Appendix R

Groundwater impact assessment

WestConnex

WestConnex Delivery Authority

Westconnex M4 East

Groundwater Impact Assessment

September 2015

Prepared for

WestConnex Delivery Authority

Prepared by

GHD Australia

Document controls

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Contents

Glossary of terms and abbreviations

Term	Meaning
ADWG	Australian drinking water guidelines
AHD	Australian height datum – A common national surface level datum approximately corresponding to mean sea level.
ANZECC	Australian and New Zealand Environment Conservation Council
Aquifer	A groundwater bearing formation sufficiently permeable to transmit and yield groundwater.
Aquitard	A formation that is of sufficiently low permeability to limit groundwater flow relative to more permeable groundwater bearing units.
ASS	Acid sulfate soils
BOM	Bureau of Meteorology
Bore	Constructed connection between the surface and a groundwater source that enables groundwater to be transferred to the surface either naturally or through artificial means.
btoc	Below top of casing – The top of the well casing where the depth to groundwater is measured from. The top of casing is usually at similar elevation to ground surface.
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site.
DECC	Department of Environment and Climate Change
DGRs	Director General's Requirements
DPI Water	Department of Primary Industries Water
Drawdown	A reduction in piezometric head within an aquifer.
DTV	Default trigger value
DWE	NSW Department of Water and Energy
EC	Electrical conductivity
EIS	Environmental impact statement
EPA	Environment Protection Authority
EP&A Act	*Environmental Planning and Assessment Act 1979*
Fracture	Cracks within the strata that develop naturally or as a result of underground works.
GDE	Groundwater dependent ecosystem
GHD	GHD Pty Ltd
GMR	Greater metropolitan region
GMS	Groundwater modelling system
Groundwater	Subsurface water that occurs in soils and geological formations.
Hydrogeology	The area of geology that deals with the distribution and movement of groundwater in soils and rocks.
Infiltration	The downward movement of water into soil and rock. It is largely governed by the structural condition of the soil, the nature of the soil surface (including presence of vegetation) and the antecedent moisture content of the soil.
Kh	Horizontal hydraulic conductivity
Kv	Vertical hydraulic conductivity
L/s/km	Litres per second per kilometre of tunnel. A measure of tunnel groundwater inflow rates
LGA	Local government area
LTAAEL	Long term average annual extraction limit
NSW	New South Wales
NOW	NSW Office of Water and now called the NSW Department of Primary Industries Water
NWQMS	National Water Quality Management Strategy
Outcrop	Where the bedrock is exposed at the ground surface.
Runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
Strata	Geological layers below the ground surface.

Term	Meaning
Structure	The combination or spatial arrangement of primary soil particles (clay, silt, sand, gravel) into aggregates such as peds or clods, and their stability to deformation.
Subsidence	Movements and deformations at the ground surface where: • The vertical downward surface movements are greater than 20 mm • The potential impacts on major surface infrastructure, structures or natural features may be significant, notwithstanding that the vertical downward surface movements are less than 20 mm.
SEARs	Secretary's environmental assessment requirements
Study area	Refers to area of assessment for the groundwater modelling, which is broadly from Cooks River in the south to Parramatta River in the north and from Homebush in the west to Leichhardt in the east.
Surface water	Water that is derived from precipitation or pumped from underground and may be stored in dams, rivers, creeks and drainage lines.
Tanked tunnel	A tunnel with a fully complete impermeable casing that achieves seepage rates that are, for all intent and purpose, negligible.
TDS	Total dissolved solids
Un-tanked tunnel	A tunnel with a fully complete impermeable liner that achieves seepage rates that are, for all intent and purpose, negligible.
Vertical subsidence	Vertical downward movements of the ground surface.
WAL	Water access licence
WM Act	*Water Management Act 2000* (NSW)
WSP	Water sharing plan

Executive summary

A groundwater impact assessment has been completed to assess the impacts of the project on the surrounding environment. The assessment was prepared to support the environmental impact statement for the project (EIS) and to address key issues outlined in the Secretary's environmental assessment requirements.

A desktop study was undertaken to characterise the existing environment and it was found that the groundwater resource in this area is of relatively low environmental value as noted by the following conditions:

- Groundwater chemistry data suggest that groundwater in all aquifers is of limited beneficial human use due to high background metals concentrations. Total dissolved solids concentrations in Ashfield Shales are also particularly high and unsuitable for human or stock purposes
- Groundwater is potentially being used at isolated locations for domestic purposes only
- Surface water systems intersecting the project are significantly modified, are concrete lined and are interpreted to have limited interaction with groundwater
- A zone of potential acid sulfate soils and wetland systems (mainly salt marsh and mangroves) was identified within the tidal fringe of the Parramatta River as potentially being sensitive. Groundwater elevations in these areas were considered to be primarily controlled by groundwater inflow or tidal inundation from the Parramatta River and as such it is considered that there is a low risk of these systems being impacted by the project.

Due to typically low inflows in the Hawkesbury Sandstone, it is common practice for tunnels excavated in the Hawkesbury Sandstone to have local treatment applied during construction to reduce inflows to acceptable levels and continue to be drained during their operation, rather than being tanked or fully watertight along their full length. Tanked tunnels are not proposed as part of the project, due to the project tunnels being largely constructed within the Hawkesbury Sandstone, the high capital expenditure associated with a significant amount of additional excavation and the pre-cast concrete structure required for their construction, and the low value of the groundwater resource. The project tunnels are therefore proposed to be constructed with treatment to maintain inflows below the design criteria of one litre per second over any given kilometre.

The assessment included the development of a numerical groundwater flow model to simulate the changes to the groundwater flow environment associated with the project. The modelling indicated the tunnelled areas would dominate the groundwater condition changes created by the project.

The long-term drawdown created by the project was identified to potentially affect a number of nearby bores that potentially use groundwater for domestic purposes. A bore survey is recommended to assess if these bores are being used, with subsequent monitoring and make good processes applying if the bores are adversely impacted (as indicated by the Aquifer Interference Policy criteria). The model has simulated the potential migration of saline water into the aquifer from Parramatta River, which would also need to be considered in make good provisions.

The drawdown cone was interpreted to extend beneath surface water features and intersect a zone of wetlands and potential acid sulfate soils near Homebush Bay. The potential for adverse impacts is expected to be low due to groundwater elevations in this area being maintained by the Parramatta River and its associated tidal fluctuations, however it is recommended that groundwater elevation monitoring is undertaken in this area with changes outside background conditions being linked to further acid sulfate soils investigations and wetland health assessments.

The models also simulated inflow volumes to the tunnels and suggest that unmitigated inflows are likely to be in the order of 1600 cubic metres per day during construction and less than 450 cubic metres per day during operation although this can vary significantly depending on the aquifer parameters used in the model. The predicted inflows are, however, within the range observed in similar tunnels in the Hawkesbury Sandstone in the Sydney area. The water sharing plan for this area suggests that there is available water in the groundwater source to accommodate these volumes. NSW Department of Primary Industries Water will be consulted with regard to approvals and licensing requirements for these volumes.

As the tunnel is tanked drained tunnel, there will be groundwater inflow in the construction phase and throughout the life of the tunnel, which will be collected and treated before discharge. Discharge could either to be sewer or surface water during construction, but on a long term basis discharge to surface water would be undertaken. A treatment plant is proposed to manage the maximum expected long term flows (17 litres per second to 1469 cubic metres per day) at the Cintra Park site. The treatment plant would be designed to treat key contaminants of concern associated with construction and operational activities and associated with background groundwater concentrations above selected criteria. The treatment criteria recommended for the treatment plant to be protective of aquatic ecosystems would include existing water quality conditions at the point of discharge, with specific environmental criteria being set using the statistical methods outlined in the Australian guidelines for water quality monitoring and reporting (ANZECC & ARMCANZ, 2000). Where there are no site data available, the lower value for the ANZECC 95th percentile default trigger value for fresh or marine water criteria would be adopted. To suitably protect recreational users potentially coming into contact with treatment plant discharge in surface water, the treatment plant discharge water quality should also meet the Australian drinking water values (NHMRC, 2013) multiplied by a factor of 10, which is in line with the approach adopted by the World Health Organisation.

To minimise groundwater seepage treatment requirements during operation, the groundwater seepage would be directed through a drainage system that is hydraulically disconnected from surface water runoff collection systems.

With the impacts identified and the management measures outlined above it is considered that adverse groundwater impacts could be effectively managed for the project.

1 Introduction

1.1 Overview of the project

The WestConnex Delivery Authority (WDA), on behalf of the NSW Roads and Maritime Services (Roads and Maritime), is seeking approval to upgrade and extend the M4 Motorway from Homebush Bay Drive at Homebush to Parramatta Road and City West Link (Wattle Street) at Haberfield. This includes twin 5.5 kilometre long tunnels and associated surface works. These proposed works are described as the M4 East project (the project). The location of the project is shown in **Figure 1.1**.

Approval is being sought under Part 5.1 of the *Environmental Planning and Assessment Act 1979* (NSW) (EP&A Act). The project was declared by the Minister for Planning to be State significant infrastructure and critical State significant infrastructure and an environmental impact statement (EIS) is therefore required.

The project is a component of WestConnex, which is a proposal to provide a 33 kilometre motorway linking Sydney's west and south-west with Sydney Airport and the Port Botany precinct. The location of WestConnex is shown in **Table 1.2**. The individual components of WestConnex are:

- M4 Widening – Pitt Street at Parramatta to Homebush Bay Drive (planning approval granted and under construction)
- M4 East (the subject of this report)
- New M5 – King Georges Road at Beverly Hills to St Peters (planning application lodged and subject to planning approval)
- King Georges Road Interchange Upgrade (planning approval granted and work has commenced)
- M4–M5 Link – Haberfield to St Peters, including the Southern Gateway and Southern Extension (undergoing concept development and subject to planning approval).

Separate planning applications will be lodged for each individual component project. Each project will be assessed separately, but the impacts of each project will also be considered in the context of the wider WestConnex.

The NSW Government has established WDA to deliver WestConnex. WDA has been established as an independent public subsidiary corporation of Roads and Maritime. Its role and functions are set out in Part 4A of the *Transport Administration (General) Regulation 20*13 (NSW). WDA is project managing the planning approval process for the project on behalf of Roads and Maritime. However, for the purpose of the planning application for the project, Roads and Maritime is the proponent.

1.2 Project location

The project is generally located in the inner west region of Sydney within the Auburn, Strathfield, Canada Bay, Burwood and Ashfield local government areas (LGAs). The project travels through 10 suburbs: Sydney Olympic Park, Homebush West, Homebush, North Strathfield, Strathfield, Concord, Burwood, Croydon, Ashfield and Haberfield.

The project is generally located within the M4 and Parramatta Road corridor, which links Broadway at the southern end of the Sydney central business district (CBD) and Parramatta in Sydney's west, about 20 kilometres to the west of the Sydney CBD. This corridor also provides the key link between the Sydney CBD and areas further west of Parramatta (such as Penrith and western NSW).

The western end of the project is located at the interchange between Homebush Bay Drive and the M4, about 13 kilometres west of the Sydney CBD. The project at this location would tie in with the M4 Widening project in the vicinity of Homebush Bay Drive.

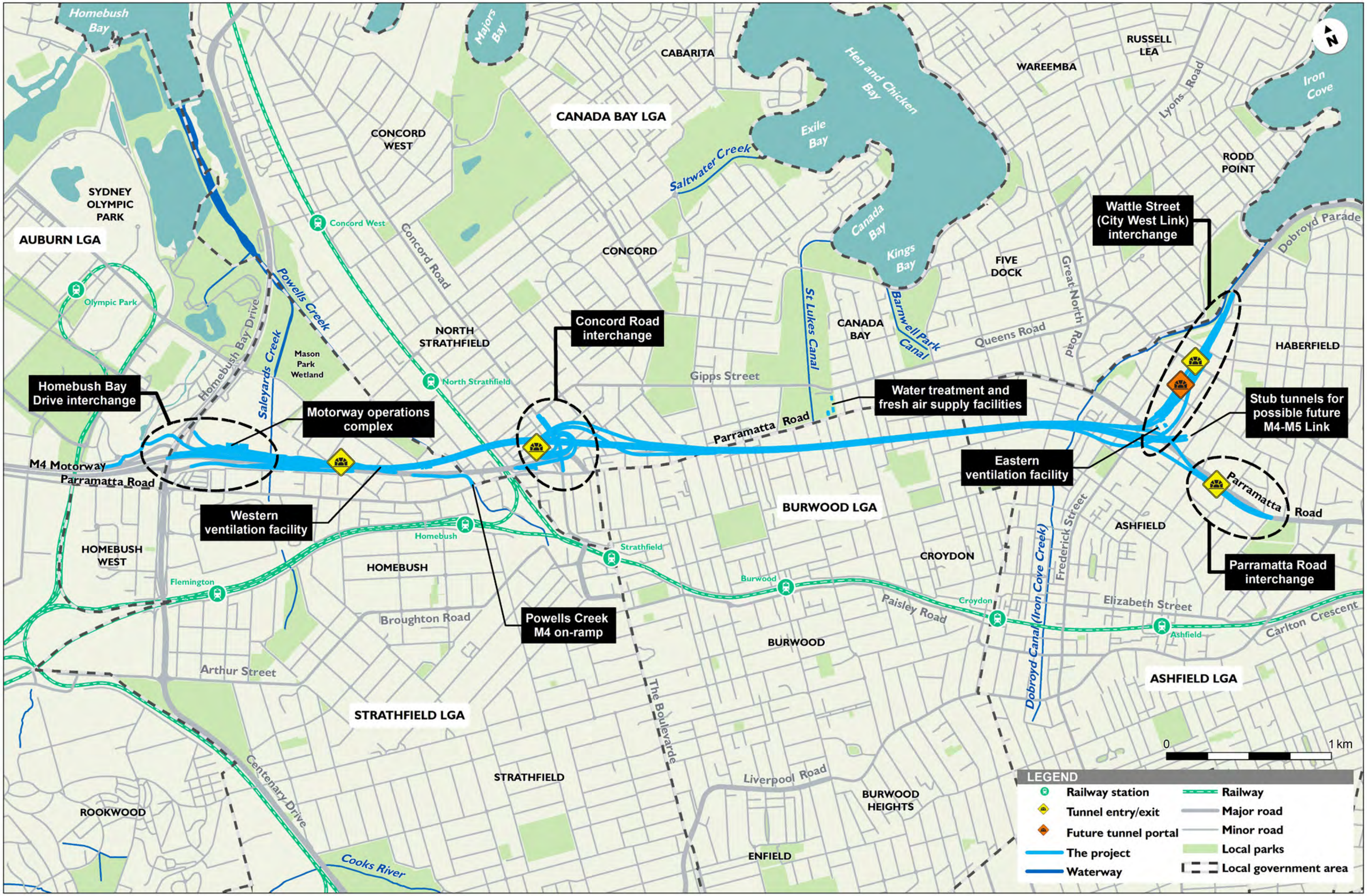


Figure 1.1 Local context of the project

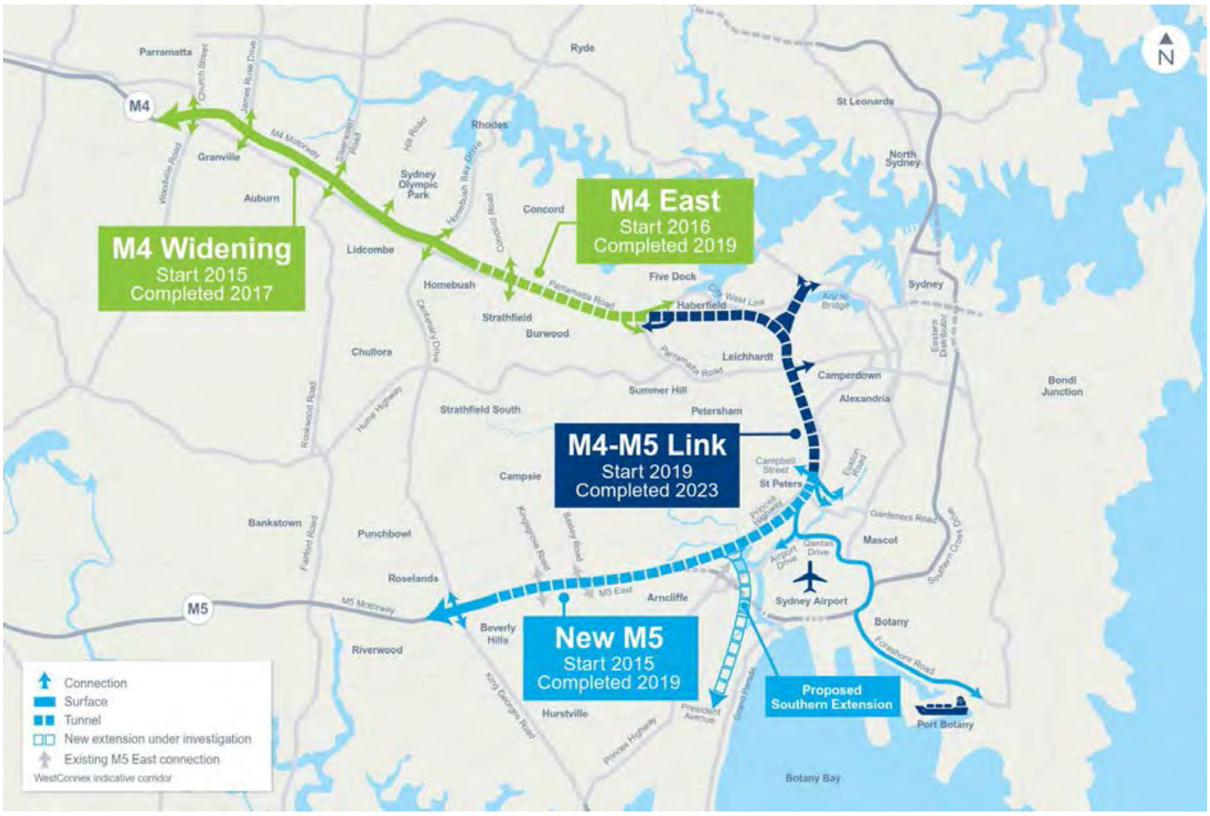


Figure 1.2 **WestConnex**

The tunnel dive structures would start at the centre of the M4, west of the existing pedestrian footbridge over the M4 at Pomeroy Street, and would continue underground to the north of the existing M4 and Parramatta Road, before crossing beneath Parramatta Road at Broughton Street at Burwood. The tunnels would continue underground to the south of Parramatta Road until the intersection of Parramatta Road and Wattle Street at Haberfield. Ramps would connect the tunnels to Parramatta Road and Wattle Street (City West Link) at the eastern end of the project. The tunnels would end in a stub connection to the possible future M4–M5 Link (M4–M5 Link), near Alt Street at Haberfield.

The project would include interchanges between the tunnels and the above ground road network, along with other surface road works, at the following locations:

- M4 and Homebush Bay Drive interchange at Sydney Olympic Park and Homebush (Homebush Bay Drive interchange)
- Powells Creek, near George Street at North Strathfield (Powells Creek M4 on-ramp)
- Queen Street, near Parramatta Road at North Strathfield (Queen Street cycleway westbound on-ramp)
- M4 and Sydney Street, Concord Road and Parramatta Road interchange at North Strathfield (Concord Road interchange)
- Wattle Street (City West Link), between Parramatta Road and Waratah Street at Haberfield (Wattle Street (City West Link) interchange)
- Parramatta Road, between Bland Street and Orpington Street at Ashfield and Haberfield (Parramatta Road interchange).

1.3 Secretary's environmental assessment requirements

The NSW Department of Planning and Environment has issued a list of Secretary's Environmental Assessment Requirements (SEARs) that inform the environmental impact assessment. **Table 1.1** displays the SEARS that are specific to groundwater; and also provides a cross reference to the relevant section(s) of this report which address these requirements.

In addition, one agency letter, which accompany the SEARs and are applicable to groundwater, was issued by NSW Department of Primary Industries Water (DPI Water).

Table 1.2 provides details of the groundwater requirements outlined in the agency letters and a cross reference to the relevant section(s) of this report which address these conditions.

Table 1.1 Secretary's Environmental Assessment Requirements (SEARs)

Requirement	Location in this report
Soil and water, including but not limited to:	
Groundwater impacts as a result of the project (including ancillary facilities such as the tunnel control centre and any deluge systems), considering local impacts along the length of the tunnels and impacts on local and regional hydrology including consideration of any Water Sharing Plan and impacts on groundwater flow.	**Chapters 2**, **3**, **4**, **5**, **6** and **7**
The SEARs also stipulate that the groundwater impact assessment must consider:	
• extent of drawdown • impacts to groundwater quality • volume of groundwater that will be taken (including inflows) • discharge requirements • location and details of groundwater management • implications for groundwater-dependent surface flows, groundwater-dependent ecological communities, and groundwater users	**Chapters 5**, **6** and **7**
Requirement	**Location in this report**
The assessment should include details of proposed surface and groundwater monitoring and be prepared having consideration to the requirements of the NSW Aquifer Interference Policy	**Chapters 3**, **6** and **7**
Identifying potential impacts of the development on acid sulfate soils in accordance with the relevant guidelines and a description of the mitigation measures proposed to minimise potential impacts	**Chapters 5** and **6**

Table 1.2 How agency comments have been addressed in this report

Agency letters	
NSW DPI Water (formerly Office of Water)	
Requirement	**Location in this report**
• Assessment of impacts to surface water and groundwater sources (both quality and quantity), water courses, riparian land and groundwater dependent ecosystems.	**Chapter 6**
• Proposed measures to mitigate impacts identified.	**Chapter 7**
• Proposed surface water and groundwater monitoring.	**Chapter 7**
• Details of water proposed to be taken (including through inflow and seepage) from each water source as defined by the relevant water sharing plans (WSPs).	**Chapter 6**
• Assessment of water licensing requirements.	**Chapters 3** and **6**

Agency letters	
• A detailed and consolidated site water balance.	**Chapter 6**
• Consideration of relevant policies and guidance.	**Chapter 4**
• Measures proposed to reduce groundwater ingress.	**Chapter 7**
• By way of specific comment, the soil and water section of the draft DGRs should be amended to include details on: – impacts on groundwater flow, – the volume of groundwater that will be taken (including inflows), and – measures proposed to minimise groundwater ingress.	**Chapters 6** and **7**
Relevant Legislation • The Environmental Impact Statement (EIS) should take into account the objects and regulatory requirements of the Water Act 1912 and Water Management Act 2000 (WMA 2000), as applicable. Proposals and management plans should be consistent with the Objects (s.3) and Water Management Principles (s.5) of the Water Management Act.	**Chapter 4**
Water Sharing Plans (WSPs) • The proposal is located within the area covered by the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources (2011) and the Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources (2011). The EIS is required to: – Demonstrate how the proposal is consistent with the relevant rules of the WSPs including rules for access licences, distance restrictions for water supply works and rules for the management of local impacts in respect of surface water and groundwater sources, ecosystem protection, water quality and surface-groundwater connectivity. – Provide a description of any site water use (amount of water from each water source) and management including all sediment dams, clear water diversion structures with detail on the location, design specifications and storage capacities for all the existing and proposed water management structures. – Provide an analysis of the proposed water supply arrangements against the rules for access licences and other applicable requirements of any relevant WSP. – Provide a detailed and consolidated site water balance.	**Chapters 4** and **6** Tunnel inflows simulated by the groundwater modelling support the surface water balance assessment and water storage requirements.

<table>
<tr><th colspan="2">Agency letters</th></tr>
<tr><td>Relevant Policies and Guidelines
• The EIS should take into account the following policies (as applicable):
– Aquifer Interference Policy (2012);
– NSW State Groundwater Policy Framework Document (1997);
– NSW State Groundwater Quality Protection Policy (1998);
– NSW State Groundwater Dependent Ecosystems Policy (2002); and
– Department of Primary Industries Risk Assessment Guidelines for Groundwater Dependent Ecosystems (2012).
– NSW Water Extraction Monitoring Policy (2007)
– Australian Groundwater Monitoring Guidelines (2012)
The EIS needs to demonstrate the proposal is consistent with the spirit and principles of these policy documents.</td><td>Chapter 4</td></tr>
<tr><td>Licensing Considerations
• The EIS is required to provide:
– Identification of water requirements for the life of the proposed project in terms of both volume and timing (including predictions of potential ongoing groundwater take following the cessation of operations at the site - i.e. evaporative loss from open voids).
– Details of the water supply source(s) for the proposal including any proposed surface water and groundwater extraction from each water source (as defined by the relevant water sharing plans) and all 'water supply works to take water.
– Explanation of how the required water entitlements will be obtained (i.e. through a new or existing licence/s, trading on the water market, controlled allocations etc.).
– Information on the purpose, location, construction and expected annual extraction volumes including details on all existing and proposed water supply works which take surface water, (pumps, dams, diversions, etc).
– Details on all bores and excavations for the purpose of investigation, extraction, dewatering, testing and monitoring. All predicted groundwater take must be accounted for through adequate licensing.
• Water allocation account management rules, total daily extraction limits and rules governing environmental protection and access licence dealings also need to be considered.</td><td>Chapters 4, 6 and 7</td></tr>
</table>

Agency letters	
Groundwater Assessment • To ensure the sustainable and integrated management of groundwater sources, the EIS needs to include adequate details to assess the impact of the project on all groundwater sources including: – The predicted highest groundwater table at the site. – Works likely to intercept, connect with or infiltrate the groundwater sources. – Any proposed groundwater extraction, including purpose, location and construction details of all proposed bores and expected annual extraction volumes. – A description of the flow directions and rates and physical and chemical characteristics of the groundwater source. – The predicted impacts of any final landform on the groundwater regime. – The existing groundwater users within the area (including the environment), any potential impacts on these users and safeguard measures to mitigate impacts. – An assessment of the quality of the groundwater for the local groundwater catchment. – An assessment of the potential for groundwater contamination (considering both the impacts of the proposal on groundwater contamination and the impacts of contamination on the proposal).	These requirements form the basis of this assessment and each point is addressed throughout the document.
– Measures proposed to protect groundwater quality, both in the short and long term. – Measures for preventing groundwater pollution so that remediation is not required. – Protective measures for any groundwater dependent ecosystems (GDEs). – Proposed methods of the disposal of waste water and approval from the relevant authority. – The results of any models or predictive tools used. • Where potential impact/s are identified the assessment will need to identify limits to the level of impact and contingency measures that would remediate, reduce or manage potential impacts to the existing groundwater resource and any dependent groundwater environment or water users, including information on: – Any proposed monitoring programs, including water levels and quality data. – Reporting procedures for any monitoring program including mechanism for transfer of information. • An assessment of any groundwater source/aquifer that may be sterilised from future use as a water supply as a consequence of the proposal.	

Agency letters	
Groundwater Dependent Ecosystems • It is suggested the EIS considers the potential impacts on any Groundwater Dependent Ecosystems (GDEs) at the site and in the vicinity of the site and: • Identify any potential impacts on GDEs as a result of the proposal including: – the effect of the proposal on the recharge to groundwater systems – the potential to adversely affect the water quality of the underlying groundwater system and adjoining groundwater systems in hydraulic connections – the effect on the function of GDEs (habitat, groundwater levels, connectivity). • Provide safeguard measures for any GDEs.	**Chapters 5**, **6** and **7**
NSW EPA	
Requirement	**Location in this report**
Acid Sulfate Soils • The potential impacts of the development on acid sulfate soils must be assessed in accordance with the relevant guidelines in the Acid Sulfate Soils Manual (Stone et al. 1998) and the Acid Sulfate Soils Laboratory Methods Guidelines (Ahern et al. 2004). • Describe mitigation and management options that will be used to prevent, control, abate or minimise potential impacts from the disturbance of acid sulfate soils associated with the project and to reduce risks to human health and prevent the degradation of the environment. This should include an assessment of the effectiveness and reliability of the measures and any residual impacts after these measures are implemented	Acid sulfate soils risk are dealt with in the soil and land contamination assessment report (GHD, 2015a). The risk of the presence of acid sulfate soils and drawdown impacts associated with the tunnel are addressed in **section 6.3.6**

Agency letters	
Water • Describe the proposal including position of any intakes and discharges, volumes, water quality and frequency of all water discharges. • Demonstrate that all practical options to avoid discharge have been implemented and environmental impact minimised where discharge is necessary. • Where relevant include a water balance for the development including water requirements (quantity, quality and source(s)) and proposed storm and wastewater disposal, including type, volumes, proposed treatment and management methods and re-use options. • Describe existing surface and groundwater quality. An assessment needs to be undertaken for any water resource likely to be affected by the proposal. • State the Water Quality Objectives for the receiving waters relevant to the proposal. These refer to the community's agreed environmental values and human uses endorsed by the NSW Government as goals for ambient waters (http://www.environment.nsw.qov.au/ieo/index.htm). Where groundwater may be impacted the assessment should identify appropriate groundwater environmental values. • State the indicators and associated trigger values or criteria for the identified environmental values. This information should be sourced from the ANZECC & ARMCANZ (2000) Guidelines for Fresh and Marine Water Quality (http://www.mincos.qov.au/publications/ Australian and New Zealand guidelines for fresh and marine water quality). • State any locally specific objectives, criteria or targets which have been endorsed by the NSW Government. • Describe the nature and degree of impact that any proposed discharges will have on the receiving environment. • Assess impacts against the relevant ambient water quality outcomes. Demonstrate how the proposal will be designed and operated to: – protect the Water Quality Objectives for receiving waters where they are currently being achieved;	**Chapters 5**, **6** and **7**
Agency letters	
– contribute towards achievement of the Water Quality Objectives over time where they are not currently being achieved. • Where a discharge is proposed that includes a mixing zone, the proposal should demonstrate how wastewater discharged to waterways will ensure the ANZECC (2000) water quality criteria for relevant chemical and non-chemical parameters are met at the edge of the initial mixing zone of the discharge, and that any impacts in the initial mixing zone are demonstrated to be reversible. • Assess impacts on groundwater and groundwater dependent ecosystems. Describe how predicted impacts will be monitored and assessed over time.	

1.3.1 Structure of this report

To address the SEARs the document has been divided into the following key sections:

- **Chapter 2** – Proposed project
- **Chapter 3** – Assessment methodology
- **Chapter 4** – Groundwater policy/guidance review, which details the NSW groundwater policy framework on which the groundwater impact assessment has been based
- **Chapter 5** – Existing environment, which describes the current environment that the project would interact with including the hydrogeological conditions and environmental values of the surrounding environment
- **Chapter 6** – Impact assessment, which characterises the impacts to groundwater dependent systems associated with the tunnel on the surrounding environment using numerical modelling techniques
- **Chapter 7** – Groundwater management, which characterises proposed management and monitoring measures required to mitigate impacts and manage tunnel inflows.

2 Proposed project

2.1 Project features

The project would comprise the construction and operation of the following key features:

- Widening, realignment and resurfacing of the M4 between Homebush Bay Drive at Homebush and Underwood Road at North Strathfield
- Upgrade of the existing Homebush Bay Drive interchange to connect the western end of the new tunnels to the existing M4 and Homebush Bay Drive, while maintaining all current surface connections
- Two new three-lane tunnels (the mainline tunnels), one eastbound and one westbound, extending from west of Pomeroy Street at Homebush to near Alt Street at Haberfield, where they would terminate until the completion of the M4–M5 Link. Each tunnel would be about 5.5 kilometres long and would have a minimum internal clearance (height) to in-tunnel services of 5.3 metres
- A new westbound on-ramp from Parramatta Road to the M4 at Powells Creek, west of George Street at North Strathfield
- An interchange at Concord Road, North Strathfield/Concord with on-ramps to the eastbound tunnel and off-ramps from the westbound tunnel. Access from the existing M4 to Concord Road would be maintained via Sydney Street. A new on-ramp would be provided from Concord Road southbound to the existing M4 westbound, and the existing on-ramp from Concord Road northbound to the existing M4 westbound would be removed
- Modification of the intersection of the existing M4 and Parramatta Road, to remove the left turn movement from Parramatta Road eastbound to the existing M4 westbound
- An interchange at Wattle Street (City West Link) at Haberfield with an on-ramp to the westbound tunnel and an off-ramp from the eastbound tunnel. The project also includes on- and off-ramps at this interchange that would provide access to the M4–M5 Link. In addition, the westbound lanes of Wattle Street would be realigned
- An interchange at Parramatta Road at Ashfield/Haberfield, with an on-ramp to the westbound tunnel and an off-ramp from the eastbound tunnel. In addition, the westbound lanes of Parramatta Road would be realigned
- Installation of tunnel ventilation systems, including ventilation facilities within the existing M4 road reserve near Underwood Road at Homebush (western ventilation facility) and at the corner of Parramatta Road and Wattle Street at Haberfield (eastern ventilation facility). The eastern ventilation facility would serve both the project and the M4–M5 Link project. Provision has also been made for a fresh air supply facility at Cintra Park at Concord
- Associated surface road work on the arterial and local road network, including reconfiguration of lanes, changes to traffic signalling and phasing, and permanent road closures at a small number of local roads
- Pedestrian and cycle facilities, including permanently re-routing a portion of the existing eastbound cycleway on the northern side of the M4 from west of Homebush Bay Drive to near Pomeroy Street, and a new westbound cycleway on-ramp connection from Queen Street at North Strathfield to the existing M4
- Tunnel support systems and services such as electricity substations, fire pump rooms and tanks, water treatment facilities, and fire and life safety systems including emergency evacuation infrastructure
- Motorway operations complex on the northern side of the existing M4, east of the Homebush Bay Drive interchange
- Provision of road infrastructure and services to support the future implementation of smart motorway operations (subject to separate planning approval)
- Installation of tolling gantries and traffic control systems along the length of the project

- Provision of new and modified noise walls
- Provision of low noise pavement for new and modified sections of the existing M4 and tunnel on- and off-ramps
- Temporary construction ancillary facilities and temporary works to facilitate the construction of the project.

An overview of the project at completion is shown in **Figure 2.1**.

The project does not include work required for reconfiguring Parramatta Road as part of the urban transformation program. The project does not include ongoing motorway maintenance activities during operation. These would be subject to separate assessment and approval as appropriate.

2.2 Construction activities

2.2.1 Overview

Construction activities associated with the project would generally include:

- Enabling and temporary works, including construction power, water supply, ancillary site establishment, demolition works, property adjustments and public transport modifications (if required)
- Construction of the road tunnels, interchanges, intersections and roadside infrastructure
- Haulage of spoil generated during tunnelling and excavation activities
- Fitout of the road tunnels and support infrastructure, including ventilation and emergency response systems
- Construction and fitout of the motorway operations complex and other ancillary operations buildings
- Realignment, modification or replacement of surface roads, bridges and underpasses
- Implementation of environmental management and pollution control facilities for the project.

For the purpose of this assessment, the project does not include surveys, sampling or investigation to inform the design or assessment, such as test drilling, test excavations, geotechnical investigations, adjustments to, or relocation of, existing utilities infrastructure, or other tests.

2.2.2 Construction footprint

The total area required for construction of the project, including construction ancillary facilities, is referred to as the 'construction footprint'. The construction footprint would be about 65 hectares in total, comprising about 48 hectares at the surface and about 17 hectares below ground.

In addition to below ground works, surface works would be required to support tunnelling activities and to construct surface infrastructure such as interchanges, tunnel portals, ventilation facilities, ancillary operations buildings and facilities, and new cycleway facilities near the Homebush Bay Drive interchange and Queen Street at North Strathfield.

The overall surface construction footprint generally aligns with the operational footprint, with the locations of future operational ancillary facilities being used to support construction work. Some additional areas adjacent to the operational footprint (around the portals and on- and off-ramps, and also at the tunnel mid-point) would also be required during the construction stage only to facilitate construction access.

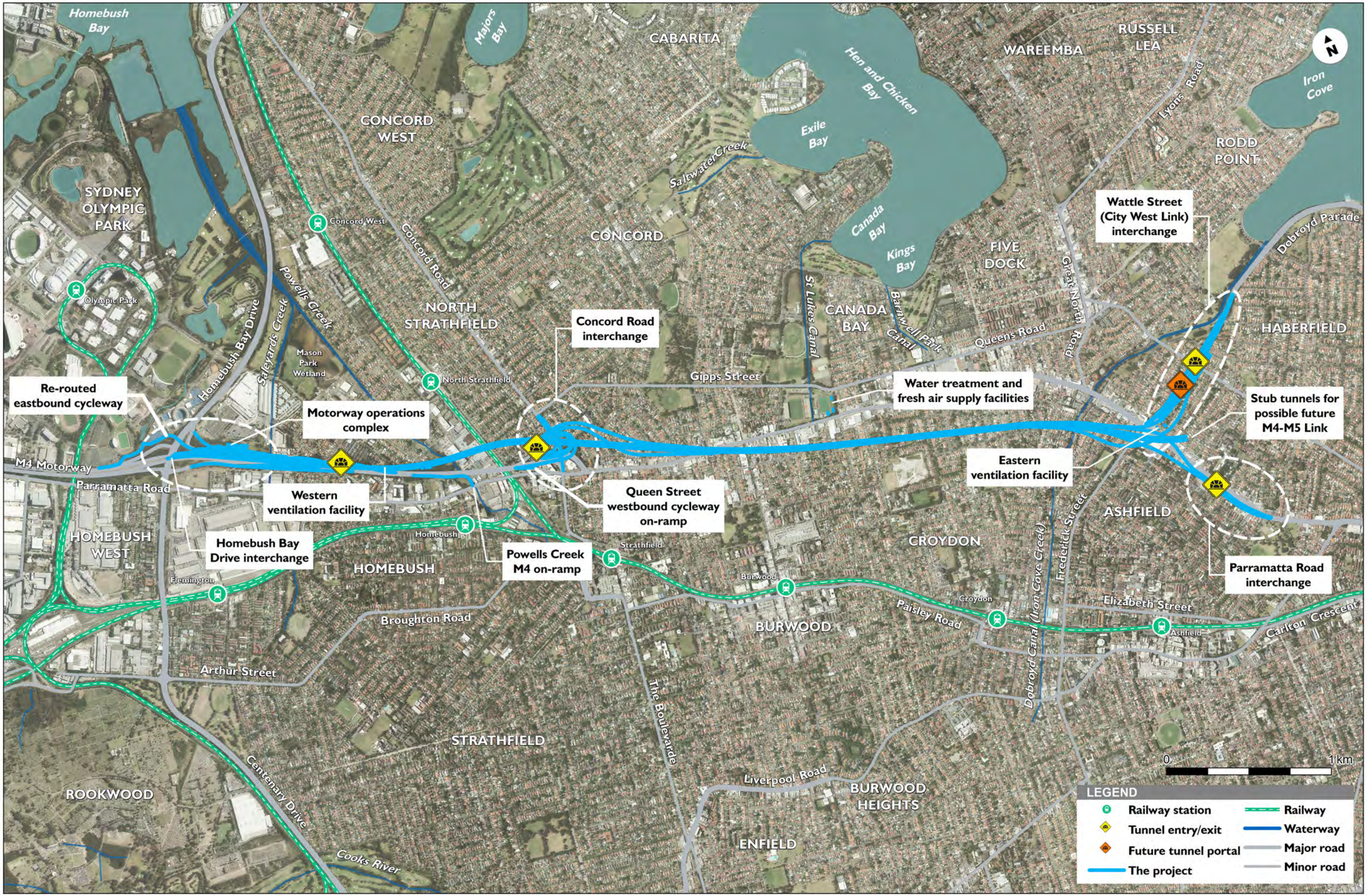


Figure 2.1 Overview of the proejct

Construction ancillary facilities currently proposed would be required at the following 10 locations:

- Homebush Bay Drive civil site (C1)
- Pomeroy Street civil site (C2)
- Underwood Road civil and tunnel site (C3)
- Powells Creek civil site (C4)
- Concord Road civil and tunnel site (C5)
- Cintra Park tunnel site (C6)
- Northcote Street tunnel site (C7)
- Eastern ventilation facility site (C8)
- Wattle Street and Walker Avenue civil site (C9)
- Parramatta Road civil site (C10).

An overview of the construction footprint is shown in **Figure 2.2**.

The final size and configuration of construction ancillary facilities would be further developed during detailed design.

2.2.3 Construction program

Subject to planning approval, construction of the project is planned to start in the second quarter of 2016, with completion planned for the first quarter of 2019. The total period of construction works is expected to be around three years, including nine months of commissioning occurring concurrently with the final stages of construction. The indicative construction program is shown in **Table 2.1**.

Table 2.1 Indicative construction program overview

Construction activity	Indicative construction timeframe															
	2016				2017				2018				2019			
Construction access excavation (all sites)		■	■	■												
Tunnelling (excavation)			■	■	■	■	■	■								
Tunnel drainage and pavement works						■	■	■	■	■						
Tunnel mechanical and electrical fitout works								■	■	■	■					
Tunnel completion works											■	■	■			
Homebush Bay Drive interchange			■	■	■	■	■	■	■	■						
M4 surface works		■	■	■	■	■	■	■	■	■	■	■				
Western ventilation facility							■	■	■	■	■					
Powells Creek on-ramp		■	■	■	■	■										
Concord Road interchange			■	■	■	■	■	■	■	■	■	■				
Wattle Street interchange		■	■	■	■	■	■	■	■	■	■	■	■			
Parramatta Road interchange		■	■	■	■	■	■	■	■	■	■	■	■			
Eastern ventilation facility		■	■	■	■	■	■	■	■	■	■	■				
Cintra Park fresh air supply facility				■	■	■	■	■	■	■	■	■	■			
Cintra Park water treatment facility										■	■					
Motorway operations complex						■	■	■								
Mechanical and electrical fitout works							■	■	■	■	■	■				
Site rehabilitation and landscaping						■	■	■	■	■	■	■	■			

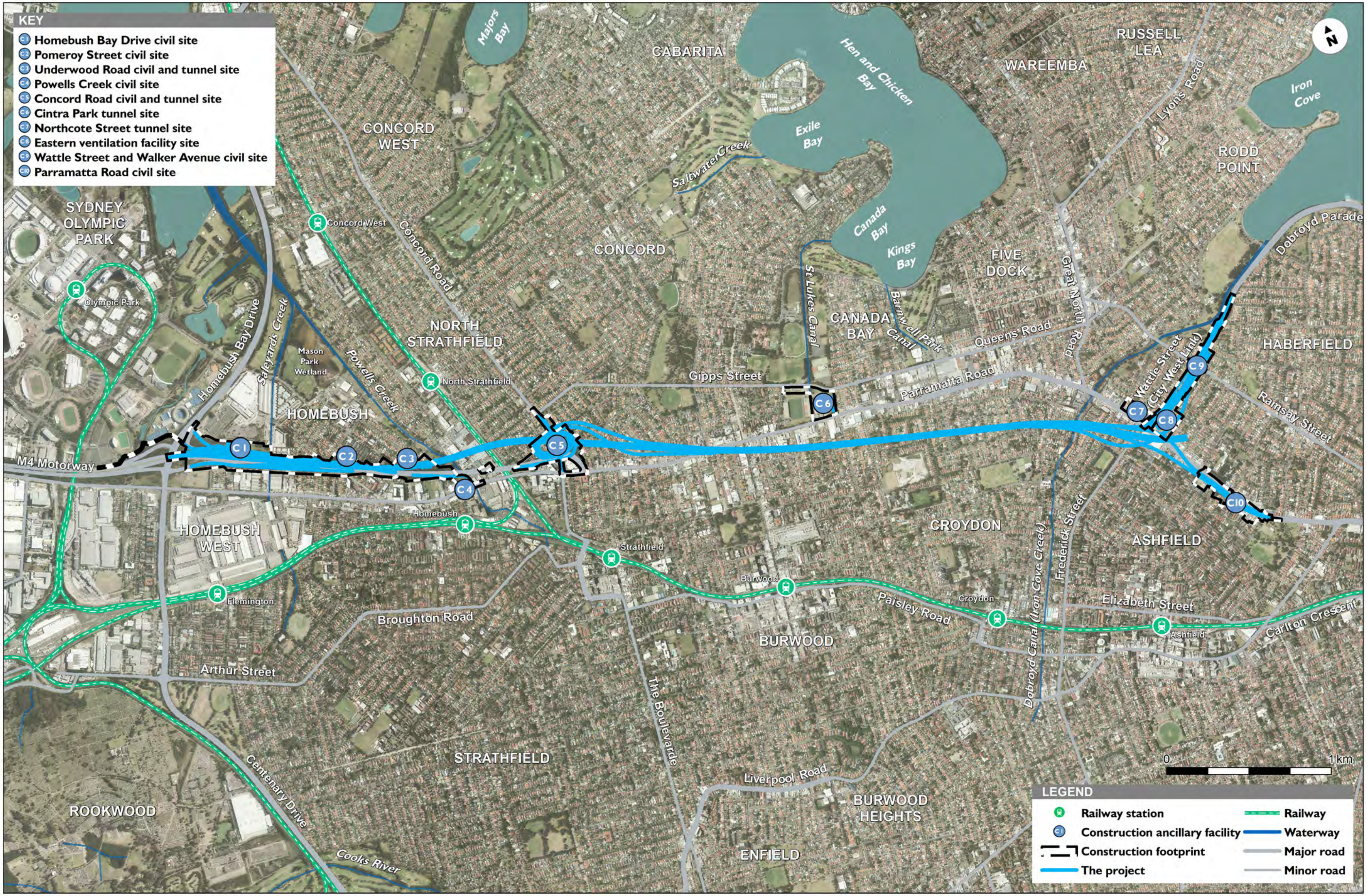


Figure 2.2 Overview of construction footprint and construction ancillary facilities

2.3 Groundwater specific aspects

Key aspects of the project with relevance to groundwater impacts include:

- Short-term drainage of excavations during tunnel construction
- Long-term dewatering of the completed tunnel during operation
- Grouting operations
- Tunnel excavations and approach structures
- Disposal of excavated waste rock
- Disposal of intercepted construction and operational inflows

These aspects of the project are summarised in the following sections.

2.3.1 Tunnel location

The alignment of the tunnel and surface geology, based on the Sydney 1:100,000 sheet are shown in **Figure 2.3**. The tunnel is primarily planned to be within the Hawkesbury Sandstone hence most issues would be associated with operations in this aquifer. Shallow aquifers may be intercepted in the shallower entry and exit areas.

The overall length of the tunnelled corridor is about 5.5 kilometres, however there are separate tunnels for eastbound and westbound traffic and for entry and exit points at Parramatta Road, Wattle Street and Concord Road. This results in total tunnelled length of around 17 kilometres, including around two kilometres of uncovered entry and exit points and around 15 kilometres of enclosed tunnel.

2.3.2 Tunnel excavation and construction

The tunnel would be excavated by road header once into competent rock.

Due to typically low inflows in the Hawkesbury Sandstone, it is common practice for tunnels excavated in the Hawkesbury Sandstone to have local treatment applied during construction to reduce inflows to acceptable levels and continue to be drained during their operation, rather than being tanked or fully watertight along their full length. Tanked tunnels are not proposed as part of the project, due to the project tunnels being largely constructed within the Hawkesbury Sandstone, the high capital expenditure associated with a significant amount of additional excavation and the pre-cast concrete structure required for their construction, and the low value of the groundwater resource. The project tunnels are therefore proposed to be constructed with treatment to maintain inflows below the design criteria of one litre per second over any given kilometre.

Water resisting treatment will include the installation of local liners, targeted grouting and strip drains where required. Dewatering would be required during construction at the face of the excavation and along the tunnel length. The project would involve the installation of ground support, including rock bolting and shotcrete as the tunnelling face is advanced. Tunnel lining would also be installed progressively following tunnel excavation. The type of lining would depend on the local geology and groundwater infiltration conditions. As the project is primarily located within low permeability sandstone and likely to be predominantly dry, a sprayed shotcrete lining would generally be used. In areas with medium groundwater inflows, an impermeable sprayed membrane would also be installed, with a shotcrete or cast in situ concrete secondary lining. Where there are significant groundwater inflows, grouting may also be used to reduce the permeability of the surrounding rock mass.

2.3.3 Long-term dewatering requirements

As the tunnel is a drained tunnel, it would require permanent dewatering. This would be done via a drainage system placed beneath the roadway at the base of the excavation and from cross passages. Inflow and runoff from the roadway would be collected from a central sump, pumped to surface and treated prior to discharge. The drainage collected system is designed to be separate from surface water collection. Based on the design requirements, inflow would need to be managed, such as by localised grouting, to achieve a long term inflow of maximum inflow of one litre per second per kilometre or a total of approximately 17 litres per second over the entire tunnel.

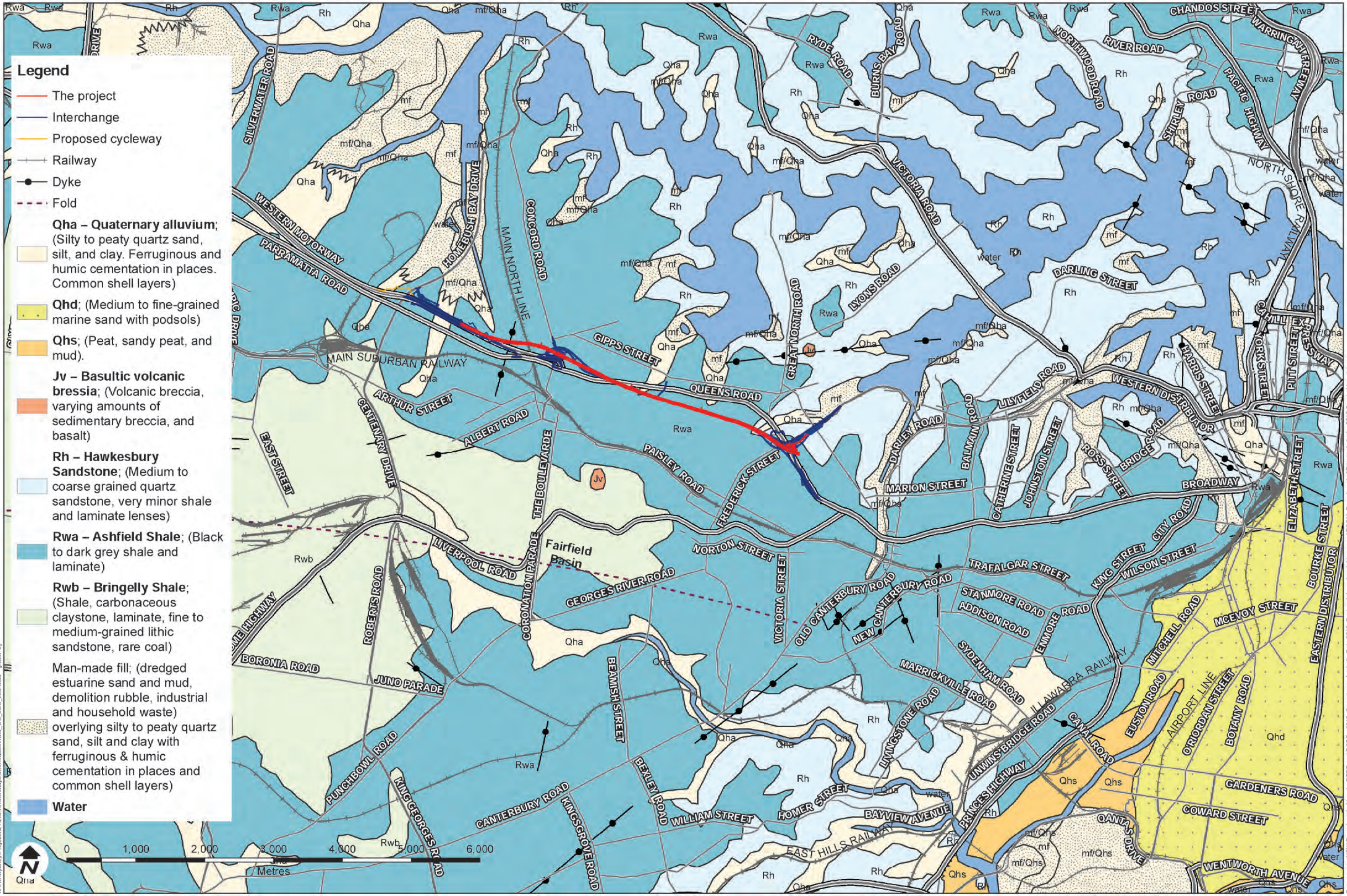


Figure 2.3 Tunnel alignment and surface geology

2.3.4 Grouting and other ancillary operations

Based on similar tunnels in the Hawkesbury Sandstone, it is likely that unacceptably high inflows may occur within geological defects in the rock, such as along localised fracture and fault zones. Typically the inflows would be reduced by selective drilling and grouting, emplaced in the order of one to 10 metres into the rock, through the tunnel wall and from cross-passages.

This is done by drilling an array of holes to intersect seepage pathways such as fractures or joints, and injecting, under pressure, a mixture of cement and other additives to fill and seal of the fractures, to build a waterproof membrane around the excavation. Grouting can be done ahead of excavation, generally in soft ground, or can be done from within completed sections of the tunnel and cross passages in competent and mostly dry rock. The cement grout may include highly alkaline sodium silicate, used to accelerate grout setting and reduce permeability, which in the short-term can lead to significantly raised pH of inflowing water and would require management to prevent potential scaling and blockage of the drainage system.

2.3.5 Tunnel excavations and approach structures

The tunnel approaches, through shallow soils, alluvium or highly weathered rock, would be by cut-and-cover methods. This is expected to include cantilever soldier pile walls with arched shotcrete between the piles and a capping beam. Strip drains would be placed behind the shotcrete and drain to the groundwater drainage system.

2.3.6 Disposal of waste rock

Waste rock would be continuously removed from the tunnel and would be disposed off-site. Based on the geology it is unlikely that there would be significant acid or metalliferous drainage risk and it has not been considered as part of this study.

2.3.7 Disposal of construction and operational inflows

During the construction and operation phase, water extracted from the tunnel, including groundwater inflow, drilling and cutting fluids and incidental runoff, would be pumped to surface and treated. For the purposes of this assessment, it is assumed it would be discharged to local stormwater systems which ultimately discharge in to the Parramatta River. The level of treatment required would depend on the inflow rate and water chemistry (which would vary between construction and operation), and the receiving environment water chemistry, which has been characterised in soils and water report (GHD, 2015a).

3 Assessment Methodology

Based on the SEARs (**section 1.3**) and the key features of the project (**Chapter 2**), this assessment included the works outlined in the following sections.

3.1.1 Project review

A review of the project was carried out with regard to identification of the key aspects of the project that may impact groundwater quality and quantity. This included identification of aspects of the project that affect groundwater inflow rates and changes to surrounding groundwater levels and flow directions in order to properly assess how the project would interact with the surrounding environment.

3.1.2 Groundwater policy/guidance review

A review of relevant groundwater policy guidance documents was carried out to identify relevant aspects and potential implications for the project. The following documents and guidelines were considered as part of the review:

- *NSW Aquifer Interference Policy* (NOW, 2012)
- *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011* (NSW) (NOW, 2011).
- *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011* (NSW) (NOW, 2011)
- *NSW State Groundwater Policy Framework Document* (DWLC, 1998)
- *NSW Groundwater Quality Protection Policy* (DLWC, 1998).
- *NSW State Groundwater Dependent Ecosystems Policy* (DLWC, 2002)
- *Risk assessment guidelines for groundwater dependent ecosystems* (NOW, 2013)
- *NSW Water Extraction Monitoring Policy* (DWE, 2007)
- Australian groundwater monitoring guidelines (ANZECC & ARMCANZ, 2000)
- *Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy (2011)* (NHMRC, 2013)
- *Australian and New Zealand guidelines for fresh and marine water quality* (ANZECC & ARMCANZ, 2000a)
- National Environmental Protection Measures (NEPC, 2013).

Groundwater management requirements adopted for the Epping to Chatswood train line and the North West Rail Link were also reviewed.

The review was used to develop overarching assessment criteria for this groundwater impact assessment, including characterisation of key water quality criteria and key groundwater drawdown/flow criteria.

3.1.3 Conceptual hydrogeological model

A conceptual model was developed that characterised and identified the key features of the surrounding/existing environment relating to groundwater, including:

- Climate, rainfall and groundwater recharge
- Geological and hydrogeological characteristics such as the primary geological units and associated hydraulic properties and estimated groundwater elevations
- Condition of the existing system with regard to both water quality and yields. This included the development of a preliminary water balance for the project
- Groundwater dependent surface water systems

- Groundwater dependent ecosystems including riparian vegetation that may be impacted by drawdown
- Groundwater users
- Contaminated land (summarised from other assessments for the project)
- Acid sulfate soils (summarised from other assessments for the project)
- The sensitivity of the current system.

Key data gaps essential for an adequate understanding of the conceptual groundwater model were highlighted during this process to help direct ongoing geotechnical investigations.

3.1.4 Characterisation of impacts to the surrounding environment

Impacts to the surrounding environment were assessed by:

- Characterising both the key potential impacting activities of the project and the magnitude of the impact (qualitatively and semi-quantitatively only)
- Undertaking numerical groundwater modelling to:
  - Estimate the range in potential inflows associated with the tunnel
  - Estimate the range in potential groundwater drawdowns due to the project and hence the potential for reduction in flows to surface water features and groundwater users
  - Characterise the uncertainty in outcomes to facilitate targeting further site investigations
- Characterising the water quality of groundwater inflows along the tunnel, for the purposes of informing treatment requirements for potential discharge to surface water
- Characterising the potential mobilisation of saline groundwater, contaminated groundwater and exposure of acid sulfate soils and the associated impacts.

The expected water ingress was compared to water allocation and availability criteria and licensing requirements in the water sharing plans.

4 Groundwater policy/guidance review

4.1 NSW Aquifer Interference Policy

The *NSW Aquifer Interference Policy* requires that potential impacts on groundwater sources, including their users and groundwater dependent ecosystems (GDEs), be assessed against minimal impact considerations, as outlined in Table 1 of the policy. If the predicted impacts are less than the Level 1 minimal impact considerations (outlined below), then these impacts would be considered as acceptable.

The *NSW Aquifer Interference Policy* was finalised in September 2012 and clarifies the water licencing and approval requirements for aquifer interference activities in NSW, including the taking of water from an aquifer in the course of carrying out mining.

The policy indicates that the interference of an aquifer from a groundwater source not covered by a water sharing plan (WSP) requires a water licence under the *Water Act 1912*. Where the activity results in the loss of water from an overlying source that is covered by a WSP, an additional water access licence (WAL) is required under the *Water Management Act 2000* (NSW) to account for this take of water.

The policy outlines the requirements for a detailed groundwater impact assessment and sets the requirement for acceptable impacts. The Hawkesbury Sandstone aquifer primarily intersected at the site, which is a highly productive aquifer in some areas even if not locally used as such, would be classed as type 3. Porous rock water sources and the conditions from Table 1 – Minimal impact considerations (1) for aquifer interference activities that apply are presented in **Table 4.1**.

Table 4.1 *NSW Aquifer Interference Policy* minimal impact criteria (NOW, 2012)

Type of impact	Minimal impact considerations (1) for aquifer interference activities
Water table impacts	1. Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic “post-water sharing plan” variations, 40 m from any (a) high priority groundwater dependent ecosystem, or (b) high priority culturally significant site, listed in the schedule of the relevant water sharing plan. A maximum of a 2 m decline cumulatively at any water supply work.
	2. If more than 10% cumulative variation in the water table, allowing for typical climatic “post-water sharing plan” variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan then appropriate studies (including the hydrogeology, ecological condition and cultural function) would need to demonstrate to the Minister’s satisfaction that the variation would not prevent the long-term viability of the dependent ecosystem or culturally significant site. If more than 2 m decline cumulatively at any water supply work then make good provisions should apply.
Water pressure impacts	1. A cumulative pressure head decline of not more than a 2 m 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.

Type of impact	Minimal impact considerations (1) for aquifer interference activities
Water quality impacts	1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.
	2. If condition 1 is not met then appropriate studies would need to demonstrate to the Minister's satisfaction that the change in groundwater quality would not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.

Note: Water supply work is any infrastructure designed to extract water from water systems in NSW.

Other considerations

In addition to the above considerations, the assessment must also consider the potential for:

- Acidity issues to arise, for example exposure of acid sulfate soils
- Waterlogging or water table rise to occur, which could potentially affect land use, groundwater dependent ecosystems and other aquifer interference activities.

Tunnel drainage potential to impact on acid sulfate soils as well as sulfidic minerals (if present) in the overlying shales hence has been considered. Waterlogging may also occur where exit structures block shallow colluvial or alluvial aquifers or if extracted groundwater is reinjected.

Applicability to this assessment

The impact limits outlined in **Table 4.1**, in terms of drawdown magnitudes and offset distances, have been considered in this assessment and inform the overall structure of the assessment. Impacts have been characterised against the limits noted in **Table 4.1**.

This assessment provides the required information on:

- Baseline groundwater conditions including groundwater depth, quality and flow
- Requirements for compliance with water access licences
- Predicted water level drawdowns, changes to groundwater quality and changes to groundwater discharges to surface water bodies and GDEs in the areas surrounding the project, during construction and after long-term operation
- Potential for the proposed tunnel to connect multiple aquifers
- The method for disposing of extracted water
- Groundwater level and chemistry monitoring, including in monitoring bores and in tunnel inflow, along with reporting requirements and trigger levels
- Contingency plans or remedial measures to instigate if trigger values are exceeded.

4.2 Water Management Act 2000 (NSW)

The aim of the *Water Management Act 2000* (NSW) (WM Act) is to ensure that water resources are conserved and properly managed for sustainable use benefiting both present and future generations. It is also intended to provide a formal means for the protection and enhancement of the environmental qualities of waterways and their in-stream uses as well as to provide for protection of catchment conditions. The WM Act is administered by DPI Water.

The WM Act applies to areas of NSW that have a water sharing plan. Water sharing plans relevant to the project include the:

- *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011* (NSW)
- *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011 (NSW)*

In accordance with Section 91F of the WM Act, an aquifer interference approval is required for an aquifer interference activity. An aquifer interference activity means an activity involving any of the following:

(a) the penetration of an aquifer,

(b) the interference with water in an aquifer,

(c) the obstruction of the flow of water in an aquifer,

(d) the taking of water from an aquifer in the course of carrying out mining, or any other activity prescribed by the regulations,

(e) the disposal of water taken from an aquifer as referred to in paragraph (d).

The project would encounter groundwater and would therefore penetrate an aquifer. The NSW Government maintains its *Aquifer Interference Policy*, which defines minimal impact considerations necessary before obtaining licences for aquifer interference activities under the WM Act. The project was assessed against the policy as part of the groundwater impact assessment (refer to **section 4.1**).

However, Section 91F of the WM Act does not currently apply. Section 88A provides that Part 3 of Chapter 3 (including Section 91F) applies to each part of the State or each water source and each type or kind of approval that relates to that part of the State or that water source that is declared by proclamation. At the time of writing, no proclamation had been made declaring that Part 3 of Chapter 3 of the WM Act applies in relation to aquifer interference approvals. Accordingly, an aquifer interference approval would not be required for the project.

Under Part 2 of Chapter 3 of the WM Act, it is an offence to take water from a source regulated by the WM Act unless in accordance with a water access licence. The project would take groundwater as a consequence of the interception of the aquifer. Roads authorities are exempt from the requirement to obtain a water access licence under Clause 2, Schedule 5 of the Water Management (General) Regulation 2011 (NSW).

4.3 Water sharing plan for the Greater Metropolitan Region Groundwater Sources

The WSP for the *Greater Metropolitan Region Groundwater Sources* covers 13 groundwater sources on the east coast of NSW. The project lies within Sydney Basin Central Groundwater Source area, porous rock aquifer. The interference and extraction of groundwater covered by a WSP requires a WAL under the WM Act. The project's location within the Sydney Basin Groundwater Source is shown in **Figure 4.1**.

Each source has rules specified in the WSP for:

- Access
- Managing water allocation accounts
- Granting and amending water supply works approvals
- Rules for the use of water supply works approvals
- Limits to availability of water
- Trading rules.

Figure 4.1 Sydney Basin Water Sharing Plan – Sydney Basin Central Groundwater Source.

For this source, the trading rules state that inputs into groundwater sources are not permitted.

There is some variation across the source rules for granting and amending water supply works approvals; more specifically these rules vary for the distance from existing bores which water supply works approvals can be granted or amended, and rules for replacement of groundwater works. In other cases specific rules apply for site specific features, for example the Sydney Basin Central Groundwater Source outlines rules for groundwater dependent culturally significant sites.

Table 4.2 identifies the water extraction entitlement for the source within the Greater Metropolitan Region (GMR) groundwater sources at the commencement of the WSP (July 2011), based on existing groundwater extraction licences at the time under the *Water Act 1912*, and the long-term average annual extraction limit (LTAAEL). The LTAAEL is an estimated sustainable extraction limit for each of the groundwater sources, based on the proportion of annual rainfall recharge that may sustainably be released for use.

Table 4.2 GMR groundwater source extraction entitlement and limit

Groundwater source	Entitlement (ML/unit share/yr)	LTAAEL (ML/yr)
Sydney Basin Central	2,592	45,915

Note: Correct at the time of commencement of the WSP (July 2011)

As the entitlement is well within the LTAAEL, it is unlikely that the WSP would restrict groundwater extraction volumes or that trading of existing licences would be required, subject to the drawdown and other impact restrictions noted elsewhere.

4.4 Water sharing plan for the Greater Metropolitan Region Unregulated River Water Sources

The *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources* (the water sharing plan), which commenced in 2011, covers 87 management zones that are grouped into six water sources. The project corridor is situated in the Northern Sydney Rivers catchment or source.

The Northern Sydney Rivers catchment is separated into management areas which include, amongst other management areas, the Lower Parramatta River management area which the project lies within.

The water sharing plan suggests that Parramatta River estuarine systems have low sensitivity to changing low and high inflow conditions of freshwater with a moderate impact from changes in groundwater inflow. The water sharing plan also suggests that the Lower Parramatta River management zone has low to moderate instream values relative to a hydrologic stress and dependence on extraction.

The water sharing rules listed in the water sharing plan for the Lower Parramatta River management zone are summarised as:

- To provide environmental flow protection – pumping is not permitted when there is no visible flow at the pump site
- Trading is permitted within the management zone subject to an assessment but is not permitted into the management zone
- High flow access licenses, which allow additional water to be accessed during high flow to offset collection during low flow, are not permitted.

The water sharing plan notes that if a channel is an entirely man-made concrete lined channel or is a sub-surface pipe containing water, then water sharing rules do not apply, however, provisions would apply to a natural creek, even if the creek has been engineered as a stormwater channel.

With regard to groundwater impacts for the project, it is expected that the most likely interaction with surface water would be through discharge of treated groundwater seepage back to surface water during construction and operation. Discharge to the creeks is expected to increase the overall flows (particularly under low flow conditions) and unlikely to result in adverse impacts to the existing water sharing conditions. Waterways near to the project corridor are generally heavily modified or concrete lined and unlikely to have significant hydraulic connection with groundwater, and as such drawdown impacts associated with tunnel inflows are expected to be minor. This is addressed further in **section 6.3.3**.

4.5 NSW Groundwater Quantity Management Policy

The principles of the *NSW Groundwater Quantity Management Policy* (DLWC, 1998) include:

- Maintain total groundwater use within the sustainable yield of the aquifer from which it is withdrawn
- Groundwater extraction shall be managed to prevent unacceptable local impacts
- All groundwater extraction for water supply is to be licensed. Transfers of licensed entitlements may be allowed depending on the physical constraints of the groundwater system.

The requirements of this policy are met by the general assessment requirements noted in **section 4.1**.

4.6 NSW Groundwater Quality Protection Policy

The objective of the *NSW Groundwater Quality Protection Policy* (DLWC, 1998) is the ecologically sustainable management of the State's groundwater resources so as to:

- Slow and halt, or reverse any degradation in groundwater resources
- Direct potentially polluting activities to the most appropriate local geological setting so as to minimise the risk to groundwater
- Establish a methodology for reviewing new developments with respect to their potential impact on water resources that would provide protection to the resource commensurate with both the threat that the development poses and the value of the resource
- Establish triggers for the use of more advanced groundwater protection tools such as groundwater vulnerability maps or groundwater protection zones.

The requirements of this policy would be met by the identification of baseline conditions for the study area and assessment of potential changes to groundwater quality as a result of the project in this report.

4.7 NSW Groundwater Dependent Ecosystems Policy

The *NSW Groundwater Dependent Ecosystems Policy* (DLWC, 2002) was designed to protect ecosystems which rely on groundwater for survival so that, wherever possible, the ecological processes and biodiversity of these dependent ecosystems are maintained or restored for the benefit of present and future generations.

As required in **section 4.1** changes in water levels and flows near identified GDEs must be assessed as part of this assessment (refer to **section 6.3.3**).

4.8 Risk assessment guidelines for groundwater dependent ecosystems

The *Risk assessment guidelines for groundwater dependent ecosystems* (NOW, 2012), comprising four volumes:

- Provides a conceptual framework for identifying and assessing ecosystems
- Provides worked examples of assessments
- Discusses the identification of high probability GDEs
- Discusses the ecological value of GDEs.

Volume 1 provides general guideline material while Volumes 2–4 are related specifically to coastal aquifers. The results from this assessment would be used by others to assess potential impacts of GDEs.

4.9 NSW Water Extraction Monitoring Policy

The *NSW Water Extraction Monitoring Policy* (DWE, 2007) sets out roles and responsibilities for the NSW Department of Water and Energy (DWE), DPI Water and holders of water extraction licences. Water NSW has the responsibility of monitoring water extraction in the regulated system, while DWE has the responsibility in the unregulated and groundwater systems. In some areas, DWE would arrange for Water NSW to carry out the duties of extraction monitoring.

Under this policy, all groundwater extraction during construction and operation of the project would need to be monitored. Typically this would comprise metering of all flows in and out of the tunnel and using the difference to identify the groundwater inflow contribution.

4.10 Australian groundwater monitoring guidelines

There are various state and federal guidelines and standards for monitoring groundwater in Australia. The guidelines and standards applicable to this project are:

- Australian Standard AS/NZS 5667.11:1998 *Water quality – Sampling – Guidance on sampling of groundwaters* (AS/ANZ, 1998)
- *NSW Guidelines for the Assessment and Management of Groundwater Contamination* (DEC, 2007)
- *Geoscience Australia – Groundwater Sampling and Analysis – A Field Guide* (Sundaram, et al., 2009).

4.11 Australian Drinking Water Guidelines

The *Australian Drinking Water Guidelines (2011)* (ADWG) (NHMRC, NRMMC, 2011) provide a framework for the appropriate management of drinking water supplies to achieve a safe and appropriate point of supply. The guidelines provide a base standard for aesthetic and health water quality levels.

Existing and potential groundwater quality has been compared against the guidelines, to identify the highest and best use of the groundwater. Comparison has also been made against ten times the ADWG (a value used as a measure of the risk from incidental ingestion of water from secondary contact, superseding the former recreational water quality guidelines) to assess the risk to the public from incidental exposure to untreated groundwater intercepted by the tunnel.

4.12 Australian and New Zealand Guidelines for Fresh and Marine Water Quality

The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (the ANZECC guidelines) (ANZECC & ARMCANZ, 2000a), part of the National Water Quality Management Strategy (NWQMS) provides a national framework for improving water quality in Australia's waterways. The main policy objective of the NWQMS is to achieve sustainable use of the nation's water resources, protecting and enhancing their quality while maintaining economic and social development.

The NWQMS process involves community and government interaction, and implementation of a management plan for each catchment, aquifer, estuary, coastal water or other water body. This includes the use of national guidelines for local implementation.

For the project, the national guidelines on water quality benchmarks, the ANZECC guidelines, provide default trigger values (DTVs) of various analytes for comparison with sampled values.

From the assessment of these DTVs, site-specific trigger values have been recommended for the project.

5 Existing environment

This section outlines the existing hydrogeology of the study area, including general water sources and groundwater inflow and outflow areas, groundwater chemistry and groundwater users.

Detailed discussions/data are presented elsewhere on groundwater dependent ecosystems (flora and fauna impact assessment, (GHD 2015)), geotechnical properties of the geology intersected by the tunnel (GHD, March 2010), acid sulfate soils (soil and land contamination assessment (GHD July 2015)) and groundwater contamination (soil and land contamination assessment (GHD July 2015)).

5.1 Land use

The project are consists primarily of urban to suburban residential, commercial and industrial use. Scattered parklands, sporting fields and the Rookwood Cemetery are the only major unpaved areas in the general region. The landscape is therefore highly modified with extensive paved areas and channelized surface water flow. Although the extensive paving limits recharge from direct rainfall precipitation, such environments typically have localised areas of increased groundwater recharge due to leaking stormwater and sewerage infrastructure, as well as enhanced recharge from irrigation of garden areas.

5.2 Physiography

5.2.1 Drainage and topography

The study area is within the lower Parramatta River Catchment, which hosts a number of surface water tributaries (ie Hawthorn Canal, Iron Cove Creek, Iron Cove, Hen and Chicken Bay, Haslams Creek, Duck River and Duck Creek). To the south of the project boundary, the land drains towards Cooks River.

The project area is situated in the inner western suburbs of Sydney and crosses 10 suburbs including Sydney Olympic Park, Homebush West, Homebush, North Strathfield, Strathfield, Concord, Burwood, Croydon, Ashfield and Haberfield.

The topography of the M4 corridor is characterised by a gentle slope towards the Parramatta River with local slopes towards creeks and embayments. To the south of the M4 corridor the surface slopes towards Cooks River. Ground surface elevations within the project boundary range from approximately 29 metres above Australian Height Datum (AHD) near Concord Road, to 0 metres AHD (sea level) along the shore of the Parramatta River and where the alignment crosses drains at George Street in North Strathfield and Croydon Road in Croydon. The maximum depth in the Parramatta River adjacent to the project boundary is around 20 metres.

The proposed western tunnel portal is located at an elevation of about 10 metres AHD, the Concord Road interchange at about 14 metres AHD, the eastern tunnel entrances (City Wattle Street and Parramatta Road interchanges) at about 5–20 metres AHD. The topography across the project boundary and local area is presented in **Figure 5.1**.

Figure 5.1 Project alignment topography and drainage

5.2.2 Rainfall

The Sydney area is characterised by a temperate (no dry season) climate under the 'modified Koepin classification' (Bureau of Meteorology (BOM) 2014) with a slight predominance of rainfall throughout the autumn to winter months. The mean annual rainfall in proximity to the site (Sydney Observatory Hill – station number 66062) is 1213 millimetres. The median (decile 5), decile 9 and decile 1 monthly rainfall are plotted in **Figure 5.2**. The cumulative monthly rainfall residual (**Figure 5.3**) shows that the study area was subjected to relatively wet years (rising line) from the start of records until the 1890s, followed by a relatively dry period (falling line) until the late 1940s, a generally wet period until the late 1980s followed by a generally dry period. The detailed curve from 1990 to 2013 (**Figure 5.4**) shows rainfall has been approximately average, hence current groundwater levels, in the absence of any disturbance such as pumping or enhanced recharge, would be close to long-term average values.

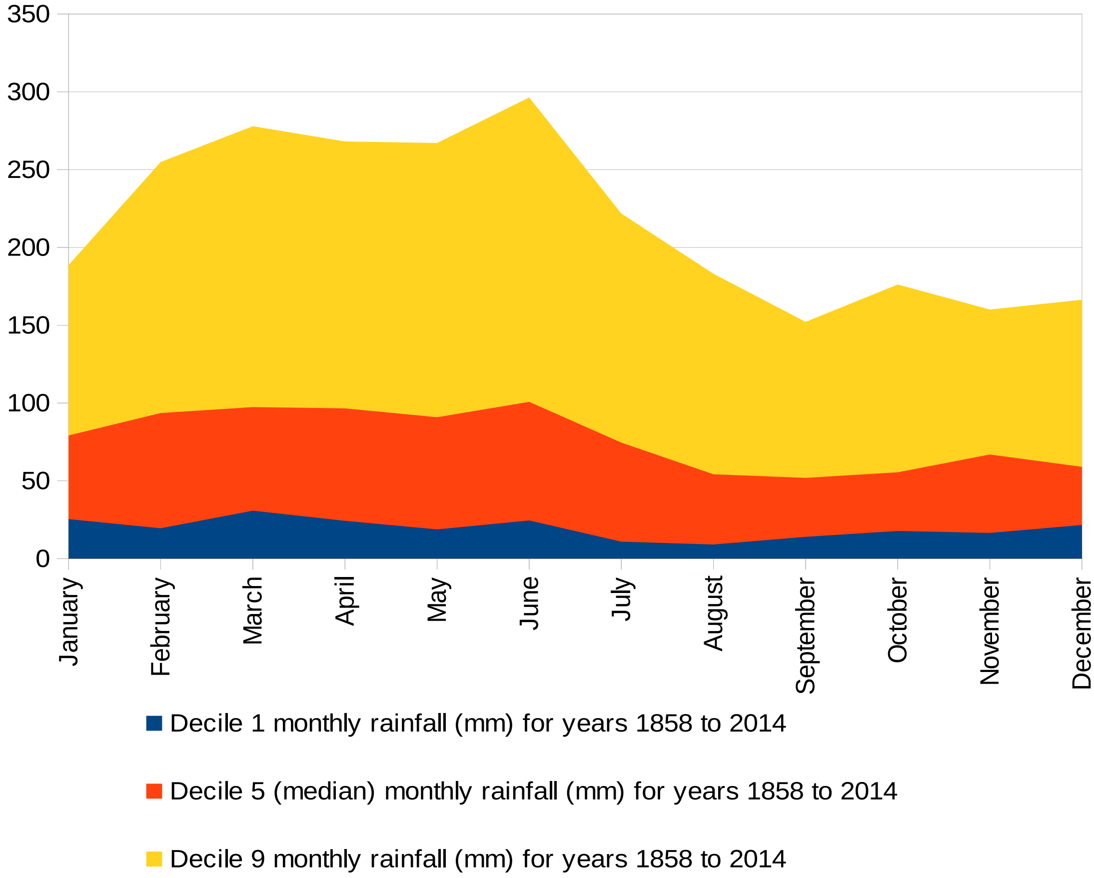


Figure 5.2 Monthly rainfall Sydney (Observatory Hill) BOM Station 66062.

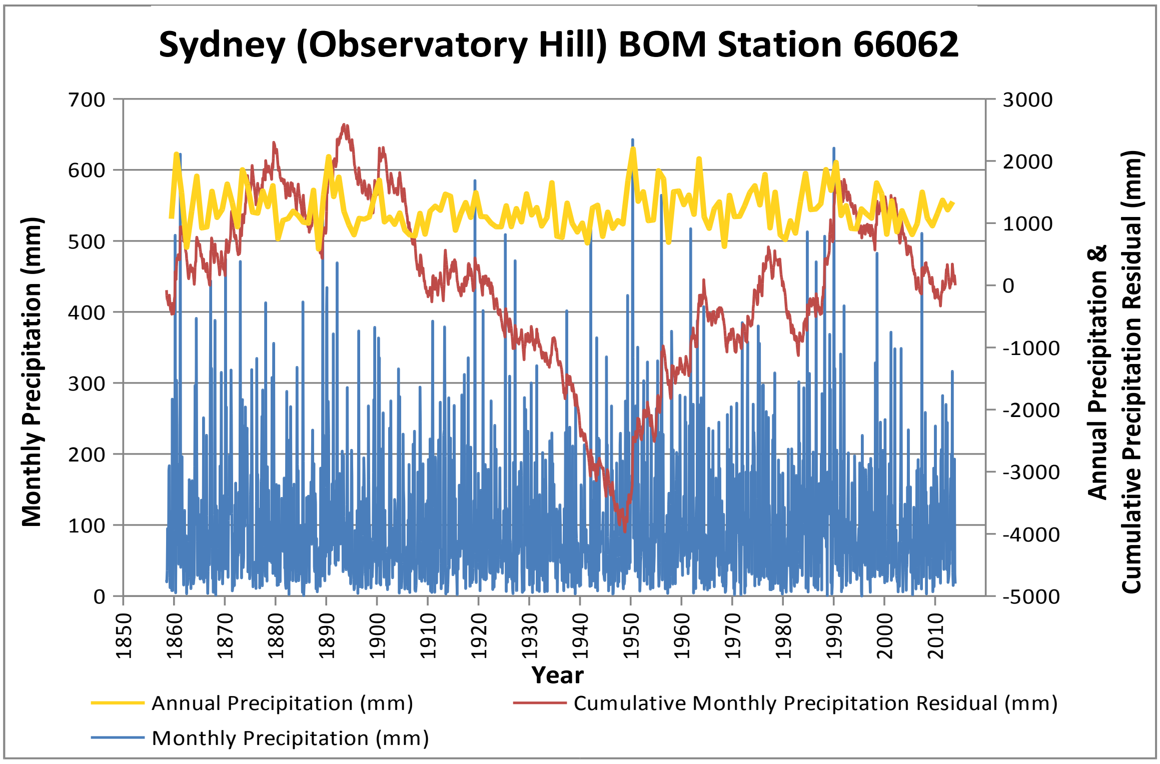


Figure 5.3 **Cumulative monthly rainfall residual Sydney (Observatory Hill) BOM Station 66062.**

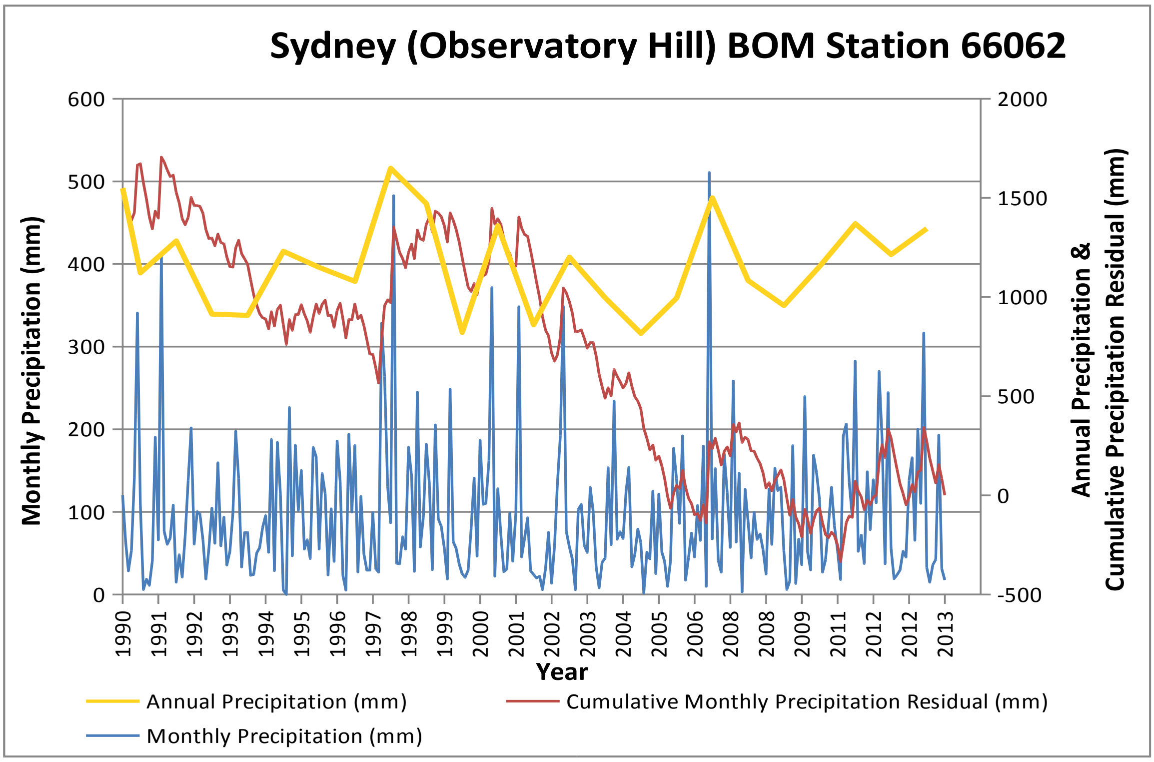


Figure 5.4 **Cumulative monthly rainfall residual 1990 to 2013 Sydney (Observatory Hill) BOM Station 66062.**

5.2.3 Geology

The study area (**Figure 2.3**) is located within the Sydney Basin. Lithologies in the study area, from youngest to oldest, comprise:

- Unlithified sediments of varying thickness (usually a few metres but known to reach 10 metres or more) mainly comprising residual soils. Alluvium and/or colluvium also occur in some creek channels and river valleys including Powells Creek, Exile Bay, Canada Bay, Kings Bay and Iron Cove Creek
- Residual soils host disjointed zones of perennial saturation, but alluvial bodies may create more extensive zones
- Basalt dykes, volcanic breccias. These intrusive features are associated with high permeability and hence high inflows in other tunnels. Recent geotechnical investigations for the project corridor have identified a number of dykes along the corridor. These include:
- a dyke in the Mittagong Formation and Hawkesbury Sandstone (see the description below), intersected about 80 metres west of Concord Road (chainage 2420 metres)
- a dolerite dyke in the Mittagong Formation and Hawkesbury Sandstone, intersected at the eastern end of Concord Oval (chainage 4060 metres)
- Some identified dykes have been projected onto the alignment at Broughton Street, at chainages 3370 and 3490 metres
- Ashfield Shale (of the Wianamatta Group), occurring as bodies of limited thickness on higher ground
- Mittagong Formation, consisting of interlayered shale and sandstone forming a thin transition zone between the Ashfield Shale and underlying Hawkesbury Sandstone
- Hawkesbury Sandstone, with a maximum thickness of 290 metres (Pells, 2004).

The 1:100,000 Sydney Basin geology map (NSW Department of Mineral Resources, 1983), indicates the surface geology of the study area primarily consists of Triassic-aged Ashfield Shale deposits (**Figure 2.3**), which comprise shallow marine sediments characterised by black to dark grey shale and laminite, and some sandstone beds. Based on bore information reviewed in the DPI Water database and the modelled geology (**section 5.2.3**), the maximum thickness of Ashfield Shale above the proposed tunnel is around 36 metres near the Concord Road ramps, thinning out to less than 20 metres over much of the eastern two kilometres of the project alignment (east of Dawson Street).

The Mittagong Formation is considered a transitional phase between the Hawkesbury Sandstone and the Ashfield Shale and generally approximates thicknesses of 5–10 metres beneath the ground surface of the project corridor. In terms of engineering properties, it is grouped with the Hawkesbury Sandstone (Pells, 2004), but has hydraulic properties similar to the overlying Ashfield Shale (Tametta & Hewitt, 2004). Geotechnical long sections (**Figure 6.3**) for the project suggest it has thicknesses of approximately 5–10 metres.

The Triassic Hawkesbury Sandstone deposits underlie the Mittagong Formation and outcrop to the northeast of the M4 corridor where the Parramatta River has incised through the overlying Ashfield Shale and Mittagong Formation deposits. The Hawkesbury Sandstone thickness in the general region is at least 180 metres (bore GW067978). The unit comprises massive and interbedded/crossbedded quartzose sandstone with a variable clay matrix. The interbedded laminite, shale and quartz to lithic sandstones of the Newport Formation provide an effectively impermeable basement to the Hawkesbury Sandstone aquifer.

Quaternary alluvium, comprising silty to peaty quartz sand, silt and clay, overlies these older deposits along the Parramatta River and where some of the larger creeks (such as Iron Cove Creek) drain into the river and estuary. In some areas they form relatively deep (in the order of 20 metres) palaeochannel fill deposits. Anthropogenic fill, consisting of dredged estuarine sand and mud, demolition rubble, industrial and household waste, overlies the alluvium in some areas at Powells Creek.

Recent geotechnical investigations for the project corridor have also identified actual or projected faulting along the corridor west of Underwood Road (chainage 1380 metres), near George Street (chainage 1940 metres), west of Queen Street (chainage 2040 metres), East of Queen Street (chainage 2260 metres), near Alexander Street (chainage 2680 metres) and West of Concord Over (chainage 3840 metres).

5.2.4 Geomorphology

Geomorphology within the study area is dominated by the incised Parramatta River/Sydney Harbour to the north and the elevated areas of Ashfield Shale to the south.

The subcrop of Ashfield Shale broadly defines the Blacktown soil landscape (Chapman & Murphy, 1989), which covers the bulk of the regional footprint. The Blacktown soil landscape group usually occurs on gently undulating rises over Wianamatta Group shales. The ground is usually at less than a five per cent slope and the vegetation, in undeveloped areas, typically comprises partly cleared eucalypt, woodlands and tall open forests. The soils range from shallow to moderately deep (less than one metre thick) and are hard setting, mottled, textured clay soils. The soils are typically moderately reactive, with highly plastic subsoil and have a low soil fertility and poor soil drainage.

The Hawkesbury Sandstone subcrop defines the Gymea soil landscape, comprising generally sandy soils over undulating to rolling low hills with local reliefs of 20–80 metres and slope gradients of 10–25 per cent with localised sandstone outcrops and scarps. Areas of highly modified Gymea landscape lie to the north of the project boundary.

Areas of Birrong soil landscape, comprising relatively level alluvial deposits along local water courses, lie alongside various creeks and gullies draining into the Parramatta River.

Figure 5.5 Soil map (derived from Soil Landscapes of the Sydney 1:100,000 Sheet (9130))

5.3 Groundwater occurrence

5.3.1 Alluvium and fill material

Given the presence of the Ashfield shale-derived soils over much of the study area **Figure 2.3** and (**Figure 5.5**), shallow and sometimes perched groundwater is located within fill material, residual soil and alluvium in low-lying areas. These materials have been the subject of various site contamination assessments and localised geotechnical investigations, detailed in the soil and groundwater quality and contamination report (GHD, 2015a). The alluvium and fill materials form discontinuous, local groundwater flow systems. Interconnection with the deeper sandstone aquifer is generally low, due to the intervening Ashfield Shale and clayey residual soils. Although the perched aquifers may be connected to the Hawkesbury Sandstone, where the shales and clayey residual soils are absent, potentially adjacent to the Parramatta River and near to Iron Cove canal, no instances of sandy alluvium or soil directly overlying sandstone were observed in drillholes completed as part of site investigations.

The unconsolidated shale-derived materials within the corridor have approximate thicknesses of 0–6 metres. The thickest zones are between Underwood Road and Ismay Avenue, in elevated areas near Scott Street and in areas flanking alluvium at Iron Cove Canal. Across the majority of the corridor the residual shale soils have approximate thicknesses of less than four metres.

Isolated locations of alluvium are intersected by the corridor at Powells Creek, where thicknesses are about five metres and at Iron Cove where the alluvium is approximately 5.5 metres thick.

East of Powells Creek the corridor intersects fill deposits that are about five metres thick, but these gradually thin as the corridor extends east toward the railway line and Queen Street. There is also a more extensive zone of fill where the corridor extends past Concord Oval which is about three metres thick. Elsewhere along the corridor fill deposits are generally absent or less than two metres thick.

Extensive fill deposits that may have discontinuous groundwater systems are separated from the Hawkesbury Sandstone by low permeability residual soils and Ashfield Shales.

5.3.2 Ashfield shale

The Ashfield Shale is a low permeability material which generally acts as an aquitard, forming an impervious confining bed to the Hawkesbury Sandstone aquifer. The shale acts as a fractured rock aquifer with hydrogeological characteristics of the shale varying with the degree of weathering and jointing.

Along the western sections of the corridor (west of Burwood Street) the Ashfield Shales approximately 15–33 metres thick. East of Burwood Street and past Concord Oval and Cintra Park to Cheltenham Road, the thickness decreases to less than five metres before undulating in thickness between five and 15 metres. The shales pinch out at Croydon Street and are absent further to the east.

5.3.3 Hawkesbury Sandstone

The Hawkesbury Sandstone exhibits primary, intergranular porosity and secondary fracture, joint and solution porosity. The fracturing density is related to local scale stress relief effects and broader scale deformation features (Russell, McKibbin, Williams, & Gates, 2009). Local fracturing and bedding plane shearing occurs in association with the stress relief effect of valley bulging and erosion, which allows upward vertical movement of the floor and shearing of the walls. Detailed analysis of permeability data, done as part of the Lane Cove tunnel assessment (Tametta & Hewitt, 2004) identified a relatively distinct decrease in permeability with depth. Subsequent work further defined this relationship (Tammetta & Hawkes, 2009).

The Hawkesbury Sandstone is a regionally significant aquifer, with relatively high yields of good quality water in many areas, although no bores tapping the aquifer were identified in within the project boundary. This may be a function of the good availability of alternative water supplies, as well as the lack of local recharge and proximity of saline coastal waters leading to more saline groundwater.

As noted earlier (**section 5.2.3**) the Hawkesbury Sandstone underlies the Ashfield Shales and the Mittagong Formation and is up to 290 metres thick beneath the corridor.

5.3.4 Igneous intrusions

Basic igneous intrusions occur throughout the Sydney Basin, commonly in the form of basaltic dykes less than one metre thick, basaltic volcanic breccias in diatremes in the order of 200–500 metres across, up to larger dolerite bodies more than one kilometre wide. The dykes are known to be areas of higher permeability than the surrounding sediments and are associated with higher inflows in tunnel excavations in the Hawkesbury Sandstone (Lees, Edwards, & Grant, 2005).

A dyke is mapped (NSW Department of Mineral Resources, 1983) as crossing the tunnel alignment at about chainage 1800 metres, and several other areas where dykes have been previously intersected in drillholes or where the projection of nearby dykes intersects the tunnel alignment. Further to this, recent geotechnical investigations carried out for the project have identified a number of dykes along the corridor which are outlined in **section 5.2.3**.

It is likely that permeability and hence inflows in these areas would be higher than in in the surrounding geology (Mittagong Formation and Hawkesbury Sandstone).

5.4 Groundwater levels and movement

A baseline groundwater monitoring program has recently commenced and includes monitoring groundwater quality at 27 monitoring wells along the project corridor. These wells are presented in **Table 5.4** and on **Figure 5.11** (see **section 5.7**). The first baseline monitoring event was completed around 23–25 June 2015, and groundwater elevations recorded immediately before sampling each well are presented in **Table 5.4**.

The groundwater elevations are presented relative to depth below the measuring point (top of the casing) which is usually near to ground surface. As the wells have not been surveyed at this time, groundwater contours have not been interpolated along the corridor.

The depth to groundwater and expected groundwater flow directions are discussed with regard to the primary water bearing geological units in more detail in the following sections.

5.4.1 Alluvium and unconsolidated materials

Groundwater levels in the alluvium are likely to be controlled by local recharge and discharge zones, with shallow groundwater flowing primarily towards the adjacent streams, with deeper flow along the axis of the alluvial valley fill. Deeper palaeochannels extending southwards from the harbour embayments (Homebush Bay, Hen and Chicken Bay and Iron Cove) may represent significant zones of high permeability, with relatively high interconnection with surface water bodies, hence groundwater levels would be controlled by nearby surface water levels.

The June 2015 groundwater monitoring event included monitoring of groundwater elevations at nine wells screened within shallow unconsolidated sediments including gravelly and sandy clays, clays and sandy clays. Groundwater elevations ranged between 0.55 metres below top of casing (btoc) in wells BH1317 and 5.03 metres btoc in well BH1365. Average groundwater elevations are approximately 2.5 metres btoc.

5.4.2 Fill material

Apart from widespread filling used to reclaim shallow areas of the harbour (**Figure 2.3**), localised areas of fill are likely under various development within the study area. Localised perched aquifers are likely in most fill areas overlying the poorly drained Blacktown soils. Where the fill overlies the Hawkesbury Sandstone and associated soils, fill is more likely to be readily drained, hence perched aquifers would be less likely except in areas of highly permeable fill and high recharge. These systems would mainly be present near to Powells Creek and Concord Oval where more extensive zones of fill are present.

Groundwater levels and flow would tend to be controlled by local discharge/drainage zones and are likely to respond rapidly to short-term rainfall events.

Groundwater elevations in the fill material are not currently being monitored as part of the existing monitoring network, nor was any groundwater encountered during drilling of the contamination assessment bores along the alignment. As such, the depths to groundwater in the fill are currently unknown. It is expected that groundwater elevations in thick fill would be similar to the depths observed for other unconsolidated materials as noted in **section 5.4.1**, and in the coastal areas would be close to sea level.

5.4.3 Ashfield Shale

Localised perched aquifers are present in areas of the Ashfield Shale where jointing and bedding plane parting is well developed, but not filled with clayey weathering products. As with most fractured rock aquifers, groundwater levels are expected to reflect local topography, due to higher recharge in elevated areas with thinner soils, as well as the decreasing permeability with depth which constrains drainage as water levels recede. The groundwater recorded in monitoring bores installed in shale for the project represents the interception of perched aquifers when compared with surface topography and adjacent surface water bodies. As such, the water levels of the bores cannot be used to calibrate the tunnel impact model.

The June 2015 groundwater monitoring event included monitoring of groundwater elevations at 13 wells screened within the Ashfield Shales. Groundwater elevations ranged between 2.2 metres btoc in well BH1369 and 7.37 metres btoc in well BH1326. Average groundwater elevations approximate 2.5 metres btoc.

5.4.4 Hawkesbury Sandstone

The Hawkesbury Sandstone forms a regional aquifer and hence is subjected to regional groundwater flow. On a broad level, flow is from the west to east, but locally, flow would be controlled by discharge generally northwards, to where the Parramatta River and Sydney Harbour embayments intersects the sandstone, and southward towards the Cooks River and Georges River. Given the presence of Ashfield Shale over much of the area (**Figure 2.3**), local recharge is expected to be minimal, hence water levels would be subject to long-term changes in regional recharge rather than short-term rainfall events. The exception is likely to be in sandstone outcrop areas to the north and in areas subject to tidal influence in the sandstone adjacent to the waterways.

The June 2015 groundwater monitoring event included monitoring of groundwater elevations at four wells screened within the Hawkesbury Sandstones. Groundwater elevations ranged between 2.28 metres btoc in well M4E-BH260 and 5.47 metres btoc in well BH1344. Average groundwater elevations are approximately 3.8 metres btoc.

5.4.5 Water level response to rainfall

Water level data are available for the Hawkesbury Sandstone, Ashfield Shale and alluvium for the period 4 February 2010 to 4 March 2010 collated as part of geotechnical studies to the east of the project footprint (GHD, March 2010), collected during investigations for previously proposed projects. The water level data, expressed as metres above AHD along with daily rainfall as millimetres, are presented in **Figure 5.6** and **Figure 5.7** and provide an example of the range of water level responses.

Bore BH3103-111A (**Figure 5.6**) screened from 6.5–9.5 metre depths in the Ashfield Shale, shows a rapid rise of approximately one metre following a rainfall event of 70 millimetres in one day, suggesting a direct connection with surface recharge. The water level rapidly returned to the baseline level within three days.

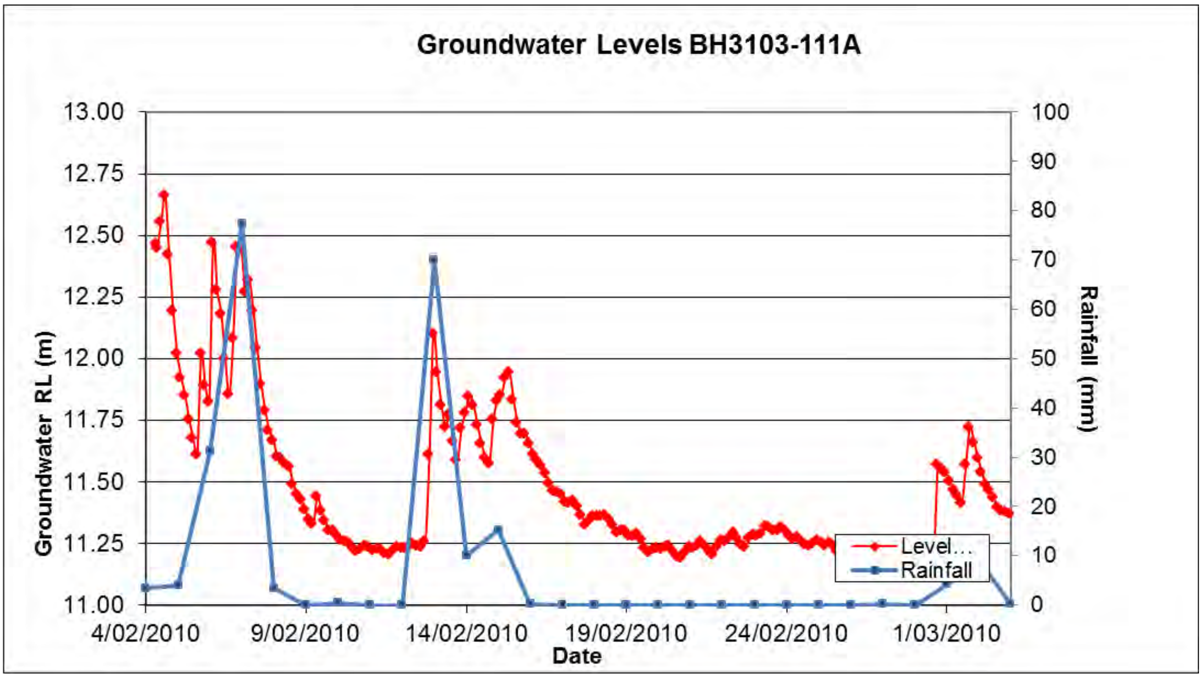


Figure 5.6 **Groundwater levels and daily rainfall BH3103-111A.**

In contrast, water level in bore BH3103-114, screened between 21–27 metre depths in Hawkesbury Sandstone, shows only a weak (possible) response of approximately 0.1 metre, delayed by two to three days after the same rainfall event, indicating there is little connection with local surface recharge. The water levels show a possible weak tidal response, although it is not known if the water levels have been barometrically corrected.

Given the limited period of water level data, these data are not considered to be suitable for providing details of seasonal groundwater level fluctuations and enables a steady-state calibration only of the groundwater model. Given the relatively small response to rainfall, however, short-term (sub-annual) fluctuations in groundwater levels are not likely to be significant in the study area.

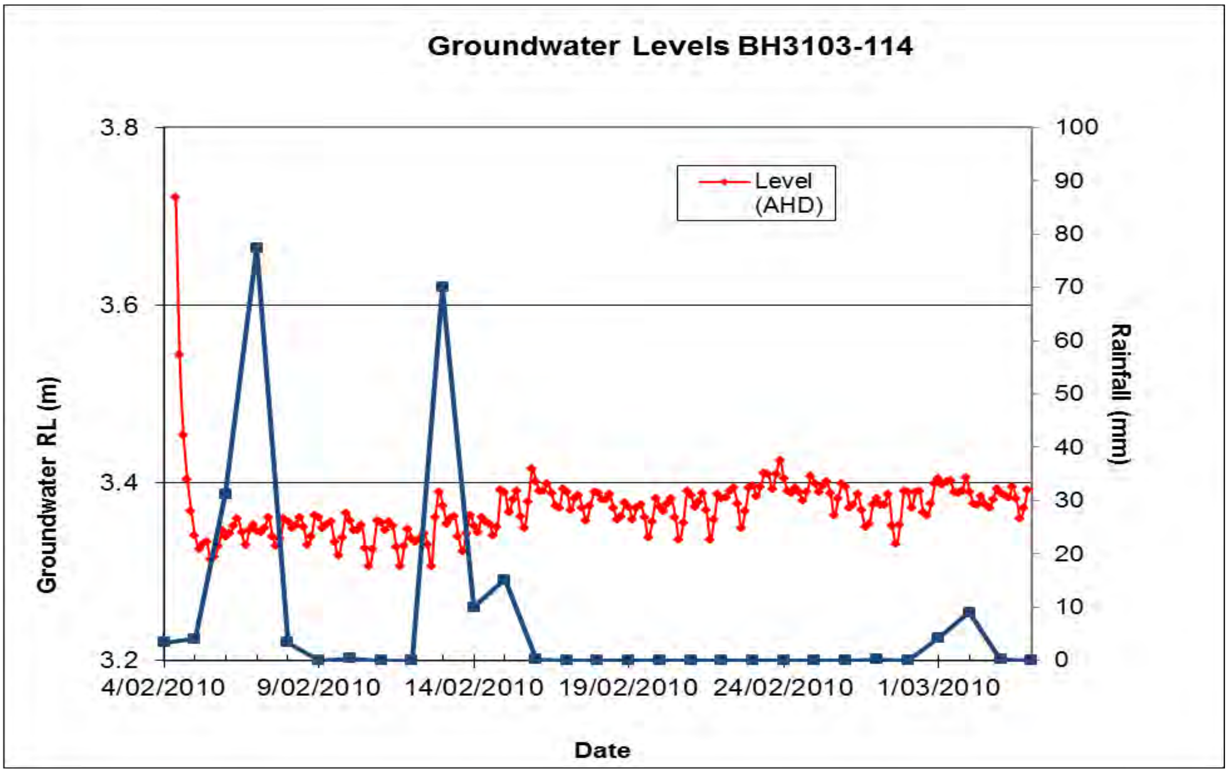


Figure 5.7 **Groundwater levels and daily rainfall BH3103-114.**

5.5 Regional hydraulic parameters

To gain a broad understanding of the potential range of hydraulic properties of the various aquifers and aquitards within the project boundary, previously published regional data have been reviewed, including results of test work for similar tunnelling projects.

5.5.1 Alluvium and fill

No site-specific data are available for alluvium in the area, but it is expected, based on typical alluvial aquifers, that hydraulic conductivity is highly variable, ranging from around 1E-03 metres per day for clayey material up to 1E+00 metres per day for sandy material, with higher hydraulic conductivity possible in poorly controlled rubble fill. As infiltration to the main tunnel would be constrained by the lower permeability of the Hawkesbury Sandstone and Ashfield Shale, the hydraulic parameters of the surficial material would not be critical for inflow estimates, but can have a significant impact on the extent of water table decline in acid sulfate soils or near groundwater-dependent ecosystems. The various declines and cut and cover sections of the project are proposed in areas where alluvial sediments are absent or less than two metres thick, therefore direct infiltration from alluvial aquifers is not expected.

Specific yields for fill and alluvium are typically in the range 0.1 to 0.3 with specific storage typically in the order of 1E-05 per metre.

5.5.2 Ashfield Shale

The bulk permeability of the Ashfield Shale in the region is typically 1E-04 to 1E-02 metres per day in fresh shale, increasing to 1E-04 to 1E-01 metres per day in the weathered shale (Hewitt, 2005).

5.5.3 Hawkesbury Sandstone

Detailed assessment of packer tests, carried out primarily from tunnel investigations in the Hawkesbury Sandstone in the Sydney metropolitan area and wider Sydney basin (Tammetta & Hawkes, 2009) showed a distinct relationship between hydraulic conductivity and depth (**Figure 5.8**). The geometric mean ranged from 1E-04 metres per day at 400 metres, 1E-03 metres per day at 200 metres, 1E-02 metres per day at 100 metres and 1E-01 metres per day near the surface (about 10 metres). Analysis of pumping tests, which test a much larger volume of aquifer, derived a hydraulic conductivity of around 1E-1-03E-1 metres per day at around a 100 metre depth, and a specific storage of 1-4.5E-06 per metre. Based on comparisons between large-scale pumping tests and packer testing data (Tametta & Hewitt, 2004), a scaling factor of approximately 3.8–4 should be applied to typical packer testing data to take into account bulk hydraulic conductivity.

Estimates of vertical hydraulic conductivity anisotropy (Kh/Kv) ranged from approximately 4–6 for shallow (about 100 metres) sandstone and 25,000 for deep (about 250 metres) sandstone. Other authors have estimated specific storage at around 1E-05 to 1E-04 (Hawkes, Ross, & Gleeson , 2009) and storage coefficients from 3.7E-03 to 1.0E-01 (Tametta & Hewitt, 2004) the latter of which is probably representative of unconfined storage or specific yield (Sy).

Regionally, the Hawkesbury Sandstone is slightly more permeable in the north-south direction, equivalent to a horizontal anisotropy (Kx/Ky) of approximately 1.5, where x is 15 degrees east (Tametta & Hewitt, 2004).

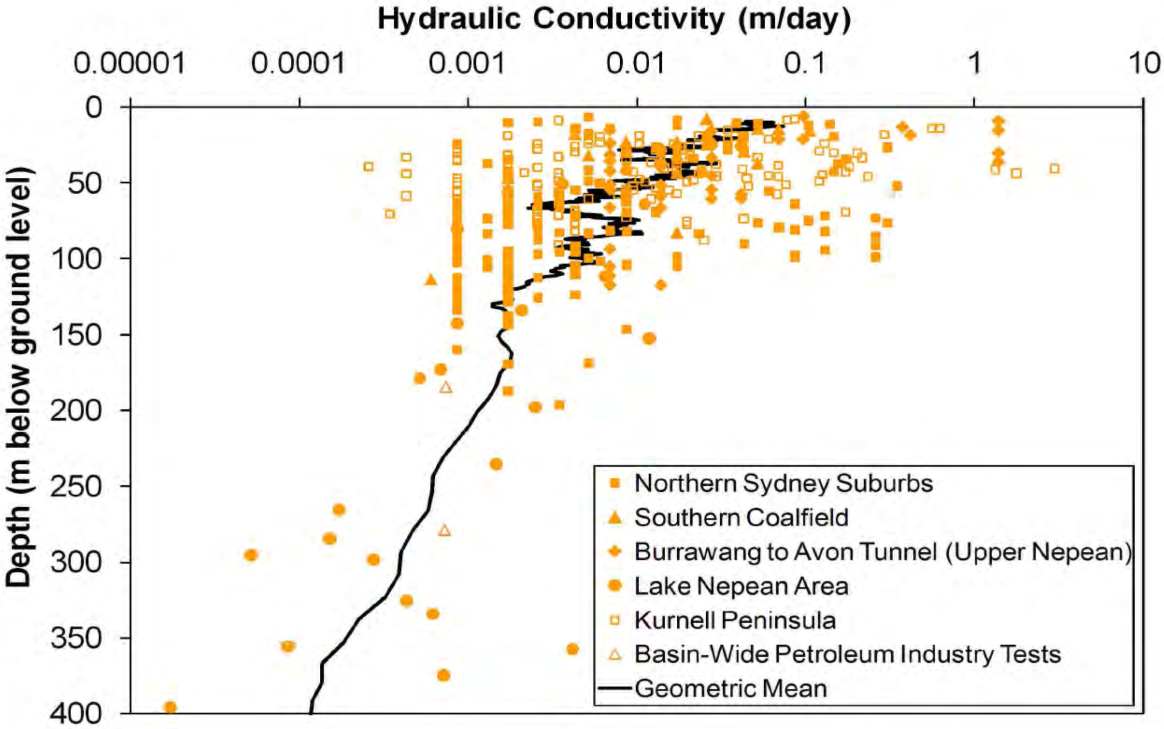


Figure 5.8 **Calculated hydraulic conductivity from packer tests in Mesozoic quartzose (Tammetta & Hawkes, 2009).**

5.5.4 Typical tunnel inflows

Hewitt (2005) provided a summary of groundwater inflows into seven tunnels excavated in the Hawkesbury Sandstone in the Sydney Region. Inflows were controlled by intersected lithology, local recharge conditions, extent of flow equilibrium, tunnel depth, whether tanked (fully impermeable liner throughout) or drained, climate, ventilation losses and the extent of ground treatment. Tunnel diameter would also impact on inflows.

Initial inflows of up to three litres per second were reported in the Epping to Chatswood Rail Line tunnel and 20 litres per second occurred in the 9.5 kilometre long Hazelbrook Sewer Tunnel in the Blue Mountains. The higher inflows of the sewer tunnel were associated with nearby valley erosion, with stress relief resulting in the opening of horizontal bedding partings and jointing (**section 5.3.3**). The long-term inflows were one litre per second per kilometre or less in all measured tunnels, excluding local high inflows, and are summarised in **Table 5.1**. It was, however, estimated that without extensive advance grouting during construction, inflows to the Northside Storage Tunnel would have been in the order of 200 litres per second (about 10 litres per second per kilometre) (Lees, Edwards, & Grant, 2005).

Table 5.1 **Measured tunnel groundwater inflows (Hewitt, 2005)**

Tunnel	Type	Length (km)	Span/diameter (m)	Maximum rock cover (m)	Long-term measured inflow (L/s/km)
Northside Storage	Water	20	6	90	0.9 (10 without extensive grouting)
Epping to Chatswood	Rail	13	7.2 (twin)	60	0.9
M5 East	Road	3.9	8 (twin)	60	0.8–0.9
Eastern Distributor	Road	1.7	12 (double deck)	40	1
Hazelbrook	Water	9.5	2	50	0.1
Cross City	Road	2.1	8 (twin)	53	<3
Lane Cove	Road	3.6	9 (twin)	60	<3

5.6 Site hydraulic parameters

Packer test results from various boreholes near and along the proposed tunnel alignment for the project (GHD, 2010) were reviewed to assess local conditions. They show a similar relationship of decreasing hydraulic conductivity with depth and a slight contrast between sandstone and shale properties.

5.6.1 Alluvium and fill

No site-specific data are available for the alluvium within the immediate tunnel alignment, but based on typical values for sandy clay to clayey sand, the hydraulic conductivity is likely to range between 1E-03 metres per day for clayey material up to 1E+00 metres per day for sandy material.

5.6.2 Ashfield Shale

The range of hydraulic conductivity values for the Ashfield Shale are summarised in **Table 5.2** and the depth relationship presented in **Figure 5.9**. The bulk hydraulic conductivity of the Ashfield Shale ranges from 2.2E-04 to 7.3E-01 metres per day. The median (50th percentile) hydraulic conductivity of the log transformed data was 1.1E-02 metres per day. The data show a very broad, poorly correlated relationship of decreasing hydraulic conductivity with increasing depth of cover, which is consistent with regional data, given the limited thickness of Ashfield Shale in the area; however the potential thickness-related variability does not appear significant when compared to the overall random variability in hydraulic conductivity. No specific areas of high or low hydraulic conductivity within the shale could be distinguished from the data.

Table 5.2 M5 packer test data summary – Ashfield Shale

Statistic (log transformed data)	Hydraulic conductivity 'K' (m/day)
Maximum	7.3E-01
90th percentile	1.7E-01
50th percentile	1.1E-02
10th percentile	4.3E-04
Minimum	2.2E-04

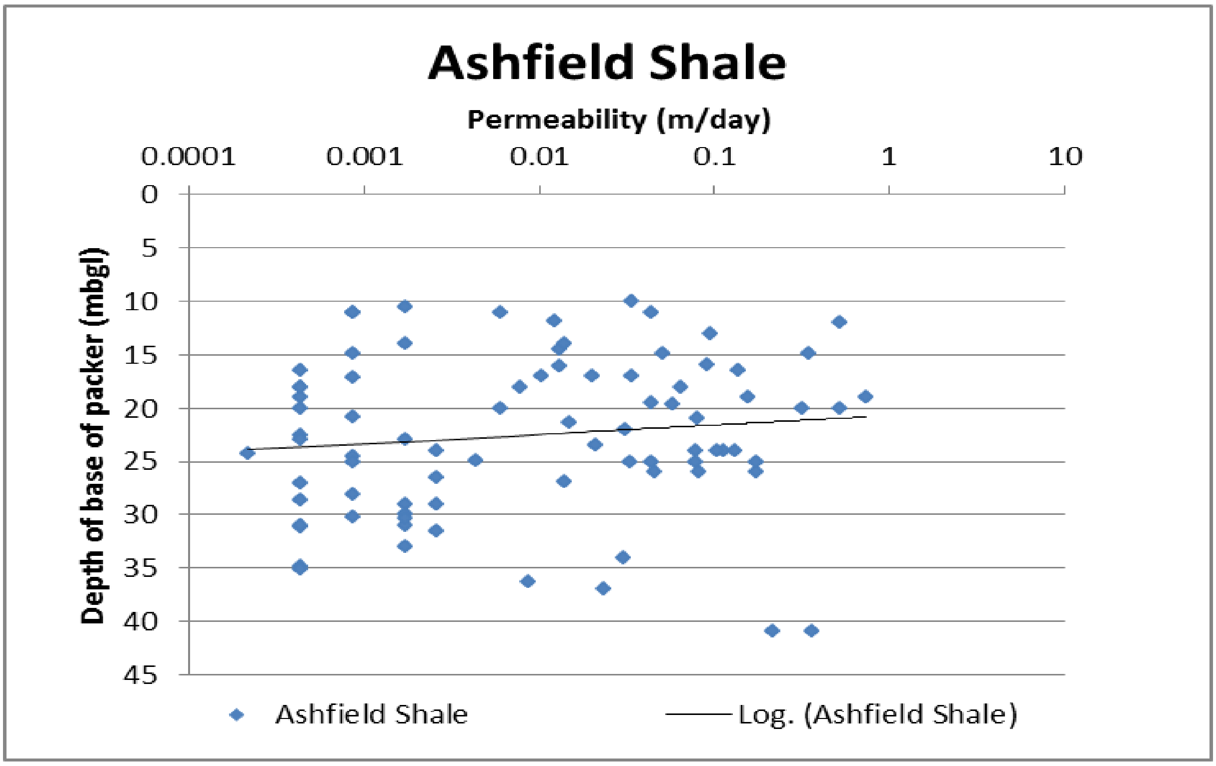


Figure 5.9 Depth versus hydraulic conductivity – Ashfield Shale

WDA (2015b) quoted packer test-derived values of:

- Shale 2.1E-08 metres per second (three tests)
- Laminite 5.3E-07 metres per second (six tests)
- Laminite/Siltstone 8.9E-08 metres per second (seven tests)
- Siltstone 5.2E-07 metres per second (19 tests)
- Sandstone/Siltstone 5.5E-08 metres per second (two tests)
- Adopted a value of 1E-07 metres per second (1E-02 metres per day) for shale units. This is consistent with the results shown in **Table 5.2**.

5.6.3 Hawkesbury Sandstone

The statistics for the log-transformed data (based on the apparent log-normal distribution) are summarised in **Table 5.3**. The data show a weak correlation of decreasing hydraulic conductivity with depth (**Figure 5.10**), although the range of depths tested is narrower that the regional data reviewed in **section 5.5.3**. The two highest hydraulic conductivity values of around 1.7E+00 metres per day were recorded in in boreholes 3103_143 and 3103_143 at a relatively shallow 15–20 metres. These boreholes were along the alignment of the topographic low leading to Iron Cove, indicating they may be within a zone of more jointed and hence more easily erodible sandstone.

In general, the local packer test data are consistent with the regional values for the same depth of cover.

Table 5.3 M5 packer test data summary – Hawkesbury Sandstone

Statistic (log transformed data)	Hydraulic conductivity ‘K’ (m/day)
Maximum	1.7E+00
90th percentile	1.4E-01
50th percentile	1.1E-02
10th percentile	8.6E-04
Minimum	4.3E-04

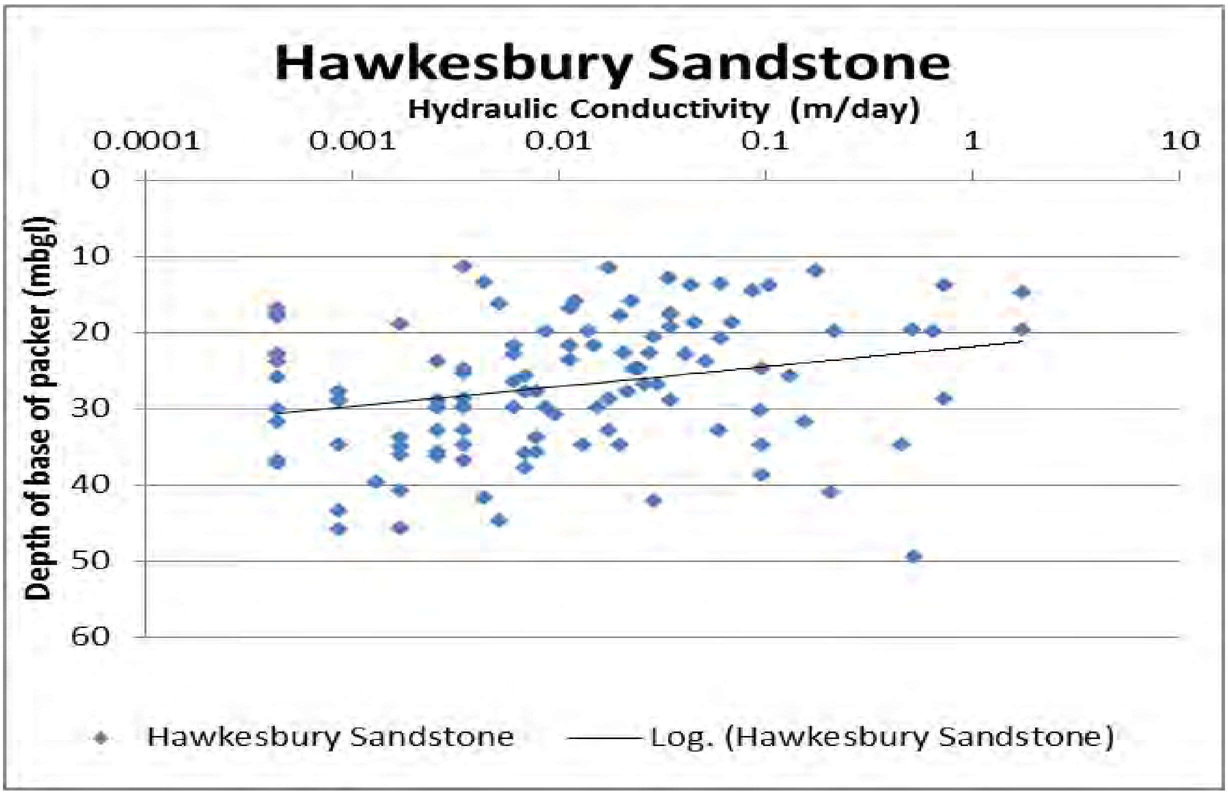


Figure 5.10 **Depth versus hydraulic conductivity - Hawkesbury Sandstone**

WDA (2015b) quoted mean packer test-derived values of 6.8 x 10-8 metres per second(10-2 metres per day) from 80 tests for sandstone, which is consistent with the results shown in **Table 5.3**.

5.7 Water chemistry

Groundwater water quality sampling was completed between 4 and 6 November 2014 as part of the soil and land contamination assessment (GHD, 2015a). This included the sampling of 15 wells along the project corridor which are presented in **Table 5.4** and on **Figure 5.11**. The installation of these wells was designed to target sources of potentially contaminating land uses along the project corridor. Further to this sampling, a baseline groundwater monitoring program has recently commenced and includes monitoring groundwater quality at 27 monitoring wells along the project corridor. These wells are also presented in **Table 5.4** and on **Figure 5.11**. The first baseline monitoring event was completed between 23 and 25 June 2015.

Surface water quality samples were taken at 12 locations on 29 June 2015, which provides an overview of the existing surface water quality along the alignment. Details of the sampling locations are presented in **Table 5.5** and in **Figure 5.11**.

This water quality monitoring data have been used to provide an overview of the existing water quality conditions along the alignment for the purposes of:

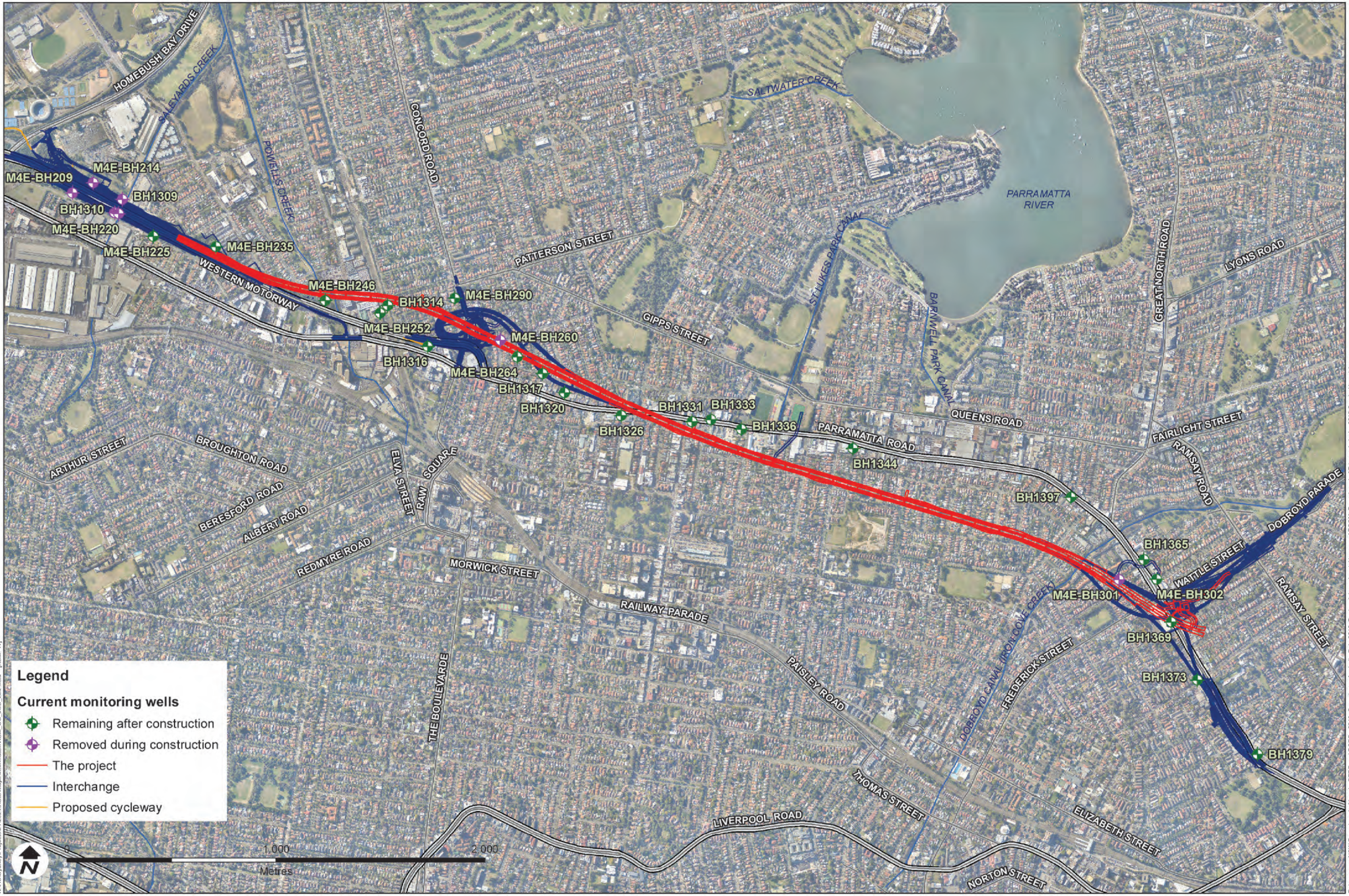
- Characterising existing impacts to groundwater quality created by the current urban environment surrounding the project corridor
- Understanding the environmental value and beneficial use potential of the existing groundwater conditions
- Characterising the potential aggressiveness of the existing water quality to project infrastructure
- Obtaining a preliminary understanding of the treatment requirements before tunnel seepage can be disposed to surface water.

Table 5.4 Groundwater monitoring well details

Bore ID	Sample event dates	Easting (m)	Northing (m)	Collar RL – m AHD	Well depth (m)	Screen top (m btoc)	Groundwater elevation (m btoc) – Jun 2015	Screen lithology	On alignment?
M4E-BH209	June 2015	321821	6251846	10.573	18	15	5.9	Siltstone	Yes
M4E-BH214	June 2015	321920	6251894	6.05	9.53	6.53	4.55	Siltstone	Yes
BH1309	Nov 2014, June 2015	322060	6251815	-	6	3	2.09	Gravelly clay	Yes
BH1310	Nov 2014, June 2015	322024	6251751	-	6	3	2.08	Sandy clay	Likely
M4E-BH220	June 2015	322042	6251746	3.352	24	21	2.69	Siltstone	Likely
M4E-BH225	June 2015	322208	6251637	9.903	17.95	14.95	6.58	Laminate	Unlikely
M4E-BH235	June 2015	322508	6251588	14.131	15.2	9	5.96	Siltstone	No (but adjacent)
M4E-BH252	June 2015	323294	6251270	10.491	28	17	3.18	Siltstone	No
BH1314	Nov 2014, June 2015	323330	6251307	-	7.5	4.5	5.29	Gravelly clay	No (but adjacent)
BH1316	Nov 2014, June 2015	323522	6251111	-	7	3.5	3.95	Shale	No
M4E-BH290	June 2015	323651	6251341	32.92	20	17	3.98	Siltstone	No
M4E-BH260	June 2015	323869	6251140	23.214	32	29	2.28	Interbedded sandstone	Yes
M4E-BH264	June 2015	323950	6251060	18.889	18	15	3.85	Laminite and siltstone	Likely
BH1317	Nov 2014, June 2015	324072	6250981	-	7	4	0.55	Gravelly clay	Likely
BH1320	Nov 2014, June 2015	324177	6250888	-	8.5	5.5	0.85	Clay	No

Bore ID	Sample event dates	Easting (m)	Northing (m)	Collar RL – m AHD	Well depth (m)	Screen top (m btoc)	Groundwater elevation (m btoc) – Jun 2015	Screen lithology	On alignment?
BH1326	Nov 2014, June 2015	324447	6250779	-	26	21.5	7.37	Shale	No
BH1331	Nov 2014, June 2015	324785	6250750	-	7	4	3.33	Shale	No
BH1333	Nov 2014, June 2015	324876	6250760	-	8	5	4.25	Shale	No
BH1336	Nov 2014, June 2015	325021	6250714	-	8	5	2.92	Clay	No
BH1344	Nov 2014, June 2015	325555	6250622	-	25	22	5.47	Sandstone	No
BH1397	June 2015	-	-	-	-	-	2.79	-	No
BH1365	Nov 2014, June 2015	326948	6250090	-	16.8	13.8	5.03	Clayey sand	No
M4E-BH301	June 2015	326830	6249993	6.904	18	15	2.82	Sandstone	Yes
M4E-BH302	June 2015	327010	6249996	10.536	50	47	4.72	Sandstone	No
BH1369	Nov 2014, June 2015	327079	6249791		8.5	5.5	2.2	Shale	Likely
BH1373	Nov 2014, June 2015	327204	6249512		8	5	1.62	Shale and gravelly clay	Unlikely
BH1379	Nov 2014, June 2015	327491	6249158		9	6	1.67	Gravelly clay	Unlikely

Note: 'm btoc' means metres below top of casing



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Data source: NSW Department of Lands: DTDB and DCDB - 2012. Geoscience Australia Data 2012, Design data and aerial imagery AECOM, Department of Primary Industry 2010 Created by: qjchung

Figure 5.11 Groundwater quality monitoring locations

Table 5.5 Surface water monitoring site details

Name	Upstream/ Downstream	Creek	Easting	Northing	Street address
POW1	Upstream	Powells Creek	323407	6250662	4 Elva St, Strathfield
POW2	Downstream	Powells Creek	322585	6252522	Mason Park, Conway Ave Homebush
SAL1	Upstream	Saleyards Creek	321495	6263956	Airey Park, Kessel Ave, Homebush
SAL2	Downstream	Saleyards Creek	322370	6252331	5 Underwood Road, Homebush
SLP1	Upstream	St Lukes Park Canal	325232	6250861	Northern carpark Concord Oval, Gipps St entrance
SLP2	Downstream	St Lukes Park Canal	325347	6251207	Crane St car park, Concord
BAR1	Upstream	Barnwell Park Canal	325995	6250844	104 William Street car park, Five Dock
BAR2	Downstream	Barnwell Park Canal	325909	6251252	2 Bellbird Close, Canada Bay
DOB1	Upstream	Dobroyd Canal	326275	6249558	Gregory Ave
DOB2	Downstream	Dobroyd Canal	327689	6250369	Henley Marine Dr, Timbrell Park
USW	Upstream	Finlaysons Creek	312451	6256914	68 Killeen Street, Wentworthville (Lytton St Park)
DSW	Downstream	Hawthorne Canal	328412	6248898	Hawthorne Pde

Note: Upstream/downstream means location relative to project alignment.

A summary of the analytical suite selected for groundwater quality monitoring events outlined previously is presented in **Table 5.6**. Individual analytes are presented in the results tables in **Appendix C**.

Table 5.6 Analytical Schedule

Analyte	Groundwater sampling November 2014	Groundwater sampling June 2015	Surface water sampling June 2015
Temperature (field)	✓	✓	✓
pH (field)	✓	✓	✓
Dissolved oxygen (field)	✓	✓	✓
Oxygen reduction potential (field)	✓	✓	✓
Electrical conductivity (field)	✓	✓	✓
pH	✓	✓	
Total dissolved solids		✓	
Suspended solids			✓
Major ions		✓	
Electrical conductivity		✓	
Dissolved metals (8 metals)	✓	✓	✓ (minus mercury)
Additional dissolved metals (12 metals)		✓	
Ferric and ferrous iron		✓	
Ammonia as N			
Total Kjeldahl nitrogen			✓
Nitrate (as N)		✓	
Nitrite (as N)		✓	
Nitrogen (total oxidised)			✓
Nitrogen (organic)		✓	
Nitrogen (Total)		✓	✓

Analyte	Groundwater sampling November 2014	Groundwater sampling June 2015	Surface water sampling June 2015
Phosphate total (P)		✓	✓
Reactive phosphorus as P		✓	
Alkalinity and hardness (as CaCO3)		✓	
Total recoverable hydrocarbons	✓		✓
Benzene, toluene, ethylbenzene, xylene (BTEX) and mono aromatic hydrocarbons	✓		✓
Polycyclic aromatic hydrocarbons (PAH)	✓		✓ (Naphthalene only)
Volatile organic compounds (VOC)	✓		
Organo chloride pesticides (OCPs)	✓		
Organo phosphate pesticides (OPPs)	✓		
Polychlorinated biphenyls (PCBs)	✓		
Chlorinated hydrocarbons	✓		
Surfactants/methylene blue active substances (MBAS)	✓		

The results of sampling events outlined above are presented in **Appendix C** and are summarised in the following sections.

5.7.1 Assessment criteria

Available water quality data were compared with established criteria for protecting the environment and human health including:

- The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ, 2000a). The surrounding waterways are within an urban environment and are expected to be moderately disturbed. As such the 95th percentile values for the protection of marine and freshwater ecosystems has been adopted. This is in accordance with the recommendations made in the guidelines (ANZECC & ARMCANZ, 2000a). Where there were no 95th percentile criteria, the low reliability criteria were adopted for screening purposes.
- The *Australian Drinking Water Guidelines* (NHMRC, NRMMC, 2011) to assess the potential health risks of incidental contact with groundwater. It is noted that the suburbs intersected by the project corridor are on reticulated water supplies and as such groundwater is not expected to be used for potable purposes.

To assess the potential health risks associated with incidental exposure to chemical contamination in recreational waters, a simple screening approach concentration of 10 times that stipulated in the drinking water guidelines was adopted. This is the general approach adopted by the World Health Organisation (WHO) and assumes that 200 millilitres per day is consumed from recreational contact with water, which is one tenth of the drinking water intake (two litres). This approach is considered to be conservative because recreational water users are unlikely to come into contact with concentrations high enough to cause adverse effects following a single exposure and because, on a long-term basis, there is unlikely to be on-going continual exposure on which the drinking water criteria are based.

Groundwater data have also been compared against available surface water data to better understand the potential for discharge of groundwater seepage to surface water during construction and operation. In this regard, and in accordance with the ANZECC & ARMCANZ (2000a) monitoring guidelines assessment framework, the primary threshold criteria are the baseline surface water quality conditions. Groundwater quality would need to meet these conditions prior to meeting the recommended ANZECC & ARMCANZ (2000a) default trigger criteria before discharge to surface water.

The soil and water quality impact assessment (GHD, 2015c) stipulates discharge water quality objectives that consider pollution reduction targets for stormwater runoff from the project. These targets are designed for developing surface treatment systems that achieve reductions in water pollutants rather than setting specific concentration criteria. These reduction targets create background receiving water quality conditions which would be required to be considered during the establishment of criteria for groundwater treatment. As such the approach adopted for groundwater treatment is considered to be consistent with the surface water quality objectives.

Sulfate and pH values from the latest groundwater monitoring event were compared against aggressivity criteria to better understand the potential impacts of existing groundwater water on subsurface infrastructure. The values adopted included the exposure classification criteria for concrete piles and steel piles presented in Australian Standard AS 2159-2009 *Piling – Design and installation*.

5.7.2 Organic constituents

The November 2014 groundwater sampling event assessed the presence of organic compounds in groundwater at 15 locations along the project corridor. The results are presented in **Appendix C** and are discussed below.

Overall there were low levels of organic compounds identified with minor detectable concentrations of total recoverable hydrocarbons (TRH) present in wells BH1326, BH1344 and BH1365.

BH1344 had one exceedance of the adopted low reliability freshwater criteria for phenanthrene (a PAH) and also had low level detectable concentrations of other PAHs, BTEX, MAH and VOCs. Based on field observations, the well location and the well depth the results for BH1344 are considered to be anomalous and will be confirmed by re-sampling for these analytes in subsequent monitoring events.

While these data only represents a snap shot of the spatial distribution of organic compounds along the project corridor, they were designed to target the main potential sources of impact along the corridor. As such, it is expected that the impacts of organic compounds in groundwater seepage into the tunnel would be limited and unlikely to require treatment before discharge. This is supported further when any point source or impact is considered relative to overall tunnel seepage.

It is noted that the tunnel would result in a wider area of drawdown than the project corridor, which could draw impact from impacted areas further afield.

Surface water had no detectable concentrations of TRH, BTEX, MAH or naphthalene suggesting that baseline surface water conditions are not impacted by these compounds. It is expected that this would be different under first flush flow conditions when the waterways are receiving the first runoff from the urban environment in which the project corridor is located.

During operation and construction of the project corridor, there would be potential for spills and leaks to occur that may enhance the potential for the presence of the chemical constituents in groundwater seepage. It is acknowledged however, that the risk would be low due to stringent protocol and management practices adopted during construction and as the concept design will ensure that groundwater seepage collection does not mix with operation activities and surface runoff.

5.7.3 Salinity

The laboratory salinity for the latest (June 2015) groundwater monitoring event ranged between an electrical conductivity (EC) of 760 microSiemens per centimetre (estimated total dissolved solids (TDS) of 490 milligrams per litre) in well BH260 and 20,000 microSiemens per centimetre (TDS of 12,000 milligrams per litre) in well BH209.

Tunnel seepage would potentially simultaneously draw groundwater from sandstone, shales and unconsolidated aquifer systems. The salinity characteristics for the different aquifer systems intersected across the corridor are summarised below:

- Shallow groundwater in unconsolidated sediments ranges between 990 microSiemens per centimetre (780 milligrams per litre TDS) and 3300 microSiemens per centimetre (2300 milligrams per litre TDS). These concentrations would have marginal suitability for potable use but have potential to be used for stock purposes

- Groundwater in Ashfield Shales ranges between 1600 microSiemens per centimetre EC (1000 milligrams per litre TDS) and 20,000 microSiemens per centimetre EC (12,000 milligrams per litre TDS). These concentrations are likely to have marginal beneficial use potential for potable or stock purposes
- Groundwater in Hawkesbury Sandstone range between 760 microSiemens per centimetre EC (490 milligrams per litre TDS) and 1700 microSiemens per centimetre EC (1100 milligrams per litre TDS). These concentrations are generally suitable for potable use.

The salinity concentrations seeping into the M4 corridor tunnel may change over time (**section 6.2.2**) if the drawdown cone intersects saline areas of the Parramatta River.

Surface water concentrations have been reported to vary significantly depending on the potential interaction with seawater from the harbour. The electrical conductivity was reported to vary between 697 microSiemens per centimetre (TDS concentration of 467 milligrams per litre) at the upstream site in Dobroyd Canal and 40,944 microSiemens per centimetre (estimated TDS concentration of 27,432 milligrams per litre) at the downstream site in Barnwell Park Canal.

Based on existing surface water quality, there is potential for discharge of groundwater seepage directly to surface water without treatment for salinity. Surface water discharge points at downstream locations with salinity levels equal to or greater than groundwater would be required, otherwise treatment for salinity would be necessary.

The downstream location at St Lukes Park Canal was different to other downstream locations monitored, as it had salinity characteristics indicative of freshwater. Discharge of untreated saline groundwater may be required further downstream of this point if the canal is to be used as a discharge point and treatment for salinity is not proposed.

5.7.4 Major ions

Concentrations of sulfate in groundwater from the latest groundwater monitoring event were consistently above human health criteria for drinking water and ranged between 2.9 milligrams per litre and 860 milligrams per litre. The values were all below the recommended recreational water criteria of ten times the drinking criteria. The data suggest the groundwater is not suitable for drinking but discharge to surface water would not represent a risk to human health.

Surface water samples were not analysed for sulfate but the typical concentration in seawater is around 2650 milligrams per litre.

5.7.5 Nutrients

From the latest groundwater monitoring event (June 2015), ammonia in groundwater sampled from BH209, BH220 and BH1309 was present at concentrations in excess of the adopted marine and freshwater criteria. These wells are screened within unconsolidated materials (at shallow depths) and in the Ashfield Shales (at depths greater than 15 metres below ground surface). There is also an exceedance of the adopted freshwater ammonia criteria at BH290, which is screened in shale at depths of 17–20 metres below ground surface. The data suggest that ammonia concentrations may require treatment before discharge to surface water, however, it can be expected that given the intermittent nature of the exceedances along the project corridor, the overall concentrations in seepage water would likely be acceptable.

Concentrations of nitrate above the adopted freshwater criteria (0.158 milligrams per litre) are present in BH1314 (1.8 milligrams per litre) and BH301 (0.4 milligrams per litre). All other reported concentrations are generally below 0.1 milligrams per litre.

Nitrate concentrations in groundwater ranged from less than the level of reporting of 0.02 milligrams per litre to a maximum of 1.83 milligrams per litre, while in surface water they range between 0.18 milligrams per litre and 1.82 milligrams per litre. This suggests that groundwater and surface water characteristics are similar, however, ammonium concentrations in groundwater (which are estimated to range between less than the level of reporting of 0.02 milligrams per litre and 5.3 milligrams per litre) and therefore seepage water may require treatment of both ammonia and nitrate before discharge to surface water.

Total phosphorus concentrations range between less than the level of reporting of 0.05 milligrams per litre and 0.39 milligrams per litre in groundwater. There are no human health and environmental criteria for phosphorus. Surface water concentrations range between 0.02 and 1.62 milligrams per litre and suggest that groundwater has similar characteristics to surface water and that treatment of phosphorus in groundwater seepage is unlikely to be required. It is noted however that concentrations in Saleyards Creek and St Lukes Park Canal are generally low and may require further consideration if they are to be discharge points for groundwater seepage.

5.7.6 Acidity

The pH values recorded in the latest groundwater monitoring event (June 2015) generally ranged between 4.3 and 7.6 with the majority being equal to or below 6.5. There was one anomalous value of 11 from well BH302, which may have been caused by grout.

Surface water values range between 7.4 and 8.4 and are slightly alkaline.

Based on the pH differences between groundwater and surface water, groundwater seepage would require pH adjustment before discharge to surface water.

During construction, there could be grouting of fractures in the tunnel wall to minimise groundwater seepage and meet the design inflow criteria. Cement grout has the potential to raise pH which would also require consideration and adjustment before discharge to surface water.

5.7.7 Metals

Data from the latest groundwater monitoring event indicate that background concentrations of cadmium, chromium, copper, manganese, nickel and zinc are present in groundwater above the adopted freshwater quality criteria. Nickel and zinc concentrations are consistently above the freshwater criteria. Total iron and beryllium concentrations are also above the adopted low reliability criteria for fresh water.

Data from the latest groundwater monitoring event indicate that background concentrations of cadmium, chromium, cobalt, copper, mercury, nickel, vanadium and zinc are present in groundwater at concentrations above the adopted marine water quality criteria. Cobalt, nickel and zinc concentrations are consistently above the marine water criteria.

Surface water concentrations of copper and zinc are present above the adopted marine and freshwater criteria at most sites, suggesting that background concentrations are naturally above criteria. These concentrations were generally in a similar range to those present in groundwater although there are isolated occurrences of higher concentrations in groundwater. Concentrations of other metals were below criteria and below concentrations observed in the groundwater, particularly for cadmium, chromium and nickel. Overall this suggests that metals in groundwater seepage would require treatment before discharge to surface water.

Concentrations of manganese and nickel were above the human health criteria for drinking water, however no concentrations of metals were above the recommended recreational water criteria of 10 times the drinking water criteria. This suggests that metals concentrations in groundwater seepage discharge to surface water are unlikely to represent a human health risk.

During operation and construction of the project corridor, there would be potential for spills and leaks to occur that may enhance the potential for the presence of the chemical constituents in groundwater seepage. It is acknowledged however, that the risk would be low due to stringent protocol and management practices adopted during construction and due to elements of the concept design that will ensure that groundwater seepage collection does not mix with operation activities and surface runoff.

5.7.8 Precipitation of iron and manganese

Dissolved iron and manganese in groundwater is derived from weathering of iron and manganese bearing minerals and rocks. Ubiquitous in groundwater, iron and manganese naturally occur where there is little or no oxygen, typically in deeper bores (but not always), in areas where groundwater flow is slow, and in areas where groundwater flows through soils rich in organic matter.

The environmental chemistry of iron and manganese is controlled primarily by pH and redox conditions; with the soluble forms of ferrous iron (Fe^{2+}) and manganese (II) dominating at lower pH and redox potential. The kinetics of manganese (II) oxidation is slower than ferrous iron in waters with pH below 8.5 (Zaw & Chiswell, 1999). Manganese (II) is also more stable over a wider oxidation potential (Eh) and pH range than ferrous iron.

Deposits formed by precipitation of iron floc and deposits associated with iron precipitating bacteria are also known as ochre. The first stage of ochre precipitation involves the formation of amorphous iron oxyhydroxides, which form through rapid hydrolysis reactions. In ochre these oxyhydroxides are often found in conjunction with filamentous iron oxidising bacteria. Over time the amorphous oxyhydroxides transform to more stable crystalline forms of iron hydroxides, such as hematite and goethite. Ochre is known to form in pipes, drains and bores, essentially anywhere there is a substrate and readily available source of soluble reduced iron (ie ferrous iron) in the groundwater. The formation of ferric oxyhydroxide floc or ochre deposits can result in severe clogging, leading to major failures in drainage systems and bores and the reduction of groundwater inflow into subsurface tunnels.

Under suitable conditions, manganese present in groundwater can also form a drain-clogging floc. Manganese will precipitate under oxidising conditions to form a black precipitate, but it is when oxidation is bacterially enhanced that the precipitate becomes more gelatinous and a bigger clogging issue. However, manganese deposits are generally less common than ochre due to the greater stability of manganese (II) over Eh and pH ranges. When present, manganese deposits often occur in conjunction with ochre.

Although the chemical oxidation of iron will produce precipitates that could cause a degree of clogging, extensive clogging mostly occurs when iron-precipitating filamentous bacteria are present. Iron precipitates are not ‘sticky’ and in themselves are not generally responsible for serious clogging issues.

Ferrous iron concentrations in groundwater flowing into a drain have been found to be a reasonable indicator of the potential for ochre clogging. Ochre formation is a complex problem involving physical, chemical and biological processes that at times can very difficult to predict and quantify. **Table 5.7** shows the estimated ochre potential based on ferrous iron concentrations in groundwater.

Table 5.7 Ochre potential based on ferrous iron concentrations (adapted from Stuyt et. al. 2005)

Ochre potential	Fe^{2+} groundwater concentration (mg/L)
Very high	>25
High	10–25
Moderate	5–10
Little	1–5
Negligible	<1

Along the project corridor, the highest concentrations of ferrous iron were observed in wells BH1320 (18 milligrams per litre), BH1344 (27 milligrams per litre in the quality assurance sample), BH1365 (26 milligrams per litre), BH1369 (23 milligrams per litre), BH1310 (14 milligrams per litre in the quality assurance sample) and BH235 (17 milligrams per litre). These wells are generally screened in a range of lithological units including shallow unconsolidated sediments, shales and sandstones. All other monitoring well concentrations were below 10 milligrams per litre.

The data suggest there is likely to be moderate potential for the development of ochre, with isolated zones of high potential for ochre development. As such, clogging issues may arise within groundwater drainage and collection systems and would need to be considered further at detailed design stage.

5.7.9 Groundwater aggressiveness and project infrastructure

Concentrations of sulfate and pH were compared to the selected aggressivity criteria. The results of the comparison are presented in **Table 5.8**. The results suggest that existing groundwater may represent a significant risk to concrete structures intersecting groundwater and therefore the design would need to consider materials that are more resistant to aggressive groundwater.

Table 5.8 Groundwater aggressiveness

Bore ID	Steel piles		Concrete piles	
	Exposure condition clays	**Exposure condition sand/gravel**	**Exposure condition clays**	**Exposure condition sand/gravel**
BH1310	non-aggressive	non-aggressive	non-aggressive	mild
BH1314	non-aggressive	non-aggressive	non-aggressive	mild
BH1315	non-aggressive	non-aggressive	non-aggressive	mild
BH1333	non-aggressive	mild	mild	moderate
BH1365	non-aggressive	mild	non-aggressive	mild
BH1369	non-aggressive	mild	mild	moderate
BH1373	non-aggressive	mild	mild	moderate
BH1379	non-aggressive	mild	moderate	severe
BH1397	non-aggressive	mild	mild	moderate
BH209	non-aggressive	mild	moderate	severe
BH220	non-aggressive	mild	moderate	severe
BH225	non-aggressive	mild	moderate	severe
BH235	non-aggressive	mild	mild	moderate
BH290	non-aggressive	non-aggressive	non-aggressive	mild
BH301	non-aggressive	mild	non-aggressive	mild
BH302	non-aggressive	non-aggressive	non-aggressive	mild
BH1309	non-aggressive	non-aggressive	non-aggressive	mild
BH1317	non-aggressive	mild	mild	moderate
BH1320	non-aggressive	mild	mild	moderate
BH1326	non-aggressive	mild	mild	moderate
BH1331	non-aggressive	non-aggressive	non-aggressive	mild
BH1336	non-aggressive	mild	moderate	severe
BH1344	non-aggressive	non-aggressive	non-aggressive	mild
BH214	non-aggressive	non-aggressive	non-aggressive	mild
BH252	non-aggressive	mild	mild	moderate
BH260	non-aggressive	non-aggressive	non-aggressive	mild
BH264	non-aggressive	non-aggressive	non-aggressive	mild
BH1310	non-aggressive	non-aggressive	non-aggressive	mild
BH1336	non-aggressive	mild	moderate	severe
BH1333	non-aggressive	mild	mild	moderate
BH290	non-aggressive	non-aggressive	non-aggressive	mild
BH1365	non-aggressive	mild	non-aggressive	mild

5.8 Acid sulfate soils and acid and metalliferous drainage

Based on the online NSW natural resources acid sulfate soil risk map (Department of Land and Water Conservation, 1997) there are several areas with an identified soil risk present in the study area, although none directly along the tunnel alignment (**section 6.3.6**).

Neither Ashfield Shale or Hawkesbury Sandstone are known to have significant net acid producing potential but elevated iron concentrations are commonly found in groundwater, including tunnel inflow in Hawkesbury Sandstone. Based on the above, it is unlikely that drainage associated the tunnel would result in oxidisation of sulfide minerals in either unconsolidated sediment or consolidated sedimentary rock within the immediate tunnel area.

5.9 Existing groundwater users

There are 30 registered groundwater bores within five kilometres of the project (**Figure 5.12**) outlined in **Table 5.9**. None of these are currently proposed to be directly modified for the project. Only one bore (GW110899) is within two kilometres of the proposed project alignment and is licenced for 'domestic' use. No usage data for the bores are available and there are no water quality data for the bores.

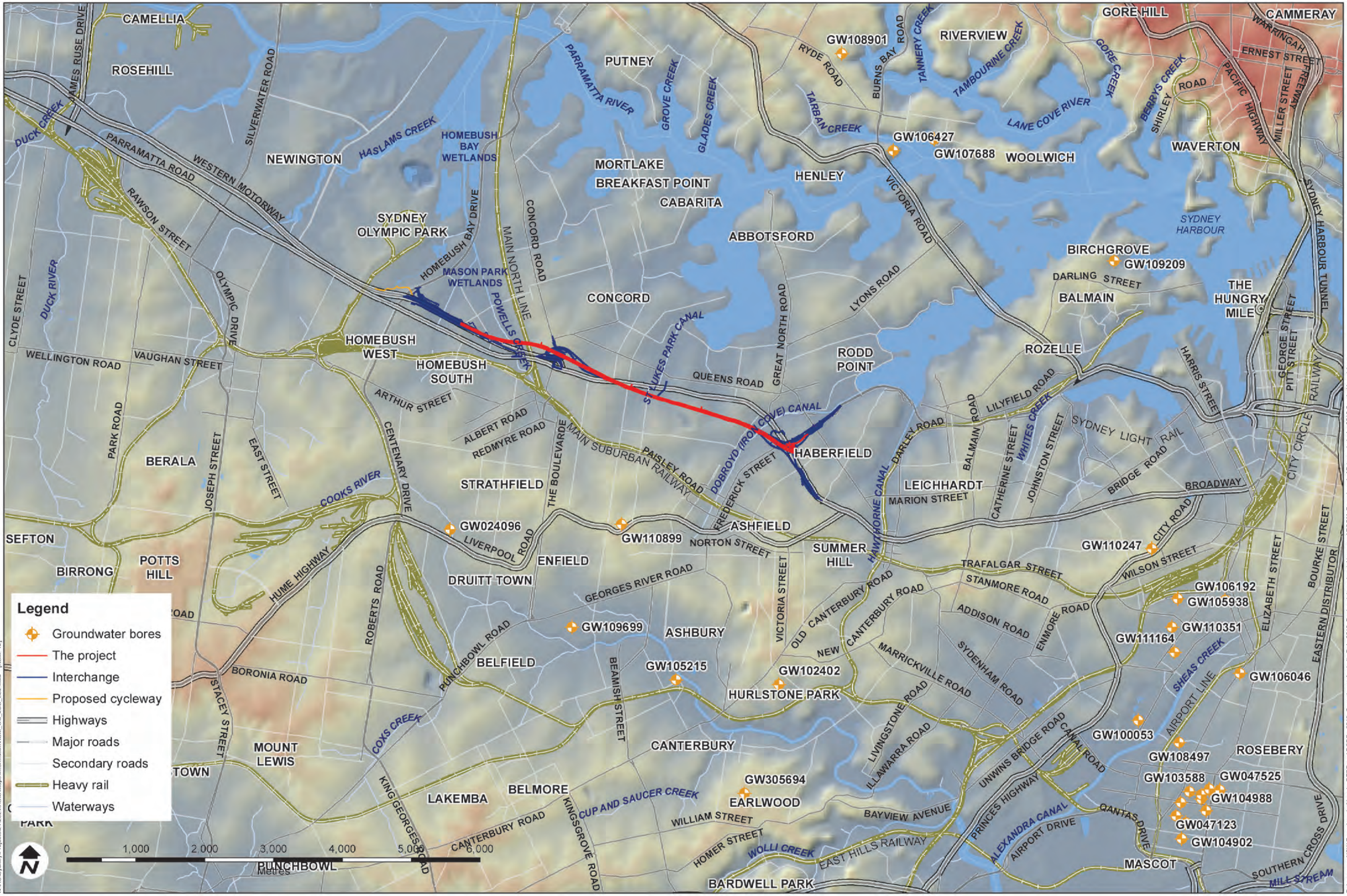

Figure 5.12 Licenced water bores within five kilometres of the project

Table 5.9 Current bore licences

GW number	Easting (m)	Northing (m)	Elevation (m AHD)	Licence status	Purpose	Date drilled
GW305694	326438	6244811	44.03	Active	Domestic	20/02/2003
GW013515	333075	6244732	8	Current	Domestic	1/01/1958
GW024068	332846	6244382	8	Current	Domestic	5/01/1966
GW024096	322168	6248643	15.96	Current	Domestic	1/01/1966
GW102402	326938	6246390	33.78	Current	Domestic	1/01/1996
GW103588	332905	6244836	8	Current	Domestic	18/02/2001
GW104297	332708	6244483	8	Current	Domestic	20/12/1994
GW104902	332787	6244151	7	Current	Domestic	27/09/1995
GW104988	333077	6244789	8	Current	Domestic	15/12/2001
GW105215	325448	6246456	5.09	Current	Domestic	6/05/2003
GW105938	332733	6247637	12.25	Current	Domestic	20/05/2005
GW106046	333636	6246554	13.56	Current	Domestic	6/07/2005
GW106192	333418	6247611	15.94	Current	Domestic	12/10/2004
GW106427	328600	6254141	19.71	Current	Domestic	1/01/1950
GW107688	329193	6254304	11.73	Current	Domestic	21/12/2006
GW109209	331813	6252542	13.47	Current	Domestic	13/08/2008
GW109699	323935	6247225	9.02	Current	Domestic	12/11/2008
GW110247	332357	6248363	41.27	Current	Domestic	16/07/2009
GW110899	324658	6248717	42.45	Current	Domestic	6/02/2010
GW111164	332686	6246860	10	Current	Domestic	22/10/2010
GW112403	333189	6244856	8.95	Current	Groundwater remediation	29/11/2007
GW112404	333190	6244861	8.98	Current	Groundwater remediation	29/11/2007
GW112405	333193	6244876	9.07	Current	Groundwater remediation	29/11/2007
GW027750	332774	6244676	8	Current	Recreation (groundwater)	12/01/1965
GW047123	333143	6244560	8	Current	Recreation (groundwater)	7/01/1973
GW047525	333343	6244859	10.12	Current	Recreation (groundwater)	5/01/1975
GW100053	332163	6245867	4	Current	Recreation (groundwater)	20/04/1994

GW number	Easting (m)	Northing (m)	Elevation (m AHD)	Licence status	Purpose	Date drilled
GW108497	332753	6245547	8	Current	Recreation (groundwater)	16/01/2008
GW108901	327852	6255549	40.50	Current	Recreation (groundwater)	6/06/2008
GW110351	332651	6247224	12.64	Current	Recreation (groundwater)	1/01/1975

5.10 Groundwater dependent ecosystems

Groundwater Dependent Ecosystems (GDEs) are ecosystems which rely on groundwater for their survival and species diversity. GDEs are broadly classified as terrestrial vegetation, river base flow systems, estuarine and near shore marine, aquifer and cave systems and wetlands (Clifton and Evans, 2001) (Hatton and Evans, 1998). The GDEs are dependent on one or more of groundwater flux, level, pressure and quality.

The most likely areas where GDEs may be present are shallow alluvial sediments along major drainage lines where the water table and associated capillary zone is within the root zone of established vegetation. There may also be localised freshwater aquatic ecosystems in areas fed by groundwater baseflow emanating from the Hawkesbury Sandstone.

The BOM internet-based atlas of identifies two wetland areas to the northwest of the project, within the model domain and in the vicinity of the Homebush Bay, which are mapped as vegetation having potentially high reliance on subsurface groundwater. These are the Mason Park and Homebush Bay wetlands.

The flora and fauna impact assessment (GHD, 2015b) highlights Mason Park wetlands as a potential sensitive wetland. The wetland is described in the assessment as:

> *A wetland comprising saltmarsh, rush swamp, mangrove forests and a small freshwater pond, as well as landscaped recreational areas.*

It also states that:

> *Mason Park wetland currently provides a mosaic of tidal pools and remnant saltmarsh vegetation once common along the Homebush Bay foreshore. In the past, this wetland has been one of the most important shorebird feeding and roosting sites in the Sydney area, and until recently has had more shorebirds per hectare than any other site in the region.*

A review of aerial photos for these wetlands suggests that they are mangrove communities which are likely to be predominantly reliant on regular tidal inundation rather than dependent on groundwater, although these areas are listed on the BOM atlas as being potentially dependent on groundwater, given that the wetlands appear to be tidally influenced, it is not expected that the wetlands are reliant on groundwater.

No other GDEs have been identified within the area subject to drawdown from the project from tunnel construction or operation.

5.11 Environmental values

5.11.1 Aquatic ecosystems

Groundwater in the area will ultimately discharge to freshwater, estuarine or marine aquatic ecosystems. As the area has been highly modified, however, it is likely that any ecosystems present are highly disturbed. As the ANZECC & ARMCANZ (2000) guidelines aim to improve the quality of disturbed ecosystems, the trigger values for 95% species protection for general water quality and 99% protection for cumulative toxins should be applied. Although existing deep groundwater quality is unlikely to meet this requirement, under natural flow conditions the groundwater is likely to be significantly diluted by surface water and shallow flow. Discharge from tunnel dewatering, however, would result in an increase in discharge rates to surface water and hence may require treatment to meet the ANZECC & ARMCANZ (2000) trigger values noted above.

5.11.2 Drinking water

The salinity of the groundwater in the area precludes use as potable supply, as does various other parameters in some bores. Consequently groundwater is unlikely to be used as a drinking water supply and hence the ADWG (NHMRC, NRMMC, 2011) do not apply directly. However, a value of ten times the ADWG is used as a measure of the risk from incidental ingestion of water from secondary contact, superseding the former 'recreational contact' guidelines (ANZECC & ARMCANZ 2000). This level is applicable in assessing the risk to workers during construction and road users and workers during operation.

5.11.3 Irrigation

The suitability of groundwater for irrigation purposes depends on multiple factors including:

- Soil type and structure (exchangeable sodium percentage)
- Vegetation species (salt tolerant versus salt sensitive vegetation)
- Irrigation application methods (surface and subsurface drip verses sprinkler)
- Ionic composition of water (sodium adsorption ratio and residual alkalinity hazard).

The suitability of groundwater in the area varies widely. Groundwater from the Ashfield Shale is generally unsuitable due to high salinity and bores in the shale generally do not have sufficient yield. The quality and yield within the Hawkesbury Sandstone is suitable for irrigation of salt tolerant crops in some areas depending of depth below the saline Ashfield Shale and proximity to the shoreline.

Given the heavily developed nature of the area, the most likely irrigation use would be for large parklands, golf courses and sporting fields.

5.11.4 Stock water

Groundwater in some bores lies within the salinity range suitable for stock drinking water. As noted above, however, the developed nature of the area makes it unlikely that groundwater would be used for stock supply.

5.12 Existing infrastructure

The corridor is currently located in a well-developed urban area. This includes established commercial, industrial, residential and recreational infrastructure. This infrastructure could be subject to subsidence if soft unconsolidated sediments on which they could be located settle due to dewatering of the tunnels during construction and/or operation of the project.

The interpreted geological and groundwater level conditions along the project corridor (see **section 5.4.1**) suggest the presence of isolated/intermittent but potentially thick unconsolidated sediment aquifers that could have potential to subside.

The subsidence associated with settlement of soft sediments, does not form part of the SEARs for the groundwater assessment, however it is noted that it is being considered as part of detailed design geotechnical investigations. The drawdown predictions developed as part of this impact assessment could be used to inform those investigations.

6 Impact assessment

6.1 Groundwater modelling

6.1.1 The need for groundwater modelling

A numerical groundwater flow model was developed to assess the following:

- Inflow in to the proposed tunnel and associated excavations, which would require either in-tunnel extraction or extraction from surrounding dewatering or depressurisation bores, and possibly treatment prior to discharge. Dewatering would be required during construction and throughout the operational life of the project
- Drawdown in groundwater levels around the tunnel, which may impact on existing groundwater users or GDEs
- Change in groundwater interaction with the nearby Parramatta River and tributaries, which may result in inflow of saline river water in to the aquifer.

6.1.2 Model objectives

Given the relative lack of long-term site-specific water level data, the potential for significant variability in the hydraulic properties along the tunnel alignment, and the lack of tested aquifer stress by groundwater extraction equivalent to the extraction likely from tunnel drainage, it is only appropriate to develop a class 1–2 model (Barnett, Townley, Post V, Evans, & Hunt, 2012), to provide an estimate inflow volumes, flow direction changes and groundwater level changes. It is expected that this model would be upgraded as site-specific data, including local transient water level and tunnel inflow data, become available during construction. To manage the uncertainty in model parameters, multiple models were run to assess the variability in results due to input parameters, primarily hydraulic conductivity.

6.1.3 Model design

The modelling scope was aimed at preparing a robust and well-documented model, suitable for use in the EIS stage of the project, and able to be modified for later use.

Modelling software

A three-dimensional groundwater flow model was constructed and run using MODFLOW, using the upstream weighted Newtonian solver. This combination is preferred as it provides a more stable solution in complex models and where cyclic drying and re-wetting of cells is required. The datasets were managed and the models run within the readily available, commercial graphical user interface Groundwater Modelling System 10 (64-bit). It does not rely on any additional scripts or macros not seamlessly included in the commercial modelling software used.

Model structure

Key geological boundaries from geotechnical investigations and registered water bores from the DPI Water database were collated and stored within the model and used along with more remote borehole and outcrop data to develop a three-dimensional model of the following broad stratigraphic horizons:

- Layer 1 – Surface soil, weathered zone and Quaternary alluvium
- Layer 2 – Ashfield Shale
- Layer 3 – Mittagong Formation
- Layers 4–6 – Hawkesbury Sandstone.

The Hawkesbury Sandstone was subdivided based on depth below the top of the formation, which controls the secondary permeability developed due to stress relief fracturing. The Hawkesbury Sandstone horizontal hydraulic conductivity was decreased and the vertical anisotropy increased with depth.

The model ground surface was developed from available digital elevation models. The surface extending below sea level, to the thalweg of the Parramatta River has been developed based on a thalweg elevation of between -10 and -20 metres AHD. It is critical to extend the model boundary below sea level to enable a realistic interaction with the submerged Hawkesbury Sandstone aquifer.

Assessment of varying model cell size with tunnel diameter (Zaidel, Markham, & Bleiker, 2010) showed that:

> *…using numerical cells exceeding the width/diameter of square-shaped shafts and tunnels by a factor of three results in a noticeable reduction of numerical errors compared with the finer grid spacings, especially with those that are close to the diameter of the simulated openings.*

Consequently, modelling of the tunnel should use cell widths of no greater than 10 metres or no less than 30 metres.

Initially an unstructured grid (MODFLOW USG) was used, however the model did not converge when running the drained tunnel simulations, hence a conventional refined grid was used (**Figure 6.1**), with a cell width across the tunnel of 10 metres (appearing as a solid colour in **Figure 6.1**) expanding out to a maximum grid spacing of 100 metres in outer parts of the model, maintaining a maximum aspect ratio of 10:1. Adjacent cell lateral dimensions change by no more than a factor of 1.5.

As the primary direction of steep hydraulic gradient was expected to be perpendicular to the tunnel axis, and expected to minimise the need for cell refinement, the grid axis was aligned along the main tunnel axis. Although this did not allow for regional hydraulic conductivity anisotropy the anisotropy was not high enough to have a significant effect on local tunnel drawdown, considering the much greater hydraulic conductivity contrast with depth.

Views of the overall model (**Figure 6.2**) and sections through (**Figure 6.3**) and across (**Figure 6.4**) the tunnel (**Figure 6.5**) are presented as follows.

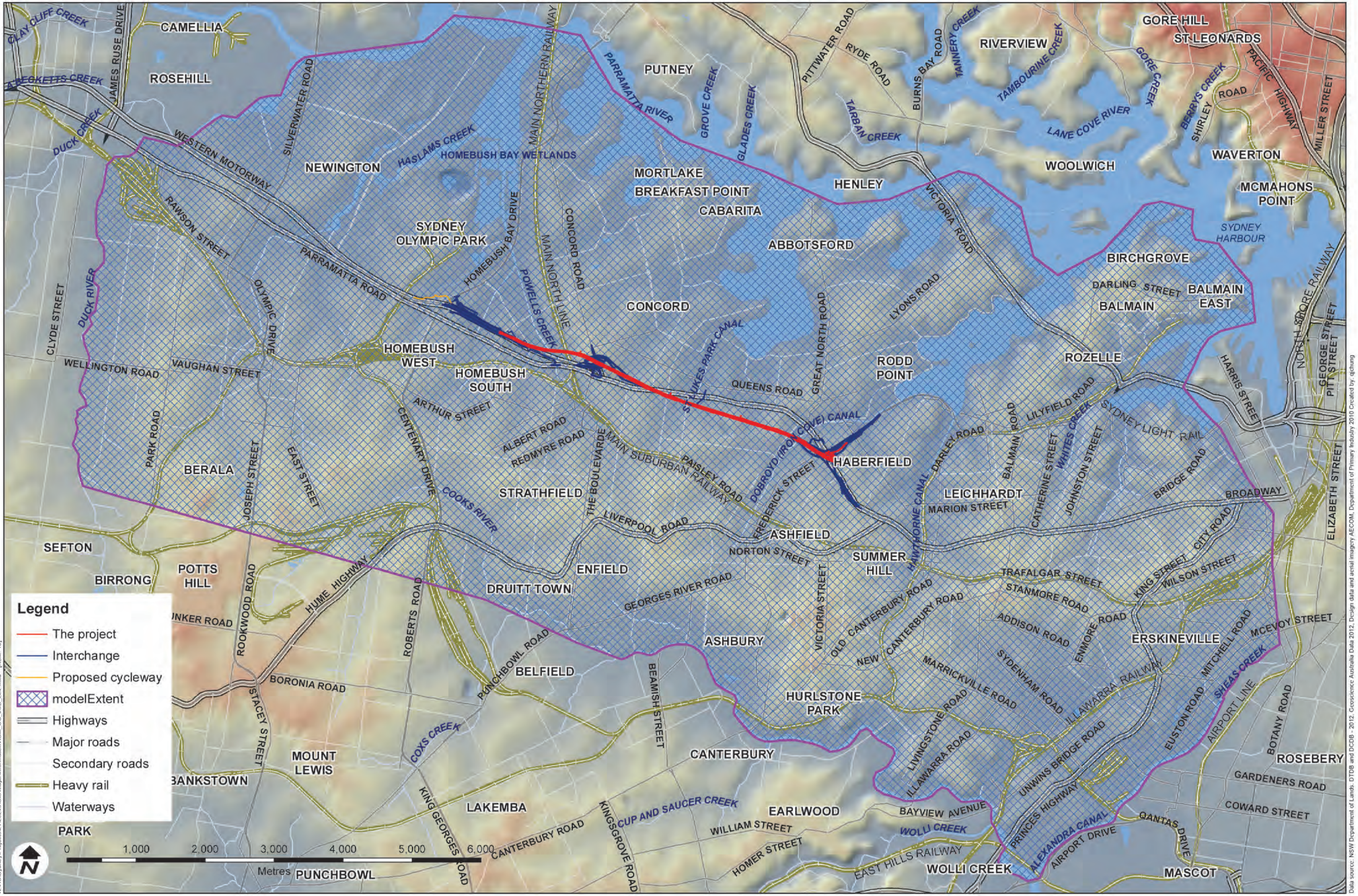

Figure 6.1 Model grid extent

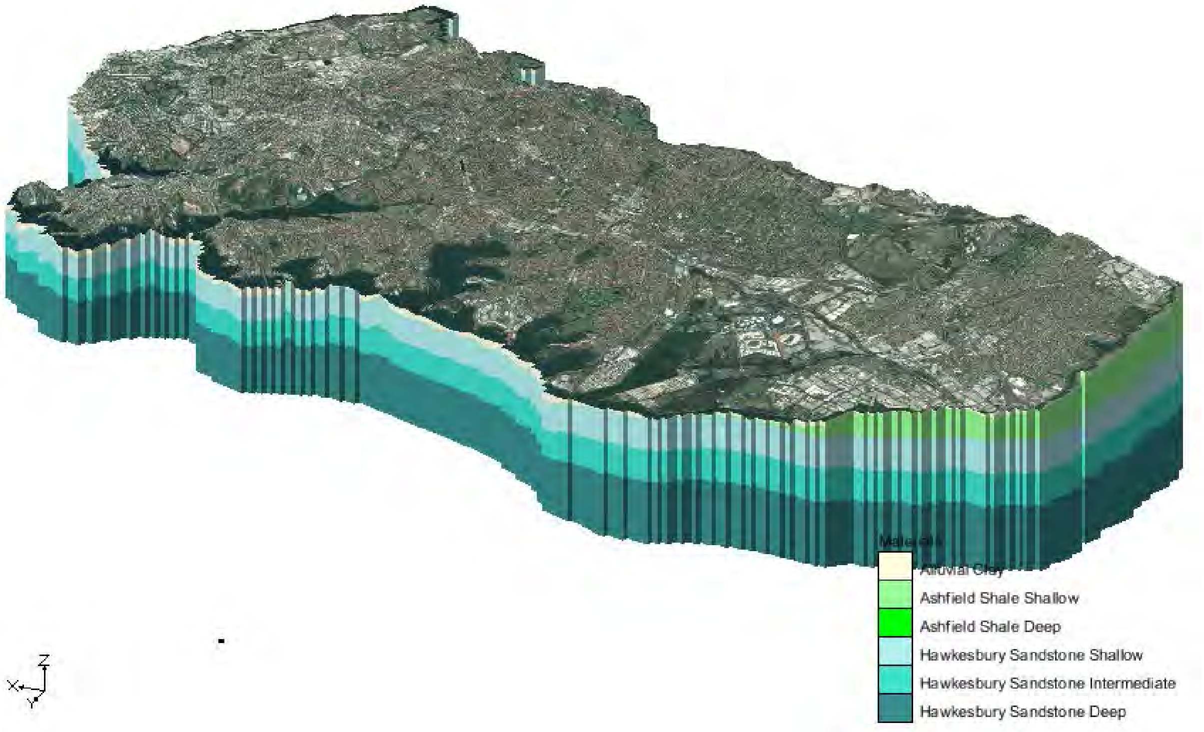

Figure 6.2 **Model orthorhombic view to southeast.**

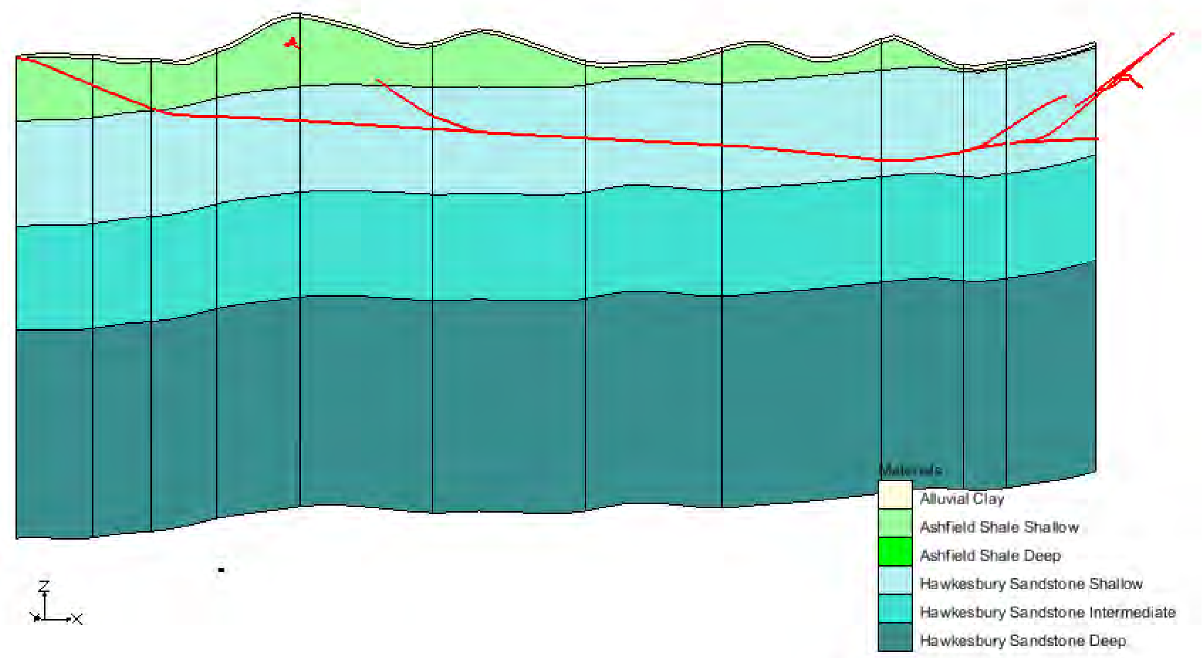

Figure 6.3 **Long section looking north.**

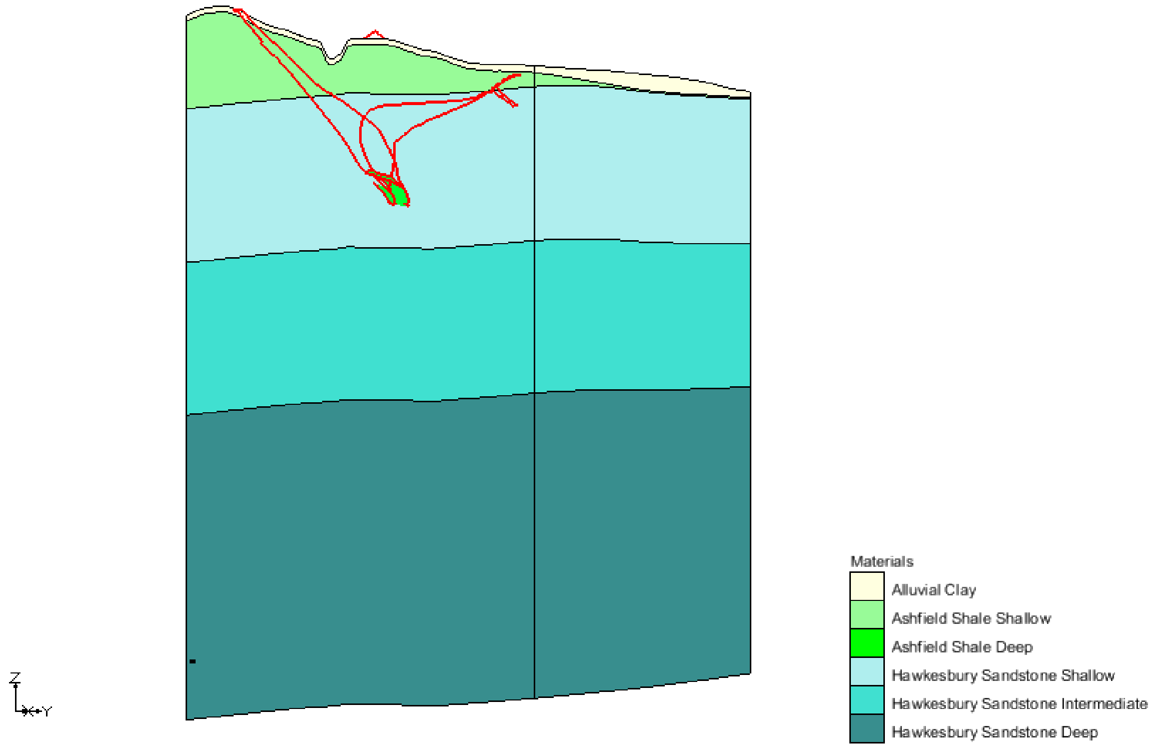

Figure 6.4 **Cross section looking west.**

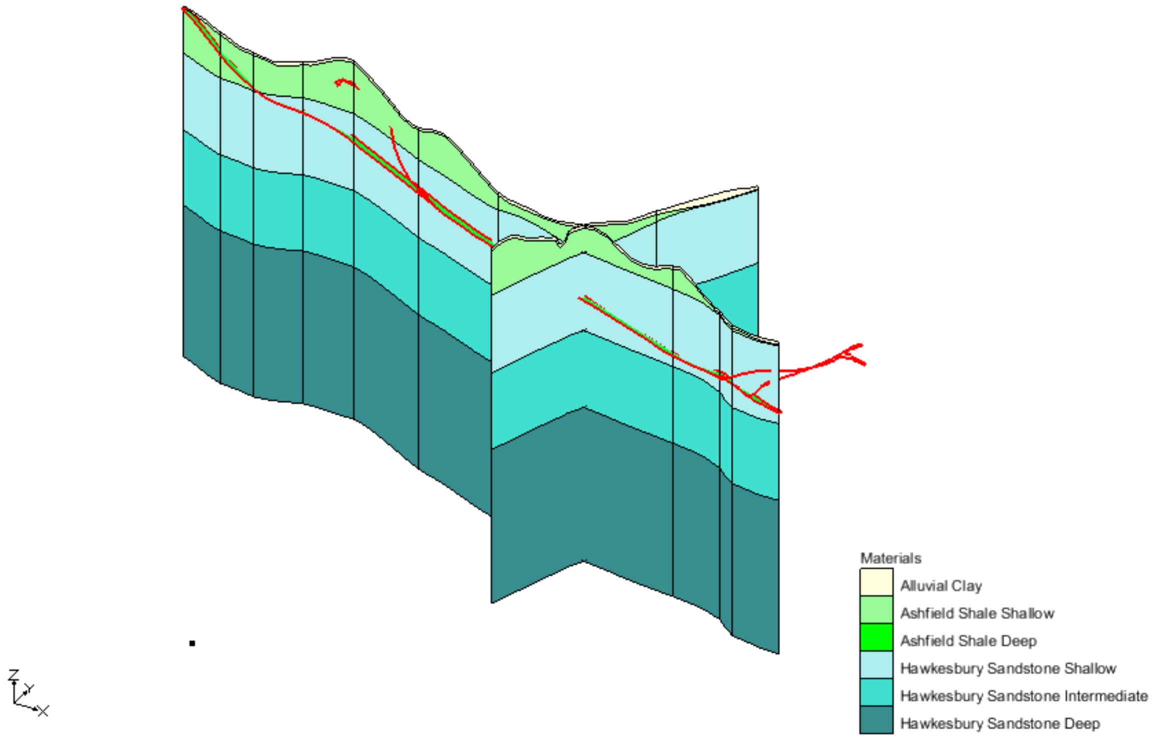

Figure 6.5 **Combined long- and cross-sections looking northwest.**

6.1.4 Adopted model initial parameters

Given the relative consistency between the data near the tunnel alignment with the regional data, the following hydraulic properties, shown in **Table 6.1** were considered to be generally representative of the material encountered around the proposed tunnel. These values do not allow for localised high permeability areas associated with major faults or igneous intrusions, but include a scale factor, (Tametta & Hewitt, 2004). The ‘lower’ value is approximately equivalent to the 10th percentile, ‘median’ the 50th percentile and ‘upper’ the 90th percentile of the log-transformed data reviewed (**section 5.6**) from the Ashfield Shale and Hawkesbury Sandstone, and typical values for alluvial clays and sands.

Table 6.1 Preliminary hydraulic conductivity values for the study area

Unit	Lower Kh (m/day)	Median Kh (m/day)	Upper Kh (m/day)	Vertical anisotropy (Kv/Kh)	Horizontal anisotropy (Kx/Ky) where x = 15o E	Specific yield (Sy)	Specific storage (Ss) per metre
Clayey alluvium and fill	0.001	0.01	0.1	10	1	0.2	1E-05
Ashfield Shale	0.0004	0.004	0.04	10	1	0.1	1E-05
Hawkesbury Sandstone <25 m depth and Mittagong Formation	0.005	0.05	0.5	10	1	0.1	1E-05
Hawkesbury Sandstone 25 m-50 m depth	0.001	0.01	0.1	100	1	0.1	1E-05
Hawkesbury Sandstone>50 m	0.0005	0.005	0.05	1000	1	0.1	1E-05

Model boundary conditions, sources and sinks

Model boundary conditions (**Figure 6.6**) were developed comprising:

- General head boundaries along the various tidal canals, Parramatta and Cooks Rivers and Sydney Harbour (shown in brown on **Figure 6.6**)
- Drain cells applied to the ground surface as a seepage face, with zero elevation offset, where groundwater discharges to surface and runs off when the water table reaches the surface but infiltration back in to the aquifer does not occur (shown in green on **Figure 6.6**)
- Drain cells representing the tunnel and approach ramps. Cells were mapped along the footprint of the main tunnel and entrance tunnels with a conductance value set above the equivalent aquifer hydraulic conductivity, to allow free drainage of the cells to the tunnel
- No-flow boundaries along likely regional flow lines or groundwater divides (southern and eastern boundaries)
- A general head boundary in the west in the Hawkesbury Sandstone, with heads based on estimated regional head values (shown in brown on **Figure 6.6**). Given the absence of measured heads in this area the level of 10 metres was selected, but it is sufficiently distant from the tunnel that it does not significantly impact results
- Steady-state recharge was applied at two different rates according to broad land use, topography and soil classifications as indicated by the polygons in **Figure 6.7**. The green areas represent moderately paved suburban sandstone areas expected to have relatively high recharge and the yellow areas represent either shale soils or highly paved industrial areas with expected low recharge.

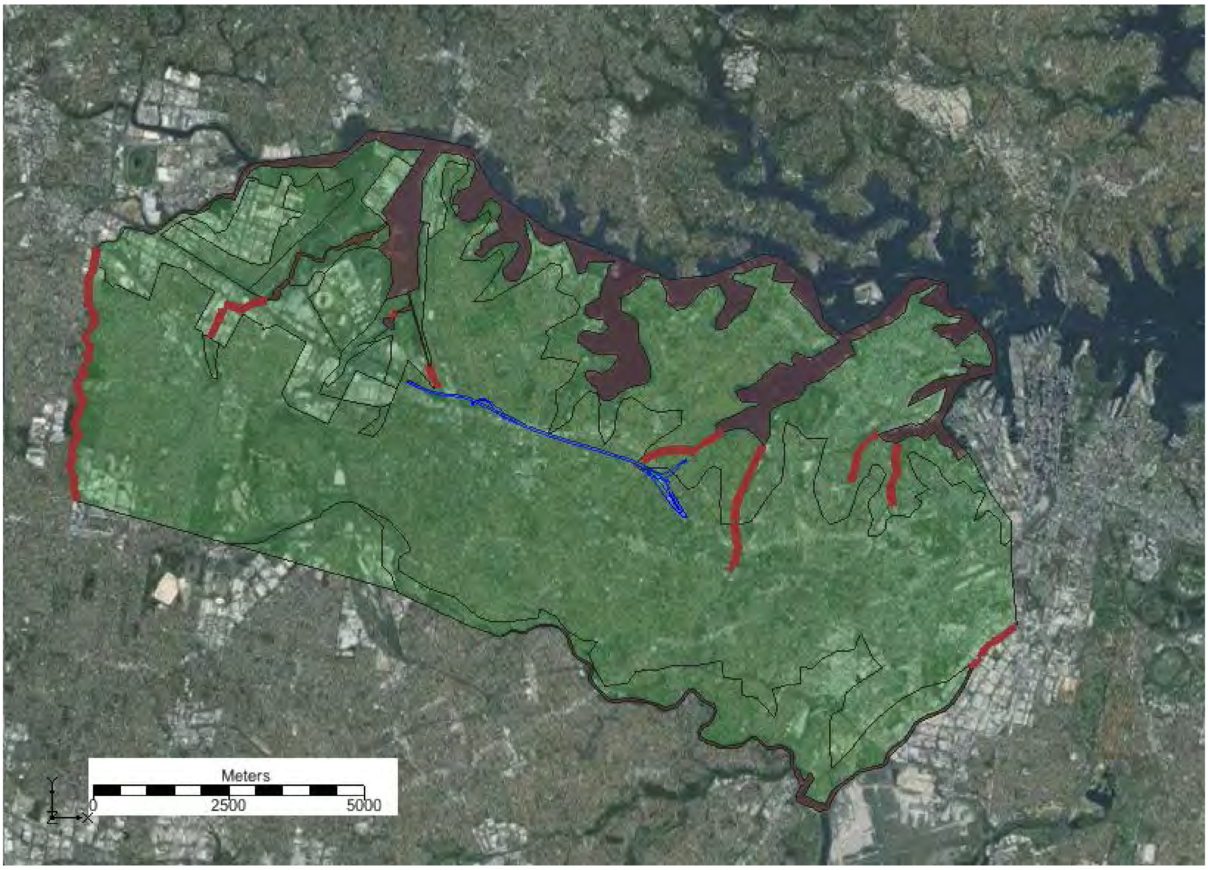

Figure 6.6 Key model boundary conditions.

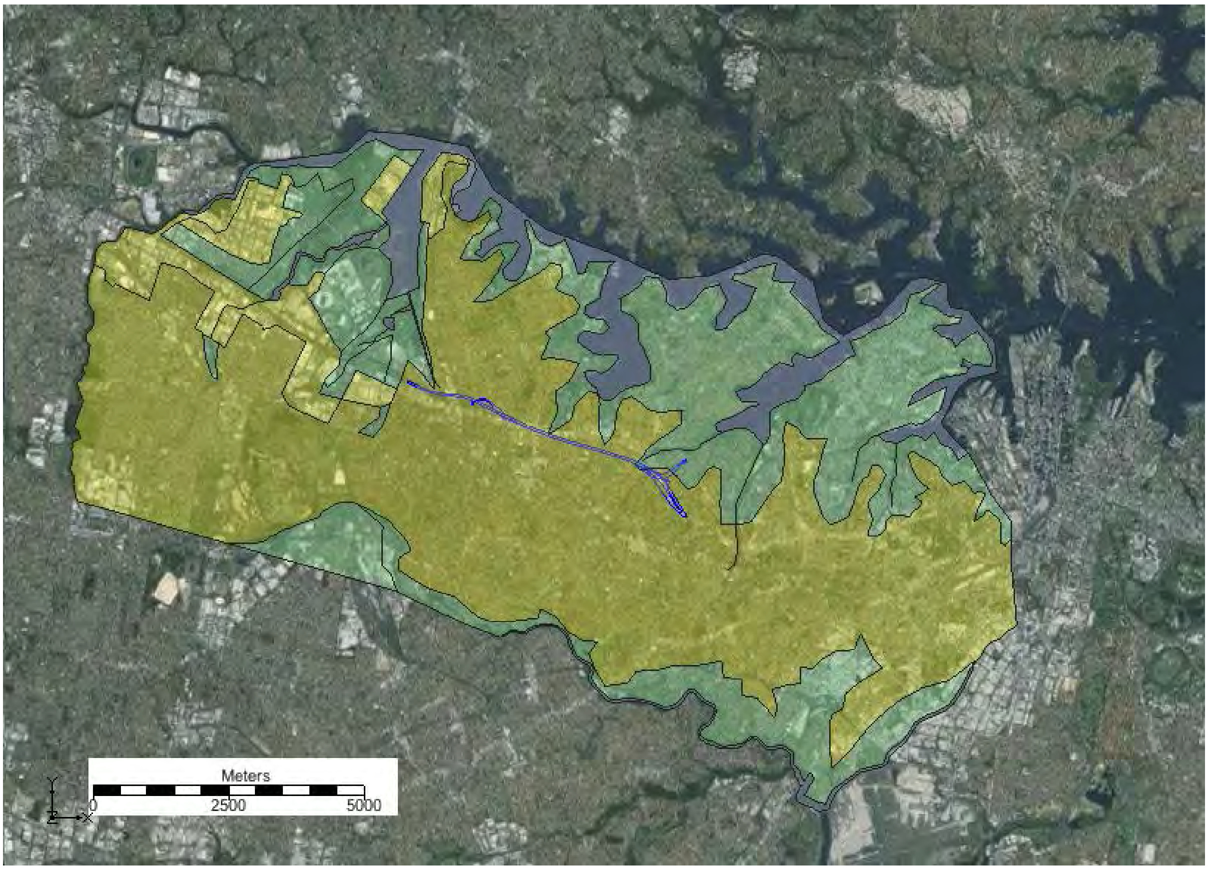

Figure 6.7 Model recharge zones.

6.2 Recharge estimates

McNally (2004) estimated recharge rates of one to two per cent of annual rainfall, based on the widespread salinity in the Wianamatta Shale. Values for the Ashfield Shale are probably similar to this value, based on the similar salinities.

The Geoscience Australia MAPCONNECT application provides an average shale area recharge estimate of 2.45 millimetres per year although estimates could be 0.05–16.39 millimetres per year depending on the groundwater salinity used. The average shale value is equivalent to about 0.2 per cent of rainfall.

Method of last resort recharge estimates on areas of Hawkesbury Sandstone outcrop Kandosols range from around 25–35 millimetres per year.

The recharge estimates above are for undeveloped areas, typically urban areas are halved due to a mixture of paving reducing impact and stormwater drain leakage promoting recharge. Some industrial areas are likely to have effectively nil recharge. The recharge rates used are discussed in **sections 6.2.1** and **6.2.2**.

6.2.1 Model calibration

Typically models are calibrated using all available water level and flow data, maintaining input parameters; and in this case recharge and hydraulic conductivity within the major geological units and land-use areas, within known bounds. If, however, calibration data are not evenly distributed over all geological and recharge zones, the resulting calibration can be biased towards achieving a good fit in one region at the expense of the others. This is a risk for the models in this report as the bulk of the water level data are within the shallow shales, but the critical impact from tunnelling is actually in the underlying sandstone. There are, however, abundant hydraulic conductivity data from local as well as regional testing.

To manage this discrepancy between calibration data density and the aquifer of interest, the model has been developed using three approaches:

- Calibration using all data
- Calibration using only sandstone data
- Stochastic predictive modelling using a distribution of likely hydraulic conductivity and recharge values, ignoring the calibration data.

Run 106 steady-state all piezometric data

After initial manual calibration and model checking, the model was automatically calibrated (run 106) using average groundwater levels from all 26 available piezometers, of which only four were within Hawkesbury Sandstone. This model required high recharge in shale areas, the lowest allowable sandstone hydraulic conductivity (**Table 6.2**) and what appear to be excessively high water levels in all layer areas beneath Ashfield Shale, with groundwater discharging to all low-lying areas (**Figure 6.3**), although water levels in layer 5 (**Figure 6.10**) were more consistent with the conceptual model. This suggests that the model was calibrating primarily to perched shale aquifer conditions and may not be ideal for assessing impacts in the tunnel area where disturbance is mostly within the sandstone. The figures show the calibration targets for each observation bore, green indicates a calibration residual of less than 2 metres, orange between two and four metres and red greater than four metres. The calibration plots and statistics (**Figure 6.11** and **Table 6.3**) indicate that the calibration is reasonable with a scaled root mean squared residual of 10 per cent. The calibrated recharge for general sandstone and alluvial areas was 2.00E-05 metres per day and the recharge for shale or industrial areas was 5.00E-05 metres per day.

Table 6.2 Run 106 calibrated parameters

Model layer	Material	Kh (m/day)
1	Alluvial clay	1.00E+00
2	Ashfield Shale shallow	1.08E-02
3	Hawkesbury Sandstone shallow	5.16E-03
4	Hawkesbury Sandstone intermediate	5.00E-03
5	Hawkesbury Sandstone intermediate	1.00E-03
6	Hawkesbury Sandstone deep	1.12E-03

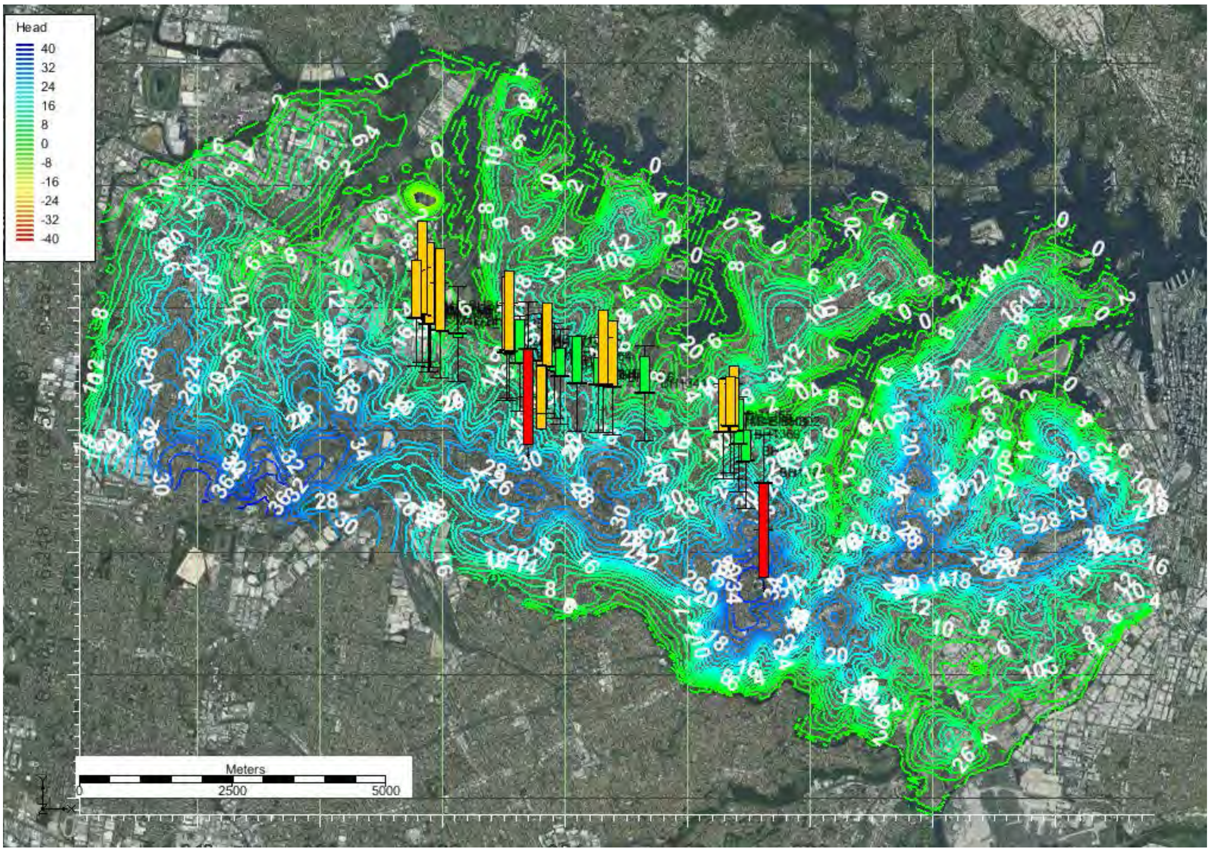

Figure 6.8 Run 106 layer 1 calibrated heads (metres AHD).