19 Groundwater

This chapter outlines the potential groundwater impacts associated with the New M5 Project (the project). A detailed groundwater assessment has been undertaken for the project and is included in **Appendix Q**.

Table 19-1 refers to the Secretary's Environmental Assessment Requirements (SEARs) as they relate to groundwater, and where in the environmental impact statement (EIS) these have been addressed.

Table 19-1 SEARs – groundwater

SEAR	Where addressed
An assessment of groundwater impacts (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. The assessment must consider:	**Chapter 19** (Groundwater)
• extent of drawdown;	**Section 19.3.2**
• impacts to groundwater quality;	**Section 19.3.6** **Section 19.4.2**
• volume of groundwater that will be taken (including inflows);	**Section 19.3.1**
• discharge requirements;	**Appendix N:** Technical Working Paper: Surface Water
• location and details of groundwater management and implications for groundwater dependent surface flows, groundwater-dependent ecosystems and groundwater users.	**Section 19.3** **Section 19.4** **Section 19.5**
The assessment must include details of proposed surface and groundwater monitoring and be prepared having consideration to the requirements of the NSW Aquifer Interference Policy;	**Section 19.5** **Chapter 16** (Soil and water)
An assessment of the potential intersection of contaminated bed sediments in the Alexandra Canal and interception of contaminated water from the Botany Sand Beds aquifer	**Chapter 18** (Contamination)

19.1 Assessment methodology

A groundwater assessment has been undertaken in relation to the existing environment to determine the potential impacts of the construction and operation of the project. A summary of the groundwater assessment is provided in this chapter. The full technical working paper is included in **Appendix Q**.

The assessment includes:

- Consideration of the existing environment that the project would interact with, including the hydrogeological conditions and environmental values of the surrounding environment
- An impact assessment, which characterises the impacts of the tunnel on groundwater dependent systems and surrounding environment using numerical modelling techniques
- Groundwater management and monitoring measures required to mitigate impacts and manage tunnel inflows.

The assessment has been undertaken with consideration of relevant legislation, policies, guidelines and water sharing plans as listed in **Table 19-2**.

Table 19-2 Relevant groundwater assessment guidelines

Policy/guidance	Relevance to project
Water Management Act 2000 (NSW)	The project would take groundwater as a consequence of the interception of the Hawkesbury Sandstone aquifer. Section 91F of the Act requires an aquifer interference approval when carrying out an aquifer interference activity. However, section 91F of the Act does not currently apply. As the project is classified as State Significant Infrastructure, Section 115ZG, Clause 1(g) states that authorisations under water use approval, water management approval or an activity approval (other than an aquifer interference approval) are not required.
NSW Aquifer Interference Policy (DPI, 2012)	The impact limits in terms of drawdown magnitudes and offset distances outlined in the NSW Aquifer Interference Policy have been considered in this assessment and inform the overall structure of the assessment.
Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011	The Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources covers 13 groundwater sources. The project lies within the Sydney Basin Central groundwater source area, which is a porous rock aquifer. Interference and extraction of groundwater typically requires a water access licence. While the project does not require an authorisation (as discussed above), an equivalent level of assessment has been carried out.
NSW State Groundwater Quantity Management Policy (NSW Office of Water, n.d.)	The requirements of this policy are met by the general assessment requirements in the Aquifer Interference Policy and Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources.
NSW Groundwater Quality Protection Policy (DLWC, 1998)	The requirements of this policy are considered through the identification of baseline conditions for the study area and assessment of potential changes to groundwater quality as a result of the project.
NSW State Groundwater Dependent Ecosystems Policy (DLWC, 2002)	This policy requires the assessment of changes in water levels and flows near identified groundwater dependent ecosystems (GDEs).
Risk assessment guidelines for groundwater dependent ecosystems (NSW Office of Water, 2012b)	Volume 1 of the guidelines provides general guiding material, while Volumes 2 through 4 relate specifically to coastal aquifers.
NSW Water Extraction Monitoring Policy (Department of Water and Energy, 2007)	Under this policy, all groundwater extraction during construction and operation of the project would need to be monitored. Typically this would involve metering of all flows in and out of the tunnel and using the difference to identify the groundwater inflow contribution.
Australian Drinking Water Guidelines (National Health and Medical Research Council, 2013)	Existing and potential groundwater quality has been compared against the guidelines to identify the highest and best use of the groundwater and to assess the risk to the public from incidental exposure to untreated groundwater intercepted by the tunnel.
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000)	The national guidelines provide default trigger values of various analytes that can be compared with sampled values from the project. From the assessment of these trigger values, site specific values have been provided for the project.
National Environment Protection (Assessment of Site Contamination) Measure 1999	This measure has been reviewed and considered as appropriate for this assessment.

Policy/guidance	Relevance to project
Health screening levels for petroleum hydrocarbons in soil and groundwater (Friebel, E. and Nadebaum, P, 2011)	This technical report provides the relevant health screening levels for the assessment of petroleum hydrocarbon contamination that could occur as a result of the construction and operation of the project.
Regional Screening Levels – Tapwater (United States Environmental Protection Agency, 2013)	This guideline has been reviewed and used for the assessment of drinking water.

19.1.1 Study area

For the purposes of the groundwater impact assessment, the study area was defined by the alignment of the project with a buffer of one kilometre.

19.1.2 Desktop review

Searches were conducted across a range of databases between April 2015 and June 2015 to assist in developing an understanding of the existing environment. The purpose of the searches was to review existing hydrogeological data including geology, groundwater levels, groundwater quality, groundwater users, GDEs, acid sulphate soils and climate. The data collation included extraction from the following databases:

- Bureau of Meteorology 2015 Australian Groundwater Explorer (formerly NSW Office of Water groundwater database) and Pinneena Groundwater Database, version 10.1, dated October 2014
- Regional geology along the project corridor, as described in the Geological Survey of NSW 1:100,000 scale Sydney Map Sheet (sheet 9130, 1983)
- Australian Soils Resource Information System
- Appendix 4 of the *Greater Metropolitan Regional Groundwater Sources Water Sharing Plan 2011*
- Bureau of Meteorology 2015 On-line climate data.

Groundwater data have also been drawn from other groundwater investigations of major developments in the area including the M5 East development (1998-2001), the New Southern Railway project (1995-2000) and the Alexandria Landfill monitoring program (1997 – ongoing). The Alexandria Landfill is described in **Section 19.2.1**. Details of data sources are provided in the technical working paper: Groundwater (**Appendix Q**).

Groundwater investigations, including drilling boreholes, packer tests, groundwater gauging, ground water sampling and hydrogeochemical analysis were conducted across the study area between September 2014 and March 2015. Selected boreholes were chosen from the investigations in order to collect baseline data for the groundwater assessment. The locations of the boreholes within the groundwater monitoring network are shown in **Figure 19-1**.

Groundwater data collected included:

- Hydraulic conductivity (the rate at which groundwater naturally moves through the rock or sediments) determined through packer tests. Packer tests (in-situ water pressure tests) are conducted during the drilling program by injecting water under various pressures into the local geology. The measured amount of water is proportional to the hydraulic conductivity of the geological sequence that was injected.
- Groundwater levels (including fluctuations), determined through groundwater gauging and data loggers
- Groundwater quality, determined through hydrogeochemical sampling and analysis.

19.1.3 Hydraulic conductivity

Hydraulic conductivity is a fundamental aquifer property that assists in understanding the tunnel water inflows or the local drawdown that may be imposed on the local hydrogeological regime. Hydraulic conductivity is measured in metres per day and is a calculation of how easily groundwater flows through a porous medium (soil matrix or rock mass) under natural conditions. The higher the value of hydraulic conductivity, the greater the movement of groundwater expected (including into unsealed underground structures such as road tunnels).

During the drilling program packer tests were conducted to measure the hydraulic conductivity of selected rock mass intervals. Packer tests (or water pressure tests) involve injecting water under pressure into an isolated rock mass interval and measuring the water ingress over a given time period. The amount of water injected is proportional to the hydraulic conductivity.

The packer test results provide a bulk hydraulic conductivity for the intervals measured including horizontal and vertical features and the rock matrix.

Packer testing was undertaken along the project alignment by conducting 158 packer tests in 35 boreholes to assess the bulk hydraulic conductivity range within the Hawkesbury Sandstone and Ashfield Shale as shown in **Figure 19-2**. Up to seven tests were performed in each borehole. The packer tests provided an indication of the ability of the local geology to allow groundwater movement and informed the hydrogeological model prepared for the study area. Further detail on Packer testing is provided in **Appendix Q**.

19.1.4 Groundwater levels

A groundwater monitoring network was established as part of the WestConnex hydrogeological investigations (AECOM, 2015j). A total of 28 monitoring wells were constructed at selected locations along the project alignment between October 2014 and March 2015. The monitoring well locations were chosen to provide a representative spread along the proposed tunnel alignment in representative lithologies (refer to **Figure 19-1**).

The majority of monitoring wells targeted the Hawkesbury Sandstone (21 of the 28 wells) since most of the project tunnels would be constructed within the competent sandstone unit. Five wells targeted the Ashfield Shale, one targeted alluvial and estuarine sediments, and one targeted a Basalt dyke.

Groundwater levels were measured periodically with an electronic dip meter and automatically on a two hour interval with data loggers. The outcomes of the groundwater level monitoring program are outlined in **Appendix Q**.

19.1.5 Groundwater quality

Groundwater was sampled and analysed to characterise the local groundwater quality of each of the main hydrogeological units; specifically to identify any spatial variability, and to identify potential groundwater contamination. Fourteen monitoring wells were selected from the groundwater monitoring network between October 2014 and March 2015 to obtain representative groundwater samples along the alignment within the Hawkesbury Sandstone and Ashfield Shale.

The key groundwater quality guideline adopted for the establishment of groundwater criteria is the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000). Given the degraded nature of the receiving waters in Alexandra Canal and Cooks River, the 90 per cent level of protection has been adopted.

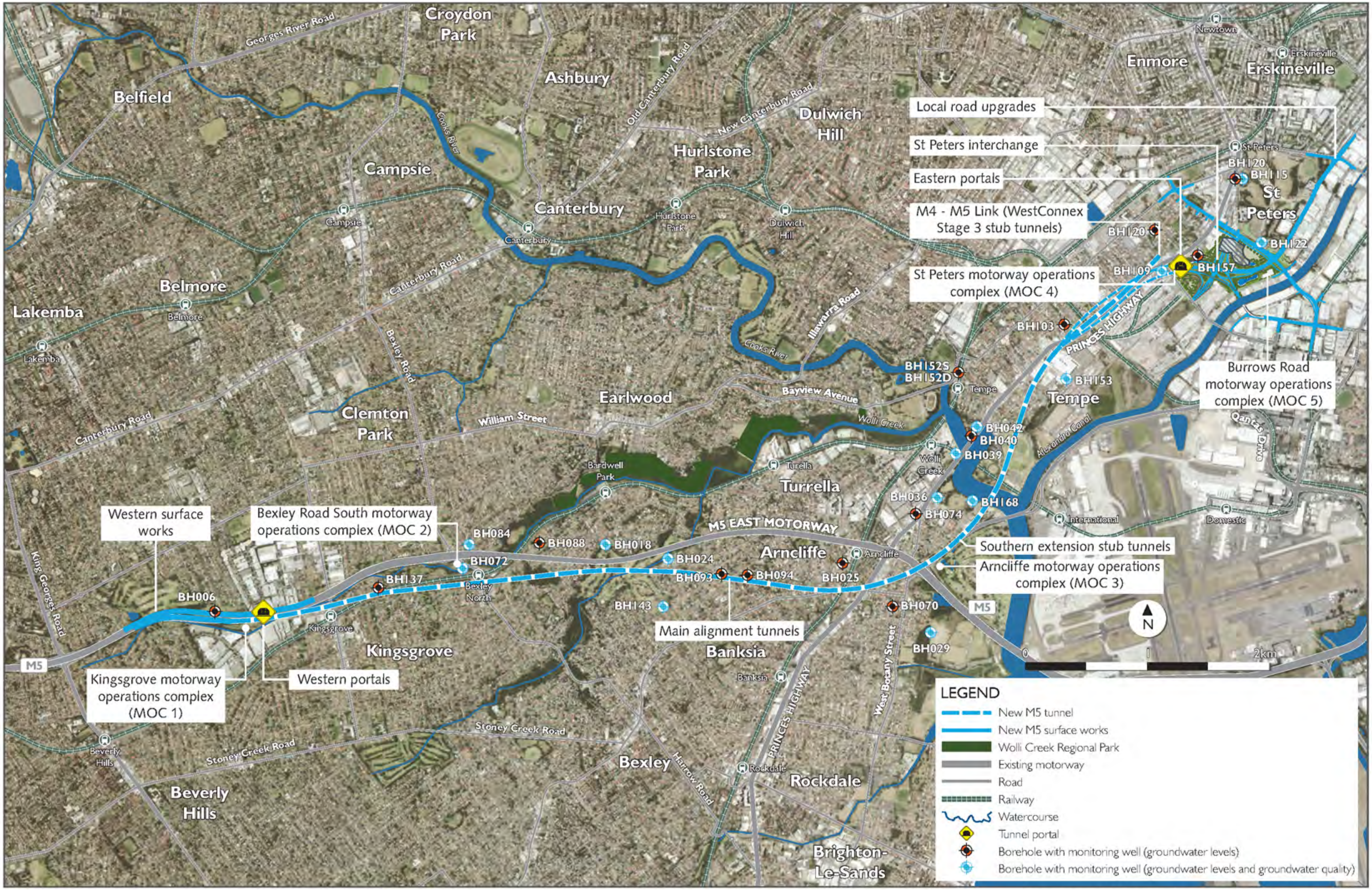

Figure 19-1 Groundwater monitoring network

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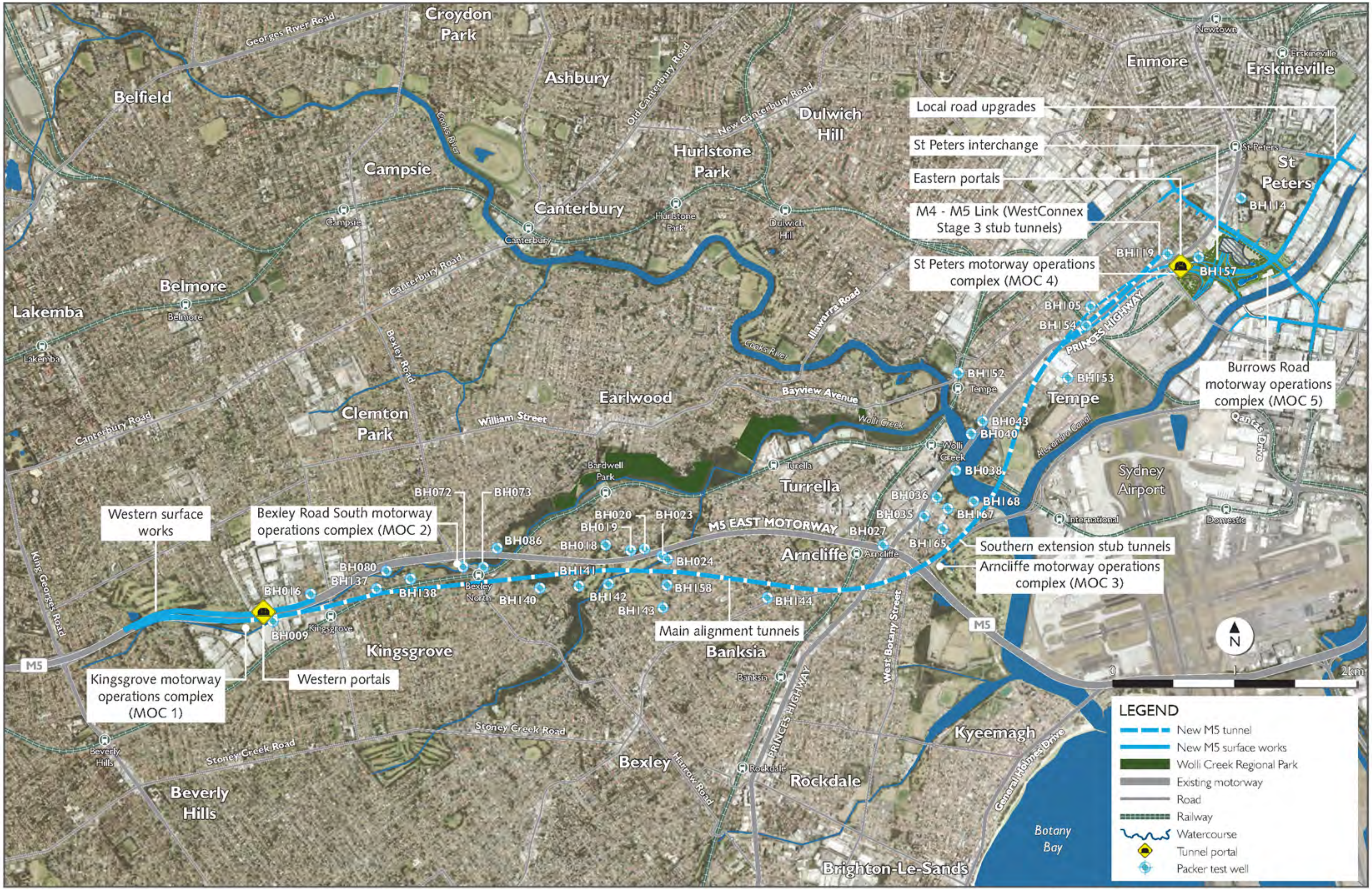

Figure 19-2 Packer test borehole locations

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Collected groundwater samples were transported to an external National Association of Testing Authorities (NATA) accredited laboratory for testing and analysis. Groundwater quality samples were tested for:

- Heavy metals and metalloids (including arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel and zinc)
- Benzene, toluene, ethylbenzene, xylene and naphthalene (BTEXN)
- Total recoverable hydrocarbons (TRH)
- Polycyclic aromatic hydrocarbons (PAHs)
- Inorganics (including major anions and cations, alkalinity, ammonia, electrical conductivity, ionic balance, total dissolved solids, pH and hardness)
- Organochlorine pesticides (OCPs)
- Organophosphate pesticides (OPPs)
- Semi volatile organic hydrocarbons (SVOCs)
- Volatile organic compounds (VOCs).

Field parameters tested were:

- Dissolved oxygen
- Electrical conductivity
- pH
- Temperature
- Redox conditions.

19.1.6 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems (GDEs) are communities of plants, animals and other organisms whose extent and life processes are dependent on groundwater, such as wetlands and vegetation on coastal sand dunes.

Sources reviewed to understand potential GDEs potentially impacted by the project include:

- *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources* (NOW, 2011)
- Bureau of Meteorology Atlas of Groundwater Dependent Ecosystems (BOM)
- Threatened species database (OEH).

19.1.7 Ground settlement

Two types of ground settlement have been considered:

- Settlement due to volume loss during tunnel excavation
- Settlement due to groundwater drawdown and subsequent ground settlement.

A well-established empirical method (Burland et al, 1977, Boscardin and Cording, 1989) was used to predict ground movement due to ground volume loss during excavation.

The estimated volume loss during excavation is dependent on the type of material being excavated as well as the excavation method. Parameters are selected to estimate the magnitude of the settlement as well as the shape and extent of the settlement trough. Initial values were chosen based on past experience and back-analysed parameters from previous projects.

The results obtained from the initial empirical analysis were validated against those obtained from numerical models carried out at typical sections. The initial empirical parameters were refined such that the results of each method were comparable and the final parameters adopted for the remainder of the tunnel alignment.

The parameters adopted for the project tunnels are provided in **Table 19-3**:

Table 19-3 Ground loss settlement parameters

Excavation type	Volume loss	Trough width parameter (k)
Driven tunnel in sandstone	0.3%	0.5
Driven tunnel in shale	0.3%	0.5
Soft ground support	0.5%	0.5
Southern Connector cavern	0.45%	0.45
St Peters Interchange cavern	0.65%	0.55
President Avenue ramps cavern	0.45%	0.45

An assessment of potential damage to nearby buildings and utilities was carried out by identifying critical zones based on the types of structures within the study area as well as the maximum predicted settlement.

Within the critical zones, those buildings representative of others in the area, or buildings that appeared prone to ground settlement, were selected for detailed analysis. Similarly, a representative sample of utilities and other infrastructure crossing the project tunnel alignments was also selected for detailed assessment including:

- General routes with a high concentration of services, usually following major roads
- Specific services such as electricity cables, sewers, water pipelines and gas mains where these are not located in the general routes above
- Railway lines, concrete drainage channels and the M5 East Motorway.

In the detailed assessment, the total combined horizontal and vertical ground movement as well as angular distortion within the structure were determined. The acceptance criteria for each type of structure are outlined in **Table 19-4**.

Table 19-4 Acceptance criteria by structure type

Type of structure	Maximum total settlement (millimetres)	Angular distortion (Maximum slope)
Low rise and non-sensitive buildings	< 30	< 1:350
High rise, sensitive or heritage buildings	< 20	< 1:500
Roads	< 40	< 1:250
Utilities	< 40	< 1:250
Railways	< 20	< 1:1000
Tunnels	< 20	< 1:1000

In the case of buildings, the strain calculated within the building was also used to allocate a damage category. The criteria used in allocating each damage category are outlined in **Table 19-5**.

Damage categories of 'negligible' to 'slight' are considered acceptable as they represent potential aesthetic damage only. The 'moderate' to 'very severe' categories are related to serviceability and stability damage and are therefore not acceptable.

The assumptions included in the settlement assessment include:

- Use of the empirical method developed by John Burland et al 1997 and Boscardin and Cording, 1989
- Case studies of tunnel settlement from previous tunnel projects in Sydney NSW.

Table 19-5 Damage category strain limits

Damage category [1]	Description [1]	Tensile strain limits (%) [2]
Negligible (damage unlikely but possible)	Hairline cracks	0 to 0.05
Very Slight	Fine cracks that are easily treated during normal decoration. Damage generally restricted to internal wall finishes. Cracks may be visible on external brickwork or masonry.	0.05 to 0.075
Slight	Cracks easily filled. Redecoration probably required. Recurrent cracks can be masked by suitable linings. Cracks may be visible externally and some repointing may be required to ensure weather tightness. Doors and windows may stick slightly.	0.075 to 0.15
Moderate	The cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and window sticking. Service pipes may fracture. Weather-tightness often impaired.	0.15 to 0.30
Severe to Very Severe	Extensive repair work involving break-out and replacing sections of walls, especially over doors and windows. Windows and door frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably; some loss of bearing in beams. Utilities disrupted.	> 0.30

1. Burland J B, Broms B B and de Mello V F B (1977).

2. Boscardin M D and Cording J (1989).

19.1.8 Groundwater modelling

A three dimensional numerical groundwater model has been developed to simulate existing groundwater conditions (CDM Smith, 2015). By simulating the project tunnel alignments the groundwater model has also been used to predict future groundwater conditions and potential project impacts.

The model has been developed in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al, 2012). The model development broadly followed the methodology outlined below:

- Review of appropriate modelling platforms to best suit the required predictive modelling along a linear feature
- Desktop review of relevant geological and hydrogeological reports within the Sydney Basin
- Desktop review of recent tunnelling projects within the Sydney region
- Collation of data and analysis of aquifer parameters
- Development of a modelling plan
- Development of a hydrogeological conceptual model
- Model development including setting model boundaries, model layers, model discretisation and modules to simulate surface water bodies and the interaction with groundwater
- Model calibration
- Sensitivity analysis
- Model predictions.

The numerical groundwater model was developed using MODFLOW-USG (2012). This version of MODFLOW was selected as it allows local grid refinement and is suited to simulating linear features (such as road tunnels).

The model was developed in steady state conditions rather than transient analysis. As a result the predictions of inflows and drawdowns are those that will apply in the long term, after equilibrium has been established. It is not known how long it will take for steady state conditions to be established.

The steady state inflows are likely to be lower than inflows during construction and the early years of operation. Conversely, the steady state predicted drawdowns are likely to be greater than those that occur during construction and the early years of operation. Predicted drawdown impacts are therefore likely to be "worst-case" impacts, but predicted inflows are likely to be "best case". As a consequence, predicted impacts on ecosystems and existing users are worst case long term impacts, and are likely to be greater than those that apply in the short term.

Further details on the method used for the groundwater modelling is provided in the Technical working paper: Groundwater (**Appendix Q**).

19.2 Existing environment

The existing environment has been characterised based on existing information and investigation data collected for the project, including:

- Topography and drainage
- Geological setting
- Hydrogeological setting, including groundwater levels and hydraulic conductivity
- Groundwater quality
- Groundwater users
- GDEs.

19.2.1 Topography and drainage

The project corridor extends from Beverly Hills, east beneath Arncliffe to St Peters. The western portion of the project corridor is relatively flat, low lying, with gentle undulating hills ranging between 30 metres Australian height datum (AHD) and 40 metres AHD, characteristic of Ashfield Shale type terrain. The topographically highest section of the project corridor is through the Bexley North and Bardwell Park areas at elevations of between 40 metres AHD to 50 metres AHD.

Wolli Creek and its southern tributary, Bardwell Creek have incised gullies through a subterranean (under the surface) sandstone and shale plateau. This plateau is higher in elevation by approximately 20 to 30 metres than other parts of the Sydney basin. Wolli Creek flows east to join the Cooks River. The Wolli Creek and Cooks River valleys widen as they approach Botany Bay and the incised valley floors have been filled with alluvial sediment to create relatively flat alluvial plains. The Wolli Creek and Cooks River channels have been modified over much of their length to improve drainage and control flooding.

The topography of the project corridor near the confluence of Wolli Creek and the Cooks River is relatively flat and low-lying (around five metres AHD to 10 metres AHD), and gradually declining towards Botany Bay. Land within and adjoining the central and north-eastern areas of the project corridor have been substantially modified over time due to land reclamation and industrial activities. The Botany Sands are present in the vicinity of Alexandra Canal.

The Alexandria Landfill is at the eastern extent of the project corridor and has been infilled by waste as part of historic landfill operations. Former brick pits beneath nearby Sydney Park in St Peters have also been infilled and re-contoured forming an irregular, man-made landform varying in elevation from 5 metres AHD to 25 metres AHD.

19.2.2 Alexandria Landfill

The Alexandria Landfill is a former quarry where weathered shale and clay was excavated for brickmaking. The landfill located at 10-16 Albert Road, St Peters extends over 15.7 hectares and is excavated to a maximum base level of around minus 31 metres AHD. The former quarry has operated as a landfill since 1988 and ceased receiving waste in late 2014. Leachate is generated on site and is collected and treated through an existing onsite leachate management system prior to off-site discharge to sewer (in accordance with the requirements outlined in the existing trade waste agreement, including testing for compliance with the environment protection licence). Leachate is generated primarily from surface water infiltration and groundwater inflow.

Surface water accumulating within the operational areas in the eastern portion of Alexandria Landfill drains to stormwater drains (with sediment control). Surface water that accumulates within the active filling area of the Alexandria Landfill collects in the leachate pond which is transferred to the leachate treatment system and is subsequently discharged to the trade waste system (sewer). Between 100,000 litres to 180,000 litres of leachate are pumped daily from the internal leachate collection system prior to environment protection licence compliance testing and disposal to sewer. Areas of the Alexandria Landfill that have been capped discharge to the stormwater system to nearby Alexandra Canal.

Groundwater flows from the Botany Sands and Ashfield Shale into the former landfill. The leachate pumping system artificially lowers the groundwater levels within the fill and Ashfield Shale and causes radial drainage centred on the leachate pump. The radial flow ensures leachate does not migrate off-site.

19.2.3 Geological setting

Regionally, the study area is located within the Permo-Triassic Sydney Basin that is characterised by sub-horizontal lying sediments of mainly sandstone and shale. To the east, the unconsolidated Quaternary aged Botany Sands overlap the basin and unconformably overlie the bedrock.

The main stratigraphic units that are expected to be encountered would comprise of the following from youngest to oldest (i.e. ground surface and down):

- Anthropogenic fill
- Quaternary Alluvium (recent beneath rivers, palaeochannels and Botany Sands)
- Jurassic Intrusions (volcanic)
- Triassic Ashfield Shale (Wianamatta Group)
- Triassic Mittagong Formation
- Triassic Hawkesbury Sandstone Formation.

Further detail on the stratigraphic units including weathering profiles and implications for hydraulic conductivity is provided in **Appendix Q**.

19.2.4 Hydrogeological setting

Across the study area the groundwater is typically a subdued reflection of the topography, with the groundwater level being deeper beneath hills and shallowest beneath creeks and gullies. Groundwater along the project alignment is recharged by rainfall runoff and infiltration.

Groundwater is present within the following hydrogeological units:

- Quaternary Alluvium
- Botany Sands Aquifer
- Palaeochannels
- Ashfield Shale
- Hawkesbury Sandstone.

Quaternary Alluvium

Quaternary alluvium (consisting of sand, silt, clay, gravels and some peat with a basal clay) underlies and flanks the Cooks River and its tributaries forming an aquifer. The depth is variable ranging from a thin surficial veneer up to 50 metres depth within the palaeochannels.

Groundwater is also present within localised alluvium in some gullies. Groundwater quality within the alluvium is variable ranging from low salinity in the upper reaches and becoming more saline and brackish in the lower reaches due to tidal influences and mixing.

The alluvium is generally of high hydraulic conductivity and the groundwater within the alluvium provides recharge to the underlying shale and sandstone via leakage. In the eastern part of the alignment the Quaternary alluvium flanks the Botany Sands. These two hydrogeological units are hydraulically connected.

The palaeochannels that occur beneath some of the major creeks or valleys extend to depths of up to 50 metres and are saturated. These palaeochannels are infilled with up to 50 metres of saturated sediments comprised of alluvium, estuarine and marine deposits.

Groundwater quality within the palaeochannels is typically saline due to recharge from the Ashfield Shale and leakage from tidally flushed rivers and tributaries. The alluvium infilling the palaeochannels is highly transmissive due to the coarse clean sands and gravels present (Parsons Brinckerhoff, 2010).

Fill is common along the project alignment ranging from shallow fill associated with landscaping to more extensive fill imported for the construction of buildings. More substantial filling has occurred along low lying areas such as reclamation works associated with the Cooks River and Alexandra Canal, Tempe Recreational Reserve, Kogarah Golf Course and Sydney Airport.

Perched groundwater is present within the fill at various locations along the alignment. The most substantial fill deposits are at the Alexandria Landfill have been infilled with uncontrolled fill to depths of 35 metres to 40 metres.

Botany Sands aquifer

The Botany Sands aquifer is a shallow, unconfined aquifer with a high hydraulic conductivity consisting of clay, silt and medium grained sand. The thickness of the unit is variable but is approximately ten metres thick at Alexandra Landfill and up to 15 metres thick at Kogarah Golf Course.

Groundwater levels are variable but under natural conditions are typically within five metres of the ground surface. Rainfall, tidal fluctuations and seasonal variations can result in temporal changes in the groundwater levels. Regionally groundwater flow is eastward discharging into Botany Bay and Alexandra Canal. The groundwater level can be influenced by other local factors such as distance from recharge and discharge areas, local development and dewatering.

The Botany Sands aquifer naturally contains low salinity groundwater which is moderately acidic. However, in many areas it has been contaminated by industrial activities, most notably in the southern portion of the aquifer near the Botany Industrial Park where groundwater use has been embargoed due to contamination. .

Variations in the groundwater quality in the Botany Sands aquifer can be attributed to a number of factors including:

- Proximity to recharge
- Presence of ponds and other wetlands (either enhanced recharge or enhanced evaporation loss)
- Localised recharge by infiltration of rainfall
- Presence of peaty sediments (elevated sulphide concentrations)
- Local seawater intrusion
- Industrial development (variety of chemical compounds)

- Application of fertilisers
- Leakage from sewage systems or petrol stations.

At the southern perimeter of the Alexandria Landfill, groundwater within the Botany Sands would have naturally flowed to the south discharging into Alexandra Canal.

Development of the quarry and later the landfill has created a sump locally reversing groundwater flow conditions within the Botany Sands. Groundwater levels within the Botany Sands between the landfill and Alexandra Canal range from minus two metres AHD to one metre AHD and are influenced locally by two groundwater extraction schemes, the landfill's leachate pumping system and discharge to the landfill and Alexandra Canal.

A groundwater divide has been inferred within the Botany Sands between the landfill and Alexandra Canal (Woodward Clyde, 1998). Groundwater to the north of the divide flows towards the landfill and groundwater to the south of the divide flows towards the canal. The presence of a groundwater divide indicates there is no groundwater flow between the landfill and Alexandra Canal. The findings of the groundwater investigations conducted as part of this groundwater impact assessment are consistent with the conclusions of Woodward Clyde. The local hydrogeological regime at Alexandria Landfill is discussed further in **Appendix Q**.

At Alexandria Landfill, groundwater flow from the Botany Sands into the landfill increases leachate generation. As part of the closure and ongoing management of the Alexandria Landfill site, it is proposed to engineer a solution by the construction of a cut-off wall to significantly reduce groundwater inflow and hence leachate generation. The cut-off wall has been designed to be around 1000 metres in length, with a thickness of 0.8 metres and hydraulic conductivity of 10^{-8} metres per second.

The Botany Sands aquifer is used beneficially for a number of purposes including irrigation, watering market gardens and domestic use. Groundwater is typically extracted from shallow spear points via vacuum extraction systems at groundwater yields typically up to two litres per second.

The NSW DPI Water advises that the whole Botany Sands hydrogeological unit is over allocated and to extract groundwater a water allocation must be bought on the open market.

Kogarah Golf Course is also underlain by the Botany Sands where ventilation shafts and tunnel ramps are to be constructed as part of the project.

Palaeochannels

Palaeochannels are ancient rivers that have subsequently become infilled with sediments. Deep incised palaeochannels have been carved into the sandstone and shale bedrock that underlie the study area and form deep drainage systems. In many cases they underlie the existing river systems such as Cooks River and Wolli Creek but also underlie Botany Sands and are independent of the current surface drainage systems such as the Arncliffe Station Palaeochannel.

The palaeochannels are of Pleistocene age and are older than the overlying Botany Sands. These palaeochannels are infilled with up to 50 metres of saturated heterogeneous sediments comprising alluvium, estuarine and marine deposits. The palaeochannels typically underlie alluvium associated with modern rivers or gullies and drain to the east towards Botany Bay. The sediments have a high hydraulic conductivity and water quality is variable but is typically saline.

Ashfield Shale

The Ashfield Shale caps ridgelines over the majority of the alignment outcropping west and north of Sydney Airport with the shale extending to a depth of up to 50 metres. The shale is a marine deposited sequence consisting of fine grained particles including clay, silt and sand that has undergone minor deformation and has developed into a laminated shale. The thickness of the shale is not well understood due to limited drilling data intersecting the shale. In general the shale can vary from a few metres thick to in excess of 50 metres.

Groundwater flow within the Ashfield Shale is poor due to the limited pore space (low porosity) and poor connectivity of the bedding planes. The majority of groundwater flow is via saturated fractures and joints with limited flow being via the rock matrix. The bulk hydraulic conductivity is typically low due to the poor connectivity of joints, fractures and bedding planes.

Regionally, the Ashfield Shale forms an aquitard reducing groundwater infiltration to the underlying Mittagong and Hawkesbury Sandstone Formations. Groundwater quality within the shale is highly variable but is typically brackish or saline, due to the marine salts contained within the shale.

The shale aquifer is characterised by low yields, limited storage and poor groundwater quality. Salinities typically range from 5,000 mg/L to 12,000 mg/L total dissolved solids (TDS) but may be up to 40,000 mg/L causing the groundwater to be corrosive to building materials.

Hawkesbury Sandstone

The Hawkesbury Sandstone is the dominant lithology across the project area and the majority of the project tunnels would be constructed through this competent sandstone. Lithologically the Hawkesbury Sandstone is described as a medium to coarse grained quartzose sandstone. The formation extends across the whole Sydney Basin and is up to 290 metres thick. The deepest boreholes drilled as part of this investigation into the Hawkesbury Sandstone was 110 metres and the base of the unit was not reached.

The Hawkesbury Sandstone is characterised as a dual porosity aquifer, possessing low intrinsic hydraulic conductivity. That is, groundwater is transmitted both within the interconnected void spaces between grains of the rock matrix (primary porosity) and also within structural features such as joints, fractures, faults, shear zones and bedding planes (secondary porosity).

The Hawkesbury Sandstone is not one aquifer but several ‘stacked aquifers’ due to the heterogeneous and layered nature of the unit. Hydraulic connectivity between the ‘stacked layers’ is variable, but it is common to have different hydraulic heads at various depths indicating poor connectivity. Interbedded shale lenses can provide local or extensive confining layers creating separate aquifers with different hydraulic properties including hydraulic heads.

The hydraulic conductivity of the Hawkesbury Sandstone is low (in the order of 10^{-3} to 10^{-1} metres per day) and fracture related storage is less than two per cent although unconfined matrix storage can be higher.

The groundwater quality within the Hawkesbury Sandstone is generally acidic and the salinity is variable but typically lower than the groundwater within the Ashfield Shale. Where the Ashfield Shale overlies the Hawkesbury Sandstone the salinity of the Hawkesbury Sandstone is typically elevated due to leakage of saline groundwater from the overlying Ashfield Shale. Groundwater within the Hawkesbury Sandstone tends to have naturally elevated iron and manganese concentrations. These elevated concentrations of dissolved iron and manganese naturally occur within the Hawkesbury Sandstone which can cause staining when discharged and oxidised.

Regionally, groundwater in the Hawkesbury Sandstone flows eastward discharging into the Tasman Sea. Recharge is via rainfall infiltration on fractured outcrop and through the soil profile. Discharge is via seepage to cliffs and creeks and evapotranspiration.

Groundwater levels

Groundwater levels are influenced by topography, creeks, rainfall, recharge and manmade structures. Natural groundwater levels are expected to generally reflect a subdued shape of the topography; the groundwater being deeper beneath hills and shallowest beneath creeks or gullies.

Measured groundwater levels within the Hawkesbury Sandstone along the alignment were lowest at Earlwood (WCXBH084 -4.93 metres AHD) and highest in Bardwell Park (WCXBH093, 24.2 metres AHD).

Monitoring has confirmed the groundwater table is impacted by infrastructure such as pumping or along the alignment of the M5 East Motorway tunnel which is a drained tunnel (allowing low levels of groundwater infiltration into the tunnel).

Conversely in some areas the local groundwater table may be elevated above natural conditions due to irrigation such as at the Kogarah Golf Course or subsurface structures such as infrastructure or building foundations that inhibit groundwater flow causing localised groundwater mounding.

Most of the project groundwater monitoring wells intersect the Hawkesbury Sandstone. All monitoring wells have been constructed with a three metre screen interval which varies in depth between 19 metres and 85 metres below ground level.

The groundwater elevation recorded at these monitoring sites is highly variable and dependent upon the topographical expression. Groundwater levels within the Hawkesbury Sandstone vary from 1.5 metres to 35 metres below ground level and from -1 to 24.2 metres AHD. Large vertical gradients are apparent in topographically high areas around Bardwell Park and Kingsgrove.

Groundwater level monitoring within the Ashfield Shale has been conducted to the east of the project alignment where the shale outcrops. Monitored groundwater levels in and around Alexandria Landfill in Ashfield Shale are influenced by the leachate pumping system that causes groundwater to flow towards the centre of the landfill. This radial flow pattern prevents contamination from the landfill dispersing into the Ashfield Shale and Botany Sands. Groundwater elevations within the Ashfield Shale vary from three to 15.5 metres below ground level or from minus 1.5 metres AHD to five metres AHD.

Limited groundwater level monitoring has been conducted within the alluvium and Basalt dykes. Groundwater levels have been measured in the Botany Sands, south of the Alexandria landfill and range from one metre below ground level to 10 metres below ground level (equivalent to minus 1.5 metres AHD to one metre AHD). Groundwater levels are influenced by groundwater abstraction and discharge to the landfill and Alexandra Canal. Groundwater levels beneath Kogarah Golf Course have not been measured but are expected to be shallow (in the order of two to three metres below ground level).

Groundwater levels within the basalt have been monitored in one monitoring well located at Tempe at 4.2 metres below ground level or minus 0.2 metres AHD.

Groundwater level fluctuations as monitored by the data loggers installed at project groundwater monitoring locations indicate that the fluctuations for most monitoring wells are less than one metre, suggesting that:

- The Hawkesbury Sandstone groundwater system is in equilibrium
- There are no external impacts on the hydrogeological regime
- Groundwater levels are not influenced by any external major feature.

In the context of tunnelling this means that hydrostatic pressures will not be significantly influenced by seasonal climatic variations, although drawdown into the tunnels is likely to be a larger influence.

Hydraulic conductivity

The packer test results are summarised in **Table 19-6**. Results of the packer tests are expressed as Lugeon units where one microlitre is equivalent to a hydraulic conductivity of 1×10^{-7} metres per second (8.8×10^{-3} metres per day).

The distribution of packer test results for all lithology's are presented in **Appendix Q**. **Table 19-6** shows that the majority of the rock mass results are classified as of low hydraulic conductivity suggesting that inflow rates would be low.

Table 19-6 Monitored hydraulic conductivity for each hydrogeological unit (metres per day)

Relative permeability	Basal	Ashfield Shale	Mittagong Formation	Hawkesbury Sandstone
Average	0.02	0.02	0.1	0.08
Minimum	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Maximum	0.04	0.07	0.9	4.3
Median	0.02	0.003	0.01	0.003
Number of samples	2	6	10	205

Due to the hydraulic conductivity in the Hawkesbury Sandstone and Ashfield Shale being mainly associated with secondary porosity (such as bedding planes, fractures and laminations), groundwater flow within the unit is primarily parallel to bedding.

Accordingly, the vertical hydraulic conductivity of the bedrock formations (vertical to bedding) is much lower than the horizontal hydraulic conductivity (parallel to bedding). This means that groundwater flow will tend to be dominated in a horizontal direction rather than vertically. The ratio of horizontal to vertical hydraulic conductivity can be around one and three orders of magnitude (ie 10 to 1,000 times).

Ashfield Shale generally has a lower overall hydraulic conductivity than Hawkesbury Sandstone, indicating groundwater flow through the shale is much slower than through the sandstone. The Ashfield Shale weathers to clay and silty clay resulting in a weathered soil profile with a reduced bulk hydraulic conductivity which can restrict recharge to the underlying shale and sandstone. Groundwater generally does not easily flow through Ashfield Shale in either a horizontal or vertical direction, particularly when compared with Hawkesbury Sandstone.

Falling head tests within the Botany Sands conducted as part of the Alexandria Landfill investigations (AECOM, 2015j) calculated a hydraulic conductivity range of 0.6 to 0.9 metres per day which was consistent with similar previous investigations,

Groundwater inflow in existing Sydney tunnels

The project tunnels would be constructed as drained tunnels, with ongoing groundwater inflow, capture and discharge. That is, the tunnel would be largely unlined allowing groundwater to seep into the tunnel from the competent Hawkesbury Sandstone and Ashfield Shale to be collected in drains within the tunnel and discharged.

The project would be constructed to limit groundwater inflow along the tunnel length to no greater than one litre per second across any given kilometre of tunnel. In areas of high local hydraulic conductivity, the natural rock mass permeability may have to be reduced by using shotcrete and grout. Groundwater inflow is to be collected in a drainage system, pumped to the surface for treatment and discharge. In contrast, undrained tunnels are lined to prevent water ingress into the tunnel, although in practice there is likely to be some minor seepage.

Limiting groundwater inflow into the tunnel to one litre per second per kilometre is a design requirement of the project. Rates of groundwater inflows from several unlined tunnels in the Sydney area with similar geology, hydrogeology and construction to the New M5 alignment have been identified in **Table 19-7**.

Inflow rates from other drained Sydney road tunnels vary from around 0.9 litres per second per kilometre inflow to less than three litres per second per kilometre.

Although these tunnels are drained, water proofing has been installed in high inflow zones to restrict groundwater inflow to the tunnels which is consistent with the proposed tunnel construction methodology for the project.

This inflow criterion refers primarily to the Hawkesbury Sandstone as the inflow from the Ashfield Shale will be significantly less due to the lower hydraulic conductivity and storativity of the shale. Any tunnel infrastructure that intersects the Botany Sands would require shoring and water proofing to stabilise the excavation and reduce the risk of groundwater inflow.

Historically in drained Sydney tunnels in the Hawkesbury Sandstone, a one litre per second per kilometre limit has developed as an average across the length of the tunnel. The criterion is not set as a regulatory requirement but has evolved as a realistic inflow rate.

In order to drive improved design outcomes, the project has applied this limit as an average measured across any kilometre of the tunnel (rather than the less stringent approach of applying it as an average along the entire tunnel). The total length of twin tunnels for the project is around nine kilometres. Therefore, the maximum discharge rate for each length of tunnel would be around nine litres per second (0.8 megalitres per day) or 18 litres per second (1.6 megalitres per day) for both tunnels.

Table 19-7 Measured inflow rates from other drained Sydney Tunnels

Tunnel	Type	Width (metres)	Length (kilometres)	Inflow (litres per second per kilometre)	Reference
Eastern Distributor Tunnel	Three lane road tunnel	12 (double deck)	1.7	1	Hewitt, 2005
Cross City Tunnel	Twin two lane road tunnels	8 (twin)	2.1	<3	Best and Parker, 2005
M5 East Motorway Tunnel	Twin two lane road tunnels	8 (twin)	3.8	0.9	Tammetta and Hewitt, 2004
Epping to Chatswood Rail Tunnel	Twin rail tunnels	7.2	13	0.9	Best and Parker, 2005
Lane Cove Tunnel	Twin three lane road tunnels	9 (twin)	3.6	0.6/1.7*	Coffey, 2012
Northside Storage Tunnel	Sewer storage tunnel	6	20	0.9	Coffey, 2012

*measured inflow in Lane Cove Tunnel varied from 1.7 litres per second per kilometre in 2001 to mid-2004 to 0.6 litres per second per kilometre in 2011.

19.2.5 Groundwater quality

The groundwater quality has been characterised prior to development to establish background conditions. This dataset will be used for comparison of post development groundwater quality monitoring. The natural groundwater quality is also required to meet discharge requirements and to inform the design of water treatment requirements. Groundwater can also be corrosive to building materials depending on hydrogeochemical factors including salinity, pH, sulfate and chloride concentrations. Understanding the corrosive nature of the natural groundwater intersected by the project assists in selecting building materials to minimise corrosive impacts to the project tunnels.

At Alexandria Landfill leachate is generated by the continual decomposition of waste within the landfill interacting with groundwater and rainfall infiltration. The leachate quality has been characterised through ongoing monitoring programs in accordance with the environment protection licence conditions. The leachate typically has elevated concentrations of ammonia and minor hydrocarbon contamination. Concentrations of total dissolved solids measured quarterly since 1996 range from 2,030 mg/ L to 6,450 mg/ L of total dissolved solids. The leachate is collected through a herringbone drainage network at the base of the landfill and pumped to an on-site treatment plant before discharge to sewer under a trade waste agreement. Leachate collection, treatment and discharge would continue after the construction of St Peters interchange through a new purpose built water treatment plant.

Background groundwater quality conditions for the various hydrogeological units are outlined in **Section 19.2.3**. A summary of the major hydrogeochemical parameters are outlined in **Table 19-8**.

Table 19-8 Summary of average major hydrogeochemical parameters

Parameter	Botany Sands	Ashfield Shale	Hawkesbury Sandstone
pH	6.2	6.2	6.25^
Salinity^^	8,983 milligrams per litre	6,537 milligrams per litre	4,560 milligrams per litre
Chloride (Cl)	2,405 milligrams per litre	1,314 milligrams per litre	777 milligrams per litre
Sulphate (SO4)	566 milligrams per litre	75 milligrams per litre	197 milligrams per litre
Total Iron (Fe)	62 milligrams per litre	10 milligrams per litre	5.1 milligrams per litre
Manganese	-	-	0.44 milligrams per litre
Number of samples	2	3	17

^Some field results not available ^^Salinity based on laboratory electrical conductivity

19.2.6 Groundwater receivers

Local groundwater use is generally low because the area has reticulated water supply provided by Sydney Water. Registered boreholes are constructed for many purposes including monitoring wells, groundwater extraction for domestic, irrigation, recreation purposes and exploration test bores.

A total of 61 registered boreholes were identified within the study area using the NSW Office of Water/ Bureau of Meteorology and Pinneena Groundwater Database (as shown in **Figure 19-3** to **Figure 19-6**). These boreholes have been grouped into five broad geographical areas. The geographical distribution of the boreholes falls within three general populations as follows.

- West of Arncliffe along existing M5 East Motorway (three boreholes) (**Figure 19-3** and **Figure 19-4**)
- At and near the Kogarah Golf Course at Arncliffe (15 boreholes) (**Figure 19-5**)
- At Tempe, St Peters and Alexandria (43 boreholes) (**Figure 19-6**)

A summary of the registered boreholes is provided in **Table 19-9**.

Table 19-9 Summary of registered bores within one kilometre of the project corridor

Purpose	Number of boreholes	Predominant lithology	Standing water level (metres)		Borehole depth (metres)	
			Minimum	Maximum	Minimum	Maximum
Water supply	31	Sand	0.3	8.22	3	108
Monitoring	21	Sand	0.16	37	2.8	162
Other	10	Sand	0.7	10.97	3.5	186

Review of the lithological data indicates the majority of boreholes are shallow (less than 10 metres) and extract groundwater from the sand. The raw bore records do not indicate the geological unit that the sand is associated with, however it is interpreted as either Botany sands or alluvium. Only 11 out of the 61 bores intersect the sandstone (eight) or shale (three). Drawdown within the alluvial boreholes is expected to be minimal as these hydrogeological systems are continually recharged.

19.2.7 Groundwater dependent ecosystems

GDEs are defined as ecosystems whose current species composition, structure and function are reliant on a supply of groundwater as opposed to surface water supplies from overland flow paths. The majority of ecosystems in Australia have little to no dependence on groundwater, although the full understanding of the role of groundwater in maintaining ecosystems is generally poor. The exception to this is wetland communities, for which it is thought that most have some level of dependence on groundwater resources. Shallow groundwater can support riparian vegetation either permanently or seasonally. Groundwater needs to be sufficiently shallow to support vegetation where root systems of vegetation communities are able to access groundwater.

A search of the GDE Atlas (Bureau of Meteorology) indicated that there are two GDEs within the study area. These include:

- Cooks River Castlereagh Ironbark Forest within Beverly Grove Park. There is about 1.8 hectares of this threatened ecological community, containing several native vegetation communities which are indicative of shallow groundwater tables and waterlogged soils. The GDE Atlas marks the Cooks River Castlereagh Ironbark Forest as being highly likely to have an inflow dependence on groundwater. The extent of this vegetation community is shown in **Chapter 21** (Biodiversity)
- The Cooks River is likely to be an inflow dependent GDE.

An additional three GDEs have been identified outside of the study area, but within the extent of land potentially impacted by groundwater drawdown:

- Seventeen hectares of Hinterland Sandstone Gully Forest with a moderate to high potential to be dependent on groundwater within Bardwell Valley Parkland and Broadford Street Reserve
- About 3.5 hectares of Coastal Sandstone Ridgetop Woodland within Stotts Reserve, Bexley North. This vegetation has a moderate to high potential to be dependent on groundwater
- About 3.4 hectares of Estuarine Fringe Forest between the southern bank of Wolli Creek and the rail line behind Wolli Creek Station, with a low to moderate potential to be dependent on groundwater

Outside the study area are the Towra Point Wetlands. These wetlands are a Ramsar listed (global environmental agreement) site and an estuarine complex comprising a mixture of spits, bars, mudflats, dunes and beaches located 6.8 kilometres south of the project corridor.

Chapter 21 (Biodiversity) further describes GDEs.

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Figure 19-3 Existing bores surrounding the project - Western surface works

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Figure 19-4 Existing bores surrounding the project - Bexley surface works

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Figure 19-5 Existing bores surrounding the project - Arncliffe surface works

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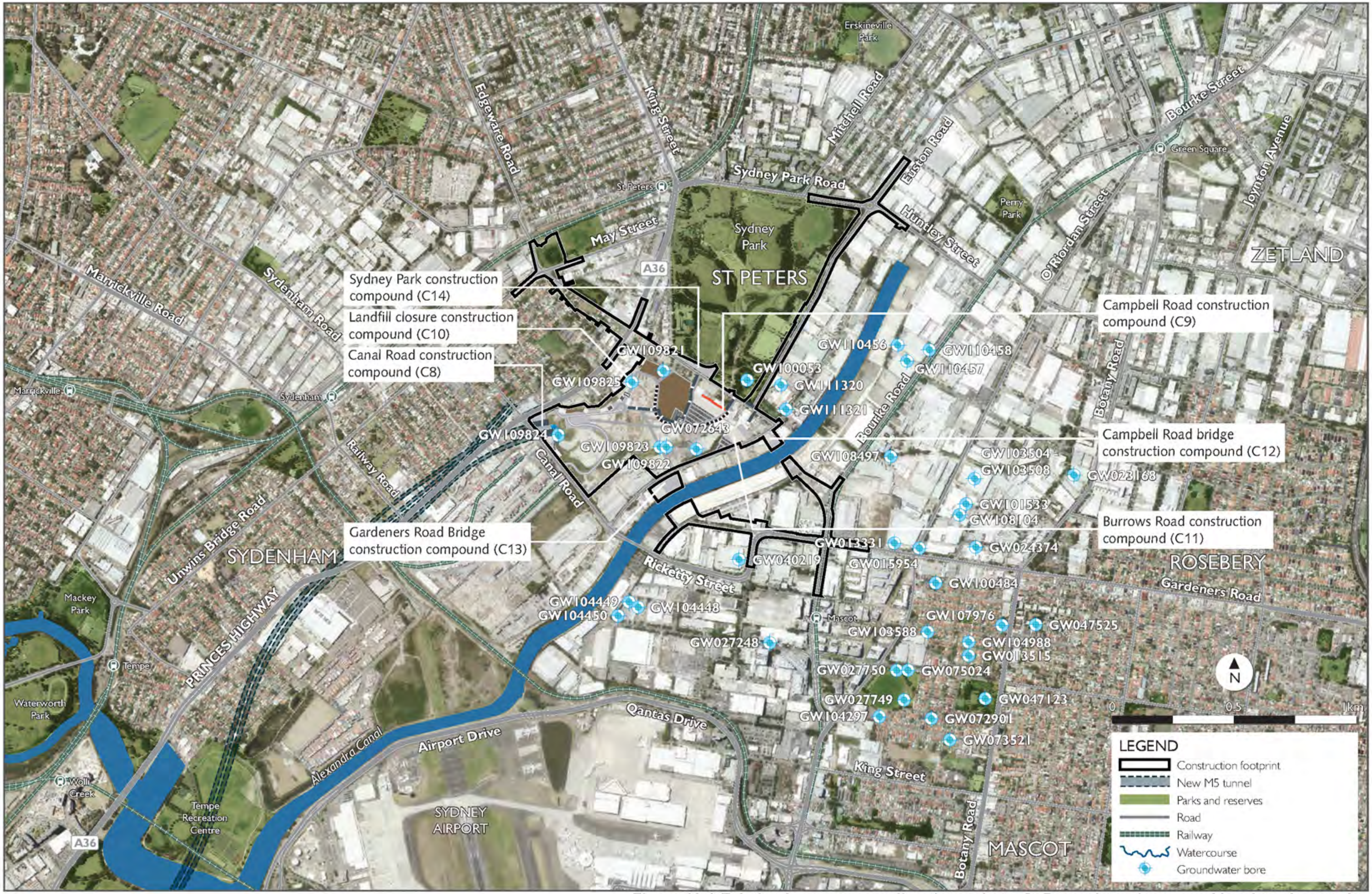

Figure 19-6 Existing bores surrounding the project - St Peters interchange and local road upgrades

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19.3 Assessment of potential impacts

Construction works and operational infrastructure have the potential to change groundwater behaviour and impact on the surrounding environment. An assessment of impacts has been carried out in accordance with the guidelines outlined in **Table 19-2**.

19.3.1 Construction

Groundwater along the project alignment has the potential to be impacted during the construction phase of the project. The potential impacts that have been identified are:

- Groundwater inflow
- Groundwater drawdown
- Reduced groundwater recharge
- Implications for existing groundwater users
- Changes in groundwater quality
- Impacts to the environment, including environmental receivers dependent on groundwater
- Disturbance of acid sulfate soils.

Each of these potential impacts is discussed below.

Groundwater inflow

Groundwater inflow is influenced by the geology and the geological structural features the tunnels intersect.

The tunnels are to be constructed predominately through the competent Hawkesbury Sandstone and to a lesser extent the Mittagong Formation and Ashfield Shale. The tunnel alignment is designed to not intersect the palaeochannels beneath Cooks River and Bardwell Valley by diving below these features. In the unlikely event that a palaeochannel is encountered, appropriate waterproofing would be installed by the construction contractor.

Groundwater inflow from the Hawkesbury Sandstone is expected to be low due to low bulk hydraulic conductivity values typically 0.008 metres per day. The Ashfield Shale overlying the Hawkesbury Sandstone typically has a lower hydraulic conductivity in the order of $1x10^{-3}$ to $1x10^{-2}$ metres per day (Hewitt, 2005) indicating groundwater inflow is expected to be lower.

Higher hydraulic conductivity values are expected along major structural features within the sandstone and shale such as joints, fractures and shear zones where higher inflows are expected. Higher inflows may also occur in dykes, Botany Sands, alluvium and palaeochannels.

Botany Sands

The majority of the project would be constructed below the Botany Sands where groundwater inflow should be limited. Beneath the Botany Sands there is a residual alluvial clay that separates the sands from the underlying bedrock and forms a hydraulic seal or aquitard. If there are locations where the clay has been eroded then there is potential for groundwater from the Botany Sands aquifer to enter the tunnel via fractured rock or downward leakage induced by drawdowns in the underlying Hawkesbury Sandstone. This downward leakage could potentially occur anywhere within the area of drawdown in the Hawkesbury Sandstone caused by tunnel drainage.

The project would have construction activity in sections of Botany Sands at Arncliffe and Alexandria Landfill. At Arncliffe, shafts to the motorway operations complex would be constructed using retaining walls to prevent groundwater inflow and stabilise the Botany Sands. Groundwater inflow from the Botany Sands is a major contributor to leachate generation at the Alexandria Landfill. Groundwater inflow at the site is currently managed by a pump and treat system, and discharged to sewer. A longer term solution for managing this inflow is discussed in Section 6.7 of the Technical working paper: Groundwater (**Appendix Q**).

Alluvium

As with the Botany Sands aquifer, alluvium associated with the Cooks River and its tributaries are saturated. Since the alluvium is hydraulically connected to the river, water can potentially flow from the alluvium via fractured sandstone or shale into the tunnel alignment.

Palaeochannels

Deep incised palaeochannels infilled with saturated sediments are present beneath the Cooks River and extend up to 50 metres below the ground surface. To reduce the risk of large groundwater inflows to the tunnel from the palaeochannels, it is proposed to construct the tunnels beneath these geological features.

Dykes

Dykes cross-cut the Hawkesbury Sandstone and Ashfield Shale and when competent or weathered to clay can form natural hydraulic barriers. Alternatively, the metamorphosed zone around the volcanic intrusion within the sandstone or shale can be fractured causing a conduit for preferred groundwater flow. Several dykes have been identified along the alignment.

Predicted groundwater inflows

Groundwater modelling predicted inflows of 1,115 cubic metres per day into the project tunnels. Over a modelled length of 20 kilometres an inflow rate of 0.63 litres per second along every kilometre of east bound (shallower) tunnel and 0.67 litres per second along every kilometre of the westbound (deeper) tunnel was predicted.

Groundwater modelling is based on well-established scientific principles, but predictions can be uncertain, because of the difficulty of inferring the properties of a large volume based on a relatively small number of measurements. In many respects, from a groundwater modelling point of view, an estimate of 0.6 litres per second along every kilometre is equivalent to an estimate of 1 litres per second along every kilometre. In this case, the fact that the model predicts a lower value for the proposed tunnels than for the existing tunnels means that geometry (depth of tunnels and hydrostratigraphy) and spatial variability in vertical and horizontal hydraulic conductivities combine to suggest smaller flows into the proposed tunnels.

The modelling has not predicted inflow rates during construction, but rather has predicted long term steady state inflows that would only apply once equilibrium has been reached. While it would in principle be possible to predict the evolution of leakage during construction, this is extremely difficult, mainly because the short term tunnel inflows are influenced by local fracturing and storage of water in nearby fracture networks (CDM Smith, 2015).

The predicted inflow rates are therefore long-term operational phase inflow rates. Initial inflows to tunnels during construction can be large, because of the large hydraulic gradients that develop near the walls, however these gradients dissipate in time as inflows approach a steady state. That is, during construction large inflows can be experienced for a short duration as the confined storage from water bearing fractures is released due to water expanding slightly as pressure drops. After the initial confined storage is released, inflow rates decline as storage is depleted and groundwater levels begin to decline. Eventually, steady state equilibrium is reached where rainfall recharge is balanced with groundwater inflow to the tunnels and the groundwater levels no longer decline due to tunnel inflows. The higher inflow rates during construction have been considered when assessing the construction impact assessment and mitigation and management measures.

It should also be stated that the model predicts average inflow rates. Higher rates are likely from zones of higher permeability, where saturated geological structural features are intersected. During construction these high inflow zones are to be grouted to reduce the inflow rate below one litre per second per kilometre.

During tunnelling, groundwater would be intersected and would be managed by either capturing the water that enters the tunnels and caverns and portals or restricting inflow by temporary dewatering or the installation of cut-off walls. During construction, long term water management solutions would also be constructed such as the installation of water proofing membranes. Groundwater inflows would be collected via the drainage system and pumped to the surface for treatment and discharge. Inflows into the tunnel during construction would be managed by contractors, and would have no immediate effect on the water table or GDEs.

It is recognised that high groundwater inflow during excavation is possible in faulted or fractured zones or other water bearing geological features such as beneath the Cooks River palaeochannels or beneath Wolli Creek. During construction, hydraulic gradients near the exterior surface of the tunnel are steep causing initial rates of inflow to be greater than at later stages.

To reduce groundwater inflows, pre-excavation pressure grouting would be undertaken to allow groundwater inflows to be more easily managed. This technique is undertaken by drilling a pattern of holes in advance of the excavation to conduct packer tests. Once the hydraulic conductivity is calculated grout is injected at a pre-determined pressure to reduce the bulk rock mass permeability. The implementation of this technique is dependent upon the local geology.

At the dive structures and shafts, groundwater flow within the fill, alluvium and weathered shale would be restricted by the construction of retaining walls such as secant pile, sheet pile walls or diaphragm walls founded in the Hawkesbury Sandstone.

The shafts constructed at the Bexley Road North and South construction compounds will intersect the Botany Sands and Hawkesbury Sandstone. Temporary shoring will be implemented during construction to stabilise the unconsolidated sands and reduce groundwater inflow. Temporary dewatering of the Botany Sands is likely to be required during construction which is typically undertaken by the installation of a series of spearpoints connected to a vacuum system. Water would be directed to the temporary construction water treatment plants prior to discharge into the stormwater system under license. Water treatment and discharge to stormwater will ensure minimal water quality impact on the local hydrology.

The shoring will be socketed into the underlying Hawkesbury Sandstone. Groundwater inflow from the Hawkesbury sandstone will be managed by the contractors in much the same way as during the road tunnelling methodology.

At Alexandria Landfill, water entering the former quarry is to be restricted by engineering solutions into the tunnel infrastructure design. Rainfall infiltration is to be restricted by capping the landfill and directing captured rainfall runoff off-site. Groundwater flow into the landfill from the Botany Sands is to be restricted by the construction of a cut-off wall around the southern perimeter of the landfill. This would locally reverse groundwater gradients away from the landfill and towards Alexandra Canal restoring pre-quarry hydrogeological conditions. The construction of the wall would reduce the pre-construction requirement of pumping groundwater from the Botany Sands to stormwater to reduce leachate generation.

Groundwater drawdown

Groundwater drawdown due to construction activities and temporary dewatering could impact the local groundwater table or surface water features where there is a hydraulic connection to groundwater. As the project tunnels would be drained structures, the tunnels could impact the natural groundwater system and potentially alter regional hydrogeological conditions.

During construction, the drawdown impacts due to tunnel construction would be minimal even though groundwater inflows are high due to high hydraulic gradients. That is, during tunnelling there is initially no drawdown at the water table, but eventually over time and certainly within tens of years, the effects of depressurisation at depth impact the water table causing a water table decline. This suggests that if water level elevations had been measured directly over the centreline of the M5 East tunnels, a transient decline would have been in observed in the past 15 years or so during which the water table would have started to fall and may ultimately have approached a steady state.

A steady state analysis predicts the equilibrium position of the water table, and the worst case scenario for the potential impact of tunnelling on the water table. The prediction remains uncertain, because of the relatively small number of measurements of water table elevation near the existing M5 East tunnels, especially directly along their centrelines.

The hydraulic conductivity of the Botany Sands is variable but previous investigations in the Botany Sands, such as at Alexandria Landfill, indicate that the hydraulic conductivity ranges from around 0.1 to five metres per day depending on the clay content. The volume of groundwater to be pumped during temporary dewatering is dependent on the hydraulic conductivity with the higher clay content reducing the volume of groundwater to be pumped. Dewatering is required to provide dry working conditions during construction.

Reduced groundwater recharge

The project is located in an urbanised part of Sydney where rainfall recharge is already reduced by hardstand areas and roofs directed to stormwater.

The majority of groundwater recharge occurs in parks, gardens, bushland and golf courses. Within the eastern portion of the project area, where the Botany Sands outcrop, groundwater recharge would be expected to be higher than areas underlain by sandstone and shale. This is due to the sands having a higher capacity to accept rainfall infiltration and the plumbing of some buildings directing stormwater to infiltration basins or trenches rather than stormwater.

The majority of the project is below ground surface and therefore is unlikely to directly impact groundwater recharge during construction. The potential impacts during the construction phase would be access roads, tracks and the isolation of areas for stockpiling of construction materials. This could potentially alter or reduce groundwater recharge. However, these impacts would be minor and temporary.

Alexandria Landfill would be capped to reduce recharge. Surface water run-off from the cap and road infrastructure would be directed off-site.

Impacts on existing users

A review of current groundwater use has been conducted to identify registered groundwater users within a one kilometre buffer of the project tunnel alignments. A three dimensional numerical groundwater model has been developed to assess the potential groundwater level drawdown at sensitive areas and where the impacts are expected to be in excess of two metres (in accordance with the Aquifer Interference Policy).

Existing users may be affected during construction through potential drawdown due to the extraction of groundwater during tunnelling. The drawdown is expected to be less in the construction phase than during the operational phase, since groundwater levels would continue to decline until steady state conditions are reached. Drawdown due to tunnel operation is discussed in **Section 19.4.2**.

There is potential for groundwater extracted from the alluvium to become more saline due to inducing saline water from tidal rivers towards groundwater bores. However, it is likely that alluvial groundwater hydraulically connected to the tidal rivers is already saline so the potential for further significant reductions in water quality is low.

Impacts to the environment

Drawdown beneath creeks and other surface water bodies could occur where they overlie the project. Losses to stream flows are dependent on the hydraulic connection between the stream channel and alluvium, and the underlying sandstone or shale. Long term predictions indicate that groundwater drawdown west of Arncliffe is expected to be less than other areas along the alignment. This is likely due to the drawdown caused by the existing drained M5 East Motorway tunnel.

The predicted extent of lateral drawdown would vary from approximately 500 metres in the western part of the project alignment to approximately one kilometre elsewhere. The lateral footprint of drawdown within the alluvium would be variable but less than the extent within the bedrock. Drawdown within the sandstone is unlikely to extend to the top of the project tunnels due to the interbedded sandstone and shale layers above the tunnels behaving as aquicludes restricting groundwater drawdown combined with rainfall recharge.

Shallow tunnels that dive beneath incised water courses or water bodies could be hydraulically connected with creek beds causing localised elevated inflows to tunnels and potential surface water losses. The alignment passes beneath several creeks. These creeks comprise of small ponds, mainly recharged by urban runoff in relatively small catchments. The tunnel cover varies between about 12 metres and 33 metres at the various watercourses and surface settlements due to groundwater drawdown are estimated at approximately 17 millimetres to 20 millimetres at these locations. Grouting or an impermeable membrane would be used where inflows are elevated beneath the watercourses to minimise these impacts.

Groundwater quality impacts

There is potential to contaminate groundwater from fuel and chemical spills, particularly if a leak or incident occurs over the Botany Sands or fractured sandstone. Spills as a result of incidents could occur during construction activities, refuelling operations or from storage areas. Stockpiling of construction materials may also introduce contaminants to the area.

Current and historical land-uses with the potential for contamination are located along the project alignment. The potential contamination risk to the project tunnels and caverns would be associated with the migration of contaminated groundwater plumes towards the tunnels. The majority of the tunnels would be constructed within the Hawkesbury Sandstone at depths greater than 20 metres at the western and eastern ends and up to 80 metres beneath Bardwell Park. Given these combined factors of the depth, location of the tunnels in relation to the contaminant source and low inflow rates, the risk of intercepting contaminated groundwater would be low.

Potential contaminated groundwater inflows could be derived from industrial sites that overlie the project tunnels at Alexandria, where the tunnels are relatively shallow but constructed within the Ashfield Shale. At 316 Princes Highway there is a former service station where underground fuel tanks remain which may potentially result in petroleum hydrocarbon impacts. Cut and cover ramp portals would be constructed near this site. However, the risk of significant interaction with contaminated groundwater in this area would be low because the ramps and project tunnels would constructed within the Ashfield Shale where the hydraulic conductivity and groundwater leakage would be low.

Leachate and elevated concentrations of ammonia are associated with the Alexandria Landfill. Geotechnical drilling to inform the design of the project did not identify localised faulting or fracturing which could provide leachate conduits.

Immediately south of the Alexandria Landfill, at the Canal Road site, lead contamination has been identified (AECOM, 2015d). The cut-off wall that would be constructed south of Alexandria Landfill (as part of the closure of the landfill) has been designed to reduce leachate generation by reducing groundwater inflow from the Botany Sands into the landfill. In addition, the lead impacted groundwater south of the landfill will continue to be directed to the landfill as a consequence of the cut-off wall where it will be extracted and treated prior to discharge to sewer.

Capping the landfill and construction of the cut-off wall is designed to reduce rainfall infiltration to the Botany Sands inside the cut-off wall. Therefore, groundwater recharge inside the cut-off wall would be reduced which would ultimately reduce the volume of leachate being generated.

Consequently the leachate generated post-construction is likely to contain a higher concentration of contaminants pre-construction that require treatment. Outside the cut-off wall, groundwater recharge is unlikely to be significantly impacted as this area will not be caped, although the paved area is likely to increase due to the construction of the road infrastructure.

Groundwater quality within the Botany Sands outside the wall is likely to be improved due to the groundwater contaminated with lead associated with the Canal Road site being captured by the cut-off wall.

The Botany Sands in the vicinity of the landfill is isolated from the remainder of the Botany Sands by the Alexandra Canal. No groundwater users have been identified within the narrow extent of sands that parallel the Alexandra Canal. Consequently construction activities are unlikely to impact any sensitive groundwater receivers.

In assessing groundwater drawdown impacts in and around the landfill the cut-off wall and landfill capping was included in the groundwater model. However these impacts were relatively minor to the local hydrogeological regime in comparison to impacts of continued leachate extraction on the depressurisation of the Ashfield Shale.

Captured groundwater and surface water as a result of tunnelling is likely to be contaminated with suspended solids and increased pH due to tunnel grouting activities. It is anticipated that about 65 per cent of water captured would be groundwater as a result of tunnelling activities with the remaining 35 per cent resulting from process water generated from construction activities. The assessment of the potential impacts from the quality of water discharged from the construction groundwater treatment plants is discussed in the Technical Working Paper: Surface Water (**Appendix N**).

Within the construction compounds there is potential to contaminate groundwater from fuel and chemical spills, including petrol, diesel, hydraulic fluids and lubricants stockpiled within the compound. Spills as a result of incidents can occur during construction activities, refuelling operations or from storage areas. Management and mitigation measures are outlined in **Section 19.4**.

Acid sulfate soils

Areas identified with suitable conditions for the presence of acid sulfate soils include alluvial deposits around creek lines such as Cooks River, Alexandra Canal, Wolli Creek and Muddy Creek. When exposed to air, either by excavation or dewatering, the iron sulfides (commonly pyrite) within acid sulfate soils can oxidise producing sulfuric acid.

The project tunnel alignments within most of the areas potentially containing acid sulfate soils is deep within the competent Hawkesbury Sandstone and beneath the alluvium. Therefore, in most areas the alluvial sediments are unlikely to be excavated and the potential for disturbance of acid sulfate soils is low.

Exceptions where acid sulfate soils may be intersected are near Alexandra Canal, at Alexandria Landfill and around the Arncliffe surface works. Near Alexandra Canal the project would be constructed at the ground surface with bridge crossings of the canal. Excavation of potential acid sulfate soils may occur during road construction works, the construction of bridge footings or dewatering.

Based on historical quarrying records at Alexandria Landfill, potential acid sulfate soils are most likely present in the southern and eastern areas of the site outside the areas that have been subject to quarrying. Acid sulfate soils could be excavated during earth moving works and/or acidic groundwater could be pumped during construction dewatering. Similarly potential acid sulfate soils may also be present beneath the Arncliffe surface works and could be excavated during the construction earthworks. Treatment of acid sulfate soils may be required as part of any re-contouring or excavation works within the Kogarah Golf Course site.

Groundwater aggressivity

Groundwater can be corrosive to building materials depending on a number of hydrogeochemical factors including salinity, pH, sulfate and chloride concentrations. Understanding the corrosive nature of the natural groundwater intersected by the project assists in selecting building materials to minimise corrosive impacts to the tunnel and its infrastructure.

Tunnel infrastructure including the construction of interchanges and installation of water proofing would be mostly located below the natural groundwater table and subjected to potential corrosion due to interaction with groundwater.

The presence of dissolved chloride and sulfate in groundwater is one of the main factors contributing to corrosion potential of concrete and steel. By application of the exposure classification in the Australian Standard AS2159-2009 for piling – design and installation, the water for all lithologies within the study area is mildly aggressive to concrete for average chloride and non-aggressive for average sulphate.

Along the project alignment, groundwater quality intersected by the project tunnels would be variable as different water bearing fractures are intersected.

Groundwater quality data indicates the groundwater with the highest aggressivity based on elevated electrical conductivity, sulfate and chloride concentrations would be in the eastern part of the project around the St Peters interchange where the Ashfield Shale outcrops. In addition, aggressive groundwater is also expected within the Hawkesbury Sandstone in the Tempe/ Arncliffe area near Cooks River. Piling standards also state that the exposure classification for piles intersecting domestic waste and industrial waste would be severe and very severe which is likely to impact the piles that would be constructed at the Alexandria Landfill site.

Corrosion and other associated impacts of high aggressivity on the tunnel infrastructure would be monitored during regular inspections outlined within the an Operational Environmental Management Plan (OEMP). Rectification of tunnel infrastructure during operations would be undertaken during regular maintenance operations as required.

The project tunnels have been designed to be drained and would require groundwater seepage, tunnel wash or deluge system water to be collected, treated and discharged. Water treatment would be required to reduce salinity and turbidity and adjust pH prior to discharge. Further information on surface water management including water treatment is provided in **Chapter 16** (Soil and water quality).

While it is acknowledged that the risk posed of the interaction with contaminated groundwater during construction within the Alexandria Landfill is low a contingency measure may include include a backup leachate treatment plant.

19.3.2 Operation

Groundwater along the project alignment has the potential to be impacted during the operational phase of the project. The potential impacts that have been identified are:

- Groundwater inflow
- Groundwater drawdown
- Changes in groundwater quality
- Impacts to the environment, including environmental receivers dependent on groundwater

Each of these potential impacts is discussed below.

Groundwater inflow

Long term groundwater inflows into the project tunnels would be influenced by the local geological and hydrogeological conditions, as outlined in the assessment of potential construction groundwater inflows.

Operational groundwater inflows are likely to be lower than the construction inflows. Based on groundwater inflows to other drained Sydney tunnels, the long term inflow is expected to be below one litre per second per kilometre.

Initial groundwater inflows into the project tunnels during construction are estimated to be between 7.6 and 18.6 litres per second (for the full tunnel lengths) depending on the actual hydraulic conductivity experienced. Inflow is likely to decrease with time as observed in other Sydney tunnels due to siltation, chemical induration and organic slimes that accumulate in intercepted geological defects, reducing the rock mass permeability. This is primarily due to the groundwater levels drawing down and inducing flow towards the tunnels from an increasingly broader region as the cone of depression expands over time. Inflows would also decline over time as groundwater pressures around the tunnel decline as the storages of higher inflow features drain.

The overall groundwater inflow is expected to achieve less than one litre per second per kilometre as high inflow zones are grouted during construction.

Groundwater inflow would be dependent on the final construction methodology and water proofing solutions as determined during detailed design. The predicted groundwater inflow rate (CDM Smith, 2015) along the 20 kilometres of project tunnels (including main alignment tunnels and ramps) is 0.63 litres per second along each kilometre of the eastbound (shallower) tunnel and ramps and 0.67 litres per second along each kilometre of the westbound (deeper) tunnel and ramps.

Groundwater drawdown

Previous tunnelling in the Hawkesbury Sandstone in the Sydney region has shown that groundwater inflow is typically highest during construction and then is reduced as the cone of drawdown expands and an equilibrium or steady state conditions are approached.

This equilibrium is achieved when the tunnel inflow is matched by rainfall recharge via infiltration. Groundwater drawdown within the palaeochannels and river alluvium would be minimal or not likely to occur as the hydraulic heads within saturated sediments are maintained by direct hydraulic continuity with surface water, supported by a slight reduction in river baseflow.

Immediately after tunnelling is completed, groundwater inflows would be at their highest but there would be no impact on the water table. With time, groundwater inflow to the tunnel would decrease while the water table would gradually decline until an equilibrium is reached.

Construction of the drained tunnels beneath the groundwater table may cause long term groundwater inflow, inducing groundwater drawdown along the tunnel alignments. There are two main mechanisms that influence groundwater drawdown, the actual water table drawdown and the hydraulic pressure drawdown.

The Hawkesbury Sandstone is also interbedded with shale lenses that locally act as aquicludes or aquitards restricting vertical groundwater movement. Shallow perched water over shale lenses (recharged by rainfall) also occurs, which potentially sustains surface ecosystems. To the west of the project alignment, the deeper groundwater table within the Hawkesbury Sandstone is already influenced by drawdown induced by the drained M5 East Motorway tunnels. Localised groundwater drawdown could also be expected around existing shafts and portals that extend below the groundwater table.

Long term dewatering caused by tunnel drainage could lower the groundwater table within the Hawkesbury Sandstone and reduce the amount of groundwater available for shallow rooted plants. The groundwater table underlying the majority of the project alignment is on average two metres below ground surface and the flora is unlikely to be completely dependent on groundwater. This would not change as the unsaturated zone is influenced by rain infiltration. The availability of water for plants in low lying areas is not expected to change due to the low permeability of the clayey soils, frequent rainfall events and higher recharge due to surface water concentration.

Residual soil profiles developed on the weathered sandstone and shale bedrock are typically relatively thin, stiff and of low compressibility. Therefore in most cases, the risks associated with water table drawdown and associated dewatering induced settlement is minor and less than the seasonal influences of shrink-swell movements in the residual clay soils. At Alexandria Landfill where the shale residual soil profile is of considerable thickness the impacts due to dewatering such as induced settlement have already occurred due to many years of artificial depressurisation caused by the leachate pumping system (AECOM, 2015k).

The predicted drawdown at the various watercourses above and around the project would vary depending on local geology, horizontal distance from the tunnel and depth to the tunnel. Typical drawdown within the alluvium has been estimated to be negligible as it is recharged by rainfall infiltration and would continue to discharge to surface water.

Long term dewatering could impact existing groundwater users registered with the NSW Office of Water. A review of the NSW Office of Water groundwater database indicates that of the registered bores within one kilometre of the project alignment approximately half are registered as being used for water supply or irrigation. The majority of these registered bores are shallow (no greater than 10 metres in depth) located within the Botany Sands, Wolli Creek and Cooks River alluvium. Groundwater drawdown at these locations due to drainage into the project tunnels is not expected due to the hydraulic connection of the alluvium with the surface water in Wolli Creek and Cooks River. A clay aquitard typically underlies the Botany Sands reducing hydraulic continuity between the alluvium and underlying sandstone.

Groundwater modelling has been used to predict potential impacts on natural systems and the groundwater table. Output from the groundwater model shows predicted groundwater table elevations after completion of the project (refer to **Figure 19-7**) and drawdown caused by the project (refer to **Figure 19-8**).

The groundwater elevations shown in **Figure 19-8** indicate an elongated cone of depression that is predicted to develop along the project tunnel alignments, especially to the west of Cooks River. The groundwater table is predicted to remain relatively high near Bardwell Creek which is attributed to the presence of deep alluvium along this drainage line.

Drawdown of the groundwater table is predicted to be less where the project tunnels pass beneath Cooks River and its connected alluvium, due to induced leakage from the river. Being connected to the ocean, the river can supply water to the tunnels below, without affecting water levels in the river. However, a gradient would develop from the river in both westerly and easterly directions. It has been previously observed that higher inflows to tunnels beneath palaeovalleys may be an effect of valley bulging, and enhanced hydraulic conductivities due to fracturing. The groundwater model suggests that higher inflows can also be explained by availability of water and rapid transfer of water to alluvium over underlying rock.

To the east of Cooks River, heading eastwards from the edge of the alluvium, the predicted drawdown would increase significantly. The sudden change in drawdown as the project alignment approaches St Peters would be due to the tunnels transitioning from sandstone into shale.

Drawdown does not extend far into the main Botany Sands aquifer, because this unit is able to transmit water (due to its higher hydraulic conductivity) with relatively flat hydraulic gradients. Groundwater modelling predicts the project would not have additional impacts in the area of the Alexandria Landfill.

Justification for a drained tunnel

The project is designed as a drained tunnel and would be constructed predominately through sandstone with sections of shale.

The option to construct drained tunnels rather than lined undrained tunnels can have a large impact on the project outcomes and economic feasibility. The decision is either driven by mitigation of potential impacts or from the outcomes of a whole of life cost assessment (i.e. capital cost versus operational cost).

A review of the ground conditions within the project corridor indicated that the hydrogeological conditions were similar to where other major Sydney drained tunnels have been successfully constructed. With the exception of Lane Cove Tunnel and the cross City Tunnel, groundwater inflows along the tunnel length have averaged below one litre per second per kilometre. Low inflow rates are maintained by grouting or otherwise sealing water bearing structural features that otherwise could provide large inflows to the tunnel.

Typically, drained tunnel sections that extend beneath creeks are grouted to reduce the risk of increased tunnel inflow. There are many other drained tunnels excavated in sandstone and shale throughout the Sydney Basin and very few undrained tunnels, in part due to the competent nature of the bedrock.

In general, DPI (Water) does not support an activity that causes perpetual inflow volumes, although in the case of constructing important major infrastructure exemptions can be granted. On-going tunnel inflows are estimated to be less than 18 litres per second (i.e. less than one litre per second per kilometre on average). To retain this volume of water within the natural groundwater system, by constructing an undrained tunnel would approximately double the project costs.

There are potential environmental, sustainability, social and safety impacts associated with excavating larger tunnels, to accommodate a liner which includes moving more spoil, and transporting and disposing of more materials for tunnels. In addition, these factors can contribute to a higher capital cost, but there would be an off-setting reduction in operating costs. On-going operating costs for a drained tunnel would include the collection, treatment and discharge of groundwater. In the absence of any indication for potential impacts associated with a loss of baseflow to creeks that may adversely affect sensitive GDEs; a reduction in groundwater levels in registered boreholes used for water supply; or damage to existing infrastructure due to the settlement of compressible soils, it was considered reasonable to specify a groundwater control (in the form of an inflow limit) instead of an undrained requirement.

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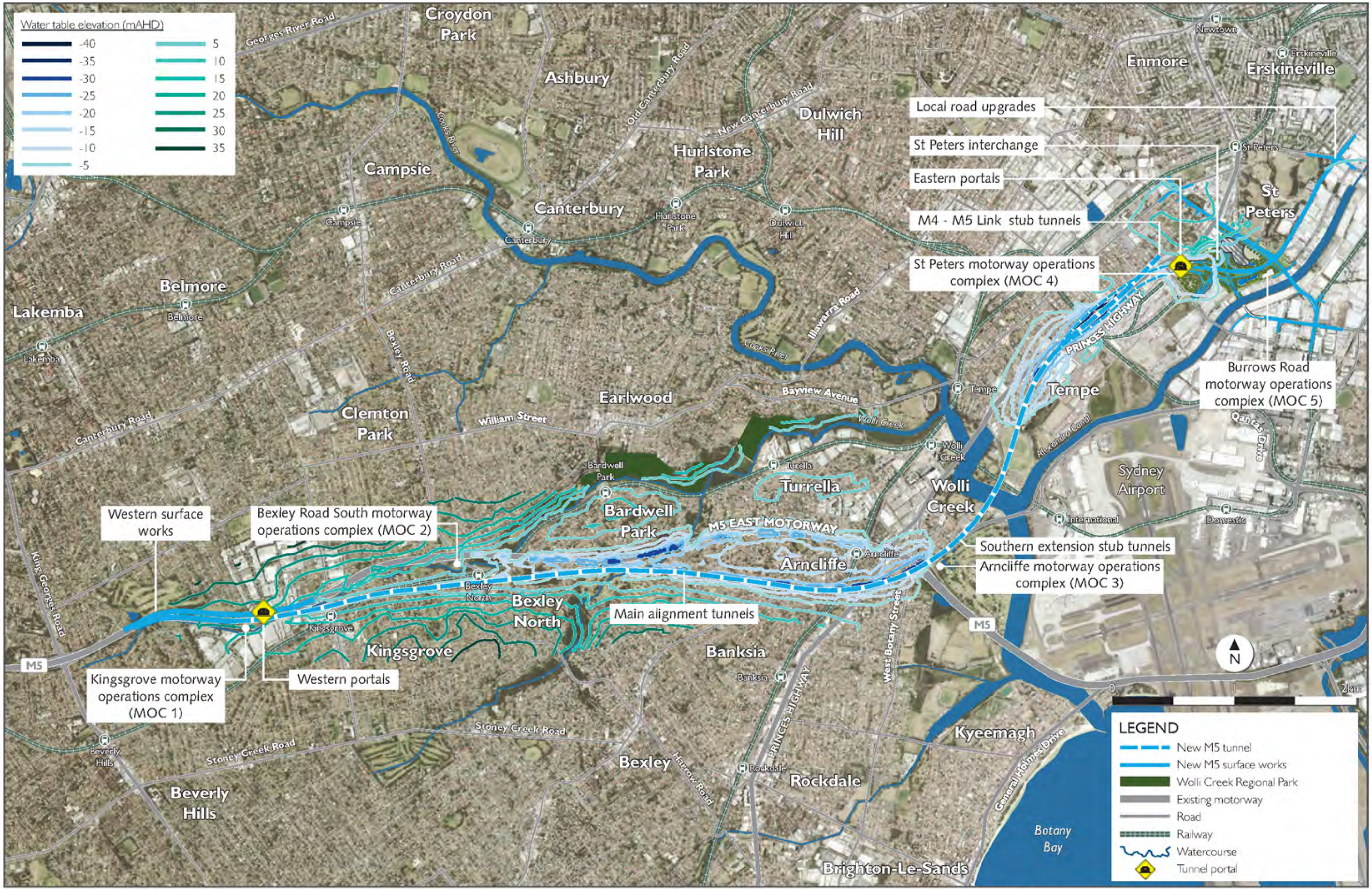

Figure 19-7 Predicted water table elevations after completion of the project

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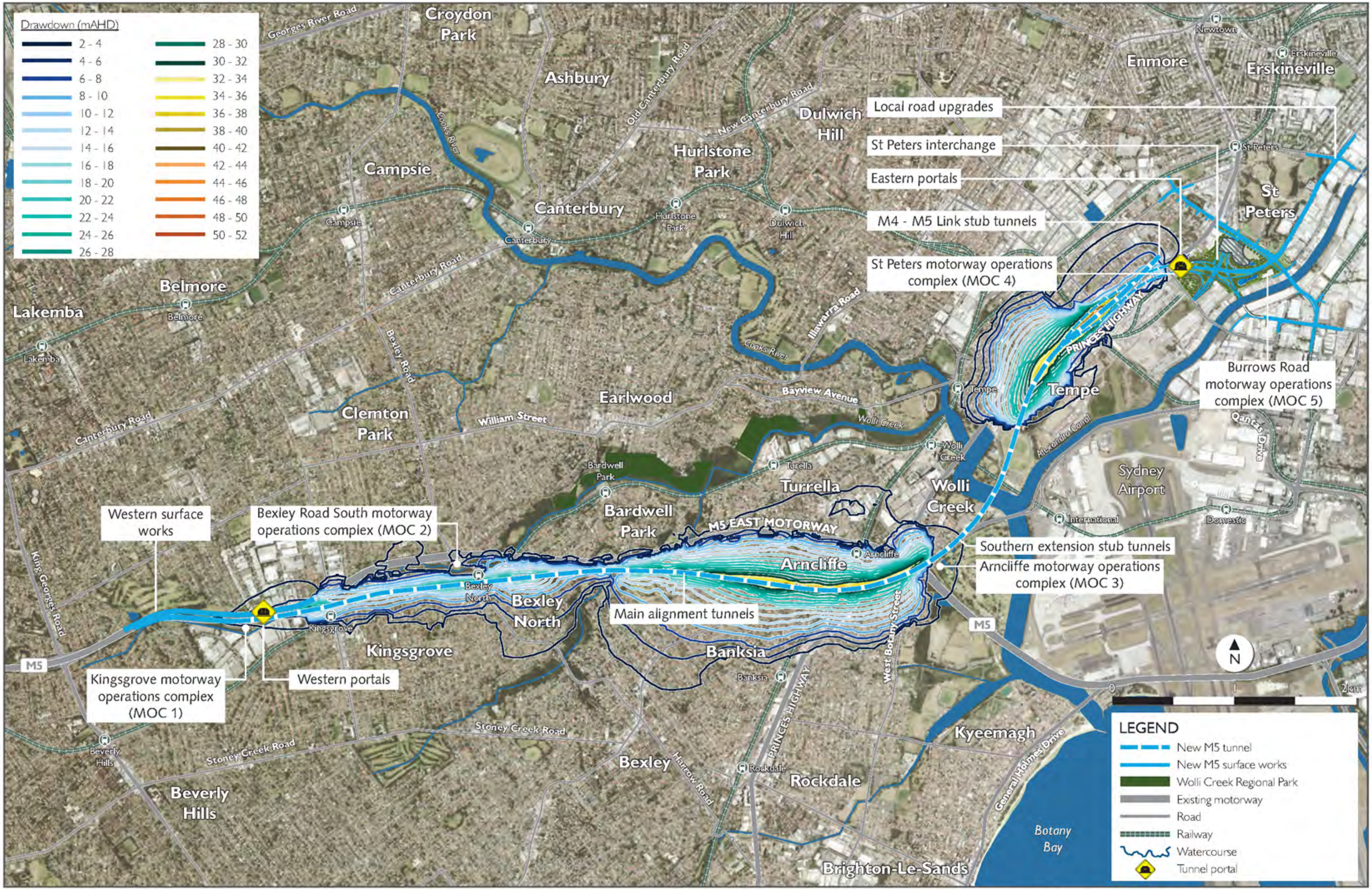

Figure 19-8 Predicted drawdown caused by the project

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Groundwater quality impacts

Road runoff can contain pollutants associated with vehicular movement and normal use due to leaks, spills and crashes. Expected contaminants from groundwater within the region indicate that contaminants would include iron, hydrocarbons (petrol, diesel, oil and grease), metals and suspended solids.

In the event of a hydrocarbon spill within the project tunnels, water and fuel would be pumped to the surface and stored in holding ponds for treatment prior to discharge. The drainage system has been designed to capture groundwater and surface water inflows to the tunnels separately via different drainage networks to streamline the treatment process. In addition, groundwater would be collected separately east and west of the sump.

The rationale is that groundwater from St Peters, Alexandria and Tempe is more likely to be contaminated than groundwater collected west of Arncliffe. Sources of potentially contaminated groundwater would be from former and current industrial areas of St Peters, Alexandria and Tempe. The risk is considered low due to the depth of the project tunnels, and where contaminated groundwater is identified, waterproofing would be applied to reduce inflows of contaminated groundwater. Calculated groundwater leakage into the project tunnels adjacent to Alexandria Landfill would consist of 86 per cent background water and 14 per cent leachate impacted groundwater.

While it is acknowledged that the risk posed by the interaction with contaminated groundwater during construction within the Alexandria Landfill is low, a backup leachate treatment plant may be provided as a contingency measure.

The water treatment plant is designed to treat water from a variety of sources including groundwater, stormwater that enters the portals and a series of smaller incidental flows including deluge for fire suppression, hydrants, fire system testing and liquid tanker spill. Predicted groundwater inflow to the tunnel is 0.65 litres per second over 20 kilometres or 13 litres per second. The water treatment plant is designed to treat a predicted maximum of 20 litres per second but could be expanded to treat 27 litres per second if required. Where there are high inflows of water such as from deluge or hydrants water would be pumped to a surface holding tank to increase water holding capacity if required,

The assessment concerning the treatment and discharge of treated groundwater can be found in the Technical Working Paper: Surface Water (**Appendix N**).

Induced drawdown caused by tunnel drainage may cause saline water to be drawn into the tunnels due to the connection with the Cooks River. The Cooks River is in hydraulic connection with alluvium and has the capacity to supply saline water to the alluvium, potentially degrading groundwater quality.

As the alluvium directly overlies the sandstone and may be in hydraulic connection there is potential for saline water to enter the sandstone. However, groundwater beneath the Cooks River is likely to already have elevated salinity and consequently the project is unlikely to further adversely impact groundwater quality beneath the river.

Impacts to existing users

The drawdown in registered bores has been predicted by the groundwater model. The modelling predicts that 11 bores would be drawn down in excess of two metres due to tunnel induced drainage. The modelled drawdown in the registered bores varies from 2.2 metres to 11.5 metres. Of these bores, only four are used for water supply – two or domestic purposes and two for industrial purposes. The remaining wells are classified as either monitoring wells, test bores or ‘other’.

Three of the water supply wells where the drawdown is predicted to be in excess of two metres are shallow bores intersecting sand where the water table is expected to be drawn down below the base of the bore. In these cases, it may be possible to extend the bores to intersect deeper groundwater. The fourth bore is constructed for industrial purposes within the Hawkesbury Sandstone to a depth of 186 metres. In this bore the groundwater table is at a depth of 93 metres and the drawdown is predicted to be 5.7 metres.

Impacts to the environment

Impacts to groundwater inflows to the Cooks River

The Groundwater Dependent Ecosystem Atlas (Bureau of Meteorology, 2015) identifies the Cooks River as being highly likely to have an inflow dependence on groundwater, meaning that the Cooks River estuary receives groundwater passively through its bed. Some of this groundwater may flow underneath the Kogarah Golf Course at Arncliffe, which could be intercepted during tunnelling. The volume and rate of groundwater flow into the Cooks River is unknown; however, the hydraulic connection to the Cooks River is likely to be limited by the concrete and brick lining along the banks.

Although the Cooks River is highly likely to receive groundwater, there are no known ecosystem components which would be significantly impacted by a reduction in groundwater as a result of groundwater interception from tunnelling.

Impacts to the Cooks River Castlereagh Ironbark Forest

Construction of the project is expected to require the clearance of 1.4 hectares of Cooks River Castlereagh Ironbark Forest, which contains several native vegetation communities which are indicative of shallow groundwater table and waterlogged soils. The GDE Atlas marks the Cooks River Castlereagh Ironbark Forest as being highly likely to have an inflow dependence on groundwater.

The residual Cooks River Castlereagh Ironbark Forest around the western surface works area may be affected by groundwater drawdown from tunnelling (refer to **Chapter 21** (Biodiversity)).

Impacts to GDEs from groundwater drawdown

The maximum amount of groundwater drawdown is expected to be about five to 10 metres. Drawdown would be the greatest directly above the main alignment tunnels, and would decrease towards the drawdown boundary. Five GDEs (including the Cooks River and the Cooks River Castlereagh Ironbark Forest) have the potential to be impacted as a result of groundwater drawdown. **Table 19-10** provides a summary of impacts to GDEs as a result of groundwater drawdown and further information, including details of the impact assessment methodology, can be found in **Chapter 21** (Biodiversity).

Table 19-10 Summary of impacts to GDEs from groundwater drawdown

GDE	Location	Summary of impact	Significance of impact
Cooks River Castlereagh Ironbark Forest	Western surface works within the construction footprint	Vegetation to be retained is likely to be highly groundwater dependent. Lowering of the water table at this location is likely to place this vegetation under stress.	Moderate
Cooks River	Adjacent to the Arncliffe (C7) construction compound	Drawdown may reduce the flow of water from aquifer to river. The current flow rate at this location is unknown, but is unlikely to be significant because large reaches of the bank and bed are lined with concrete or brick.	Low
Hinterland sandstone gully forest	Within Bardwell Valley Parkland and Bradford Street Reserve outside of the construction footprint but within the groundwater drawdown extent	Drawdown could lower groundwater to a point where it is below the roots of dependent trees. As this GDE is near the edge of the drawdown boundary, the impact is not expected to be significant	Low
Coastal sandstone ridgetop woodland	Within Stotts Reserve, Bexley North outside of the construction footprint but within the groundwater drawdown extent	Stotts Reserve is located directly above the main alignment tunnel. Drawdown could be up to 10 metres, and if trees are dependent on groundwater, a large part of the reserve could show signs of stress in prolonged dry periods.	Moderate

GDE	Location	Summary of impact	Significance of impact
Estuarine fringe forest	Between the southern bank of Wolli Creek and the rail line behind Wolli Creek Station, outside of the construction footprint but within the groundwater drawdown extent	This tract of vegetation is on the bank of Wolli Creek, near the edge of the drawdown boundary. It is unlikely that drawdown would have a significant impact.	Low

Impacts to wetlands from groundwater drawdown

Outside the study area is the Towra Point Wetlands. These wetlands are located 6.8 kilometres south of the study area, separated from the project by Botany Bay, and are a sufficient distance from the project to not be impacted by the drawdown around the tunnels. The Eve Street Marsh and Landing Lights wetlands are underlain by saturated alluvial sediments that flank Cooks River. The project tunnels would be located to the north of these wetlands within the Hawkesbury Sandstone. Any leakage from the alluvium into the sandstone and project tunnels would be replaced by surface water from Cooks River. In addition these wetlands are tidal and regularly flushed further suggesting the wetlands are unlikely to be impacted by the project.

Groundwater modelling has predicted that groundwater drawdown at Tempe Wetlands located close to Alexandra Canal would be negligible (CDM Smith, 2015). This is because the Cooks River and Alexandra Canal are tidal, with water levels controlled by the sea. Landing Lights Wetland, Eve Street Wetland and Marsh Street Wetland are located in alluvium, on the fringe of an area where there may be groundwater table decline when steady state has been reached. The presence of a low permeability organic layer beneath the alluvium would restrict groundwater leakage from the alluvium. In addition, groundwater drawdown at the wetlands may be less than predicted by the groundwater model as recharge over the alluvium is likely to be higher than the 40 millimetre per year set for the whole regional model. Furthermore, predicted drawdown may be less than calculated due to a phenomenon known as induced recharge. That is, as the groundwater table declines, the vegetation takes less water (evapotranspiration is reduced), such that the difference between (net recharge to the groundwater table) increases. Therefore, by this mechanism the predicted drawdown is less than actual.

Impacts to other vegetation from groundwater drawdown

There is potential for groundwater drawdown to impact trees near watercourses. The majority of the project alignment has a water table below about two metres depth and below the growth zone. Trees are not completely dependent on the water table, as trees survive in unsaturated soils and rocks. This would not change as the unsaturated zone is influenced by rain infiltration. In low lying areas the low permeability of the clayey soils in combination with frequent rainfall events and higher recharge due to surface water concentration is not expected to change availability of water for plants. The predicted drawdown at the various creeks varies depending on local geology, horizontal distance from the tunnel and depth to the tunnel.

Ground settlement

A list of reference buildings and assessment results for potential ground settlement impacts is provided in **Table 19-11**. These building locations have been identified along the project alignment in areas most likely to be affected by peak ground settlement effects based on tunnelling activities and local geology. **Table 19-12** provides a summary of maximum vertical settlement as calculated at key locations. **Figure 19-9** to **Figure 19-13** provide the predicted vertical settlement contours due to tunnel excavation along the project alignment.

Most of the buildings have a predicted settlement of less than 20 millimetres and have been assessed as having a building damage category of ‘negligible’. The exceptions are those buildings located nearest the tunnel portals and cavern locations. The Southern extension caverns and the M4-M5 Link caverns have a predicted settlement higher than 20 millimetres but are less than the limit of 30 millimetres for non-sensitive buildings. The St Peters interchange eastern portals predicted settlement exceeds the 30 millimetres for non-sensitive buildings.

Two buildings at Canal Road in St Peters have an assessed damage category of 'very slight'. These damage categories may result in cosmetic damage only. All investigated buildings have a maximum predicted slope less than 1:500.

Table 19-11 Select reference buildings and predicted settlement

Building reference	Address	Maximum settlement (mm)	Maximum slope (1:X)	Maximum tensile strain (%)	Damage category
B1	14-26 Commercial Road, Kingsgrove	12.1	1201	0.042	Negligible
B2	30 Commercial Road, Kingsgrove	13.1	1021	0.039	Negligible
B3	6 Shaw Street, Bexley North	9.5	3591	0.003	Negligible
B4	238 Slade Road, Bexley North	10.4	3760	0.004	Negligible
B5	197 Slade Road, Bexley North	10.3	3125	0.011	Negligible
B6	23-25 Forest Road, Arncliffe	6.5	10896	0.001	Negligible
B7	140 Princes Highway, Arncliffe	9.3	11381	0.001	Negligible
B8	132-138 Princes Highway, Arncliffe	9.2	9209	0.001	Negligible
B9	M5 East Motorway Control Centre	8.6	8893	0.004	Negligible
B10	32 Valda Avenue, Arncliffe	14.6	5720	0.002	Negligible
B11	24A Marsh Street, Arncliffe	24.0	2222	0.003	Negligible
B12	28 Marsh Street, Wolli Creek	22.0	2361	0.005	Negligible
B13	20 Levey Street, Wolli Creek (Mercure Sydney Airport)	10.0	4850	0.003	Negligible
B14	1 Levey Street, Wolli Creek	9.8	5869	0.002	Negligible
B15	728-750 Princes Highway, Tempe	8.8	6601	0.003	Negligible
B16	634-726 Princes Highway, Tempe	9.7	5636	0.006	Negligible
B17	545 Princes Highway, Tempe	24.5	2959	0.004	Negligible
B18	541-543 Princes Highway, Tempe	28.6	3699	0.006	Negligible
B19	9 Samuel Street, Tempe	25.8	2166	0.003	Negligible
B20	489 Princes Highway, Sydenham	9.1	10283	0.001	Negligible
B21	42 Reilly Lane, Sydenham	8.8	9583	0.001	Negligible
B22	459-461 Princes Highway, Sydenham	8.4	27218	0.001	Negligible

Building reference	Address	Maximum settlement (mm)	Maximum slope (1:X)	Maximum tensile strain (%)	Damage category
B23	574 Princes Highway, St Peters	7.7	5682	0.007	Negligible
B24	347 Princes Highway, St Peters	12.9	3035	0.003	Negligible
B25	380-396 Princes Highway, St Peters	8.7	3989	0.005	Negligible
B26	364-370 Princes Highway, St Peters	9.9	3548	0.028	Negligible
B27	321-323 Princes Highway, St Peters	10.0	10273	0.002	Negligible
B28	309 Princes Highway, St Peters	6.2	7660	0.011	Negligible
B29	295 Princes Highway, St Peters	7.4	6548	0.010	Negligible
B30	344 Princes Highway, St Peters	13.4	1725	0.007	Negligible
B31	340 Princes Highway, St Peters	19.3	1028	0.021	Negligible
B32	1-3 Canal Road, St Peters	16.9	649	0.065	Very slight
B33	6 Canal Road, St Peters	29.7	501	0.073	Very slight

Table 19-12 Maximum vertical settlement at key locations

Location	Maximum calculated surface settlement (mm)
Main alignment tunnels near the western surface works, Kingsgrove	25.5
Southern Connector Junction Caverns	24.3
St Peters Interchange Junction Caverns	28.5
St Peters interchange eastern portals	35.3

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Figure 19-9 Settlement contours - map 1

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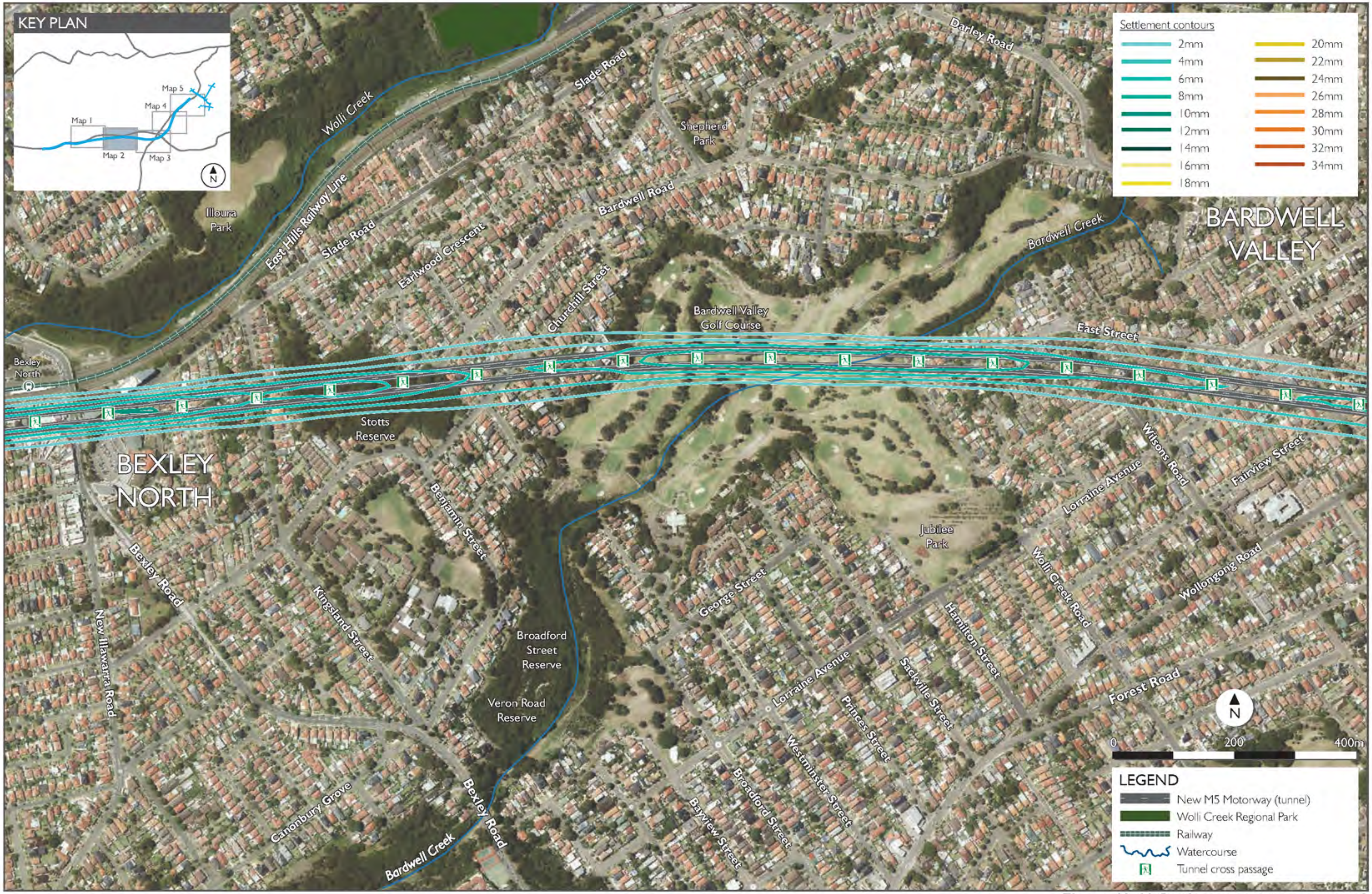

Figure 19-10 Settlement contours - map 2

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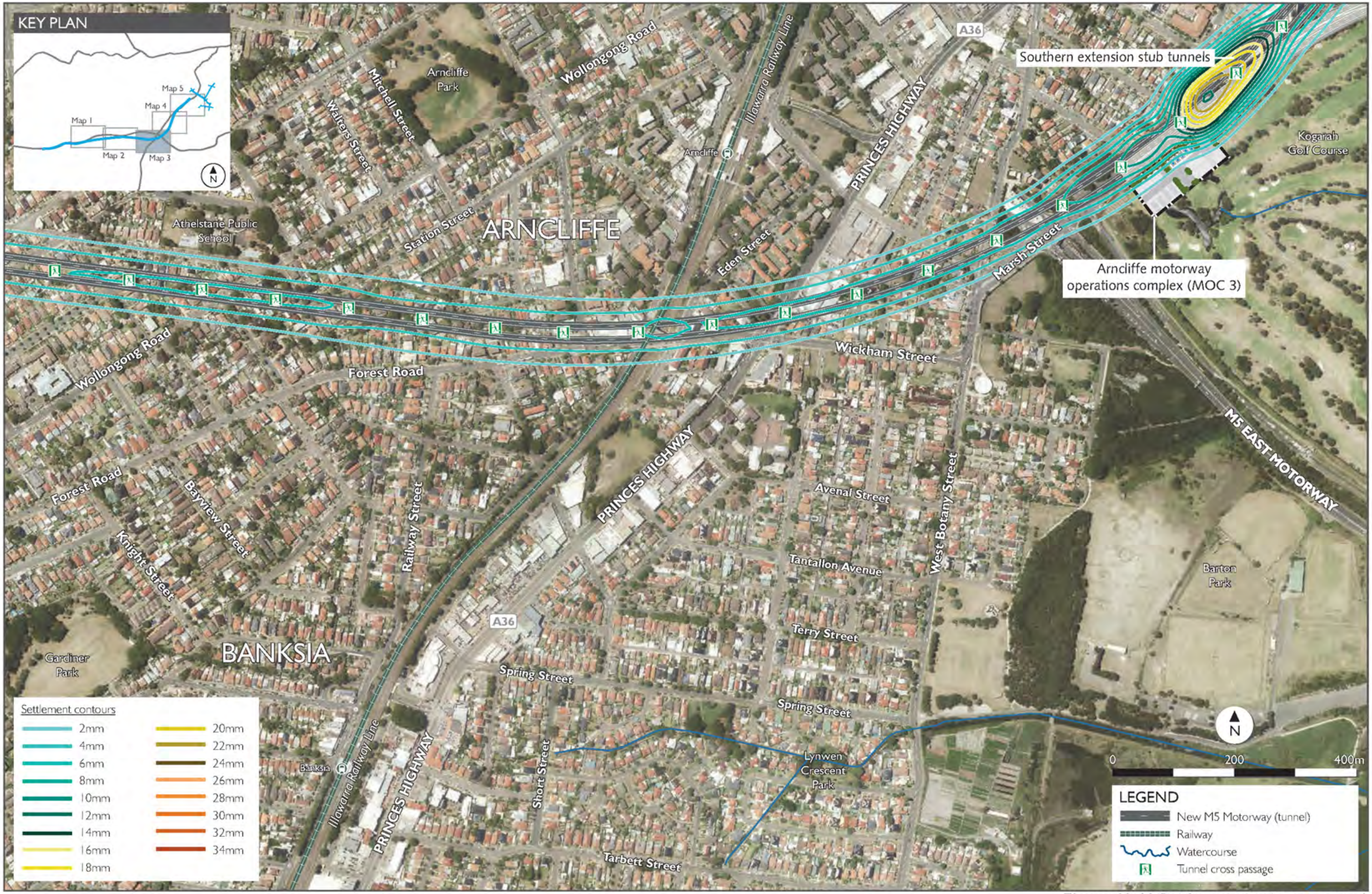

Figure 19-11 Settlement contours - map 3

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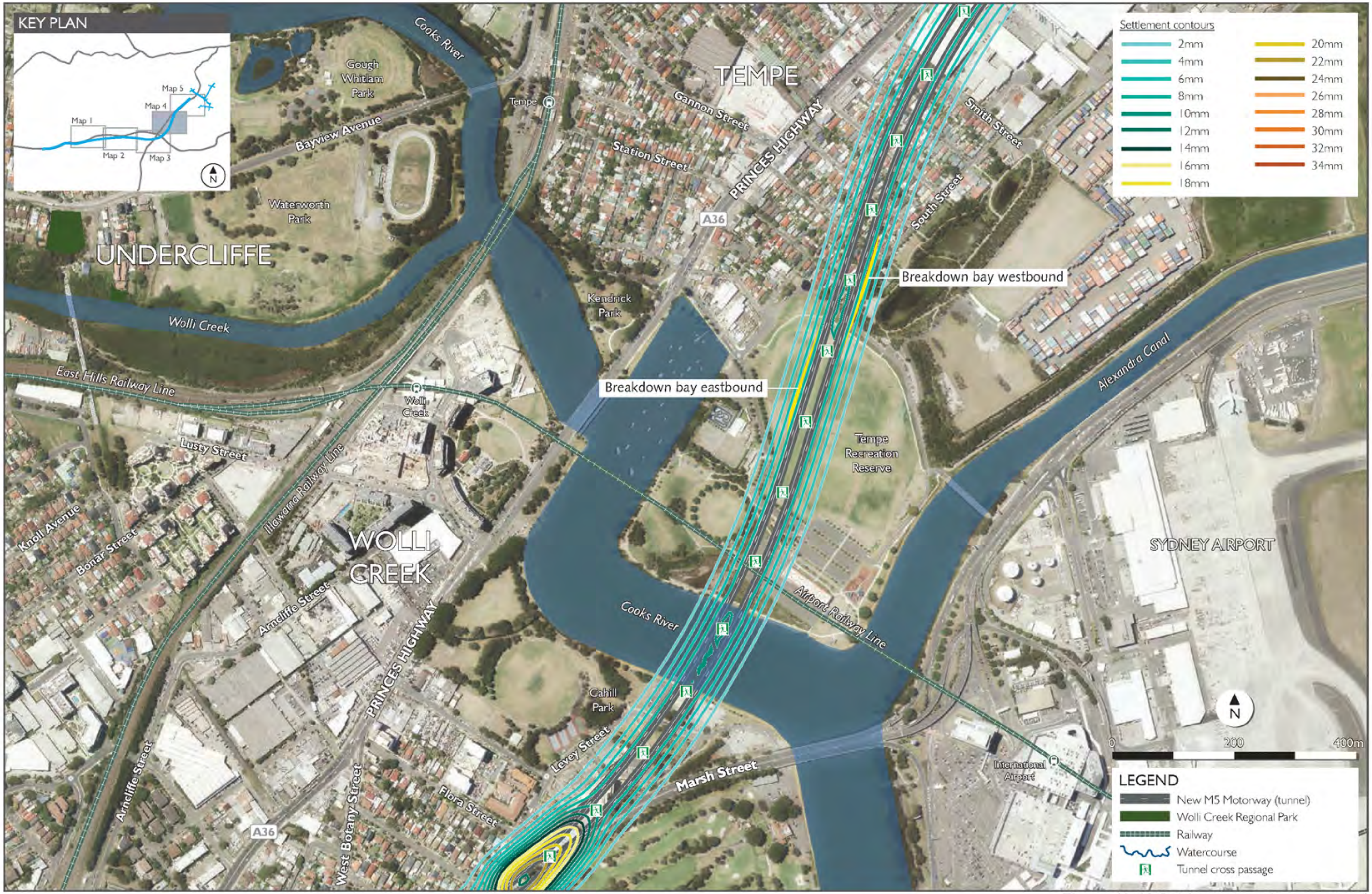

Figure 19-12 Settlement contours - map 4

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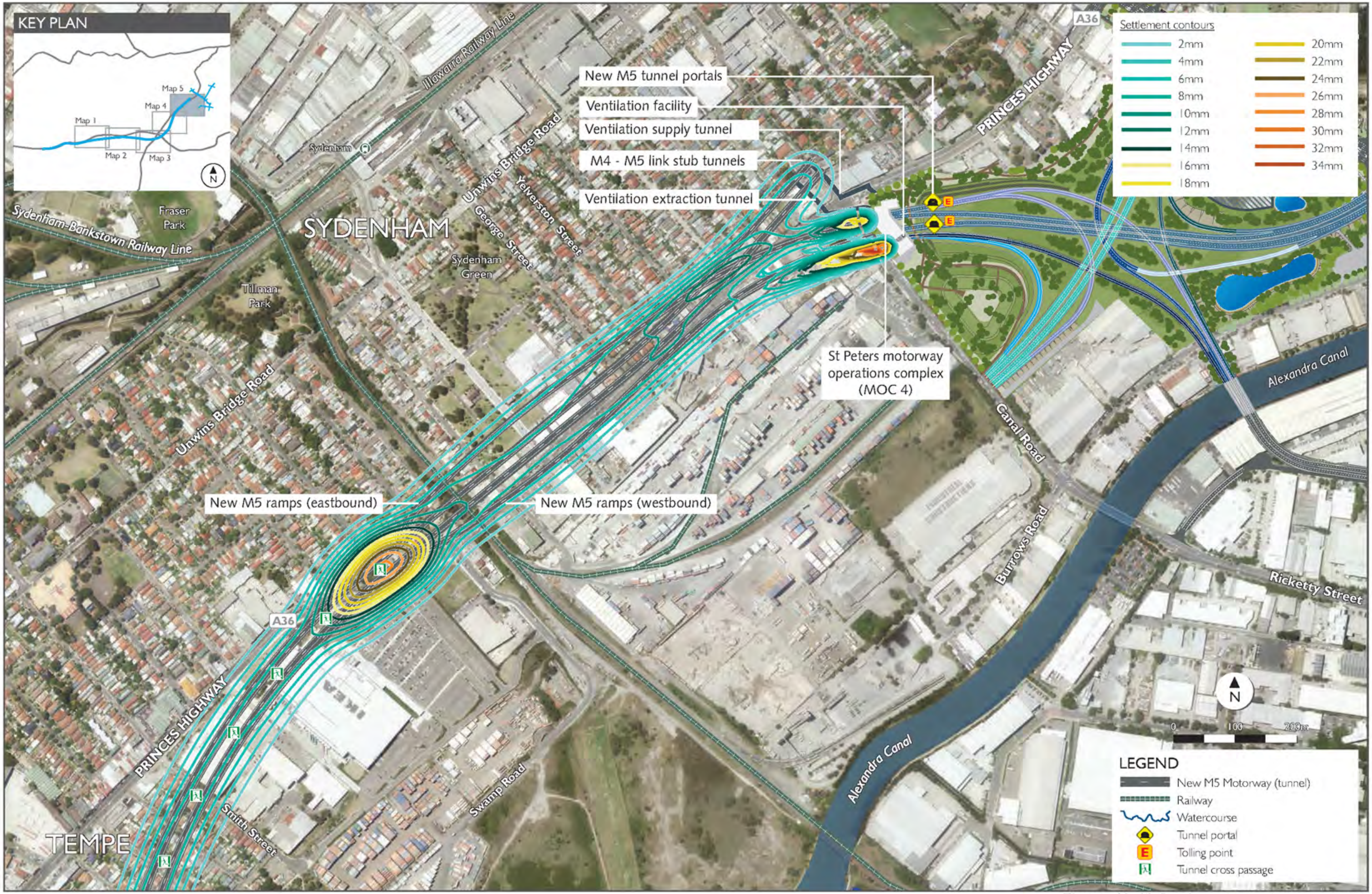

Figure 19-13 Settlement contours - map 5

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Potential settlement impacts on utilities have also been assessed. A summary of the utilities assessment is shown in **Table 19-13**

All of the assessed utilities have predicted settlement less than 40 millimetres and angular distortion predicted to be less than 1:250.

At Canal Road, St Peters the predicted settlement is 36.2 millimetres and the worst angular distortion is calculated as about 1:400. Potential settlement impacts in this location would be within acceptable limits, and represent the point of maximum predicted impact.

The predicted ground movement at rail lines and tunnels would also be less than the allowable limits adopted in this assessment.

Notwithstanding these results, and since the ground movement is approaching close to the vertical settlement and angular distortion limits for some roads, utilities and buildings, further detailed investigation would be carried out in these areas during the project's detailed design phase, and prior to construction. Where the risk of settlement induced damage is assessed to be high, additional ground support measures may be implemented to control ground movement and limit surface settlement.

Table 19-13 Utilities and predicted settlement

Category	Reference	Description/ location	Maximum settlement (mm)	Maximum slope (1:X)
Roads	U101	Kingsgrove Avenue, Kingsgrove	10.3	9992
	U102	Kingsgrove Road, Kingsgrove	8.0	2976
	U103	Bexley Road, Bexley North	9.8	3477
	U104	Princes Highway, Arncliffe	9.1	10129
	U105	West Botany Street, Arncliffe	8.8	9556
	U106	Marsh Street, Arncliffe	23.4	4609
	U107	Princes Highway, Tempe to St Peters	24.4	4701
	U108	Canal Road, St Peters	36.2	397
Utilities	U201	TransGrid transmission cable	6.0	14958
	U202	TransGrid transmission cable	10.9	5749
	U203	TransGrid transmission cable	35.5	411
	U204	Gas main	10.7	3559
	U205	Gas main	8.8	9311
	U206	Gas main	9.7	5502
	U207	Gas main	9.9	5172
	U208	Water main	9.9	7511
	U209	Sewer main	10.6	6462
	U212	Power line	8.7	8361
	U213	Power line	18.0	677
Other infrastructure	U301	M5 East Motorway, Kingsgrove	6.6	22301
	U302	M5 East Motorway tunnels, Bardwell Park	0.2	227145
	U303	M5 East Motorway tunnel portals westbound	9.3	6026
	U304	M5 East Motorway main tunnel portals westbound	9.8	5852
	U305	M5 East Motorway main tunnel portals eastbound	9.7	6045
	U306	M5 East Motorway ramp tunnel portals eastbound	8.9	6469
	U307	Passenger railway (Kingsgrove - Bexley North)	10.0	12494
	U308	Passenger railway (Arncliffe)	6.8	8643

Category	Reference	Description/ location	Maximum settlement (mm)	Maximum slope (1:X)
	U309	New Southern Railway (Tempe)	14.1	1466
	U310	Freight rail line, Sydenham	10.2	5544
	U311	Wolli Creek	24.0	528

Groundwater drawdown settlement

Settlement due to groundwater drawdown has been calculated based on geological interpretation of boreholes in the vicinity of the project tunnel. The drawdown at each borehole has been estimated and the resulting consolidation settlement calculated according to the depth of overlying soft ground and the degree of consolidation that may occur in that material.

Generally, in areas with the deepest sediment deposits, the drawdown settlement has been calculated to be 20 millimetres to 25 millimetres. This settlement is expected to decrease with distance from the project tunnels (due to smaller drawdown) and with shallower rock head level.

The assessment carried out does not take into account the degree of consolidation that may have already occurred due to previous projects. The impact of groundwater drawdown in the zone above the existing M5 East Motorway tunnels is expected to be reduced due to the drawdown that is anticipated to have already occurred in that area.

Combined settlement

For the Project, the maximum predicted settlement due to groundwater drawdown does not coincide with settlement due to ground loss.

The settlement caused by redistribution of stress around a tunnel usually occurs within a few days of the tunnel face advancing. The methodology for estimating such settlement is industry standard and is based upon an empirical methodology that dates back to the 1960s and which is extremely well documented. This methodology involves the estimation of a displacement field of horizontal and vertical movement. This is characterised by two parameters which are based both on previous history in very similar tunnels in Sydney and on the results of numerical modelling. The models prediction of the response of buildings and services to this type of settlement is also based on industry standard methodology, which is also extremely well documented. The response of the buildings are based on combining predictions of horizontal strain and bending strain imposed upon the buildings by the displacement field as calculated. In summary:

- Settlement caused directly by the tunnel excavation process occurs very quickly after the tunnel passes the point of concern
- There is a well-documented empirical and numerical methodology for predicting the displacements due to the tunnel excavation process
- There is a well-documented methodology for predicting the possibility of building damage caused by the above displacements
- The method states that building damage is caused by horizontal and bending movements imposed on the building by the above settlements.

In the case of settlement caused by groundwater drawdown, there are significant differences. Each of the calculation steps are subject to significant uncertainty. The predicted magnitude of the groundwater drawdown settlement can be quite high, but the settlement is usually spread over a wide area and is unlikely to cause significant horizontal strain or bending strain in buildings. The settlement that occurs due to groundwater drawdown generally occurs very slowly, possibly over years, and is often indistinguishable from settlement that is already occurring due to groundwater drawdown that might already be occurring and seasonal effects related to swell and shrinkage of the soil.

In summary:

- Settlement caused by groundwater drawdown can have a significant magnitude, yet not cause damage to buildings
- There is considerable uncertainty in the methodology and assumptions used in calculating this settlement.

For these reasons, it is considered that the two settlement predictions do not need to be combined. A prediction of five millimetres of groundwater drawdown settlement over the alignment is not significant and most groundwater drawdown settlement predictions involve zero horizontal strain and negligible bending due to the large area over which it occurs. It is likely that the ground already moves more than this in response to annual fluctuations of rainfall and evapotranspiration. However, a prediction of five millimetres is the industry standard threshold for tunnel excavation settlement, and numbers greater than this are associated with measurable and significant horizontal and bending strains on buildings and services.

Settlement near tunnel portals

Settlement associated with construction of the western tunnel portals and associated trough structure may arise from the drawdown of the groundwater table during construction. Predicted settlement associated with the trough structure at the western portals could be as high as 40 millimetres., However, it is expected that these calculated settlements would be an overestimate of settlement due to the conservative settlement model underestimating the level of pre-consolidation in the ground.

Settlement in the vicinity of the eastern portals would be limited due to the presence of shallow shale rock and the stiffness of the pile wall at the portals, adjacent to Canal Road. There may also be some minor settlement arising from the excavation of the driven tunnel with shallow rock cover under the road. Accordingly, the settlements arising from cut and cover construction are expected to be less than 25 millimetres.

Summary of impacts having regard to the Aquifer Interference Policy

The predicted groundwater impacts have been compared against the minimal impact criteria in the NSW Aquifer Interference Policy (NoW, 2012a).

The majority of the study area is considered to be within a ‘less productive groundwater source’ within fractured rock, based on the low number of registered bores in the area. The groundwater within the Botany Sands is considered to be in a ‘highly productive groundwater source’.

The minimal impact considerations for ‘less productive groundwater’ in a fractured rock aquifer are considered in **Table 19-14**. The minimal impact considerations for ‘highly productive groundwater’ in a coastal aquifer are presented in **Table 19-15**.

Table 19-14 Minimal Impact Considerations for a 'less productive fractured rock aquifer'

Minimal impact considerations	Response
Water Table – Level 1 Less than or equal to 10 per cent cumulative variation in the water table, allowing for typical climatic 'post water sharing plan' variations, 40 metres from any: High priority groundwater dependent ecosystem, or High priority culturally significant site listed in the schedule of the relevant water sharing plan, or A maximum of a two metre decline cumulatively at any water supply work.	There are no high priority GDEs listed under Schedule 4 of the Greater Metropolitan Regional Groundwater Sources Water Sharing Plan that are within the Hawkesbury Sandstone or Ashfield Shale. No culturally significant sites have been identified in the Greater Metropolitan Regional Groundwater Water Sharing Plan. Groundwater modelling has indicated that there is one registered bore within a one kilometre radius of the project tunnels that intersects Hawkesbury Sandstone and the groundwater drawdown at this location is predicted to be in excess of two metres. In this case the bore is 186 metres deep and the predicted drawdown is 5.7 metres. This impact could potentially be addressed by lowering the pump in the borehole by five to 10 metres.
Water Table – Level 2 If more than 10 per cent cumulative variation in the water table, allowing for typical climatic 'post water sharing plan' variations, 40 metres from any: High priority groundwater dependent ecosystem, or high priority culturally significant site, listed in the schedule of the relevant water sharing plan, if appropriate studies demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than a two metre decline cumulatively at any water supply work then make good provisions should apply.	
Water Pressure – Level 1 A cumulative pressure head decline of not more than a two metre decline, at any water supply work.	The groundwater modelling has included the cumulative impacts of the existing M5 East Motorway tunnels. Mitigation measures have been recommended for the one bore where it has been predicted that the drawdown exceeds a water level decline of more than two metres. This mitigation measure includes lowering the pump in the borehole by five to 10 metres.
Water Pressure – Level 2 If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	

Minimal impact considerations	Response
Water Quality – Level 1 Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	The beneficial use category of groundwater will not be changed beyond 40 metres of the tunnel. Level 2 does not apply as Level 1 criteria are not exceeded.
Water Quality – Level 2 If the Level 1 requirement is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.	

Table 19-15 Minimal impact considerations for a 'highly productive coastal aquifer'

Minimal impact considerations	Response
Water Table – Level 1 Less than or equal to 10 per cent cumulative variation in the water table, allowing for typical climatic 'post water sharing plan' variations, 40 metres from any: High priority groundwater dependent ecosystem, or High priority culturally significant site listed in the schedule of the relevant water sharing plan, or A maximum of a two metre decline cumulatively at any water supply work.	There are no high priority GDEs listed under Schedule 4 of the Greater Metropolitan Regional Groundwater Sources Water Sharing Plan. There are two wetlands near the project corridor at Tempe known as the Eve Street Wetland and Landing Lights Wetland. Groundwater modelling conducted as part of this investigation suggests that the groundwater table at these wetlands is unlikely to undergo a water level decline of more than two metres. No culturally significant sites have been identified in the Greater Metropolitan Regional Groundwater Water Sharing Plan

Minimal impact considerations	Response
Water Table – Level 2 If more than 10 per cent cumulative variation in the water table, allowing for typical climatic ‘post water sharing plan’ variations, 40 metres from any: High priority groundwater dependent ecosystem, or high priority culturally significant site, listed in the schedule of the relevant water sharing plan, if appropriate studies demonstrate to the Minister’s satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than a two metre decline cumulatively at any water supply work then make good provisions should apply.	Groundwater modelling has predicted that three water supply bores within a one kilometre radius of the project tunnels are likely to be drawn down by more than two metres. Mitigation measures for these impacts include drilling deeper bores at these locations, or if not possible providing connection to the reticulated water supply or providing monetary compensation.
Water Pressure – Level 1 A cumulative pressure head decline of not more than a two metre decline, at any water supply work.	The groundwater modelling has included the cumulative impacts of the existing M5 East Motorway tunnels. Mitigation measures have been provided for the three water supply bores where it has been predicted that the drawdown exceeds a water level decline of more than two metres. Mitigation measures for these impacts include drilling deeper bores at these locations, or if not possible providing connection to the reticulated water supply or providing monetary compensation.
Water Pressure – Level 2 If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister’s satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	
Water Quality – Level 1 Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity	The beneficial use category of groundwater would not be changed beyond 40 metres of the project tunnels. Level 2 does not apply as Level 1 criteria are not exceeded.
Water Quality – Level 2 If the Level 1 requirement is not met then appropriate studies will need to demonstrate to the Minister’s satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.	

19.4 Environmental management measures

Mitigation and management measures would be implemented during construction and operation of the project to reduce or eliminate the risks posed to the existing groundwater regime. These environmental mitigation measures, including management, engineering solutions and monitoring, are summarised in **Table 19-16**.

Table 19-16 Environmental mitigation and management measures – groundwater

Impact	No.	Environmental management measure	Timing
Construction			
Disturbance of acid sulfate soils during excavation	GW01	An Acid Sulfate Soil Management Plan (ASSMP) would be prepared including the measures and monitoring to be undertaken where potential acid sulfate soils are expected. The plan would outline the type of treatment required for acid sulfate soils, bunding and requirement for treatment ponds.	Pre-Construction
Intersection of saline soils and groundwater	GW02	A groundwater and soil salinity report would be prepared prior to the commencement of earthworks to assess the potential impacts to the local hydrogeological regime.	Pre-Construction
Failure of the leachate pumping system	GW03	Contingency measures to address leachate management at the Alexandria Landfill during construction and prior to the commissioning of the new leachate treatment plant would be explored during detailed design. Identified measures would be detailed in the Construction Environmental Management Plan and implemented during construction.	Construction
Migration of contaminated groundwater into the tunnels.	GW04	The tunnel construction program would be constructed in accordance with an overarching Construction Environmental Management Plan for the project which would include measures to manage contaminated groundwater issues. This may include removal of the source of the contamination by excavation and remediation of shallow impacted soils or engineering a solution to prevent the migration of contaminated groundwater into the tunnels.	Construction
Intersection of shallow perched groundwater within Alexandria Landfill or Botany Sands	GW05	Intersected shallow contaminated groundwater would be directed to the construction water treatment plant prior to discharge. Elsewhere, collection and treatment options would be considered and releases made under relevant discharge criteria.	Construction

Impact	No.	Environmental management measure	Timing
Intersection of shallow contaminated groundwater during construction activities at Arncliffe	GW06	The intersection of shallow groundwater at the Arncliffe construction compound (C7) would be managed under Construction Environmental Management Plan(s) for the project. In the event that contaminated groundwater is intersected the approach would be to either remove the source of the contamination by excavation and remediation of shallow impacted soils or engineering a solution to prevent the migration of contaminated groundwater into the project tunnels.	Construction
Unsustainable release of groundwater resources	GW07	Treated waste water would be stored and re-used for project purposes wherever possible. Groundwater reuse would be in accordance with the policies of sustainable water use of the NSW Office of Water, such as dust suppression and earthworks	Construction
Excessive inflows during construction that may exceed the design inflow criterion of 1L/sec/km	GW08	Where saturated faults and fractures are intersected additional rock support would be installed in order to ensure tunnel stability. Appropriate waterproofing measure to reduce the inflow to an acceptable quantity will be applied as required. Measures can range from a spray- on membrane to grouting or installation of a sheet membrane	Construction
Possible high groundwater inflows and sustained pressure heads (no drawdown) beneath the Cooks River and higher fracture permeabilities	GW09	Where higher than expected inflows are experienced as beneath the Cooks River and under other major surface water features, appropriate waterproofing measure to permanently reduce the inflow to an acceptable quantity will be applied as required. Measures can range from a spray-on membrane to grouting or installation of a sheet membrane depending on the inflow volume	Construction
Aggressive groundwater chemistry such as elevated sodium, chloride, ammonia, low pH conditions that are aggressive to concrete and steel.	GW10	Building materials that are resistant to aggressive groundwater conditions would be selected.	Detailed design

Impact	No.	Environmental management measure	Timing
Spills and incidents relating to fuels, oils, lubricants and refuelling.	GW11	The project works would be undertaken in accordance with a Construction Environmental Management Plan(s) for the project which would include the following management measures: • Stockpiles of fuels, hazardous liquids and chemicals would be stored in an impervious bunded area in accordance with Australian Standards and EPA guidelines • The storage of fuels and chemicals would be limited to locations more than 40 metres from any water course • Refuelling of vehicles and machinery would occur off-site where possible or in a designated re-fuelling area • Vehicles would be properly maintained to minimise the risk of fuel/oil leaks and routine inspections of construction equipment would be undertaken to identify any fuel/oil leaks • Emergency spill kits would be kept on-site and project personnel would be aware of the location of spill kits and trained in their use • Hazardous materials handling procedures would be documented and implemented • In the event of an incident resulting in impacts to human health or the environment, works would cease immediately and the EPA would be notified (if required) • Erosion and sediment control measures would be regularly inspected, and particularly following rainfall events. The controls would remain in place until construction works are completed and areas are stabilised	Construction
Groundwater inflow into tunnels exceeding project requirements	GW12	A tunnelling procedure that details a methodology to determine when and what type of waterproofing is required to be installed during construction would be implemented during construction. Pre-excavation pressure grouting may also be used in locations identified that could produce substantial inflows to reduce groundwater inflows to an acceptable level. Post grouting (ie grouting undertaken post excavation) may also be required to further reduce groundwater inflows. Post grouting would occur within one month post excavation.	Construction

Impact	No.	Environmental management measure	Timing
Construction of the tunnels could adversely impact surface and groundwater quality, resources and wetlands.	GW13	A groundwater monitoring program would be prepared and implemented to monitor groundwater impacts during construction. The program would be developed in consultation with the EPA, DPI (Fisheries), NSW DPI Water and relevant councils.	Construction
Cracking creek beds, localised elevated inflows to tunnels from fractured rock beneath the creeks and potential surface environmental consequences from the increased flows	GW14	Where the project alignment passes close to watercourses and inflows are elevated, appropriate waterproofing measures to permanently reduce the inflow to an acceptable quantity would be applied as required	Construction
Impact to existing registered bores.	GW15	In the event that the drawdown in a water supply bore or irrigation bore exceeds two metres (in accordance with the Aquifer Interference Policy) measures would be taken to 'make good' the impact by restoring the water supply to pre-development levels. The measures taken would be dependent upon the location of the impacted bore and would be determined in consultation with the affected licence holder but could include, deepening the bore, providing a new bore or providing an alternative water supply.	Construction Operation
Ground settlement	GW16	A Settlement Monitoring Plan would be prepared that would provide details on: • Location of monitoring points • Duration of monitoring • Data collection and review • Roles and responsibilities for review of data • Triggers and actions for corrective actions	Construction
	GW17	Building conditions surveys would be undertaken in the zone of influence of the tunnel settlement where the settlement is expected to have a potential impact. In the unlikely event that any damage occurs to a property, appropriate rectifications would be carried out.	Construction
	GW18	Services in locations where differential/ angular settlement is anticipated would be identified. A monitoring plan, triggers and actions would be agreed with the relevant utility owner prior to potential impacts occurring.	Construction

Impact	No.	Environmental management measure	Timing
	GW19	A monitoring program, undertaken as part of the Settlement Management Plan, would be carried out prior to excavation until all relevant settlement has stabilised. Monitoring would be for a period of not less than six months after settlement has stabilised.	Construction
Operation			
On-going groundwater extraction and treatment during operation	OpGW01	An OEMP would be prepared and implemented to outline management measures for groundwater inflows, treatment and discharge and protocols for spillages or incidents. Monitoring parameters may include groundwater levels, groundwater quality including field parameters, laboratory analytes and sample frequency.	Operation
Build-up of precipitated iron (slimes) and silt and sand due to slaking of the sandstone.	OpGW02	The drainage system would be regularly maintained in accordance with the Operational Environmental Management Plan.	Operation
Impact on surface and groundwater quality, resources and wetlands as a result of operation	OpGW03	A groundwater quality monitoring program would be prepared and implemented to monitor groundwater impacts during tunnel operations. The program would be developed in consultation with the EPA, DPI (Fisheries), NSW DPI Water and relevant councils.	Operation
Failure of the leachate pumping system	OpGW04	Contingency measures to address leachate management in the event of pump failure would be explored during detailed design and implemented in the Landfill Closure Plan.	Operation

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