17 Groundwater and geology

This chapter outlines the potential groundwater and geology impacts associated with the project. A detailed groundwater assessment has been undertaken for the project and is included in **Appendix K** (Groundwater technical report). A qualitative subsidence assessment is included in this chapter.

Table 17-1 sets out the SEARs relevant to groundwater and geology and identifies where the requirements have been addressed in this EIS.

Table 17-1 SEARs – Groundwater and geology

SEARs	Where addressed in this EIS
Health and safety	
The assessment must: 2 (f) assess the likely risks of the project to public safety, paying particular attention to pedestrian safety, subsidence risks, bushfire risks and the handling and use of dangerous goods	Section 17.3.3 and section 17.4.3
Socio-economic, Land Use and Property	
4. The Proponent must assess potential impacts on the Muddy Creek constructed channel such as damage due to subsidence.	Section 17.4.10
Water - Hydrology	
1. The Proponent must describe (and map) the existing hydrological regime for any surface and groundwater resource (including reliance by users e.g. bore water for domestic use and irrigation, and for ecological purposes and groundwater dependent ecosystems) likely to be impacted by the project, including rivers, streams, wetlands and estuaries as described in Appendix 2 of the Framework for Biodiversity Assessment – NSW Biodiversity Offsets Policy for Major Projects (OEH, 2014).	Section 17.2, Chapter 12 (Biodiversity) and Chapter 18 (Surface water and flooding)
2. The Proponent must prepare a detailed water balance for ground and surface water including the proposed intake and discharge locations (including mapping of these locations), volume, frequency and duration for both the construction and operational phases of the project.	Section 17.3.8, section 17.4.9 and Chapter 18 (Surface water and flooding)
3. The Proponent must assess and model the impact of the construction and operation of the project and any ancillary facilities (both built elements and discharges) on surface and groundwater hydrology in accordance with the current guidelines, including:	Refer below
(a) natural processes within rivers, wetlands, estuaries, and floodplains that affect the health of the fluvial, riparian, estuarine systems and landscape health (such as modified discharge volumes, durations and velocities), aquatic connectivity, water dependent fauna and flora and access to habitat for spawning and refuge;	Chapter 12 (Biodiversity) and Chapter 18 (Surface water and flooding)
(b) impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, change in groundwater levels, barriers to flows, implications for groundwater dependent on surface flows, ecosystems and species, groundwater users and the potential for settlement	Section 17.3 and section 17.4
(c) changes to environmental water availability and flows;	Section 17.3 and section 17.4
(f) measures to mitigate the impacts of the proposal and manage the disposal of produced and incidental water	Chapter 18 (Surface water and flooding)
4. The assessment must provide details of the landform (following completion) of the sites to be excavated or modified (e.g. portals and cut and cover works), including void management and rehabilitation measures.	Section 17.4.7
5. The Proponent must identify any requirements for baseline monitoring of hydrological attributes	Section 17.1.3

SEARs	Where addressed in this EIS
6. The assessment must include details of proposed surface and groundwater monitoring	Section 17.3.5 and section 17.4.8
7. Proposed tunnels must be designed to minimise impacts on aquifers, groundwater flows and groundwater dependent ecosystems	Section 17.2.1, section 17.2.4, section 17.2.8 and section 17.3.3.
Water - Quality	
1. The Proponent must: (a) describe the background conditions for any surface or groundwater resource likely to be affected by the development	Section 17.2.
(j) identify proposed monitoring locations, monitoring frequency and indicators of surface and groundwater quality	Section 17.4.8
Soils	
5. The Proponent must assess whether salinity is likely to be an issue and if so, determine the presence, extent and severity of soil salinity within the project area	Section 17.2.4 and section 17.3.4
6. The Proponent must assess the impacts of the project on soil salinity and how it may affect groundwater resources, hydrology and vegetation	Section 17.3.3 and section 17.4.3
8. The Proponent must assess the impact of any disturbance of contaminated groundwater and the tunnels should be carefully designed so as to not exacerbate mobilisation of contaminated groundwater and/or prevent contaminated groundwater flow	Section 17.2.5, section 17.3.4 and section 17.4.4

17.1 Assessment approach

A groundwater assessment has been undertaken to address the relevant SEARs outlined in **Table 17-1**. The groundwater assessment has been reviewed by an independent technical peer reviewer in accordance with the *Australian Groundwater Modelling Guidelines*[1]. The assessment describes the existing groundwater environment and determines the potential impacts of the construction and operational of the project on groundwater flows, groundwater levels and water quality. A summary of the groundwater assessment for the project is provided in this chapter. The full assessment is included in **Appendix K** (Groundwater technical report) and 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 tunnels on groundwater dependant ecosystems (GDEs) and surrounding environment using numerical modelling techniques to quantify impacts
- Groundwater management and monitoring measures required to manage potential impacts on the groundwater regime.

The assessment has been undertaken with consideration of relevant legislation, policies, guidelines and water sharing plans listed below and in **Table 17-2**.

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[1] Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A and Boronkay A (2012); Australian Groundwater Modelling Guidelines, Waterlines Report Series No 82, National Water Commission, Canberra, 191 pp. June.

Table 17-2 Overview of relevant groundwater legislation and policy

Legislation or policy	Relevance
Water Management Act 2000 (NSW) (WM Act)	• Section 5.23(1)(g) of the EP&A Act provides for the exemption of state significant infrastructure projects from requiring a water use approval, a water management approval or an activity approval (other than an aquifer interference approval) • Provides for the administration of water sharing plans • It should be noted that aquifer interference activity approval provisions have not yet commenced, but are administered under the WM Act.
Water Act 1912 (NSW)	• Provides for the administration of water access licenses and the trade of water licences and allocations.
NSW Aquifer Interference Policy	• Manages the impacts of aquifer interference activities in accordance with the WM Act and water sharing plans • The policy prescribes that aquifer interference activities must address minimal impact considerations • The policy prescribes that in the event that actual impacts are greater than predicted there should be sufficient monitoring in place.
Water Sharing Plan, Greater Metropolitan Region, Groundwater Sources	• Water sharing plans manage the long term surface and groundwater resources of a defined area • The Water Sharing Plan, Greater Metropolitan Region, Groundwater Sources outlines rules for the sharing and sustainability of water between various uses such as town water supply, stock and domestic, industry and irrigation.

The compliance of the project with the legislation and guidelines outlined in **Table 17-2** is demonstrated in detail in **Appendix K** (Groundwater technical report).

This report has been prepared with reference to the following documents:

- *NSW State Groundwater Policy Framework Document* (NSW Department of Land and Water Conservation (DLWC) 1998)
- *NSW Groundwater Quality Protection Policy* (DLWC 1998)
- *NSW Groundwater Dependent Ecosystems Policy* (DLWC 2002)
- *NSW Groundwater Quantity Management Policy* (DLWC undated)
- *Risk assessment guidelines for groundwater dependent ecosystems* (NSW Office of Water (NoW) 2013a)
- Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) *National Water Quality Management Strategy Australian Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ 2000)
- *NSW Water Extraction Monitoring Policy* (NSW Department of Water and Energy (DWE) 2007)
- *NSW Aquifer Interference Policy* (NoW 2012)
- *Guidelines for riparian corridors on waterfront land* (DPI 2012)
- *Acid Sulfate Soils Assessment Guidelines* (NSW Department of Planning (DoP) 2008)
- *Acid Sulfate Soils Manual* (Acid Sulfate Soils Management Advisory Committee 1998)
- *Framework for Biodiversity Assessment – Appendix 2* (NSW Office of Environment and Heritage (OEH) 2014)

- Managing Urban Stormwater: Soils and Construction Volume 1 (Landcom 2004) and Volume 2 (NSW Department of Environment, Climate Change (DECC) 2008)
- *NSW Sustainable Design Guidelines Version 4.0* (Transport for NSW 2017)
- *Risk Assessment Guidelines for Groundwater Dependent Ecosystems* (NoW 2012)
- *Using the ANZECC Guidelines and Water Quality Objectives in NSW* (NSW Department of Environment and Conservation (DEC) 2006)
- *Approved Methods for sampling and Analysis of Water Pollutants in NSW* (DECC 2008)
- *Overview of the Australian Guidelines for Water Recycling: Managing Health and the Environmental Risks. National Resource Management Ministerial Council Environmental Protection and Heritage Council* (Australian Health Ministers Conference, 2006).

A qualitative assessment of the potential for the project to create ground movements and settlement was also undertaken.

17.1.1 Study area

A three-dimensional numerical groundwater model was developed to predict future groundwater conditions and potential impacts related to the project (refer to **section 17.1.5**).

For the purposes of the groundwater impact assessment, the study area is the domain considered by the groundwater model. The model domain (study area) includes the operational infrastructure of the project, extending outwards into areas where potential groundwater impacts could occur as a result of construction or operation of the project. The study area is shown in **Figure 17-1** and covers an area of around 90 square kilometre area bounded by:

- Botany Bay, Botany, Eastlakes, Roseberry and Zetland to the east
- Ashbury, Dulwich Hill, Enmore and Erskineville to the north
- Hurlstone Park, Earlwood, Bardwell Park, Bexley, Carlton, Carss Park and Blakehurst to the west and
- Sans Souci to the south.

The study area partially includes the M4 East, the New M5 Motorway and the M4 M5 Link motorways to predict cumulative drawdown impacts.

For the purposes of assessing the potential for ground movements, the area of potential impact was identified by adopting an angle of draw of 15 degrees from the depth of the tunnel. This is the zone of expected ground movements relating to the project, although the range of movement is related to the tunnel depth at each location.

17.1.2 Desktop study

The following database searches were conducted to summarise the existing environment:

- *Australian Soils Resource Information System acid sulfate soils*, accessed December 2017
- Bureau of Meteorology *Australian Groundwater Explorer*, (formerly DPI-Water groundwater database) accessed December 2017
- *Greater Metropolitan Regional Groundwater Sources Water Sharing Plan*, Appendix 4
- Bureau of Meteorology Atlas of Groundwater Dependent Ecosystems, accessed January 2018
- Bureau of Meteorology online climate data, accessed January 2018
- NSW Environment Protection Authority (NSW EPA) Contaminated Land Record, accessed January 2018.

17.1.3 Field investigation

Groundwater field investigations, including drilling boreholes, monitoring well installation, water pressure testing, groundwater gauging, groundwater sampling and hydrogeochemical analysis, were undertaken across the study area as part of the F6 Extension geotechnical drilling program initially between October 2014 and March 2015 and later between July 2016 and February 2018. Groundwater monitoring has been undertaken at 20 monitoring well locations which are shown in **Figure 17-2** and this monitoring is ongoing.

Groundwater data collected included:

- Hydraulic conductivity (i.e. the rate at which groundwater naturally moves through the rock or sediments)
- Groundwater levels (including fluctuations), determined through groundwater gauging (i.e. monitoring levels in groundwater wells) and data loggers
- Groundwater quality, determined through hydrogeochemical sampling and analysis.

Hydraulic conductivity

Hydraulic conductivity assists in the understanding of tunnel water inflows or the local drawdown (i.e. the reduction in the water level) 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).

Packer tests (or water pressure tests) were conducted to measure the hydraulic conductivity of selected rock mass intervals. Packer tests involve injecting water under pressure into a 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. Site specific hydraulic conductivity tests by slug testing was conducted by SMEC, 2018 (refer to section 4 of **Appendix K** (Groundwater technical report) for further information).

Groundwater levels

Groundwater gauging was conducted throughout the field programs, measuring standing water levels manually with an electronic dipper. The data loggers were then installed to measure groundwater level fluctuations automatically at one hourly intervals. The loggers were suspended in each monitoring well at a depth of about five metres below the standing water level.

Groundwater quality

Groundwater samples were collected from the monitoring well network for laboratory analysis. Groundwater was sampled and analysed to characterise the local groundwater quality of each of the main hydrogeological units; specifically to identify any spatial and temporal variability, and to identify potential groundwater contamination.

Groundwater quality samples were tested for the following components:

- Heavy metals and metalloids (including arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel and zinc)
- Nutrients (nitrate, nitrite, ammonia and reactive phosphorous)
- Benzene, toluene, ethylbenzene, xylene and naphthalene (BTEXN)
- Total recoverable hydrocarbons (TRHs)
- Polycyclic aromatic hydrocarbons (PAHs)
- Inorganics and field parameters (including major anions and cations, alkalinity, ammonia, temperature, 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)

- Polyfluoroalkyl Substances (PFAS) (tested at one location in the alluvium).

Groundwater aggressivity was also assessed, to gauge the extent to which the natural groundwater may corrode or degrade materials such as steel and concrete, which may be used in the construction of tunnel infrastructure.

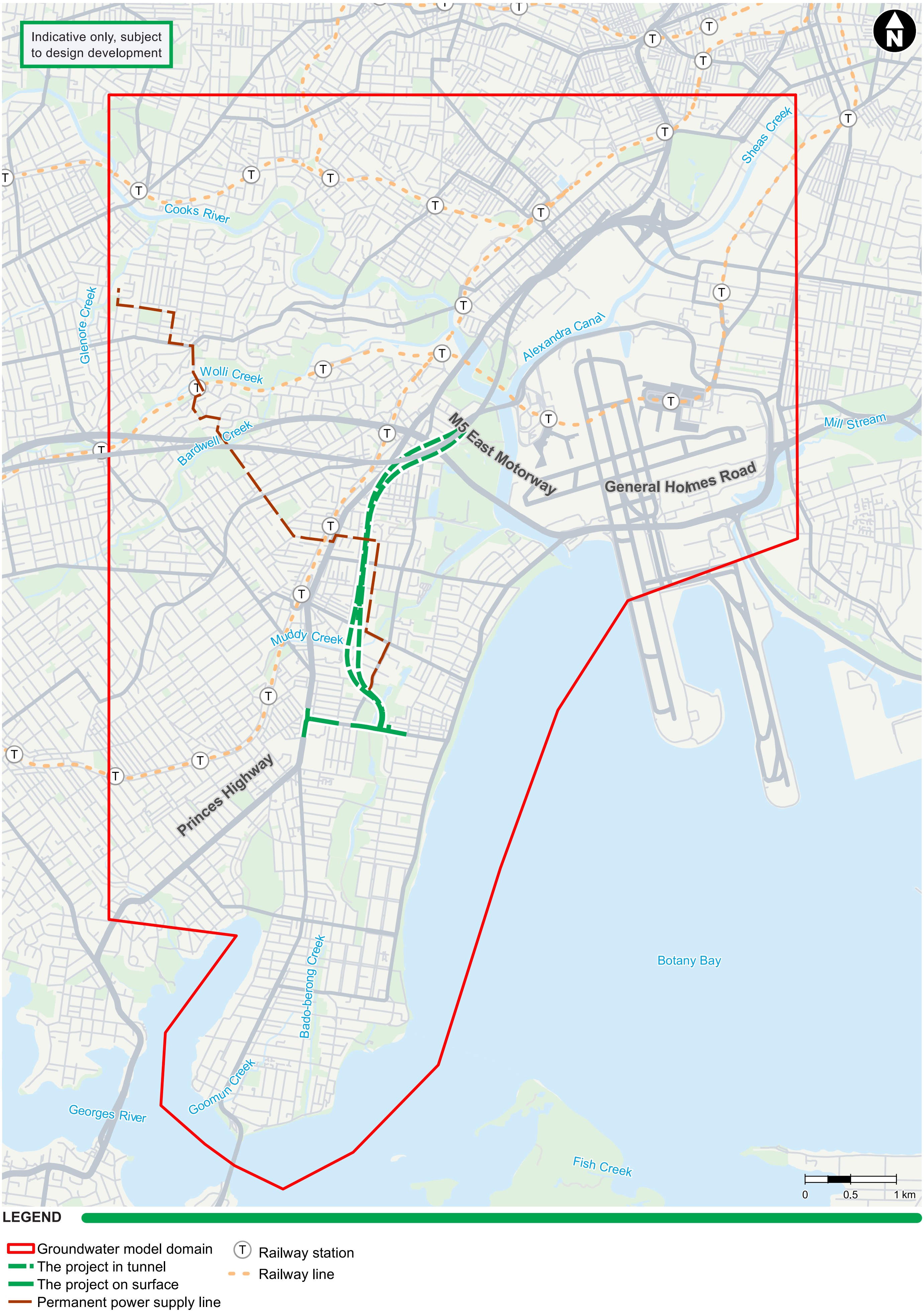
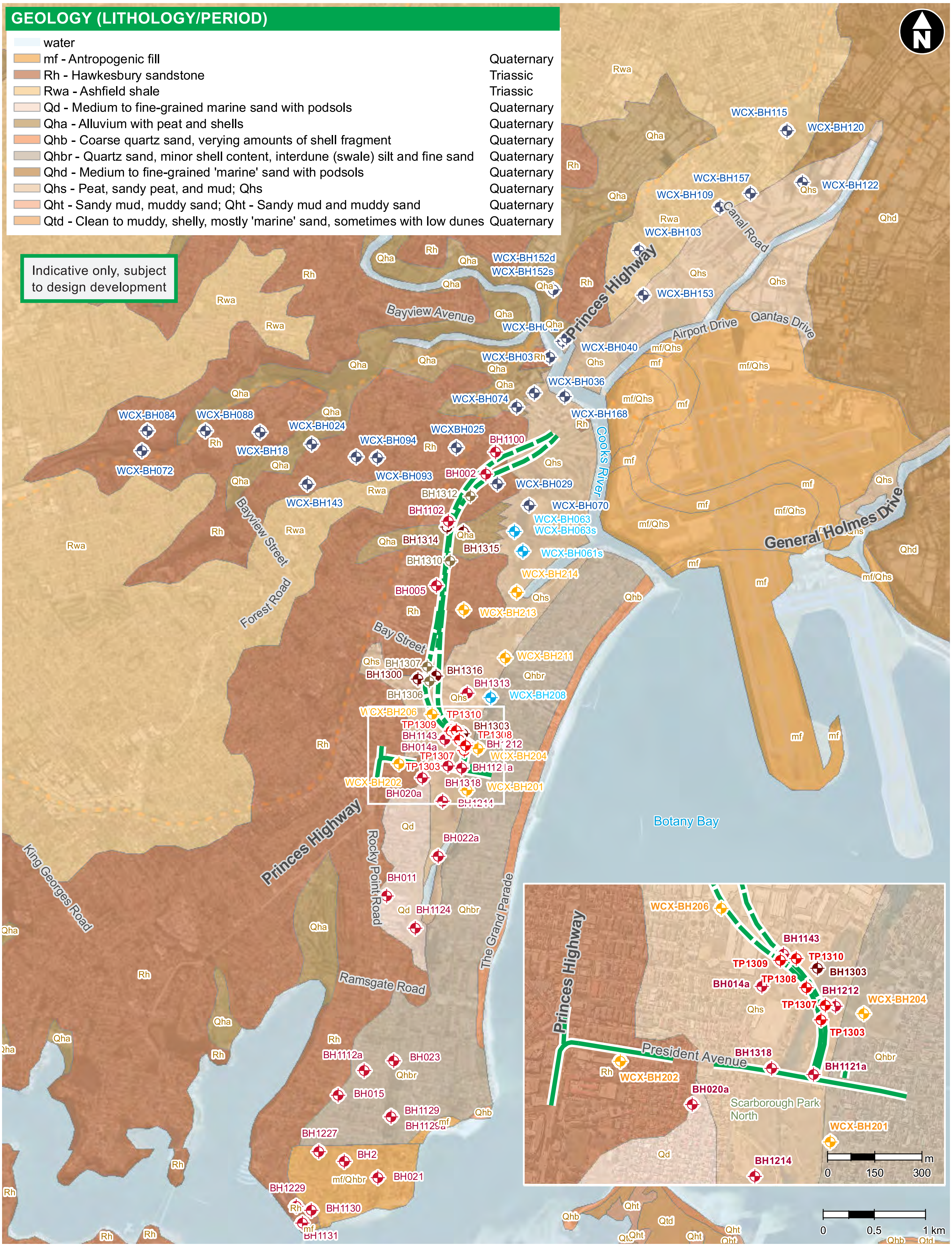


Figure 17-1 Groundwater assessment study area



LEGEND

- The project in tunnel
- The project on surface
- F6 Monitoring well location
- F6 Vibrating wire piezometer
- Monitoring well location RMS, 2015
- Test Pit location SMEC, 2018
- Monitoring well location AECOM, 2017
- Monitoring well location SMEC, 2018
- New M5 Monitoring well location, AECOM (unpublished)

Figure 17-2 Groundwater monitoring locations

17.1.4 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. Priority GDEs are ecosystems with a high ecological value which are considered high priority for management action as defined in the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources* (2011). Sources reviewed to understand potential GDEs that may be affected by the project include:

- *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011*. Schedule 4 of the Plan identifies high priority GDEs and Appendix 2 identifies GDEs
- Atlas of Groundwater Dependent Ecosystems
- The Biodiversity Assessment Report for the project as contained in **Appendix H** (Biodiversity development assessment report).

17.1.5 Groundwater modelling

A three-dimensional numerical groundwater model was developed in accordance with the Australian Groundwater Modelling Guidelines[2] to simulate existing groundwater conditions, project infrastructure, caverns and associated subsurface ancillary infrastructure including ventilation shafts. The active model domain extends over a 7.5 x 12 kilometre area centred on the project alignment as shown in **Figure 17-1**. The model domain partially includes the New M5 Motorway and the M4-M5 Link motorways to predict cumulative drawdown impacts. The model also allows for future stages of the F6 Extension (subject to separate assessment and planning approval).

The groundwater model was used to predict future groundwater conditions and potential impacts related to the project during the construction and operational phases. Both steady state (where the magnitude and direction of flow is constant across the whole model domain) and transient (where the magnitude and direction of flow is changing across the model domain) models were developed and calibrated.

Three predictive model scenarios were run to replicate the construction and long term operational groundwater impacts of the project as follows:

- Scenario 1: A ‘Null’ run (as per Barnett *et al* 2012), which does not include current approved WestConnex tunnel projects (M4 East, New M5 Motorway and M4-M5 Link) projects but does include the existing drained M5 tunnels
- Scenario 2: Scenario 1 plus the current approved WestConnex tunnel projects (M4 East, New M5 Motorway and M4-M5 Link)
- Scenario 3: Scenario 2 plus the project.

Impacts associated with Scenario 3 minus the impacts associated with Scenario 2 represent project specific impacts.

The groundwater model was prepared by RPS Group Australia[3]. Further information regarding the groundwater model is provided in section 3.3.3 of **Appendix K** (Groundwater technical report) and a description of the models design, parameters, grid, hydraulic boundaries and assumptions, is provided in Annexure G of **Appendix K** (Groundwater technical report).

17.1.6 Cumulative impact assessment

Cumulative impacts are determined by considering project specific impacts combining with other impacts to affect the same resources or receptors in a way where the sum of the impacts is greater than the individual. Cumulative groundwater impacts can be related to groundwater extraction (active and passive), groundwater drawdown, and groundwater quality.

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[2] Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A and Boronkay A (2012); Australian Groundwater Modelling Guidelines, Waterlines Report Series No 82, National Water Commission, Canberra, 191 pp. June.

[3] RPS (2018); F6 Extension. Groundwater Model report. RPS Group Australia. Report Number HS2017/01. Prepared for AECOM, June.

A cumulative impact assessment has been conducted as part of the groundwater modelling on the local hydrogeological regime taking into account other relevant infrastructure including the New M5 Motorway, M4 East tunnels, M4-M5 Link and the existing M5 East tunnels. The proposed future Sydney Gateway project has not been included in the groundwater cumulative impact assessment, as the updated road infrastructure is to be constructed along the ground surface and is unlikely to substantially impact groundwater.

The groundwater model has been used to quantify cumulative impacts of nearby tunnelling projects on the hydrogeological regime. Impacts associated with groundwater model Scenario 3 (see above) represent cumulative impacts.

17.1.7 Ground movement assessment

Background

Ground movement is an expected outcome of tunnelling projects. The ground movement anticipated is predominantly settlement (also termed subsidence). Upward ground movement (also termed heave) may also occur.

The causes of ground movement due to tunnelling can be classified as:

- Consolidation of the soil profile - due to water inflow in to the tunnel resulting in groundwater drawdown in the overlying soil profile. This results in an increase in stress in the soil matrix as water is lost from the soil pores (settlement only)
- Tunnel induced movement - due to the change in stresses in the surrounding rock mass and ground loss caused by the tunnel excavation (settlement or upward heave).

Consolidation is significant only where water seepage into the tunnel results in the drainage of a thick layer of compressible water saturated soils. Along the F6 Stage 1 alignment, these conditions are only encountered where the alignment crosses several palaeochannels that are infilled with compressible water saturated soil.

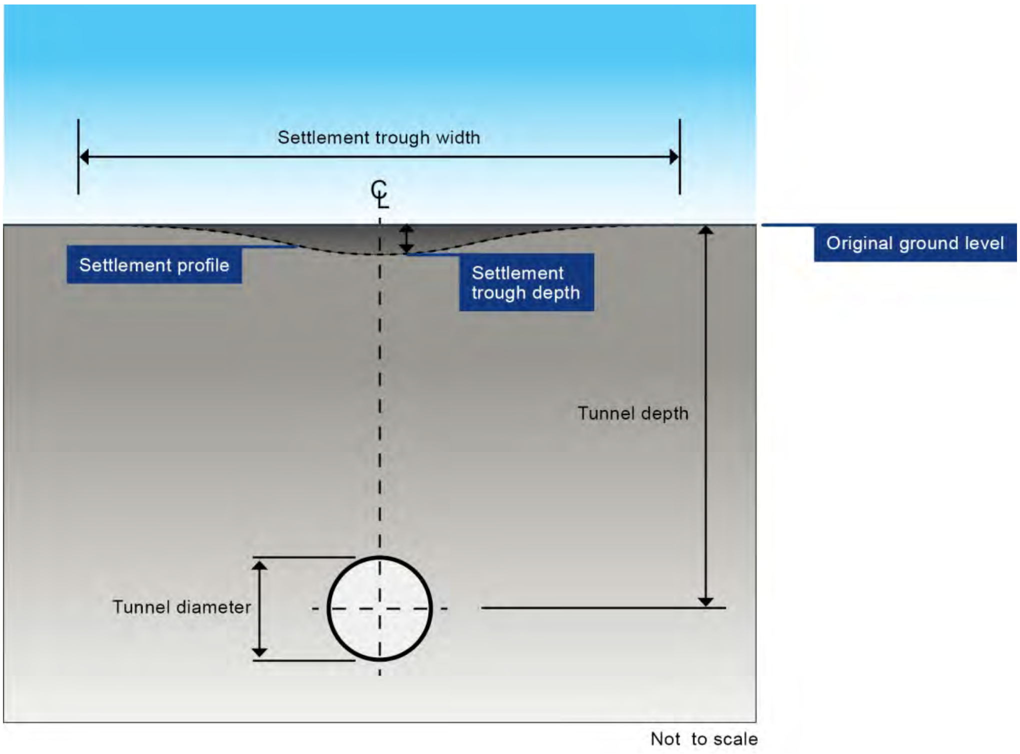
Tunnel induced movement is anticipated to be the prevalent mechanism causing ground settlement, given the tunnel profile is primarily located within competent bedrock overlain by thin residual soils that are not compressible or continually water saturated.

Both vertical and lateral ground movement would be associated with a settlement trough. The ground settlement profile generated is typically concave in shape and termed a settlement trough as shown in **Figure 17-3**. Damage to structures and services damage associated with settlement can occur where the structure or service is subjected to tensile strains. Tensile strain can depend on where the structure or service is located with respect to the settlement curve and the shape of the curve itself.

When the tunnel is sufficiently deep or the ground is sufficiently stiff, the surface movements can be negligible. It is also possible that upward movement (heave) can be induced by the release of high in-situ stresses in the rock mass. In the Sydney Basin substantial horizontal in situ stresses are present at shallow depths, exceeding the vertical stress due to gravity (Chesnut, 1983 and Enever et al., 1984). This can cause the sides of a tunnel excavation to move inwards (converge), bringing the tunnel walls together and causing the crown to move upwards.

The shape, width and magnitude of the tunnel excavation induced settlement trough is dependent on a number of factors including:

- The depth and size (span) of the tunnel
- The distance between tunnels where multiple tunnels are proposed
- The geotechnical conditions, particularly the stiffness of the rock mass
- The excavation methodology, sequence and allowable advance before the installation of tunnel support
- The tunnel support design and actual performance
- The permeability of the soil and rock and the degree of hydraulic connection between the various soil and rock strata.



Note - CL refers to centre line

Figure 17-3 Typical settlement profile[4]

Relevant criteria

Settlement criteria have been specified in the conditions of approval for recent tunnelling projects in Sydney including the WestConnex M4 East and New M5 projects and the NorthConnex project. These criteria are summarised in **Table 14-3** and it is expected that they would be adopted for this project. The additional criterion of tensile strain is included, which addresses the cause of potential building damage.

Settlement criteria for individual utilities and infrastructure would be determined in consultation with the relevant authorities prior to the commencement of any construction potentially affecting the individual utilities or infrastructure.

Further investigations to support the detailed design of the project would confirm predicted ground movements.

Table 17-3 Settlement criteria

Beneath structure/facility	Maximum settlement (mm)	Maximum angular distortion (probability)	Limiting tensile strain (per cent)
Buildings – Low or non-sensitive properties (i.e. less than or equal to two levels and carparks)	30	1 in 350	0.1
Buildings – High or sensitive properties (i.e. greater than or equal to 3 levels and carparks)	20	1 in 500	0.1
Roads and parking areas	40	1 in 250	N/A
Parks	50	1 in 250	N/A

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[4] C. Jeremy Hung, PE, James Monsees, PhD, PE, Nasri Munfah, PE, and John Wisniewski, PE (2009)Technical Manual for Design and Construction of Road Tunnels – Civil Elements

17.2 Existing Environment

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

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

17.2.1 Existing and proposed infrastructure

Existing infrastructure

The project alignment, including the permanent power supply corridor, transects an urban environment that consists of established industrial, commercial, recreational and residential areas. In some areas, there is major existing or proposed infrastructure that has deep foundations that may influence the project or the local hydrogeological regime. Major existing infrastructure is listed below:

- Kogarah Golf Course and reserves
- Bardwell Valley Golf Club
- Surface roads such as the M5 East Motorway and the Princes Highway
- Sydney Airport
- Industrial and commercial areas around Bay Street and President Avenue at Kogarah
- Existing tunnels including
  - The M5 East Motorway tunnels which are a pair of undrained (tanked) twin road tunnels around five kilometres in length located in Arncliffe

The Airport Link rail tunnel which consists of around 10 kilometres of undrained (tanked) tunnel. The tunnel extends from Green Square Station in the north, and passes beneath the domestic and international terminals at Sydney Airport, beneath the Cooks River and eventually joining the above ground rail system near Wolli Creek Station.

Proposed project infrastructure

The mainline tunnels for the project have been designed to minimise the intersection of highly permeable material (e.g. alluvium or deeply weathered sandstone) that could result in high groundwater inflows into the tunnels. The tunnel alignment avoids the underlying palaeochannels and unsuitable geology that lies to the east of the project alignment.

The project tunnels would operate predominately as drained (i.e. not tanked) tunnels. Drained tunnels are typically constructed in structurally competent rock such as the Hawkesbury Sandstone with some waterproofing to reduce groundwater inflows along particular tunnel sections. Allowing groundwater flow into the tunnel reduces an external hydrostatic pressure (pressure exerted by water due to the force of gravity) building up behind tunnel lining (which would be included in an undrained scenario), placing less stress on the underground infrastructure.

Where the tunnels intersect alluvium, or deeply weathered sandstone, groundwater inflows are likely to exceed the project design criterion of one litre per second per kilometre of tunnel and cause excessive drawdown within the alluvium or sandstone. To restrict groundwater inflow into the project tunnels, driven tunnel and cut-and-cover sections located within alluvium and deeply weathered sandstone would be constructed with an impermeable lining. The undrained (tanked), sections of the tunnels would be constructed with a full perimeter waterproofing membrane to prevent groundwater flow into the tunnels.

Where cut and cover structures pass through alluvium, such as for the entry and exit ramp tunnels that would pass through alluvium beneath Rockdale Bicentennial Park, they would be constructed with impermeable diaphragm walls. Diaphragm walls are constructed by excavating a trench to bedrock and filling the trench with a cement slurry and reinforcing to form a barrier wall.

Throughout the operational phase of the project, groundwater and surface water entering the tunnels would be captured and treated separately. The primary features of the drainage design for the collection of groundwater during operation of the tunnels include:

- Provision for the collection of sub-surface water seepage
- Collection of water from ventilation shafts and tunnels
- Allowance for cleaning and maintenance of the drainage system.

The operational tunnel design would incorporate a permanent drainage system and sumps at low points to capture groundwater ingress. Groundwater is to be treated at the water treatment plant at the Arncliffe Motorway Operations Complex (MOC1).

Other proposed and approved infrastructure projects

A number of other proposed and approved infrastructure projects in the vicinity of the project have the potential to cause cumulative impacts on the local environment, including:

- New M5 Motorway, which would consist of about nine kilometres of twin motorway drained tunnels between the existing M5 East Motorway (between King Georges Road and Bexley Road) and St Peters
- M4 East, which would extend from the widened M4 Motorway at Homebush to Haberfield consisting of 5.5 kilometres of three lane twin drained tunnel
- M4-M5 Link, which would extend from the M4 East at Haberfield to the New M5 Motorway at St Peters with about eight kilometres of twin motorway tunnels consisting of drained and tanked sections of tunnel
- Proposed future Sydney Gateway, which consists of new road infrastructure linking the New M5 Motorway at St Peters interchange with Sydney Airport and the Port Botany precincts. Sydney Gateway is subject to a separate environmental impact assessment and approval process
- Sydney Metro a rail alignment linking the north-west region to the Sydney CBD and further south to Bankstown. The Chatswood to Sydenham portion of the project was approved in early January 2017. The alignment would consist of 15.5 kilometres twin railway tunnels extending from Chatswood, beneath Sydney Harbour to Sydenham.

17.2.2 Topography and drainage

The project is located within the Cooks River catchment, which covers an area of about 10,200 hectares. Wolli Creek is a major waterway located to the immediate north of the project. Wolli Creek is tidal in its lower reaches and is a tributary of the Cooks River. The main surface water features in the vicinity of the project are the Cooks River and its tributaries; the Marsh Street, Eve Street Wetlands and Landing Lights Wetland at Arncliffe; and Kings Wetland and Rockdale Wetlands at Kogarah. The Towra Point Wetlands, which are Ramsar listed, are located outside of the study area, around seven kilometres to the south east.

The project extends across low lying and elevated areas from the New M5 Motorway at Arncliffe to President Avenue, Kogarah.

Wolli Creek and its southern tributary, Bardwell Creek have incised gullies through a subterranean (under the surface) sandstone (Hawkesbury Sandstone) plateau, which is higher in elevation than in other parts of the Sydney basin. Wolli Creek flows to the east to join the Cooks River which is to the north of the project. 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 flat alluvial plains.

Elevated ground (considered to be about relative level (RL) +10 metres Australian Height Datum (AHD) to RL+30 metres AHD) is generally underlain by shallow Hawkesbury Sandstone. Low areas (about RL+3 metres AHD to RL+10 metres AHD) generally cross Quaternary Alluvium. The geological setting of the project is described further in **section 17.2.3**.

Low lying areas are located:

- At the intersection of the project with New M5 Motorway at Arncliffe
- South of Rockdale

Elevated areas are located from:

- Wickham Street to Spring Street at Arncliffe
- Tabrett Street, Banksia to around Bay Street, Brighton-Le-Sands.

Catchments and watercourses within the study area are shown in **Figure 17-4**.

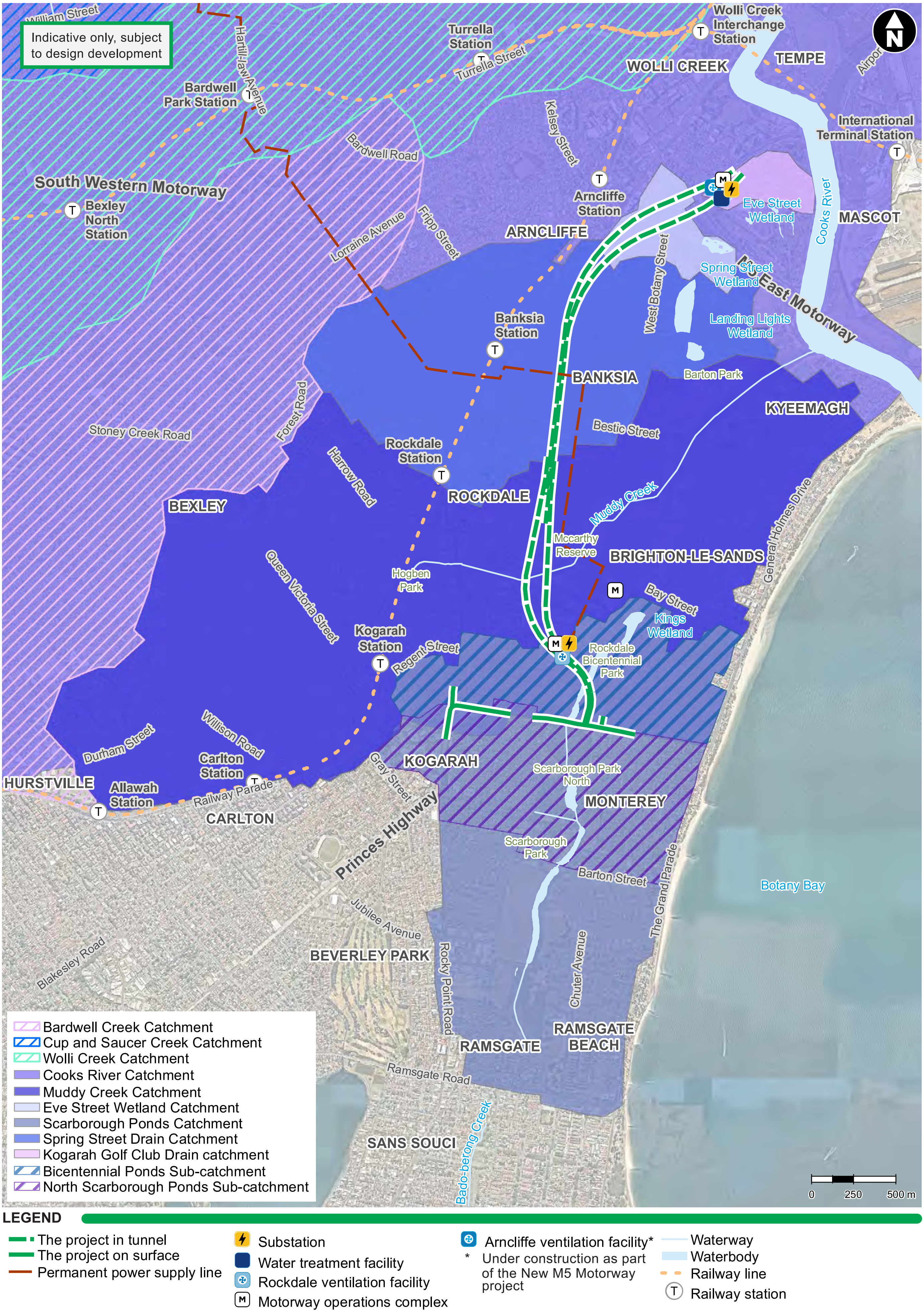

Figure 17-4 Catchments and watercourses in the study area

17.2.3 Geological setting

Regionally, the study area is located within the Permo-Triassic Sydney Basin that is mainly characterised by sandstone and areas of alternating layers of sandstone and shale. The project is underlain primarily by the Hawkesbury Sandstone and some complex quaternary sediments. The main stratigraphic units that have been encountered within the study area, from youngest to oldest, are:

- Anthropogenic fill
- Quaternary alluvium (generally beneath rivers, palaeochannels and Botany Sands)
- Jurassic intrusions (e.g. dykes, which are younger vertical rock layers between older layers of rock)
- Triassic Hawkesbury Sandstone Formation.

Areas of higher elevation and westerly sections along the tunnel alignment consist of Triassic aged Hawkesbury Sandstone. The Hawkesbury Sandstone is the dominant lithology across the project and is present beneath the entire length of the project alignment and at depth where the Cooks River palaeochannel is incised. The formation extends across the whole Sydney Basin and is up to 290 metres thick.

The low elevation areas along the tunnel alignment consist of Quaternary alluvium with areas of former swamps consisting of man-made fill. The man-made fill often contains dredged estuarine sand and mud, demolition rubble and industrial and domestic waste.

The alluvium extends further west in the location of a drainage line that runs east to Muddy Creek from the western side of Banksia and also west of Rockdale Industrial area along Muddy Creek, where it extends west of the Princes Highway in Kogarah. The alluvium usually consists of a mixture of peat, sandy peat, and mud; coarse quartz sand with varying amounts of shell fragments; and medium to fine grained marine sand with podsols.

The geology of the study area is shown in **Figure 17-5**. Further detail on the stratigraphic units is provided in **Appendix K** (Groundwater technical report).

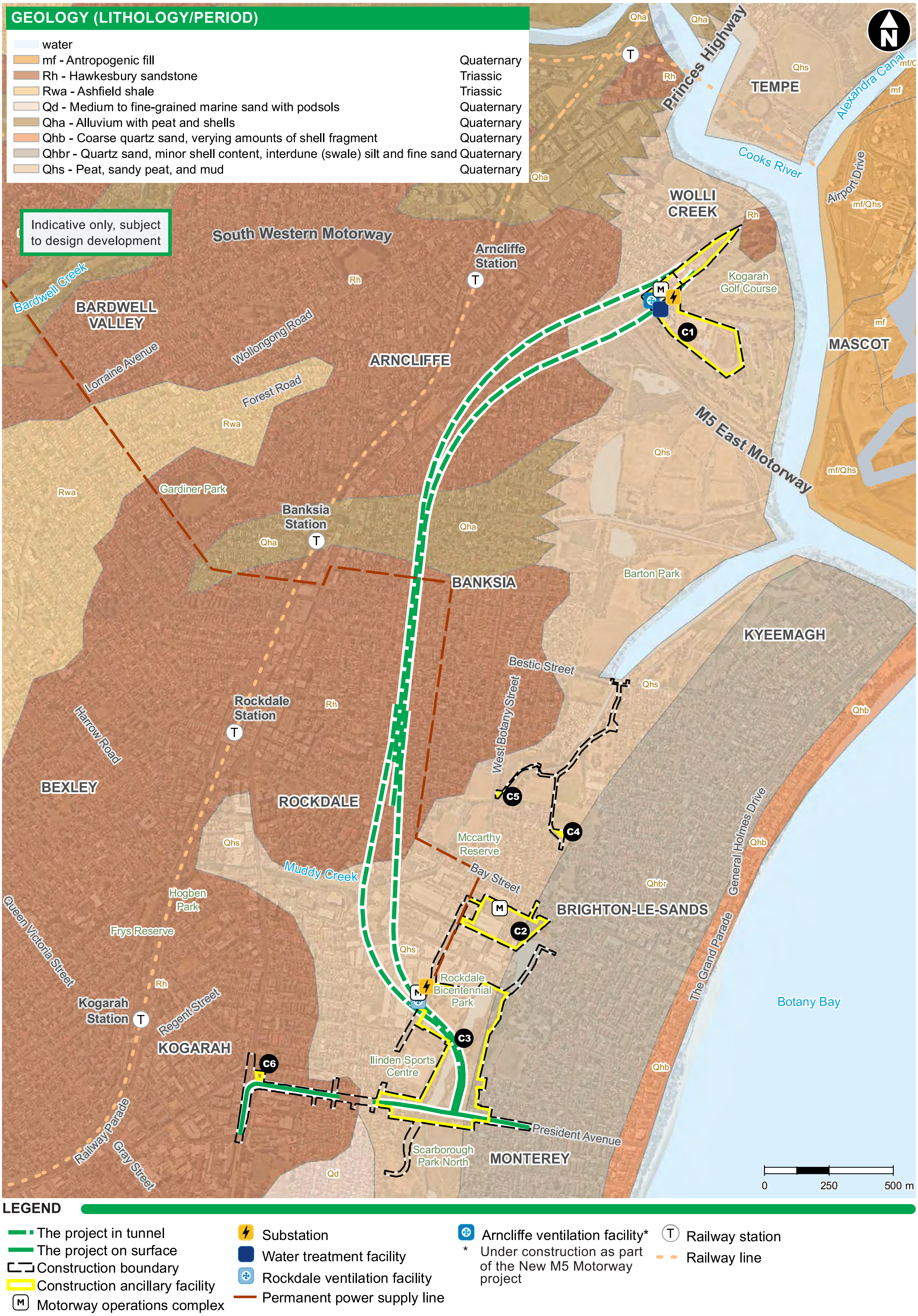

Figure 17-5 Project geological setting

17.2.4 Hydrogeological setting

Across the study area, the groundwater levels are typically deeper beneath hills and shallowest beneath creeks and gullies. Groundwater within the vicinity of the project is recharged by rainfall runoff and infiltration. Perched groundwater (i.e. groundwater at a level above the regional water table) may be encountered within fill and natural soils in more elevated areas. In lower lying areas tidal influences are typically experienced within close proximity to the foreshore. Seasonal variations in groundwater levels can be expected in response to natural climatic variation.

Groundwater within the vicinity of the project is present in the following hydrogeological units:

- Quaternary alluvium around the edges of Muddy Creek, Cooks River and the Rockdale Wetlands
- Botany Sands Aquifer
- Hawkesbury Sandstone
- Geological structural features (such as dykes, fault zones and palaeochannels).

The hydrogeological characteristics of the hydrogeological units outlined above are described in detail in the sections below.

The hydrogeological setting of the project has also been characterised by:

- The development of hydrogeological cross-sections extending from St Peters to Sans Souci and Botany Bay to the south
- A review of groundwater inflow in existing Sydney tunnels within Hawkesbury Sandstone.

The hydrogeological cross sections and review of groundwater inflow in existing Sydney tunnels are provided in the sections below.

Quaternary alluvium

Modern alluvium outcrops around the flanks of Cooks River and Muddy Creek form an unconfined aquifer which is generally of high permeability. Groundwater flow within the shallow alluvium associated with the Rockdale Wetlands is to the south, discharging into the Georges River. Typical hydraulic conductivity values are between 0.01 and 1 metre per day. Groundwater within the alluvium can be a source of either recharge or discharge to the Cooks River and Muddy Creek depending on whether upward or downward hydraulic gradients are present. Recharge to the alluvium is via direct rainfall recharge and runoff or surface water inflow. Groundwater baseflow (the groundwater that discharges to a creek or river) is restricted where the natural system has been modified and the creeks concrete lined.

The palaeochannels (ancient river systems eroded deeply into the landscape and subsequently infilled with saturated alluvial sediments) of the Cooks River and Georges River and the palaeochannel under what is now Towra Point, extend to depths of up to 25 metres and are saturated with groundwater.[5] In contrast to the surficial alluvium groundwater flow within the deeper palaeochannels is eastward discharging into Botany Bay. Groundwater quality within the palaeochannels is expected to be saline due to leakage from tidally flushed rivers and tributaries. The alluvium infilling the palaeochannels is highly transmissive (i.e. groundwater can easily flow through the alluvium) given the coarse sands and gravels present and a low clay content in this area.

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[5] Albani, A.D., Rickwood, P.C.,Quilty, P.G. and Tayton J.W.; (2015); The morphology and late Quaternary paleogeomorphology of the continental shelf off Sydney NSW, Australian Journal of Earth Sciences, 62 681-694, 2015.

Botany Sands aquifer

Groundwater is present within the Botany Sands as a shallow unconfined aquifer (where water is able to seep from the ground surface directly to the aquifer because no impermeable layer is present). Groundwater levels are variable but are typically within five metres of the ground surface when not influenced by localised pumping. Regional groundwater flow is eastward discharging into Botany Bay. The Botany Sands aquifer naturally contains moderately low salinity groundwater (generally less than 2000 milligrams per litre) and is moderately acidic but is vulnerable to contamination because of the unconfined nature of the aquifer and the urban environment. This vulnerability is evident to the north where the aquifer near the Botany Industrial Park has been embargoed for groundwater use due to contamination.

Recharge to the Botany Sands aquifer is via direct rainfall, locally enhanced by rainfall runoff and by rainfall infiltration in green spaces such as parks, gardens and golf courses. Groundwater recharge has typically decreased with increased urbanisation due to enhanced runoff from hardstand areas directing stormwater directly into Botany Bay. Groundwater discharge is via localised pumping or natural discharge to Botany Bay.

Groundwater from the Botany Sands aquifer has historically been used beneficially for a number of purposes including irrigation, watering market gardens and domestic use. Groundwater is typically extracted from shallow areas via vacuum extraction systems at groundwater yields typically up to two litres per second. The NSW Department of Primary Industries – Water (DPI – Water) advises that the whole Botany Sands hydrogeological unit is over allocated and to extract groundwater, a water allocation license must be bought on the open market.

The project alignment intersects the Botany Sands to the south near President Avenue, Kogarah, however in this area the tunnels for the project would be constructed as undrained (tanked) or as cut and cover structures with secant pile walls constructed to bedrock to prevent groundwater ingress. While the tunnels are designed to not receive any direct inflow from the Botany Sands, groundwater from the Botany Sands may be hydraulically linked with the drained tunnels. The residual alluvial clay that separates the sands from the underlying bedrock forms a hydraulic seal that would reduce vertical leakage restricting groundwater drawdown due to the project.

Hawkesbury Sandstone

The tunnel alignment is designed to allow the majority of the tunnels to be excavated from within Hawkesbury Sandstone as the engineering properties of the sandstone are suited to tunnelling. The Hawkesbury Sandstone is characterised as a ‘dual porosity aquifer’, which means that groundwater is transmitted by both the primary porosity – or interconnected void space between grains of the rock matrix – and the secondary porosity, which is due to secondary structural features such as joints, fractures, faults, shear zones and bedding planes.

The Hawkesbury Sandstone is not one aquifer but several ‘stacked aquifers’, given the heterogeneous and layered nature of the unit. Interbedded shale lenses can provide local or extensive confining layers, creating separate aquifers with different hydraulic properties including hydraulic heads (i.e. the elevation of groundwater in a monitoring well that the column of water would naturally attain).

The hydraulic conductivity of the Hawkesbury Sandstone is low, which means the groundwater flow through the sandstone is in the order of millimetres to centimetres per year. High groundwater yields can sometimes be pumped from the Hawkesbury Sandstone, particularly when saturated fractures are intersected. Increased groundwater flow to tunnels is typically associated with the intersection of such major joints or fractures.

Groundwater flow within the Hawkesbury Sandstone is dominated by secondary fracture flow. Regionally, groundwater flow is eastward, discharging into the Tasman Sea. Discharge is also via seepage from outcrops in topographically elevated areas, and evapotranspiration. Recharge is via rainfall infiltration on fractured outcrop and through leakage from the soil profile and alluvium.

Groundwater within the Hawkesbury Sandstone is generally acidic but of low salinity. A basin wide salinity map[6] indicates that groundwater within the Hawkesbury Sandstone in the study area is of much poorer quality water than in other areas of the basin. Elevated concentrations of dissolved iron and manganese naturally occur within the Hawkesbury Sandstone which can cause staining when discharged and oxidised. In tunnels groundwater ingress becomes oxidised and can cause the dissolved iron and manganese to precipitate forming sludge in drainage lines.

Geological structural features

The geology along the project alignment is expected to be cross-cut by geological structural features such as dykes and fault zones.

The intersection of dykes during tunnel construction can either increase or decrease groundwater ingress to the tunnel depending on the weathering of the dyke and what units or structures it cross-cuts. A fractured dyke cross-cutting water bearing structural features can provide a conduit for groundwater to flow directly into the tunnel.

Fault zones can have a significant impact on rock mass permeability and groundwater flow causing preferential flow paths, although not all structural features are saturated and hence transmissive. During construction, water-bearing fractures and faults can release groundwater initially when intersected, which would decline as the storage is depleted.

Hydrogeological cross-sections

A north-south oriented hydrogeological cross-section extending from St Peters to Sans Souci and Botany Bay to the south is presented in **Figure 17-6**. The section is based on boreholes and monitoring wells constructed during the investigation and shows the monitoring wells, screen intervals and nine model layers. The cross-sections also present the simplified geology, the water table and tunnel alignment for the project and New M5 Motorway.

The cross section shows the Ashfield Shale to the north at St Peters which is underlain and flanked to the south by Hawkesbury Sandstone. The Hawkesbury Sandstone is overlain by alluvium and thick sequences of alluvium that represent palaeochannels beneath Cooks River, Muddy River and Sans Souci.

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[6] Russell G. 2007. Hawkesbury Sandstone Groundwater Attributes and Geological Influences. UTS/UNSW 20th Anniversary Hydrogeology Symposium 20 July 2007, University of Technology, Sydney.

Indicative only, subject to design development

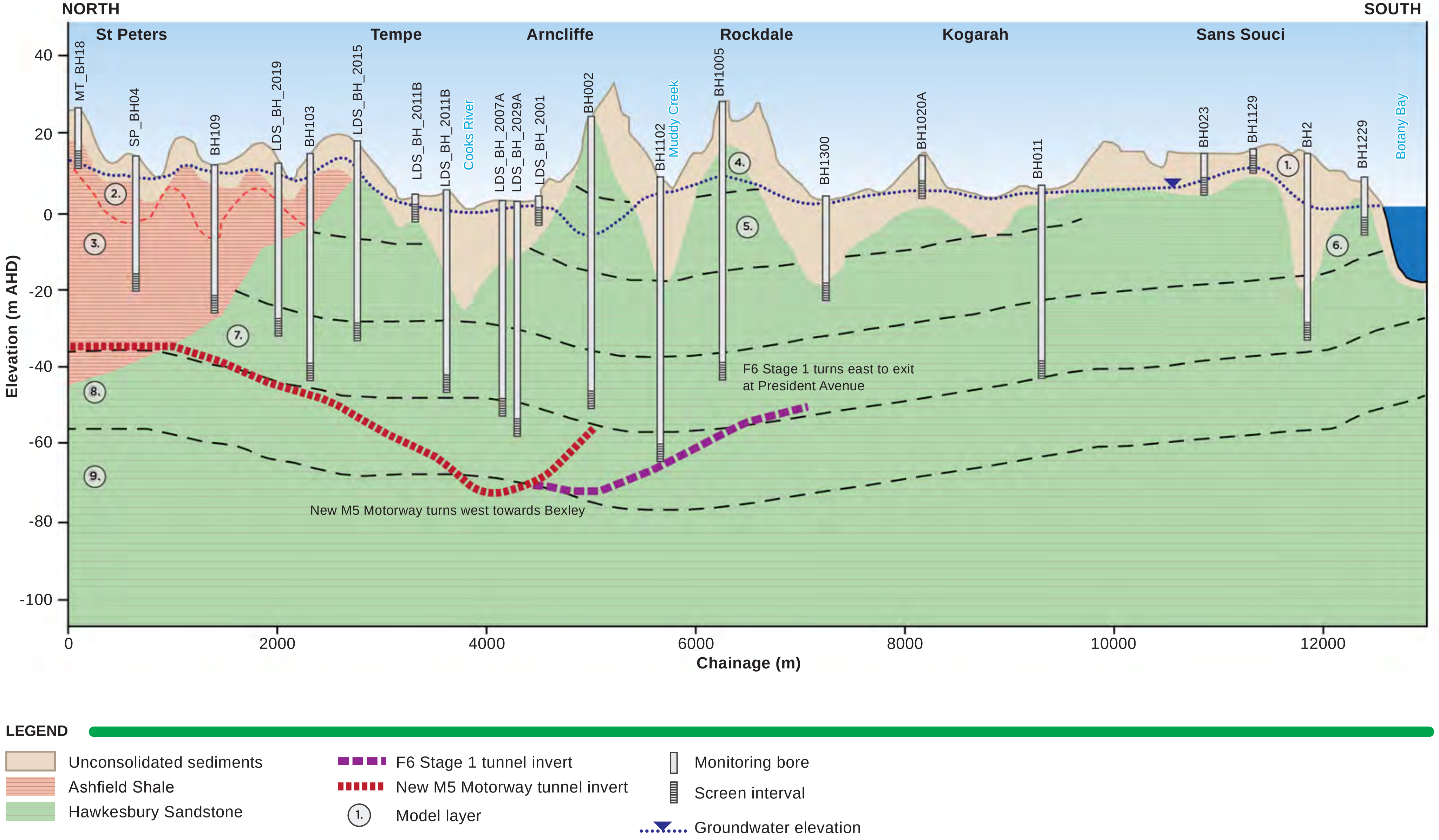

Figure 17-6 Hydrogeological cross section (extending from St Peters to Sans Souci and Botany Bay)

Groundwater inflow in existing Sydney tunnels within Hawkesbury Sandstone

Within the Hawkesbury Sandstone, water inflow is dependent upon the number and size of saturated secondary structural features intersected. Rates of water inflow have been monitored in recent years from several unlined tunnels in the Sydney area with similar geology, hydrogeology and construction to that proposed for the project. These inflow rates are considered long term flow rates throughout the operational life of the infrastructure, and are summarised in **Table 17-4**.

Drainage inflow as summarised in **Table 17-4** varies from 0.6 litres per second per kilometre to up to 1.7 litres per second per kilometre.

Table 17-4 Measured drainage inflow rates from other Sydney tunnels

Tunnel	Year opened	Type	Width (metres)	Length (kilometres)	Drainage inflow (litres per second per kilometre)	Reference
Eastern Distributor	1999	3 lane road (twin)	12 (Double deck)	1.7	1	Hewitt 2005
M5 East Motorway	2001	Twin 2 lane road	8 (twin)	3.8	0.9	Tammetta and Hewitt 2004
Epping to Chatswood	2009	Twin rail	7.2 (twin)	13	0.9	Best and Parker 2005
Lane Cove	2007	Twin 3 lane road	9 (twin)	3.6	0.6/1.71	Coffey 2012
Northside Storage	2000	Sewer storage	6	20	0.9	Coffey 2012
Cross City Tunnel	2005	Twin 2 lane road	8 (twin)	2.1	>3	Hewitt 2005

Notes:
1 Measured inflow in Lane Cove Tunnel varied from 1.7 L/s/km (2001 – mid-2004) to 0.6 L/s/km (2011)

Predicted inflows to the proposed New M5 Motorway and M4 East tunnels have been calculated by numerical modelling published in the respective environmental impact statements. At the New M5 Motorway, groundwater modelling predicted an average inflow rate over the full length of the tunnel of 0.63 litres per second (L/sec) along the eastbound tunnel and 0.67 litres per second along the westbound tunnel.[7]

For the M4 East, groundwater modelling predicted inflows to the drained tunnels which extend over a combined length of 17 kilometres. Groundwater modelling predicted inflow rates between 0.3 and 0.9 litres per second per kilometre of tunnel[8].

Groundwater inflows to the M4-M5 Link tunnels were predicted to be below the 1 litre per second per kilometre of tunnel criteria for any kilometre of tunnel.

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[7] CDM Smith, (2016). WestConnex Stage 2. New M5 Groundwater Modelling Report

[8] WestConnex Delivery Authority (2015); WestConnex M4 East EIS.

17.2.5 Groundwater quality

Table 17-5 provides a baseline for the existing groundwater quality within the study area. The groundwater quality criteria for the project have been developed in accordance with guidelines from ANZECC. For analytes not covered by the ANZECC guidelines the amended National Health and Medical Research Council (NHMRC) Australian Drinking Water Guidelines[9] have been adopted.

To assess the potential impacts of groundwater to building materials, dissolved sulfate, chloride and pH values are assessed against the aggressivity criteria outlined in the exposure classification criteria for concrete and steel piles presented in the relevant Australian Standard.[10]

Table 17-5 Groundwater quality within the study area

Parameter	Alluvium	Hawkesbury Sandstone
Groundwater temperature	Measured groundwater temperatures varied over a narrow range between 19.6 and 22.1°C. Seasonally, groundwater temperatures are expected to vary by one or two degrees, although there was no variation between aquifers.	Consistent with alluvium
Electrical conductivity	Variable, ranging from 254 µS/cm to 17,100 µS/cm. Elevated electrical conductivity values in excess of 10,000 µS/cm are attributed to tidal mixing with groundwater. The groundwater is generally below 3000 µS/cm which suggests the alluvium is recharged by rainfall infiltration with minimal tidal interaction.	Variable, ranging from 516 µS/cm to 10,400 µS/cm. As for the alluvium the range of results is attributed to the degree of tidal mixing with rainfall infiltration and leakage from the overlying alluvium.
pH	Acidic (pH 5 to 6.5). Some instances of pH greater than 10 which is attributed to interference of cement grout in monitoring wells.	Acidic (pH 5 to 6.5). Some instances of pH greater than 10 which is attributed to interference of cement grout in monitoring wells.
Major cations (calcium, magnesium, sodium and potassium) and major anions (chloride, sulfate, carbonate and bicarbonate)	Groundwater is low in magnesium and sulphate with variable proportions of calcium, sodium, potassium, carbonate, bicarbonate and chloride. The variable proportion of calcium is attributed to variable amounts of shells within the alluvial sands. Similarly the variable proportions of sodium and chloride is attributed to the variable mixing of tidal waters with groundwater.	Groundwater is dominated by sodium and chloride which is attributed to tidal influences and interaction with sea water. Groundwater in the Hawkesbury Sandstone has low proportions of magnesium and sulphate.
Heavy metals (arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc)	Measured background metals concentrations have exceeded the adopted groundwater concentration guideline for arsenic, iron, lead, manganese and zinc. In most cases the guidelines have been marginally exceeded, indicating that background levels are naturally elevated. However the alluvial groundwater consistently has elevated iron, manganese and zinc.	Measured background metals concentrations have exceeded the guideline concentration value for arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc. In most cases the guidelines have been marginally exceeded, however the concentrations of manganese, iron and zinc consistently are elevated. Dissolved iron and manganese in groundwater are known to be elevated within the Hawkesbury Sandstone. The consistent exceedance of dissolved zinc criteria across the study area suggests the elevated dissolved zinc concentrations are at background levels.

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[9] National Health and Medical Research Council (NHMRC) Australian Drinking Water Guidelines (2015)

[10] Australian Standard, (2010); Piling – Design and Installation. Australian Standard. Standard AS 2159-2009 Third Edition, including Amendment No 1 (October 2010).

Parameter	Alluvium	Hawkesbury Sandstone
Nutrients (including nitrite as N, nitrate as N, reactive phosphorus), and ammonia	Nitrite and nitrate concentrations ranged from below detection limits to 0.19 and 1.9 milligrams per litre (mg/L) respectively. In comparing these results to the amended Australian Drinking Water Guidelines, nitrite and nitrate concentrations are below the health criteria of three and 50 mg/L respectively indicating background nutrient levels are low. Reactive phosphorous as P concentrations ranged from below detection limits to 0.4 mg/L, indicating phosphorous levels are also low. Ammonia concentration values in the alluvium range from 0.01 to 63 mg/L exceeding the guideline value of 0.91 mg/L. Elevated dissolved ammonia may be due to the proximity to former landfill sites, natural decaying vegetation or the use of fertilisers in parklands constructed over the alluvium.	Dissolved nitrite and nitrate concentrations range from below detection limits to 0.05 and 1.7 mg/L respectively. In comparing these results to the Australian Drinking Water Guidelines, nitrite and nitrate are below the health criteria of 3 and 50 mg/L respectively indicating nutrient levels are low. In comparison to the overlying alluvium, nitrite and nitrate concentrations in the Hawkesbury Sandstone are significantly lower. Ammonia values are relatively consistent ranging from 0.039 to 1.96 mg/L. Phosphorous as P ranged from below detection limits to 0.08 milligrams per litre, indicating phosphorous levels are very low.
Groundwater aggressivity	Groundwater is mildly aggressive with respect to average chloride, pH and sulfate to concrete piles.	Groundwater is mildly aggressive with respect to average chloride, pH and sulfate to concrete piles.

17.2.6 Groundwater contamination

An assessment of contamination risk within the study area is provided in **Appendix J** (Contamination technical report) which is summarised in **Chapter 16** (Soils and contamination). Areas within the vicinity of the project that may contain contaminated soil and/or groundwater due to past or present land use practices have been investigated. A summary of existing potential or known groundwater contamination within the study area is provided in **Table 17-6**. Refer to **Chapter 16** (Soils and contamination) for further information.

Table 17-6 Existing groundwater contamination within the study area

Project area	Groundwater contamination
Mainline tunnel	Groundwater contamination sampling was conducted in five monitoring wells installed along the alignment where areas of former historical landfilling took place. Despite there being many land-uses along the alignment that could impact groundwater quality such as light industry, market gardens and mechanical workshops, there was only one groundwater exceedance detected along the alignment.
Arncliffe ventilation and tunnel site and construction ancillary facility (C1)	There were no groundwater samples analysed during the contaminated land investigation at this location. There is potential for groundwater contamination to be present due to the historical use of pesticides and herbicides at market gardens and a golf course and areas of historical landfilling nearby.
Arncliffe water treatment plant	There were no groundwater samples analysed during the contaminated land investigation at this location. There is potential for groundwater contamination to be present due to historical landfilling, the historical use of pesticides and herbicides at market gardens and potential filling with dredged material from the Cooks River
Rockdale ventilation facility and construction ancillary facility (C2)	One borehole, identified in the NSW Government groundwater database is present at the site and indicates the groundwater level is shallow (less than two metres below the ground surface). There is potential for groundwater contamination to be present due to the historical use of pesticides and herbicides for agricultural purposes and former, current and surrounding industrial properties used for chemical manufacturing.
President Avenue intersection and construction ancillary facility (C3)	There were five groundwater samples analysed during the contaminated land investigation at this location and extensive soil samples were analysed. The soil analytical results indicated that there were some abnormally high metals results which may be due to degraded metal alloy waste in the fill sampled.
Shared cycle and pedestrian pathways and construction ancillary facilities (C4 and C5)	There were no groundwater samples analysed during the contaminated land investigation at this location. There is the potential for groundwater contamination to be present due to the historical use of pesticides and herbicides at market gardens at this location.
Princes Highway construction ancillary facility (C6)	There were no groundwater samples analysed during the contaminated land investigation at this location. The site is currently under assessment by the NSW EPA for contamination. There is the potential for groundwater contamination to be present due to the site's history as a 7-Eleven Service Station.
Permanent power supply corridor	There is potential for groundwater contamination to be present due to the former, current and surrounding industrial properties used for chemical manufacturing.

17.2.7 Groundwater users

A review of bores registered with DPI – Water (as of 10 January 2018) identified 373 boreholes within a two kilometre radius of the project alignment. There may also be other private bores present within the two kilometre radius that have not been registered with DPI – Water. The majority of registered boreholes are shallow and intersect the alluvium of the Botany Sands aquifer. The type and lithology of the registered boreholes are outlined in **Table 17-7** and **Table 17-8**.

Table 17-7 Types of registered boreholes within a two kilometre radius of the project alignment

Borehole type	Number of boreholes
Domestic	345
Industrial	1
Irrigation	7
Monitoring	9
Recreation	7
Test	2
Unknown	2

Table 17-8 Lithology of registered boreholes within a two kilometre radius of the project alignment

Borehole lithology	Number of boreholes
Ashfield Shale	1
Botany Sands	362
Hawkesbury Sandstone	1
Not specified	9

17.2.8 Groundwater dependent ecosystems

The Botany Wetlands/Lachlan Swamps located in Centennial Park is identified as a high priority GDE in the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011* and the Botany Sands Groundwater Source extends to these wetlands. Potential impacts to the Botany Wetlands/Lachlan Swamps are assessed in **section 17.3.3**.

The Atlas of Groundwater Dependent Ecosystems 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 beneath 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 tunnelling as part of the New M5 Motorway project indicates a strong hydraulic connection with the new tunnels and the alluvium flanking the Cooks River via fractures in the Hawkesbury Sandstone. Impacts to the Cooks River Castlereagh Ironbark Forest GDE and Cooks River GDE as a result of the project are assessed in **section 17.3.3** and **section 17.4.3**.

A search of the Atlas of Groundwater Dependent Ecosystems also identified the presence of additional GDEs within or near to the project corridor:

- Hinterland sandstone gully forest with moderate to high potential for groundwater dependence at Bardwell Valley Parkland and Broadford Street Reserve
- Coastal sandstone ridgetop woodland with moderate potential for groundwater dependence at Stotts Reserve at Bexley North
- Estuarine fringe forest and mangrove forest with low to moderate potential for groundwater dependence between the southern bank of Wolli Creek and the railway line behind Wolli Creek station.

Potential impacts to these GDEs are assessed in **section 17.3.3** and **section 17.4.3.**

The Rockdale Wetlands are potentially dependent on groundwater. There is likely to be some connection between groundwater and the wetlands, through a direct hydraulic connection, and via the roots of wetland vegetation. The Atlas of Groundwater Dependent Ecosystems identifies that the Landing Lights, Eve Street, Spring Street, King Street and Marsh Street Wetlands do not have groundwater dependence.

Assessment of groundwater dependent ecosystems for the New M5 Motorway project

Impacts to the following GDEs were assessed as part of the EIS for the New M5 Motorway project

- Cooks River Castlereagh Ironbark Forest GDE
- Cooks River GDE
- Hinterland sandstone gully forest with moderate to high potential for groundwater dependence at Bardwell Valley Parkland and Broadford Street Reserve
- Coastal sandstone ridgetop woodland with moderate potential for groundwater dependence at Stotts Reserve at Bexley North
- Estuarine fringe forest and mangrove forest with low to moderate potential for groundwater dependence between the southern bank of Wolli Creek and the railway line behind Wolli Creek station.

Potential impacts to these GDEs were assessed in New M5 Motorway EIS, which determined that there would be low impacts to the Hinterland sandstone gully forest, Estuarine fringe forest and Cooks River GDEs and, moderate impacts to the Coastal sandstone ridgetop woodland and Cooks River Castlereagh Ironbark Forest GDEs. It should be noted that the majority of the Cooks River/Castlereagh Ironbark forest and Cooks River GDE at Kingsgrove would be cleared during the construction of the New M5 Motorway project.

Potential impacts to these GDEs from the New M5 Motorway project are considered to be relevant to the assessment of this project (F6 Extension Stage 1) because the New M5 Motorway is located closer to the GDEs. Impacts anticipated for the New M5 Motorway project would be therefore expected to be greater than impacts associated with this project. Notwithstanding, an assessment of potential impacts to these GDEs for the project has been undertaken and is provided in **section 17.3.3** and **section 17.4.3.** This assessment is informed by the groundwater model for the project and the model domain partially includes the New M5 Motorway to predict cumulative drawdown impacts.

17.3 Potential impacts – construction

Construction works including the construction of permanent infrastructure have the potential to change groundwater behaviour and impact on the surrounding environment. An assessment of potential impacts has been undertaken which is summarised below and provided in full in **Appendix K** (Groundwater technical report).

Groundwater within parts of the study area has the potential to be impacted during the construction phase of the project. The potential impacts that have been identified are:

- Reduced groundwater recharge
- Tunnel groundwater inflow
- Groundwater level decline including potential impacts on:
  - GDEs
  - Surface water and baseflow (the groundwater that discharges to a creek or river)
  - Existing groundwater users
- Changes in groundwater quality
- Groundwater drawdown which may result in ground movement (settlement).

A detailed groundwater balance has been calculated for the construction of the project. This is discussed further in **section 17.3.8** and in **Appendix K** (Groundwater technical report).

17.3.1 Reduced groundwater recharge

During construction, the establishment of paved construction ancillary facilities, cut-and-cover tunnel sections leading to the tunnel portals and approach roads would temporarily alter or reduce groundwater recharge. The construction ancillary facilities and paved contractor compounds at the Arncliffe construction ancillary facility (C1), Shared cycle and pedestrian pathways construction ancillary facilities (C4 and C5) and Princes Highway ancillary facility (C6) would create additional temporary impervious surfaces during construction. However, the impacts of these surfaces are temporary and considered minor since their construction would not substantially reduce groundwater recharge during construction. The Rockdale construction ancillary facility (C2) and President Avenue construction ancillary facility (C3) would be located primarily on existing impervious surfaces and would therefore not substantially impact local groundwater recharge during construction.

The risks during construction would be that access roads and bunded isolation areas for stockpiling of construction materials could alter or reduce groundwater recharge. Stockpiling areas would be required for the new cuttings and embankments along President Avenue which would temporarily reduce groundwater recharge, if run-off is directed off-site. These impacts are considered minimal, as the affected areas are small compared to the overall project, and temporary, as the various structures and compounds would be removed at the end of the construction phase of the project.

17.3.2 Tunnel groundwater inflow

Groundwater inflow during construction would be dependent upon a number of factors including tunnelling progress; tunnelling construction methodology (including tunnel lining methods and locations and the success of pre-excavation pressure grouting (pre-grouting)); whether fractured zones are intersected and localised groundwater gradients and storativity (the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer). Pre-grouting is undertaken by drilling a pattern of holes in advance of the excavation to conduct packer tests and calculate the hydraulic conductivity. Grout is then injected at a pre-determined pressure to reduce the bulk rock mass permeability.

Initial inflows to tunnels can be large, because of the large hydraulic gradients that initially develop near the tunnel walls; however, these gradients would reduce in time as drawdown impacts extend to greater distances from the tunnels and inflows approach steady state conditions. Higher inflow rates are likely from zones of higher permeability, where saturated geological structural features are intersected by the tunnels.

The tunnel construction program for the New M5 Motorway project at Arncliffe has experienced higher than anticipated groundwater inflows due to fractured sandstone beneath the Cooks River Palaeochannel.[11] Based on the geotechnical investigations and packer tests conducted as part of fields investigations for the project, higher groundwater inflows are expected at the northern ends of the mainline tunnels. During construction these high inflow zones are to be grouted to reduce the inflow rate to below the criterion of one litre per second per any kilometre length of tunnel.

Tunnel groundwater inflow from the Hawkesbury Sandstone is expected to be highest during construction, as hydraulic gradients would be at their highest during this time and would then decline as steady state conditions are reached. Groundwater modelling has predicted groundwater inflows to the tunnels after grouting and access decline during construction, to range between 0.06 megalitres per day (21.9 megalitres per year) in 2021 and 0.37 megalitres per day (135 megalitres per year) in 2023.

Tunnel groundwater inflow from the Botany Sands aquifer would also occur during construction. Over the construction period, tunnel inflow from the Botany Sands aquifer would range from 0.08 megalitres per day in 2021 to 0.19 megalitres per day in 2022.

During tunnel construction, groundwater entering the tunnel would be managed by either capturing the water that enters the tunnels and portals or by restricting inflow, through temporary dewatering or the installation of cut-off walls (which limit the movement of groundwater) in cut-and-cover sections. The volume of groundwater and treatment requirements would differ depending on the depth of the tunnel to be constructed, and the geological units through which it passes. It is recognised that high groundwater inflow during excavation is possible in faulted or fractured zones such as beneath the Cooks River palaeochannel and in the alluvium. The wastewater management system for the project is designed to treat and discharge groundwater as well as stormwater and other intersected water.

During construction, long term water management solutions would also be established such as the installation of water proofing membranes or undrained (tanked) tunnels. Groundwater inflows would be collected via a temporary drainage system collecting water from the road header or tunnel boring machine (refer to **Chapter 7** (Construction) for further information regarding tunnelling methodology) and pumping it to the surface for treatment and discharge. Water inflows, treatment and discharge would be managed in accordance with a water management plan, which would form part of the Construction Environmental Management Plan (CEMP) for the project.

To reduce long term groundwater inflows, pre-grouting may be undertaken, for example, to allow groundwater inflows to be more easily managed. The implementation of this technique is dependent upon the local geology, in particularly the orientation and density of water bearing rock defects. Another option to reduce the bulk rock mass permeability and long term inflows, is the installation of water proofing membranes during construction.

Dewatering during construction

Groundwater extraction from the dewatering of the Botany Sands aquifer during construction has been predicted using the groundwater model during the construction of the entry and exit ramps for the President Avenue intersection (1.5 kilometres long) (Q1 2021 to Q1 2022) and the tunnel access decline to the mainline tunnels (Q1 2021). The model calculated groundwater extraction as follows:

- Entry and exit ramps for the President Avenue intersection: 0.66 megalitres per day (299 megalitres over the period Q1 2021 to Q1 2022)
- Access decline: 1.3 megalitres per day (144 megalitres in total over the period Q1 2021).

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[11] Golder Associates (2017); Design Package Report. Hydrogeological Design Report. (FD). The New M5 Design and Construct. Report No M5N-GOL-DRT-100-200-GT-1525-R, dated April.

Water take from the Metropolitan Groundwater Resource

The predicted maximum annual water take from the Metropolitan Groundwater Resource during construction is 431 megalitres (Year 2021) due to tunnel inflows and temporary dewatering associated the entry and exit ramps for the President Avenue intersection and the tunnel access decline excavations. The majority of this extraction (380 ML) is due to the temporary dewatering.

Predicted water take from tunnel inflows for the Botany Sands and Sydney Basin Central groundwater resources compared to the Long Term Average Annual Extraction Limits (LTAAEL) is presented in **Table 17-9**. Comparison of predicted tunnel inflows indicates the reduction in the groundwater availability within the Botany Sands during construction would be reduced by 2.8 per cent of the LTAAEL. Similarly, the predicted reduction in the groundwater availability during construction would be reduced by 0.05 per cent of the LTAAEL for the Sydney Basin Central groundwater resource.

Table 17-9 Groundwater extraction from the Metropolitan Regional Groundwater Resources during construction

Aquifer	LTAAEL (megalitres per year)	Water take (megalitres per year)	Percentage of LTAEEL (%)
Botany Sands	14,684	409	2.8
Sydney Basin Central	45,915	22	0.05

Source: NoW, 2011 and RPS, 2018

17.3.3 Groundwater level decline

Groundwater drawdown

Groundwater drawdown due to construction activities and temporary dewatering could impact the local water table, hydraulic pressures or surface water features where there is hydraulic connectivity. As the majority of the tunnel lengths are drained structures (i.e. not tanked), the tunnel inflows could impact the natural groundwater system and potentially alter regional hydrogeological conditions.

During construction, the regional extent of drawdown impacts due to tunnel construction would be minimal even though groundwater inflows are high. This is due to groundwater storage depletion within the Hawkesbury Sandstone from the immediate vicinity of the tunnel, restricting the lateral extent of drawdown and the relatively short construction timeframe.

As construction continues, the groundwater inflows to the tunnel would decrease but the depressurisation caused by the tunnel inflows would spread to the surface causing the water table to decline and would extend outwards to progressively greater distances until steady state conditions are reached. The longer term regional impacts on groundwater levels would therefore be greater and would progressively increase until steady state conditions are reached which is expected to be well after the completion of construction as predicted by the model.

Grouting (Injecting grout to reduce the bulk rock mass permeability) would be undertaken throughout the construction program to reduce groundwater inflows and hence limit the groundwater level decline. Groundwater levels would be monitored throughout the construction phase in accordance with a Construction Soil and Water Management Plan (CSWMP) to be developed as part of the CEMP. Additional groundwater modelling would be conducted by the contractors during the construction program using measured tunnel inflow rates and monitored groundwater drawdown to better calibrate the model and refine model predictions.

Potential impacts on groundwater dependent ecosystems

The closest high priority GDEs are the Botany Wetlands and Lachlan Swamps within the Botany Sands, located in Centennial Park around eight kilometres north-east of the project footprint. These wetlands are at a sufficient distance from the project footprint to not be impacted by the project during construction and operation.

There is limited information available regarding water level fluctuations within the Rockdale Bicentennial Park Wetland, however the natural variation has been estimated at 0.5 metres. Consequently, according to this criteria a predicted drawdown in excess of 0.05 metres would require adaptive management. Groundwater modelling has predicted that the long term surface water drawdown in Rockdale wetlands is in excess of 0.05 meters (ranging between 0.02 and 0.19 metres)

However the wetlands are not classified as a high priority GDE and the wetlands are highly modified to act as flood mitigation basins. Consequently the projected groundwater drawdown would be less than predicted because of the continual inflow of stormwater and floodwaters.

Potential impacts to the Cooks River Castlereagh Ironbark Forest, Cooks River, Hinterland sandstone gully forest, Coastal sandstone ridgetop woodland and Estuarine fringe forest and mangrove forest GDEs were assessed as being low as a result of groundwater level decline during the construction of the project.

Elsewhere within the study area, wetlands and swamps have limited groundwater dependence and are therefore unlikely to be adversely impacted by groundwater level decline associated with the construction phase of the project.

Long term dewatering caused by tunnel drainage is anticipated to lower the water table water pressure levels within the Hawkesbury Sandstone, which would reduce the amount of groundwater available for shallow rooted plants. The minimum depth of the water table underlying the majority of the project footprint is on average one metre below ground surface. Areas where the water table is shallow, such as along the Rockdale Wetlands corridor, are typically subjected to flood inundation which would provide water periodically for shallow rooted plants that may have some groundwater dependence. At other more elevated topographic areas, such as parts of Arncliffe, the water table is much deeper below ground surface and consequently flora is unlikely to be dependent on groundwater.

Following the completion of tunnel construction, groundwater would be available for partially groundwater dependent flora, as the unsaturated soil zone would not be affected by the project and would continue to receive rain infiltration. Shallow perched water (water located at an elevation higher than the local water table) is expected to be present irregularly along the alignment and could partially sustain surface ecosystems. However, partially groundwater dependent flora would primarily be dependent upon rainfall recharge and moisture within the unsaturated soil zone. In low lying areas, the project is not expected to substantially change the availability of water for plants due to the low permeability of fine soils in combination with frequent rainfall events and higher recharge compared to elevated sites.

An assessment of the impacts to natural processes as a result of the operational discharges which may affect the health of the fluvial, riparian and estuarine systems and landscape health within the study area is provided in **Appendix L** (Surface water technical report). No wetlands, marine waters or natural floodplain systems are considered to be substantially impacted by the project. Impacts to aquatic connectivity and habitat are considered in **Appendix H** (Biodiversity development assessment report).

The mainline tunnels for the project have been designed to minimise high groundwater inflows into the tunnels as described in **section 17.2.1**. Potential impacts associated with groundwater inflows such as groundwater level decline and potential impacts to GDEs have therefore been minimised in the design of the mainline tunnels.

Potential impacts on surface water and baseflow

Surface water features within or in proximity to the project footprint are described in **section 17.2.2**. Where groundwater is hydraulically linked with surface water, groundwater drawdown can impact on surface water flows.

Decreased surface water flows can occur either as a reduction in baseflow, or as streambed leakage that are dependent on the hydraulic connection between the stream channel and alluvium, the underlying sandstone and the relative water levels of the creek and groundwater.

Since the majority of the creeks and drains within the study area are concrete lined, the risk for surface water seep into the tunnels via leakage to the alluvium is considered to be low. There may be some seepage from the creeks due to cracks in the aged concrete.

There is unlikely to be any direct surface water inflow to the tunnels from the alluvium since in the southern part of the alignment where the tunnels intersect alluvium, the tunnels are to be undrained (tanked), or cut and cover sections are to be constructed by diaphragm walls, preventing direct inflow from the alluvium. Elsewhere along the alignment the tunnels are designed to dive beneath the Cooks River Palaeochannel to reduce groundwater ingress to the tunnels from the alluvium.

The Sydney Water proposal to naturalise sections of Muddy Creek is likely to increase groundwater recharge and may partially increase the baseflow to the creek.[12]

Potential impacts to baseflow for major creeks has been modelled and calculated initial baseflow, project baseflow and the reduction in baseflow are summarised in **Table 17-10**.

Table 17-10 Predicted changes to baseflow for the construction of the project

Scenario	Muddy Creek	Spring Street Drain	Cooks River	Wolli Creek	Bardwell Creek
Existing baseflow (m^3 per day)	29.9	198.8	10.6	106.6	126.1
Project baseflow (m^3 per day)	26.5	142.4	10.6	106.6	126.1
Baseflow reduction (m^3 per day)	3.4	56.4	0.0	0.0	0.0
Percentage reduction	11.5	28.4	0.0	0.0	0.0

Muddy Creek and Spring Street Drain are the only streams or channels in the study area that are expected to experience a reduction in baseflow during construction. However, since both channels are predominately concrete lined and tidally influenced, the baseflow contribution to the total streamflow is expected to be negligible. The majority of stream flow would be derived from surface run-off and tidal waters at low elevation. Of this small proportion, there is a predicted 11.5% and 28.4% reduction in baseflow at the end of construction.

Potential impacts on existing groundwater users

A review of current groundwater use has been conducted to identify registered groundwater users within a two kilometre buffer of the project footprint. In accordance with the *NSW Aquifer Interference Policy*, existing groundwater bores impacted by the lowering of groundwater levels in excess of two metres due to the project would be protected by to the ‘make good’ provisions.

The groundwater model has been used to assess the potential groundwater level drawdown for registered groundwater users. The groundwater modelling indicates that during construction, no registered wells would be drawn down in excess of two metres.

Groundwater drawdown is expected to be comparatively minor during the construction phase compared to the operational phase, as long term groundwater levels would continue to decline until steady state conditions are reached.

Saltwater intrusion

During construction there are unlikely to be any impacts associated with saline groundwater entering the tunnels. Saltwater intrusion would commence as soon as the hydraulic pressure within the aquifer declines due to groundwater drawdown via the tunnels, causing the displacement of the less-saline water along the shoreline with more saline tidal water.

The nearest tidal water bodies are Cooks River, Muddy Creek, and Botany Bay located 450 metres, 700 metres and 1000 metres east of the project alignment respectively. However, during construction saline groundwater would not inflow to the tunnels from tidal areas because the tidal surface waterbodies are a considerable distance from the tunnels. The calculated groundwater travel times from these waterbodies are too long for saline water to reach the tunnels. Close to the shoreline, groundwater quality would become more saline during the construction period due to saltwater intrusion. However the slight salinity increase is unlikely to impact on the environment since the groundwater along the tidal fringe is naturally saline due to tidal mixing. There are no registered water supply wells or priority groundwater dependent ecosystems along this tidal fringe which may be impacted by groundwater intrusion.

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[12] https://www.sydneywatertalk.com.au/muddycreek

Ground movement (settlement)

Ground movement (settlement) or subsidence due to the compression of the soil structure from groundwater drawdown is discussed in **section 17.3.9**.

17.3.4 Groundwater quality

Groundwater quality risks from construction activities include potential groundwater contamination from fuel, oil or other chemical spills and from the captured groundwater intersected during tunnelling. There is also potential to intersect acid sulfate soils and contaminated groundwater associated with previous industrial land use. As groundwater drawdown increases due to tunnel inflows, there is the potential for tidal waters to be drawn towards the tunnels, causing saltwater intrusion. Groundwater quality from monitoring wells and groundwater collected during tunnelling would be monitored throughout the construction phase in accordance with the CSWMP. These potential risks to groundwater quality are discussed further in the following sections.

Spills and incidents

There is potential to contaminate groundwater through incidents within the construction ancillary facilities associated with the storage of hazardous materials or refuelling operations. Groundwater could become contaminated via fuel and chemical spills, petrol, diesel, hydraulic fluids and lubricants, particularly if a leak or incident occurs over the alluvium, a palaeochannel or fractured sandstone. Stockpiling of construction materials may also introduce contaminants that could potentially leach into and contaminate local groundwater.

The risks to groundwater as a result of such incidents would be managed through standard construction management procedures in accordance with site specific environmental management plans developed for the project as outlined in **Chapter 16** (Soils and contamination). Runoff from high rainfall events during construction would be managed in accordance with the measures outlined in **Chapter 18** (Surface water and flooding). Following high rainfall events, groundwater quality impacts would be minor, as the majority of runoff would discharge to receiving waters.

Intercepting contaminated groundwater

A number of sites with the potential for groundwater contamination due to various current and historical land-uses are located along the project alignment as outlined in **section 17.2.6**. A potential contamination risk would be associated with the migration of contaminated groundwater plumes towards the tunnels.

The majority of the tunnels are to be constructed within the Hawkesbury Sandstone at depths between 20 metres and up to 62 metres below ground surface level. In general, the risk of intersecting contaminated groundwater decreases the deeper the tunnel depth.

There is potential to intersect contaminated groundwater during construction while excavating the portals and dive structures that are constructed from the top down, although groundwater would typically be isolated from these structures by excavation support options such as diaphragm walls, sheet piled walls or secant piled walls. Contaminated groundwater, if intersected, would enter the tunnels and would be treated prior to discharge at one of the water treatment plants.

During ground excavation works associated with the construction of the entry and exit ramps at the President Avenue intersection, potentially contaminated shallow groundwater is likely to be encountered within the alluvium and would require management during construction. During this construction phase localised temporary dewatering may be required subject to the detailed design of the project. Groundwater would be pumped to the on-site temporary water treatment plants at the President Avenue construction ancillary facility (C3) and discharged in accordance with the adopted discharge criteria.

Groundwater and surface water captured as a result of tunnelling is likely to be contaminated with suspended solids and increased pH due to tunnel grouting activities. These flows would be captured and treated prior to discharge via water treatment plants located at construction ancillary facilities. Where possible, the treated water would be reused during construction for purposes such as dust suppression, wheel washing and plant washing, rock bolting, earthworks or irrigation before discharge. Groundwater reuse would be undertaken in accordance with *National Water Quality Management Strategy* (DPI–Water 2006). The volume of recycled water required for beneficial use would be variable and dependent on site conditions and would be likely be driven by a demand for beneficial use water.

Large portions of the Botany Sands are known to be contaminated from a variety of sources primarily related to previous industrial land-use, however the groundwater in the project area has generally low levels of contamination compared to the groundwater within Botany Management Zone 1, north of the project.

Given the tunnel depth, location of the tunnel in relation to the contaminant sources and low predicted inflow rates, the risk of intercepting contaminated groundwater within the Hawkesbury Sandstone is considered to be low. The risk of contaminated groundwater ingress from the alluvium is also considered low because the tunnel is to be tanked in the alluvium, restricting groundwater movement from the alluvium.

Groundwater treatment

The volume of groundwater and treatment requirements would differ depending on the depth of the tunnel, and the geological units and structures through which the tunnel passes. During construction, the wastewater generated in the tunnel would be captured, tested and treated at a construction water treatment plants prior to reuse or discharge, or disposal offsite if required.

Based on the knowledge gained from the adjoining tunnelling projects (M4 East, New M5 Motorway and M4-M5 Link as part of the WestConnex program of works), it is likely that the water treatment plants would be required to include pH correction as well as the ability to reduce concentrations of iron, manganese, suspended solids, ammonia, nitrate and hydrocarbons. The existing groundwater quality within the study area (refer to **section 17.2.5**) indicates that the groundwater may require treatment for these compounds as well as nitrogen and total phosphorus. Other metals including copper, chromium, lead, nickel and zinc were also recorded at elevated levels on a limited number of occasions within the study area. The type, arrangement and performance of the construction of water treatment facilities would be developed and finalised during detailed design in consideration of ANZECC (2000) guideline levels (marine, freshwater and recreational protection levels).

The receiving waterways and ambient water quality of Muddy Creek and Botany Bay are highly disturbed compared to the treated water discharge quality. The level of groundwater treatment would consider the characteristics of the discharge and receiving waterbody, any operational constraints or practicalities and associated environmental impacts and be developed in accordance with ANZECC (2000). If the project is approved, discharge criteria would be specified in the project conditions of approval.

The assessment of the potential impacts of the quality of water discharged from the water treatment plants during construction is discussed in **Chapter 18** (Surface water and flooding).

Acid sulfate soils

The majority of the tunnels for the project would be deep and extend below the areas where potential acid sulfate soils (PASS) would be expected to be found. However, PASS have been identified at the following areas within the vicinity of the project:

- Within locally derived fill associated with the palaeochannel beneath the project alignment near Bay Street at Bright-Le-Sands
- Within low-lying natural soil in the area that would be excavated for the entry and exit ramps at the President Avenue intersection at Kogarah.

The excavation entry and exit ramps at the President Avenue intersection may uncover PASS which would require treatment and removal in accordance with the CEMP developed for the project.

When exposed to air, the iron sulphides (commonly pyrite) within acid sulfate soils can oxidise, producing sulphuric acid. The soils become exposed to air by either excavation or dewatering. Components of the project that could intercept acid sulfate soils include:

- Temporary and permanent surface infrastructure including building foundations, roads and stormwater drainage structures
- Ventilation and access shafts
- Underground components of bridge and portal structures
- Shallow areas of tunnels located within alluvium.

PASS could be disturbed by the project and may cause the generation of acidic runoff and/or the increased acidity of groundwater. The risks associated with PASS and acid sulfate soil would be managed under a CSWMP as part of the CEMP prepared in accordance with *NSW Acid Sulfate Soils Manual* (Stone *et al* 1998). At locations where works would disturb alluvium acid sulfate, tests should be conducted. The CSWMP would include water quality monitoring and acid sulfate soil management.

Soil salinity

Salts naturally present in soil and rock are mobilised in the subsurface by the movement of groundwater. The concentration of salts within the soil is related to the geological unit from which the soil is derived.

Salt concentrations within soils derived from the Hawkesbury Sandstone are typically low. Concentrations of salts within alluvium can be extremely variable depending on the origin of the alluvium. Salt concentrations within marine derived alluvium or alluvium that is tidally influenced would be high, whereas fluvial sediments (sediments derived from rivers or creeks) deposited in a fresh water creek system would be expected to have low salt concentrations. Under shallow groundwater conditions, saline groundwater may be drawn to the ground surface, precipitating the salts as the water evaporates.

Urban salinity is a problem when the natural hydrogeological balance is disturbed by human interaction through the removal of deep rooted trees (causing groundwater levels to rise and potentially dissolve and mobilise salts from the soil profile) or construction of structures that intersect the water table. Since the majority of deep rooted trees were removed from the study area over 150 years ago, a new equilibrium has been established and the removal of any further remaining trees on the new equilibrium would not be substantial. The development of urban salinity may cause corrosion of building materials, degrade surface water quality or prevent the growth of all but highly salt tolerant vegetation.

During construction of the project, there is potential for salts within the alluvium beneath the entry and exit ramps at the President Avenue intersection to be mobilised by local dewatering or associated with the tunnel construction program. Tunnels constructed within the alluvium are to be undrained (tanked), and consequently could alter local flow paths creating groundwater mounding causing the dissolution of soil salts. Groundwater collected during the temporary dewatering program would be directed towards a modified drainage system for off-site discharge removing any mobilised salts from the system.

17.3.5 Groundwater monitoring

Groundwater monitoring would be carried out during construction. The monitoring program would be designed to monitor:

- Groundwater levels (manual monitoring and automatic monitoring by data loggers)
- Groundwater quality (within key monitoring wells and tunnel inflows)
- Groundwater inflows to the tunnels.

Groundwater would be monitored in the alluvium and Hawkesbury Sandstone. The construction groundwater monitoring network would use a sub-set of the current monitoring wells identified in this chapter and **Appendix K** (Groundwater technical report). It may be necessary to construct additional monitoring wells if some of the existing wells are damaged during construction or other key areas are identified during the detailed design phase where monitoring is required.

It is expected that manual groundwater level monitoring and groundwater quality monitoring would be undertaken monthly. The quality and volume of tunnel inflows are expected to be monitored weekly.

The following analytes are likely to be sampled:

- Field Parameters (pH, electrical conductivity, dissolved oxygen, temperature and redox conditions)
- Metals (arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc)
- Nutrients (nutrients (nitrate, nitrite, Total Kjeldahl Nitrogen (TKN), ammonia and total phosphorous)
- Major cations (sodium, potassium, calcium, magnesium) and anions (chloride, sulphate, carbonate, bi-carbonate).

The analytes to be sampled and the frequency and type of reporting would be confirmed by the construction contractors.

The monitoring program would be developed in consultation with the NSW Environment Protection Authority (NSW EPA), NSW Department of Industry – Water (DI-Water) and Bayside Council and documented in the CSWMP to be developed as part of the CEMP for the project.

17.3.6 Construction ancillary infrastructure and facilities

The majority of ancillary infrastructure proposed as part of the project is above ground and would not impact the hydrogeological regime. Ancillary infrastructure that may impact groundwater during construction includes:

- Tunnel portals
- Ventilation shafts and tunnels
- Water treatment facilities
- Ancillary facilities
- Drainage channels and wetland areas.

During the construction of below ground tunnel ancillary infrastructure such as ventilation shafts or tunnel portals, sheet piling may be installed to assist temporary dewatering. Construction barrier structures such as sheet piling would be in place temporarily and groundwater levels would be restored after the barriers are removed. The tunnel portals and cut-and-cover construction options may include secant piled walls or diaphragm walls socketed into the underlying bedrock to prevent the ingress of alluvial or perched groundwater into the tunnels. Ventilation tunnels and facilities are to be constructed as drained tunnels. This infrastructure has been included in the groundwater model.

The water treatment facilities are to be constructed to enable captured groundwater and surface water to be treated and discharged within the appropriate guideline concentration values. The water treatment plants are not expected to impact groundwater other than groundwater being taken from the local hydrogeological system (refer to **section 17.3.3**). Potential surface water impacts such as discharge from the water treatment plant that could increase flows to local waterways are discussed in **Chapter 18** (Surface water and flooding).

17.3.7 Utility adjustments

Utility adjustments would be required during the construction phase. These would include the protection of existing utilities, construction of new utilities and relocation of existing utilities. The majority of the utility adjustments would occur in new utility service corridors along President Avenue and along the cut and cover sections linking the tunnels with the entry and exit ramps at the President Avenue intersection. The utilities to be impacted include:

- Sewer
- Water mains
- Electricity cables
- Telecommunications including fibre optic cables
- Gas mains.

These works would involve excavating utility trenches to varying depths and are likely to intersect the shallow water table within the alluvium. During trench excavations sheet piling may be required to temporarily provide support in the alluvium and to restrict groundwater inflows to the trench. Once the sheet piling is removed, groundwater levels would return to pre excavation levels. The trenches may be encased in concrete or plastic pipes to water proof the utility service corridors. Deeper trenches or excavations may require temporary dewatering during the construction phase.

Where feasible, the new utility corridors are designed to contain multiple utilities to minimise the land required for construction. These works would be undertaken in accordance with the CSWMP to manage potential impacts to groundwater. Refer to **Chapter 14** (Property and land use) for further information regarding utility works for the project.

17.3.8 Groundwater balance

The simulated water balance for the end of construction (Year 2024) is summarised in **Table 17-11**. The groundwater balance confirms that the major water inflows during the construction phase would be from rainfall infiltration, river leakage and storage. Conversely, the major outflows would be via evapotranspiration, river baseflow and regional flow with additional water being extracted as the tunnels progress. The net loss in storage of 1.06 megalitres per day indicates the tunnel is draining water from the local hydrogeological system.

Table 17-11 Simulated groundwater balance – construction (Year 2024)

Water component	Inputs (recharge) (megalitres per day)	Output (discharge) (megalitres per day)
Rainfall infiltration	4.92	0.00
Evapotranspiration	0.00	4.22
Groundwater Extraction[1]	0.00	0.03
River inflow/outflow	3.24	1.56
Tunnels (M5 East and New M5 Motorway)	0.00	1.10
Regional boundary flow	0.34	1.15
Tidal seepage	0.15	1.65
Storage	3.28	2.22
TOTAL	11.93	11.93

Notes:
1 Extraction from Alexandria Landfill

17.3.9 Ground movement (tunnel induced)

Areas most likely to be affected by ground movement are usually those where tunnelling is closest to the ground surface (shallowest), such as around the tunnel portals and entry and exit ramps, and in areas where the soils are more compressible such as where palaeochannels are infilled with alluvial and marine deposits. Areas overlying locations where the mainline tunnels are at greater depths and in bedrock are unlikely to experience ground movement.

Short term ground movements (settlement or ground heave) due to the tunnel excavation and associated construction works are likely to occur during the construction phase. Settlement due to groundwater drawdown is likely to develop over a period of time post tunnel construction (discussed in **section 17.4.10**).

Tunnel Induced Movement

Tunnel induced ground movements arise when the actual ground loss caused by the excavation exceeds the theoretical excavation volume. For the F6 Stage 1 Mainline this is thought to be the prevalent mechanism causing ground movement, given the tunnel profile is primarily located within competent bedrock with minimal impact to the groundwater profile.

Ground movements would occur primarily during the construction phase of the project and would typically be in the form of a surface settlement trough which develops ahead, above and behind the tunnel excavation face. Generally settlements would be greatest in magnitude directly above the tunnel centreline and subside to the sides and ahead of the tunnel face.

Tunnel induced ground movements would only occur during the construction phase, but consolidation and compression settlement could commence in the construction phase and continue into the operational phase.

Preliminary, indicative, estimates of the tunnel induced ground settlements are provided **Table 17-12**. These predicted impacts are shown on **Figure 17-7**.

Table 17-12 Preliminary, indicative tunnel inducted ground settlement estimates

Tunnel Element	Depth below Ground Surface	Estimated Settlement
Cut and cover structure	5-10 metres	Nil
Twin Tunnels	<40 metres	10mm to 25mm
Twin Tunnels	40 metres to 60 metres	5mm to 10mm
Twin Tunnels	>60 metres	2mm to 5mm
Cavern	40 metres	10mm to 30mm

Impacts to Structures

The manner in which a structure responds to ground movements depends upon its size, design and materials. For instance a timber or steel frame structure may be flexible, deflecting as the ground moves. In contrast, a masonry building, subject to similar displacements, may behave in a more brittle manner. The degree of movement experienced by a structure is also dependant on its foundation type. Deep foundations might support a structure from outside the zone of movement, isolating the structure from the adjacent surface level changes. Settlement assessments of all potentially affected structures, utilities and civil infrastructure would be undertaken during detailed design prior to construction.

It is generally accepted that the risk of damage to surface features is negligible when subjected to total settlements of less than 10 mm. For the majority of the tunnel length, the ground settlement is predicted to be less than 10mm due to the depth of the tunnel. Increased levels of settlement (up to around 30mm) may be observed at the southern end of the project, where the tunnel is shallower.

Monitoring of settlement throughout the construction program would be included as part of the CEMP and may include the installation of settlement markers or inclinometers. Pre-construction condition surveys of property and infrastructure that could be impacted by settlement would be undertaken before the commencement of construction activities. In the event that project settlement criteria (which would be determined in the conditions of approval for the project, if approved) are exceeded during construction for property and infrastructure, measures would be taken to 'make good' or to manage the impact (refer to **section 17.1.7** for further information regarding settlement criteria). Environmental management measures to control groundwater inflows (which influence groundwater drawdown and therefore ground movement) during construction are outlined in **section 17.6**.

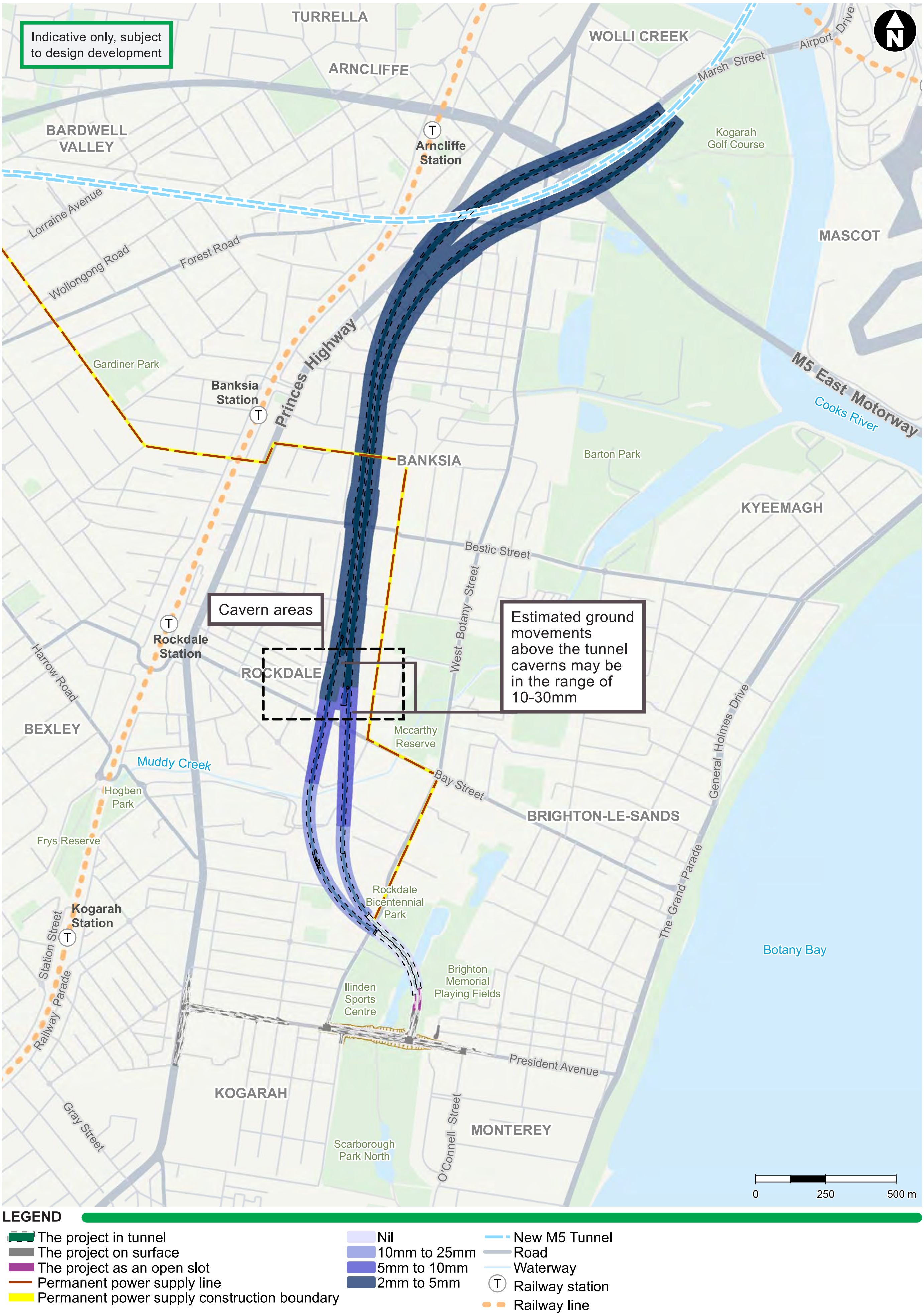

Figure 17-7 Preliminary indicative ground movements as a result of the project

17.4 Potential impacts – operation

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

- Reduced groundwater recharge
- Tunnel groundwater inflow
- Groundwater level decline including impacts on:
    - Long term groundwater flow
    - Groundwater drawdown
    - GDEs
    - Existing groundwater users
    - Baseflow
    - Ground settlement
- Groundwater quality
- Barriers to groundwater flows from operational infrastructure and ancillary infrastructure.

A detailed water balance has been calculated to predict the long-term impacts from operation of the project. This is discussed further in **section 17.4.9** and in **Appendix K** (Groundwater technical report).

17.4.1 Reduced groundwater recharge

The alluvium along the Rockdale Wetlands corridor is recharged by direct rainfall and leakage from the Rockdale Wetlands. A new pavement drainage system to accommodate road widening at President Avenue would direct runoff into water quality basins before discharge into either Rockdale wetland or North Scarborough Pond. Although the runoff to the ponds is likely to marginally increase due to the higher volumes of captured run-off, groundwater recharge should remain the same as the rate of leakage from the Rockdale Wetlands should remain constant. The Rockdale Wetlands and Scarborough Ponds would continue to behave as a flood storage area which would reduce the impacts of flooding along the connected wetland system.

The development of impervious surfaces along the alignment such as the widened road at President Avenue would increase the volume and rate of runoff, and reduce local groundwater recharge.

The majority of the project is below ground surface and is unlikely to directly impact groundwater recharge. Given the limited increase in surface area of the surface road infrastructure, including operational infrastructure such as the motorway operations complexes, ventilation infrastructure, substations and water treatment plants, it is considered that the reduction in rainfall recharge across the study area would be negligible.

17.4.2 Tunnel groundwater inflow

Inflow to the drained tunnel is influenced by tunnel construction methods, as well as the local geology and hydrogeological features of geological features such as hydraulic conductivity, storativity and hydraulic connectivity.

The project tunnels would be excavated primarily from Hawkesbury Sandstone with some sections transitioning through alluvium. To reduce groundwater inflow, the tunnels are designed to minimise intersecting the alluvium by diving beneath the Cooks River Palaeochannel. Where the tunnels rise to the surface at the President Avenue intersection entry and exit ramps, it is not possible to avoid the alluvium so the tunnels would be undrained (tanked) to reduce groundwater inflow.

Conservative estimates of tunnel inflows can be made by assuming a maximum uniform groundwater inflow rate of one litre per second per kilometre along the whole drained tunnel length during operation of the project. The total tunnel length including motorway and ventilation tunnels is around 8,460 metres. The total tunnel length of drained tunnel is 6,840 metres.

Assuming a worst case scenario of a uniform groundwater inflow rate of one litre per second per kilometre along the whole tunnel length, a groundwater inflow of around 6.84 litres per second (0.6 megalitres per day) would be expected. This approach is a conservative inflow estimate as the tunnels are designed to restrict groundwater inflow to below one litre per second per any kilometre length.

Long term groundwater inflows have been modelled and vary over time as local conditions change. After the commencement of operations in 2024, the estimated long term inflows into the motorway tunnels are predicted to be 222 megalitres per year, reducing to 216 megalitres per year in 2100.

Inflow from specific hydrogeological units

Groundwater inflow from the Hawkesbury Sandstone is expected to be low along the majority of the alignment due to low bulk hydraulic conductivity values of typically 0.008 metres per day.

The alignment intersects the Botany Sands Source Management Zone, however there would be no direct inflow of groundwater from the Botany Sands into the tunnels because the sections of tunnels intersecting the alluvium are to be undrained (tanked). There are however likely to be indirect inflows from the Botany Sands aquifer, as the Hawkesbury Sandstone is likely to be hydraulically connected to the Botany Sands aquifer. These indirect inflows would be low given the low bulk hydraulic conductivity of Hawkesbury Sandstone.

There is no direct inflow to the tunnels from the alluvium since the tunnels are designed as undrained (tanked) where the alluvium is intersected. Cut-and-cover sections that intersect the saturated alluvium are to be constructed with cut-off walls and diaphragm walls to restrict long term tunnel leakage from the alluvium. There may be indirect inflows however, given that alluvium is hydraulically connected to surface waterbodies and that water can potentially leak from the wetlands, ponds and creeks via the alluvium and fractured sandstone (refer to **section 17.4.3** for further information regarding leakage).

Dykes may affect tunnel drainage in the short term as competent (fresh) dykes or dykes weathered to clay can form natural hydraulic barriers. Conversely the zone around a dyke within sandstone can be fractured causing a conduit for groundwater flow.

Water take from the Metropolitan Groundwater Resources

The predicted long term water take from each of the Greater Metropolitan Regional Resources due to tunnel inflows and compared to the LTAAEL is summarised in **Table 17-13**. Comparison of predicted tunnel inflows indicates the long term reduction in the groundwater availability within the Botany Sands over the life of the project would vary from 66 megalites per year (2025) to 51 megalitres per year (2100) which represents 0.35 to 0.45 per cent of the LTAAEL. Annual rainfall recharge to the Botany Sands Aquifer is 30,424 megalitres. Therefore the predicted groundwater ‘take’ from the Botany sands represents between 0.17 and 0.22 percent of the available recharge.

Similarly the predicted long term tunnel inflows represent a small percentage of the LTAAEL for the Sydney Basin Central which range from 0.47 per cent to 0.48 per cent. Long term inflows to the Sydney Basin Central Regional Groundwater Resources decline as storage declines over the project life.

Table 17-13 Groundwater extraction from the Metropolitan Regional Groundwater Resources during operation

Aquifer	LTAAEL (megalitres per year)	Water take (megalitres per year)		Percentage of LTAEEL (%)
Botany Sands	14,684	66	51	0.35 to 0.45
Sydney Basin Central	45,915	222	216	0.47 to 0.48

Source: NoW, 2011 and RPS, 2018

Management of groundwater inflows

Grouting and the installation of waterproof membranes would reduce groundwater inflow to the tunnels. Groundwater inflow at dive structures, ventilation shafts and cut-and-cover sections would be restricted by the construction of diaphragm walls and cut-off walls constructed in good quality Hawkesbury Sandstone. Tunnel inflows would be monitored in accordance with a groundwater monitoring plan (GMP) which would form part of the Operational Environmental Management Plan (OEMP) or Environmental Management System (EMS) for the project. The GMP would outline the process of monitoring and management measures for groundwater inflows. Groundwater flow meters would be spaced at a minimum of one kilometre intervals to ensure the minimum inflow criteria is being met.

Measures to manage groundwater inflows are summarised in **section 17.6**.

17.4.3 Groundwater level decline

Long term groundwater inflow

Previous tunnelling in the Hawkesbury Sandstone in the Sydney region has shown that groundwater inflow is typically highest during construction and then steadily reduces as an equilibrium or steady state conditions are reached. This equilibrium is achieved when the tunnel inflow is matched by rainfall recharge via infiltration and/or surface water inflows.

Based on historical groundwater inflows to other drained Sydney tunnels, the long term inflow rate into the project tunnels is expected to be below the one litre per second per kilometre for any kilometre tunnel length. Specific zones capable of higher rates of inflow identified during construction would require treatment such as grouting, to reduce the bulk permeability of the rock mass to reduce inflow rates to meet the design inflow criterion.

Groundwater modelling has calculated inflows for the construction and operations phases. At project opening (2024) tunnel inflows are estimated to be 222 megalitres per year, declining to 216 megalitres per year at the end of the model simulation in 2100. As observed in other Sydney tunnels, inflow is likely to decrease with time.

Groundwater drawdown

Construction of drained tunnels beneath the water table is expected to cause long term ongoing groundwater inflow to the tunnels, inducing groundwater drawdown along the project footprint during its operation. Actual groundwater drawdown of the water table would be dependent on a number of factors including hydraulic parameters and proximity to the project footprint. Immediately after tunnelling is completed, groundwater inflows would be at their highest. With time, groundwater inflow to the tunnel would decrease, while the water table would gradually decline until a new equilibrium is reached.

Groundwater drawdown within the palaeochannels and river alluvium within the study area would be minimal as the hydraulic heads within saturated sediments are in part maintained by direct hydraulic continuity with surface water, supported by a reduction in stream baseflow (refer to **section 17.4.3**).

Calculated long term (Year 2100) drawdown for the project within the alluvium and Hawkesbury Sandstone is presented in **Figure 17-8** and **Figure 17-9** respectively.

Long term (Year 2100) drawdown for the project within the alluvium is centred on Spring Street Drain and Muddy Creek. The maximum drawdown within the alluvium is 5.3 metres where Spring Street Drain directly overlies the tunnels. The drawdown extent to the 2.0 metre drawdown contour extends approximately 200 metres either side of the drain. To the south at Muddy Creek and the access decline drawdown reaches a maximum of 0.6 metres.

Long term (Year 2100) drawdown for the project within the Hawkesbury is elongated along the tunnel alignment extending approximately 350 metres from the tunnel alignment to the two metres drawdown contour. The maximum drawdown is 33 metres over the access decline to the north decreasing to 30 metres at Arncliffe.

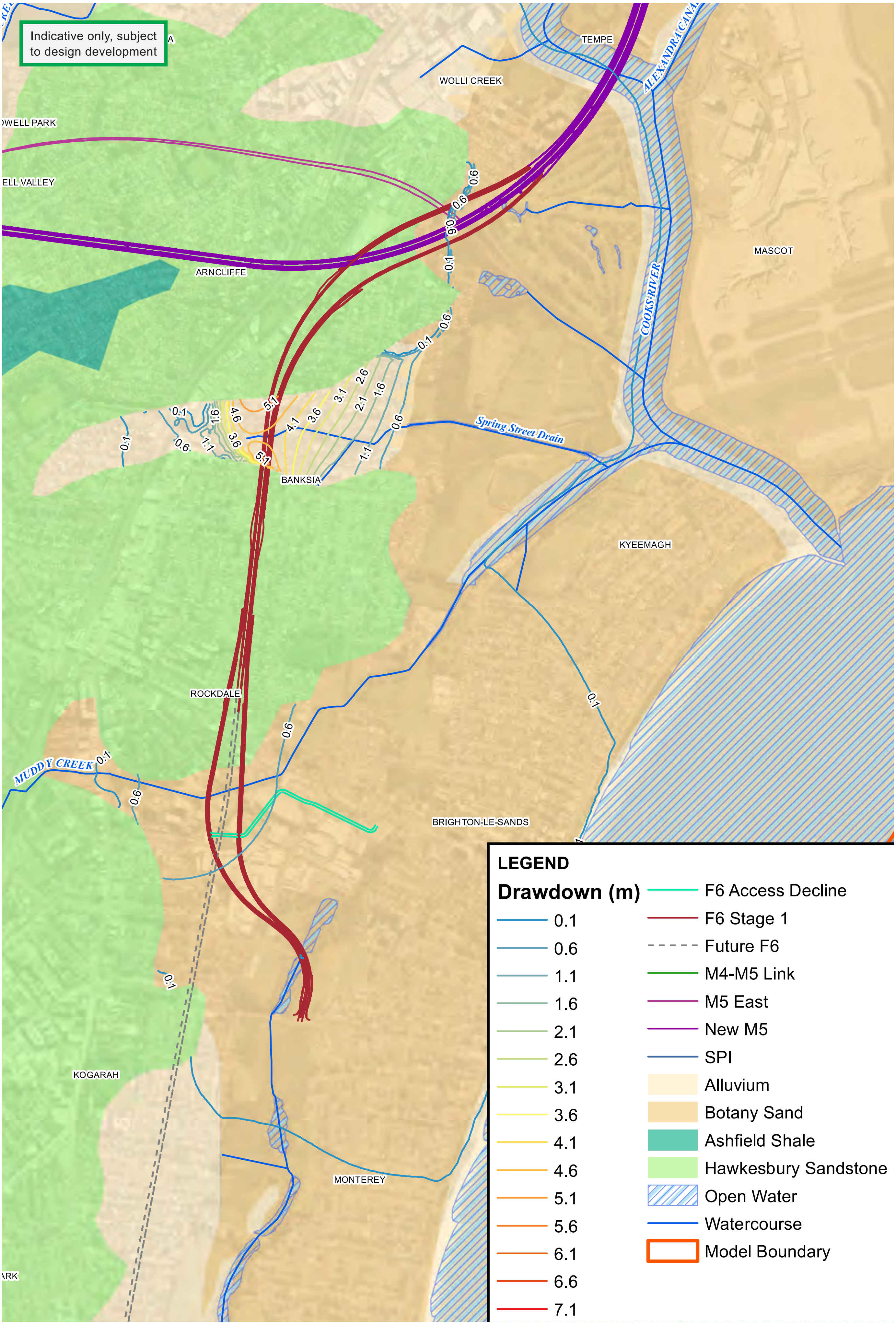

Figure 17-8 Predicted long term (Year 2100) drawdown in the alluvium for the project (RPS, 2018)

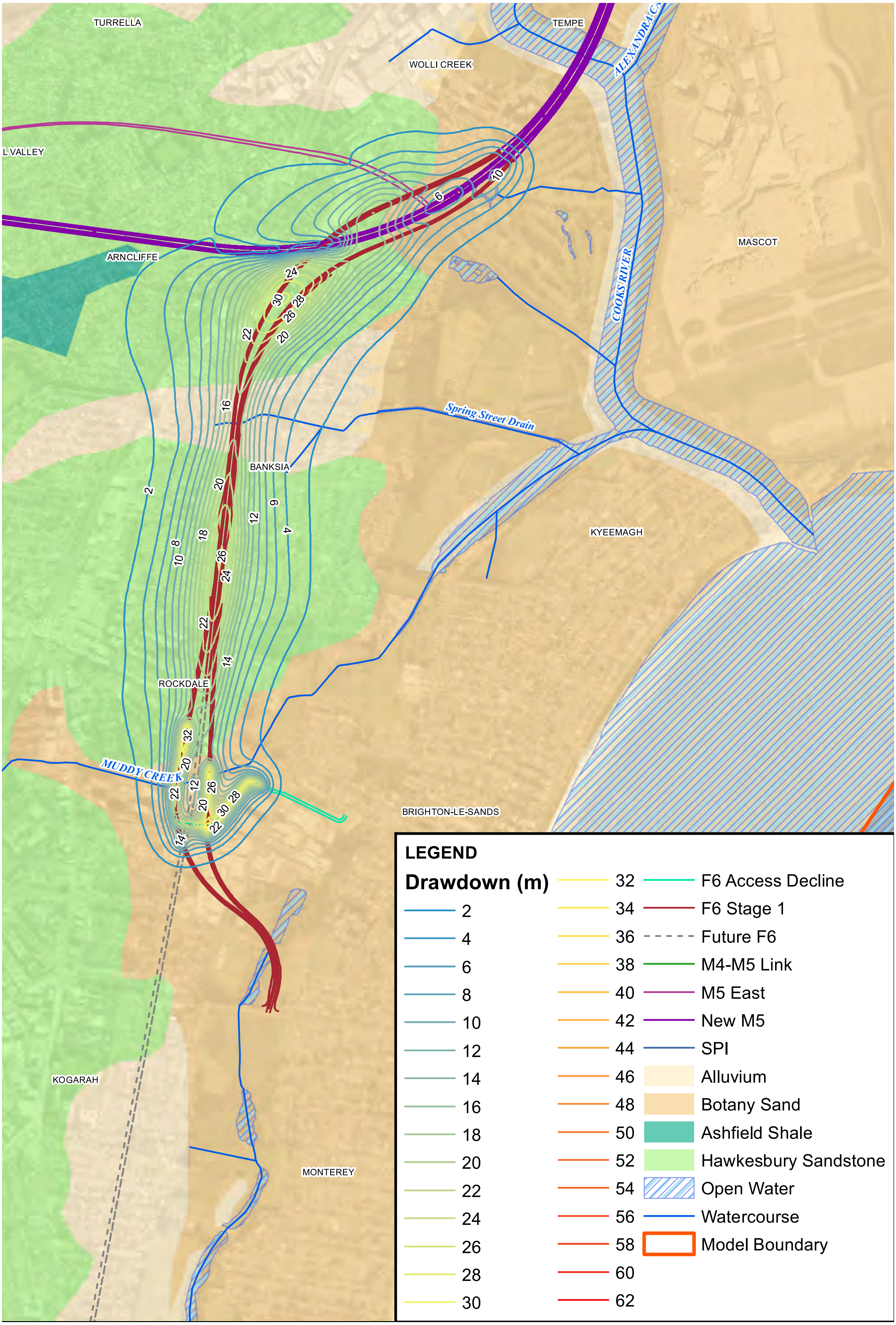

Figure 17-9 Predicted long term (Year 2100) drawdown in the Hawkesbury Sandstone for the project (RPS, 2018)

Potential impacts to groundwater dependent ecosystems

Wetlands within the project area include the Landing Lights, Eve Street, Spring Street, King Street and Marsh Street Wetlands. The potential for impacts drawdown at these locations has been investigated for the project. Drawdown in excess of the seasonal variation of 0.05 metres is predicted at these wetlands with long term drawdown predicted to vary from 0.28 metres at Landing Lights Wetland to 0.47 metres at the Marsh Street Wetland. These predicted drawdowns are not considered to be of concern because the wetlands are not dependent on groundwater as described in **section 17.2.8**.

For the Rockdale wetlands, groundwater modelling predicts the long term surface water drawdown in as being in excess of 0.05 meters. However, as described in **section 17.3.3** the wetlands are not classified as high priority and in fact are highly modified to act as flood mitigation basins. Consequently the predicted groundwater drawdown would be less than predicted because of the continual inflow of stormwater and floodwaters.

Long term dewatering caused by tunnel drainage is predicted to lower the water table and water pressure levels within the Hawkesbury Sandstone, reducing the amount of groundwater available for some shallow rooted plants as described in **section 17.3.3**.

Potential impacts to the Cooks River Castlereagh Ironbark Forest, Cooks River, Hinterland sandstone gully forest, Coastal sandstone ridgetop woodland and Estuarine fringe forest and mangrove forest GDEs were assessed as being low as a result of groundwater level decline during the operation of the project.

An assessment of the impacts to natural processes as a result of the operational discharges which may affect the health of the fluvial, riparian and estuarine systems and landscape health within the study area is provided in **Appendix L** (Surface water technical report). No wetlands, marine waters or natural floodplain systems are considered to be substantially impacted by the project. Impacts to aquatic connectivity and habitat are considered in **Appendix H** (Biodiversity development assessment report).

Potential impacts on existing groundwater users

The majority of registered bores within two kilometres of the project footprint are shallow bores extracting groundwater from the Botany Sands for domestic use. A total of 360 boreholes within a two kilometre radius of the project footprint are registered for water supply or irrigation.

Groundwater modelling has been used to predict drawdown at the location of registered bores across the project footprint. In accordance with the *NSW Aquifer Interference Policy,* a predicted drawdown of greater than two metres would require adaptive management. Only five bores are predicted to be impacted by a long term drawdown in excess of two metres, directly attributable to the project. These bores are shallow water supply wells as summarised in **Table 17-14** with a maximum predicted long term drawdown of 3.78 metres (GW024062).

Table 17-14 Predicted long term drawdown in registered bores in excess of two metres

Registered Bore ID	Use	Depth (metres)	Screened Geology	Drawdown (metres) Year 2100
GW024062	Water Supply	3.6	Alluvium	3.78
GW108295	Domestic	8.0	Alluvium	2.07
GW108439	Domestic	8.0	Alluvium	2.32
GW110735	Domestic	8.0	Alluvium	2.16
GW023194	Water Supply	4.8	Sandstone	2.51

Potential impacts on surface water and baseflow

Predicted long term changes in baseflow as a result of the project are summarised in **Table 17-15**. Although the baseflow component of surface flow is reduced in several of the water courses, the volumes are small and it is possible that the overall contribution to river flow from groundwater input is even smaller due to the waterways being mostly lined channels, including Muddy Creek.

Table 17-15 Predicted long term changes to baseflow (Year 2100)

Scenario	Muddy Creek	Spring Street Drain	Cooks River	Wolli Creek	Bardwell Creek
Existing baseflow (m^3 per day)	36.6	139.8	14.1	55.6	103.7
Project baseflow (m^3 per day)	29.2	83.2	14.1	55.6	103.7
Baseflow reduction (m^3 per day)	7.4	56.6	0.0	0.0	0.0
Percentage reduction	20.4	40.5	0.0	0.0	0.0

Muddy Creek and Spring Street Drain are the only streams or channels in the study area that are expected to experience a long term reduction in baseflow from the operation of the project. However since both channels are predominately concrete lined and tidally influenced, the baseflow contribution to the total streamflow is expected to be a negligible proportion. The majority of stream flow would be derived from surface run-off and tidal waters at low elevation. Of this small proportion, there is a predicted long term 20.4% and 40.5% reduction in baseflow. Further afield but within the model domain, there are no predicted impacts on Wolli Creek and Bardwell Creek during construction caused by the project.

The Rockdale wetlands and Scarborough Ponds are not concrete line and are therefore in hydraulic connection with the underlying alluvium. Any decline in water levels in these waterbodies is likely to be in part balanced with diverted stormwater and floodwaters in the flood mitigation scheme for the project (refer to **Chapter 18** (Surface water and flooding)).

Sydney Water is proposing to naturalise parts of creek channels within the project footprint, including sections of Muddy Creek. Removal of sections of the concrete-lined base would allow more groundwater and surface water interaction leading to a higher contribution of baseflow to surface water flow in the creeks. The impact of a reduction in baseflow due to the project and a reduction in hydraulic heads would be in part balanced by the proposed naturalisation works, resulting in future additional surface water recharge via bed leakage when the water table is below the creek bed.

No permanent springs that contribute to surface flow or river baseflow have been identified within the project footprint.

Saltwater intrusion

Saltwater intrusion would commence as soon as the hydraulic pressure within the aquifer declines due to groundwater drawdown via the tunnels causing the displacement of fresher water along the shoreline with more saline tidal water. In some locations, saline intrusion could cause saline water to reach the tunnels.

A capture zone analysis has been undertaken as part of the groundwater modelling to investigate the movement of saline water. From this analysis it is not possible to quantify volumes or concentrations of saline water entering the tunnels and consequently the following discussion is qualitative.

The capture zone analysis indicates that groundwater from the tidal zones associated with the Botany Sands aquifer, Cooks River/Alexandra Canal, Wolli Creek and Spring Street Drain would at some stage be drawn down, increasing in velocity towards the tunnels. There is potential for saline intrusion of tidal waters to impact the water quality of natural groundwater at Spring Street Drain and in the alluvial aquifer at Arncliffe which may reduce the quality of groundwater being used to irrigate the Kogarah Golf Course. Salt water intrusion of the saline waters of Botany Bay is not predicted to be drawn towards the tunnels as the gradient near Botany Bay remains towards the coast.

Travel times for tidal water to enter the tunnels in the project area range from 46 years at Spring Street Drain to 127 years at the project mainline tunnel.

Initial saline groundwater inflows represent extremely small inflow which would slowly become a larger proportion of flow over time. Groundwater quality in the tunnel catchment zones would slowly become more saline over thousands of years. Since the operational lifetime for major infrastructure is in the order of 100 years, the slow salinity increase would have minimal impacts on the tunnels, infrastructure and the environment in the short term. There is the potential to increase the salinity in registered groundwater bores due to saltwater intrusion however, the slow progress of saline groundwater is expected to have a minimal impact on these bores over a period of 100 years.

Groundwater quality and inflow would be routinely monitored and treated as required prior to discharge in accordance with the OEMP for the project.

Ground movement (settlement)

Potential impacts related to settlement during operation from groundwater drawdown are discussed in **section 17.4.10**.

17.4.4 Groundwater quality

Intercepting contamination groundwater

The tunnel drainage infrastructure is designed to capture two separate drainage streams consisting of groundwater ingress and stormwater ingress consisting of runoff from portals, spills, maintenance washdown water and fire suppressant deluge. The quality of the two tunnel streams are expected to vary considerably and consequently are to be treated differently prior to discharge.

Groundwater quality monitoring indicates the groundwater within the study area is brackish with elevated metals and nutrients recorded during groundwater sampling. In order to prevent adverse impacts on downstream water quality within the Cooks River, treatment facilities would be designed so that the effluent would be of suitable quality for discharge to the receiving environment (refer to **Appendix L** (Surface water technical report) for further information)).

Water treatment may involve:

- Flocculation to reduce total suspended solids
- Ion exchange to reduce salinity, nutrients and dissolved solids
- Reduction of iron and manganese concentrations
- Reverse osmosis to reduce salinity and remove organic impurities
- pH correction through the addition of lime or acid.

During the operational phase collected groundwater is to be transferred to the water treatment plant at the Arncliffe Motorway Operations Complex (MOC1). The tunnel operational water treatment facilities would be designed such that effluent would be of suitable quality for discharge to the receiving environment (refer to **Appendix L** (Surface water technical report)). Nutrient treatment options (for example ion exchange or reverse osmosis) within the water treatment plant would be investigated during detailed design with consideration to other factors such as available space, increased power requirements and increased waste production.

Corrosion by groundwater

Tunnel infrastructure including the construction of ancillary infrastructure would be mostly located below the water table and the building materials would therefore potentially be subjected to corrosion due to interaction with groundwater. There are a number of factors that contribute to corrosion, which are related to groundwater aggressivity and include chloride, sulfate, pH and resistivity. The presence of dissolved chloride and sulfate in groundwater is one of the main factors contributing to corrosion potential of concrete and steel.

The aggressivity assessment (**section 17.4.4**) indicates that groundwater within the alluvium and Hawkesbury Sandstone is mildly aggressive to concrete piles with respect to chloride, pH and sulfate. For steel piles, groundwater within the alluvium and Hawkesbury Sandstone is non aggressive to steel piles with respect to chloride and pH but is severely aggressive with respect to resistivity.

17.4.5 Barriers to groundwater flow from operational infrastructure

Below ground infrastructure, such as a tunnels, can create physical barriers that cause temporary or permanent interruptions to groundwater flow. Temporary impacts may be seen after heavy rainfall, when infiltration to the water table and lateral flow are slowed by the barrier, creating a build-up of groundwater behind the barrier (groundwater mounding).

During the operation of the tunnels, physical barriers to groundwater flow are unlikely for a number of reasons. The majority of the tunnels (including ventilation tunnels) are designed to be drained, which would allow groundwater to seep into the tunnel rather than creating a physical barrier to groundwater flow.

Only limited sections of the tunnels are to be undrained (tanked) preventing groundwater ingress. These sections of the tunnels are to be constructed within alluvium and are unlikely to create a physical barrier as the tunnels would not fully penetrate the alluvium which would allow groundwater to flow around (above or below) the tunnel. Grouting of highly permeable zones to reduce the bulk hydraulic conductivity and tunnel inflows are unlikely to create hydraulic barriers to regional flow, as the grouting would be localised and not applied through the full thickness of the aquifer.

Although the project tunnels are unlikely to create physical barriers, drained tunnels may create hydraulic barriers impacting local groundwater flow patterns. The hydraulic barrier is formed by lowering groundwater levels centred on the tunnel alignment and, in some cases, locally reversing the groundwater flow direction. Permanent drawdown around the drained tunnels is likely to occur as discussed in the sections above. The creation of a groundwater ‘sink’ would occur along the alignment and extend to a level beneath the tunnel invert.

At tunnel portals or cut-and-cover sections (such as at the President Avenue intersection entry and exit ramps), the potential interruption of groundwater and possible groundwater mounding caused by the installation of cut-off walls would be avoided by the inclusion of drainage blankets or drains in the detailed design.

17.4.6 Barriers to groundwater flow from ancillary infrastructure

The following ancillary infrastructure may impact groundwater during operation of the project:

- Tunnel portals
- Ventilation tunnels and systems
- Utility adjustments
- Drainage channels and wetland areas.

Options for the construction of tunnel portals and cut-and-cover structures include secant piled walls or diaphragm walls socketed into the underlying bedrock to prevent the long term ingress of alluvial or perched groundwater into the tunnels. The construction of these structures would potentially alter local groundwater flow directions and could act as barriers to groundwater flow. Mitigation measures such as the installation of drainage blankets to direct groundwater around these barriers would be explored during the detailed design of the project.

Ventilation tunnels are likely to be constructed as drained tunnels. Impacts to the hydrogeological regime due to additional drained tunnels are likely to slightly increase groundwater inflows and the lateral extent of groundwater drawdown. This infrastructure has been included in the groundwater model which informs this assessment.

Utility corridors and drainage channels are unlikely to be constructed at a depth to impact groundwater. Potential impacts due to discharge are discussed in **Appendix L** (Surface water technical report).

17.4.7 Impacts to the final landform

The primary impact on the final landform would likely to be due to groundwater drawdown in the alluvium, Botany Sands and bedrock aquifers. Drawdown in the unconsolidated alluvial sediments and Botany Sands could result in ground settlement, which is discussed in **Chapter 14** (Property and land use). Groundwater drawdown in the Hawkesbury Sandstone beneath the alignment is unlikely to cause substantial settlement due to the competent nature and the geotechnical properties of the sandstone. Ongoing groundwater inflow near tidal surface water features may cause localised saltwater intrusion over time, resulting in an increase in groundwater salinity.

Groundwater settlement within the alluvium is likely to be greater compared to the Hawkesbury sandstone because of the unconsolidated lithology within the alluvium. Settlement induced by groundwater drawdown would only occur in the alluvium when the drawdown exceeds the natural range of groundwater level fluctuation. The natural level of fluctuation in the area is estimated to be one metre and therefore the majority of the project alignment would not be impacted by settlement within the alluvium. Groundwater settlement may occur within the alluvium beneath the Spring Street Drain where the maximum drawdown in the alluvium is predicted to be 5.3 metres. The amount of settlement would depend on the geotechnical properties of the alluvium and is predicted to extent approximately 200 metres to the east and 400 metres to the west of the alignment.

Operational infrastructure would occupy excavated areas for the project. The final landform for the project would not include voids that would require management or rehabilitation during operation. Proposed landscaping details for the final landform are provided in **Appendix C** (Place making and urban design).

17.4.8 Groundwater monitoring

The groundwater monitoring program prepared and implemented during construction (**section 17.3.5**) would be augmented and continued during the operational phase. Groundwater would be monitored during the operation phase for three years or as otherwise required by the project conditions of approval and would include trigger levels for response or remedial action based on monitoring results and relevant performance criteria.

The exact nature and frequency of the ongoing groundwater monitoring during operation would be determined by the project operator in consultation with the NSW EPA, DI-Water and the Bayside Council and would be documented in the OEMP or EMS. Additional groundwater monitoring wells are likely to be required once the tunnels are constructed. The location, depth and purpose of monitoring wells would be decided in consultation with the NSW Department of Planning and Environment (DP&E) and DI-Water.

17.4.9 Groundwater balance

The simulated water balance for the long term operation phase (Year 2100) is summarised in **Table 17-16**. The water balance has been developed based on the transient groundwater model, averaged over the operational life of the project.

The operational water balance confirms that regional boundary flows and rainfall infiltration is the primary recharge parameter and the primary discharge parameters are evapotranspiration, river leakage and discharge to tidal areas.

Table 17-16 Simulated groundwater balance – construction (2024)

Water component	Inputs (recharge) (megalitres per day)	Output (discharge) (megalitres per day)
Rainfall infiltration	4.35	0.00
Evapotranspiration	0.00	4.90
Groundwater Extraction[1]	0.00	0.05
River inflow/outflow	2.68	1.98
Regional boundary flow	0.31	1.17
Tidal seepage	0.10	1.67

Water component	Inputs (recharge) (megalitres per day)	Output (discharge) (megalitres per day)
Tunnels (M5 East and New M5 Motorway)	0.00	0.38
Total without storage	7.44	10.15
Storage	5.72	3.01
Total with storage	13.16	13.16
Net change in storage	-2.71	

Notes:
1 Extraction from Alexandria Landfill

A complete water balance for surface water and groundwater inputs and outputs is provided in **Chapter 18** (Surface water and flooding) and in **Appendix L** (Surface water technical report).

17.4.10 Ground movement (settlement)

Ground movement induced by tunnel excavation during construction is discussed in **section 17.3.9**. Impacts related to settlement during operation may be caused by groundwater drawdown, which occurs over a longer timeframe as opposed to settlement impacts from tunnel construction.

When groundwater levels are drawn down, the unconsolidated sediments hosting the groundwater are subjected to an increase in effective stress (the force that keeps soil particles together), and the sediment may experience settlement. If the degree of settlement is sufficient, it can result in damage to structures within the groundwater drawdown zone of influence. Settlement associated with construction tunnelling occurs within a shorter timeframe compared to settlement associated with groundwater drawdown, which occurs over a longer timeframe.

The tunnels have been designed to dive beneath the majority of the Cooks River Palaeochannel to reduce groundwater ingress to the tunnels from the alluvium and therefore reduce settlement. Where tunnels rise to the ground surface in the southern part of the alignment, the alluvium would be intersected. Tunnel sections intersecting the alluvium would be undrained (tanked) to minimise groundwater ingress. Cut and cover sections forming part of the entry and exit ramps at the President Avenue intersection would be constructed with diaphragm walls to reduce tunnel groundwater ingress. Elsewhere along the alignment, the hydraulic conductivity of the Hawkesbury Sandstone would be decreased by grouting which would decrease groundwater inflow and hence reduce settlement.

Small scale dewatering of the alluvium and Hawkesbury Sandstone may be required during construction which would result in an increase in effective stress potentially leading to ground settlement. It is anticipated that dewatering the Hawkesbury Sandstone would result in negligible settlement.

Although the groundwater model has predicted groundwater drawdown within the alluvium, the model is a regional groundwater model and is not considered appropriate for use in estimating groundwater induced settlement at a more localised level. Detailed settlement modelling would be required to be undertaken by the construction contractors during the detailed design phase, as part of the detailed design where the water table within alluvium may be drawn down.

A geotechnical model of representative geological and groundwater conditions would be prepared during detailed design. The model would be used to assess predicted settlement impacts and ground movement caused by excavation and tunnelling on adjacent property and infrastructure.

Consolidation of the soil profile

The sensitivity of individual geotechnical units to settlements is a function of their strength, stiffness, and the stress history of the unit. The estuarine and aeolian soils infilling the palaeochannels along the project alignment range from very soft to firm in consistency, and the sands range from very loose to medium dense in density. Such soils have limited bearing capacity and are susceptible to settlement primarily by consolidation. If the vertical stress regime is increased, the clay soils would undergo consolidation settlement as well as creep settlement, resulting in settlement possibly continuing over a long period of time.

In order to reduce the magnitude settlements in the upper soil profile due to groundwater drawdown, tunnel alignments have been designed to dive below the palaeochannel on the mainline. However, at President Avenue the tunnel alignments intercept the deep palaeochannels or come in close proximity. For these locations watertight cut and cover structures or tanked tunnel sections have been nominated to minimise the amount of groundwater drawdown and potential for tunnel induced ground loss.

It is anticipated that where compressible soils are exposed under loaded structural elements, the loads would be transferred by into more competent bedrock, thereby limiting the creep settlement component.

With the exception of the palaeochannels, groundwater drawdown caused by the tunnel is expected to be generally confined to bedrock and not induce consolidation in the soils overlying the bedrock. On this basis, surface settlement due to drawdown of groundwater is expected to be negligible along the tunnel alignment other than at the palaeochannels in the vicinity of Spring Street, Bay Street and President Avenue. Preliminary estimates of the ground settlements at these locations are provided in **Table 17-17**.

Table 17-17 Preliminary estimates for ground settlements overlying palaeochannels

Location	Estimated Groundwater Drawdown		Preliminary estimates for ground settlement
Spring Street Palaeochannel	6.1m	23.5m	30mm to 50mm
Bay Street Palaeochannel	0.7m	17m	10mm to 20mm
President Ave Palaeochannel	0.3m	21m	2mm to 5mm

Muddy Creek constructed channel

The Muddy Creek constructed channel is a concrete lined stormwater drain managed by Sydney Water. The project tunnels would be located more than 50 metres below the channel level.

The Muddy Creek constructed channel lies within a palaeochannel eroded into Sandstone bedrock and is infilled with a thick sequence of alluvial and marine deposits. Depths to rock are expected to exceed 30 metres. The hydrogeology is anticipated to be complex with the potential for aquifers in the alluvial and marine deposits, and bedrock. Groundwater flows in bedrock would be influenced by localised areas of relatively high permeability rock associated with stress relief under the palaeochannel.

The project’s tunnels would cross under the palaeochannel, with a cover of about 20 metres of rock between tunnel crown and the base of the palaeochannel. Groundwater inflows into the tunnels beneath Muddy Creek may be significant and measures such as grouting to reduce rock mass permeability and/or localised tanking would be used to meet the contractual tunnel inflow limits. However, it is anticipated that groundwater inflow into the tunnels would induce groundwater drawdown in the alluvium at Muddy Creek, which would potentially result in settlement impacts to the Muddy Creek channel. The risks associated with water table drawdown within the alluvium beneath Muddy Creek and associated dewatering induced settlement is dependent upon the amount of groundwater drawdown within the alluvium and the geotechnical properties of the soil. The tunnels have been designed to reduce groundwater drawdown within the unconsolidated sediments by constructing tanked (undrained) tunnel sections through the alluvium which would also minimise settlement in these areas.

The range of potential settlement impacts to the Muddy Creek channel may include concrete cracking, opening of expansion joints, pooling water, and misalignment of slabs. A geotechnical model of representative geological and groundwater conditions would be prepared during the detailed design phase prior to the commencement of tunnelling. The model would be used to assess predicted settlement impacts (including at Muddy Creek) and ground movement during the construction and operation of the project.

17.5 Potential impacts – cumulative

Cumulative impacts are those that act together with other impacts to affect the same resources or receptors in a way where the sum of the impacts is greater than the individual. Cumulative groundwater impacts can be related to groundwater extraction (active and passive), groundwater drawdown, and groundwater quality.

The groundwater model has been used to predict cumulative groundwater tunnel inflows at the end of construction (Year 2024) and throughout the operations phase (to Year 2100) of the project. The maximum calculated inflow rates are summarised in **Table 17-18**.

Table 17-18 Predicted maximum cumulative tunnel inflows

Modelling scenario	Combined tunnel length	Year	Max inflow (megalitres per day)	Max inflow (litres per second per kilometre of tunnel)
Scenario 1	4 kilometres	2016	0.32	0.92
Scenario 2	21.2 kilometres	2023	0.95	0.52
Scenario 3	27.7 kilometres	2023	1.52	0.62

During construction, cumulative impacts on groundwater would be greatest at the northern extremity of the project near the confluence with the New M5 Motorway at Arncliffe. Modelling predicts an increase in drawdown of 0.5 metres (total drawdown of 4.1 metres) within the alluvium beneath Spring Street Drain due to cumulative impacts with the nearby New M5 Motorway tunnelling in September 2024. Cumulative drawdown within the Hawkesbury Sandstone at the end of construction is predicted to reach 61 metres to the invert of the tunnel at the connection with the New M5 Motorway at Arncliffe.

Once the full extent of the WestConnex projects is operational, groundwater drawdown due to the cumulative impact of the three tunnel projects is not expected to be greater than in any one section of the overall project footprint.

Long term cumulative groundwater tunnel inflows may cause groundwater salinity to increase due to surface water from tidal reaches being drawn into or towards the tunnels. Initially, the saline water would be a small fraction of total tunnel ingress but this is expected to increase over time as water is drawn from further afield, although it would always be a minor component of total inflow.

The groundwater modelling has predicted that five registered bores would be drawn down in excess of two metres due to the project and two additional bores would be impacted due to the cumulative impacts of nearby tunnel projects. No additional cumulative impacts are expected at the Rockdale Bicentennial Park and Scarborough Park wetlands.

Cumulative groundwater drawdown has the potential to contribute to settlement. Settlement within the Hawkesbury sandstone is not expected to exceed likely project settlement criteria due to the competent nature of the sandstone. Additional settlement within the alluvium around Spring Street Drain due to cumulative drawdown may occur. Localised groundwater modelling would be undertaken during the detailed design phase to support a detailed settlement analysis.

Refer to **Appendix K** (Groundwater technical report) for further information regarding the assessment of cumulative groundwater impacts.

17.6 Management of impacts

Mitigation and management measures would be implemented during construction and operation of the project to reduce or eliminate the risks to the existing groundwater regime. These environmental mitigation measures, including management, engineering solutions and monitoring, are summarised in **Table 17-19**. These measures would be complemented by the environmental management measures outlined in **Chapter 16** (Soils and contamination) and **Chapter 18** (Surface water and flooding).

Based on the mitigation and management measures it is considered that potential groundwater impacts that may arise as a result of the construction and operation of the project can be effectively managed.

Table 17-19 Environmental management measures – Groundwater and geology

Impact	Reference	Environmental management measures	Timing
Groundwater			
Operational tunnel inflows higher than expected which may exceed the inflow criteria of 1 L/sec/km for any kilometre length of tunnel.	GW1	Where fractured Hawkesbury Sandstone is intersected, a combination of techniques will be investigated to reduce the bulk hydraulic conductivity.	Construction
	GW2	Appropriate measures will be identified and included in the detailed design to reduce the inflow into the tunnels. A target of one litre per second per kilometre for any kilometre length of the tunnel during operation will be adopted.	Detailed design
Groundwater drawdown impacting a water supply well water level by more than two metres	GW3	Impacts on water supply bores will be 'made good' as soon as practicable. Where water supply bores cannot be made good, alternate measures are to be implemented to replace supply.	Construction and Operation
Alteration of groundwater flows and levels due to the installation of subsurface project components	GW4	Measures to reduce potential impacts to groundwater flows due to subsurface components of the project will be identified and included in the detailed construction methodology and the detailed design as relevant.	Detailed design
Actual groundwater inflows and drawdown in adjacent areas exceed predictions	GW5	A detailed groundwater model will be developed by the construction contractor. The model will be used to predict groundwater inflow rates and volumes within the tunnels and groundwater levels (including drawdown) in adjacent areas during construction and operation of the project.	Detailed design
	GW6	Groundwater inflow and groundwater levels will be monitored during construction and compared to the model predictors and groundwater performance criteria. The detailed groundwater model will be updated based on the results of the monitoring as required and proposed management measures to minimise potential groundwater impacts adjusted accordingly to ensure that groundwater inflow performance targets are met.	Construction
Impacts to groundwater quality, groundwater levels or groundwater flows	GW7	Prior to construction, a groundwater monitoring program will be prepared and implemented to monitor groundwater levels, construction and operational groundwater inflows in the tunnels, and groundwater quality in the three main aquifers impacted by construction works. The program will identify groundwater monitoring locations, performance criteria in relation to groundwater inflow and levels, and potential remedial actions that will be considered to address potential impacts. As a minimum, the program will include monthly manual groundwater level and quality monitoring and weekly monitoring of inflow volumes and quality.	Prior to construction

Impact	Reference	Environmental management measures	Timing
Adverse impacts on the local hydrogeological regime due to groundwater discharge	GW8	An operational water treatment plant will be constructed at the Arncliffe Motorway Operations Complex (MOC1) to manage and treat groundwater from the tunnel prior to discharge. Discharge will be undertaken in accordance with the approval conditions and agreed discharge criteria. A summary of the proposed discharge criteria is provided in **Chapter 18** (Surface water and flooding).	Operation
Treated groundwater may be discharged to stormwater without consideration to a suitable sustainable use.	GW9	Sustainable water re-use options will be reviewed for treated groundwater during operations.	Construction
Geology (ground movement)			
Ground movements may cause impacts to structures on the surface.	GM10	A geotechnical model of representative geological and groundwater conditions will be prepared by the construction contractor during the detailed design phase prior to the commencement of tunnelling. The model will be used to assess predicted settlement impacts and ground movement during the construction and operation of the project	Detailed design
	GM11	Further assessment of potential settlement impacts, including numerical geotechnical modelling will be undertaken prior to excavation and tunnelling to assess the cumulative predicted settlement, ground movement, stress redistribution and horizontal strain profiles caused by excavation and tunnelling, including groundwater drawdown and associated impacts, on adjacent surface and sub-surface structures. Criteria for surface and sub-surface structures at risk will be determined in consultation with the owner(s) of the structures. Where modelling predicts exceedances of these criteria, an instrumentation and monitoring program will be implemented to measure settlement, distortion or strain as required. Appropriate mitigation measures will be identified and implemented in consultation with the owner(s) prior to excavation and tunnelling works to where possible not exceed the settlement criteria.	Detailed design

17.7 Environmental risk analysis

An environmental risk analysis was undertaken for groundwater and is provided in **Table 17-20** below.

A level of assessment was undertaken commensurate with the potential degree of impact the project may have on that issue. This included an assessment of whether the identified impacts could be avoided or minimised (for example, through design amendments). Where impacts could not be avoided, environmental management measures have been recommended to manage impacts to acceptable levels.

The residual risk is the risk of the environmental impact after the proposed mitigation measures have been implemented. The methodology used for the environmental risk analysis is outlined in **Appendix O** (Methodologies).

Table 17-20 Environmental risk analysis – Groundwater

Summary of impact	Construction/ operation	Management and mitigation reference	Likelihood	Consequence	Residual risk
Impacts to groundwater dependent ecosystems resulting from groundwater drawdown	Construction and operation	GW6, GW7, GW8, GW9	Likely	Minor	Low
Potential for large quantities of inflows of groundwater during construction which would result in increased groundwater drawdown	Construction	GW1, GW2, GW3, GW4, GW5	Likely	Minor	Low
Impacts to structures and surfaces resulting from ground movements.	Construction	GM10, GM 11	Likely	Minor	Low

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