19 Groundwater

This chapter outlines the potential groundwater impacts associated with the M4-M5 Link project (the project). A detailed groundwater assessment has been undertaken for the project and is included in **Appendix T** (Technical working paper: Groundwater).

The Secretary of the NSW Department of Planning and Environment (DP&E) has issued environmental assessment requirements for the project. These are referred to as Secretary's Environmental Assessment Requirements (SEARs). **Table 19-1** sets out these requirements and the associated desired performance outcomes that relate to groundwater and identifies where they have been addressed in this environmental impact statement (EIS).

Table 19-1 SEARs - groundwater

Desired performance outcome	SEARs	Where addressed in the EIS
3. Health and safety The project avoids, to the greatest extent possible, risk to public safety.	2. The assessment must: (e) 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;	Subsidence risks are discussed in **section 19.3.8**.
10. Water - Hydrology Long term impacts on surface water and groundwater hydrology (including drawdown, flow rates and volumes) are minimised. The environmental values of nearby, connected and affected water sources, groundwater and dependent ecological systems including estuarine and marine water (if applicable) are maintained (where values are achieved) or improved and maintained (where values are not achieved). Sustainable use of water resources.	1. The Proponent must describe (and map) the existing hydrological regime for any surface and groundwater resource (including reliance by users and for ecological purposes) likely to be impacted by the project, including stream orders, as per the FBA.	The existing hydrological regime for groundwater is described (and mapped) in **section 19.2**.
	2. The Proponent must prepare a detailed water balance for ground and surface water including the proposed intake and discharge locations, volume, frequency and duration for both the construction and operational phases of the project.	**Section 19.3.9** and **section 19.4.9** detail a project construction and operational water balance respectively.
	3. The Proponent must assess (and model if appropriate) the impact of the construction and operation of the project and any ancillary facilities (both built elements and discharges) on surface and groundwater hydrology in accordance with the current guidelines, including:	Refer below
	(a) natural processes within rivers, wetlands, estuaries, marine waters and floodplain that affect the health of the fluvial riparian estuarine or marine system and landscape health (such as modified discharge volumes, durations and velocities), aquatic connectivity and access to habitat for spawning and refuge;	Impacts on natural processes are assessed in **Chapter 15** (Soil and water quality), **Chapter 17** (Flooding and drainage) and **Chapter 18** (Biodiversity).
	(b) impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, barriers to flows, implications for groundwater dependent surface flows, ecosystems and species, groundwater users and the potential for settlement;	**Section 19.3** and **section 19.4** outline potential impacts on groundwater flow during the construction and operation of the project respectively.

Desired performance outcome	SEARs	Where addressed in the EIS
	(f) water take (direct or passive) from all surface and groundwater sources with estimates of annual volumes during construction and operation;	Groundwater intake assessed in section **19.3.2** and section **19.4.2**.
	5. The assessment must include details of proposed surface and groundwater monitoring.	**Section 19.5** outlines the proposed groundwater monitoring for the project and surface water monitoring is described in **Chapter 15** (Soil and water quality).
	6. The proposed tunnels should be designed to prevent drainage of alluvium in the palaeochannels.	As described in **section 19.4.2** the project tunnels have been designed to avoid palaeochannels where possible. At the Rozelle Rail Yards tunnels intersecting the alluvium are to be fully lined to prevent direct inflow of groundwater from the alluvium. A specific management measure to this effect for the detailed design stage is included in **section 19.5**.
11. Water - Quality The project is designed, constructed and operated to protect the NSW Water Quality Objectives where they are currently being achieved, and contribute towards achievement of the Water Quality Objectives over time where they are currently not being achieved, including downstream of the project to the extent of the project impact including estuarine and marine waters (if applicable).	1. The Proponent must: (i) identify proposed monitoring locations, monitoring frequency and indicators of surface and groundwater quality.	**Section 19.1.3** outlines the field investigations and groundwater monitoring undertaken to inform groundwater modelling for the project. **Section 19.5** outlines the proposed groundwater monitoring for the project. Surface water monitoring is described in **Chapter 15** (Soil and water quality).

Desired performance outcome	SEARs	Where addressed in the EIS
13. Soils The environmental values of land, including soils, subsoils and landforms, are protected. Risks arising from the disturbance and excavation of land and disposal of soil are minimised, including disturbance to acid sulfate soils and site contamination.	5. The Proponent must assess the impacts of the project on soil salinity and how it may affect groundwater resources and hydrology.	Impacts to groundwater from the project related to soil salinity are discussed in **section 19.3.4**.
	7. 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.	Potential impacts related to the disturbance of contaminated groundwater are discussed in **section 19.3.4**, including an outline of tunnel design measures which aim to avoid the mobilisation of contaminated groundwater.

19.1 Assessment methodology

A groundwater assessment has been undertaken to address the relevant SEARs outlined in **Table 19-1**. The assessment describes the existing groundwater environment and determines the potential impacts of the construction and operation of the project on groundwater flows, groundwater levels and water quality. A summary of the groundwater assessment is provided in this chapter. The full assessment is included in **Appendix T** (Technical working paper: Groundwater).

The assessment includes:

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

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

Table 19-2 Relevant groundwater assessment legislation and guidelines

Policy/guidance	Relevance
Water Management Act 2000 (NSW)	· State significant development and State significant infrastructure projects are exempt from requiring some water supply works approvals and controlled activity approvals · Aquifer interference activity approval provisions have not yet commenced but are administered under the *Water Act 1912* (NSW) · Water sharing plans are administered under this Act.
Water Act 1912 (NSW)	· Administration of water access licences and the trade of water licences and allocations.

Policy/guidance	Relevance
NSW Aquifer Interference Policy (NSW Office of Water (NoW) 2012)	· Manages the impacts of aquifer interference activities in accordance with the *Water Act 1912* (NSW) and water sharing plans · Aquifer interference activities must address minimal impact considerations as outlined in the policy · In the event that actual impacts are greater than predicted, the policy requires that sufficient monitoring be put in place.
Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011	· Water sharing plans (regulations under the *Water Management Act 2000* (NSW)) manage the long-term surface and groundwater resources of a defined area · The plan outlines rules for the sharing and sustainable use of water between various uses such as town water supply, stock and domestic, industry and irrigation.

The project's compliance with the legislation and guidelines outlined in **Table 19-2** is demonstrated in detail in **Appendix T** (Technical working paper: Groundwater).

The groundwater assessment has been prepared with reference to the following additional applicable documents:

- NSW 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 (NoW 2013)
- Australia and New Zealand Environment and Conservation Council (ANZECC) and Agriculture Resource Management Council of Australia and New Zealand (ARMCANZ) National Water Quality Management Strategy Australian Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ 2000)
- *NSW Water Extraction Monitoring Policy* (Department of Water and Energy (DWE) 2007)
- *NSW Aquifer Interference Policy* (NoW 2012)
- Guidelines for riparian corridors on waterfront land (NSW Department of Primary Industries (DPI) 2012)
- Water Sharing Plan, Greater Metropolitan Regional Groundwater Sources Background Document, Sydney (NoW 2011).

19.1.1 Study area

A three-dimensional numerical groundwater model was developed to predict future groundwater conditions and potential impacts related to the project (see **section 19.1.5**).

For the purposes of the groundwater impact assessment, the study area is the domain considered by the groundwater model. The model domain (study area) extends over an area of about 11 by 11 kilometres and is centred on the mainline tunnel alignment and partially includes the neighbouring M4 East and New M5 projects. The northern boundary of the study area is represented by the central channel of the Parramatta River/Sydney Harbour. The study area is shown in **Figure 19-1**.

19.1.2 Desktop review

The following database searches were conducted to inform a review of the existing environment:

- Australian Soils Resource Information System acid sulfate soils, accessed May 2016
- Bureau of Meteorology (BoM) 2016 Australian Groundwater Explorer (formerly DPI-Water groundwater database), accessed December 2016
- Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources (2011). Schedule 4 of the Plan identifies high priority groundwater dependent ecosystems (GDEs) and Appendix 2 identifies GDEs
- BoM 2016 Atlas of Groundwater Dependent Ecosystems, accessed October 2016
- BoM 2017 online climate data, accessed March 2017
- NSW Environment Protection Authority (NSW EPA) Contaminated Land Record, accessed November 2016.

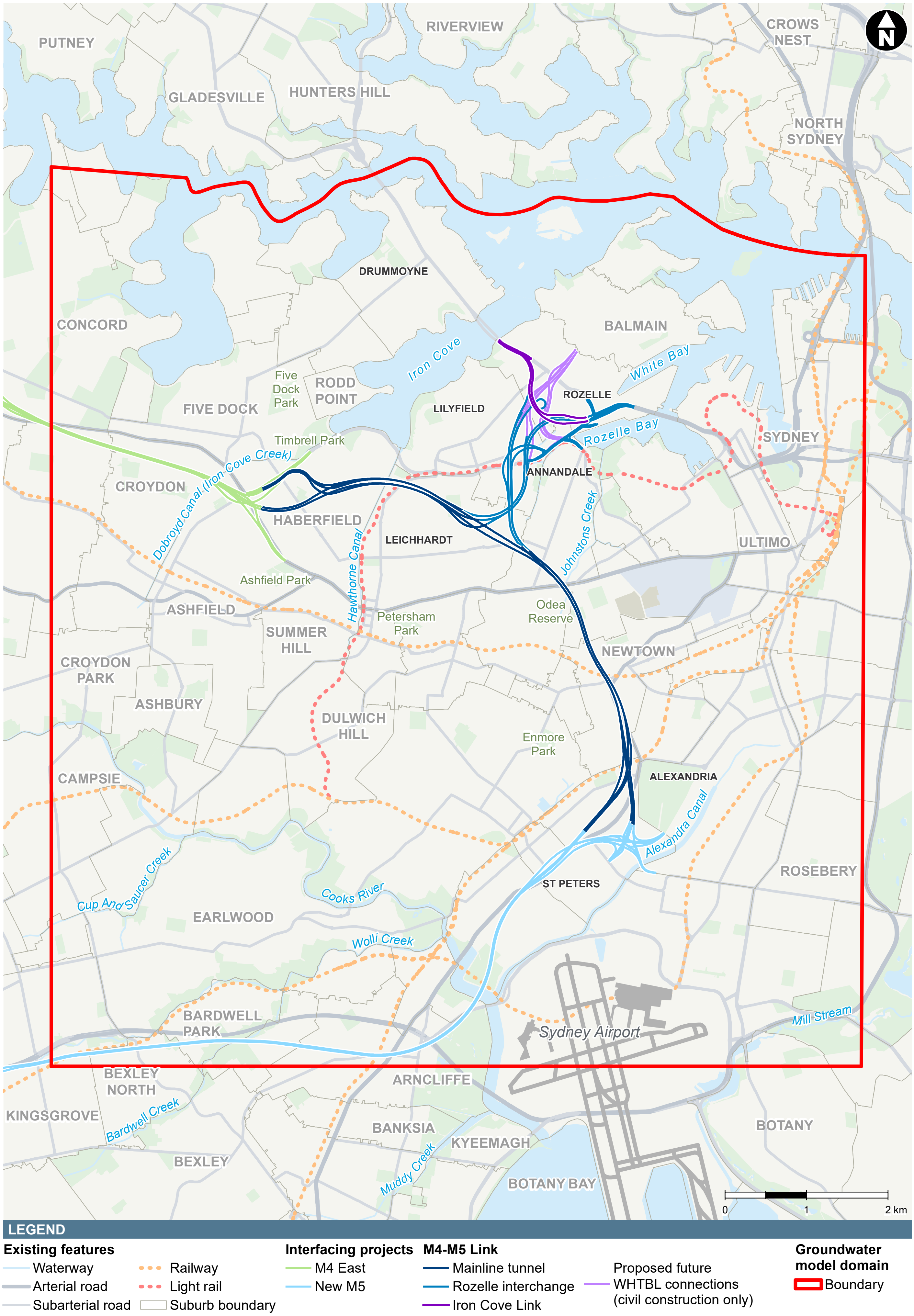

Figure 19-1 Groundwater assessment study area

19.1.3 Field investigation

Groundwater field investigations, including drilling boreholes, packer tests, groundwater gauging, groundwater sampling and hydrogeochemical analysis, were conducted across the study area between June 2016 and May 2017. During investigations, 58 boreholes were converted to monitoring wells. The locations of monitoring wells used in this investigation are presented in **Figure 19-2**. The selection of monitoring well locations was based on the initial project design and subsequent changes during concept design development. Consequently, some monitoring wells have become redundant as the alignment has changed during the development of the concept design.

Groundwater data collected included:

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

Hydraulic conductivity

Hydraulic conductivity is a fundamental aquifer property that assists in understanding the tunnel water inflows or the local drawdown (ie 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.

Tests undertaken in the field, such as packer tests, primarily measure the horizontal hydraulic conductivity, and consequently laboratory testing was undertaken to also assess vertical hydraulic conductivity. Selected core samples (63.5 millimetre diameter and about 0.25 metres long) were collected during the field program for laboratory testing of hydraulic conductivity and porosity (a measure of the void (empty) spaces within a material that water can flow through). The data was used to support the groundwater modelling.

Groundwater levels

Groundwater gauging was conducted throughout the field program that commenced in June 2016, taking monthly measurements of standing groundwater levels using an electronic dipper. Data loggers were installed in most of the monitoring wells to automatically measure groundwater levels at one-hour intervals, to monitor both short-term and long-term groundwater level fluctuations. The loggers were suspended in each monitoring well at a depth of about five metres below the standing water level.

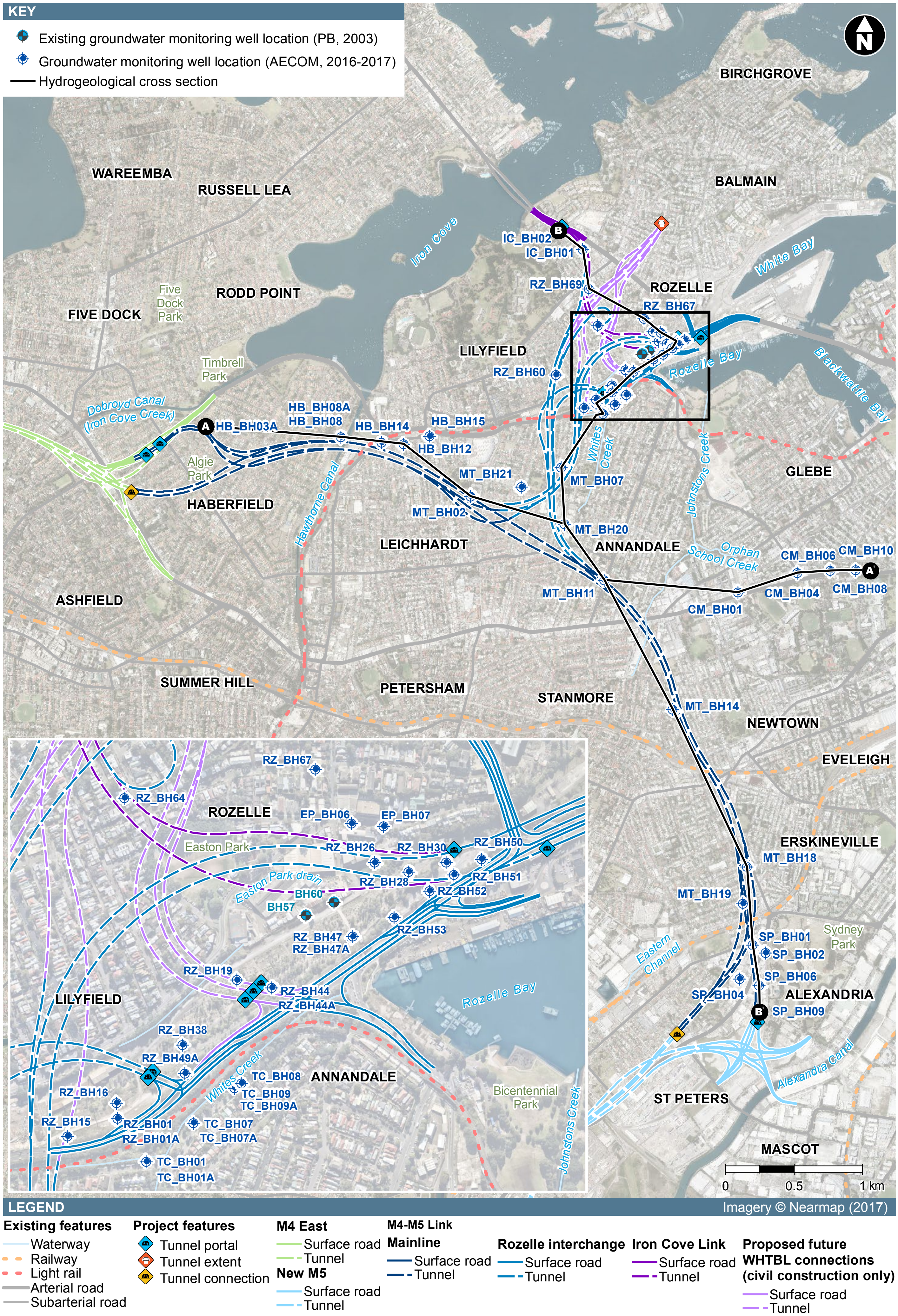

Figure 19-2 Locations of monitoring wells constructed for groundwater field investigations

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)
- Benzene, toluene, ethylbenzene, xylene and naphthalene (BTEXN)
- Total recoverable hydrocarbons (TRHs)
- Polycyclic aromatic hydrocarbons (PAHs)
- Inorganics (including major anions and cations, alkalinity, ammonia, electrical conductivity, ionic balance, total dissolved solids, pH and hardness)
- Organochlorine pesticides (OCPs)
- Organophosphate pesticides (OPPs)
- Semi-volatile organic hydrocarbons (SVOCs)
- Volatile organic compounds (VOCs)
- Sulfate reducing bacteria (which promotes the increased corrosion of metals).

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.

The monitoring wells were sampled monthly using low flow sampling or a double valve stainless steel bailer (a hollow tube used to retrieve groundwater samples from below the ground surface). Sampling was typically scheduled for the middle of the month. During groundwater sampling, discharge water was directed through a flow cell to measure field parameters including dissolved oxygen, electrical conductivity, pH, temperature and oxidation-reduction conditions.

19.1.4 Groundwater dependant 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
- BoM Atlas of GDEs
- Threatened species database (NSW Office of Environment and Heritage (OEH))
- The Biodiversity Assessment Report for the project as contained in **Appendix S** (Technical working paper: Biodiversity).

19.1.5 Groundwater modelling

A three-dimensional numerical groundwater model was developed to simulate existing groundwater conditions, proposed tunnel alignments, caverns and associated subsurface ancillary infrastructure. The groundwater model was used to predict future groundwater conditions and potential impacts related to the project.

The groundwater model was prepared by HydroSimulations (HydroSimulations 2017) and developed in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al. 2012). The model was developed broadly as follows:

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

The numerical groundwater model was developed using MODFLOW-USG (2012). This version of MODFLOW was selected as it allows local grid refinement and is suited to simulating linear features such as road tunnels. MODFLOW is the industry standard groundwater modelling platform and was used for the M4 East and New M5 projects' groundwater impact assessments.

Both transient and steady state models were developed and calibrated:

- The transient model predicts groundwater drawdown that would occur while the groundwater system is establishing a new equilibrium (following the commencement of the construction of the project)
- The steady state model predicts groundwater drawdown that would occur in the long term, after a new equilibrium has been established (at some point in time following the completion of the construction of the project)
- The groundwater model has been used to predict influences on the project as well as the cumulative impacts (see **section 19.1.6**) for the other WestConnex projects as follows:
  - Scenario 1: A 'Null' run does not include any WestConnex projects but does include the existing drained M5 East tunnels
  - Scenario 2: The 'Null' run in Scenario 1, plus the approved WestConnex tunnel projects (M4 East and New M5)
  - Scenario 3: The 'Null' run in Scenario 1, plus the approved WestConnex tunnel projects (M4 East and New M5) in Scenario 2, and the M4-M5 Link project

  The impacts of the M4-M5 Link project were computed by the model by subtracting the Scenario 3 impacts from those of Scenario 2
- The groundwater model has provided outputs for the year 2023 (for predicted groundwater conditions representative of end of the construction of the project) and for the year 2100 (for groundwater conditions representative of the long term operation of the project).

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

19.1.6 Cumulative impact assessment

Cumulative impacts are those that act together with other impacts to affect the same resources or receptors such that the accumulation of the impacts is the sum of the individual impacts. Cumulative groundwater impacts include groundwater extraction, groundwater drawdown, and groundwater quality.

A quantitative cumulative impact assessment of the local hydrogeological regime, for the WestConnex M4 East and New M5 projects[1] has been undertaken by application of the groundwater modelling. A qualitative groundwater cumulative impact assessment has been undertaken for other infrastructure projects including the Sydney Metro City and Southwest project, proposed future Western Harbour Tunnel and Beaches Link and the proposed future F6 Extension and is provided in **Chapter 26** (Cumulative impacts).

The objectives of the cumulative impact assessment are to:

- Use the groundwater model to predict the cumulative impacts on groundwater due to the project in combination with other WestConnex tunnel projects (M4 East and New M5)
- Qualitatively assess the cumulative impacts of the project, other WestConnex projects and other proposed infrastructure projects (outlined in **section 19.2.1**).

19.2 Existing environment

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

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

19.2.1 Existing and proposed infrastructure

The project footprint transects an urban environment that consists of established industrial, commercial, recreational and residential areas. In some areas, major existing or proposed infrastructure may influence the project or the local hydrogeological regime. Major existing infrastructure is listed below and shown in **Figure 19-3**:

- Former Alexandria landfill at St Peters
- Sydney Park at St Peters
- King George Park at Rozelle
- Easton Park at Rozelle
- Rozelle Rail Yards at Rozelle
- White Bay redevelopment precinct at Rozelle
- Bicentennial Park at Glebe
- Existing tunnels (M5 East motorway tunnels and Airport Link rail tunnel)
- Surface roads and rail (including the Princes Highway, Parramatta Road, Victoria Road, the Western Distributor, Inner West rail line, Bankstown rail line and Inner West Light Rail line).

[1] The project does not include consideration of the WestConnex M4 Widening and King Georges Road Interchange Upgrade component projects because they do not involve tunnelling and therefore are not associated with potential groundwater impacts.

A number of other infrastructure projects (including proposed and approved projects) in the vicinity of the proposed M4-M5 Link project have the potential to cause cumulative impacts on the local environment, (refer to **Chapter 26** (Cumulative impacts)) including:

- WestConnex New M5 project, which will 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
- WestConnex M4 East project, which will extend from the existing M4 Motorway at Homebush to Haberfield, consisting of 5.5 kilometres of three-lane twin drained tunnel
- Sydney Metro City and Southwest, which is a proposed rail alignment comprising two stages, with Stage 1 linking Chatswood to Sydenham and Stage 2 linking Sydenham to Bankstown. The alignment would consist of 15.5 kilometre twin railway tunnels
- Western Harbour Tunnel and Beaches Link, which is a proposed future project that would, via the Western Harbour Tunnel component, provide a further tunnel crossing of Sydney Harbour to the west of Sydney Harbour Bridge which, together with WestConnex, would act as a western bypass of the Sydney CBD
- F6 Extension, which is a proposed future connection linking the F6 Motorway to the New M5 Motorway at Arncliffe
- Sydney Gateway, which is a proposed future connection linking the New M5 at the St Peters interchange with the Sydney Airport and the Port Botany precinct
- White Bay Power Station redevelopment, which is proposed in accordance with The Bays Precinct Transformation Plan.

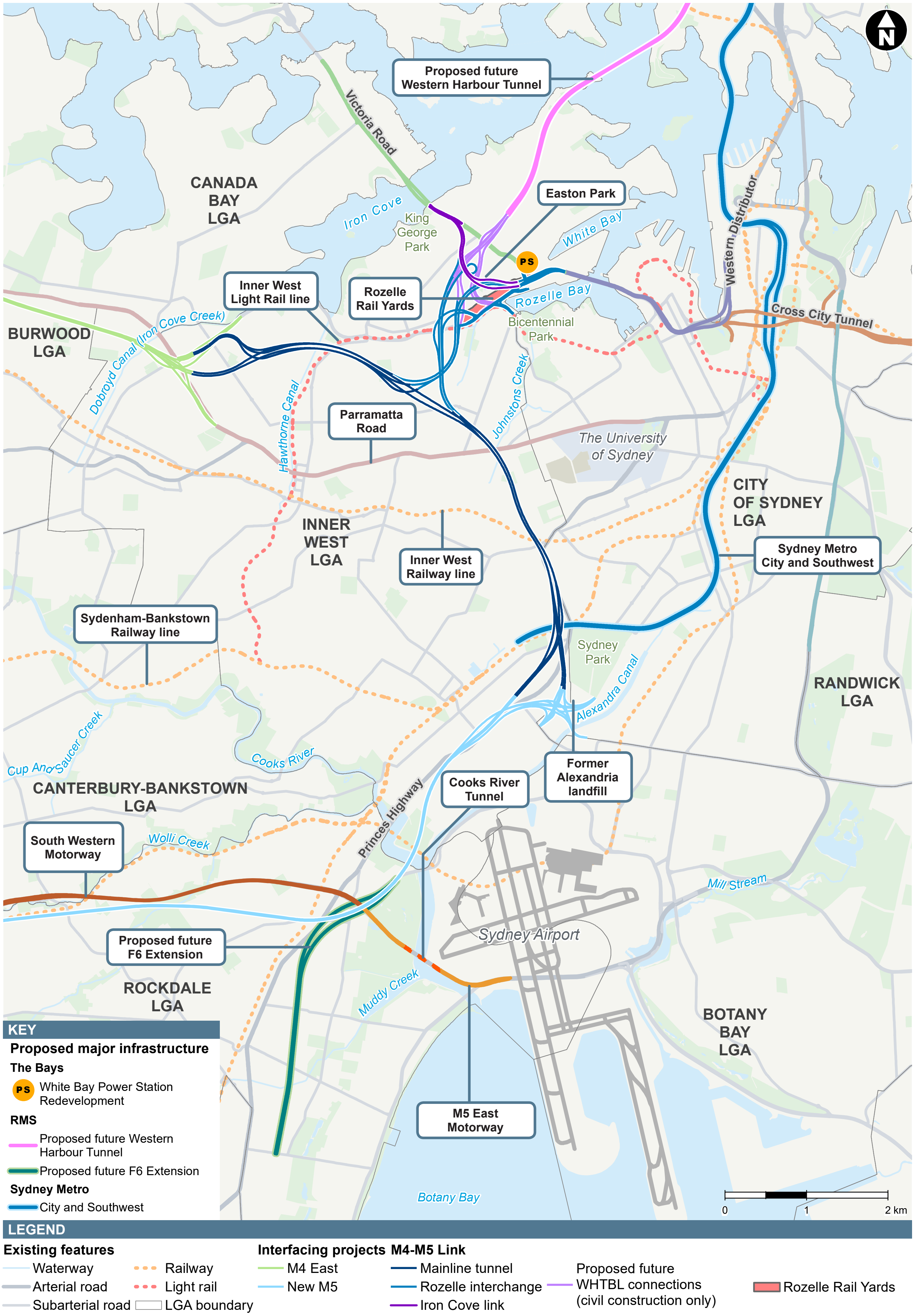

Figure 19-3 Existing and proposed major infrastructure

19.2.2 Topography and drainage

The project footprint extends from the M4 East at Haberfield, through the proposed interchange at Rozelle, emerging at the St Peters interchange. The topography of the project footprint is relatively flat and low lying, ranging from sea level (adjacent to Sydney Harbour at White Bay, Rozelle Bay, Iron Cove and the Alexandra Canal) up to 33 metres Australian Height Datum (AHD) at Lilyfield, where the Hawkesbury Sandstone outcrops.

The majority of the project footprint is located in a heavily urbanised area and is drained by the stormwater network. The primary surface water features in the groundwater assessment study area (see **Figure 19-4**) are the creeks, infilled creeks and canals. The footprint is covered by five catchments that discharge into Sydney Harbour and Botany Bay, as shown in **Figure 19-4**.

Dobroyd Canal (Iron Cove Creek) is a lined channel that drains Haberfield, discharging into Iron Cove on the Parramatta River. The lower tidal section of Iron Cove Creek is known as Dobroyd Canal. Draining Haberfield and Leichhardt is Hawthorne Canal, a lined channel that discharges into Iron Cove. Johnstons Creek is a lined channel that drains Annandale and Glebe, discharging into Rozelle Bay. Similarly, Whites Creek is a brick and concrete-lined channel that flows through the suburbs of Leichhardt and Marrickville, discharging to Rozelle Bay. Easton Park drain is located south of Easton Park.

Patches of coastal saltmarsh occur along the edge of Rozelle Bay and Johnstons Creek to the south of the project footprint. To the south, the suburbs of Newtown, Enmore and St Peters are drained by the lined Eastern Channel that discharges to the Cooks River. Wolli Creek, Bardwell Creek and Mill Stream are unlined and are outside the immediate project footprint, but are included in the groundwater study area to identify potential impacts associated with groundwater drawdown. Further to the south, Alexandra Canal drains into the Cooks River.

The majority of the creeks and canals in the model domain are concrete lined. In the concrete lined creeks, seepage to groundwater is limited to water flowing through fractures within the concrete lining, and along unlined stretches or naturalised areas. Lower reaches of the concrete lined channels are expected to leak more where the channels are tidally influenced and receive more water than the upper reaches.

Sydney Water is in the process of naturalising some creeks and canals (to replace the concrete lining with a natural permeable stream base, planting natural vegetation and re-contouring river banks). Parts of the Cooks River have been naturalised and it is proposed to naturalise parts of Johnstons Creek, Whites Creek and Dobroyd Canal (Iron Cove Creek) in the near future. No natural wetlands have been identified within the project footprint or area of predicted drawdown impact (see **section 19.3.3** and **section 19.4.3**). No natural springs have been identified within the project footprint.

Surface water and groundwater in the Sydney Basin is described at a large scale in the Water Sharing Plan for the Greater Metropolitan Region (NoW 2011). Within the porous rock aquifer, the level of connection between groundwater and surface water is stated as low to moderate, with the estimated travel time between groundwater and unregulated rivers being in the order of years to decades.

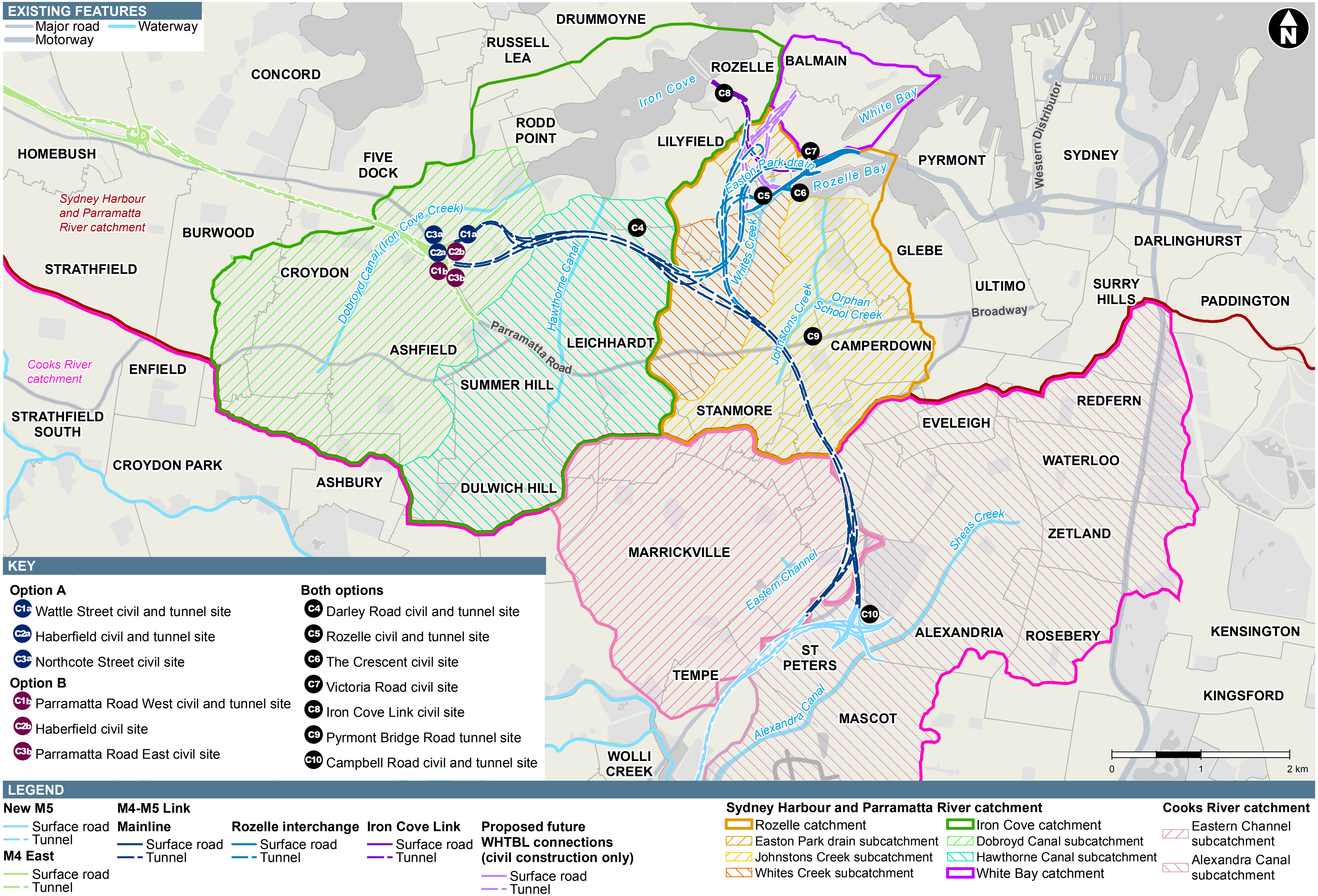

Figure 19-4 Surface water catchments within study area

19.2.3 Geological setting

Regionally, the project footprint is located within the Permo-Triassic Sydney Basin, which is characterised by sub-horizontal sedimentary sequences, mainly sandstone and shale. The project footprint is underlain by two main geological units (bedrock units), Ashfield Shale and Hawkesbury Sandstone. These are sometimes separated by the transitional Mittagong Formation. To the east of the project footprint, the unconsolidated Quaternary-aged Botany Sands overlap the Sydney Basin and the bedrock.

The main stratigraphic units that have been encountered within the study area, from youngest to oldest, are:

- Anthropogenic fill
- Quaternary alluvium (recent beneath rivers, palaeochannels and Botany Sands)
- Jurassic intrusions (ie dykes, which are basaltic intrusive rocks)
- Triassic Ashfield Shale (Wianamatta Group)
- Triassic Mittagong Formation
- Triassic Hawkesbury Sandstone Formation.

The geology of the study area is shown in **Figure 19-5**. Further detail on the stratigraphic units, including weathering profiles and implications for hydraulic conductivity, is provided in **Appendix T** (Technical working paper: Groundwater).

19.2.4 Groundwater recharge

The project is located in an urbanised part of Sydney where rainfall recharge to groundwater has been reduced by hardstand captured runoff and roof runoff being directed to stormwater. The majority of groundwater recharge occurs in parks, gardens, bushland and creeks prior to discharge into Sydney Harbour.

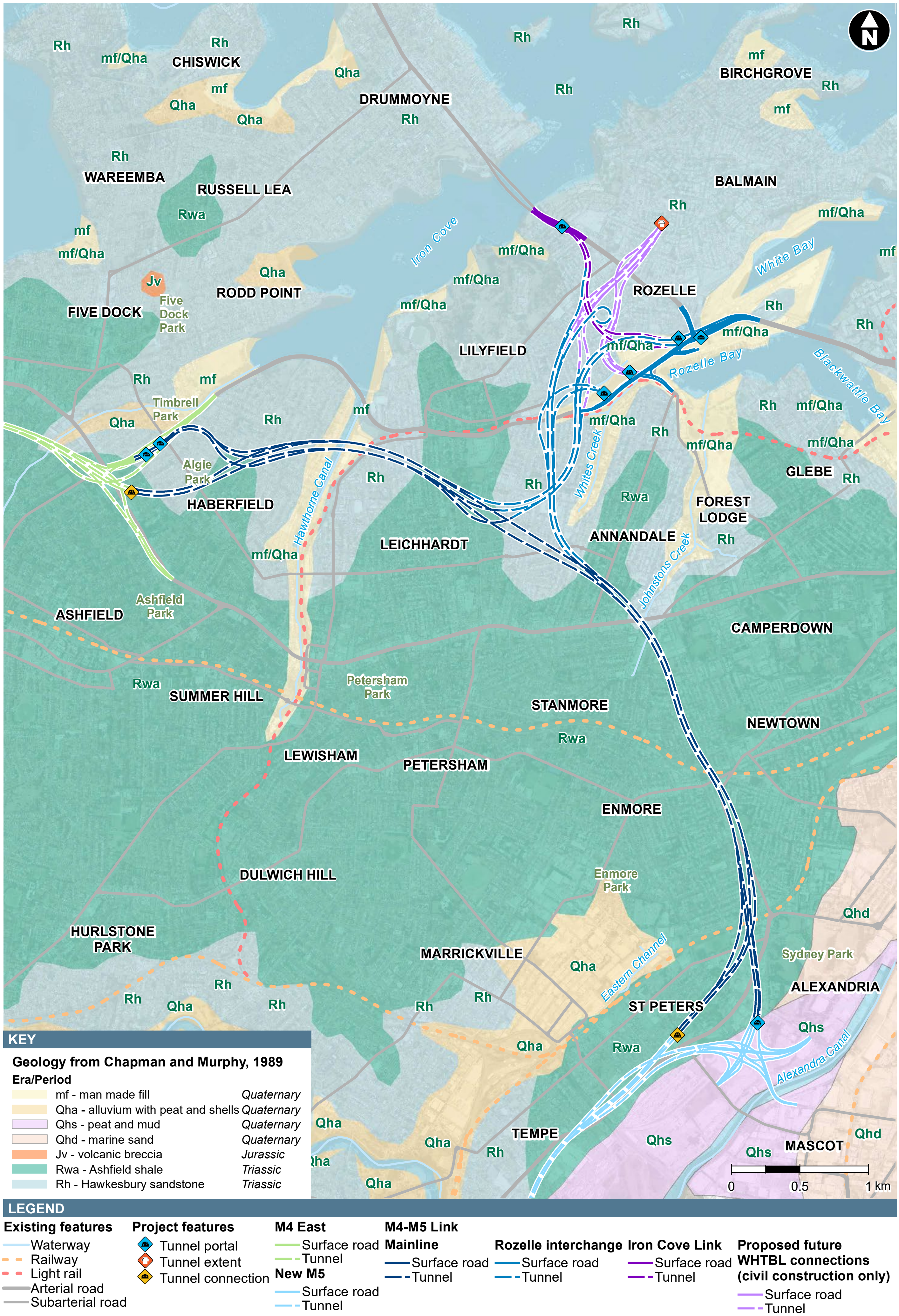

Figure 19-5 Geology in the study area

19.2.5 Hydrogeological setting

Across the study area the groundwater levels are typically deeper beneath hills and shallowest beneath creeks and gullies. Groundwater within the project footprint is recharged by rainfall runoff and infiltration. Groundwater is present within the following hydrogeological units:

- Quaternary alluvium
- Botany Sands aquifer
- Ashfield Shale
- Mittagong Formation
- Hawkesbury Sandstone.

Quaternary alluvium

Modern alluvium outcrops around the edge of the harbour at Rozelle Bay and is present beneath fill, together with slightly older alluvium infilling palaeochannels (these are ancient river systems eroded deeply into the landscape and subsequently infilled with saturated alluvial sediments), forming an unconfined aquifer. The alluvium surrounding creeks is generally of high permeability and the groundwater within the alluvium can be a source of either recharge or discharge, depending on whether upward or downward hydraulic gradients are present.

As the alluvium is hydraulically connected to the creeks, the groundwater levels are shallow and typically within one metre of the ground level. Hawthorne Canal, Whites Creek, Johnstons Creek and Dobroyd Canal (Iron Cove Creek) are concrete lined, thereby limiting the hydraulic connection between surface water and groundwater.

The palaeochannels that occur beneath some of the major watercourses or valleys in the study area extend to depths of up to 25 metres and are saturated with groundwater. Groundwater within the palaeochannels is typically saline, due to recharge from the Ashfield Shale and leakage from tidally flushed rivers and tributaries. The alluvium infilling the palaeochannels is highly transmissive due to the coarse clean sands and gravels present.

Botany Sands aquifer

Groundwater is present within the Botany Sands as a shallow unconfined aquifer. Groundwater levels are variable but are typically within five metres of the ground surface when not influenced by localised pumping. Regionally, groundwater flow is eastward, discharging into Botany Bay and Alexandra Canal. The Botany Sands aquifer naturally contains low salinity groundwater and is moderately acidic, but in many areas has been contaminated by industrial activities, most notably in the southern portion of the aquifer near the Botany Industrial Park.

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 via vacuum extraction systems, at groundwater yields typically up to two litres per second. DPI-Water advises that the whole Botany Sands hydrogeological unit is over allocated and domestic use has been embargoed since 2007 due to groundwater contamination.

While the Botany Sands are not intersected by the project, groundwater from the Botany Sands may be hydraulically linked with the drained M4-M5 Link tunnels. The residual alluvial clay that separates the sands from the underlying bedrock forms a hydraulic seal that would reduce groundwater drawdown due to the project. Groundwater flow to the Ashfield Shale is also expected to be low due to the shale’s low hydraulic conductivity.

Ashfield Shale

Groundwater flow within the Ashfield Shale is low due to the limited pore space and poor connectivity of the bedding planes. The majority of groundwater flow is via saturated fractures and joints, although these features can also reduce groundwater flow locally, if infilled with secondary mineralisation. The bulk hydraulic conductivity is typically low. Regionally, the Ashfield Shale reduces groundwater infiltration to the underlying Mittagong and Hawkesbury Sandstone Formations.

Groundwater quality within the shale is highly variable but is typically brackish or saline, due to the marine salts contained within it. The shale aquifer is characterised by low yields, limited storage and poor groundwater quality. Due to elevated salinity, low pH and the presence of sulphides, the groundwater can be corrosive to tunnel and infrastructure building materials.

Mittagong Formation

The Mittagong Formation is a relatively thin transition unit, where present, between the Ashfield Shale and Hawkesbury Sandstone. Although the Mittagong Formation is siltier than the Hawkesbury Sandstone, the hydraulic properties of the two formations are similar. The Hawkesbury Sandstone and Mittagong Formation are hydraulically connected. Groundwater quality is generally poor, due to leakage from the Ashfield Shale and the high clay content of the Mittagong Formation.

Hawkesbury Sandstone

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’, due to 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 (ie 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 (Hawkes *et al* 2009). 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. Recharge is via rainfall infiltration on fractured outcrops and through the soil profile and alluvium. Discharge is via seepage to cliffs, such as the exposed quarried sandstone cutting at the Rozelle Rail Yards, and via creeks and evapotranspiration.

Groundwater quality within the Hawkesbury Sandstone is generally acidic but of low salinity. The salinity of the upper part of the aquifer, however, can be elevated due to leakage from the Ashfield Shale. 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, causing the dissolved iron and manganese to precipitate and form sludge in drainage lines.

Groundwater levels and movement

Natural groundwater levels are influenced by topography, creeks, rainfall, recharge and manmade structures. Groundwater levels are related to the position of a well in the landscape, with the groundwater table generally displaying gentler gradients but similar flow directions to the surface topography. Locally, the water table can be impacted by infrastructure such as pumping (for example, leachate pumping from landfills), groundwater resource pumping or localised temporary dewatering. Conversely, in some areas the local water table may be elevated above natural conditions due to irrigation, such as at Sydney Park or Bicentennial Park, or by subsurface structures including infrastructure or building foundations that restrict groundwater flow and cause localised groundwater ‘mounding’.

Baseline groundwater level data has been collected in the groundwater monitoring network installed within the study area. The monitoring network consists of 58 monitoring wells intersecting groundwater from the alluvium, Ashfield Shale and Hawkesbury Sandstone.

Alluvium

Groundwater levels within the alluvium are monitored at 10 monitoring wells installed for the project. Groundwater levels are primarily controlled by local recharge and discharge conditions.

Since the alluvium is typically low-lying and connected to surface water within creeks or Sydney Harbour, the elevation of the water table within the unconfined aquifers is typically less than five metres AHD. Groundwater levels measured within the shallow alluvium (around The Crescent at Annandale) measured from 0.47 metres AHD to 1.08 metres AHD. Similarly, the groundwater levels measured within the deep palaeochannel (within the Rozelle Rail Yards at Rozelle) range from 1.11 metres AHD to 2.04 metres AHD.

Comparison of the two sets of groundwater levels indicate the water levels in the palaeochannel are higher by about 0.5 metres than the shallow alluvium, indicating there is upward pressure from the palaeochannel into the shallow alluvium, and groundwater from the palaeochannel may be discharging into the shallow alluvium. In each case, groundwater within the alluvium is flowing eastward, discharging into Rozelle Bay.

Ashfield Shale

Groundwater levels within the Ashfield Shale are monitored within the Camperdown and St Peters precincts of the project at eight monitoring wells. At St Peters, groundwater levels are influenced by ongoing leachate pumping from the former Alexandria Landfill (Hawkes and Evans 2016). As part of the landfill rehabilitation plan the former landfill will be capped to reduce rainfall infiltration and leachate generation. A cut-off wall along the eastern perimeter of the landfill is also proposed to be constructed to reduce groundwater inflow from the Botany Sands.

The highest groundwater level measured in the Ashfield Shale was measured at Camperdown, at an elevation of 22.1 metres AHD, where the topography along the alignment is at a high point. At the southern part of the proposed alignment next to the St Peters interchange, groundwater flows towards the western part of the landfill due to ongoing leachate pumping. This radial flow pattern and reversed hydraulic gradients prevent leachate contamination from dispersing into the Ashfield Shale.

Hawkesbury Sandstone

Groundwater levels within the Hawkesbury Sandstone are monitored at 40 monitoring wells within the study area. The elevation of measured groundwater levels ranges from 0.63 metres AHD beneath the Rozelle Rail Yards to 20.27 metres AHD beneath Camperdown. Artesian groundwater (groundwater under pressure) within the Hawkesbury Sandstone has been intersected at two monitoring wells in the low-lying areas beneath Hawthorne Parade. At this location the groundwater is under pressure and would flow from the well if a well cap is not in place.

At Haberfield, measured groundwater levels within the Hawkesbury Sandstone are variable and range from 0.5 metres to eight metres AHD. The groundwater elevation tends to reflect the position of the monitoring well in the landscape, with the hydraulic head increasing with distance from Rozelle Bay and Iron Cove.

Geological structural features

The solid geology within the project footprint is cross cut by a number of geological structural features that may impact groundwater flow. These include:

- Dykes, such as those identified within the sandstone cutting north of the Rozelle Rail Yards and 150 metres east of the Rozelle Rail Yards and beneath the Hawthorne Canal palaeochannel
- Geological faults (a fracture within rock where displacement may have occurred), which are typically found within the Hawkesbury Sandstone. The presence of geological faults is associated with increased groundwater inflows.

Hydraulic conductivity

Hydraulic conductivity and porosity testing was conducted during the field investigation program to provide parameters to support the groundwater modelling. Packer test results are summarised in **Table 19-3**. Results of the packer tests are expressed as Lugeon units, where one Lugeon unit is equivalent to a hydraulic conductivity of 1×10^{-7} metres per second (8.8×10^{-3} metres per day).

The distribution of packer test results for all hydrogeological units is presented in **Appendix T** (Technical working paper: Groundwater). **Table 19-3** shows the majority of the rock mass results are of low permeability, suggesting that inflows along the majority of the tunnels would be low. To provide an understanding of the measured bulk hydraulic conductivity within the Ashfield Shale and Hawkesbury Sandstone, statistics including mean, maximum, minimum and standard deviation are presented in **Table 19-3**. No site specific data was collected during the groundwater investigations for the hydraulic conductivity of the alluvium. Typical hydraulic conductivity values for similar lithologies across the Sydney Basin would be expected to range from 0.001 metres per day for clayey alluvium up to 1 metre per day for sandy alluvium.

Table 19-3 Monitored hydraulic conductivity for each hydrogeological unit

Relative permeability (metres per day)	Ashfield Shale	Hawkesbury Sandstone
Mean	0.017	0.10
Minimum	0.010	0.012
Maximum	0.12	1.17
Standard deviation	0.024	0.21
Number of samples	24	181

The majority (86 per cent) of packer tests were conducted within the Hawkesbury Sandstone, which is reflective of the majority of the tunnels being located within this stratigraphic unit. For comparison, hydraulic conductivity values within the Hawkesbury Sandstone across the whole Sydney Basin were compiled by McKibbin and Smith (2000) from the DPI-Water groundwater database, with results ranging between 0.01 and 0.15 metres per day. The range identified by McKibbin and Smith (2000) is higher than the packer test results obtained for the groundwater investigations, which is attributed to the majority of results being derived from test pumping results data, obtained from successful production bores that intersect highly permeable faults and fractures.

Groundwater inflow in existing Sydney tunnels

Within the Hawkesbury Sandstone, Mittagong Formation and Ashfield Shale, water inflow is dependent upon the number and aperture of saturated secondary geological structural features intersected. Rates of water inflows have been monitored in recent years from several unlined tunnels in the Sydney area with similar geology, hydrogeology and construction to that proposed by the M4-M5 Link project. These inflow rates are considered long-term flow rates throughout the operational life of the infrastructure, and are summarised in **Table 19-4** (after Hewitt 2005).

Drainage inflow varies from 0.6 litres per second per kilometre to up to 1.7 litres per second per kilometre.

Table 19-4 Measured drainage rates from other Sydney tunnels

Tunnel	Opened	Type	Width (m)	Length (km)	Drainage inflow (L/sec/km)
Eastern Distributor	1999	Three-lane road	12 (double deck)	1.7	1
M5 East Motorway	2001	Twin two-lane road	8 (twin)	3.8	0.9
Epping to Chatswood	2009	Twin rail	7.2 (twin)	13	0.9
Lane Cove Tunnel	2007	Twin three-lane road	9 (twin)	3.6	0.6/1.7*
Cross City Tunnel	2005	Twin two-lane road	8 (twin)	2.1	>3

Note:

* 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 M4 East and New M5 project tunnels have been calculated by numerical modelling published in the respective environmental impact statements for those projects which have obtained planning approval and are currently under construction.

For the New M5 project, groundwater modelling over a modelled length of about 20 kilometres (including the combined length of the mainline tunnels as well as tunnel ramps) predicted an inflow rate of 0.63 litres per second per kilometre of tunnel along the eastbound tunnel and 0.67 litres per second per kilometre of tunnel along the westbound tunnel (CDM Smith 2015).

Similarly, for the M4 East project, groundwater modelling was undertaken to predict inflows to the drained tunnels. The M4 East tunnels extend over a combined length of about 12 kilometres (including the combined length of the mainline tunnels as well as tunnel ramps). Groundwater modelling predicted inflow rates between 0.3 and 0.9 litres per second per kilometre of tunnel (WestConnex Delivery Authority 2015).

19.2.6 Groundwater quality

Table 19-5 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 (2000). For analytes not covered by the ANZECC (2000) guidelines the amended National Health and Medical Research Council (NHMRC) Australian Drinking Water Guidelines (2015) have been adopted.

Table 19-5 Groundwater quality within the study area

Parameter	Alluvium	Ashfield Shale	Hawkesbury Sandstone
Groundwater temperature	Measured groundwater temperatures varied over a narrow range between 14 and 26.5°C. Seasonally, groundwater temperatures tended to vary by one or two degrees, although there was no variation between lithologies.		
Electrical conductivity	Variable, ranging from 328 to 34,900 µS/cm	2860 µS/cm	1700 µS/cm
pH	Weakly acidic (pH 6.5)	Acidic (pH 5 to 6.5)	Acidic (pH 5 to 6.5)
Major cations (calcium, magnesium, sodium and potassium) and major anions (chloride, sulfate, carbonate and bicarbonate)	Groundwater within the alluvium is dominated by sodium, magnesium, chloride and bicarbonate. The dominance of sodium and chloride is attributed to tidal influences and interaction with sea water in Rozelle Bay.	The hydrogeochemical signature of groundwater from the Ashfield Shale is highly variable, which may be due to the intermittent development of secondary mineralisation such as calcite (calcium carbonate) and siderite (iron carbonate) and the variable flushing of salts of marine origin.	Groundwater derived from the Hawkesbury Sandstone is dominated by sodium and chloride, which may be in part due to the influence of saline harbour water.
Heavy metals (arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc)	The maximum recorded values of these metals exceeded the guideline concentration values for all but cadmium and nickel. In most cases the exceedance is marginal, indicating that background levels are already elevated.	The maximum recorded values exceeded the guideline concentration values for chromium, copper, iron, manganese, nickel and zinc. Iron and manganese are commonly elevated within the Ashfield Shale.	The maximum recorded values exceeded the guideline concentration values for chromium, copper, iron, lead, manganese, nickel and zinc. In most cases the guidelines have been marginally exceeded; however, the groundwater consistently has elevated iron and manganese.
Nutrients (including nitrite as N, nitrate as N, reactive phosphorus), and ammonia	Nitrite and nitrate concentrations ranged from below detection limits to 0.31 and 2.38 mg/L respectively, indicating background nutrient levels are low. Reactive phosphorous as P ranged from below detection limits to 0.04 mg/L, indicating phosphorous levels are also low. Ammonia values ranged from 3.81 to 5.76 mg/L, exceeding the guideline value of 0.91 mg/L.	Nitrite and nitrate concentrations ranged from below detection limits to 0.1 and 1.17 mg/L respectively, indicating background nutrient levels are low. Reactive phosphorous as P ranged from below detection limits to 0.67 mg/L, indicating reactive phosphorous levels are low. Ammonia values ranged from 0.2 to 3.19 mg/L, averaging 1.2 mg/L, exceeding the guideline value of 0.91 mg/L.	Nitrite and nitrate concentrations ranged from below detection limits to 1.18 and 1.31 mg/L respectively, indicating background nutrient levels are low. Reactive phosphorus as P ranged from below detection limits to 0.16mg/L indicating reactive phosphorus levels are very low. Ammonia values ranged from 0.2 to 3.41 mg/L, averaging 0.93 mg/L, marginally exceeding the guideline value of 0.91 mg/L.

Parameter	Alluvium	Ashfield Shale	Hawkesbury Sandstone
Sulfate reducing bacteria (measured as a colony forming unit (CFU) per 100 ml)[1]	Sulfate reducing bacteria was not assessed for alluvium.	No pattern with hydrogeological units was assessed for sulfate reducing bacteria because many samples were above the measurement limit (500,000 CFU/ml). Seawater is a known prime habitat for sulfate reducing bacteria, and it is possible that the dissolution of marine salts from the Ashfield Shale into the Hawkesbury Sandstone makes the groundwater prone to sulfate reducing bacteria growth.	
Soil salinity	Salt concentrations within the alluvium are variable, and impacted by tidal influences.	Ashfield Shale typically has a high salt content due to the presence of connate marine salts.	Salt concentrations within the Hawkesbury Sandstone are variable.
Groundwater aggressivity[1]	Groundwater aggressivity was not assessed for alluvium.	Groundwater within the Ashfield Shale is: · Non-aggressive towards concrete piles for average concentrations of chloride, pH and sulfate · Non-aggressive towards steel piles for average concentrations of chloride and pH · Moderately aggressive towards steel pipes for groundwater with low conductivity.	Groundwater within Hawkesbury sandstone is: · Mildly aggressive towards concrete piles for average concentrations of chloride, pH and sulfate · Mildly aggressive towards steel piles for average concentrations of chloride and pH · Severely aggressive towards steel piles for groundwater with low conductivity.

Note:

1 Further assessment of the risk posed by the presence of sulfate reducing bacteria and groundwater aggressivity would be undertaken prior to construction. A corrosion assessment would be undertaken by the construction contractor to assess the impact on building materials that may be used in the tunnel infrastructure such as concrete, steel, aluminium, stainless steel, galvanised steel and polyester resin anchors.

19.2.7 Contamination

An assessment of contaminated land risk is provided in **Appendix R** (Technical working paper: Contamination) which is summarised in **Chapter 16** (Contamination). Areas within the project footprint that may contain contaminated soil and/or groundwater due to past or present land use practices have been investigated. During routine monthly groundwater monitoring as part of the hydrogeological investigation a suite of contaminants was assessed for laboratory analysis including cations and anions, heavy metals and nutrients. Groundwater contamination monitoring was conducted in September and November 2016 to support the site contamination investigation as summarised in **Chapter 16** (Contamination). Key sites investigated are discussed below.

Rozelle Rail Yards

The Rozelle Rail Yards are located to the north and northwest of Rozelle Bay. Roads and Maritime is planning to carry out a limited suite of site management works on part of the Rozelle Rail Yards site which include the removal of rail and rail-related infrastructure including vegetation, buildings and stockpiles. The works are needed to manage the existing environmental and safety issues at the site and would also improve access to surface conditions, which would allow for further investigation into the location of utilities and the presence of contamination and waste. The works would benefit future uses of the site (including construction of the M4-M5 Link project if it is approved).

The site management works were subject to a separate environmental assessment. The works were assessed in a review of environmental factors (REF) which was approved by Roads and Maritime under Part 5 of the *Environmental Planning and Assessment Act 1979* (NSW) in April 2017. The works commenced in mid-2017 and are anticipated to be conducted over a period of 12 months.

Contamination investigations undertaken at the Rozelle Rail Yards as part of the REF and for this EIS have confirmed varying concentrations and types of contamination at a number of locations across the site. The contamination is considered likely to be related to historical land uses and the importation of fill materials of unknown origin. This has resulted in the presence of variable concentrations of heavy metals, PAHs, TRHs, and bonded and friable asbestos in the soils, fill, ballast and existing stockpiles. However, elevated concentrations of these contaminants are not found in all locations across the site. Further investigation of the site would be completed once infrastructure and vegetation has been cleared as part of the site management works.

Contaminated groundwater has also been identified; however, this contamination is relatively minor and limited to exceedances of:

- Zinc and copper in one location
- Zinc in one other location
- TRHs, naphthalene and Bis(2-ethylhexyl) phthalate in one location.

The excavation of low lying natural soil during the tunnel excavation program may also uncover potential acid sulfate soils (PASS). Consequently, the risks associated with PASS and other contaminants of concern would be managed under a Construction Soil and Water Management Plan (CSWMP), which would outline requirements for the management of potential acid sulfate soils.

The primary risk to groundwater is the migration of contaminated groundwater due to altered groundwater flow paths from tunnel construction. The tunnel and cut-and-cover sections through the Whites Creek alluvium beneath the Rozelle Rail Yards would be constructed as undrained (tanked) (ie lined) to avoid the ingress of groundwater from the palaeochannels, minimising the potential for contaminated groundwater migration.

Leichhardt

The Hawthorne Canal and Leichhardt North area has undergone historic, widespread land reclamation with fill from unknown sources, indicating that subsurface soil contamination could be present in some areas. Other potential soil contamination sources include the storage and use of chemicals, pesticides, fuels and oils, and hazardous building materials at the former Public Works Depot and the former Ordnance Depot within Blackmore Park. There are potentially pockets of soil contamination present across these areas that could contaminate groundwater within the underlying palaeochannels. The tunnels are to be constructed at depth to extend beneath the palaeochannel associated with the Hawthorne Canal so groundwater from the alluvium would not directly flow into the tunnels. PASS have been mapped across the majority of this area. At The Crescent, shallow alluvial groundwater may have become contaminated with hydrocarbons via hydraulic connection with Whites Creek or activities associated with the light rail line and former freight line.

Haberfield and St Peters

Contamination investigations undertaken for the M4 East and New M5 projects have been reviewed to provide an understanding of potential groundwater contamination in the vicinity of the Wattle Street interchange at Haberfield and the St Peters interchange at St Peters, respectively.

Wattle Street interchange

It was determined that the risk of potential groundwater contamination in the vicinity of the Wattle Street interchange at Haberfield is low. Potential contaminating land uses were identified as being located topographically down-gradient of the project and therefore would be unlikely to impact groundwater within the project footprint.

St Peters interchange

The St Peters interchange is to be constructed on a rehabilitated Alexandria Landfill as part of the New M5 project. Leachate is still generated from the former landfill and will continue to be pumped and treated on site before disposal off site. Leachate generation will be reduced by improving internal drainage and capping of the landfill. A cut-off wall is to be constructed along the eastern perimeter of the landfill to reduce groundwater inflow from the Botany Sands aquifer as part of the New M5 project.

The New M5 tunnels and access portals through the former landfill are to be undrained (tanked), preventing the ingress of contaminated groundwater into the tunnel drainage system. The deeper tunnels constructed in the Hawkesbury Sandstone or Ashfield Shale are to be drained, but are unlikely to intersect contaminated groundwater. The risk of contaminated groundwater entering the project tunnels at St Peters from leachate derived from the landfill is low, because leachate will continue to be pumped, collected and treated in a newly constructed water treatment plant as part of the New M5 project, drawing groundwater away from the tunnels. Leachate generation is to be reduced due to the cut-off wall that is to be constructed along the eastern perimeter of the landfill to reduce groundwater inflow and capping the former landfill to reduce rainfall infiltration.

Hydrocarbon contamination identified within the weathered clay and residual shale is attributed to fuel leaks and spills from the nearby service station.

19.2.8 Existing groundwater users

A review of bores registered with DPI-Water and accessed through the BoM (on 9 May 2016) identified 197 boreholes within a two kilometre radius of the project footprint. There may also be other private bores present within the two kilometre radius that have not been registered with DPI-Water. The distribution of registered boreholes extracted from the database is shown in Annexure B of **Appendix T** (Technical working paper: Groundwater). In analysing the data, there are two distinct types of bores: bores with recorded hydrogeological data (66), and bores with only the borehole number and coordinates recorded (131).

Typically, boreholes with only coordinates recorded are monitoring wells constructed as part of contamination investigation programs. In most cases these monitoring wells would no longer be monitored, as the site investigation or remediation programs are completed and the sites have been redeveloped. Analysis of the remaining data indicates that the majority of registered wells are constructed for monitoring purposes, with the minority developed for recreation and domestic water supply (see **Table 19-6**).

Table 19-6 Summary of DPI-Water registered bores within two kilometres of the project footprint

Purpose	Number of bores	Predominant lithology	SWL* min	SWL max	Bore depth min	Bore depth max
			(metres below ground level)			
Recreation	1	sandstone	11.6	11.6	180	180
Domestic	4	sand	4	31	2.5	210
Monitoring	61	shale/sandstone	0.4	7.7	1.3	48

Note:

* SWL = Standing Water Level

Review of the lithological data indicates that the majority of boreholes are shallow (less than 10 metres below ground surface) and monitor groundwater in the sand, clay, shallow sandstone or shale. The majority of monitoring wells are clustered at various investigation sites within the study area. A 180 metre deep recreation bore is located at Redfern Park within the Hawkesbury Sandstone, and is used to irrigate Redfern Oval. Four domestic bores are located within the study area, ranging in distance between 210 metres and 1,480 metres from the tunnel corridor. It is not known if these bores are still used for domestic use or have been abandoned. A 210 metre deep bore (GW110247) at the University of Sydney at Camperdown extracts groundwater from the Hawkesbury Sandstone and is registered for domestic use.

Even though groundwater quality is generally good within the Hawkesbury Sandstone, groundwater use across most of the study area is low, as bore yields are typically low and the area has access to reticulated water. At Rozelle Rail Yards, there are few registered monitoring wells, suggesting that there have been limited historical groundwater investigations undertaken at this former industrial site (prior to the investigations undertaken for this assessment), or that monitoring wells have not been registered.

19.2.9 Groundwater dependent ecosystems

A review of the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources* (2011) and the *National Atlas of Groundwater Dependent Ecosystems* (viewed 22 August 2016) indicated there are no high priority GDEs within the study area (as identified in **Chapter 18** (Biodiversity)). The nearest high priority wetlands are the Botany Wetlands and Lachlan Swamps within the Botany Sands, located at Centennial Park, around five kilometres east of the easternmost point of the project footprint, and beyond the range of potential impact.

19.3 Assessment of potential construction impacts

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

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 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 19.3.9** and in **Appendix T** (Technical working paper: Groundwater).

19.3.1 Reduced groundwater recharge

Surface disturbance due to the project construction would include paved construction ancillary facilities, acoustic sheds, cut-and-cover sections leading to the tunnel portals, and approach roads. Construction ancillary facilities would create additional temporary impervious surfaces during construction. The impacts of these surfaces, however, are considered minor and would not significantly reduce groundwater recharge during construction. In many instances construction ancillary facilities would be located on existing impervious surfaces and would therefore not impact local groundwater recharge during construction.

The risks during construction would be that access roads, tracks and the bunded isolation areas for stockpiling of construction materials could alter or reduce groundwater recharge. These impacts are considered minimal, as the affected area is small compared to the overall project footprint, and temporary, as the various structures would be removed at the end of the construction phase.

19.3.2 Tunnel inflow

The short term 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-grouting), fractured zones intersected, 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 the process of pumping grout into the sandstone or shale in pre-determined areas by drilling and injection to reduce the bulk rock permeability before tunnel advancement.

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. During construction these high inflow zones would be grouted to reduce the inflow rate. Groundwater from the Botany sands aquifer is likely to enter the tunnel indirectly through hydraulic connection with the Hawkesbury Sandstone, however a capture zone analysis undertaken as part of the groundwater modelling confirms the Botany Sands would not be a dominant source of water to the tunnels during construction.

The groundwater modelling has predicted groundwater inflows to the tunnels during construction. Initial groundwater inflows to the tunnels during construction are estimated to range between 0.45 megalitres per day and 2.87 megalitres per day. The maximum inflows are predicted to peak towards the end of construction in 2021 at 2.45 megalitres per day or 0.77 litres per second per kilometre, which remains below the overall WestConnex tunnel inflow criterion of one litre per second per kilometre for any kilometre length of the tunnel.

The predicted water take during construction (year 2023) from each of the Greater Metropolitan Regional resource due to tunnel inflows is compared to the long term average annual extraction limit (LTAAEL) and is summarised in **Table 19-7**. Comparison of predicted tunnel inflows indicates the reduction in the groundwater availability within the Botany Sands during construction will be reduced by 0.004 per cent of the LTAAEL. Similarly the predicted reduction in the groundwater availability during construction will be reduced by 661 megalitres per year (ML/year) or 1.4 per cent of the LTAAEL for the Sydney Basin Central groundwater resource. These predicted water ‘take’ represent a small proportion of the available water within the water sharing plan.

Table 19-7 Groundwater extraction from the Metropolitan Regional Groundwater Resources during construction (Year 2023)

Aquifer	LTAAEL (ML/year)	Water take (ML/year)	Percentage of LTAAEL
Botany Sands	14,684	0.62	0.004
Sydney Basin Central	45,915	661	1.4

Source: NoW, 2011 and HydroSimulations, 2017

During construction, groundwater would be intersected and managed by either capturing the water that enters the tunnels, caverns 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 Hawthorne Canal palaeochannel and in the alluvium. Groundwater intersected during the construction of the tunnels would be the primary source of wastewater. The wastewater management system would be designed to treat and discharge groundwater as well as stormwater and other intersected water streams.

During construction, long-term water management solutions, such as the installation of water proofing membranes, would also be installed as required. Groundwater inflows would be collected from the low points of tunnel excavations via a temporary drainage system and would be pumped to the surface for treatment and discharge. Water inflows, treatment and discharge would be managed in accordance with a CSWMP that would form part of the Construction Environmental Management Plan (CEMP) for the project.

Construction options at Wattle Street, Haberfield

The modelling has been undertaken for construction Option A at Haberfield, and therefore the modelling results reflect tunnelling from Wattle Street civil and tunnel site (C1a) and Haberfield civil and tunnel site (C2a). Refer to **Chapter 6** (Construction work) for further information regarding the construction ancillary facility options at this location.

If Option B for the construction configuration at Haberfield occurs where tunnelling would be undertaken from Parramatta Road West civil and tunnel site (C1b), there would likely be a slight increase in inflow volume due to the increased construction access tunnel length required. It is expected that the change to the rate of inflow (in litres per second per kilometre) would be low, as this additional tunnelling would be through good quality Hawkesbury Sandstone and would not intersect alluvium.

19.3.3 Groundwater level decline

Groundwater modelling has been used to predict groundwater levels at the end of the construction period (2023) within the alluvium, Ashfield Shale and Hawkesbury Sandstone. The degree of drawdown is dependent on a number of factors including the geology intersected, the hydrogeology and the tunnel configuration and depths. Within the alluvium, the groundwater levels are predicted to form a steep elongated cone of depression along the tunnel alignment due to downward leakage to the underlying Hawkesbury Sandstone. However, the depressed groundwater contours are localised, extending no further than about 500 metres from the tunnels, indicating localised changes to groundwater flow patterns with negligible impacts on the regional groundwater flow.

At the end of construction, steep localised cones of depression are predicted to develop beneath Newtown and St Peters within the Ashfield Shale. Local groundwater sinks are created at these locations due to the low hydraulic conductivity of the shale and the influence of the leachate pumping at the former Alexandria Landfill. In this case the groundwater level decline is due to leachate pumping from the landfill and not the project.

At the end of construction, the maximum drawdown is predicted to be 42 metres centred on the Rozelle interchange. Drawdown within the alluvium is predicted to be up to 10 metres but in some areas it would be limited by the thickness of the alluvium. The groundwater levels within the

Hawkesbury Sandstone are predicted to be depressed along the tunnels at the end of the construction period. While the impacts are localised, with two metres or more drawdown extending no further than around 600 metres from the tunnels, the groundwater sink predicted to develop would create a hydraulic barrier along the length of the tunnel alignment, reversing groundwater gradients. Below the base of the tunnel, groundwater flow would cease being drawn upwards into the tunnel and natural groundwater flow within the sandstone would continue uninterrupted below the tunnels.

The predicted groundwater elevations at the end of the construction phase (2023) for the project are presented **Figure 19-6**. The predicted groundwater elevations presented in **Figure 19-6** include the total drawdown for the alluvium, Ashfield Shale and Hawkesbury Sandstone.

Groundwater drawdown

Groundwater drawdown due to construction activities and temporary dewatering would impact the local water table, potentiometric pressures in the deeper Ashfield Shale and the Hawkesbury Sandstone, or surface water features where there is hydraulic connectivity. As the majority of the tunnel lengths are drained structures (ie 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 the generally low hydraulic conductivity of the Ashfield Shale and the Hawkesbury Sandstone restricting the extent of drawdown during the relatively short construction timeframe.

As construction continues, drawdown would decrease as the cone of depression expands progressively outwards over time. As the depressurisation caused by the tunnel inflows propagates to the surface, causing the water table to decline, inflows would extend outwards to progressively greater distances until steady state conditions are reached, which is expected to be well after the completion of construction.

Groundwater levels would be monitored throughout the construction phase in accordance with a CSWMP. Additional groundwater modelling is proposed to be conducted by the contractors during construction using measured tunnel inflow rates and monitored groundwater drawdown to better calibrate the model and predict impacts.

The project does not propose to extract groundwater during the construction or operational phases for project purposes. Re-use of treated groundwater would be considered in accordance with the DPI-Water re-use policy, the National Water Quality Management Strategy (DPI-Water 2006).

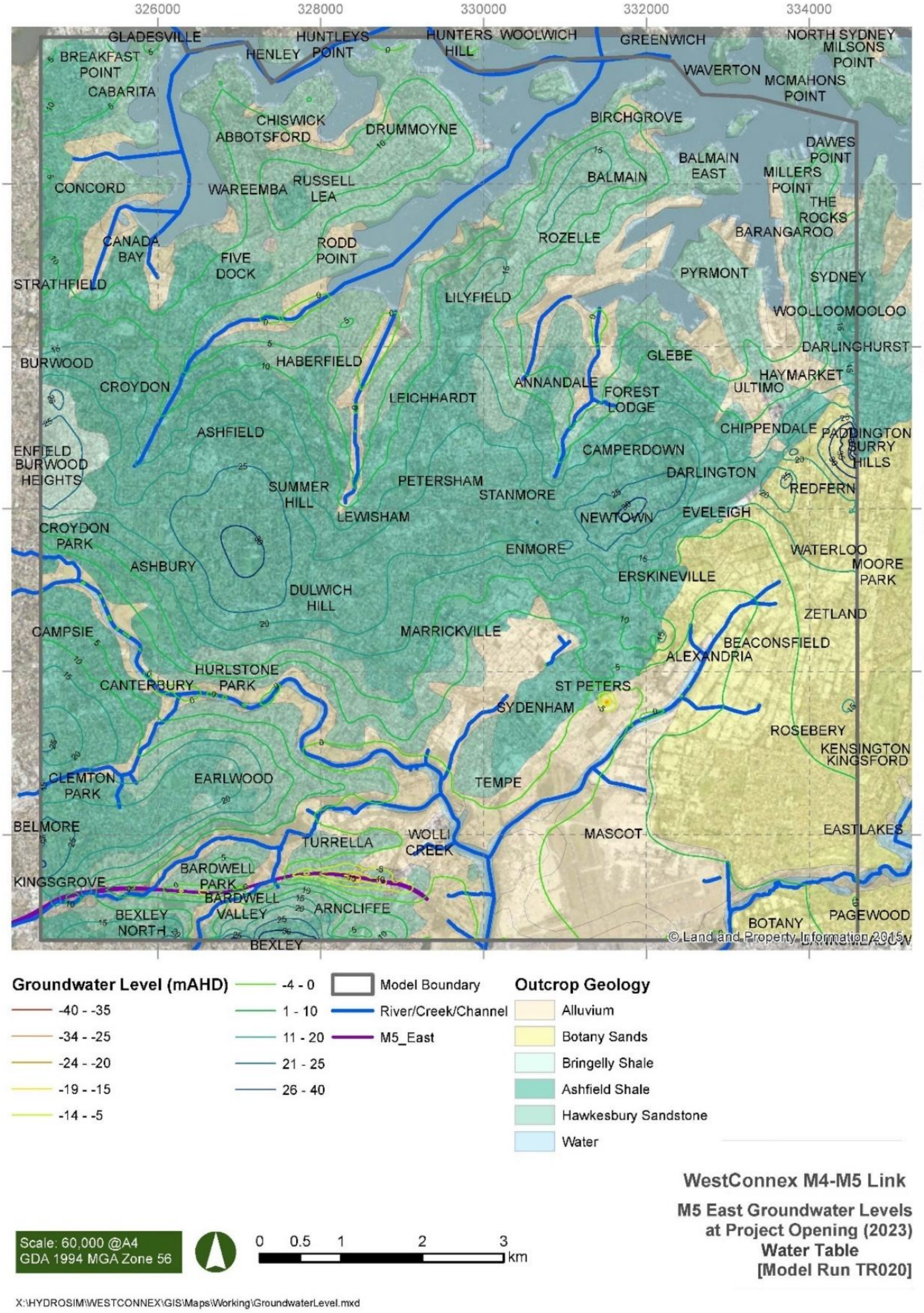

Figure 19-6 Water table elevations for the project at the end of construction (2023)

Potential impacts on groundwater dependent ecosystems

In accordance with the *NSW Aquifer Interference Policy*, groundwater drawdown must be within an allowable range of ten percent of baseline levels within 40 metres of a significant GDE. No priority GDEs have been identified within the project footprint. The closest priority GDEs are the Botany Wetlands and Lachlan Swamps within the Botany Sands, located at Centennial Park, around five kilometres east of the project footprint. These wetlands are at a sufficient distance from the project footprint not to be impacted by the project. Potential impacts on these wetlands and GDEs due to the New M5 project were assessed in the New M5 EIS.

There is a manmade wetland constructed at Whites Creek Valley Park at Annandale, immediately west of Whites Creek. This wetland is unlikely to have any groundwater dependence as it continually receives low flows from Whites Creek. Groundwater levels within the Whites Creek alluvium are unlikely to be adversely impacted during construction because the tunnels are below the alluvium. Groundwater levels are predicted to be drawn down in the Hawkesbury Sandstone but are unlikely to have any groundwater dependence in this area.

Potential impacts on surface water and baseflow

Surface water features within the study area are described in **section 19.2.2**. Groundwater inflows to the tunnels that would have the potential to impact surface water levels are unlikely for the section of the tunnels that would be constructed through the Whites Creek alluvium beneath the Rozelle Rail Yards. This is because these sections of the tunnels would be undrained (tanked) and the majority of the creeks and canals are concrete lined. Consequently, the risk of surface water from creeks or canals seeping into the tunnels via leakage to the alluvium is considered low. There may be some seepage from the canals through cracks in the aged concrete.

The Sydney Water proposals to naturalise sections of Whites Creek, Johnstons Creek and Dobroyd Canal (Iron Cove Creek) are likely to increase groundwater recharge and may partially increase the baseflow to these creeks through the removal of sections of concrete-lined bases which would allow more groundwater and surface water interaction leading to a higher contribution of baseflow to surface water flow.

Surface water can only flow to the groundwater system when the groundwater levels are lower than the surface water levels, or when the alluvial water table falls below the surface water level in the creeks. In the lower catchment reaches, if brackish water from Whites Creek or Johnstons Creek replaces groundwater lost from the alluvium, the groundwater quality may become degraded. Under conditions where groundwater levels are higher than surface water levels and creeks are not concrete lined, groundwater would naturally discharge into Whites Creek or Johnstons Creek.

Where the channels are concrete lined, groundwater would be expected to flow within the alluvium surrounding the channel, discharging downstream directly into Rozelle Bay or Parramatta River. However, if groundwater levels are lowered due to tunnel inflows, then the direction of groundwater flow could be altered or reversed. Therefore, there is potential for groundwater quality to decline as a result of the groundwater drawdown of the brackish water. The natural groundwater is already known to be brackish in the lower lying reaches of the catchment where there is natural tidal interaction. Higher in the catchments, any groundwater loss from the creeks to groundwater via leakage should not degrade groundwater quality, as the surface water would be of lower salinity.

Predicted impacts of construction on baseflow for major watercourses have been modelled (refer to **Appendix T** (Technical working paper: Groundwater)). Baseflow is simulated in the model only when groundwater reaches the ground surface and enters the drainage system. It is expected that the majority of river flow would be derived from stormwater runoff rather than baseflow.

Predicted changes in baseflow at the end of construction are summarised in **Table 19-8**.

Table 19-8 Predicted changes to baseflow at the end of construction

Mid 2023	Hawthorne Canal	Dobroyd Canal (Iron Cove Creek)	Whites Creek	Johnstons Creek
Base case (m^3/day)	298	281	177	289
Reduction in baseflow (m^3/day)	96	14	132	59
Percentage reduction (%)	32	5	75	20

During construction, the baseflow to major watercourses is reduced by between five and 75 per cent. These predicted baseflow reductions are not considered likely to impact the local environment, as the majority of baseflow is anticipated to be derived from surface water runoff. Consequently, groundwater is unlikely to sustain ecosystems before discharging into Rozelle Bay or the Parramatta River.

At Whites Creek, there may be some leakage through the aged cracked concrete that could contribute to baseflow, however this leakage would be minor. Although the baseflow component of streamflow in Whites Creek would be substantially reduced, it is expected that the overall contribution to river flow from groundwater input is relatively small due to Whites Creek being lined and tidally influenced and the catchment being heavily urbanised. There is no predicted impact due to project construction activities on other major watercourses near the New M5 project, including Cooks River, Wolli Creek and Bardwell Creek.

Potential impacts on existing groundwater users

A review of current groundwater use has been conducted to identify registered groundwater users within two kilometres of the project footprint (see **section 19.2.8**).

The groundwater model has been used to assess the potential groundwater level drawdown at sensitive areas and for registered groundwater users. Where the impacts are expected to exceed minimal impact considerations as specified in the *NSW Aquifer Interference Policy* (NoW 2012), mitigation measures have been recommended (see **section 19.5**). Potential impacts on existing users during construction include drawdown in registered bores due to the drawdown of groundwater during tunnelling. The groundwater model predicted that no registered bore within two kilometres of the project footprint would be drawn down more than two metres (the minimum impact criterion under the *NSW Aquifer Interference Policy*) during the project construction program.

In the event that groundwater users experience a decline in groundwater levels in existing bores in excess of two metres as a result of the project, provisions would be implemented to 'make good' the supply by restoring the water supply to pre-development levels. The measures taken would be dependent upon the location of the impacted bore, but could include deepening the bore, providing a new bore, providing an alternative water supply, or alternatively providing appropriate monetary compensation.

19.3.4 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. Contaminants within soils at the Rozelle Rail Yards could be mobilised by altered groundwater flow paths. 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 a 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 to the project footprint 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** (Contamination) and **Chapter 25** (Hazard and risk). Runoff from high rainfall events during construction would be managed in accordance with the measures outlined in **Chapter 15** (Soil and water quality). 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 footprint, as outlined in **section 19.2.7**. A potential contamination risk would be associated with the migration of contaminated groundwater plumes towards the tunnels.

The majority of the tunnels would be constructed within the Hawkesbury Sandstone at depths greater than 20 metres (at the western and eastern ends) and up to 50 metres beneath Newtown and parts of Leichhardt. 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.

Contaminant groundwater investigations have been conducted in the investigation phases of the EIS and have identified some areas where contaminated groundwater may occur, such as the Alexandria Landfill at St Peters, the Rozelle Rail Yards at Rozelle and former industrial sites in areas such as Alexandria and Haberfield. Contaminated groundwater, if intersected, would enter the tunnels and would be treated prior to discharge at one of the water treatment plants.

The primary risk to groundwater quality is the migration of contaminated groundwater along altered groundwater flow paths due to the tunnel construction. At the Rozelle Rail Yards, groundwater beneath the site within the alluvium is shallow and impacted by historical industrial land uses. Potential contaminants of concern include heavy metals (arsenic, cadmium, copper, lead, nickel and zinc) and hydrocarbons. Tunnel sections through the alluvium would be constructed as undrained (tanked), and cut-off walls would be installed to reduce the ingress of groundwater from the palaeochannels, minimising potential contaminated groundwater migration and addressing the requirements of DPI-Water. However, shallow groundwater is likely to be encountered and would require management during ground excavation works associated with the construction of the tunnel access decline.

Potential contaminated groundwater inflows could be derived from industrial sites that overlie the tunnels at Alexandria and St Peters, where the tunnels are relatively shallow (about 20 metres below ground surface) but constructed within the Ashfield Shale. This area historically contained potentially contaminating operations such as petrol stations, several vehicle service centres, dry cleaners, car manufacturing and mechanical workshops. The risk of intersecting shallow contaminated groundwater is considered low, because the tunnels would be constructed within the Ashfield Shale, where the hydraulic conductivity and groundwater leakage would be low.

At Hawthorne Canal and around Leichhardt North, the fill from unknown sources flanking Iron Cove deposited during historical land reclamation works is potentially contaminated and may have impacted local groundwater. Similarly, there are other potential soil contamination sources, such as the storage and use of chemicals, pesticides, fuels and oils and hazardous building materials in the former Public Works Depot at Blackmore Park, which may have impacted shallow groundwater quality within the alluvium and palaeochannels. The risk of intersecting shallow contaminated groundwater is considered low, because the tunnels are to be constructed below the potentially contaminated fill and alluvium within the Hawkesbury Sandstone.

Groundwater and surface water captured as a result of tunnelling are 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 the policies of sustainable water use of DPI-Water. The volume of recycled water required for beneficial use would be variable and dependent on site conditions. The estimated total volume of water required during construction is estimated to be around 900 megalitres (refer to **Appendix Q** (Technical working paper: Surface water and flooding)). It is expected that there would be a water surplus during construction and recycled water for operational purposes would be used in preference to potable water.

At St Peters interchange there is known groundwater contamination, including elevated ammonia, associated with the former Alexandria Landfill. Geotechnical drilling as part of the project did not identify localised faulting or fracturing, which could provide leachate conduits to the tunnels. Although the tunnel depths are shallow near the portals, the risk of landfill contaminated groundwater being intersected by the tunnels is considered low as a cut-off wall is to be constructed along the eastern perimeter of the landfill to reduce groundwater inflow and continual leachate pumping from the former landfill will maintain internally directed groundwater gradients and pumped groundwater will be treated by the landfill water treatment plant.

Large portions of the Botany Sands are contaminated from a variety of sources, primarily related to previous industrial land use. Groundwater from the Botany Sands aquifer is likely to enter the tunnel indirectly through hydraulic connection with the Hawkesbury Sandstone. However, a capture zone analysis undertaken as part of the groundwater modelling confirms the Botany Sands would not be a primary source of groundwater to the tunnels during construction.

Given the tunnel depth, location of the tunnel in relation to the contaminant sources, and low inflow rates predicted, the risk of intercepting contaminated groundwater is considered to be low. All groundwater captured during construction would be directed to water treatment plants at the following construction ancillary facilities and treated to meet relevant discharge criteria prior to discharge:

- Haberfield civil and tunnel site (C2a)
- Parramatta Road West civil and tunnel site (C1b)
- Darley Road civil and tunnel site (C4)
- Rozelle civil and tunnel site (C5)
- Iron Cove Link civil site (C8)
- Pyrmont Bridge Road tunnel site (C9)
- Campbell Road civil and tunnel site (C10).

Groundwater treatment

The volume and treatment requirements for groundwater would vary for different geological units and tunnel depths. Groundwater and surface water captured as a result of tunnelling are likely to be contaminated with suspended solids and increased pH due to tunnel grouting activities. During construction, the wastewater generated in the tunnel (including collected groundwater) would be captured, tested and treated at a construction water treatment plant (if required) prior to reuse or discharge, or disposal offsite if required.

Based on the knowledge gained from the previous WestConnex projects (M4 East and New M5) it is likely that the water treatment plants would be required to include pH correction as well as the ability to remove iron, manganese, suspended solids and hydrocarbons. The existing groundwater quality within the study area (refer to **section 19.2.6**) indicates that groundwater in the study area may also be impacted by elevated levels of ammonia, total nitrogen and total phosphorus compared to ANZECC (2000) guideline levels (marine, freshwater and recreational protection levels). Other metals including copper, chromium, lead, nickel and zinc have been recorded at elevated levels on a limited number of occasions. The type, arrangement and performance of construction water treatment facilities would be developed and finalised during detailed design.

The receiving waterways and ambient water quality are all highly disturbed compared to the 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) and with consideration of the relevant NSW Water Quality Objectives. Ultimately the water quality objectives would be set by the catchment manager of the receiving waters in consultation with the NSW EPA.

The assessment of the potential impacts of the quality of water discharged from the water treatment plants during construction is discussed in **Chapter 15** (Soil and water quality).

Acid sulfate soils

PASS have been identified within natural alluvium beneath the Rozelle Rail Yards and possibly within the alluvium along Hawthorne Canal. When exposed to air (through actions such as excavation or dewatering), the iron sulphides (commonly pyrite) within acid sulfate soils can oxidise, producing sulphuric acid.

Acid sulfate soils could be disturbed by the project and may cause the generation of acidic runoff and/or the increased acidity of groundwater. At Rozelle Rail Yards, the excavation of low-lying natural soil for tunnel infrastructure may uncover PASS, which will require treatment and removal under the CEMP. The risks associated with PASS would be managed under an ASSMP as discussed in **Chapter 15** (Soil and water quality).

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.

Within the study area, the Ashfield Shale typically has a high salt content due to the presence of marine salts. Salt concentrations within soils derived from the Hawkesbury Sandstone and alluvium are variable, and within the alluvium are impacted by tidal influences. Under shallow groundwater conditions, saline groundwater may be drawn to the ground surface by capillary action or altered recharge/discharge conditions, precipitating the salts as the water evaporates.

'Urban salinity' becomes 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 project footprint 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 to be mobilised by local dewatering or associated with the tunnel construction program. Tunnels constructed within the alluvium are to be tanked, and consequently could alter local flow paths, creating groundwater mounding and causing the dissolution of soil salts. Beneath the Rozelle Rail Yards, where the undrained (tanked) tunnels are to be constructed in the Whites Creek alluvium, saline groundwater reaching the ground surface would be directed towards the modified drainage system, thereby removing the mobilised salts from the system. It is unlikely the salts within the Ashfield Shale would become mobilised, as the drained tunnels are expected to draw down the water table, preventing the groundwater reaching the ground surface. The impact of the project on groundwater resources or hydrology, based on the mobilisation of saline soils, is therefore likely to be negligible.

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 fresher water along the shoreline with more saline tidal water. During construction, saline groundwater inflow to the tunnels from tidal areas would be negligible because of the considerable distance of the tidal surface waterbodies are from the tunnels and the slow calculated groundwater travel times. Close to the shoreline, groundwater quality would become slightly more saline during the construction period due to saltwater intrusion. However, the low salinity increase would be unlikely to impact the environment since the groundwater along the tidal fringe is naturally saline due to tidal mixing. In addition, there are no registered water supply wells or priority groundwater dependent ecosystems along this tidal fringe.

19.3.5 Groundwater monitoring

Groundwater monitoring would be carried out during construction for monitoring wells and groundwater collected during tunnelling. The monitoring program would be designed to monitor:

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

The monitoring program would identify groundwater monitoring locations, performance criteria in relation to groundwater levels, quality and inflows and potential remedial actions that would be considered to address any non-compliances with performance criteria.

Groundwater levels and quality would be monitored in the alluvium, Hawkesbury Sandstone and Ashfield Shale. The monitoring wells in the monitoring program used to inform this assessment would be used as required for monitoring. 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 reactive 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 groundwater monitoring program would be developed in consultation with the NSW EPA, DPI-Fisheries, DPI-Water and the Inner West and City of Sydney councils and documented in the CSWMP to satisfy the project conditions of approval.

19.3.6 Ancillary infrastructure

Ancillary infrastructure to be constructed to support the project includes the following:

- Operational facilities for electronic tolling and traffic control
- Fire safety systems and emergency access and evacuation
- Utilities including power supply and water supply
- Buildings such as water treatment facilities and electrical substations
- Ventilation tunnels and systems
- Tunnel portals
- Construction ancillary facilities

- Five motorway operation complexes. The type of facilities constructed at each of these complexes would include substations, water treatment facilities, ventilation facilities, offices, on-site storage and parking for employees.

The majority of these features are above ground and would not impact the hydrogeological regime. Activities that may impact groundwater during construction include:

- Tunnel portals
- Ventilation tunnels and systems
- Water treatment facilities
- Construction 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. Groundwater levels would be restored after the barriers are removed.

19.3.7 Utility works

The project would involve utility works that would include the protection of existing utilities, construction of new utilities and relocation of existing utilities. The majority of the utility works would occur in new utility service corridors at the Iron Cove Link, parallel to Victoria Road and within and surrounding the Rozelle Rail Yards. The utilities to be impacted include:

- Sewer mains
- Water mains
- Electricity cables
- Telecommunications including fibre optic cables
- Gas mains
- Sydney trains electrical infrastructure.

These works would involve excavating trenches to varying depths and may intersect the water table. At the Iron Cove Link impact on groundwater is expected to be minimal as the groundwater level is typically below the estimated depth of utility trenches. In contrast, at the Rozelle Rail Yards the water table is shallow and within one metre of the ground surface indicating that utility trenches are likely to intersect the groundwater. 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 construction footprint. These works would be undertaken in accordance with the Utilities Management Strategy and the CSWMP.

19.3.8 Ground movement (settlement)

Ground movement (settlement) or subsidence can be caused by volume loss due tunnel excavation or due to the compression of the soil structure due to groundwater drawdown. This discussion relates to groundwater movement due to groundwater drawdown.

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.

Within the M4-M5 Link project footprint, residual soil profiles developed on the weathered sandstone and shale bedrock are typically relatively thin, stiff and of low compressibility and as such would be less susceptible to ground settlement. Settlement within the alluvium would be dependent on the amount of groundwater drawdown and would be expected to be greater than that within the Hawkesbury Sandstone and Ashfield Shale, due to the competent nature and geotechnical properties these bedrock units. Monitoring of settlement throughout the construction program would be included as part of the CEMP.

Since ground settlement due to groundwater drawdown would be more likely to occur within the alluvium, the tunnels would be constructed in accordance with design measures to minimise settlement within the alluvium. Design measures include constructing tanked tunnels through the alluvium to minimise groundwater drawdown. Below Hawthorne Canal and Johnstons Creek, the tunnels have been designed to dive beneath the alluvium to reduce groundwater ingress, which would reduce potential settlement. During tunnel construction, the bulk hydraulic conductivity of the Hawkesbury Sandstone would be decreased by grouting off the tunnel faces, decreasing groundwater inflow and thereby reducing potential settlement.

Small scale dewatering of the alluvium and Hawkesbury Sandstone may be required during construction. This could result in an increase in effective stress, leading to ground settlement. Movement in clay soils between hydrogeological units would cause both consolidation settlement and creep settlement, which may result in settlement continuing over a long period of time.

Although the groundwater model has predicted groundwater drawdown within the alluvium and Botany Sands, it is not considered appropriate to use these regional results to calculate localised ground settlement. The model is a regional groundwater model and is not considered appropriate for use in estimating groundwater induced settlement at a more localised level. A preliminary assessment based on geotechnical conditions has been carried out to assess the potential for ground movement as a result of the project and the results of this assessment are provided in **Chapter 12** (Land use and property).

A geotechnical model of representative geological and groundwater conditions would be prepared by the construction contractor prior to excavation and tunnelling for the project. The model would be used to assess predicted settlement impacts and ground movement caused by excavation and tunnelling on adjacent property and infrastructure. Management measures to control groundwater inflows (which influence groundwater drawdown and therefore ground movement) during construction are outlined in **section 19.5**.

Pre-construction condition surveys of potentially impacted property and infrastructure would be undertaken before the commencement of construction activities that would pose a settlement risk, to determine appropriate settlement criteria to prevent damage. In the event that the geotechnical model identifies potential exceedances of settlement criteria, management measures such as appropriate support and stabilisation structures would be implemented to minimise settlement impacts on property and infrastructure.

A settlement monitoring program would be carried out during construction (in accordance with a Settlement Monitoring Plan) and would include a quantitative assessment to develop settlement criteria for tunnel excavation works. In the event that settlement criteria are exceeded during construction for property and infrastructure, measures would be taken to ‘make good’ or to manage the impact.

Further details regarding settlement are provided in **Chapter 12** (Land use and property).

19.3.9 Groundwater balance

The groundwater model was used to quantify potential impacts for the project. The simulated groundwater balance computed for the end of the construction phase (2023) is summarised in **Table 19-9** and is based on the detailed water balance presented in **Appendix T** (Technical working paper: Groundwater).

Table 19-9 Simulated water balance – construction (2023)

Water balance component	Inputs (recharge) (ML/day)	Output (discharge) (ML/day)
Rainfall infiltration	9.52	0.00
Evapotranspiration	0.00	1.53
River inflow/outflow	1.60	12.44
Project tunnels	0.00	2.87
Pumping wells	0.00	0.05
Regional boundary flow	24.95	21.40
Tidal seepage	1.43	0.88
Storage	3.26	1.59
TOTAL	**40.76**	**40.76**

Additional detail on the water balance is provided in **Appendix T** (Technical working paper: Groundwater), including a hydrogeological conceptual model which provides further detail on the components of the water balance.

The water balance confirms that the major water inflows during the construction phase would be derived from regional boundary flow and rainfall infiltration. Conversely, major outflows are regional boundary flow and river outflow. The total inputs and outputs indicate that the water components are balanced.

At the completion of construction in 2023 there would be a net loss in storage of 1.67 megalitres per day (3.26 megalitres per day storage input and 1.59 megalitres per day storage discharge), indicating that water is being drained from the system. In the context of the Sydney Basin, 1.67 megalitres per day is negligible (less than 0.3 per cent of the annual recharge rate of 229,223 megalitres per year for the Sydney Basin Central) (NoW 2011).

19.4 Assessment of potential operation impacts

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

A detailed water balance has been calculated to predict the long-term impacts from operation of the project.

19.4.1 Reduced groundwater recharge

The Rozelle Rail Yards are underlain by alluvium, where groundwater recharge would be expected to be higher than in areas underlain by sandstone and shale. The Rozelle Rail Yards currently behave as a flood storage area where much of the floodwaters would recharge the alluvium. Post construction of the project, the area would be drained by flood channels to minimise flooding, which may result in a reduction of natural groundwater recharge. Parts of the Rozelle Rail Yards not used for road infrastructure would be converted to new open space. These areas would continue to receive rainfall recharge.

Following the completion of construction, construction ancillary facility sites would be rehabilitated. In the event that sites previously used for construction ancillary facilities are used for open space or project landscaping, rainfall recharge in these areas would increase; however, recharge quantities would be minor. The majority of the project is below ground and is unlikely to directly impact groundwater recharge (see **section 19.4.6**). Above ground, the surface area of the road network would slightly increase with additions in some key areas such as City West Link, Victoria Road, Anzac Bridge and The Crescent.

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, the reduction in rainfall recharge across the project footprint is considered negligible.

19.4.2 Tunnel inflow

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

The project tunnels are to be constructed predominantly through the Hawkesbury Sandstone and, to a lesser extent, through the Mittagong Formation and Ashfield Shale. To minimise groundwater inflow, the tunnels are designed to avoid the palaeochannels present by diving beneath Hawthorne Canal and tanking (ie lining to prevent groundwater ingress) sections of the tunnel through the Whites Creek alluvium beneath the Rozelle Rail Yards.

Conservative estimates of tunnel inflows can be made by assuming a maximum groundwater inflow rate of one litre per second per kilometre along the whole drained tunnel length during operation of the project, although inflow rates in some sections of the tunnels would be less than the maximum allowed rate. The total combined length of the mainline tunnels, Iron Cove Link and Rozelle interchange tunnels is around 47,940 metres. The total tunnel length of drained tunnel is 44,950 metres.

Assuming a worst case scenario of a uniform groundwater inflow rate of one litre per second per kilometre for any kilometre length of the tunnel along the whole drained tunnel length, a groundwater inflow of around 44.95 litres per second (3.9 megalitres per day) would be expected, although (as explained above) this is an overestimate.

At the Rozelle interchange, groundwater inflows in each tunnel would be further restricted due to the number of tunnels close to each other and the associated interference of available groundwater flowing into these multiple tunnels.

The regional impact on the Sydney Basin Central of long-term groundwater tunnel inflows (or 'take') as a result of the project is estimated to vary from 1.74 megalitres per day (635 megalites per year) in 2023 reducing to 0.99 megalitres per day (361 megalitres per year) in 2100. The total regional recharge across the Sydney Basin is 229,223 megalitres per year. Consequently, the groundwater 'take' due to long-term groundwater inflow to the tunnels represents 0.27 per cent of the annual recharge across the Sydney Basin in 2023 and 0.15 per cent in 2100.

Groundwater inflow from the Hawkesbury Sandstone is expected to be low due to low bulk hydraulic conductivity values (typically 0.008 metres per day). The Ashfield Shale overlying the Hawkesbury Sandstone typically has an even lower hydraulic conductivity, in the order of 0.001 metres per day (Hewitt 2005), indicating groundwater inflow is expected to be lower in the Ashfield Shale compared to the Hawkesbury Sandstone. The tunnels do not pass through the Botany Sands or Zone 2 of the

Botany Sands Source Management Zone, so there would be no direct inflow of groundwater from the Botany Sands into the drained tunnels.

Alluvium associated with the creeks, canals and edge of the Sydney Harbour and Parramatta River in the study area is partly saturated. Since the alluvium is hydraulically connected to surface waterbodies, water can potentially flow from Rozelle Bay or the Parramatta River via the alluvium and fractured sandstone or shale into the project footprint. Although the majority of the creeks and canals are concrete lined, there remains good hydraulic connection with the groundwater within the alluvium outside the main channels. There is no direct inflow to the tunnels from the alluvium since the tunnels are designed as undrained (tanked) where the alluvium is intersected.

The overall impact of tunnel inflow on groundwater is considered to be minor.

19.4.3 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 is reduced as the cone of drawdown expands and equilibrium or a steady state condition is reached. This equilibrium is achieved when the tunnel inflow is matched by rainfall recharge via infiltration and/or surface water inflows. Long-term groundwater inflows to the tunnels are influenced by the geology intersected and the tunnel construction methods used to reduce the bulk hydraulic conductivity. Long-term groundwater inflow rates are expected to be lower than construction inflow rates for the project.

The reduction in long-term inflow rates is due to the ‘cone’ of drawdown depression expanding laterally at a rate that is proportional to the log of time. As the cone of depression expands further, the hydraulic gradients towards the tunnels reduce. Drawdown is derived from storage depletion but would be partly offset by recharge, both in the short term and long term.

Based on historical groundwater inflows to other drained Sydney tunnels (**section 19.2.5**), the long-term inflow rate into the project tunnels is expected to be below the one litre per second per kilometre design criterion for any kilometre tunnel length. Specific zones capable of higher rates of inflow identified during construction would be treated to reduce inflow rates to meet this criterion.

Groundwater modelling has calculated inflows for the construction and operations phases of the project. At project opening (2023), tunnel inflows are estimated to be 441 megalitres per year, declining to 267 megalitres per year at the end of the model simulation in 2100. As observed in other Sydney tunnels, the inflow rate 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 tunnel alignment. Actual groundwater drawdown of the water table would be dependent on a number of factors, including proximity to the tunnel alignment and the specific geological conditions present. Immediately after tunnelling is completed, groundwater inflows would be at their highest, but with time, groundwater inflow to the tunnel would decrease while the water table decline would continue to gradually expand outwards from the tunnels until equilibrium is reached.

In zones where the inflow rates are likely to exceed one litre per second per kilometre for any kilometre length of tunnel, water bearing fractures/rock defects would be pre-grouted during construction to reduce ongoing groundwater inflow. This grouting would also reduce long-term drawdown impacts. Groundwater movement is restricted in Hawkesbury Sandstone because it is interbedded with shale lenses that discourage groundwater movement. Groundwater drawdown within the palaeochannels and river alluvium within the project footprint would be low because the tunnel sections that intersect the alluvium are to be undrained (tanked). In addition, groundwater levels may be partly maintained by direct hydraulic continuity with surface water.

The predicted drawdown at the various creeks varies depending on local geology, horizontal distance from the tunnel, depth to the tunnel and tunnel design. For some sections, the tunnels have been designed so there would be no direct inflow from the alluvium into the tunnels. This would be achieved by:

- Tanking the tunnels where the alluvium is intersected, such as beneath the Rozelle Rail Yards
- Designing the tunnels to dive beneath the alluvium, such as at Hawthorne Canal
- Constructing cut-off walls where the portals and cut-and-cover sections intersect alluvium, such as at Haberfield.

Drawdown within the alluvium would be variable as it is dependent on a number of factors including leakage to the underlying Hawkesbury Sandstone, rainfall recharge and surface water interaction.

Potential groundwater drawdown due to the project for the long term (2100) has been calculated and is presented in **Figure 19-7**. The drawdown presented in **Figure 19-7** is the total drawdown for the alluvium, Ashfield Shale and Hawkesbury Sandstone.

While the tunnels constructed within the alluvium are proposed to be undrained (tanked), groundwater is predicted to leak from the alluvium into the underlying sandstone, resulting in a decline in the water table within the alluvium. When there is insufficient rainfall recharge or surface water inflow at locations where the alluvium is shallow, the alluvium may be drawn down due to the induced tunnel leakage.

Long-term drawdown (Year 2100) within the Ashfield Shale and Hawkesbury Sandstone extends to the tunnel invert and continues to spread laterally over time. Predicted drawdown in the Hawkesbury Sandstone at Rozelle is a maximum depth of 55 metres, extending laterally 1.4 kilometres either side of the tunnel to the two-metre drawdown contour.

Similarly near St Peters interchange within the Ashfield Shale, groundwater is predicted to be drawn down to the tunnel invert to a depth of 44 metres, with the drawdown extending laterally 0.5 kilometres either side of the tunnel to the two-metre drawdown contour. The reduction in the lateral extent of drawdown within the Ashfield Shale compared to the Hawkesbury Sandstone is due to the sandstone being more permeable than the shale.

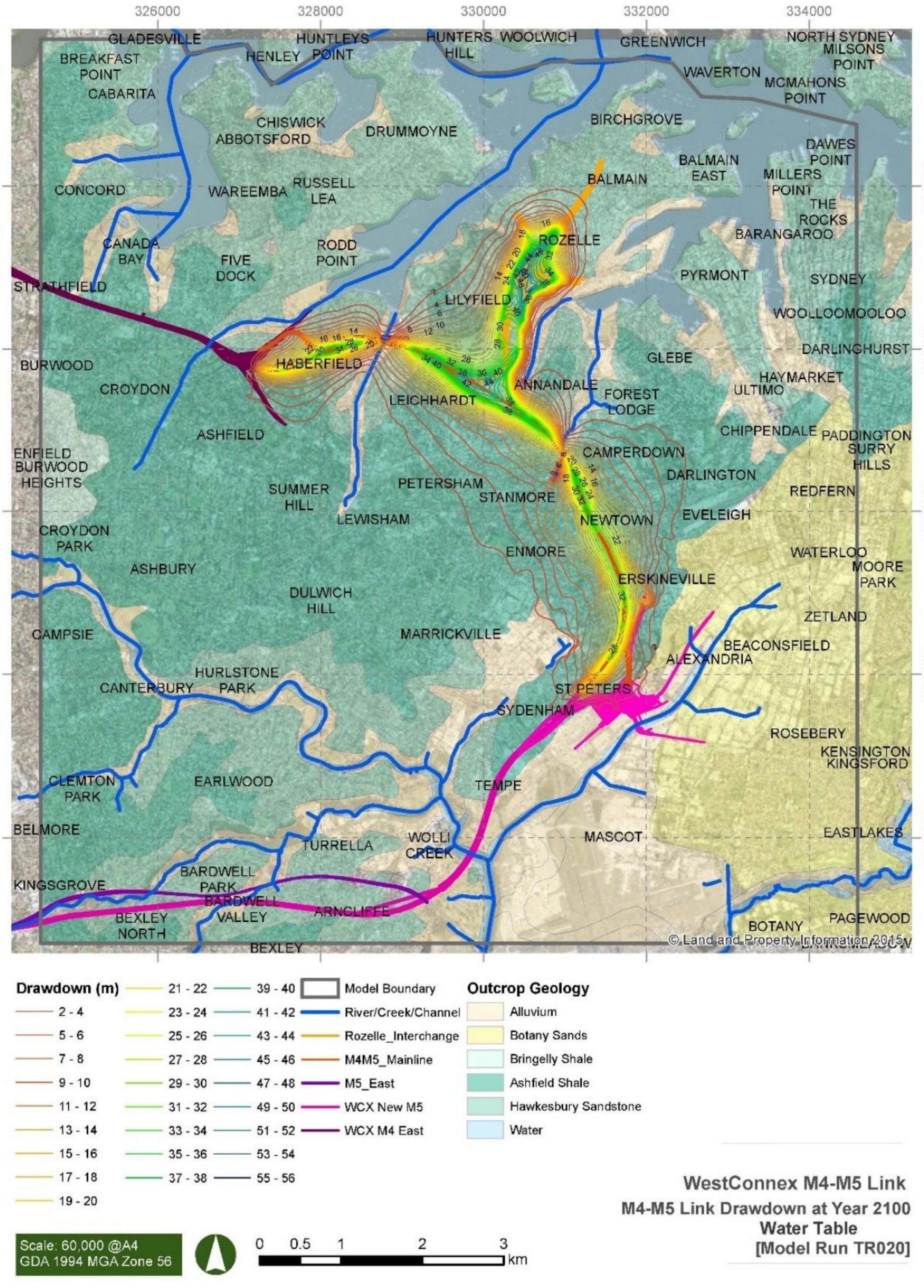

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Figure 19-7 Predicted groundwater drawdown for the project during operation (2100)

Potential impacts on groundwater dependent ecosystems

As identified in **section 19.2.9**, there are no priority GDEs identified in the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources within five kilometres of the project footprint. Consequently, no priority GDEs are likely to be impacted by groundwater level decline associated with the long-term operation of the project. The closest priority GDEs are the Botany Wetlands and Lachlan Swamps within the Botany Sands, located at Centennial Park, around five kilometres east of the project footprint. These wetlands are at a sufficient distance from the project footprint not to be impacted by the project. Potential impacts on these wetlands and GDEs due to the New M5 project were assessed in the New M5 EIS.

Long-term dewatering caused by tunnel drainage could lower the water table and hydraulic heads within the Hawkesbury Sandstone, reducing the amount of groundwater available for non-priority GDE shallow rooted plants. The minimum depth of the water table underlying the majority of the alignment is on average two metres below ground surface. Areas where the water table is shallow, such as at the Rozelle Rail Yards, are typically subjected to periodic flood inundation, which would provide water for shallow rooted plants that may have some groundwater dependence. Continued flood inundation would recharge to the alluvium, although flows would be reduced due to the installation of flood mitigation measures as part of the project (see **Chapter 17** (Flooding and drainage)). At other more elevated topographic areas such as Rozelle, Leichhardt and Newtown, the water table is much deeper below ground surface and consequently flora is unlikely to be dependent on groundwater.

In low-lying areas, such as the Rozelle Rail Yards or close to Rozelle Bay the availability of water for plants is not expected to change, given the high permeability of the sandy soils in combination with frequent rainfall events and higher recharge than elevated sites.

Potential impacts on existing groundwater users

Long-term dewatering caused by tunnel drainage could impact existing groundwater users registered with DPI-Water. A review of the DPI-Water groundwater database indicates that of the registered bores within two kilometres of the proposed project footprint, the majority are registered as monitoring wells. Only five bores are registered for water supply or irrigation. Of these five wells, four are domestic wells and the fifth is registered for irrigation. Two of the domestic wells are located within the Botany Sands and are no longer permitted to be used for domestic purposes due to restrictions imposed by DPI-Water.

Groundwater modelling has been used to predict drawdown at the location of registered bores across the project footprint. Only one bore (GW110247) located in the University of Sydney grounds at Camperdown is registered for domestic use and is predicted to have a drawdown in excess of two metres that is directly attributable to the project. This bore is predicted to have a drawdown of about 2.4 metres to the hydraulic head in Hawkesbury Sandstone by the end of the long-term simulation in 2100. Given the standing water level is recorded as 31 metres below ground level and the bore is 210 metres deep, the drawdown is likely to have a negligible impact on the bore capacity, however the drawdown in excess of two metres triggers ‘make good provisions’ in accordance with the Aquifer Interference Policy. The impact on water quality in GW110247 due to saltwater intrusion is also anticipated to be negligible, since the bore is at least two kilometres from the nearest saltwater body at Rozelle Bay and predicted saline water travel times are in excess of 1,000 years.

Potential impacts on surface water baseflow

Within the Hawkesbury Sandstone (and to a lesser extent the Ashfield Shale), saturated secondary structural features can be hydraulically connected to the creeks and canals or their associated alluvium, providing a pathway for surface water to seep into the tunnels.

Losses to stream flows can occur either as a reduction in baseflow, or as streambed leakage from the creeks and canals, and are dependent on the hydraulic connection between the stream channel and alluvium, the underlying sandstone or shale, and the relative water levels of the creek and groundwater. Groundwater contributions to creek baseflow occur only when the water table elevation is above the creek bed, allowing groundwater to flow to the creek. Conversely, stream bed leakage occurs when the water table elevation is below the creek bed level and groundwater seeps into the underlying lithologies. The concrete lining of creeks would reduce stream bed leakage and baseflow.

Predicted long-term changes to baseflow from the groundwater modelling as a result of the project are summarised in **Table 19-10**. Although the baseflow component of river flow is significantly reduced in several of the watercourses, it is expected that the overall contribution to flow in these watercourses from groundwater is relatively small, since the watercourses are mostly lined channels. It is expected that the majority of flow would be derived from stormwater runoff.

Table 19-10 Predicted long term changes to baseflow

January 2100	Hawthorne Canal	Dobroyd Canal (Iron Cove Creek)	Whites Creek	Johnstons Creek
Base case (m^3/day)	291	274	174	282
Reduction in baseflow (m^3/day)	136	20	145	79
Percentage reduction (%)	47	7	83	28

A water quality objective outlined in **Chapter 15** (Soil and water quality) is to 'maintain groundwater within natural levels and variability that are critical to surface flows and ecosystems of the upper estuary' in the Sydney Harbour and Parramatta River Catchment. Potential groundwater drawdown due to the project for the long-term (2100) has been calculated and is presented in **Figure 19-7**. These figures show that groundwater drawdown would not extend as far to the north as Rozelle Bay and therefore the natural variability of groundwater levels adjacent to Sydney Harbour and the Parramatta estuary would not be impacted by the project.

Groundwater modelling has predicted the potential for varying decreases in creek base flow during the operation of the project, however under current conditions these creeks are concrete lined, restricting groundwater entering the surface water flow during high flow conditions. It is therefore expected that these reductions in base flow would not substantially impact the ecosystems of the upper estuary catchment. If sections of these creeks are naturalised, groundwater recharge would be enhanced, increasing the groundwater component available to surface water flows.

Long-term, the baseflow to major non-tidal creeks is predicted to be reduced by between seven per cent and 83 per cent as a result of the project operation. Although the predicted percentage reduction in baseflow in Hawthorne Canal and Whites Creek is substantial, this reduction represents a small reduction in stream flow, since baseflow, as simulated in the model, only represents the occasions when the groundwater reaches ground level and enters the channels. It is expected that the majority of stream flow would be derived from rainfall runoff and tidal inflow.

There is no impact predicted on the baseflow of other major creeks near the New M5 project footprint (including Cooks River, Wolli Creek and Bardwell Creek) due to the M4-M5 Link project.

Sydney Water is proposing to naturalise parts of creek channels within the project footprint, including sections of Whites Creek, Johnstons Creek at Annandale and Dobroyd Canal (Iron Cove Creek) in Haberfield. 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. Therefore, the impact of a reduction in surface water flow due to the project in these creeks would be in part balanced by the proposed naturalisation works, resulting in additional surface water recharge via bed leakage when the water table is below the creek bed.

Ground movement (settlement)

Impacts related to settlement during operation would be consistent with the impacts related to settlement outlined in **section 19.3.8.** Impacts related to settlement during operation would be from groundwater drawdown, which occurs over a longer timeframe as opposed to settlement impacts from tunnel construction.

A geotechnical model of representative geological and groundwater conditions would be prepared by the construction contractor during the detailed design phase prior to and the commencement of tunnelling. The model would be used to assess predicted settlement impacts and ground movement during the operation of the project. Management measures to control groundwater inflows (which influence groundwater drawdown and therefore ground movement) during the operation of the project are outlined in **section 19.5**.

A settlement monitoring program would be carried out during operation (in accordance with a Settlement Monitoring Plan) at properties and infrastructure where exceedances of the settlement criteria are identified. In the event that settlement criteria are exceeded during operation for property and infrastructure, measures would be taken to ‘make good’ the impact.

Further details regarding settlement are provided in **Chapter 12** (Land use and property).

19.4.4 Groundwater quality

Intercepting contaminated groundwater

There is a risk that contaminated groundwater within the study area (such as a hydrocarbon plume emanating from a former service station or industrial site, for example) could be intercepted during operation of the project, as groundwater is induced to flow towards the tunnel. Altered groundwater flow paths due to the tunnels and hydraulic gradient changes may locally cause existing contaminant plumes (if present) to migrate towards the tunnel alignment. Tunnel inflow quality and quantity would be routinely monitored prior to treatment to detect changes in water quality and treat as needed.

Leachate and elevated concentrations of ammonia are currently generated at the former Alexandria Landfill site. The risk of contaminated groundwater entering the project tunnels from leachate derived from this site is considered low, since the cut-off wall that is to be constructed along the eastern perimeter of the landfill would reduce groundwater inflow cut off walls, the landfill will be capped and ongoing leachate pumping system to be operated as part of the New M5 project will direct groundwater flow towards the leachate pumps and away from the project tunnels.

Contamination generated within the tunnels during operation is unlikely to impact the local hydrogeological regime as groundwater gradients are towards the tunnel. The contamination would be captured within the tunnel drainage system and removed during the treatment process prior to discharge.

At the Rozelle Rail Yards, there is a risk that the groundwater within the alluvium is contaminated from a variety of previous industrial activities. The risk of intersecting shallow contaminated groundwater during the operation of the project is considered to be low, because the tunnels intercepting the alluvium in this area would be undrained (tanked). However, there may be hydraulic connection between the Hawkesbury Sandstone and alluvium, through which potentially contaminated groundwater could enter the tunnel. Tunnel inflow quality and quantity would be routinely monitored prior to treatment to detect changes in water quality, in accordance with an OEMP or Environmental Management System (EMS).

Groundwater from the Botany Sands aquifer is likely to enter the tunnel through hydraulic connection with the Ashfield Shale and Hawkesbury Sandstone at Alexandria. However, analysis undertaken as part of the groundwater modelling indicates the Botany Sands would not be a dominant long-term source of water to the tunnels. Groundwater from the Botany Sands near Alexandria has the potential to be contaminated, but the groundwater entering the tunnel would be treated prior to discharge.

Captured contaminated groundwater through tunnel inflows would be treated in water treatment plants proposed at Rozelle and Darley Road Leichhardt in accordance with the discharge criteria outlined in **Chapter 17** (Flooding and drainage).

The quality of tunnel inflows would be monitored throughout the operational phase to allow the operation of the water treatment plants to be modified as required to meet the adopted discharge criteria. The monitoring strategy would be included in the OEMP or EMS. Other risks associated with contamination during the operation of the project would be managed in accordance with the measures outlined in **Chapter 16** (Contamination).

Groundwater treatment

Treated flows from the Rozelle water treatment plant would drain via a constructed wetland to Rozelle Bay. Treated flows from the Darley Road water treatment plant would be discharged to Hawthorne Canal. A small portion (around 1.6 kilometres) of M4–M5 Link tunnel would also drain to the New M5 operational water treatment plant at Arncliffe.

The existing groundwater quality within the study area (refer to **section 19.2.6**) is brackish with elevated metals and nutrients recorded during groundwater sampling. Total metal, nutrient and ammonia loading to Hawthorne Canal and Rozelle Bay would be likely to increase due to the addition of water from treated groundwater discharges. While the total loading of these contaminants would increase for both treated and non-treated groundwater discharge scenarios, the treatment of groundwater for the project would result in comparatively lower impacts due to the reduced concentration of contaminants after treatment. In order to prevent adverse impacts on downstream water quality within Rozelle Bay and Hawthorne Canal, water treatment facilities would be designed so that the effluent would be of suitable quality for discharge to the receiving environment. By adding additional water to Hawthorne Canal the mass of contaminants would increase (whether treated or not) but the concentration of contaminants in the receiving water would decline if the water is treated, which is beneficial.

The operational water treatment plant at Rozelle and Darley Road would have iron and manganese treatment capabilities. The proposed constructed wetland at Rozelle would remove a proportion of the nutrient and metal load. As no constructed wetland is proposed at Darley Road, opportunities to incorporate other forms of nutrient treatment (for example ion exchange or reverse osmosis) within the plant at Darley Road would be investigated during detailed design with consideration of other factors such as available space, increased power requirements and increased waste production and appropriate discharge criteria.

For groundwater quality, receiving water quality and proposed treatment, the concentration of the key constituents in the treated discharge to Rozelle Bay are unlikely to be significantly higher than the baseline concentration of the constituents in Rozelle Bay. Due to the mixing and dilution affect which would occur at the outlet to the receiving waters, impacts on ambient water quality are likely to be negligible and localised to near the outlet.

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 would be developed in accordance with ANZECC (2000) and with consideration of the relevant NSW Water Quality Objectives. Ultimately, the water quality objectives would be set by the catchment manager of the receiving waters in consultation with the NSW EPA.

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.

Over time, saline intrusion is expected to result in saline water reaching the tunnels. The proportion of saline water flowing into the tunnels, however, would be low. A capture zone analysis has been undertaken as part of the groundwater modelling to investigate salt water intrusion within the tunnel catchment areas. From this analysis it is not possible to quantify volumes or concentrations of saline water entering the tunnels and therefore the following discussion is based on a qualitative analysis.

Alexandra Canal and Whites Creek

Travel times for saline water to enter the tunnels within the alluvium have been tabulated for minimum, maximum and average times (refer to **Appendix T** (Technical working paper: Groundwater)). The minimum travel times for saltwater particles to enter the tunnels from Alexandra Canal and Whites Creek are predicted to be two days and eight days respectively, although these water particles would have a negligible impact on groundwater quality. Initially (minimum travel time), the saline water would be a small fraction of total groundwater entering the tunnel but this is expected to increase over time as water is drawn from further afield. Estimated travel times for saline water to enter the tunnel during operation according to the groundwater model would to be 30 years at Alexandra Canal and 13 years at Whites Creek, although the saline water entering the tunnels would be a minor component of total inflow and changes to groundwater quality are expected to be minimal.

Tidal zones

The capture zone analysis indicates that tidal water from the tidal zones associated with the Parramatta River would enter the project tunnels at the proposed Rozelle interchange. Similarly, groundwater from the alluvium associated with the Cooks River would enter the project tunnels near the St Peters interchange.

As groundwater levels are drawn down below sea level, saline waters from tidal waterbodies would start flowing towards the tunnels and would ultimately enter the tunnels via hydraulic connection with the alluvium. Initially, the saline water would be a small fraction of total groundwater entering the tunnels, but this is expected to increase over time, as groundwater is drawn from further afield. Average times for saline water to enter the tunnels are predicted to be more than 100 years and maximum times are in the order of thousands of years.

As a result, 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 should have minimal impacts on the tunnels and infrastructure in the project's operational lifetime. Similarly, while there is the potential to increase the salinity in registered water supply bores due to saltwater intrusion, the slow progress is expected to have a minimal impact on these bores over a period of 100 years.

Under natural conditions within the Hawkesbury Sandstone, a low salinity water layer towards the top of the aquifer is often present. Shallow rooted plants may have a partial dependency on the low salinity groundwater layer; however, it is expected that these plants would be sustained primarily through rainfall recharge and soil moisture.

In accordance with the OEMP or EMS groundwater quality and tunnel inflow would be routinely monitored and treated, as required, prior to discharge (refer below).

19.4.5 Groundwater monitoring

The groundwater monitoring program prepared and implemented during construction would be augmented and continued during the operational phase. Groundwater would be monitored during the operations 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.

At least three monitoring wells and vibrating wire piezometers (VWPs) should be constructed as close as possible to the tunnel centrelines to allow for the comparison of pore pressures and standing water levels. The wells could be constructed about 5-10 metres above the top of the tunnel crown to allow for groundwater drawdown monitoring in the Hawkesbury Sandstone.

The exact nature and frequency of the ongoing groundwater monitoring during operation would be determined by the project operator.

The operational groundwater monitoring program would be developed in consultation with the NSW EPA, DPI-Fisheries, DPI-Water and the Inner West and City of Sydney councils and documented in the OEMP or EMS.

19.4.6 Ancillary infrastructure

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

- Tunnel portals
- Ventilation tunnels and systems
- Water treatment facilities
- Utility works
- Drainage channels and wetland areas.

The tunnel portals and cut-and-cover structures are likely to be constructed in bedrock to prevent the ingress of groundwater into the tunnels. Ventilation tunnels are likely to be constructed as drained tunnels. This infrastructure has been included in the groundwater model, so impacts such as groundwater drawdown or groundwater ingress due to tunnel seepage are discussed in this chapter.

The water treatment facilities would be constructed to enable captured groundwater and surface water that enters the tunnels to be treated and discharged in accordance with *NSW Water Quality and River Flow Objectives* (NSW Department of Environment, Climate Change and Water 2006) (refer to **Chapter 15** (Soil and water quality) for further detail). The water treatment plants are not expected to impact groundwater, since it would be above ground level and have no interaction with the water table. Utility corridors, drainage channels and wetland areas are likely to impact groundwater at the Rozelle Rail Yards since groundwater levels are typically less than one metre below ground level. Temporary dewatering or the installation of temporary sheet piling may be required to manage groundwater during construction.

19.4.7 Barriers to groundwater flow from operational infrastructure

Below ground infrastructure, such as a tunnel below the water table, 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. Permanent impacts may be caused by the compartmentalisation of an aquifer through the construction of a barrier boundary that alters groundwater flow patterns.

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 in the Whites Creek Alluvium beneath the Rozelle Rail Yards would be undrained (tanked) to prevent groundwater ingress. These sections of the tunnels would be constructed within alluvium and are unlikely to create a physical barrier, as the tunnels would not fully penetrate the alluvium water table, thus allowing groundwater to flow around (above or below) the tunnel.

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 this groundwater 'sink' would occur along the alignment and extend to a level beneath the tunnel invert. Below this level, there would be no discernible lowering of groundwater pressures, and the groundwater flow pattern would remain unchanged.

At tunnel portals or cut-and-cover sections, 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.

19.4.8 Groundwater management

Where higher long-term groundwater inflows into the proposed tunnels are identified during construction, these could be reduced using methods such as pre-grouting and the installation of waterproofing. However, because the proposed tunnels are designed as drained tunnels, with groundwater being captured, treated and discharged at the surface, the need for this measure is likely to be minimal. Strip drains or similar would be installed behind wall panels to assist in dissipating groundwater.

Tunnel drainage and treatment infrastructure would be designed to accommodate groundwater ingress. Separate sumps would be provided at tunnel low points to collect tunnel drainage from separately from groundwater ingress.

Groundwater would be pumped from the sumps to a water treatment plant at the Darley Road motorway operations complex (MOC1) at Leichhardt, with treated flows ultimately discharged to Hawthorne Canal or to the sewer and at the Rozelle East motorway operations complex (MOC3) with treated flows discharged via a constructed wetland within the Rozelle Rail Yards to Rozelle Bay. Further information regarding tunnel drainage and treatment infrastructure is provided in **Chapter 5** (Project description).

The beneficial reuse of the treated water would also be considered, the most likely reuse option being the irrigation of parks and playing fields, for example at the proposed Rozelle interchange. Groundwater reuse would be in accordance with DPI-Water policies for sustainable water use.

19.4.9 Groundwater balance

A groundwater balance has been prepared for the transient simulation (see **section 19.1.5**) and was run to predict the long-term operations impacts. The estimated water balance is summarised in **Table 19-11** and is based on the detailed water balance presented in **Appendix T** (Technical working paper: Groundwater).

Table 19-11 Estimated water balance – project operation (year 2100)

Water balance component	Inputs (recharge) (ML/day)	Output (discharge) (ML/day)
Rainfall infiltration	10.80	0.00
Evapotranspiration	0.00	1.61
River inflow/outflow	1.44	12.8
Tunnels (M4-M5 Link)	0.00	0.67
Pumping wells (Alexandria Landfill)	0.00	0.08
Regional boundary flow	24.60	21.1
Tidal seepage	1.20	0.89
Storage	2.87	3.58
TOTAL	**40.9**	**40.7**

Additional detail on the water balance is provided in **Appendix T** (Technical working paper: Groundwater), including a hydrogeological conceptual model which provides further detail on the components of the water balance.

The transient water balance confirms that the regional boundary flows and rainfall infiltration are the primary recharge parameters, and the primary discharge parameters are river outflow and regional outflow. The total recharge and discharge components match within an acceptable margin of error, indicating the water components of the model balance.

19.5 Environmental management measures

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 19-12**.

Table 19-12 Environmental management measures – groundwater

Impact	No.	Environmental management measure	Timing
Construction			
High groundwater inflows in excess of the one litre per second per kilometre design criterion, which would cause significant groundwater inflows and groundwater drawdown	GW1	Groundwater inflows within the tunnels will be minimised by designing the final tunnel alignment to minimise intersections with known palaeochannels and alluvium present in the project footprint.	Construction
	GW2	Appropriate waterproofing measures will be identified and included in the detailed design to permanently reduce the inflow into the tunnels to below one litre per second per kilometre for any kilometre length of the tunnel.	Construction
	GW3	Appropriate measures will be investigated and implemented at dive structures and shafts and for cut-and-cover sections of the tunnel to minimise groundwater inflow.	Construction
Corrosion of building materials by sulfate reducing bacteria	GW4	Further assessment of the risk posed by the presence of sulfate reducing bacteria and groundwater aggressivity will be undertaken prior to construction. A corrosion assessment will be undertaken by the construction contractor to assess the impact on building materials that may be used in the tunnel infrastructure such as concrete, steel, aluminium, stainless steel, galvanised steel and polyester resin anchors. The outcomes of the corrosion assessment will be considered when selecting building materials likely to encounter groundwater.	Construction
Groundwater drawdown impacting a water supply well water level by more than two metres	GW5	In accordance with the Aquifer Interference Policy, measures will be taken to 'make good' the impact on an impacted water supply bore by restoring the water supply to pre-development levels. The measures taken will be dependent upon the location of the impacted bore but could include, for example, deepening the bore, providing a new bore or providing an alternative water supply.	Construction
Alteration of groundwater flows and levels due to the installation of subsurface project components	GW6	Potential impacts associated with subsurface components of the project intercepting and altering groundwater flows and levels will be considered during detailed design. Measures to reduce potential impacts will be identified and included in the detailed construction methodology and the detailed design as relevant.	Construction
Actual groundwater inflows and drawdown in adjacent areas exceed expectations	GW7	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.	Construction

Impact	No.	Environmental management measure	Timing
	GW8	Groundwater inflow within and groundwater levels in the vicinity of the tunnels will be monitored during construction and compared to model predictions and groundwater performance criteria applied to the project. The 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 criteria are met.	Operation
Operation			
Impacts on groundwater quality or groundwater levels	OGW9	A groundwater monitoring program will be prepared and implemented to monitor groundwater inflows in the tunnels and groundwater levels as well as groundwater quality in the three main aquifers and inflows during construction. 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 any non-compliances with performance criteria. As a minimum, the program will include manual groundwater level and quality monitoring monthly and inflow volumes and quality weekly. The monitoring program will be developed in consultation with the NSW EPA, DPI-Fisheries, DPI-Water, City of Sydney Council and Inner West Council.	Operation
	OGW10	The groundwater monitoring program prepared and implemented during construction will be augmented and continued during the operational phase. Groundwater will be monitored during the operations phase for three years or as otherwise required by the project conditions of approval and will include trigger levels for response or remedial action based on monitoring results and relevant performance criteria. At least three monitoring wells and vibrating wire piezometers (VWPs) should be constructed as close as possible to the tunnel centrelines to allow for the comparison of pore pressures and standing water levels. The wells could be constructed about 5-10 metres above the top of the tunnel crown to allow for groundwater drawdown monitoring in the Hawkesbury Sandstone. The operational groundwater monitoring program will be developed in consultation with the NSW EPA, DPI-Fisheries, DPI-Water and the Inner West and City of Sydney councils and documented in the OEMP or EMS.	Operation

Impact	No.	Environmental management measure	Timing
Corrosive groundwater could adversely impact the tunnel and associated infrastructure	OGW11	Where the corrosion assessment that will be carried out prior to construction indicates potential issues, corrosion and other associated impacts of highly aggressive groundwater on the tunnel infrastructure will be monitored during operations. The monitoring program will be documented in the OEMP or EMS. Corroded or otherwise impacted infrastructure will be repaired or replaced as required to maintain operational integrity of the road infrastructure.	Operation
Groundwater drawdown due to the project may exceed two metres in registered bores or at other receptors	OGW12	In accordance with the Aquifer Interference Policy, measures will be taken to 'make good' the impact on an impacted water supply bore by restoring the water supply to pre-development levels. The measures taken will be dependent upon the location of the impacted bore but could include, for example, deepening the bore, providing a new bore or providing an alternative water supply.	Operation

Based on the above 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.