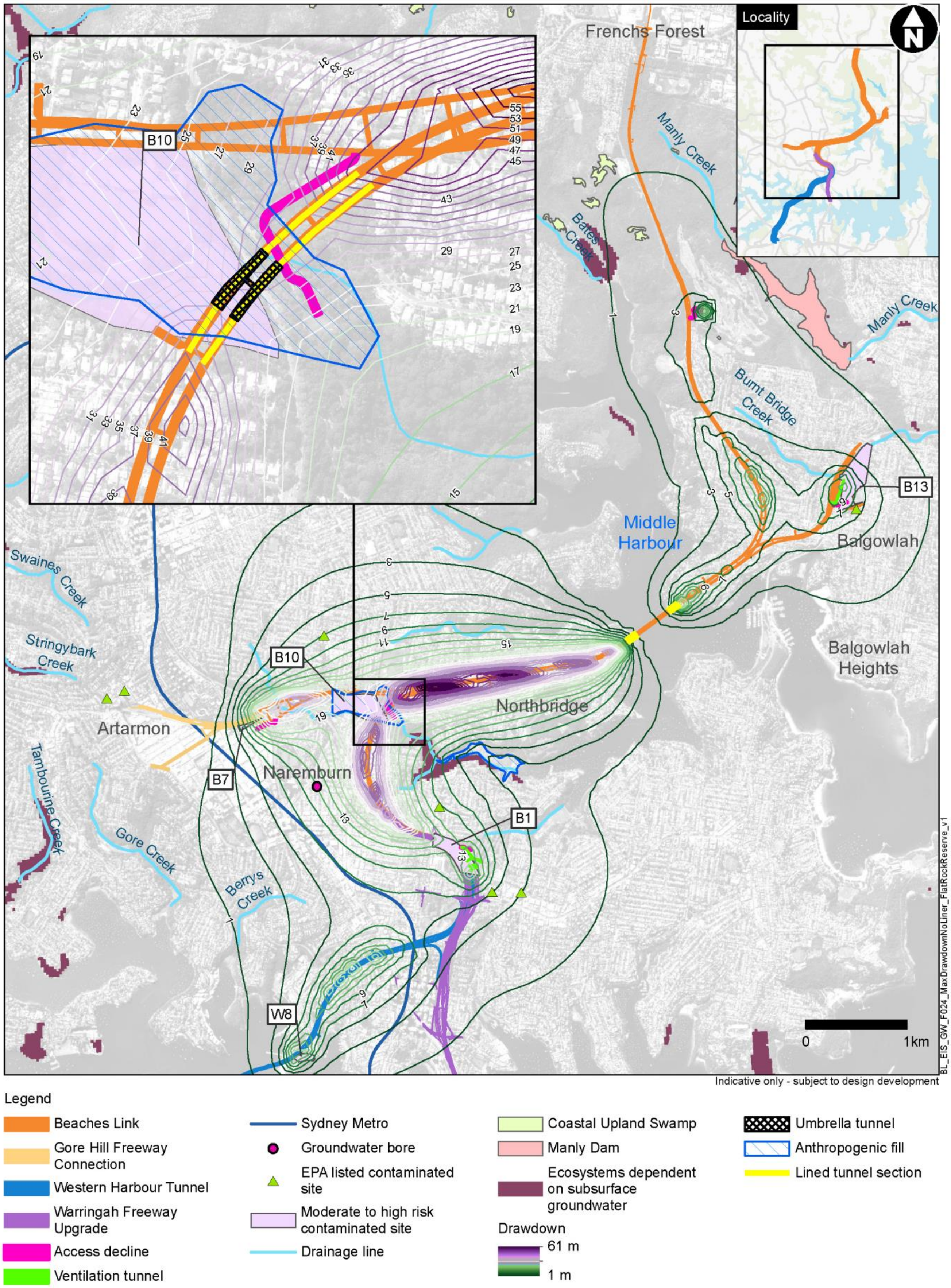


Figure A1-38: Predicted maximum drawdown after about 100 years – Flat Rock Reserve unlined tunnel scenario

Attachment 2 Conceptual hydrogeological cross-sections

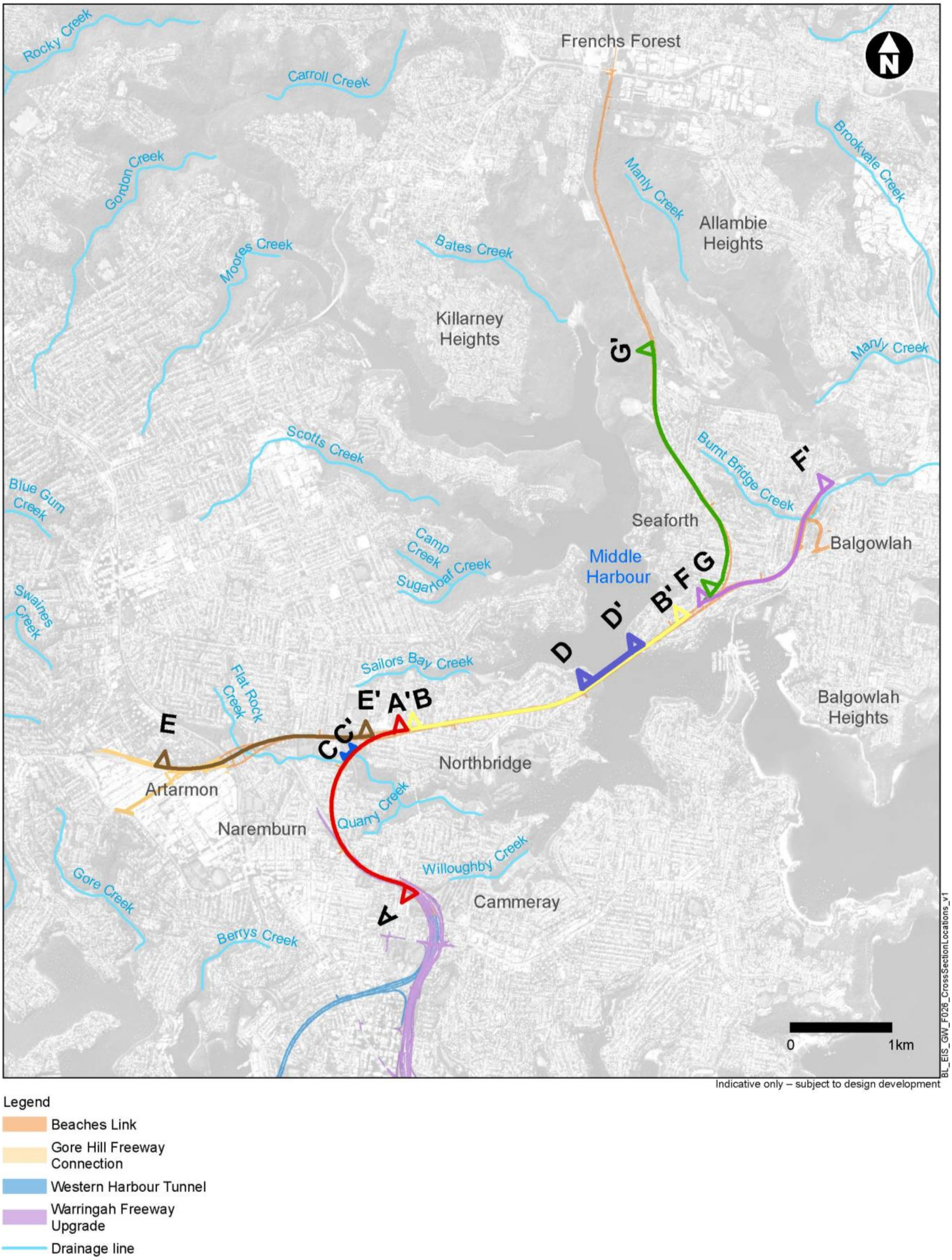


Figure A2-1: Location of hydrogeological cross-section lines

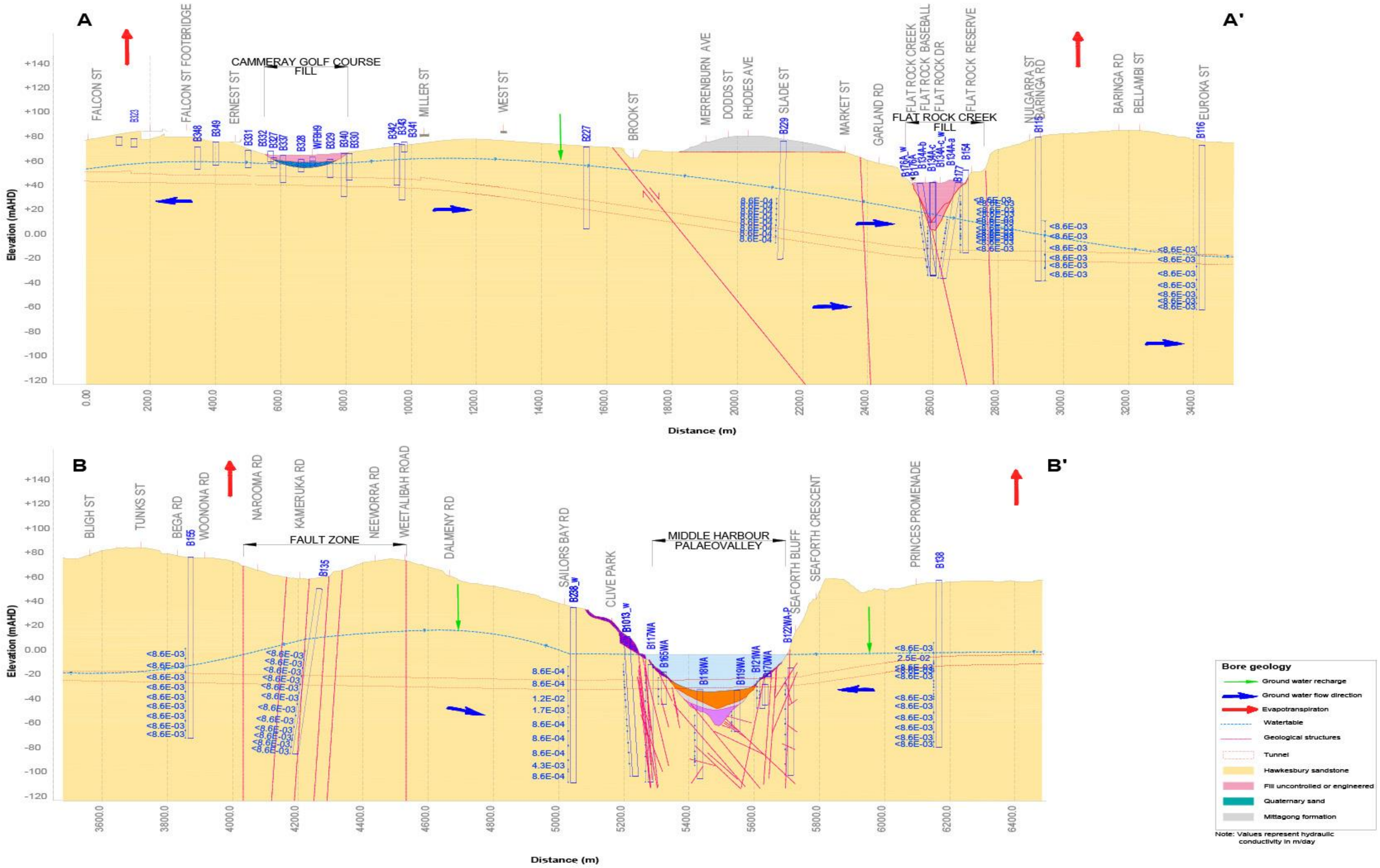


Figure A2-2: Hydrogeology along the proposed project alignment from Warringah Freeway to Middle Harbour (indicative only)

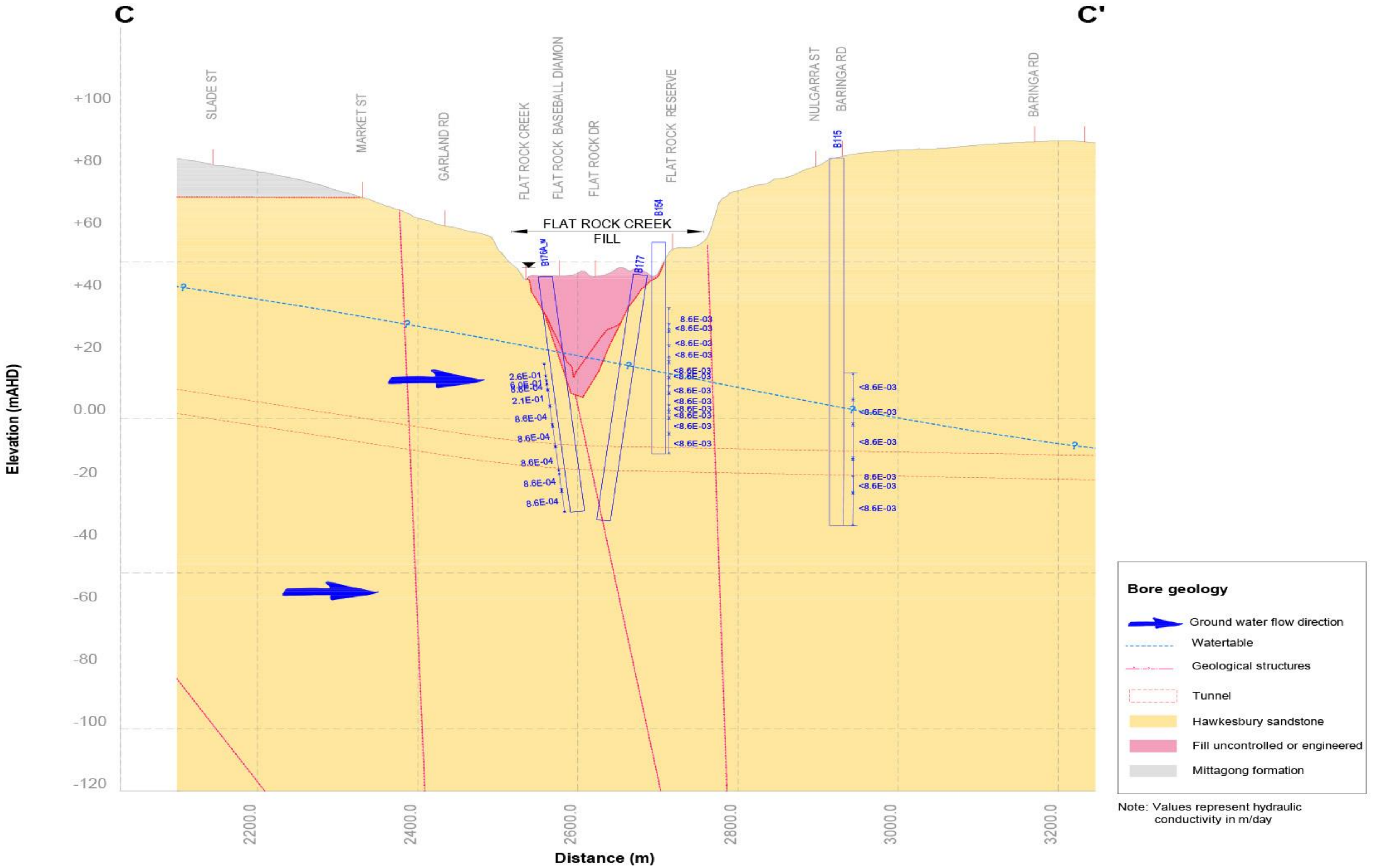


Figure A2-3: Hydrogeology at Flat Rock Creek (indicative only)

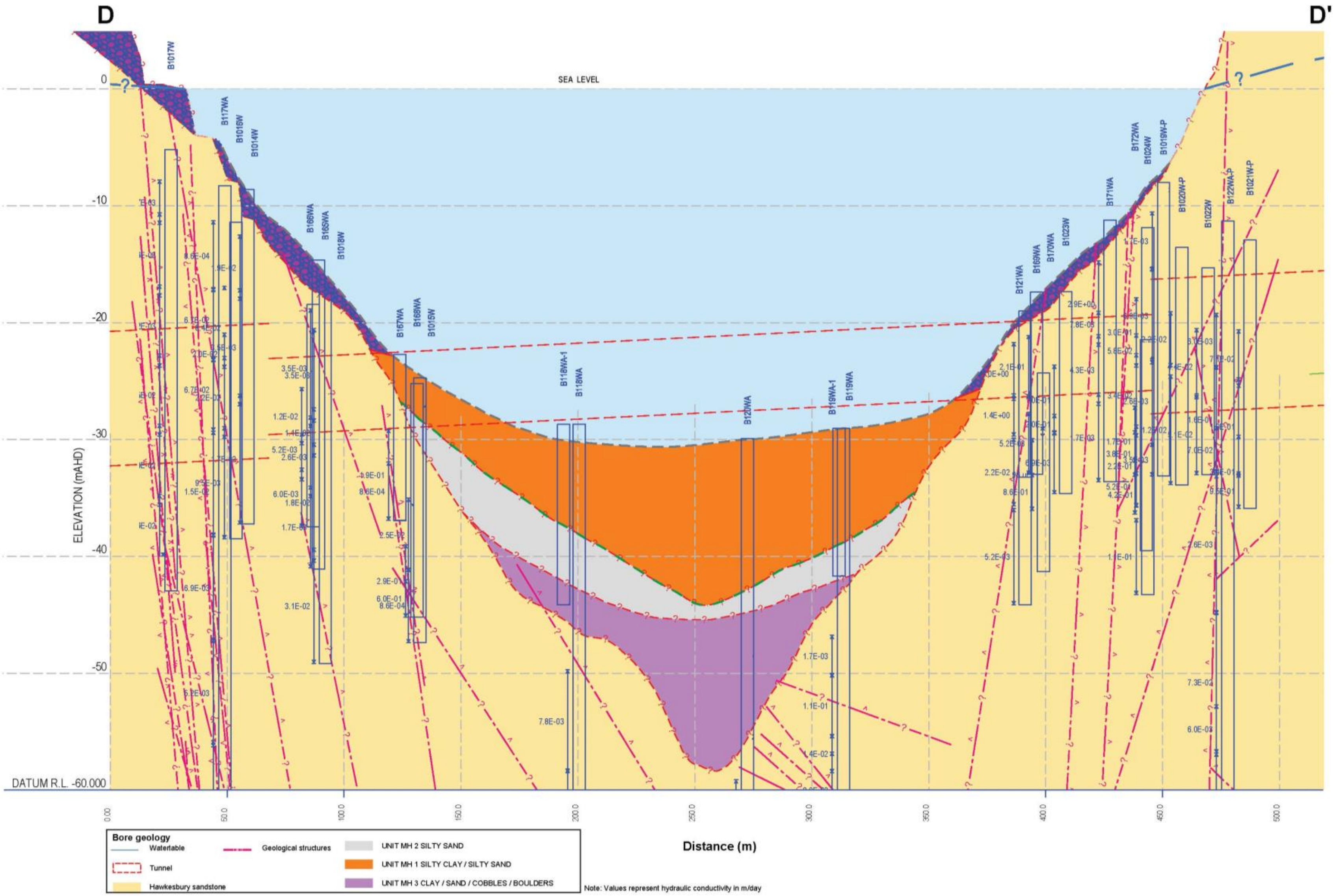


Figure A2-4: Hydrogeology at Middle Harbour (indicative only)

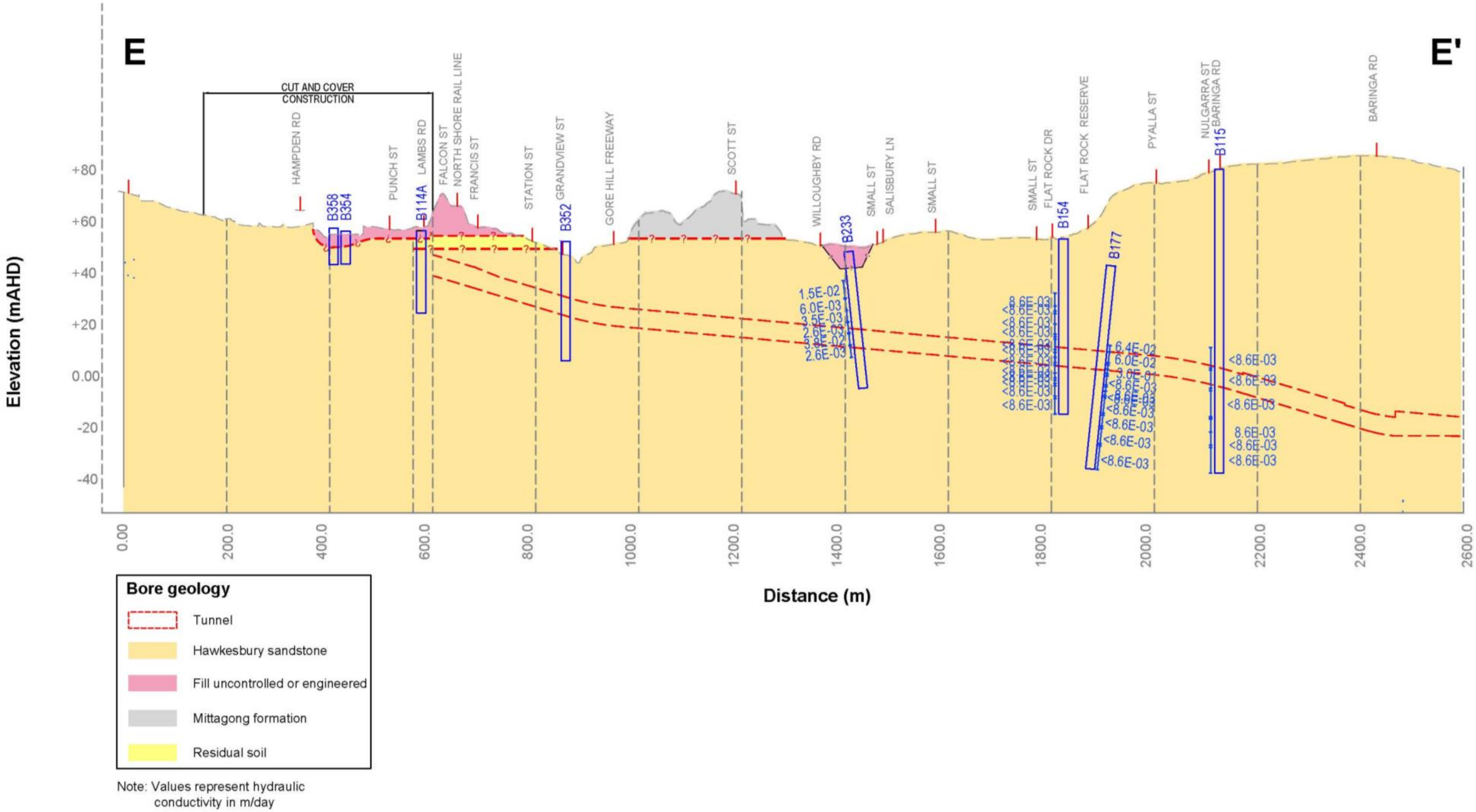


Figure A2-5: Hydrogeology along the project alignment from the Gore Hill Freeway tunnel connection to the proposed Beaches Link mainline tunnel (indicative only)

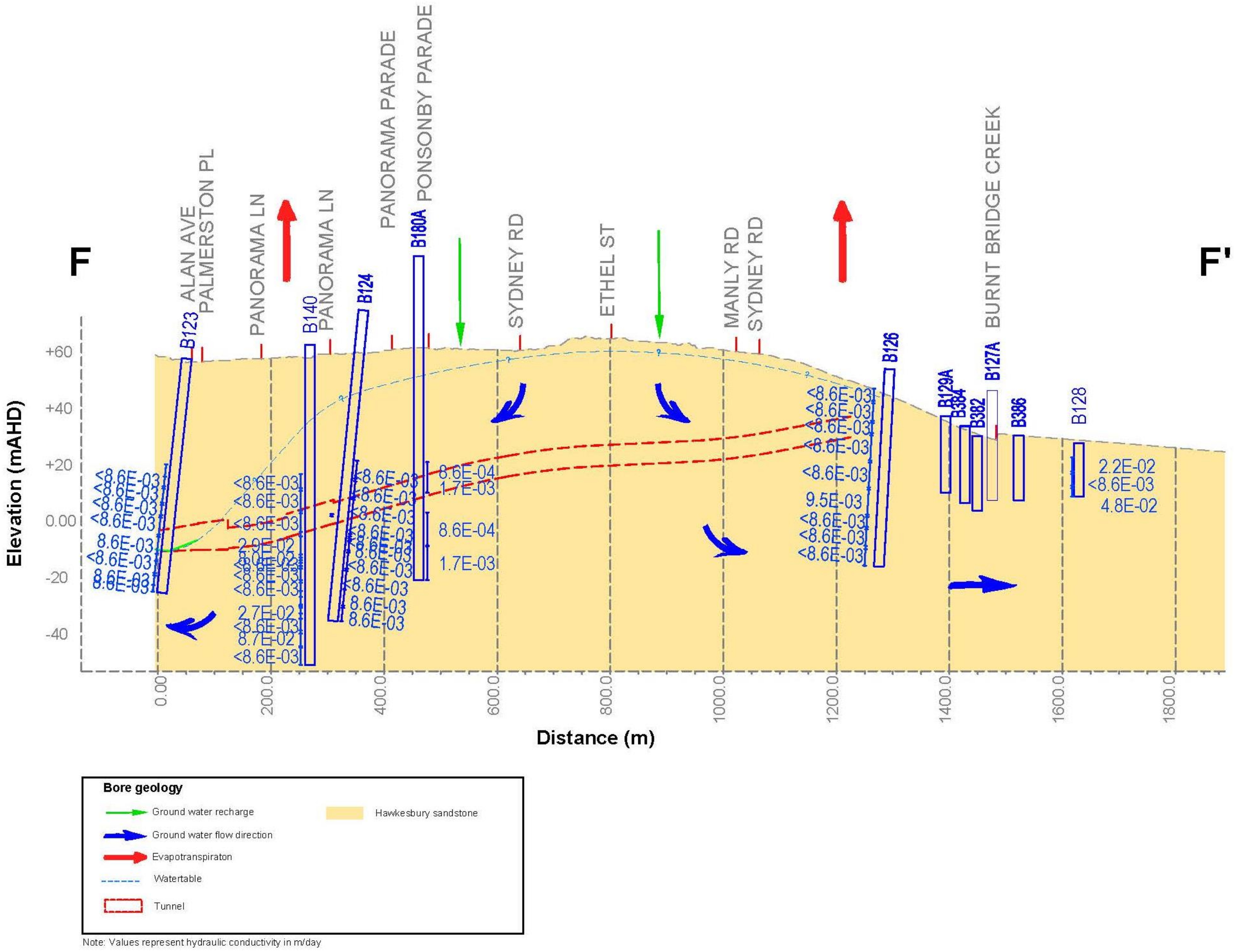


Figure A2-6: Hydrogeology along the project alignment from Seaforth to Balgowlah (indicative only)

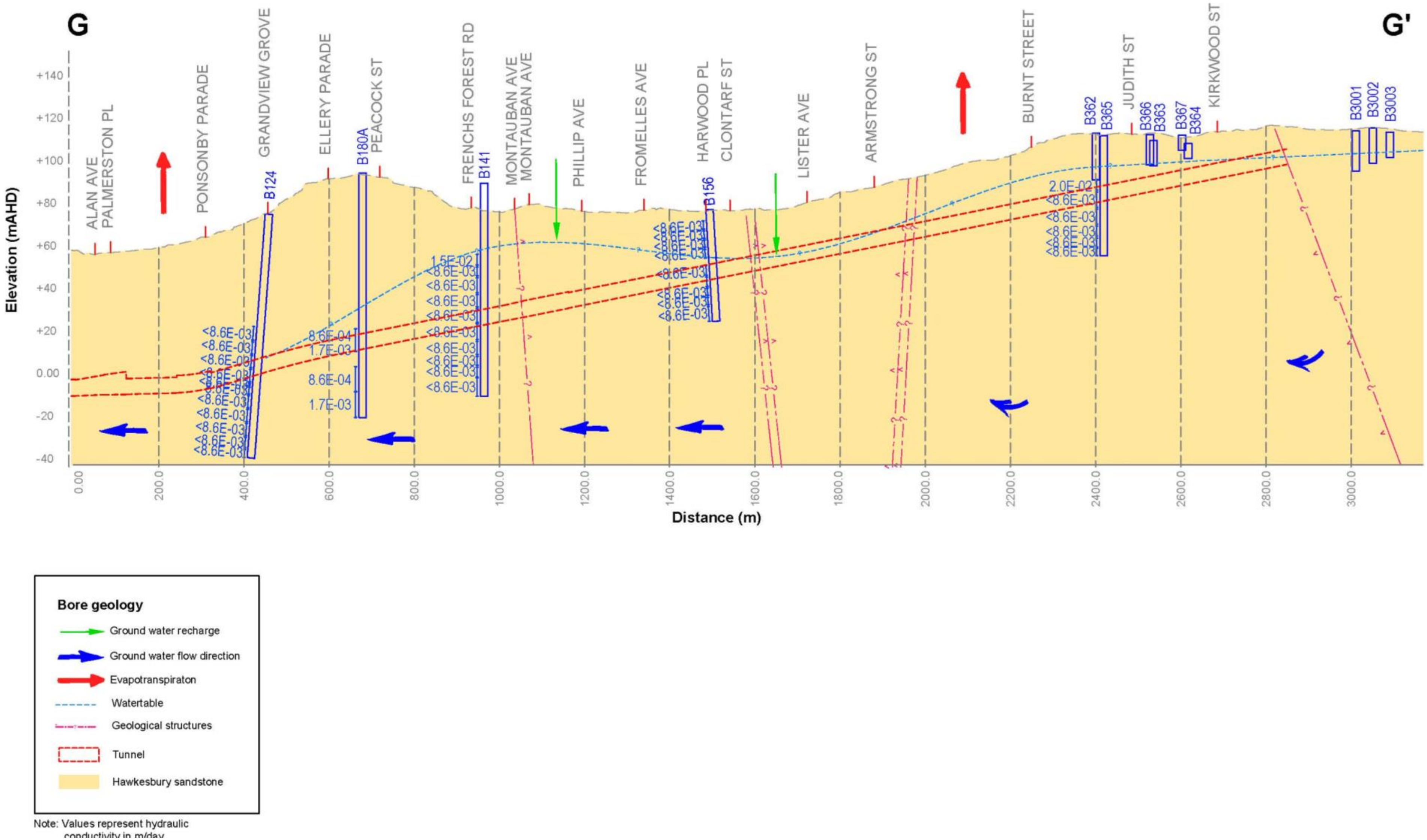
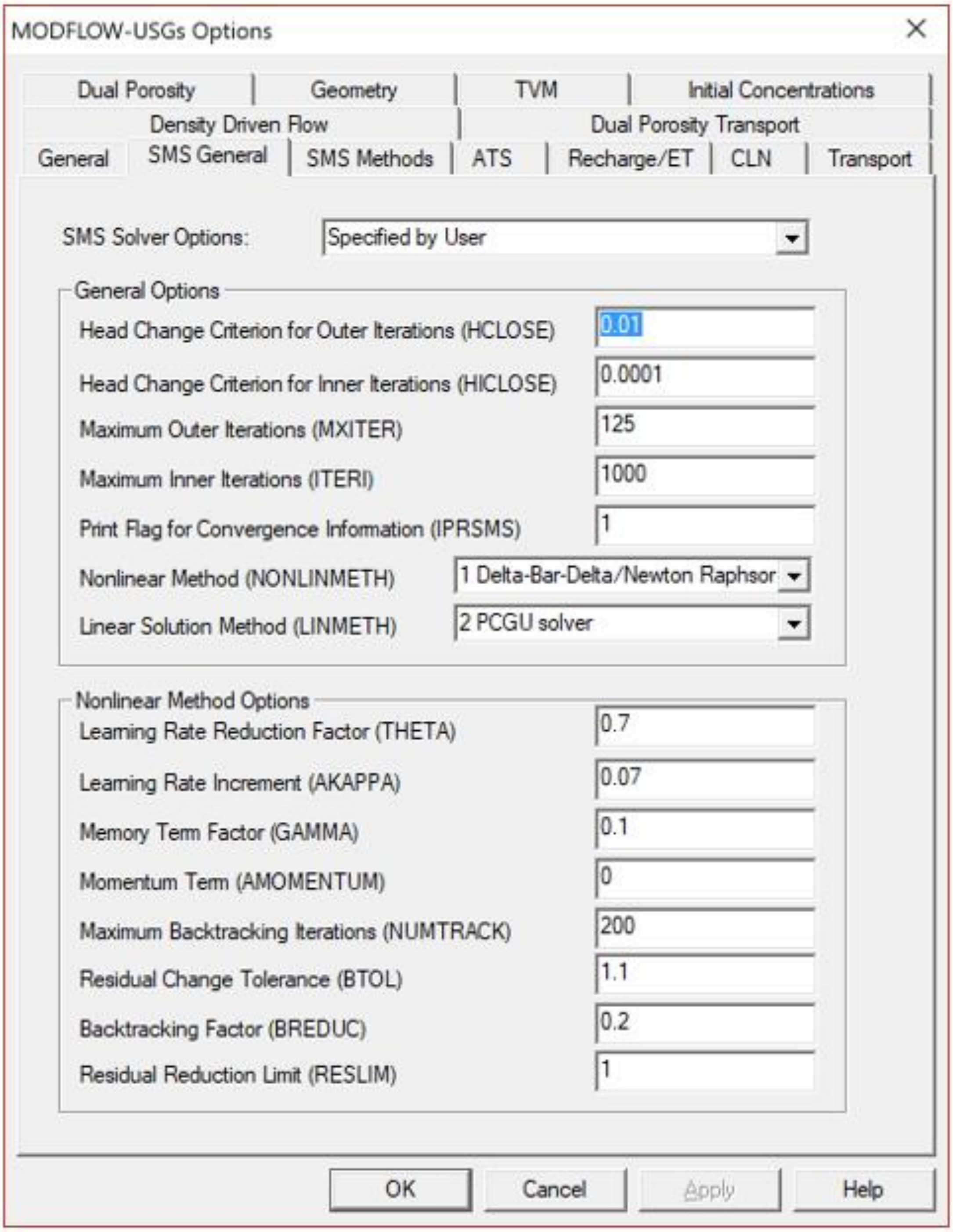
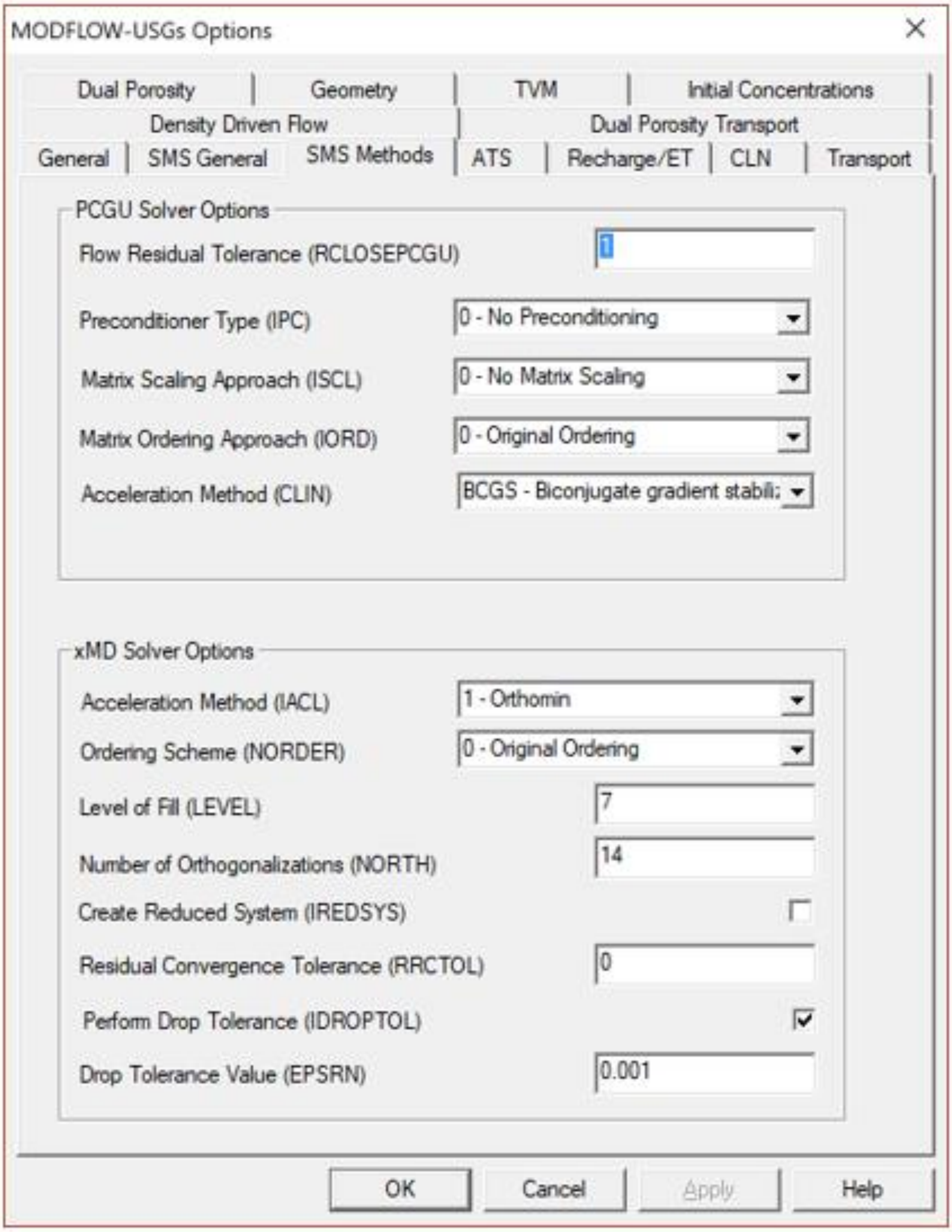


Figure A2-7: Hydrogeology along the project alignment from Seaforth to Wakehurst Parkway (indicative only)

Attachment 3 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

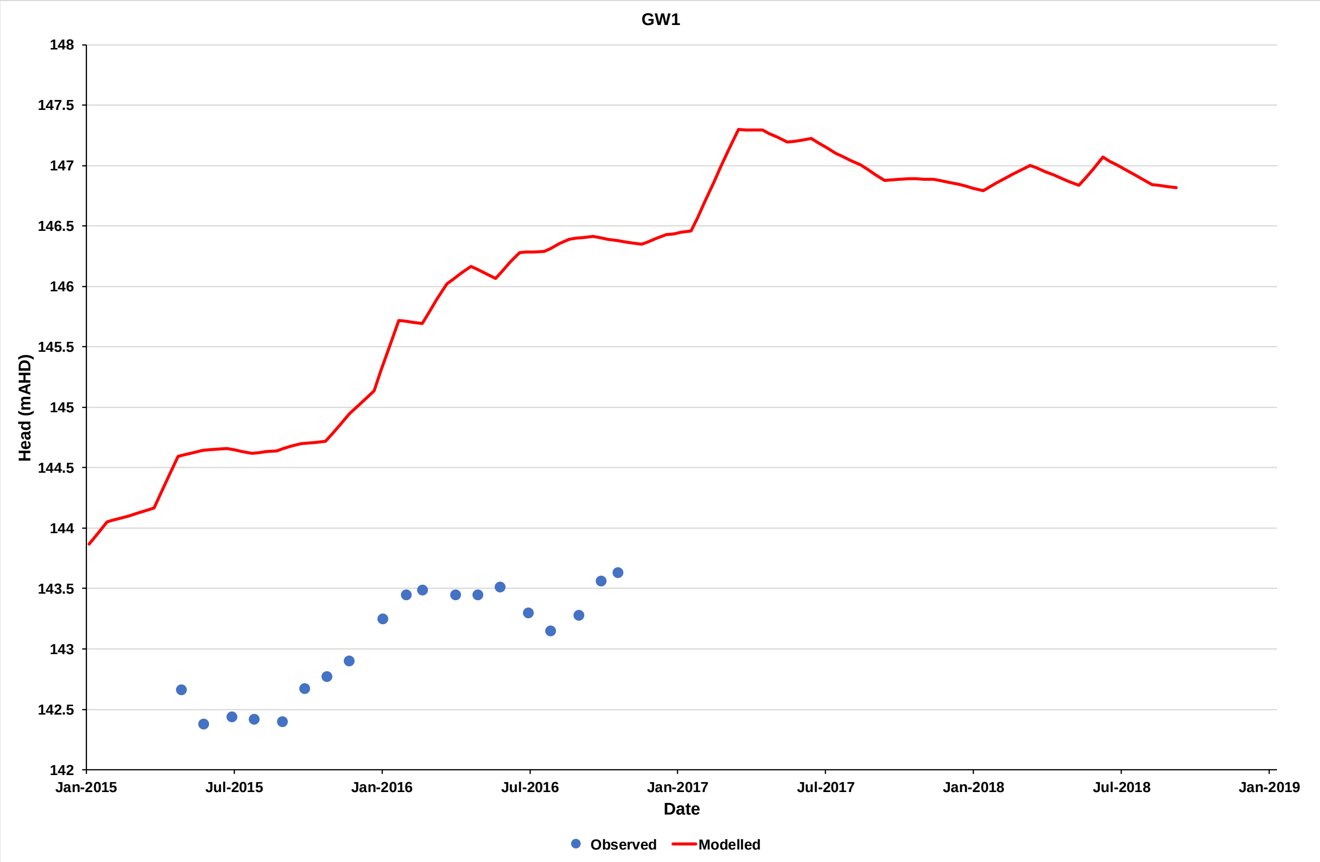

MODFLOW-USGs Options
Dual Porosity
Geometry
TVM
Initial Concentrations
Density Driven Flow
Dual Porosity Transport
General
SMS General
SMS Methods
ATS
Recharge/ET
CLN
Transport
PCGU Solver Options
Flow Residual Tolerance (RCLOSEPCGU)
1
Preconditioner Type (IPC)
0 - No Preconditioning
Matrix Scaling Approach (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

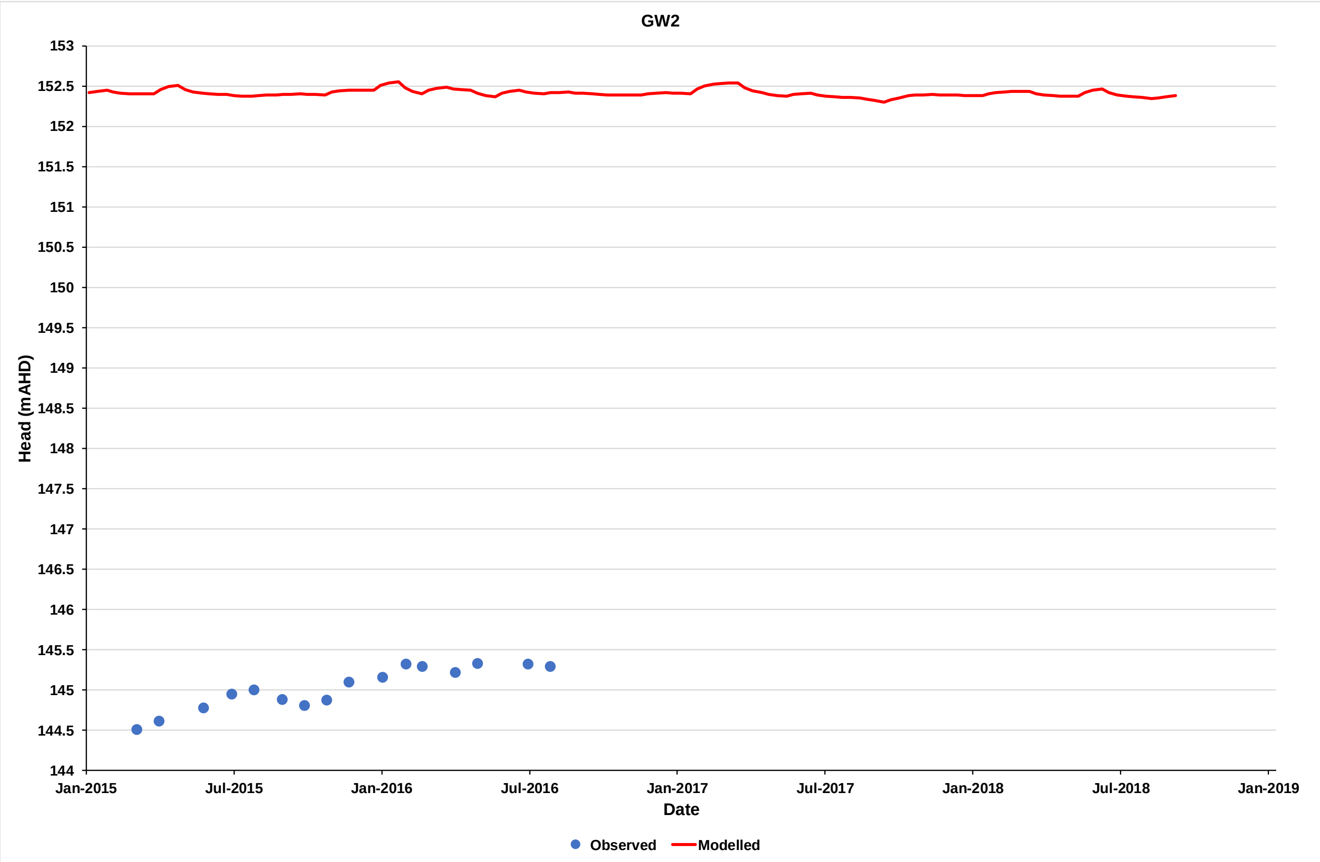
Attachment 4 Calibration bore information - steady state calibration

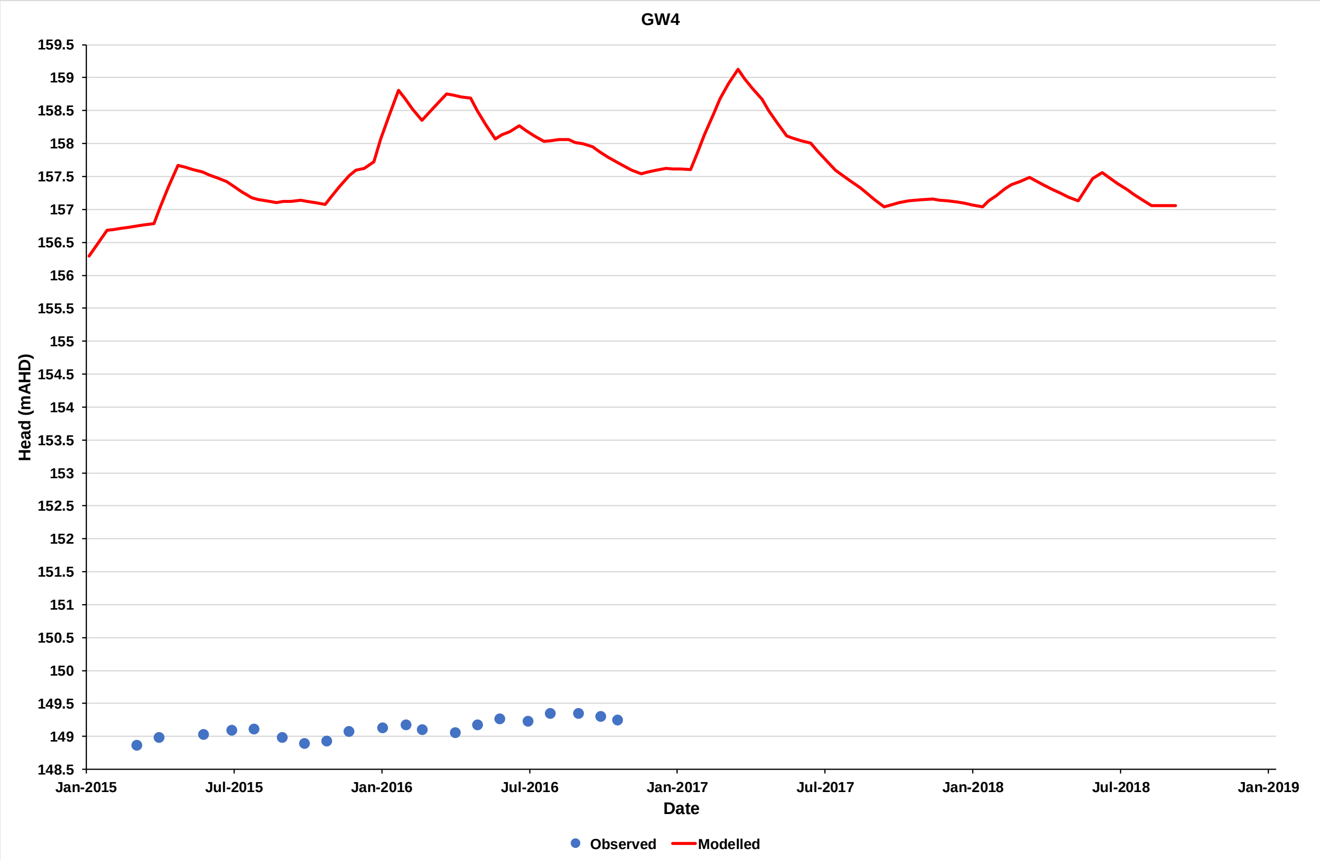
Name	X (mMGA)	Y (mMGA)	Z (mAHD)	Screen (mBGL)	Average SWL (mAHD)	Project/Type	Date recorded	Suitability for calibration
SRT_BH017	334111	6254365	62.9	36.1-39.80	43.60	Metro	16/09/2015	High
SRT_BH018	333390	6255706	90.75	18.8-26.0	77.66	Metro	15/09/2015	High
SRT_BH019	333308	6255819	84.43	3.75-7.5	81.81	Metro	18/09/2015	High
B114A	332643	6257062	74.36	25-31	64.35	Beaches Link and Western Harbour Tunnel - GDP	4/08/2017	High
B127A	338070	6259609	49.46	35-38	32.08	Beaches Link and Western Harbour Tunnel - GDP	3/08/2017	High
B134A-b	333870	6257108	45.67	28.5-31.5	20.68	Beaches Link and Western Harbour Tunnel - GDP	3/08/2017	High
B134A-c	333868	6257112	45.63	57.5-60.5	20.00	Beaches Link and Western Harbour Tunnel - GDP	4/08/2017	High
B238	336173	6257786	38.91	129.9-132.9	2.93	Beaches Link and 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	Beaches Link and Western Harbour Tunnel - AEC	10/08/2017	High
B128	338487	6259592	63.47	45.7-48.7	28.75	Beaches Link and Western Harbour Tunnel - AEC	25/08/2017	High
B133	333489	6254554	60.97	123.5-126.5	35.73	Beaches Link and Western Harbour Tunnel - AEC	1/09/2017	High
B138	337119	6258385	65.671	99.5-102.5	5.85	Beaches Link and Western Harbour Tunnel - AEC	15/08/2017	High
B140	337516	6258803	92.37	48.2-51.2	3.81	Beaches Link and Western Harbour Tunnel - AEC	10/08/2017	High
B154	333821	6257311	56.29	50-53	24.79	Beaches Link and Western Harbour Tunnel - AEC	9/08/2017	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
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	Jul-Nov 2017	High
B156_1	337228	6259860	79.93	50.2	44.80	Vibrating wire piezometer	Jul-Nov 2017	High

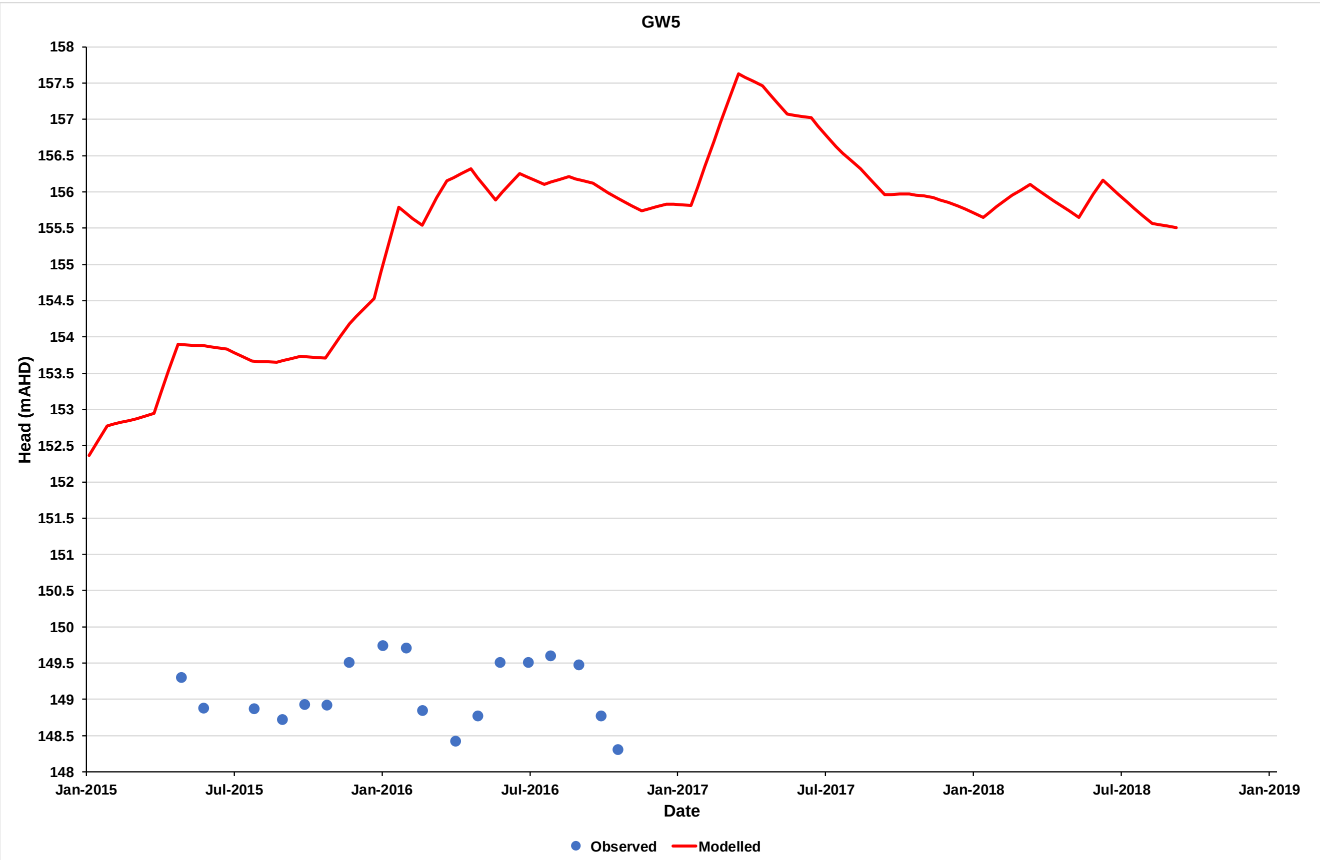
Note 1: Assumption: Screen is located at bottom of bore.

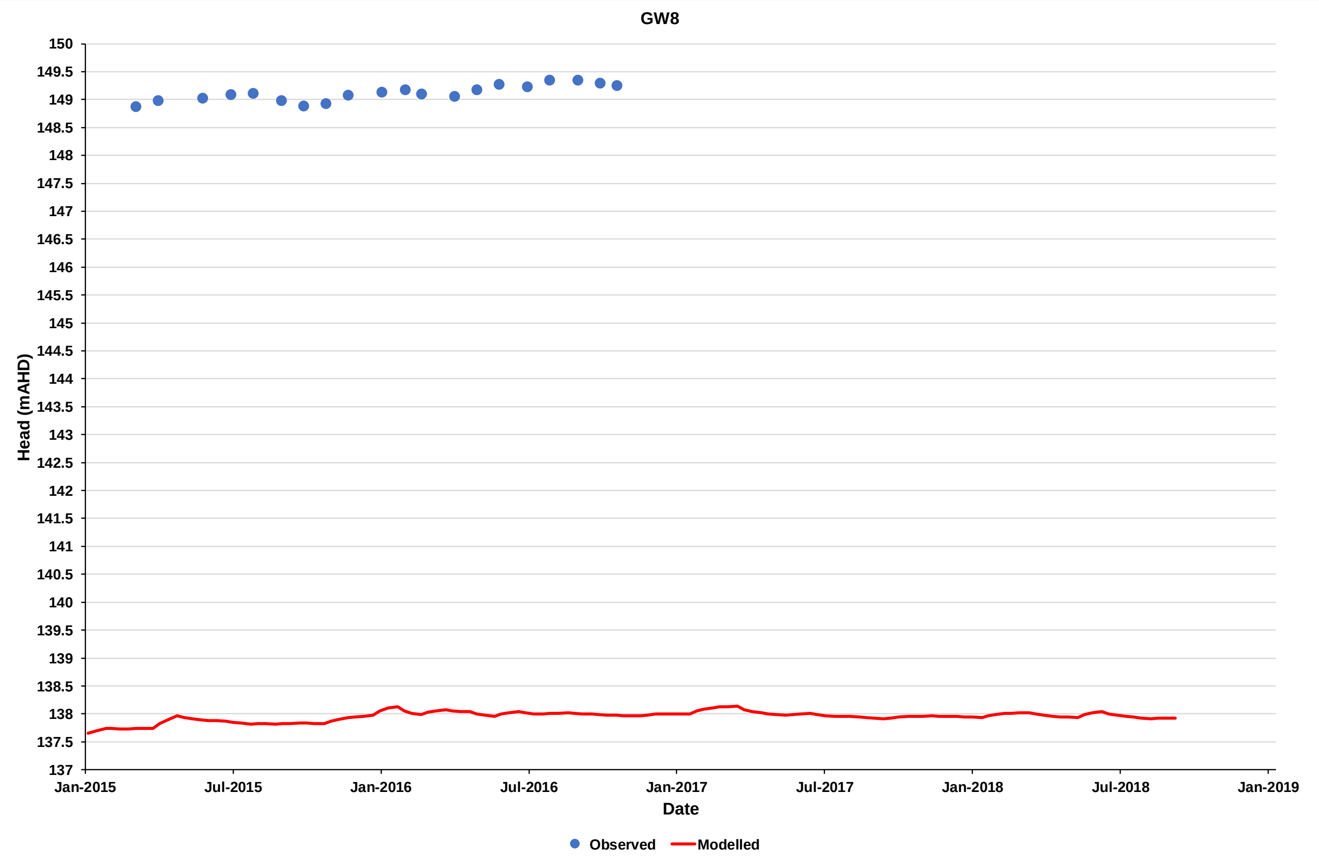
Attachment 5 Calibration hydrographs – Transient North Model

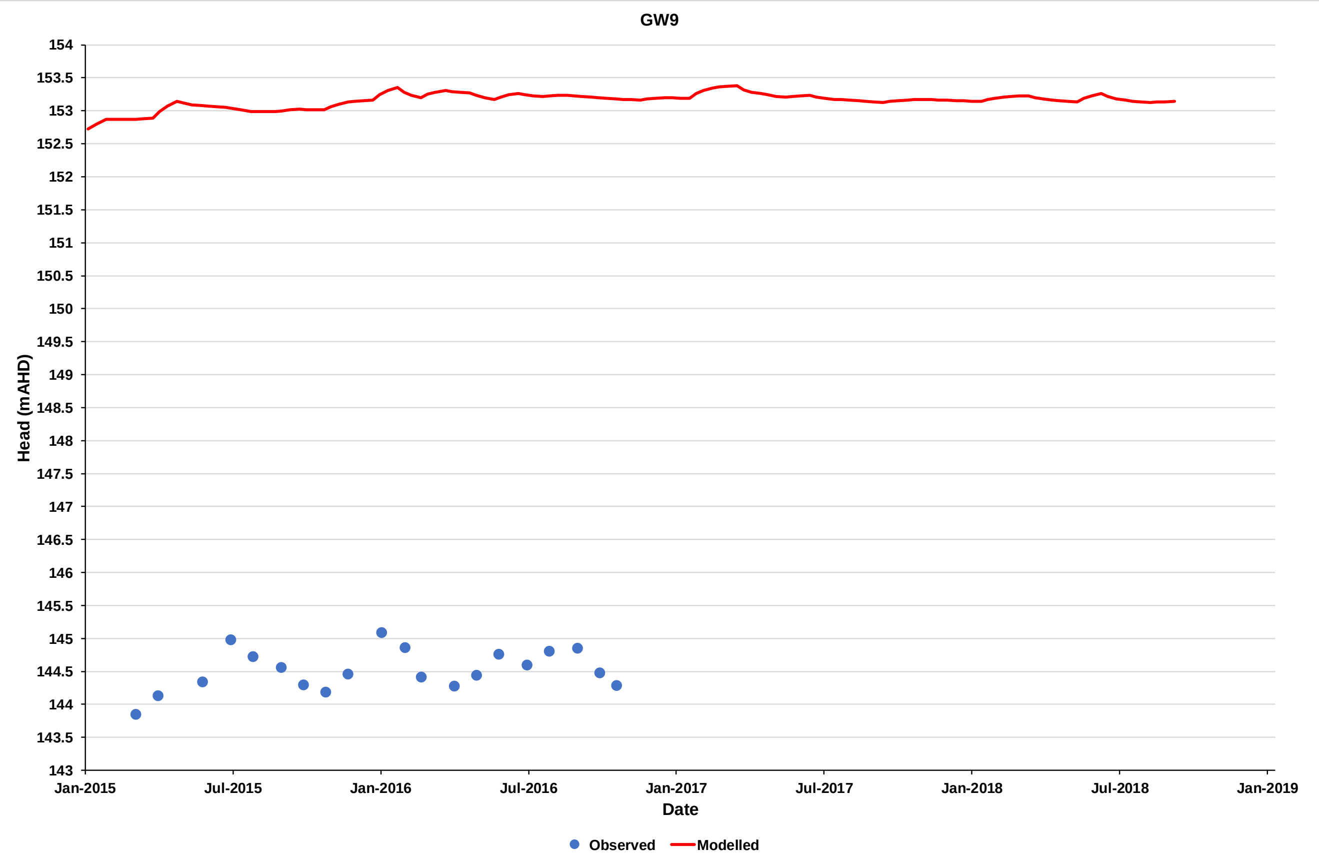

GW1
148
147.5
147
146.5
146
145.5
145
144.5
144
143.5
143
142.5
142
Head (mAHD)
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

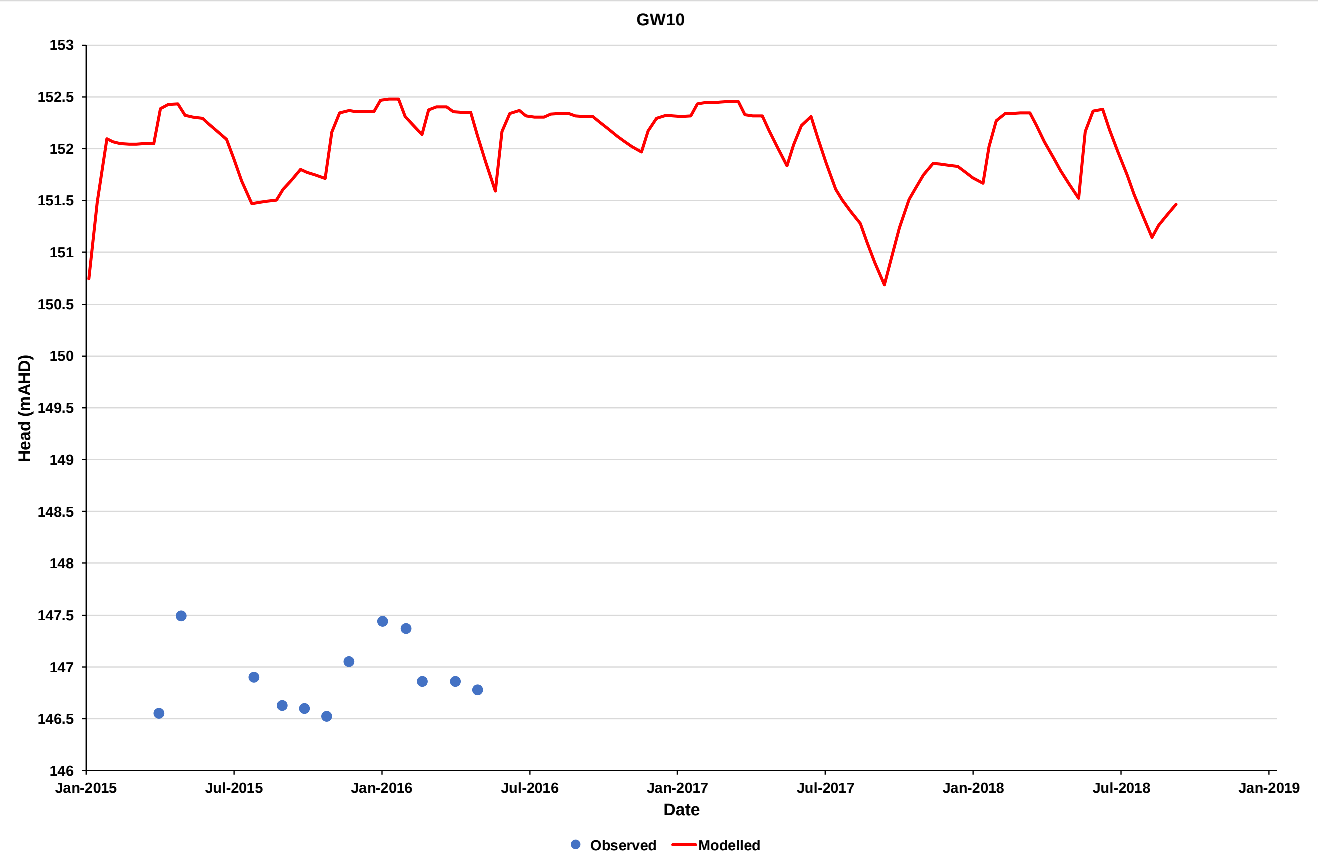

GW2
153
152.5
152
151.5
151
150.5
150
149.5
149
148.5
148
147.5
147
146.5
146
145.5
145
144.5
144
Head (mAHD)
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

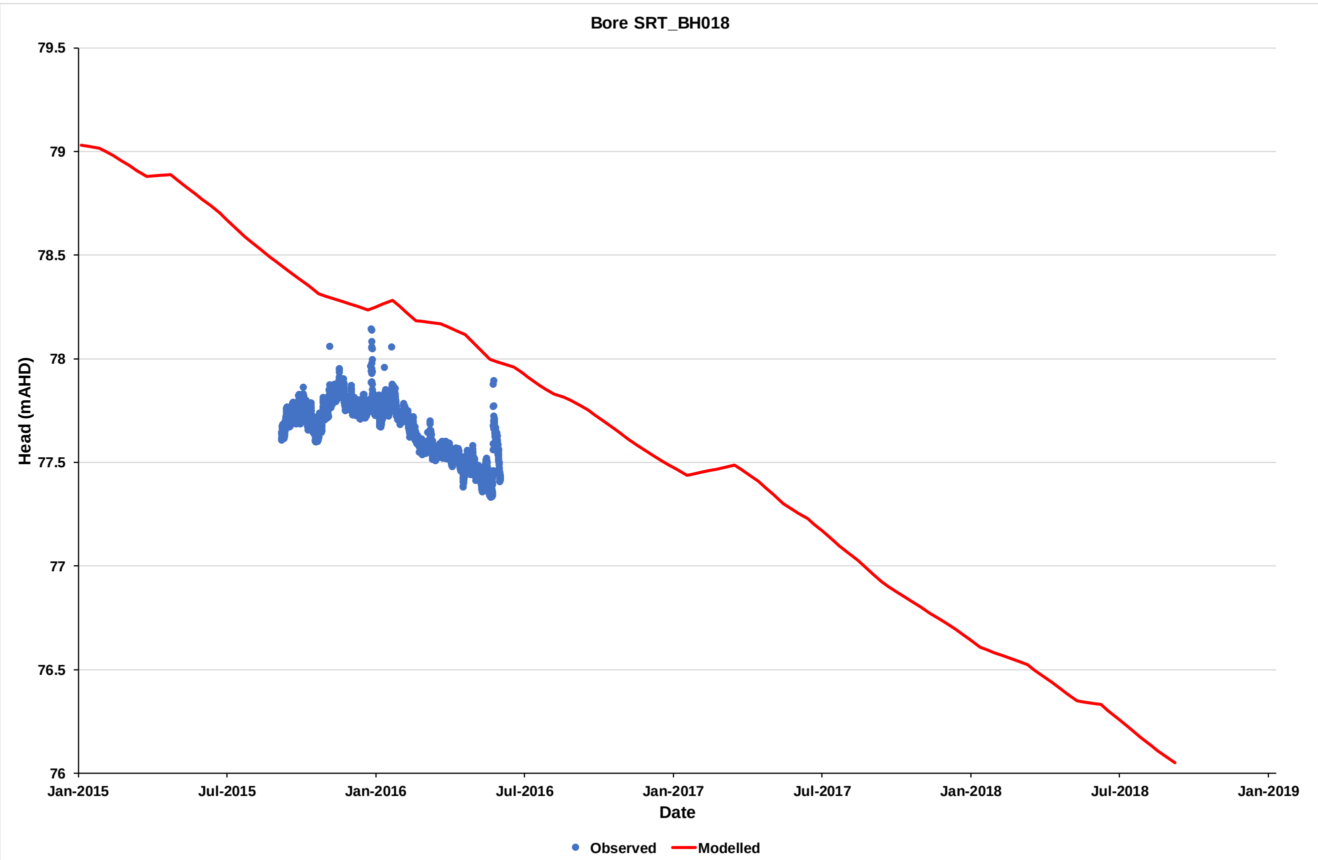

GW4
Head (mAHD)
159.5
159
158.5
158
157.5
157
156.5
156
155.5
155
154.5
154
153.5
153
152.5
152
151.5
151
150.5
150
149.5
149
148.5
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

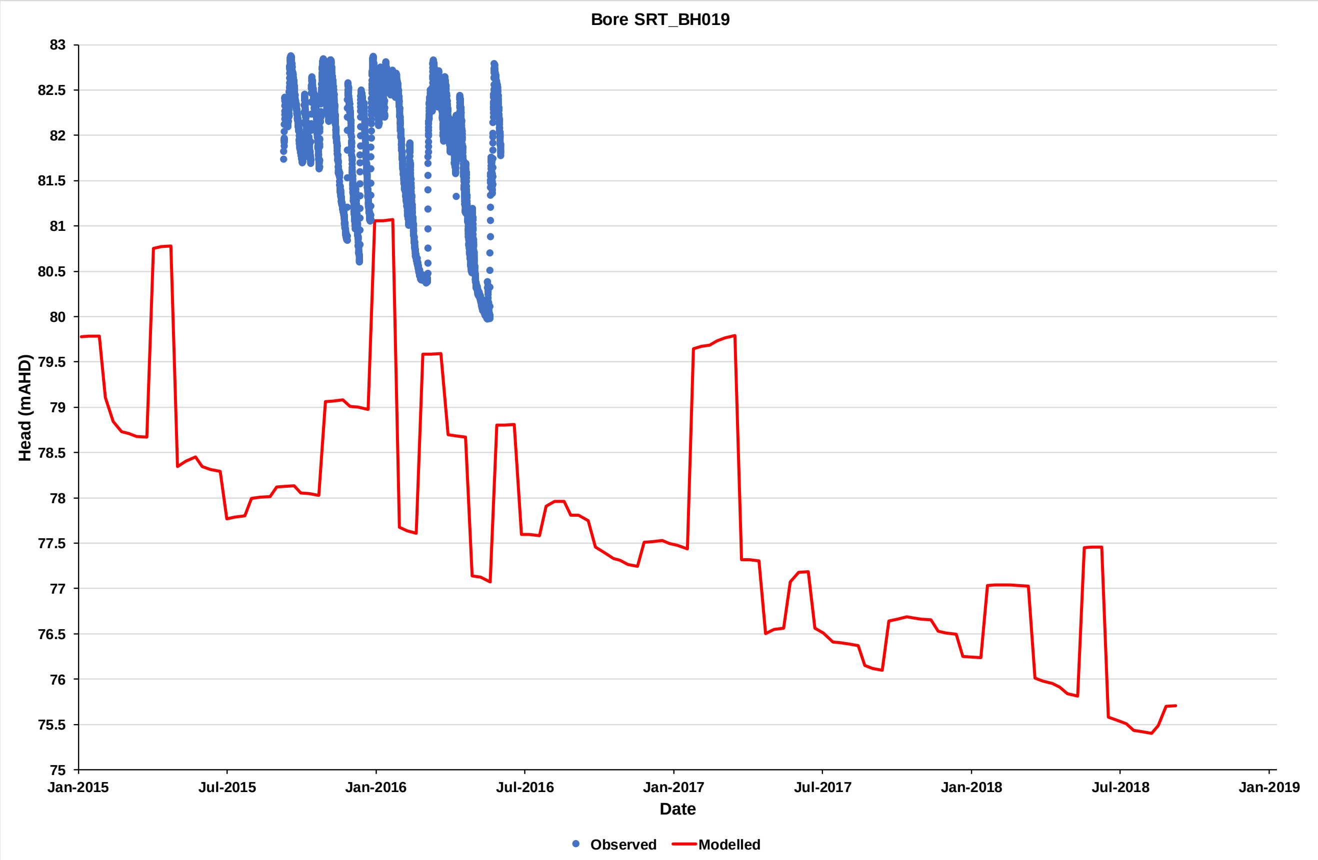

GW5
Head (mAHD)
158
157.5
157
156.5
156
155.5
155
154.5
154
153.5
153
152.5
152
151.5
151
150.5
150
149.5
149
148.5
148
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

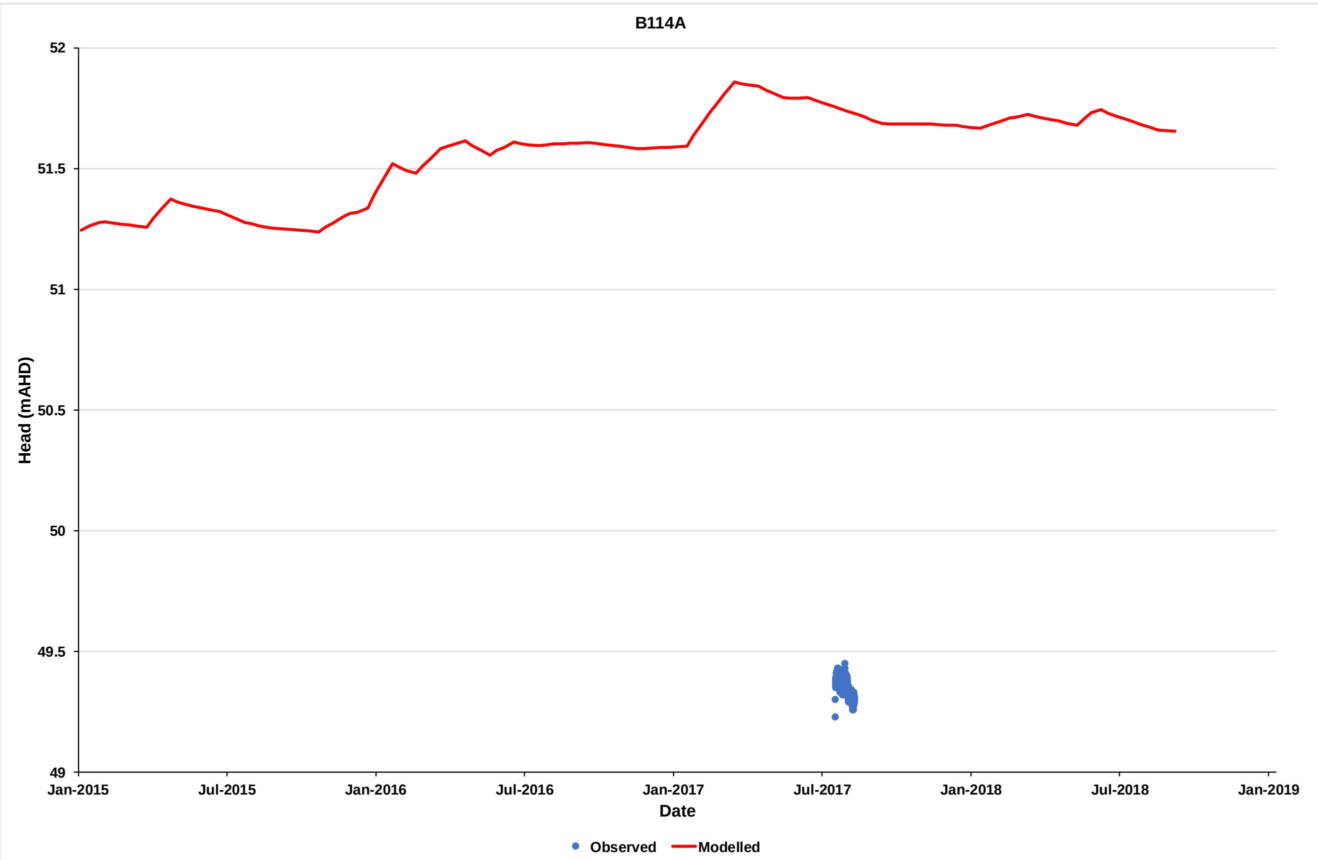

GW8
Head (mAHD)
150
149.5
149
148.5
148
147.5
147
146.5
146
145.5
145
144.5
144
143.5
143
142.5
142
141.5
141
140.5
140
139.5
139
138.5
138
137.5
137
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

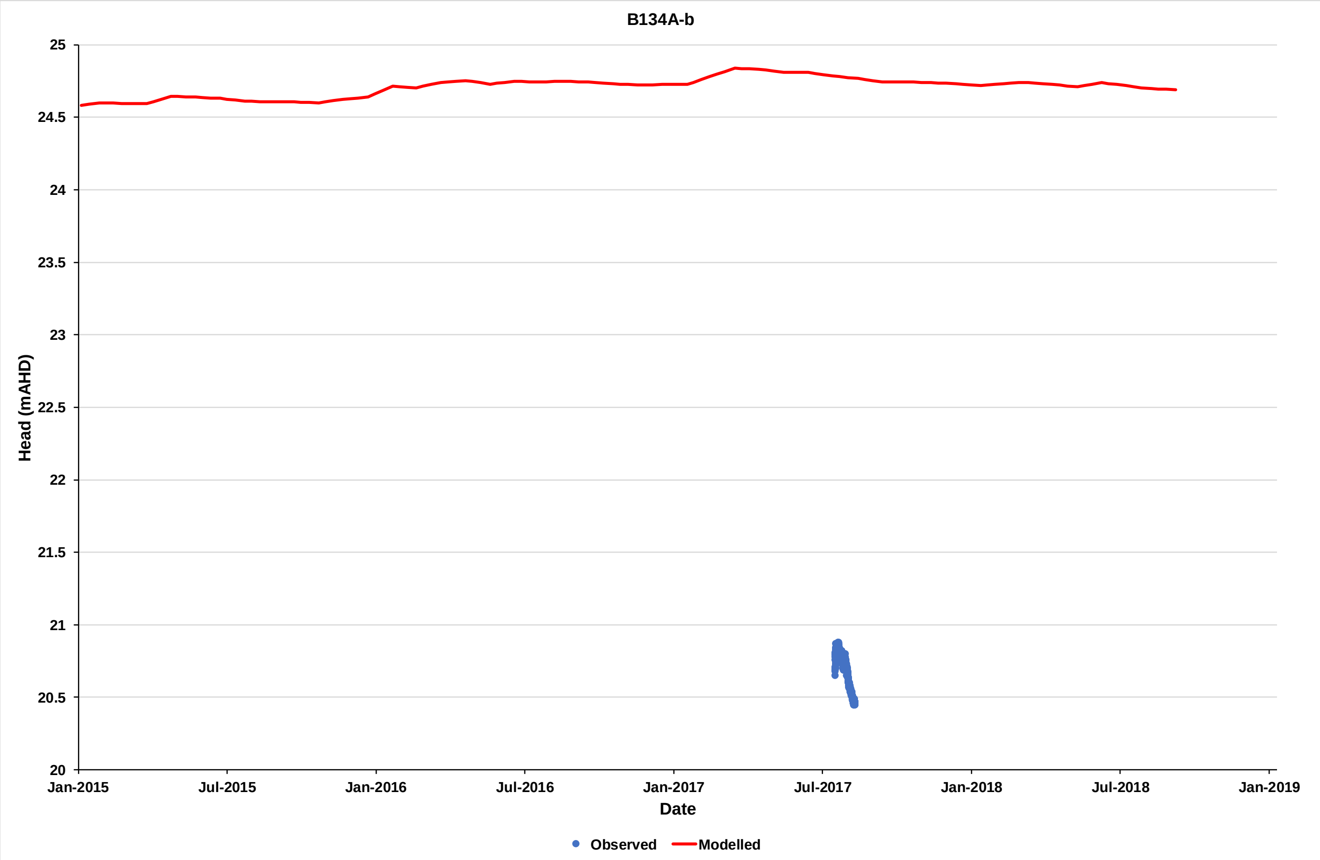

GW9
Head (mAHD)
154
153.5
153
152.5
152
151.5
151
150.5
150
149.5
149
148.5
148
147.5
147
146.5
146
145.5
145
144.5
144
143.5
143
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

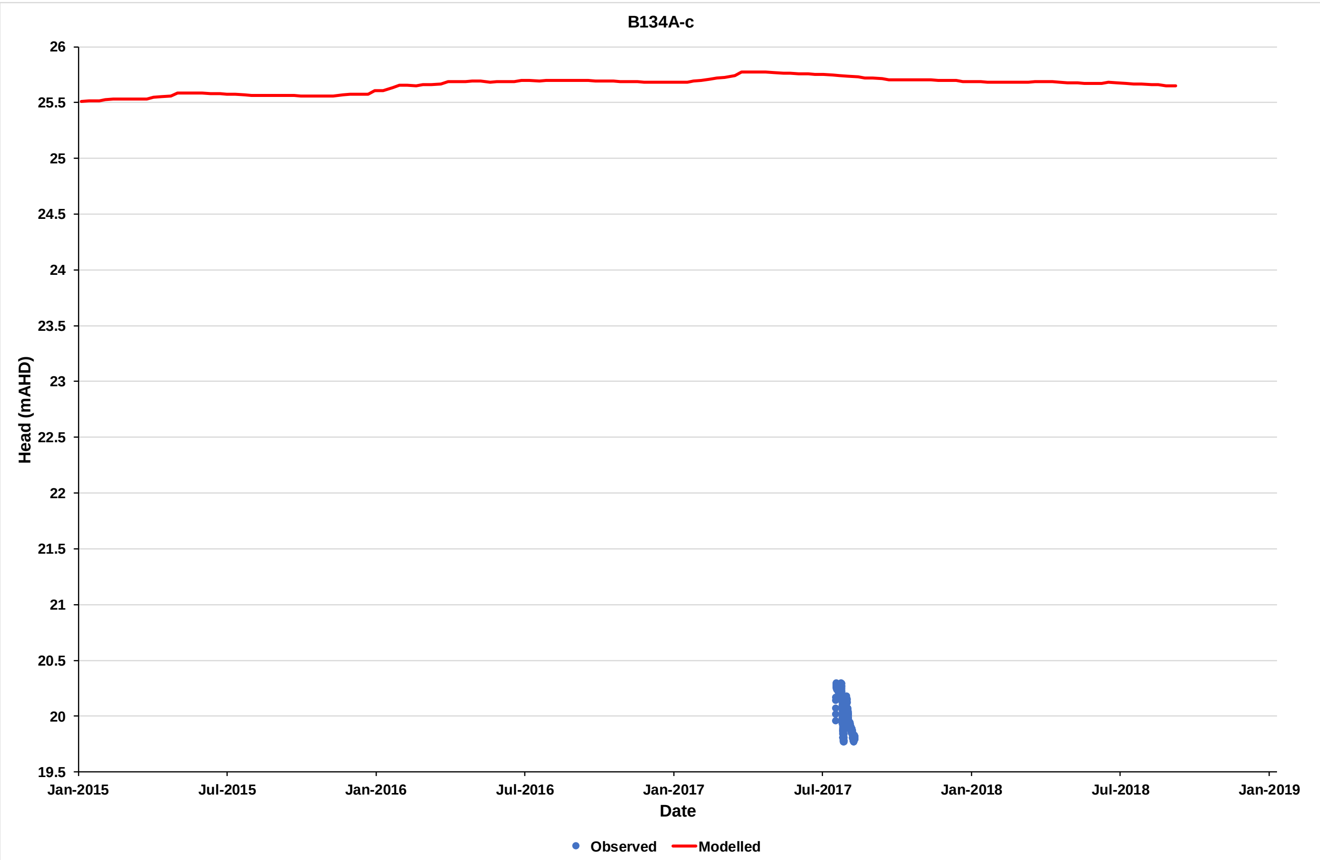

GW10
Head (mAHD)
153
152.5
152
151.5
151
150.5
150
149.5
149
148.5
148
147.5
147
146.5
146
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

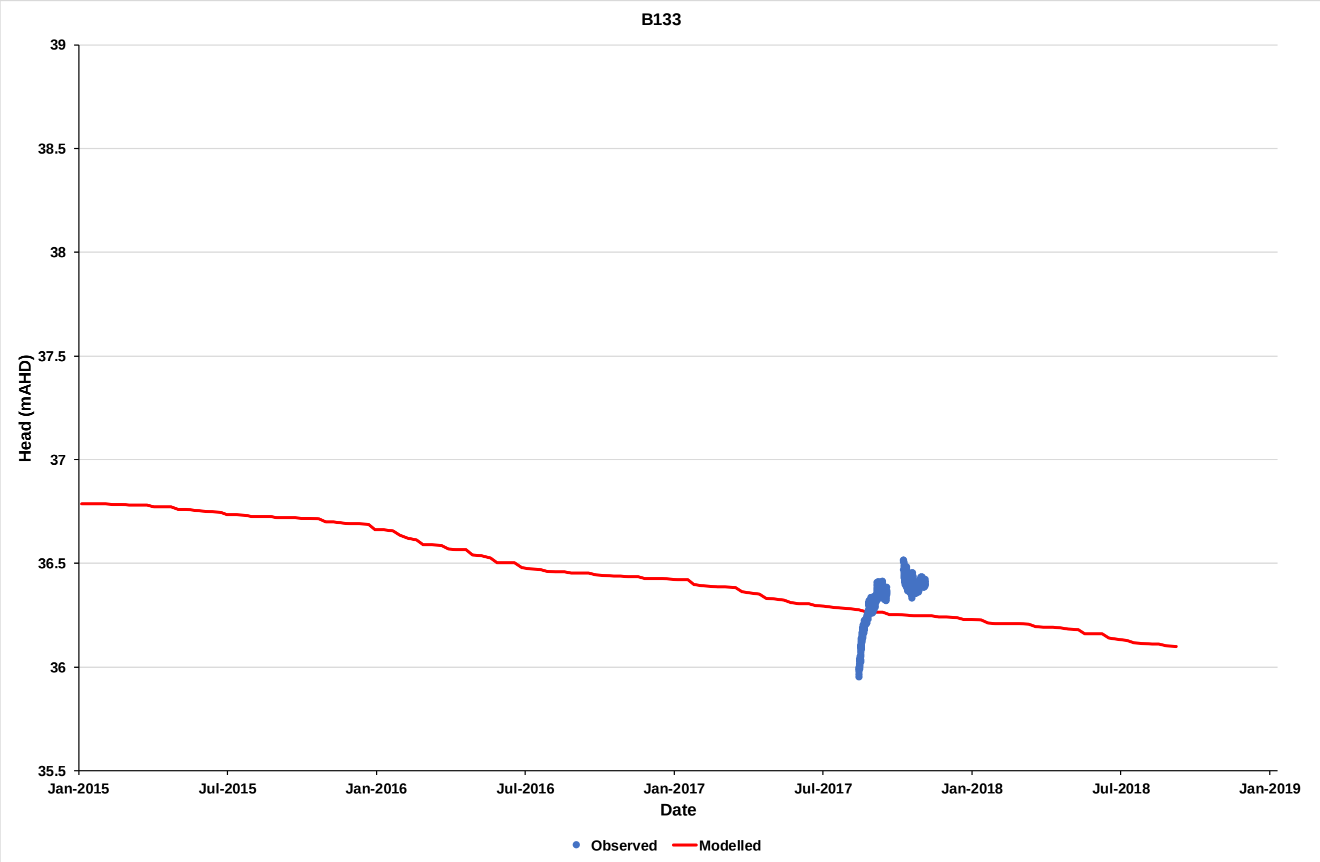

Bore SRT_BH018
Head (mAHD)
79.5
79
78.5
78
77.5
77
76.5
76
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

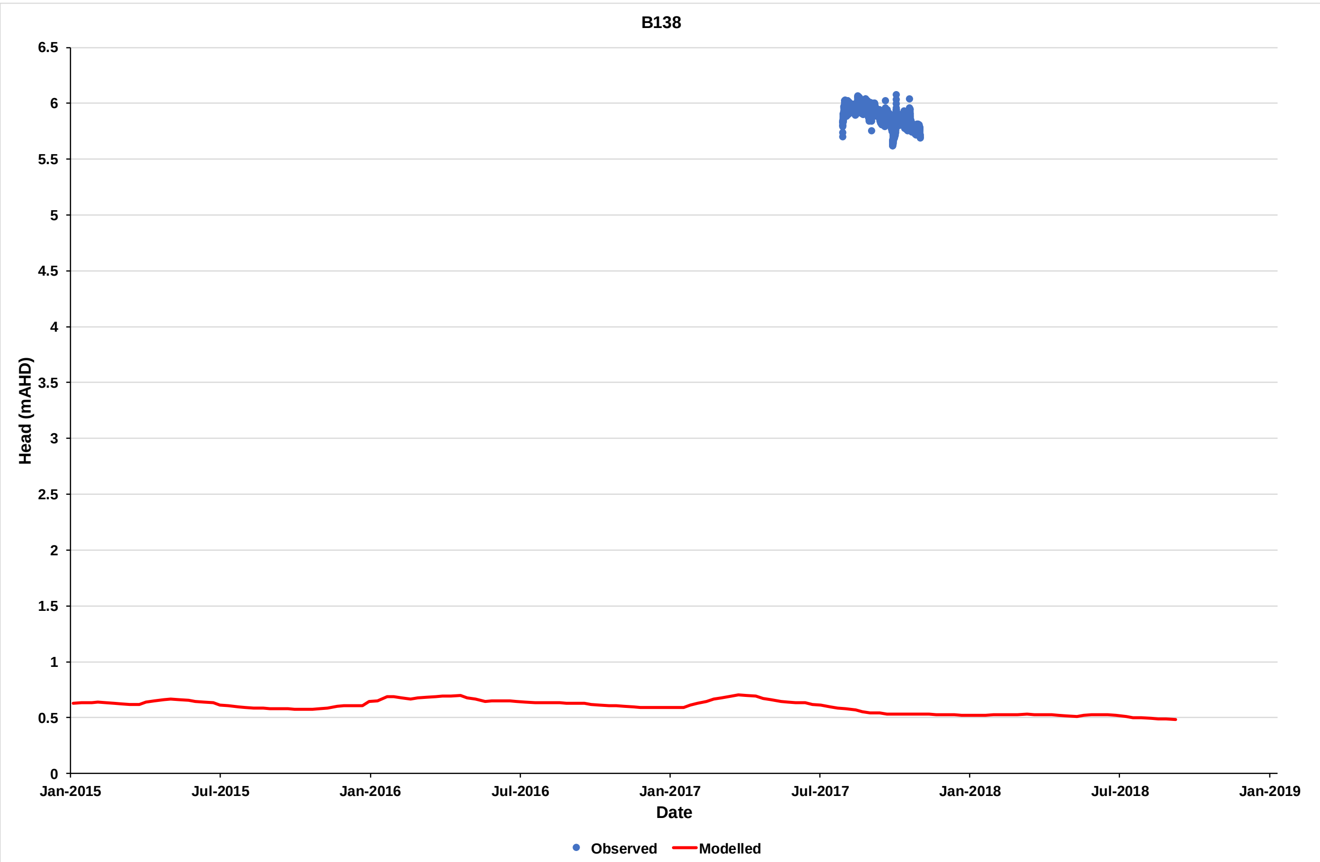

Bore SRT_BH019
Head (mAHD)
83
82.5
82
81.5
81
80.5
80
79.5
79
78.5
78
77.5
77
76.5
76
75.5
75
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

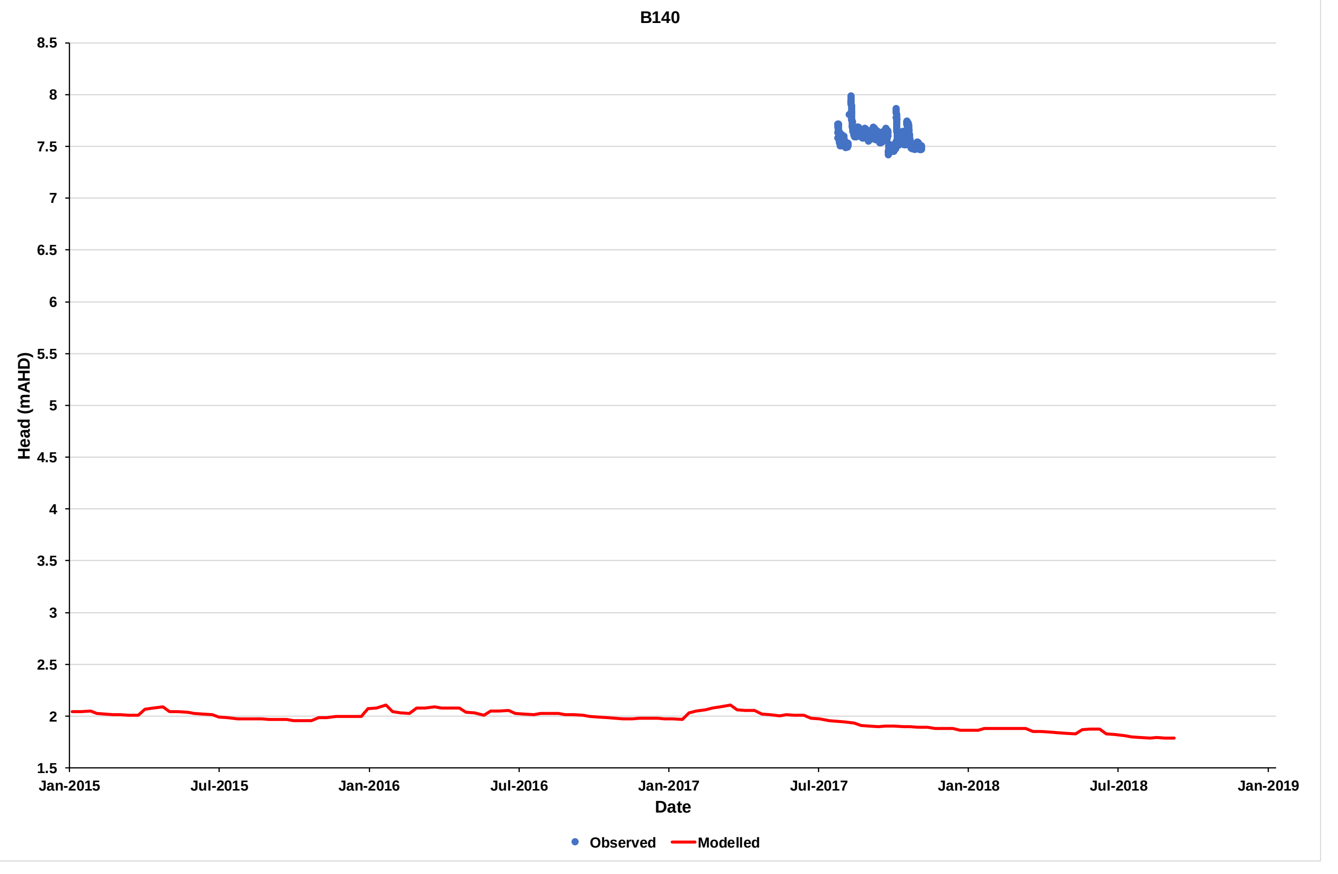

B114A
Head (mAHD)
52
51.5
51
50.5
50
49.5
49
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

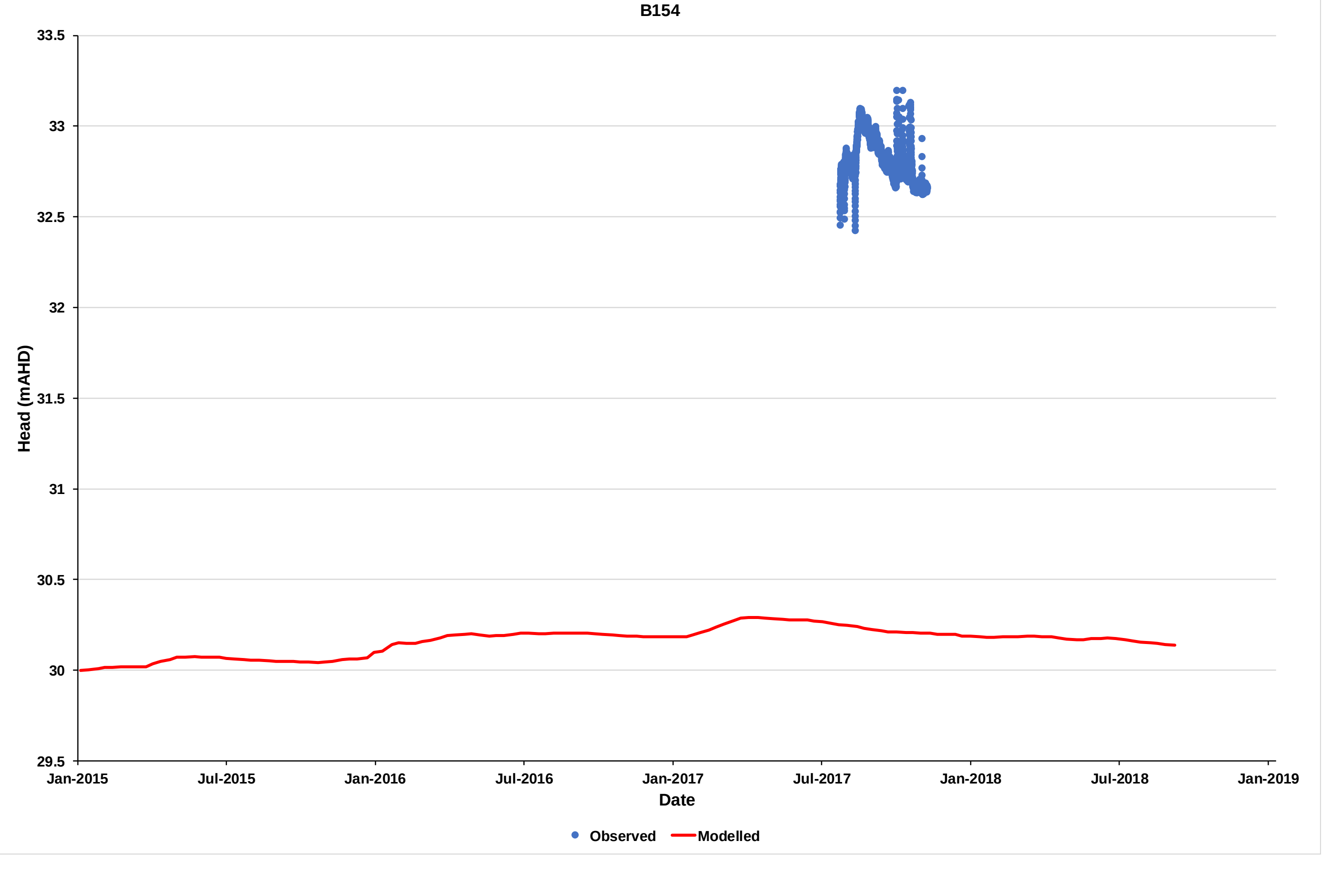

B134A-b
Head (mAHD)
25
24.5
24
23.5
23
22.5
22
21.5
21
20.5
20
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

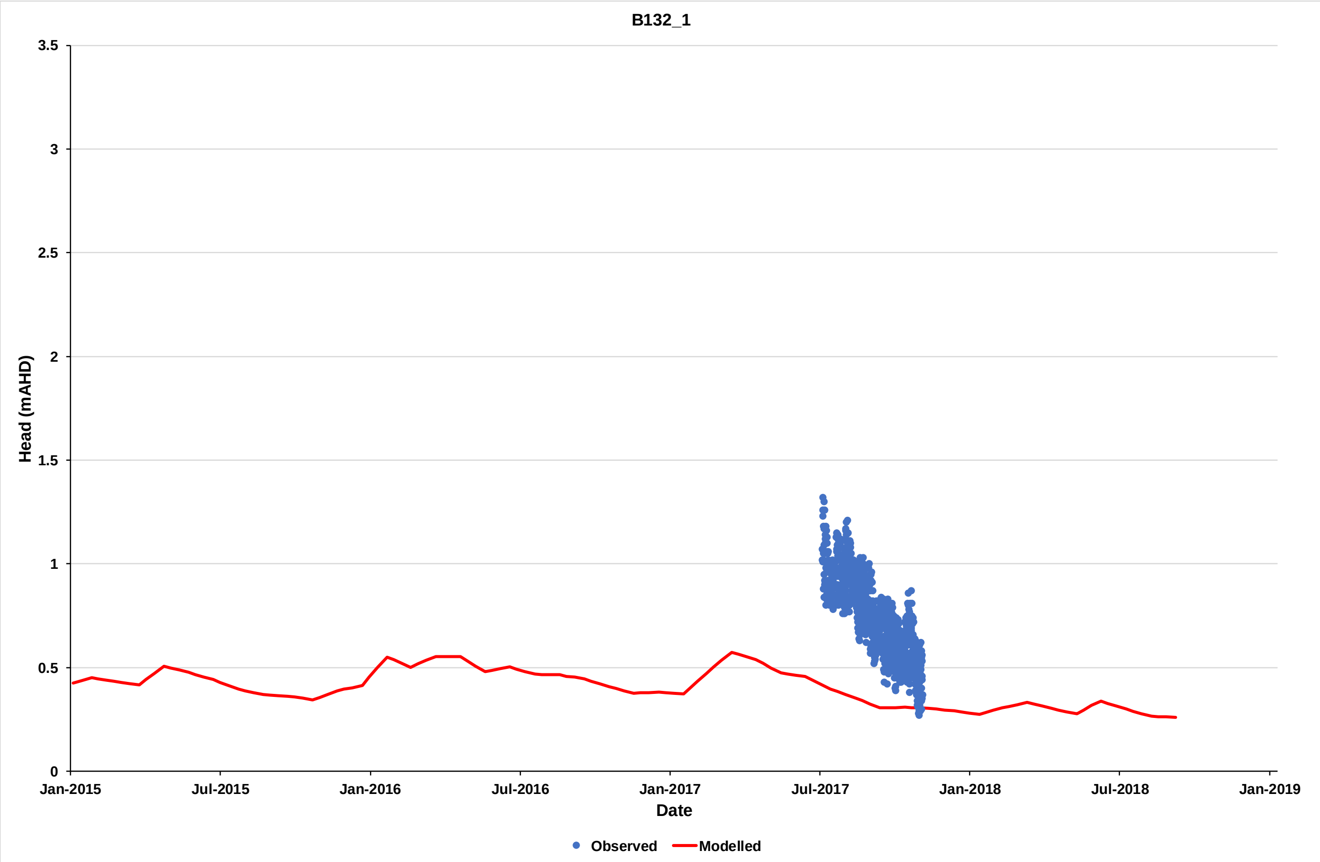

B134A-c
Head (mAHD)
26
25.5
25
24.5
24
23.5
23
22.5
22
21.5
21
20.5
20
19.5
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

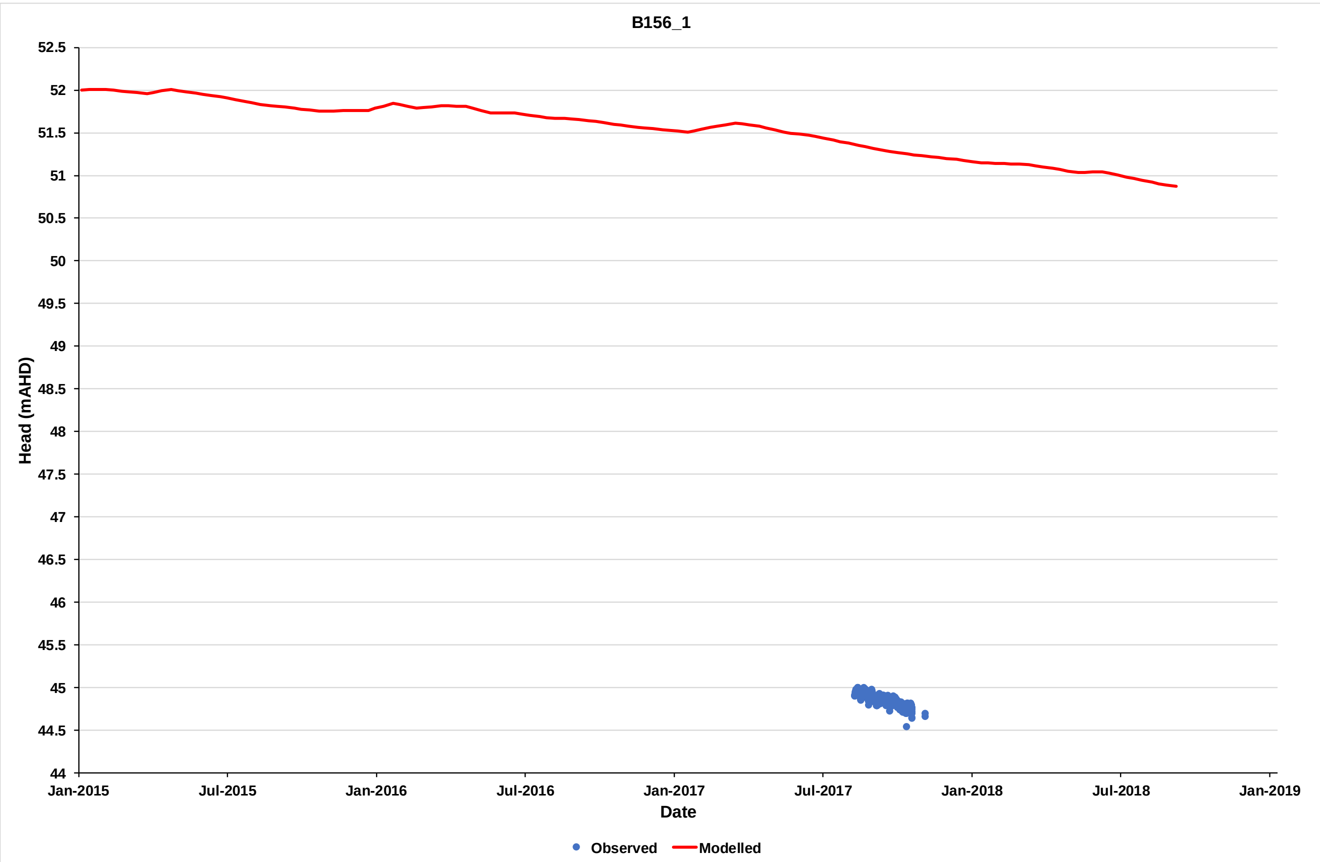

B133
Head (mAHD)
39
38.5
38
37.5
37
36.5
36
35.5
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled


B138
Head (mAHD)
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

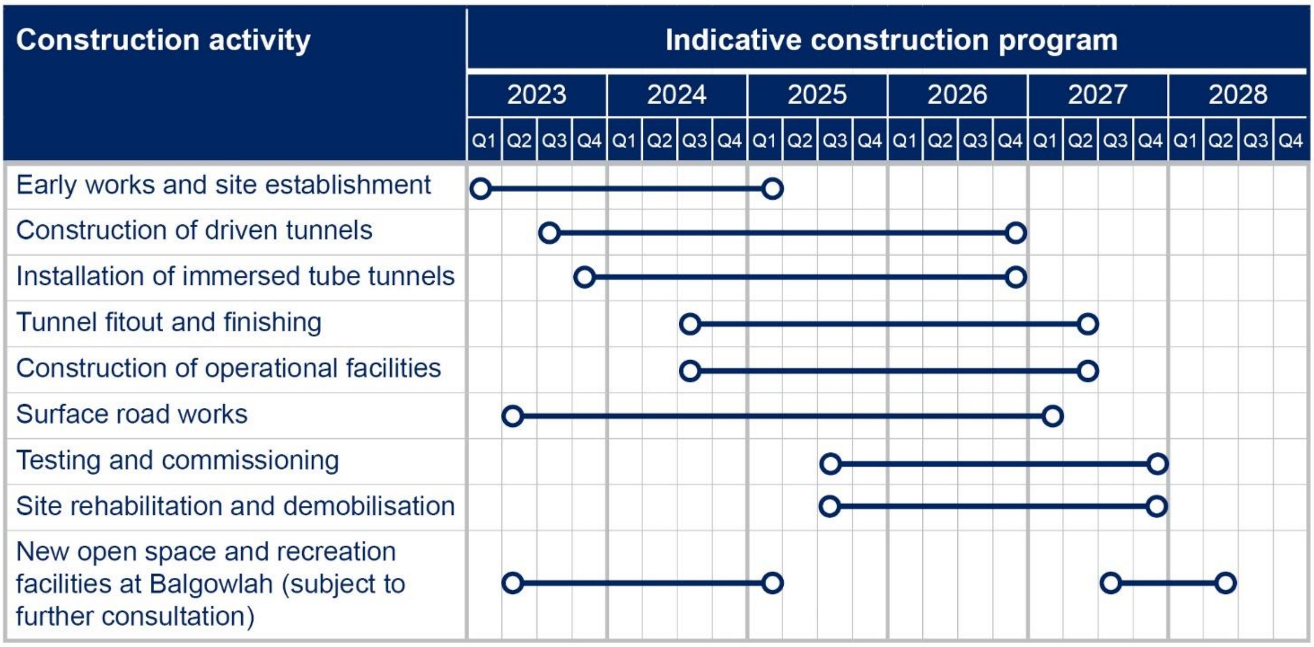

B140
Head (mAHD)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled


B154
Head (mAHD)
33.5
33
32.5
32
31.5
31
30.5
30
29.5
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled


B132_1
Head (mAHD)
3.5
3
2.5
2
1.5
1
0.5
0
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled


B156_1
Head (mAHD)
52.5
52
51.5
51
50.5
50
49.5
49
48.5
48
47.5
47
46.5
46
45.5
45
44.5
44
Jan-2015
Jul-2015
Jan-2016
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Date
Observed
Modelled

Attachment 6 Simplified construction staging summary


Construction activity
Indicative construction program
2023
2024
2025
2026
2027
2028
Q1 Q2 Q3 Q4
Early works and site establishment
Construction of driven tunnels
Installation of immersed tube tunnels
Tunnel fitout and finishing
Construction of operational facilities
Surface road works
Testing and commissioning
Site rehabilitation and demobilisation
New open space and recreation facilities at Balgowlah (subject to further consultation)

Attachment 7 SEEP/W hydraulic conductivity functions

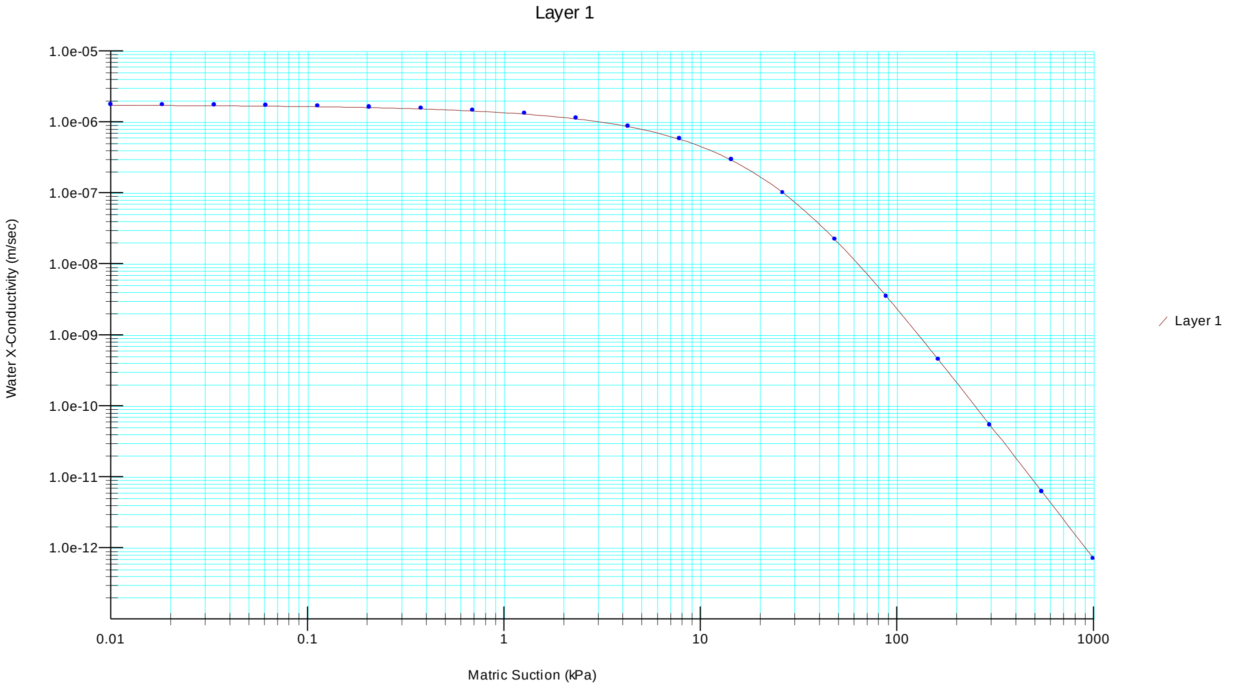


Figure A7-1: Layer 1 hydraulic conductivity function.

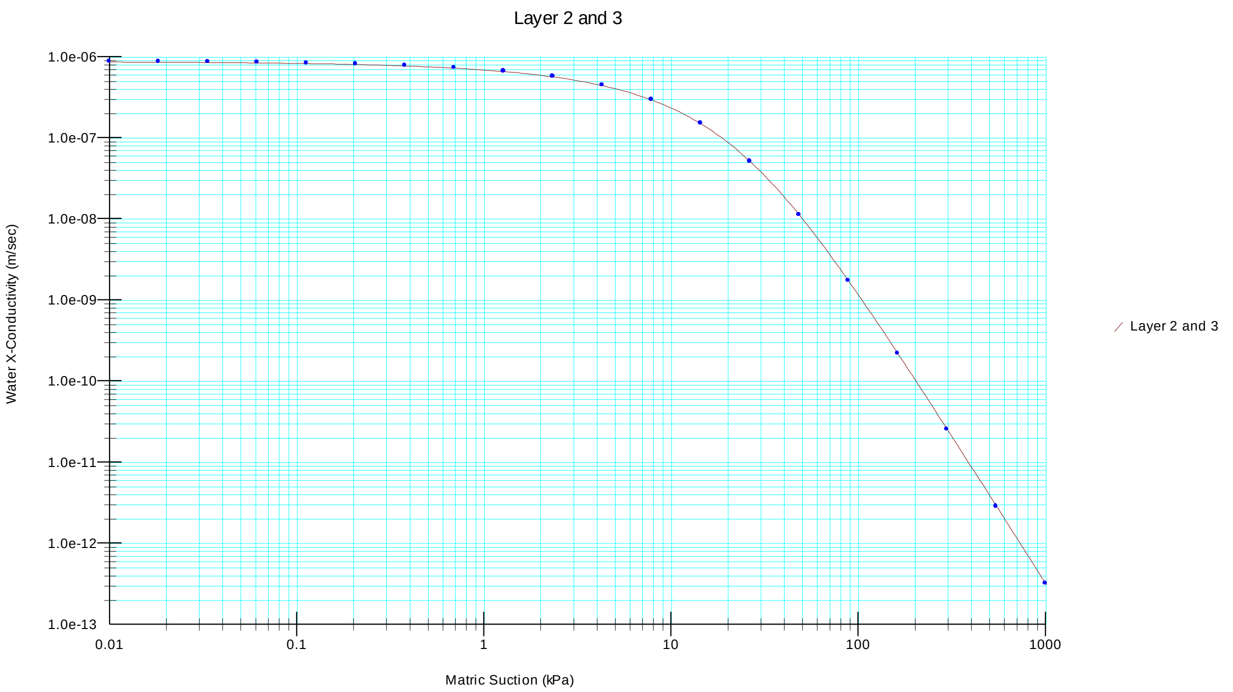


Figure A7-2: Layer 2 and 3 hydraulic conductivity function.

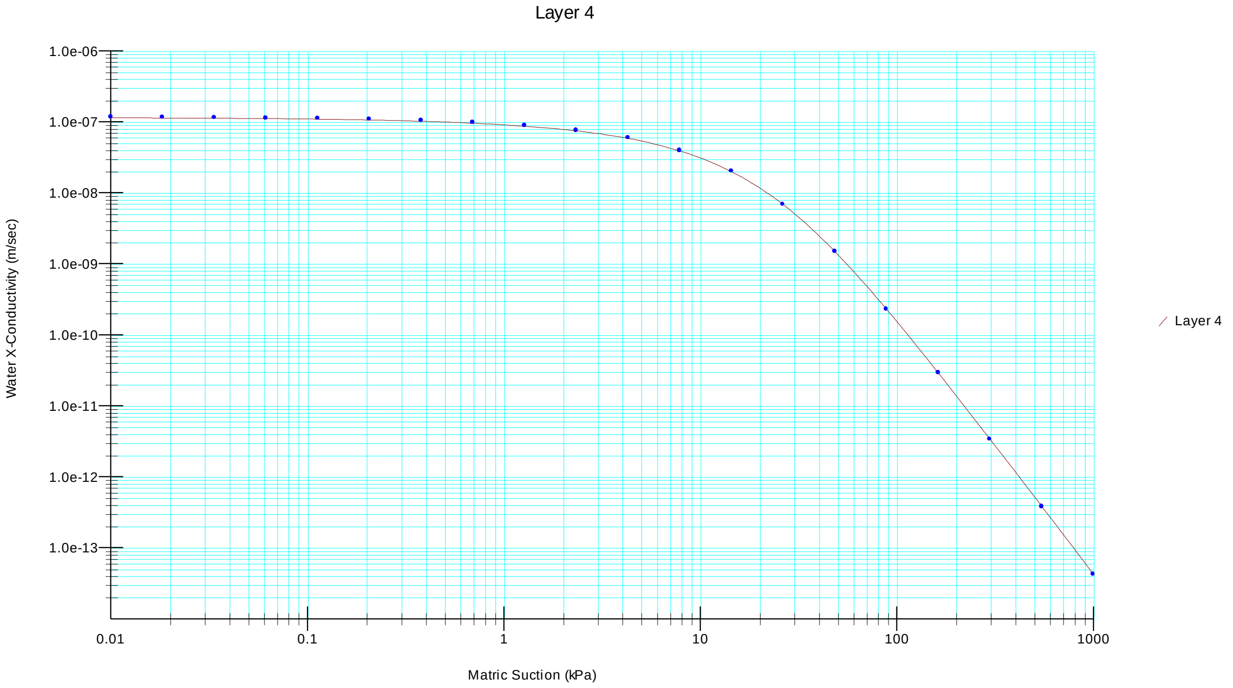


Figure A7-3: Layer 4 hydraulic conductivity function.

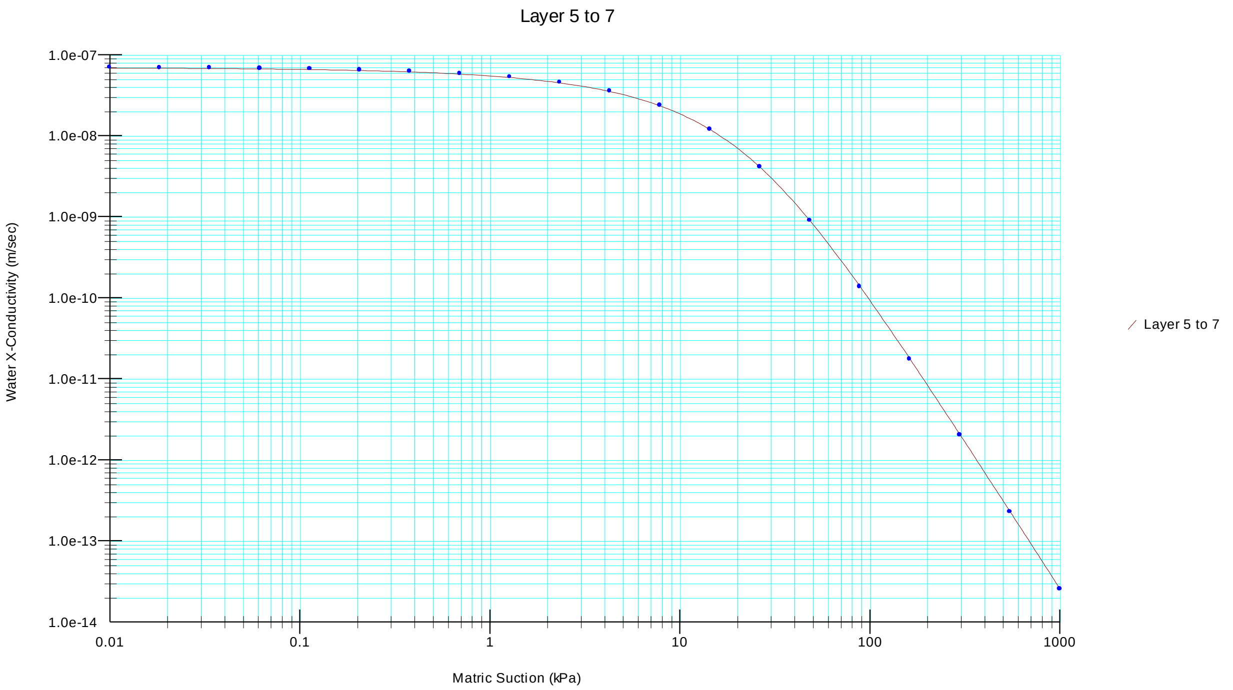


Figure A7-4: Layer 5 to 7 hydraulic conductivity function.

Attachment 8 SEEP/W water content functions

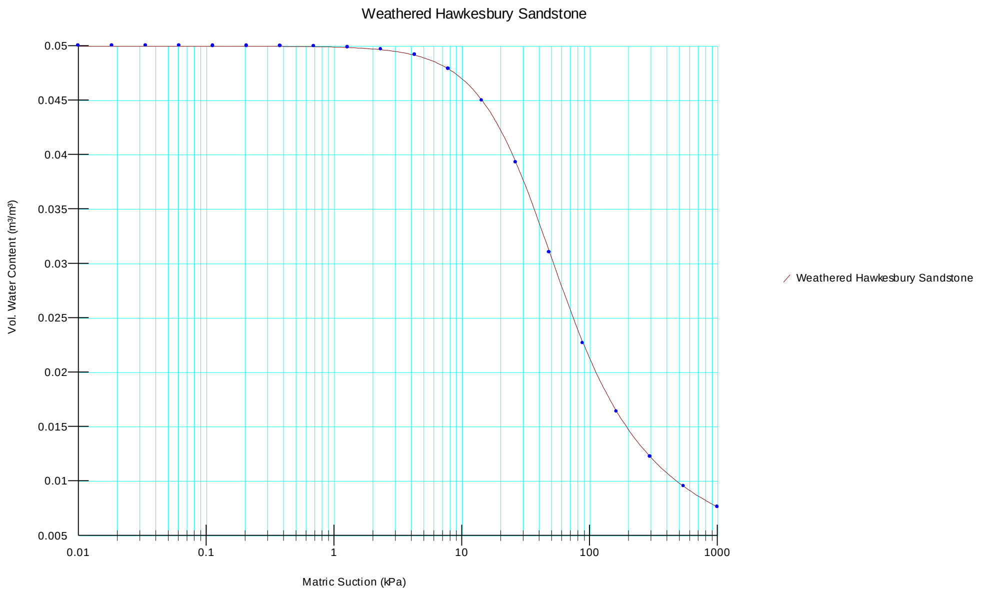


Figure A8-1: Water content function assigned to weathered Hawkesbury Sandstone in Layer 1.

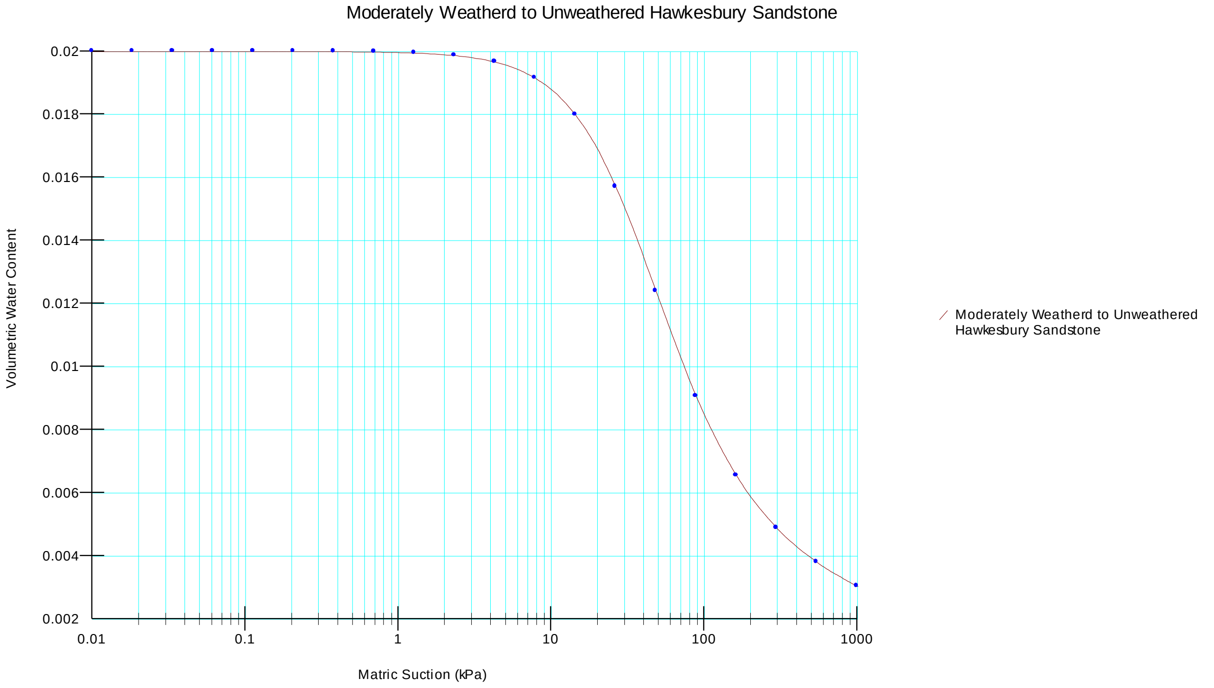


Figure A8-2: Water content function assigned to Layer 2 to Layer 7.