NSW GOVERNMENT

Roads and Maritime Services

F6 Extension Stage 1

New M5 Motorway at Arncliffe to President Avenue at Kogarah

Environmental Impact Statement

Appendix K
Groundwater Technical Report

Volume 6

K

Contents

Glossary of terms and abbreviations

Term	Definition
Aeolian	Clays, silts and sands that have been deposited by wind.
AHD	Australian Height Datum. The standard reference level used to express the relative elevation of various features. A height in metres AHD is essentially the height above sea level.
AIP	The Aquifer Interference Policy (AIP) is NSW government legislation administered by DPI-Water that explains the process of administering water policy under the Water Management Act 2000 (WM Act) for activities that interfere with the aquifer.
Alluvium	Sediments (clays, sands, gravels and other materials) deposited by flowing water. Deposits can be made by streams on river beds, floodplains and alluvial fans.
Anisotropic	The condition under which one or more of the hydraulic properties of an aquifer varies according to the direction of flow.
ANZECC	Australian and New Zealand Guidelines for Fresh and Marine Water Quality
Aquiclude	An aquiclude is a geological material through which zero flow occurs.
Aquifer	Geologic formation, group of formations, or part of a formation capable of transmitting and yielding quantities of water.
Aquifer properties	The characteristics of an aquifer that determine its hydraulic behaviour and its response to abstraction.
AIP	The Aquifer Interference Policy (AIP) is NSW government legislation administered by DPI-Water that explains the process of administering water policy under the Water Management Act 2000 (WM Act) for activities that interfere with the aquifer.
Aquitard	A low permeability unit that can store groundwater and also transmit it slowly from one aquifer to another.
ARMCANZ	Agriculture and Resource Management Council of Australia and New
Arterial roads	The main or trunk roads of the state road network.
Average recurrence interval (ARI)	An indicator used to describe the frequency of floods. The average period in years between the occurrence of a flood of a particular magnitude or greater. In a long period of say 1,000 years, a flood equivalent to or greater than a 100 year ARI event would occur 10 times. The 100 year ARI flood has a one per cent chance (i.e. a one-in-100 chance) of occurrence in any one year. Floods generated by runoff from the study catchments are referred to in terms of their ARI, for example the 100 year ARI flood.
Bore	A cylindrical drill hole sunk into the ground from which water is pumped for use or monitoring.
Borehole	A hole produced in the ground by drilling for the investigation and assessment of soil and rock profiles.
BTEXN	Benzene, toluene, ethylbenzene, xylene and naphthalene
BoM	Bureau of Meteorology
Catchment	The area from which a surface watercourse or a groundwater system derives its water.
CBD	Central business district
CEMP	Construction Environmental Management Plan. A plan developed for the construction phase of a project to ensure that all contractors and sub-contractors comply with the environmental conditions of approval for the project and that environmental risks are properly managed.
Clearing	The removal of vegetation or other obstacles at or above ground level.

Term	Definition
Concept design	Initial functional layout of a road/road system or other infrastructure. Used to facilitate understanding of a project, establish feasibility and provide basis for estimating and to determine further investigations needed for detailed design.
CSWMP	Construction Soil and Water Management Plan
Cumulative impacts	Combination of individual effects of the same kind due to multiple actions from various sources over time.
Cut-and-cover	A method of tunnel construction whereby the structure is built in an open excavation and subsequently covered.
DEC	(NSW) Department of Environment and Conservation
DECC	(NSW) Department of Environment, Climate Change
DI - Water	NSW Department of Industry – Water, formerly DPI-Water. State agency responsible for managing groundwater and surface water.
Diaphragm wall	A diaphragm wall is constructed by excavating a trench to the bedrock and filling the trench with a cement slurry and reinforcing to form a barrier wall.
Discharge	A release of water from a particular source. The volume of water flowing in a stream or through an aquifer past a specific point over a given period of time.
DIWA	Directory of Important Wetlands of Australia
DLWC	NSW Department of Land and Water Conservation
DoP	NSW Department of Planning. Predecessor agency to the NSW Department of Planning and Environment.
DPE	NSW Department of Planning and Environment
DPI-Fisheries	NSW Department of Primary Industries – Fisheries. State agency responsible for managing fisheries.
DPI-Water	NSW Department of Primary Industries – Water.
Drainage	Natural or artificial means for the interception and removal of surface or subsurface water.
Drained structure	Is an excavation or tunnel that allows groundwater to flow into the structure through defects in the rock. The groundwater is collected and pumped out. Drained tunnels are typically constructed in competent rock such as the Hawkesbury Sandstone and may be constructed with minimal water proofing to reduce groundwater inflows along some tunnel sections.
Drawdown	A lowering of the water table in an unconfined aquifer or the potentiometric surface of a confined aquifer caused by the groundwater inflow to tunnels or pumping of groundwater from wells.
Driven tunnel	Mechanical excavation of a tunnel through rock by a road header or tunnel boring machine, driven along the tunnel alignment from the tunnel entrance.
DRN	Drain
DWE	NSW Department of Water and Energy
Dyke	A vertical or sub-vertical geological structure composed of igneous rock that typically cross cuts the host rock. The dyke is formed as magma from a larger igneous body intrudes the host rock typically along structural weaknesses.
Earthworks	Operations involved in loosening, excavating, placing, shaping and compacting soil or rock.
Ecology	The study of the relationship between living things and the environment.

Term	Definition
ESD	Ecologically sustainable development. As defined by the Protection of the Environment Administration Act 1991 (NSW), requires the effective integration of economic and environmental considerations in decision making processes including: The precautionary principle. Inter-generational equity. Conservation of biological diversity and ecological integrity. Improved valuation, pricing and incentive mechanisms (includes polluter pays, full life cycle costs, cost effective pursuit of environmental goals).
Ecosystem	As defined in the Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth), an ecosystem is a 'dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit'.
EEC	Endangered ecological community. An ecological community identified by the Threatened Species Conservation Act 1995 (NSW) that is facing a very high risk of extinction in New South Wales in the near future, as determined in accordance with criteria prescribed by the regulations, and is not eligible to be listed as a critically endangered ecological community.
EC	Electrical Conductivity. A unit of measurement for water salinity. One EC equals one micro –Siemen per centimetre (µS/cm) measured at 25^{o}C.
EIS	Environmental impact statement
Emission	The discharge of a substance into the environment.
EMS	Environmental management system. A quality system that enables an organisation to identify, monitor and control its environmental aspects. An EMS is part of an overall management system, which includes organisational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing and maintaining the environmental policy.
Environment	As defined within the Environmental Planning and Assessment Act 1979 (NSW), all aspects of the surroundings of humans, whether affecting any human as an individual or in his or her social groupings.
EP&A Act	Environmental Planning and Assessment Act (1979) (NSW)
Ephemeral	Existing for a short duration of time.
ET, ETV	Evapotranspiration
FD	Finite difference
Fractured Rock Aquifer	Occur in sedimentary, igneous and metamorphosed rocks that have been subjected to disturbance, deformation or weathering, which allow water to move through joints, bedding planes and faults. Although fractured rock aquifers are found over a wide area, they generally contain much less groundwater than alluvial and porous sedimentary aquifers.
GDEs	Groundwater dependent ecosystems. Refers to communities of plants, animals and other organisms whose extent and life process are dependent on groundwater, such as wetlands and vegetation on coastal sand dunes.
GIS	Geographic information systems
GMP	Groundwater monitoring plan
Groundwater	Water located within an aquifer or aquitard that is held in the rocks and soil in interconnected pores or fractures located beneath the water table.

Term	Definition
Groundwater Flow System	A groundwater flow system is a model developed by hydrogeologists to describe and explain the behaviour of groundwater in response to recharge. It is similar to a conceptual model which considers the geology, hydrogeology, hydraulic properties of the landscape and the aquifer(s).
Ha	Hectares
Habitat	The place where a species, population or ecological community lives (whether permanently, periodically or occasionally).
Holocene	A geological epoch or time period that extends from the Pleistocene epoch (11,700 years before present day to the present).
HQ	Refers to the diameter of drill core in the diamond drilling technique. HQ drilling produces a 96 mm borehole and 63.5 mm diameter drill core.
Hydrocarbon	Any organic compound – gaseous, liquid or solid – consisting only of carbon and hydrogen.
Hydraulic conductivity	The rate at which water of a specified density and kinematic viscosity can move through a permeable medium (notionally equivalent to the permeability of an aquifer to fresh water).
Hydraulic gradient	The change in total groundwater head with a change in distance in a given direction, which yields a maximum rate of decrease in head.
Hydrogeology	The study of subsurface water in its geological context.
Hydrology	The study of rainfall and surface water runoff processes.
Impact	Influence or effect exerted by a project or other activity on the natural, built and community environment.
K_h	Horizontal hydraulic conductivity
K_v	Vertical hydraulic conductivity
LGA	Local government area
LiDAR	Light Detection and Ranging. A remote sensing technique that produces detailed 1 metre topographic contours used for input into the groundwater model
Local road	A council controlled road which provides for local circulation and access.
LTAAEL	Long Term Average Annual Extraction Limit as outlined in the water sharing plan
Lugeon	The lugeon (L) is a unit of measure to quantify hydraulic conductivity, generally used by geotechnical engineers in describing packer tests. 1L represents 1 x 10^{-7} m/sec (8.6 x 10^{-3} m/day in a homogeneous isotropic medium).
MAH	Monocyclic aromatic hydrocarbons
Model area	Area covered by the groundwater model as shown on Figure 3-4.
MODFLOW	A three-dimensional finite-difference groundwater model
NATA	National Association of Testing Authorities
NEPM	National Environment Protection (Assessment of site Contamination) Measure 2013
NoW	NSW Office of Water
NSW EPA	Environmental Protection Authority (NSW)
OEH	Office of Environment and Heritage
OEMP	Operational Environment Management Plan. A plan developed for the operational phase of a project to ensure that the operator complies with the environmental conditions of approval for the project and that environmental risks are properly managed.

Term	Definition
Operational water treatment plant	A treatment plant to treat groundwater for the operational phase of the project. This differs from the water treatment plants which would be temporary during the construction phase and treat captured surface water and groundwater.
Packer test	A packer test is a technique used during the drilling of a borehole to measure the hydraulic conductivity of the lithology. Inflatable packers are lowered down the borehole to isolate the depth interval to be measured.
Palaeochannel	Ancient river systems eroded deeply into the landscape and infilled with alluvial sediments. These systems often underlie modern creek or river systems but not always.
Palaeovalley	Palaeovalleys are broad ancient features that are formed by palaeochannels incising the valley through the host rock. A palaeovalley can contain numerous palaeochannels.
PASS	Potential acid sulfate soils
Perched Water	Unconfined groundwater held above the water table by a layer of impermeable rock or sediment.
PEST	Parameter Estimation
Piezometer (monitoring well)	A non-pumping monitoring well, generally of small diameter that is used to measure the elevation of the water table or potentiometric surface. A piezometer generally has a short well screen through which water can enter.
Pleistocene	A geological epoch or time period that extends from the 2,6000,000 years before present to the Holocene epoch 11,700 years before present.
Pollutant	Any matter that is not naturally present in the environment.
Project footprint	The land required to construct and operate the project. This includes permanent operational infrastructure (including the tunnels), and land required temporarily for construction.
RCH	Recharge. The process that replenishes groundwater usually by rainfall infiltration to the water table and by river water entering the saturated aquifer; the addition of water to an aquifer.
REF	Review of Environmental Factors
Revegetation	Direct seeding or planting (generally with native species) within an area in order to re-establish vegetation that was previously removed from that area.
Riparian	Relating to the banks of a natural waterway.
RIV	Rivers
Roads and Maritime	Roads and Maritime Services
Runoff	The portion of water that drains away as surface flow.
Salinity	The concentration of dissolved salts in water, usually expressed in EC units or milligrams of total dissolved solids per litre (mg/L TDS). The conversion factor between EC and mg/L is dependent on the chemical composition of the water, but a conversion factor of 0.6 mg/L TDS = 1EC unit is commonly used as an approximation.
SEARs	Secretary's Environmental Assessment Requirements
Secant pile wall	A continuous barrier wall formed by constructing intersecting reinforced concrete piles socketed into bedrock.
Sensitive receiver	A location where a person works or resides, including residential, hospitals, hotels, shopping centres, play grounds, recreational centres or similar.
Slug test	A hydraulic test conducted in a monitoring well to measure the hydraulic conductivity of the screened lithology. The test is conducted by adding or removing a slug of water and monitoring the response.

Term	Definition
Ss	Specific storage – the volume of water released from storage in a confined aquifer
SSI	State significant infrastructure
Steady state	Steady state flow conditions occur when the magnitude and direction of flow is constant across the whole model domain. Compare to transient flow conditions.
Storativity	The volume of water an aquifer releases from, or takes into storage, per unit surface area of the aquifer per unit change in head. It is equal to the product of specific storage (Ss) and aquifer thickness. In an unconfined aquifer the storativity is known as the specific yield (Sy).
Study area	The area which is included in the groundwater assessment and in which there may be groundwater interaction or potential groundwater impacts occur as a result of the project.
Surface water	Water flowing or held in streams, rivers and other wetlands in the landscape.
Sy	Specific yield – the volume of water released from storage in an unconfined aquifer unit of surface area.
Tanked structure	A tanked structure is constructed with a fully impermeable casing or membrane that reduces inflows to such an extent that for all intents and purposes are considered negligible.
Transient conditions	During transient flow conditions the magnitude and direction of flow change with time in accordance with impacts imposed within the model domain.
TRH	Total recoverable hydrocarbons
Tributary	A river or stream flowing into a larger river or lake.
Trough structure	A construction technique at the transition from the portal to the tunnel, commonly constructed in poor ground conditions such as alluvium or weathered bedrock. The trough structure is a rectangular shape with no surface covering.
Tunnel portal	The entrance/exit to the tunnel.
Vadose zone	Within an aquifer the vadose zone is the unsaturated zone between the water table and ground surface.
Vulnerable	As defined under the Threatened Species Conservation Act 1995 (NSW), a species that is facing a high risk of extinction in NSW in the medium-term future.
VWP	Vibrating wire piezometers
WAL	Water access license
Water table	The surface of saturation in an unconfined aquifer at which the pressure of the water is equal to that of the atmosphere.
Waterway	Any flowing stream of water, whether naturally or artificially regulated (not necessarily permanent).
WM Act	Water Management Act 2000 (NSW)

Executive summary

Project overview

NSW Roads and Maritime Services (Roads and Maritime) is seeking approval to construct and operate the F6 Extension Stage 1 from New M5 Motorway at Arncliffe to President Avenue at Kogarah) (the project), which would comprise a new multi-lane road between the New M5 Motorway at Arncliffe and President Avenue at Kogarah and would connect underground with the New M5 Motorway tunnel and to a new surface level intersection at President Avenue, Kogarah. It will connect St George, Sutherland Shire and Illawarra regions to the Sydney motorway network.

Approval is being sought under Part 5, Division 5.2 of the *Environmental Planning and Assess ment Act 1979* (NSW) (EP&A Act) for the project. A request has been made for the NSW Minister for Planning to specifically declare the project to be State significant infrastructure and also critical State significant infrastructure. An environmental impact statement (EIS) is therefore required.

This groundwater impact assessment forms part of the EIS for the project and has been prepared in accordance with NSW water policy under the *Water Management Act 2000* (NSW), administering water policy under the *Aquifer Interference Policy 2012* (AIP) (NSW Office of Water (NoW) 2012) and the *Greater Metropolitan Region Groundwater Source Water Sharing Plan* (NoW 2011). This groundwater impact assessment has been prepared to meet the NSW Department of Planning and Environment Secretary's Environmental Assessment Requirements (SEARs) issued on 23 January. The impact assessment has also considered comments made by government agencies and addresses potential groundwater impacts during the construction and long term operational phases.

The project would include the following primary components (as related to the groundwater assessment):

- An underground connection to the existing stub tunnels at the New M5 Motorway at Arncliffe
- Twin motorway tunnels (around three kilometres in length) between the New M5 Motorway at Arncliffe and President Avenue, Kogarah
- An intersection at President Avenue, including:
  - On and off ramps, including sections of tunnel to provide connections to the mainline tunnel
  - A tunnel portal at Brighton-Le-Sands within Rockdale Bicentennial Park East, to provide connections to President Avenue
- A widened President Avenue at the location of the intersection, including slip lanes to provide a connection to the project
- Intersection improvements at the President Avenue / Princes Highway intersection
- Mainline tunnel stubs to allow for connections to future stages of the F6 Extension
- Shared cycle and pedestrian pathways connecting Bestic Street to Civic Avenue, Kogarah via Rockdale Bicentennial Park
- Operational Motorway Control Centre to be located off West Botany Street, Rockdale
- Ancillary infrastructure and operational facilities for signage (including electronic signage), ventilation structures and systems at Rockdale, fire and safety systems, emergency evacuation and smoke extraction infrastructure and an operational water treatment facility
- Temporary construction and ancillary facilities and temporary works to facilitate the construction of the project.

The tunnels are to be constructed to depths up to 100 metres below the ground surface with the deepest tunnel sections being where the project meets the New M5 Motorway tunnel stubs at Arncliffe. Tunnelling is expected to commence in 2020 and be completed by 2024. The majority of the tunnels are to be constructed below the water table predominately within the Hawkesbury Sandstone but also within the alluvium and Botany Sands.

The majority of the tunnels are to be constructed as drained tunnels to allow groundwater to passively drain into the tunnel from the sandstone.

During construction, groundwater is to be directed into temporary detention ponds and treated at water treatment plants located at construction compounds, prior to discharge through the Rockdale wetlands and the Cooks River. During long term operation of the project, groundwater is to be directed to the Arncliffe water treatment plant which is to be discharged into the Cooks River. Undrained or tanked tunnel sections are to be constructed where the tunnel intersects unconsolidated saturated alluvium where sediments of the Cooks River palaeochannel are intersected.

The project is designed to achieve a maximum inflow of one litre per second per kilometre for any kilometre length of tunnel, with the exception of the tunnel sections of the Rockdale access decline which have a maximum inflow of two litres per second per kilometre for any kilometre of tunnel. To achieve this design criterion, waterproofing may be required in parts of the tunnels to reduce the bulk rock permeability. As such, the approach to the control of water inflow into the tunnel is proposed to consist of a suite of options, ranging from areas where no waterproofing would be required to areas where a waterproof membrane may need to be applied combined with shotcrete or pressure grouting applied to undrained or tanked sections of tunnel. Waterproofing options would be explored further during the detailed design phase.

Methodology

A desktop study was undertaken to describe the existing environment and characterise the geology and hydrogeology. In addition, other relevant environmental features including the existing infrastructure, rainfall and climate, physiography and surface water features were described. A combined hydrogeological and geotechnical field investigation was undertaken which included the excavation of geotechnical boreholes and the construction of monitoring wells. During the drilling program, packer tests were conducted at multiple depth intervals to assess the hydraulic conductivity of the lithologies intersected. Groundwater monitoring data has been collated from previous investigations commencing in 2015, to monitor groundwater levels and groundwater quality. This data has been combined with monitoring data collected during the current investigation to characterise the hydrogeology within the alluvium, including palaeochannel sediments and Hawkesbury Sandstone.

The hydraulic parameters identified within the field investigation and from desktop investigations were used to support the development of a three dimensional numerical groundwater model. The model domain extends over an area of approximately 7.5 x 12 square kilometres, which has been selected to include the geological and hydrogeological features that are considered important to assess potential groundwater impacts relating to the project. The MODFLOW model was developed in accordance with the Australian Modelling Guidelines (Barnett *et al.,* 2012). The model was calibrated in steady state and transient modes to simulate the existing conditions and predict impacts during the construction and operations phases. The model was also used to predict cumulative impacts with the adjacent WestConnex projects. The following three scenarios were modelled:

- Scenario 1: A 'Null' run (as per Barnett *et al.,* 2012) without the F6 Extension or the WestConnex projects but including the existing drained M5 East tunnels
- Scenario 2: The 'Null' run in Scenario 1, plus the approved WestConnex tunnel projects (M4 East, New M5 Motorway and M4-M5 Link)
- Scenario 3: A run as for Scenario 2 plus the project.

Existing environment and design considerations

The existing groundwater environment and relevant elements of the project design are as follows:

- Groundwater along the project footprint is present within the fill, alluvium (including palaeochannel sediments) and Hawkesbury Sandstone. The Ashfield Shale is not expected to be intersected by the project tunnels but it outcrops to the east and north, within the model domain
- The majority of the tunnels are to be constructed within the competent Hawkesbury Sandstone, and below the water table

- The tunnels would be constructed as drained tunnels (unlined) with a design criterion of a maximum of one litre per second per kilometre for any kilometre length of tunnel of on-going 'drainage' water into each tunnel during operations. The exception to this is the Rockdale access decline tunnel where the design criterion is two litres per second per kilometre for any kilometre length of this tunnel. The tunnels have been designed to minimise the intersection with palaeochannels by diving beneath Spring Street Drain and tanking the tunnel as it emerges through the alluvium at the President Avenue Ramps. Appropriate waterproofing measures would be implemented during construction to permanently reduce the inflow into the tunnels to an acceptable inflow to meet the design criterion. This may include the installation of shotcrete, grouting or the installation of a sheet membrane, for example. Strip drains or similar would be installed behind wall panels to assist in dissipating groundwater
- Undrained (tanked) tunnel sections are to be constructed where the tunnels intersect unconsolidated saturated alluvium as the tunnels emerge at the surface at the President Avenue ramps
- During construction of dive structures and shafts, groundwater flow within unconsolidated sediments, fill, alluvium and weathered sandstone would be restricted by the construction of retaining walls such as secant pile or diaphragm walls founded in good quality Hawkesbury Sandstone
- A review of existing drained tunnels in Sydney (Eastern Distributor, M5 East Motorway, Epping to Chatswood rail line, Lane Cove Tunnel and Northside Storage tunnel) excavated predominately within the Hawkesbury Sandstone showed that tunnel inflows range from 0.6 to 1.7 litre per second per kilometre. At the adjoining New M5 Motorway project, groundwater modelling predicted an average inflow rate over the full tunnel length of 0.63 litre per second along every kilometre of eastbound tunnel and 0.67 litre per second along every kilometre of the westbound tunnel.

Construction impacts

- The findings of the groundwater impact assessment during the construction phase of the project are as follows: There is likely to be a temporary reduction in groundwater recharge during construction although these impacts are considered minor
- Groundwater inflow from the Hawkesbury Sandstone is expected to be highest during construction. Groundwater modelling has predicted groundwater inflows to the tunnels (after grouting) and access declines during construction to range between 0.14 megalitres per day (51.1 ML/yr) in 2021 and 0.55 megalitres per day (200 ML/yr) in 2023 as predicted in the groundwater modelling construction phase
- Groundwater extraction via dewatering from the Botany Sands alluvium would be required during the construction of the cut-off walls for the President Avenue ramps. Extracted groundwater from the Botany Sands would be directed into a pre-treatment basin, treated in the construction water treatment plant and discharged into the stormwater network as outlined in the **Appendix L** (Surface water technical report) in the EIS.
- The predicted maximum annual water take from the Greater Metropolitan Regional groundwater resource during construction of the project is 248 ML/year (Year 2023). Of this extraction, 76.7 ML is due to extraction from the Botany Sands aquifer. Comparison of predicted tunnel inflows indicates that the reduction in the groundwater availability within the Botany Sands during construction of the project is predicted to be reduced by 0.52 per cent of the Long Term Average Annual Extraction Limit (LTAAEL). Similarly the predicted reduction in the groundwater availability will be reduced by 171 ML/year or 0.37 per cent of the LTAAEL for the Sydney Basin Central groundwater resource during construction of the project
- Groundwater modelling has predicted that at the end of construction, the maximum drawdown within the alluvium is at Spring Street Drain and this drawdown is estimated to be two metres. Similarly the maximum drawdown in the sandstone at the end of construction is predicted to be a lowering of groundwater levels by 24 metres at Arncliffe, where the tunnels are deepest
- Groundwater quality is unlikely to be substantially impacted during construction unless there are accidents or spills or contaminated groundwater is intersected. Mitigation measures have been identified and will be instigated in the unlikely event these occurrences take place.

Construction mitigation measures

- Throughout the construction phase of the project, water would be managed and monitored under a Construction Environmental Management Plan (CEMP) developed by the construction contractor. Performance outcomes and commitments will be managed under the CEMP and sub-plans with corresponding procedures. The CEMP would be a 'live' document with the capacity to be updated if conditions are different from those expected. As part of the CEMP, a Construction Soil and Water Management Plan would be developed that addresses:
  - Groundwater management including monitoring
  - Surface water management including monitoring
  - Acid sulfate soils
- Groundwater monitoring indicates that inflows to the tunnels are likely to be of poor quality due to elevated natural salinity and elevated background metal concentrations. Tunnel inflow water would also have a high turbidity and pH due to the influence of tunnel grouting and would require treatment prior to discharge. Tunnel inflow water captured during construction, would be tested and treated at construction water treatment plants prior to reuse or discharge, or disposal offsite as required
- During construction, fuels, oils and wastes would be managed in appropriate bunded areas and managed under spill prevention protocols and response procedures.

Operational impacts

The findings of the groundwater impact assessment during the operations phase of the project are as follows:

- After the commencement of operations in 2025 the estimated long term inflows into the motorway tunnels are predicted to be 222 megalitres per year, declining to 216 megalitres per year at the end of the model simulation in 2100
- The drawdown for the project within the Hawkesbury Sandstone would be elongated along the alignment, extending approximately 350 metres from the alignment. Drawdown within the Botany Sands is centred on Spring Street Drain and Muddy Creek with a maximum predicted drawdown of 5.3 metres. The drawdown extent to the 2.0 metre drawdown contour extends approximately 200 metres either side of the drain
- Construction of drained tunnels beneath the water table is expected to cause long term ongoing groundwater inflow to the tunnels, inducing groundwater drawdown along the project footprint during its operation
- The Botany Sands are to be intersected by the tunnels, but the tunnels would be undrained (tanked) along these sections of tunnels to minimise groundwater ingress. Although there will be no direct alluvial groundwater extracted from the Botany Sands, there would be indirect groundwater inflow from the hydraulic connection with the Hawkesbury Sandstone. Groundwater modelling indicates that the drawdown propagation into the Botany Sands would be at a maximum at the Spring Street Drain, drawing down 5.3 metres. Elsewhere, the drawdown within the Botany Sands is minimal with a predicted drawdown of 0.6 metres over the access decline at Rockdale
- No priority GDEs are likely to be substantially impacted by groundwater level decline associated with the long term impacts of the project
- Five non-monitoring bores are predicted to be impacted by a long term drawdown in excess of two metres that is directly attributable to the project
- 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 beneath the shoreline tidal water courses with more saline water. Saline intrusion from Botany Bay is not expected to occur, as the hydraulic gradient on the shoreline would be maintained.

Operational mitigation measures

Throughout the operational phase of the project, water would be managed and monitored under an Operational Environmental and Management Plan (OEMP) or Environmental Management System

(EMS). Performance outcomes and commitments would be managed by an OEMP and sub-plans or through an EMS with corresponding procedures. The OEMP or EMP would be a 'live' document with the capacity to be updated if conditions are different from those expected. As part of the OEMP, plans and protocols would be developed for:

- Groundwater management and monitoring
- Surface water management and monitoring
- Drainage system maintenance to remove build-up of precipitated iron (slimes), silt and sand due to slaking of the sandstone.

Potential mitigation measures identified for the operations phase are as follows:

- Tunnel inflows during operation are to be directed towards a water treatment plant at Arncliffe. The tunnel operation water treatment facilities would be designed such that effluent would be of suitable quality for discharge to the receiving environment
- Tunnel drainage systems could become blocked due to the precipitation of naturally high iron concentrations within the groundwater. The tunnel drainage system would be regularly maintained in accordance with the protocols outlined in the OEMP to remove build-ups of precipitated iron (slimes) and silt and sand due to slaking of the sandstone
- The groundwater aggressivity assessment indicates that some of the groundwater to be intersected is corrosive towards concrete and steel. A more detailed aggressivity assessment should be undertaken during detailed design 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, building on the dataset collected in this assessment
- The groundwater is corrosive due to naturally low pH and elevated concentrations of sulfate and chloride. Corrosion and other associated impacts of highly aggressive groundwater on the tunnel infrastructure would be monitored during regular routine inspections as outlined in the OEMP
- Groundwater drawdown may induce ground settlement with the potential to impact existing buildings or infrastructure. Localised settlement modelling including detailed calculated drawdown is recommended to be conducted as part of detailed design. Prior to the commencement of tunnelling, dilapidation assessments should be undertaken on buildings and structures that have been identified as potentially being adversely impacted by settlement due to tunnelling. Should excessive settlement that has the potential to impact on structures be predicted, then different construction techniques or ground preparation works could be explored to minimise settlement. Settlement monitoring would be undertaken in accordance with the protocols developed in the OEMP and may include the installation of settlement markers or inclinometers. The OEMP would also identify structures that could be impacted by settlement and set settlement trigger levels
- As with construction, settlement monitoring would be undertaken during operation at properties and infrastructure where exceedances of the settlement criteria are predicted
- In principle, groundwater drawdown induced by tunnel drainage could impact groundwater-dependent ecological communities, if present. A review of the Greater Metropolitan Water Sharing Plan within five kilometres of the project footprint did not identify any priority groundwater dependent ecosystems. Consequently, no priority groundwater dependent ecosystems (GDEs) are likely to be impacted by groundwater level decline associated with the long term impacts of the project
- A review of the DI-Water groundwater database within a two kilometre radius of the tunnel footprint identified 360 registered boreholes for water supply or irrigation. The majority of these are shallow spearpoints extracting water from the Botany Sands for domestic use. Groundwater modelling predicts that only five of these registered bores would be drawn down in excess of two metres due to tunnel induced inflows. In accordance with the AIP, if the performance of these bores were adversely affected, measures would be taken to 'make good' the impact by restoring the water supply to pre-development levels. The measures taken in this case could include, lowering the pump in the borehole, drilling a replacement bore or providing an alternative water supply
- Groundwater baseflow to creeks represents the occasions when groundwater reaches the ground surface and enters the drainage system. It is predicted that long term baseflow will be reduced by up to about 20 and 40 per cent in Muddy Creek and Spring Street Drain respectively due to the

project. Although the baseflow component in these drainage systems would be substantially reduced, the overall reduction in river flow is small because baseflow only represents a small percentage of total stream flow in these two systems. There is no predicted impact on the baseflow of other major creeks due to the project including Cooks River, Wolli Creek and Bardwell Creek

- Long term drawdown (2100) within the Hawkesbury Sandstone due to the project is predicted to be up to 33 metres at Arncliffe where the tunnel is deepest. The project drawdown extent within the Hawkesbury Sandstone is elongated along the alignment extending approximately 350 metres from the alignment
- At the Spring Street Drain, groundwater monitoring indicates that there is hydraulic connection between the Hawkesbury Sandstone and the alluvium. The groundwater model predicts that as a result there will be drawdown in the palaeochannel. Drawdown in the palaeochannel sediments would in part be balanced by increased rainfall recharge and stormwater recharge in the wetlands to be constructed. Drawdown within the alluvium could induce settlement, potentially impacting existing and future infrastructure in those areas. Detailed localized settlement analysis is to be conducted during the detailed design phase
- The groundwater and surface water quality monitoring program would continue throughout the construction phase and continue for at least three years after the completion of construction or as directed by the conditions of consent to be issued by DPE. The program shall be developed by the contractors in consultation with the NSW Environment Protection Authority (NSW EPA), NSW Department of Primary Industries – Fisheries (DPI-Fisheries), DI-Water and Bayside Council. Monitoring locations from the existing groundwater and surface water monitoring networks would form the basis of this monitoring program.

Cumulative impact mitigation measures

Cumulative impacts are those that act together with other impacts to affect the same resources or receptors in a way where the sum of the impacts is greater than the individual. The groundwater model was designed to predict cumulative impacts for the existing WestConnex projects and the project during the construction and operation phases. Mitigation and management measures have been developed to reduce cumulative impacts as follows:

- Cumulative groundwater impacts due to drawdown caused by the WestConnex tunnel projects (M4 East, New M5 Motorway and M4-M5 Link) and the project are predicted to be minimal. Monitoring of groundwater levels, quality and tunnel inflows would be undertaken quarterly throughout the construction programs in accordance with the CEMPs for each project
- The long term cumulative groundwater drawdown or groundwater inflows due to the WestConnex tunnel projects are minimal as the tunnel projects do not overlap, however as they are adjoining, the total impacts are similar to those of a continuous tunnel. The project tunnels are to be constructed to comply with a maximum design inflow criterion of one litre per second per kilometre for any kilometre length of tunnel. Groundwater monitoring would be conducted in accordance with the OEMP to monitor the groundwater drawdown, inflows and settlement triggering mitigation measures to be implemented as required. In the event of groundwater inflows above the design criterion, mitigation measures to be considered would include reducing the rock mass permeability by, post construction grouting in key areas of the project tunnels
- Long term cumulative groundwater tunnel inflows due to the cumulative impacts of the WestConnex tunnels and the project may cause groundwater salinity to increase, due to surface water from tidal reaches being drawn towards the tunnels. Over tens or hundreds of years, saline water may enter the tunnels initially as a small fraction of total tunnel inflow. This is expected to increase over time as water is drawn from further afield, although it will always be a minor component of total groundwater inflow and would only occur in a timeframe beyond the design life of the tunnels

- Cumulative impacts with future and current tunnel projects have been considered, including Sydney Metro City and Southwest and the future Western Harbour Tunnel and Beaches Link. These tunnels are located north of the project study area adjoining the M4-M5 Link WestConnex tunnels and consequently are not likely to cause cumulative impacts with the project. The proposed future Sydney Gateway project has not been included in the groundwater cumulative impact assessment because the updated road infrastructure is to be constructed along the ground surface and is unlikely to substantially impact groundwater.

1 Introduction

The project would comprise a new multi-lane road link between the New M5 Motorway tunnel underground at Arncliffe and an intersection at President Avenue at Kogarah.

1.1 Overview of the project

Key components of the project would include:

- An underground connection to the existing stub tunnels at the New M5 Motorway at Arncliffe
- Twin motorway tunnels (around four kilometres in length) between the New M5 Motorway at Arncliffe and President Avenue, Kogarah
- A tunnel portal and entry and exit ramps connecting the tunnels to a surface intersection with President Avenue
- Intersection improvements at the President Avenue / Princes Highway intersection
- Mainline tunnel stubs to allow for connections to future stages of the F6 Extension
- Shared pedestrian and cycle pathways connecting Bestic Street, Rockdale to Civic Avenue, Kogarah via Rockdale Bicentennial Park (including an on-road cycleway)
- An Operational Motorway Control Centre to be located off West Botany Street, Rockdale
- Ancillary infrastructure and operational facilities for signage (including electronic signage), ventilation structures and systems at Rockdale, fire and safety systems, and emergency evacuation and smoke extraction infrastructure
- A proposed permanent power supply connection from the Ausgrid Canterbury subtransmission substation
- Temporary construction ancillary facilities and temporary works to facilitate the construction of the project.

Once complete, the F6 Extension Stage 1 would improve connections and travel times between Sydney and the Princes Highway and enhance connections for residents and businesses within the broader regional area as well as promote and support economic development in areas to the south, such as Sutherland and the Illawarra.

Approval for the project is being sought under Part 5, Division 5.2 of the EP&A Act. Future stages of the F6 Extension would be subject to separate planning applications and assessments would be undertaken accordingly.

The configuration and design of the project will be further developed to take into consideration the outcomes of community and stakeholder engagement.

1.2 Project location

This project would be generally located within the Bayside local government area. The project commences about 8 kilometres south west of the Sydney central business district (CBD). The proposed President Avenue intersection would be located about 11 kilometres south east of the Sydney CBD.

1.3 Purpose of this report

This report has been prepared to address the Secretary's Environmental Assessment Requirements (SEARs) in relation to groundwater. This report defines the hydrogeological conditions for the project and has been prepared to support the Environmental Impact Assessment (EIS). The report is based on published information and from site investigation information gathered by Roads and Maritime Services (Roads and Maritime).

The purpose of this groundwater assessment report is to:

- Meet the requirements of the Secretary's Environmental Assessment Requirements (SEARs) and the *Aquifer Interference Policy 2012* (AIP) (NSW Office of Water (NoW) 2012)
- Establish baseline conditions to inform the EIS and to assist with the development of mitigation measures
- Provide baseline conditions for input into the groundwater model
- Establish baseline conditions for comparison with water quality and water level conditions during the construction and operational phases, including identification of areas of potential groundwater contamination
- Characterise groundwater quality and identify potential aggressive groundwater to inform the development of the concept design for the project
- Assess the potential groundwater impacts during construction and operational phases
- Assess the potential cumulative impacts on the hydrogeological regime due to the project and other relevant projects
- Develop mitigation measures to eliminate or manage the potential impacts of the project on the hydrogeological regime during construction and operational phases.

1.4 SEARs and Agency comments

The NSW Department of Planning and Environment (DPE) issued SEARs for the project on 23 January 2018. The SEARs relating to hydrogeological impacts, and where these requirements have been addressed in this report, are listed in **Table 1-1**. Details of hydrogeological comments outlined in agency letters received and where these requirements have been addressed in this report are summarised in **Table 1-2**. Ongoing consultation with NSW Department of Primary Industries – Water (DPI-Water) has being undertaken during the preparation of this report and will continue as the design progresses.

Table 1-1 How SEARs have been addressed in this report

Desired Performance Outcome	Key Issue SEARs	Where addressed in this EIS
2. Environmental Impact Statement		
The project is described in sufficient detail to enable clear understanding that the project has been developed through an iterative process of impact identification and assessment and project refinement to avoid, minimise or offset impacts so that the project, on balance, has the least adverse environmental, social and economic impact, including its cumulative impacts.	The Proponent must consider the interactions between mitigation measures, between impacts and between measures and impacts. The Proponent must identify other environmental impacts (such as impacts on wetlands and passive and active recreation areas, visual amenity, sedimentation and erosion and surface and groundwater quality and flows) and proposed measures for managing and/or mitigating the level of impact. The proponent must conduct an assessment of the cumulative impacts of the project taking into account other projects that have been approved but where construction has not commenced, projects that have commenced construction, and projects that have recently been completed.	Mitigation measures are outlined in section 8 along with construction impacts in section 5, operational impacts in section 6 and Cumulative impacts from other projects in section 7. Wetlands are discussed in sections 4.4.3, 4.4.4, 5.4.1 and 6.3.3. Groundwater quality is discussed in sections 4.11, 5.5 and 6.5. Groundwater flows are discussed in sections 5.2 and 6.2. Cumulative impacts are discussed in section 7.
9. Water - Hydrology		
Long term impacts on surface water and groundwater hydrology (including drawdown, flow rates and volumes) are minimised.	1. The Proponent must describe (and map) the existing hydrological regime for any surface and groundwater resource (including reliance by users e.g. bore water for domestic use and irrigation, and for ecological purposes and groundwater dependent ecosystems) likely to be impacted by the project, including rivers, streams, wetlands and estuaries as described in Appendix 2 of the Framework for Biodiversity Assessment – NSW Biodiversity Offsets Policy for Major Projects (OEH, 2014).	The existing hydrogeological environment and resources are described in section 4.4 and 4.8. The surface water and resources and biodiversity are described in Appendix L (Surface water technical report) and Appendix H (Biodiversity development assessment report) of the EIS.
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).	2. The Proponent must prepare a detailed water balance for ground and surface water including the proposed intake and discharge locations (including mapping of these locations), volume, frequency and duration for both the construction and operational phases of the project.	The groundwater balance is outlined in section 5.8.1 for Construction and section 6.9 for Operation. The surface water balance is outlined in Appendix L (Surface water technical report) of the EIS.
Sustainable use of water resources.	3. The Proponent must assess and model the impact of the construction and operation of the project and any ancillary facilities (both built elements and discharges) on surface and groundwater hydrology in accordance with the current guidelines, including: (a) natural processes within rivers, wetlands, estuaries, and floodplains that affect the health of the fluvial, riparian, estuarine systems and landscape health (such as modified discharge volumes, durations and velocities), aquatic connectivity, water dependent fauna and flora and access to habitat for spawning and refuge;	Potential impacts on groundwater hydrology from ancillary facilities are assessed in **section 5.6** and **section 6.6.** Potential impacts to surface water hydrology are assessed in Chapter 12 (Biodiversity) and Chapter 18 (Surface water and flooding)

Desired Performance Outcome	Key Issue SEARs	Where addressed in this EIS
	(b) impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, change in ground water levels, barriers to flows, implications for groundwater dependent on surface flows, ecosystems and species, groundwater users and the potential for settlement	Temporary or permanent interruption to groundwater flow is described in section 6.7. The extent of groundwater drawdown and groundwater levels is discussed in sections 5.3, 5.4 and 6.3. Surface flows are described in sections 5.4.2 and 6.3.5. GDEs are discussed in sections 4.4.4, 5.4.1 and 6.3.3. Groundwater users are discussed in sections 4.12, 5.4.3 and 6.3.4. Settlement is discussed in section 6.4 and Chapter 14 of the EIS.
	(c) changes to environmental water availability and flows;	Changes to baseflow are assessed in section 5.4.2 and section 6.3.5.
	(f) measures to mitigate the impacts of the proposal and manage the disposal of produced and incidental water	Groundwater take has been modelled (Annexure F) for the construction and operational phases and is discussed in Sections 5 and 6. The groundwater take in relation to the LTAAEL is discussed in sections 4.12.1, 5.2.2 and 6.2. Surface water take is outlined in Appendix L of the EIS.
	5. The Proponent must identify any requirements for baseline monitoring of hydrological attributes	Groundwater baseline monitoring is outlined in sections 4.9, 4.10 and 4.11.
	6. The assessment must include details of proposed surface and groundwater monitoring	Proposed groundwater monitoring is outlined in sections 4.9, 5.5.7 and 6.5.5. Surface water monitoring is outlined in Appendix L (Surface water technical report) of the EIS.
	7. Proposed tunnels must be design to minimise impacts on aquifers, groundwater flows and groundwater dependent ecosystems	Tunnel design relating to minimising impacts is discussed in section 6.3.1.

Desired Performance Outcome	Key Issue SEARs	Where addressed in this EIS
10. Water - Quality		
The project is designed, constructed and operated to protect the NSW Water Quality Objectives where they are currently being achieved, and contribute towards achievement of the Water Quality Objectives over time where they are currently not being achieved, including downstream of the project to the extent of the project impact including estuarine and marine waters (if applicable).	1. The Proponent must: (a) describe the background conditions for any surface or groundwater resource likely to be affected by the development	The existing groundwater conditions are described in section 4
	(j) identify proposed monitoring locations	Proposed groundwater monitoring is outlined in sections 4.9, 5.5.7 and 6.5.5. Surface water monitoring is outlined in Appendix L (Surface water technical report) of the EIS.
13. Soils		
The environmental values of land, including soils, subsoils and landforms, are protected.	5. The Proponent must assess whether salinity is likely to be an issue and if so, determine the presence, extent and severity of soil salinity within the project area	An assessment of the likelihood of salinity and associated impacts is included in sections 4.5, 5.5.5 and 6.5.3.
	6. The Proponent must assess the impacts of the project on soil salinity and how it may affect groundwater resources, hydrology and vegetation	An assessment of the impacts of the project on soil salinity and how it may affect groundwater resources and hydrology is provided in section 5.5.5. The impacts on vegetation is discussed in Appendix H (Biodiversity Development Assessment Report) of the EIS.
Risks arising from the disturbance and excavation of land and disposal of soil are minimised, including site contamination.	8. The Proponent must assess the impact of any disturbance of contaminated groundwater and the tunnels should be carefully designed so as to not exacerbate mobilisation of contaminated groundwater and/or prevent contaminated groundwater flow	An assessment of the potential for the tunnels to intercept contaminated groundwater is included in sections4.16, 5.5.2 and 6.5.1. Risks associated with disturbing acid sulphate soils are described in sections 4.6 and 0.

Table 1-2 How agency comments have been addressed in this report

Comment	Where addressed in this report
NSW Office of Heritage Council	
2d consider impacts to the item of significance caused by, but not limited to, vibration, demolition, archaeological disturbance, altered historical arrangements and access, increased traffic, visual amenity, landscape and vistas, curtilage, subsidence, hydrological changes and architectural noise treatment (as relevant) and includes measures to mitigate impacts;	Potential hydrological changes are discussed in sections 5.1 and 6.1 (reduced groundwater recharge), 5.3 and 6.3 (predicted groundwater decline) 5.4 and 6.3 (groundwater level drawdown), 5.5 and 6.5 (groundwater quality), 6.4 (ground settlement) and 6.8 impacts to the final landform.
5 impacts to the Kings Wetland and Patmore Swamp should be assessed with appropriate mitigation measures recommended to minimise impacts associated with reduced and modified flows during and after construction.	Potential impacts to wetlands are discussed in sections 5.4.1 and 6.3.3. Mitigation measures are discussed in section 8.
NSW Office of Environment and Heritage Comment	
The Rockdale Wetlands and Recreation Corridor including the Eve Street Wetlands, Spring Street Wetland, Landing Lights Wetland, Scarborough Ponds and Scott Park Wetland have a high conservation value. The Landing Lights Wetland contains some of the last remaining saline wetlands on the Cooks River, including Coastal Saltmarsh. While the Landing Lights and Spring Street Wetlands have declined over a number of years that represent an important resource for native fauna and migratory species.	Potential impacts to wetlands are discussed in sections 5.4.1 and 6.3.3.
NSW Ministry of Health Comment	
The Document (DPE, 2017) identifies that there are 'a substantial number of groundwater bores in close proximity to the project corridor.' and has identified 35 for household water supply (washing and toilets), fifteen fore community water supply, two for water supply for irrigated agriculture and two for water supply and recreation purposes. With the potential for considerable unknown bores and for contaminated groundwater during construction, this issue should be considered for its potential human health impact and discussed in the Human Health Risk Assessment. It will also require a community communication strategy to minimise health impacts.	Potential groundwater contamination is discussed in sections 4.16, 5.5.2 and 6.5.1. Groundwater users are discussed in sections 4.12, 5.4.3 and 6.3.4. A human health risk assessment is included in Appendix F (Human Health Technical Report) of the EIS.
Crown Lands and Water	
9. Water Hydrology	
2. The Proponent must provide full technical details and data of all surface and groundwater conceptual models and detailed quantitative modelling.	The groundwater conceptual model is outlined in section 4 and specifically in section 4.14. The surface water conceptual model is outlined in Appendix L (Surface water technical report) of the EIS.
3. The Proponent must prepare a detailed water balance for ground and surface water including the proposed intake and discharge locations (including mapping of these locations), volume frequency and duration for both the construction and operational phases of the project, and identify an adequate and secure water supply for the life of the project.	The water balance is outlined in sections 5.8.1 and 6.9. Discharge locations are outlined and discussed in Appendix L (Surface water technical report) of the EIS. The water take and impacts in relation to the LTAAEL are discussed in sections 4.12.1, 5.2.2 and 6.2.

Comment	Where addressed in this report
NSW Office of Heritage Council	
The Proponent must assess 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: (b) impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, change in groundwater levels, barriers to flows, implications for groundwater dependence on surface flows, ecosystems and species, groundwater users and the potential for settlement. Impacts should be determined using a detailed groundwater model based on adequate baseline data (12 months minimum) and aquifer investigation including pump testing in high yield areas and packer testing, and monitoring across the entire F6 extension corridor.	The following potential impacts are discussed as follows: Sections 5.6 and 6.6 Ancillary infrastructure and facilities Section 5.7 Utility adjustments Section 6.7 interruption to groundwater flow Sections 5.4 and 6.3 extent of groundwater drawdown Sections 4.4.3, 4.4.4, 5.4.1 and 6.3.3 groundwater dependence Sections 4.12, 5.4.3 and 6.3.4 Groundwater users Annexure F Groundwater Modelling Report Section 4.13.4 packer testing and test pumping Section 4.9, 4.10, 4.11, 5.5.7 and 6.5.5 baseline data monitoring
7. The assessment must include details of proposed surface and groundwater monitoring for the life of the project, including a minimum of 12 months baseline monitoring. Long term monitoring bores should be located to allow ongoing monitoring following completion of construction.	Proposed groundwater monitoring is described in sections 5.5.7 and 6.5.5. Proposed surface water monitoring is discussed in Appendix L (Surface water technical report) of the EIS.
8. The proposed tunnels must be designed to prevent impacts on aquifers and minimise impacts on groundwater flows and groundwater dependent ecosystems, including appropriate measures to ensure groundwater inflows do not exceed the one litre per second per kilometre for any kilometre length of tunnel.	The following items relating to tunnel inflows are discussed in the following sections: Section 2.1 tunnel design criteria Sections 5.2 and 6.2 predicted tunnel inflows Sections 4.4.3, 4.4.4, 5.4.1 and 6.3.3 groundwater dependence Section 6.2.4 management of inflows.

1.5 Structure of this report

This report is structured as follows:

- **Chapter 1** – **Introduction**
- **Chapter 2** – **The project** describes the project features, construction activities and geological features that relate to groundwater
- **Chapter 3** – **Assessment methodology** describes the methodology undertaken for the impact assessment
- **Chapter 4** – **Existing environment** describes the existing environment (natural and built) prior to project commencement
- **Chapter 5** – **Assessment of construction impacts** describes the potential impacts on groundwater inflow, groundwater drawdown and groundwater quality resulting from the project, during the construction phase

- **Chapter 6** – **Assessment of operational impacts** describes the potential impacts on groundwater inflow, groundwater drawdown and groundwater quality resulting from the project, during the ongoing operations phase
- **Chapter 7** – **Assessment of cumulative impacts** describes the cumulative groundwater impacts due to existing infrastructure that impact groundwater and the project
- **Chapter 8** – **Management of impacts** provides a summary of environmental safeguards, mitigation measures, management and monitoring responsibilities in relation to groundwater impacts for the project
- **Chapter 9** – **Policy compliance** describes how the project complies with the *NSW Aquifer Interference Policy* and the Water Sharing Plan
- **Chapter 10** – **Conclusions** summarises the outcomes of the groundwater impact assessment
- **Chapter 11** – **References**.

2 The Project

2.1 Project features

The project would comprise a new multi-lane underground road link between the New M5 Motorway and a surface intersection at President Avenue, Kogarah.

Key components of the project would include:

- Twin mainline tunnels. Each mainline tunnel would be around 2.5 kilometres in length, sized for three lanes of traffic, and line marked for two lanes as part of the project
- A tunnel-to-tunnel connection to the New M5 Motorway southern extension stub tunnels, including line marking of the New M5 Motorway tunnels from St Peters interchange to the New M5 Motorway stub-tunnels
- Entry and exit ramp tunnels about 1.5 kilometres long (making the tunnel four kilometres in length overall) and a tunnel portal connecting the mainline tunnels to the President Avenue intersection
- An intersection with President Avenue including entry and exit ramps and the widening and raising of President Avenue
- Upgrade of the President Avenue / Princes Highway intersection to improve intersection capacity
- Shared cycle and pedestrian pathways connecting Bestic Street, Brighton-Le-Sands to Civic Avenue, Kogarah (including an on-road cycleways)
- Three motorway operation complexes:
  - Arncliffe, including a water treatment plant, substation and fitout (mechanical and electrical) of a ventilation facility currently being constructed as part of the New M5 Motorway project
  - Rockdale (north), including a motorway control centre, deluge tanks, a workshop and an office
  - Rockdale (south), including a ventilation facility, substation and power supply.
- Reinstatement of Rockdale Bicentennial Park and recreational facilities
- In-tunnel ventilation systems including jet fans and ventilation ducts connecting to the ventilation facilities
- Drainage infrastructure to collect surface water and groundwater inflows for treatment
- Ancillary infrastructure for electronic tolling, traffic control and signage (both static and electronic signage)
- Emergency access and evacuation facilities (including pedestrian and vehicular cross and long passages); and fire and life safety systems
- New service utilities, and modifications and connections to existing service utilities
- A proposed permanent power supply connection from the Ausgrid Canterbury subtransmission substation, to Rockdale Motorway Operations Complex south.

The project does not include ongoing motorway maintenance activities during operation or future upgrades to other intersections in the vicinity during operation. These works are permitted under separate existing approvals and / or are subject to separate assessment and approval in accordance with the EP&A Act.

The key features of the project are shown on **Figure 2-1**.

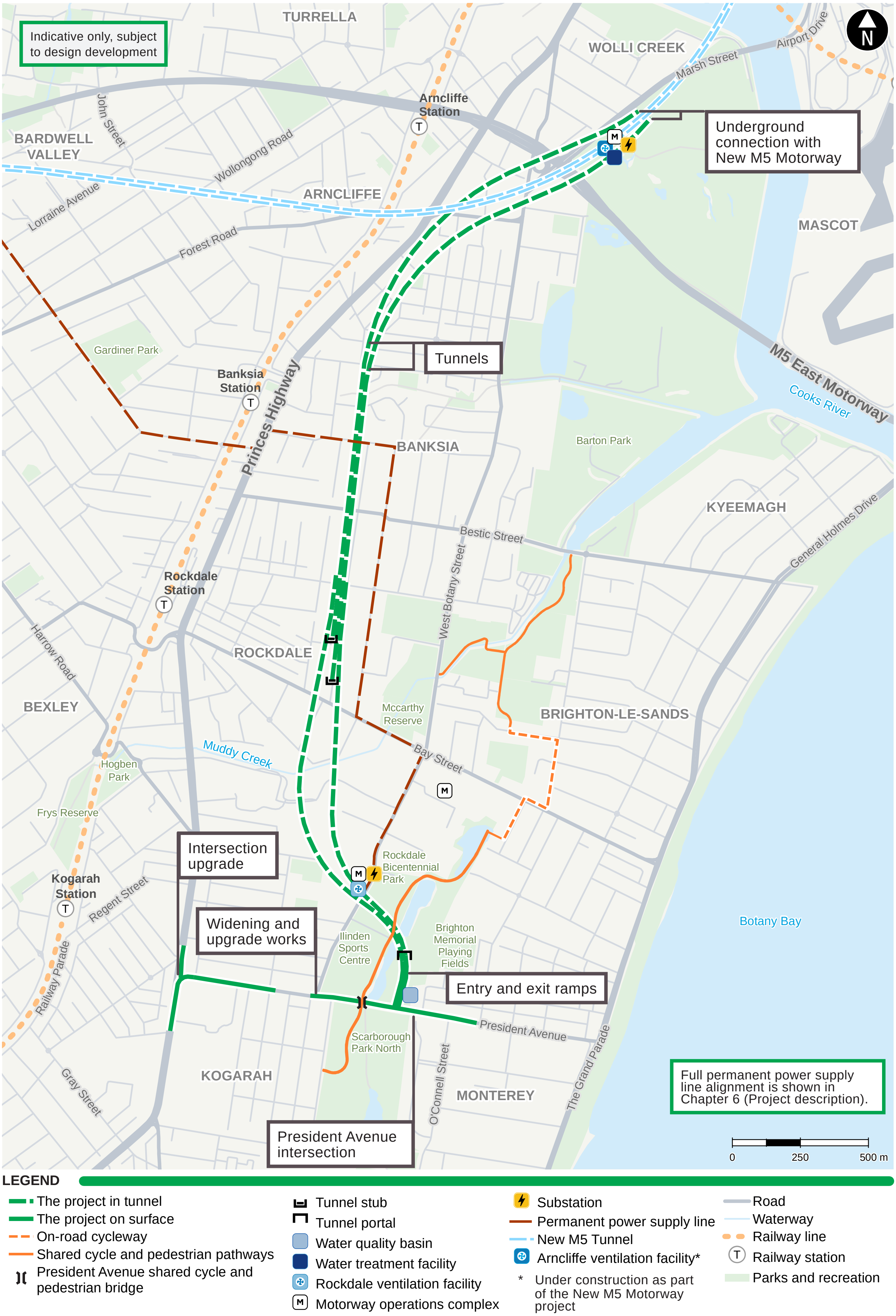


Figure 2-1 Project features

2.2 Construction

2.2.1 Construction activities

The proposed construction activities for the project would include:

- Preparatory investigations
- Site establishment and enabling work
- Tunnelling
- Surface earthworks and structures
- Construction of motorway operations complexes
- Drainage and construction of operational water management infrastructure
- Construction of the permanent power supply connection
- Road pavement works
- Finishing works.

These activities would generally be undertaken within the following construction ancillary facilities:

- Arncliffe construction ancillary facility (C1) at Arncliffe, within the Kogarah Golf Course currently being used for the construction of the New M5 Motorway
- Rockdale construction ancillary facility (C2) at Rockdale, within a Roads and Maritime depot at West Botany Street
- President Avenue construction ancillary facility (C3) at Rockdale, north and south of President Avenue within Rockdale Bicentennial Park and part of Scarborough Park North, and a site west of West Botany Street
- Shared cycle and pedestrian pathways construction ancillary facilities (C4 and C5) at Brighton-le-Sands, within the recreation area between West Botany Street and Francis Avenue, near Muddy Creek
- Princes Highway construction ancillary facility (C6), on the north-east corner of the President Avenue and Princes Highway intersection.

2.2.2 Construction boundary

The area required for project construction is referred to as the ‘construction boundary’. This comprises the surface construction works area, and construction ancillary facilities (refer to **Figure 2-2**). Utility works to support the project would occur within and outside the construction boundary (refer to **Chapter 7** (Construction) of the EIS).

In addition to these works, the underground construction boundary (including mainline tunnel construction and temporary access tunnels) is also shown on **Figure 2-2**.

C1

- Tunnelling and spoil handling
- Construction of MOC1 (Water treatment plant, substation)
- Fitout, testing and commissioning of tunnels and MOC 1

C2

- Construction of the decline tunnel
- Tunnelling and spoil handling
- Pavement works for internal access road
- Construction of MOC2
- Reconfiguration of the site to enable ongoing/future use for maintenance activities

C3

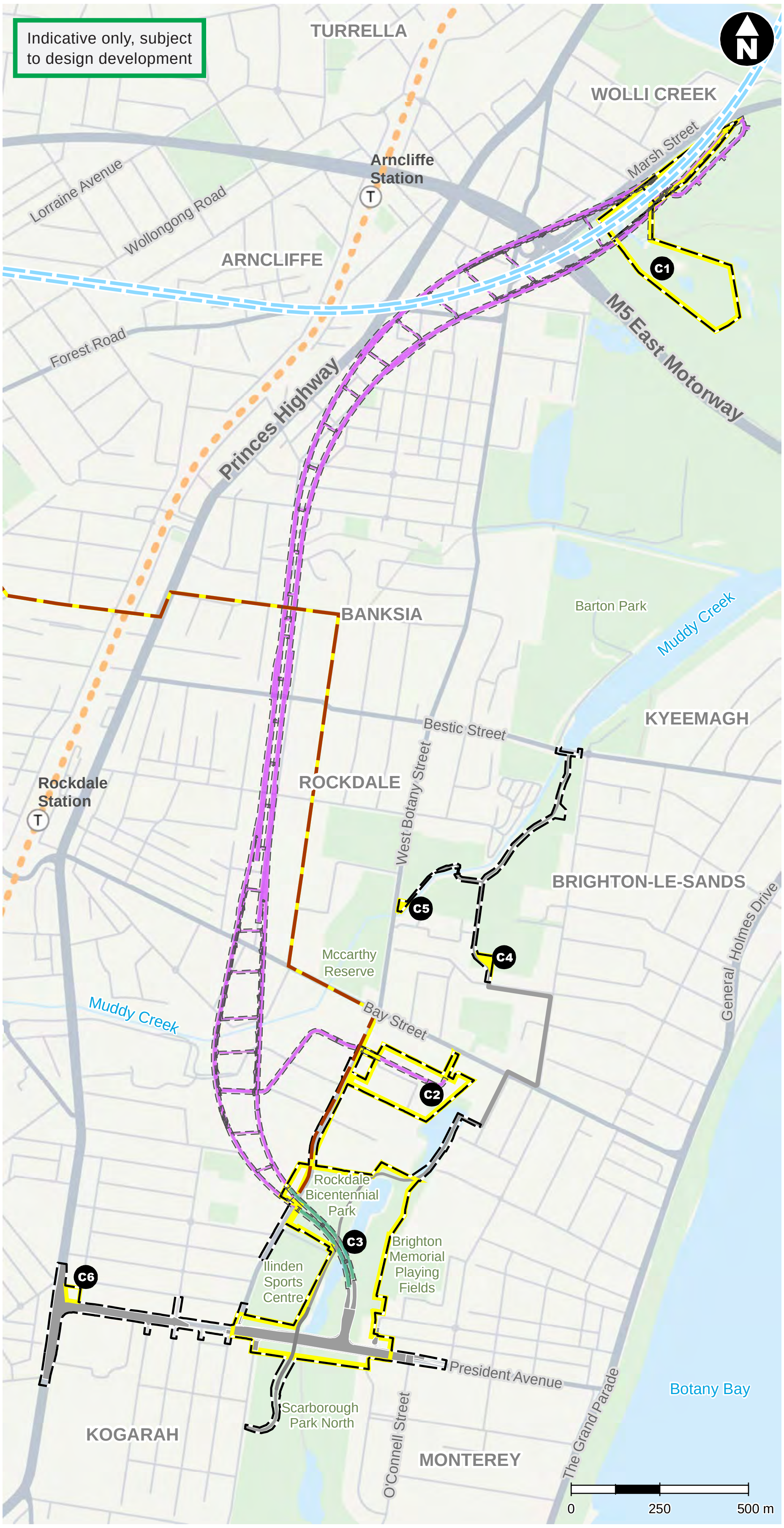
- Demolition of buildings and vegetation clearing and removal
- Relocation of utilities
- Temporary stockpiling of spoil and fill materials
- Management of any contaminated land, including acid sulphate soils
- Construction of cut-and-cover structures
- Construction of MOC3 (Rockdale ventilation facility and substation)
- President Avenue intersection upgrade works
- Construction of shared pedestrian and cyclist path and overpass

C4/C5

- Site establishment
- Vegetation clearing and removal, topsoil stripping areas and land-form shaping
- Temporary stockpiling of materials
- Construction of the shared pedestrian and cyclist path
- Finishing works including lighting, line marking and signage installation

C6

- Property adjustment and demolition
- Relocation of utilities, stormwater infrastructure, underground storage tanks and substation
- Laydown and parking of construction vehicles and equipment
- Reinstatement of site



LEGEND

- Surface works
- Construction boundary
- Cut-and-cover structures
- Underground construction
- Construction ancillary facility
- Permanent power supply line
- Permanent power supply construction route
- New M5 Tunnel
- Road
- Waterway
- Railway line
- Railway station
- Parks and recreation

Figure 2-2 Overview of construction boundary and ancillary features

2.2.3 Construction program

The project would be constructed over a period expected to be around four years, including commissioning which would occur concurrently with the final stages of construction (refer to **Figure 2-3**).

The project is expected to be completed towards the end of 2024.

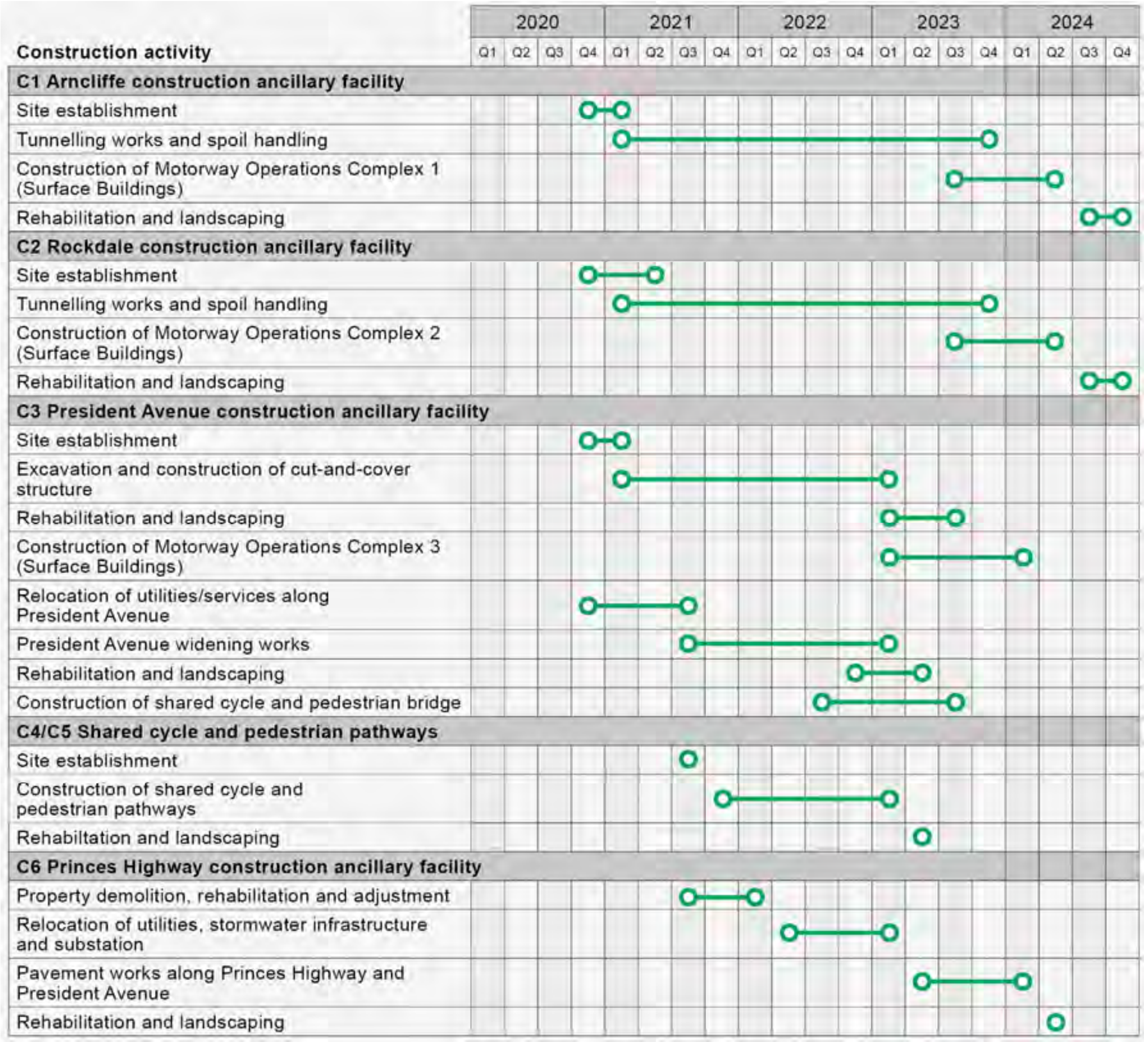


Figure 2-3 Indicative construction program

For the purpose of groundwater modelling, the construction program has been separated into three month stress intervals commencing in January 2020 through to the end of September 2024, representing a period of 3561 days. The operational phase was modelled as the time after construction until Year 2100.

2.3 Groundwater specific aspects of the project

The construction and operation of the project would potentially impact on groundwater quality, groundwater flows and groundwater levels due to tunnelling activities and associated works. This groundwater impact assessment describes the existing environment and predicts potential impacts of the project and outlines mitigation measures to eliminate or reduce the potential impacts to the hydrogeological regime. A numerical groundwater model has been developed to quantify potential impacts.

2.3.1 Tunnel alignment

The tunnels would comprise two mainline tunnels (about three kilometres in length) in each direction, together with entry and exit ramp tunnels to President Avenue (about 1.5 kilometres in length). Each mainline tunnel would extend from the underground connection with the New M5 Motorway through to stub tunnels to be construction for connection to a potential future stage of the F6 Extension (just north of Bay Street). The mainline tunnel would be connected to the surface road network at President Avenue via the entry and exit ramp tunnels leading to and from the surface.

The design of the mainline tunnels have been aligned to minimise intersecting highly permeable material that could result in high groundwater inflows into the tunnels. The proposed mainline tunnel alignment avoids the underlying palaeochannels and unsuitable geology that lies further east of the project alignment. The horizontal alignment maximises the extent of the project footprint within competent Hawkesbury Sandstone and minimises the alignment traversing immediately beneath sensitive environmental areas, creeks and wetlands to reduce the risk of surface water leakage.

The vertical tunnel alignment dives beneath palaeochannels where possible to reduce groundwater and surface water inflows into the tunnels. Where the project footprint intersects palaeochannels and alluvium, the tunnels would be tanked to prevent groundwater inflow in these areas. In addition, the proposed depth of the tunnels within the Hawkesbury Sandstone maximises the rock cover and reduces the risk of significant groundwater inflows from potential hydraulic connections with the palaeochannels and surface water systems.

The depths of the tunnels are variable are variable as shown on **Figure 2-4**. The tunnels are deepest in Arncliffe at around 100 metres below the ground surface where the alignment dives beneath the New M5 Motorway tunnels. The tunnels progressively become shallower to the south where the alignment reaches the ground surface at the President Avenue intersection.

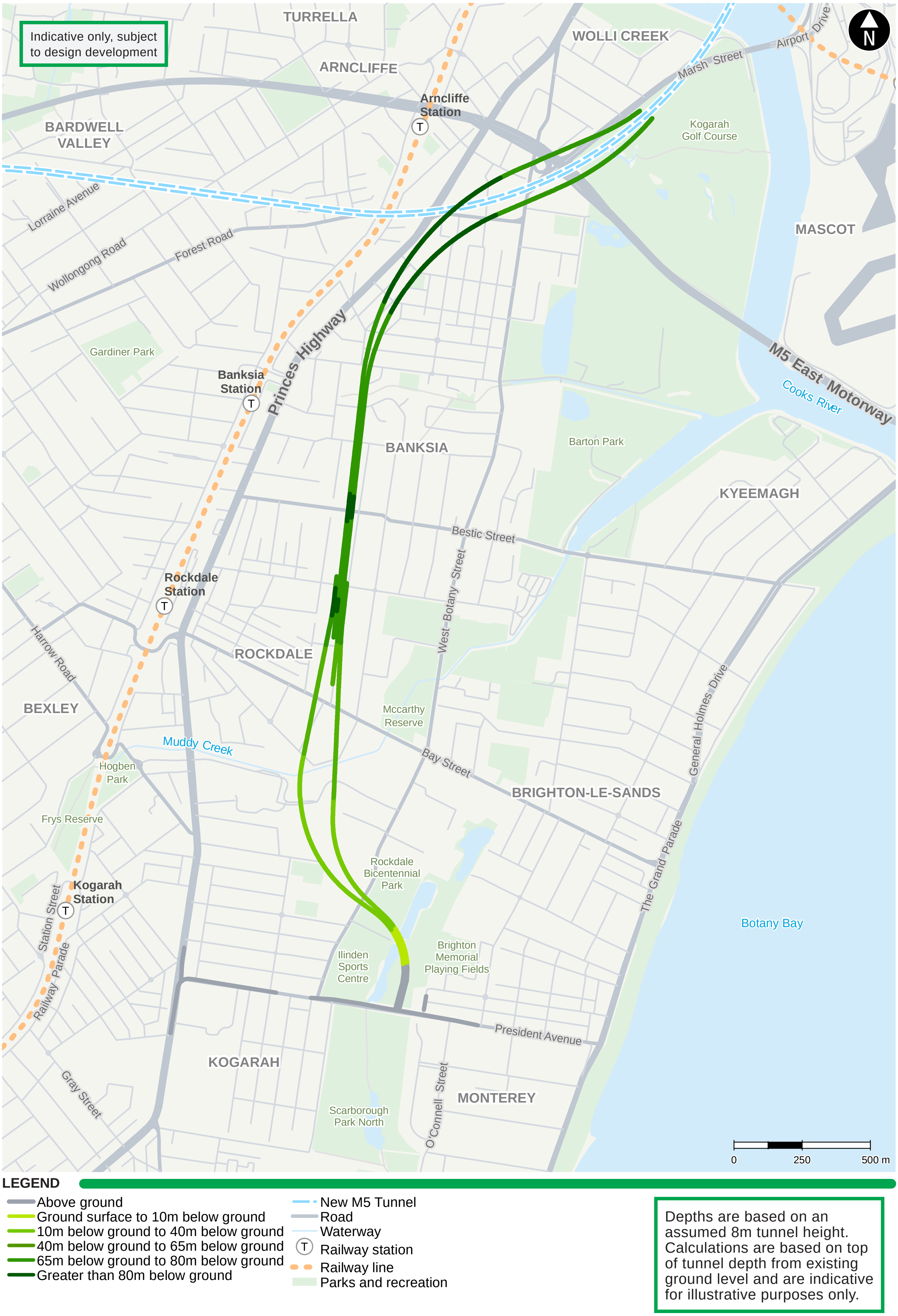


Figure 2-4 Indicative tunnel depths - mainline tunnels

2.3.2 Tunnel lining

The project tunnels would operate, predominately, as drained (i.e. not tanked) tunnels. Drained tunnels are typically constructed in structurally competent rock such as Hawkesbury Sandstone with some waterproofing to reduce groundwater inflows along particular tunnel sections. Allowing groundwater flow into the tunnel reduces an external hydrostatic pressure building up behind any tunnel lining in an undrained scenario, placing less stress on the underground infrastructure. Strip drains or similar would be installed behind wall panels to assist in dissipating groundwater. It is intended that the waterproofing and drainage requirements for the project tunnels would be consistent, as far as possible, with the adjoining New M5 Motorway tunnels.

Where the tunnels intersect alluvium, or deeply weathered sandstone, groundwater inflows are likely to exceed the design criterion of one litre per second per kilometre (L/sec/km) for any kilometre length of tunnel and have the potential to cause excessive drawdown within the alluvium or sandstone. To restrict groundwater inflow into the project tunnels, driven tunnel and cut-and-cover sections located within alluvium and poor quality sandstone would be constructed with an impermeable lining. The allowable inflow criterion in the drained section of the Rockdale construction access decline is 2L/sec/km for any kilometre length of tunnel (Bamser 2018).

The undrained, or fully tanked, sections of the tunnels would be constructed with a full perimeter waterproofing membrane to prevent groundwater flow into the tunnels. The indicative extent of drained and undrained tunnels is shown in **Figure** 2-5.

A cut and cover structure would be installed to house the motorway ramp tunnels as they pass through alluvium, beneath Rockdale Bicentennial Park. The cut-and-cover structure would be constructed with impermeable diaphragm walls.

Based on the current design at the time of this assessment, the total length of tunnel sections and construction access for the project is around 8,460 metres as outlined in **Table 2-1**. Of this total, around 6,840 metres are drained tunnels, 630 metres are undrained (tanked) tunnels, around 780 metres are to be constructed as cut and cover and around 210 metres are to be constructed as an open slot (roadway that is excavated below ground level and supported on both sides by diaphragm walls with no roof) **Figure 2-3**. The design, and subsequent length of tunnel sections, may change during detailed design.

Table 2-1 Approximate tunnel lengths along the F6 Extension Stage 1 New M5 Motorway, at Arncliffe, to President Avenue, at Kogarah

Tunnel elements	Drained (untanked)	Undrained (tanked)	Cut and cover	Slot	Total
Mainline tunnel southbound	2600	-	-	-	2600
Mainline tunnel northbound	2450	-	-	-	2450
Exit Ramp S/B	560	240	320	80	1200
Exit Ramp N/B	800	310	265	55	1430
Construction Access	426	80	200	78	784
Total	6836	630	785	213	8464

During construction, local grouting may be required in some sections of the tunnels to reduce rock permeability in order to meet the groundwater inflow criterion of one litre per second per kilometre for any kilometre length of tunnel. As such, the approach to control water ingress into the tunnel through rock defects consists of a suite of options, ranging from areas where no waterproofing may be required to areas where grouting or tanking may be required and/or a membrane may need to be applied to divert water into the groundwater drainage system.

There are some parts of the tunnel that would intersect fractured sandstone and secondary geological structural features such as water bearing faults, joint sets, dykes and shear zones, which without waterproofing, could result in higher groundwater ingress to the tunnel above the design criterion. At the portals, where the tunnels dive below the ground surface, cut-off walls would be installed along cut-and-cover sections to reduce groundwater ingress into the portals. At the President Avenue ramps, cut-off walls would be required to reduce groundwater ingress from the alluvium. The cut and cover and slot sections would be constructed with diaphragm walls or cut-off walls (for example) to control groundwater. During construction, localised dewatering within the alluvium may also be required. In this case dewatering is the process of removing groundwater from part of an aquifer, by pumping or some other mechanism, to produce temporary dry conditions during construction. Once the dewatering is completed and the pumps are switched off, groundwater levels outside the diaphragm walls would return to their natural pre-construction conditions.

In areas of high local hydraulic conductivity and elevated groundwater ingress, the natural rock mass permeability would be reduced during construction, for example by pressure cementing and the installation of water proof membranes. The waterproof membrane is installed between the primary shotcrete layer and the secondary lining layer (shotcrete or cast *in situ* concrete as applicable). In general, the waterproof membrane would be either a spray-applied membrane or pre-formed sheets fixed to the tunnel excavation. Spray-applied membranes, in conjunction with a shotcrete lining, would typically be used in localized areas where the geometry of the tunnel surfaces is complicated (e.g.at tunnel junctions). If localised grouting fails to reduce water inflows to below the design criterion, then the section of tunnel would be tanked. An option in such tunnels is to install a full perimeter waterproofing membrane around the exterior of the tunnel lining, including the invert, to form an ‘undrained’ (tanked) tunnel. In this case the undrained tunnel is designed for the exterior hydrostatic pressure.

Figure 2-5 Indicative extent of drained and undrained tunnels

2.3.3 Construction groundwater treatment and disposal

During construction, groundwater inflows would be directed behind the tunnelling progress and collected via a temporary tunnel drainage system and pumped to the surface for water quality treatment prior to discharge. Wastewater generated in the tunnel would be captured, tested and treated at temporary water treatment plant constructed at the Arncliffe construction ancillary facility (C1) and Rockdale construction ancillary facility (C2) prior to reuse or discharge, or disposal offsite if required (see **Appendix L** of the EIS (Surface water technical report)). Water treatment would address a series of analytes as outlined in the Construction Environment Management Plan (CEMP), to reduce turbidity, salinity and any compounds that exceed the discharge criteria.

2.3.4 Operational groundwater treatment and disposal

Throughout the operations phase, groundwater and surface water entering the tunnels will be captured and treated separately. The operational tunnel design would incorporate a permanent drainage system and sumps at low points to capture groundwater ingress. The primary features of the drainage design for the collection of groundwater during operation of the tunnels include:

- The collection of sub-surface water seepage
- Collection of water from ventilation shafts and tunnels
- Cleaning and maintenance of the drainage system.

Groundwater is to be treated at a new operational water treatment plant at Arncliffe and discharged to the Cooks River.

3 Assessment methodology

3.1 Relevant guidelines and policies

Groundwater in NSW is regulated by DI-Water under the *Water Act 1912* (NSW) (Water Act) and the *Water Management Act 2000* (NSW) (WM Act). The WM Act is gradually replacing the planning and management frameworks in the Water Act, although some provisions of the Water Act remain in operation. The WM Act regulates water use for rivers and aquifers where water sharing plans have commenced, while the Water Act continues to operate in the remaining areas of the state. If an activity results in a nett loss of either groundwater or surface water from a source covered by a water sharing plan, then an approval and/or license is required. The WM Act requires:

- A water access licence to take water
- A water supply works approval to construct a work
- A water use approval to use the water.

The Aquifer Interference Policy (AIP) (NoW 2012) explains the process of administering water policy under the WM Act for activities that interfere with the aquifer. The AIP outlines the assessment process and modelling criteria that DI-Water apply to assess aquifer interference projects. This assessment process and modelling criteria have been adopted for this hydrogeological assessment. Minimum impact considerations required under the AIP, for example, have been assessed for the project and are outlined in **section 9.2** of this report.

Key components of the AIP are:

- Where an activity results in the loss of water from the environment, a water access licence (WAL) is required under the WM Act to account for this water take
- An activity must address minimal impact considerations in relation to the water table, groundwater pressure and groundwater quality
- Where the actual impacts of an activity are greater than predicted, planning measures must be put in place ensuring there is sufficient monitoring.

The project is located in the *Greater Metropolitan Region Groundwater Source Water Sharing Plan* (the Plan) (NoW 2011) which commenced on 1 July 2011. Within the Plan, the project footprint is subject to the rules of the Sydney Basin Central Groundwater Source which outline the recommended management approaches of surface and groundwater connectivity, minimisation of interference between neighbouring water supply works, protection of water quality and sensitive environmental areas and limitations to the availability of water. The Sydney Basin Central Groundwater Source covers the majority of the project footprint and is a porous hard rock aquifer. Any minor groundwater within alluvium or the regolith overlying the Hawkesbury Sandstone or Ashfield Shale is considered to be part of the porous rock groundwater source. Therefore, the un-mapped alluvium does not have an assigned extraction limit and any ‘take’ would come from the underlying porous rock source (NoW 2011).

Groundwater within the Sydney Basin Central Groundwater Source is declared a less productive groundwater source by DI-Water and thus the less productive minimal impact considerations of the AIP with respect to porous and fractured rock water sources apply. Key considerations for the Sydney Basin Central Groundwater Source with respect to the level 1 minimal harm considerations of the AIP are:

- Water table impacts:
  - Less than or equal to 10 per cent cumulative variation in the water table allowing for typical climatic ‘post-water sharing plan’ variations, 40 metres from any high priority groundwater dependent ecosystem or high priority culturally significant site listed in the Schedule of the water sharing plan
  - A maximum of two metres cumulative groundwater level decline at any water supply works
- Water pressure impacts:
  - A cumulative pressure head decline of not more than two metres at any supply work

- Water quality impacts:
  - Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.

These considerations are specifically addressed in **section 9.2**.

At the northern and southern ends of the alignment, the tunnels are proposed to be driven through the Botany Sands aquifer. This alluvial and coastal sand bed aquifer is proposed to be bisected by the tunnels near Arncliffe and Banksia and along the coastal fringe at Kogarah. The aquifer is managed under Zone 1 and 2 of the Botany Sands Groundwater Source Management Zone. The tunnels intersecting the Botany Sands are to be undrained (tanked) to prevent direct groundwater inflow from the alluvial aquifer. However it is possible the project could impact the hydrogeological regime of the Botany Sands due to an existing hydraulic connection with the Hawkesbury Sandstone. Consequently, the potential impacts on the Botany Sands groundwater source have been assessed in this investigation.

Groundwater within Zone 2 of the Botany Sands Groundwater Source Management Zone is declared a highly productive groundwater source by DI-Water. Consequently, the highly productive minimal impact considerations of the AIP with respect to coastal aquifer water sources apply. Although Zone 2 is impacted by industrial contamination to the east of the project, this contamination and the subsequent commercial extraction embargo managed by DI Water would not be expected to impact the project groundwater because it is outside the project footprint.

Developments conducted on waterfront land and along major creeks and canals, are regulated by the WM Act in accordance with the *Guidelines for riparian corridors on waterfront land* (DPI-Water 2012). These guidelines state that waterfront land includes the bed and bank of any river, lake or estuary and all land within 40 metres of the highest bank of the waterbody. The project footprint does not include waterfront land as defined by the guidelines, since the tunnels are greater than 40 metres from major creeks, rivers and the foreshore. Controlled activities on waterfront land are administered by DI-Water and include removal of vegetation, earthworks and construction of temporary detention basins. A controlled activity approval must be obtained from DI-Water prior to commencing the controlled activity, however a water use approval under section 89, a water management work approval under section 90 or an activity approval (other than an aquifer interference approval) under section 91 of the WM Act are not required for SSI projects.

An overview of the relevant legislation and policy and their project implications is provided in **Table 3-1**.

Table 3-1 Overview of relevant groundwater legislation and policy

Policy	Relevance
Water Management Act 2000 (NSW)	• 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 WM Act • 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.
NSW Aquifer Interference Policy (NoW 2012)	• Manages the impacts of aquifer interference activities in accordance with the WM Act 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 there should be sufficient monitoring in place.
Water Sharing Plan, Greater Metropolitan Region Groundwater Sources (NoW 2011)	• Water Sharing Plans manage the long term surface and groundwater resources of a defined area • The plan outlines rules for the sharing and sustainability of water between various uses such as town water supply, stock and domestic, industry and irrigation.

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

- *NSW State Groundwater Policy Framework Document* (NSW Department of Land and Water Conservation (DLWC) 1998)
- *NSW Groundwater Quality Protection Policy* (DLWC 1998)
- *NSW Groundwater Dependent Ecosystems Policy* (DLWC 2002)
- *NSW Groundwater Quantity Management Policy* (DLWC undated)
- *Risk assessment guidelines for groundwater dependent ecosystems* (NSW Office of Water (NoW) 2013a)
- Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) *National Water Quality Management Strategy Australian Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ 2000)
- *NSW Water Extraction Monitoring Policy* (NSW Department of Water and Energy (DWE) 2007)
- *NSW Aquifer Interference Policy* (NoW 2012)
- *Guidelines for riparian corridors on waterfront land* (DPI 2012)
- *Acid Sulfate Soils Assessment Guidelines* (NSW Department of Planning (DoP) 2008)
- *Acid Sulfate Soils Manual* (Acid Sulfate Soils Management Advisory Committee 1998)
- *Framework for Biodiversity Assessment – Appendix 2* (NSW Office of Environment and Heritage (OEH) 2014)
- Managing Urban Stormwater: Soils and Construction Volume 1 (Landcom 2004) and Volume 2 (A. Installation of Services; B. Waste Landfills; C. Unsealed Roads; D. Main Roads; Mines and Quarries) (NSW Department of Environment, Climate Change (DECC) 2008)
- *NSW Sustainable Design Guidelines Version 3.0* (Transport for NSW 2013)
- *Risk Assessment Guidelines for Groundwater Dependent Ecosystems* (NoW 2012)
- *Using the ANZECC Guidelines and Water Quality Objectives in NSW* (NSW Department of Environment and Conservation (DEC) 2006)
- *Approved Methods for sampling and Analysis of Water Pollutants in NSW* (DECC 2008)
- *Overview of the Australian Guidelines for Water Recycling: Managing Health and the Environmental Risks. National Resource Management Ministerial Council Environmental Protection and Heritage Council. Australian Health Ministers Conference, 2006.*
- Australian Modelling Guidelines: Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A and Boronkay A (2012); Australian Groundwater Modelling Guidelines, Waterlines Report Series No 82, National Water Commission, Canberra, 191 pp. June.

3.2 Key assumptions

The following key assumptions have been made in relation to this assessment:

- The tunnels have been designed to allow a maximum inflow rate of one litre per second per kilometre for kilometre length of tunnel, which is consistent with the maximum allowed design inflow criterion for the project
- The amount of baseline monitoring data available at the time of preparing the EIS (12 months of monitoring data since January 2016) satisfies the conditions of the AIP
- The hydrogeological properties used in the impact assessment are based on bulk average hydrogeological properties derived from desktop investigations and from field data collected during the hydrogeological investigations conducted to support this impact assessment
- The project tunnels are mostly below sea level and thus groundwater gradients from the surface waterbodies would be towards the tunnels

- The cumulative impact assessment considers potential impacts from the existing M5 East tunnels, M4 East tunnels, New M5 Motorway tunnels and M4-M5 Link tunnels
- Further qualitative cumulative impact assessment considers potential impacts from the Sydney Metro City and Southwest rail alignment and the future Western Harbour Tunnel and Beaches Link motorway.

3.3 Methodology

To satisfy the SEARs, the groundwater assessment methodology for the hydrogeological impact assessment has been prepared to consider the regulatory aspects of the Greater Sydney regional groundwater resources as follows:

- Collation of available geological and hydrogeological data including monitoring data for input into the numerical groundwater model
- Desktop investigation to describe the existing environment, accessing government databases as required and reviewing existing reports
- Preparation of a description of the major features of the project and potential impacts on groundwater in terms of quality and groundwater levels
- Identification of groundwater dependent ecosystems and groundwater users
- Preparation of a calibrated numerical groundwater model (including steady state and transient models, see **section 3.3.4** for further detail regarding the groundwater model) to simulate the hydrogeological conditions along the project footprint, predict impacts on groundwater dependencies and users, calculate groundwater drawdown and prepare a water balance
- Quantification of potential impacts during construction and the operation of the project, through the groundwater model, including groundwater drawdown at groundwater dependencies and groundwater users, groundwater inflows and inferred changes to groundwater quality due to potential saltwater intrusion
- Preparation of an outline of a groundwater monitoring and management plan for the construction and operational phases of the project with consideration of the requirements of the AIP
- Conducting a minimal impact assessment in accordance with the AIP
- Assessment of cumulative impacts of the project on the local hydrogeological regime taking into account the construction and operation of other infrastructure including the New M5 Motorway, M4-M5 Link and existing M5 East tunnels
- Outlining appropriate mitigation and management measures to eliminate or reduce the potential impact on the groundwater regime.

3.3.1 Study area

The study area for the groundwater assessment includes the project footprint, extending outwards into areas where potential groundwater impacts could occur as a result of construction or operation of the project. The model footprint as outlined in **Figure 3-1** covers approximately 90 km^2 and is bounded by:

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

The project has been divided into four design components described in **Table 3-2**.

Table 3-2 Project design components

Component	Proposed structure
Proposed new southbound/northbound motorway carriageway	Driven mainline tunnel from New M5 Motorway stub tunnels to President Avenue
Southbound/northbound exit/entry ramps to/from President Avenue	Driven, cut and cover, slot/open trough at President Avenue surface link
Construction access tunnel	Driven and cut and cover construction access tunnel from the Roads and Maritime compound (Rockdale construction ancillary facility (C2)) to the southbound exit ramp
Bedrock profile along West Botany Street	Northbound and southbound ramp tunnels that cross perpendicular to West Botany Street.

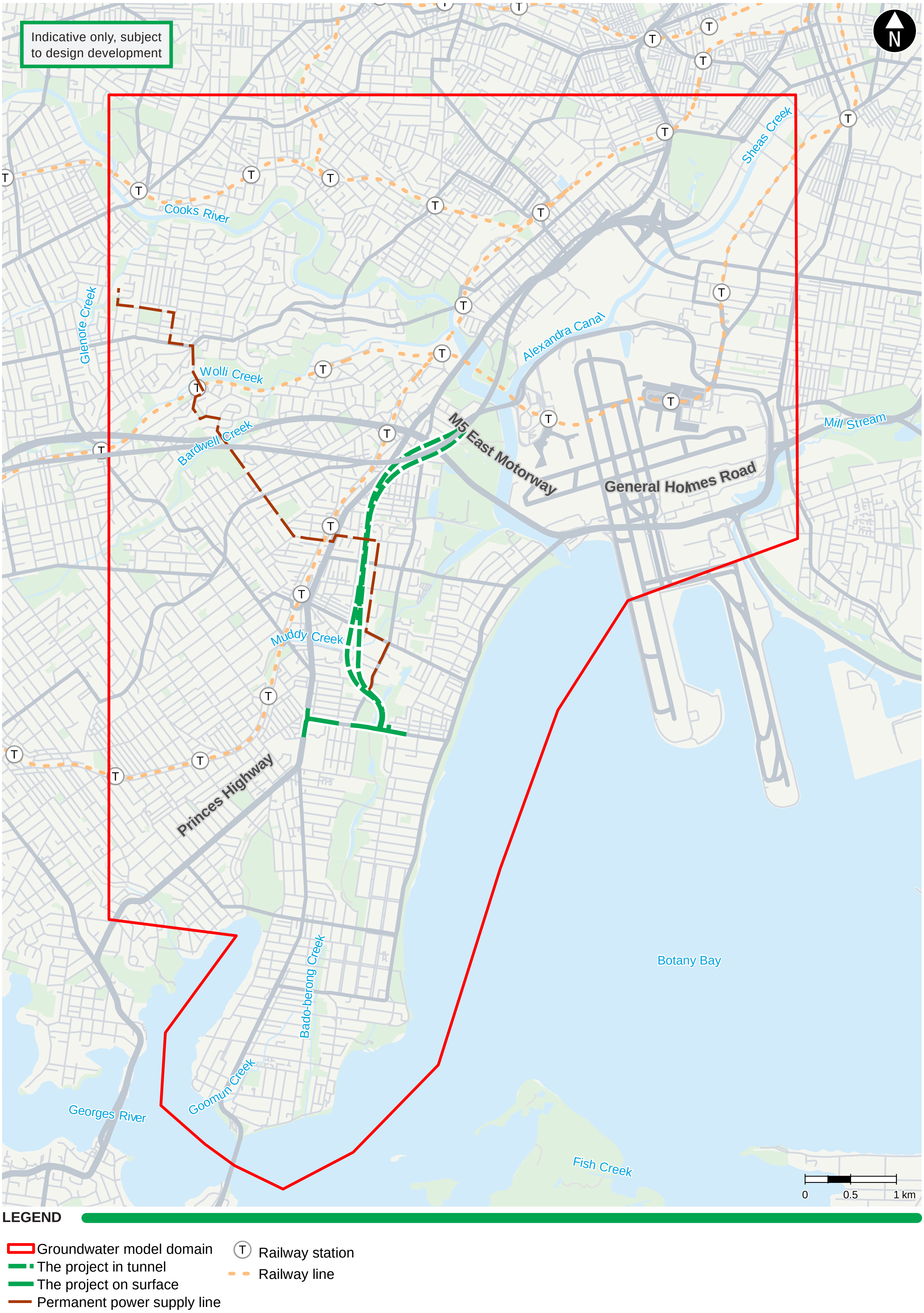


Figure 3-1 Groundwater assessment study area (model domain)

3.3.2 Desktop assessment

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

- *Australian Soils Resource Information System acid sulfate soils*, accessed December 2017
- Bureau of Meteorology (BoM) 2016 *Australian Groundwater Explorer* (formerly DPI-Water groundwater database), accessed December 2017
- *Greater Metropolitan Regional Groundwater Sources Water Sharing Plan*, Appendix 4
- BoM 2018 *Atlas of Groundwater Dependent Ecosystems*, accessed January 2018
- BoM 2018 online climate data, accessed January 2018
- NSW EPA Contaminated Land Record, accessed January 2018.

3.3.3 Field investigations

Two field investigations were conducted which provide site specific data for the project. The first field investigation was conducted by AECOM in 2014-2015 as part of baseline monitoring for the New M5 Motorway project (Roads and Maritime 2015). The second field investigation by SMEC commenced in 2017 for the F6 project and will continue through until the construction phase.

Both field investigations commenced with a geotechnical drilling program to conduct packer testing and the construction of groundwater monitoring wells at selected locations. This investigation was followed up by groundwater monitoring that included manual groundwater gauging, the installation of dataloggers to automatically gauge groundwater levels and groundwater quality monitoring.

Packer tests

Packer tests (*in situ* water pressure tests) were conducted on selected boreholes to calculate the bulk hydraulic conductivity of the test interval during the drilling program. The packer testing involves hydraulically isolating an interval up to 10 metres within the borehole with an inflatable packer and injecting water into the interval under various pressures. The water flow into the borehole is recorded over a range of ascending and descending water pressures. The packer test analysis is based on the water inflow into the test section being proportional to the hydraulic conductivity. The packer test results from each field program are discussed in **section 4.13.4**.

Monitoring well installation

The geotechnical drilling program utilised by the project was undertaken between October 2014 and March 2015 (Roads and Maritime 2015) and between July 2016 and November 2017 (SMEC 2018a). During the drilling program, 66 selected boreholes were converted to monitoring wells. The locations of monitoring wells constructed throughout this investigation are shown on **Figure 4-12**.

Monitoring well location selection was based on the initial project design and subsequent changes during design development. Screen sections were selected in the expected tunnel zone over lithologies that displayed the most secondary structural features, to provide a good connection between the monitoring well and screened aquifer. At some locations where alluvium was present, nested monitoring wells were constructed. Monitoring wells were constructed with bentonite seals either side of the well screen within the borehole annulus and at ground surface to minimise the risk of groundwater migration from other aquifers and surface water ingress. At the completion of the monitoring well installation, airlift development was conducted to remove silt and clay particles from the well and to ensure good hydraulic connection between the well and the aquifer. The wells were surveyed to obtain their co-ordinates and elevation relative to metres AHD (Australian Height Datum). Monitoring well construction details are summarised in Table B1, **Annexure B**.

Groundwater gauging

Groundwater gauging was conducted throughout the field programs, measuring standing water levels manually with an electronic dipper. Measured standing water levels are presented in Summary Table B1 in **Annexure B**. Data loggers were installed in each of the monitoring wells after well development. The data loggers were installed to automatically measure groundwater level fluctuations at one hourly intervals. The loggers were suspended in each borehole at a depth of about five metres below the standing water level. Once collated, the data is presented in hydrographs and compared to daily rainfall measured at Sydney Observatory (**Annexure C**).

Groundwater sampling and hydrogeochemical analysis

Groundwater samples were collected from the monitoring well networks for laboratory analysis (RMS, 2015 and SMEC 2017/2018a) following development. Analytes included: heavy metals and metalloids (arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel and zinc), nutrients (nitrate, nitrite, ammonia and reactive phosphorous, inorganics (including major anions and cations, alkalinity, electrical conductivity, ionic balance, total dissolved solids, pH and resistivity).

Hydrogeochemical results are presented in Summary Tables B3, B4 and B5 in **Annexure B**. A suite of dissolved contaminants included organochlorine pesticides (OCPs), organophosphate pesticides (OPPs), semi volatile organic hydrocarbons (SVOCs) and volatile organic compounds (VOCs), total recoverable hydrocarbons (TRH), benzene, toluene, ethylbenzene, xylene and naphthalene (BTEXN), polycyclic aromatic hydrocarbons (PAHs) was included in the contamination monitoring outlined in **section 4.16**.

3.3.4 Groundwater numerical modelling

A three-dimensional numerical groundwater model was developed in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al.,* 2012) to simulate existing groundwater conditions, project footprint, caverns and associated subsurface ancillary infrastructure including ventilation shafts. The active model domain extends over a 7.5 x 12 square kilometre area centred on the project alignment. The model domain partially includes the M5 East, the New M5 Motorway and the M4-M5 Link motorways to predict cumulative drawdown impacts. The model also allows for inclusion of potential future stages of the F6 Extension until the Georges River. The southern boundaries are defined by Botany Bay and the central channel of the Georges River.

The model domain is shown on **Figure 3-1**. The groundwater model was used to predict future groundwater conditions and potential impacts related to the project during the construction and operational phases. Both steady state and transient models were developed and calibrated.

The groundwater model was prepared by RPS Group Australia (RPS 2018). The groundwater modelling report, which describes the model design, parameters, grid, hydraulic boundaries and assumptions, is provided in **Annexure F**. The groundwater model was peer reviewed in accordance with Barnett *et al.,* 2012.

Groundwater model development methodology

The model was developed in accordance with Barnett *et al.,* 2012 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 including M4 East, New M5 Motorway and M4-M5 Link
- 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.

Numerical modelling has been undertaken using geographic information systems (GIS) in conjunction with MODFLOW-USG (Version 1.2), which is distributed by the United States Geological Survey (USGS). MODFLOW-USG is a relatively new version of the popular MODFLOW code (McDonald and Harbaugh 1988) developed by the USGS. MODFLOW applies a series of process modules to simulate hydrogeological conditions such as recharge (RCH), rivers (RIV), drains (DRN) and evapotranspiration (ET, EVT). MODFLOW is the industry standard groundwater modelling platform and was used to predict groundwater impacts for the M4 East, New M5 Motorway and M4-M5 Link Motorway groundwater impact assessments. The model has been constructed as a Confidence Level 2 (Class 2) model in accordance with Barnett *et al.,* 2012.

The model domain is discretised into nine layers with the upper three layers representing fill, regolith, alluvium, Botany Sands (layer 1), upper Ashfield Shale (layer 2), lower Ashfield Shale/Mittagong Formation (layer 3). The lower six layers represent the Hawkesbury Sandstone.

The groundwater model for the project:

- Simulated rainfall recharge using the RCH module
- Prescribed head boundary conditions at the coastline and along tidal rivers using constant head boundary conditions or general head boundaries
- Simulated watercourses using the RIV module with minor drainage lines simulated by the DRN module
- Used 'drain' cells to represent the project footprint
- Applied evapotranspiration (ET or EVT) boundary conditions along drainage lines
- Applied horizontal and vertical hydraulic conductivities and storage properties for alluvium, shale and sandstone.

Rates of flow from rivers to project tunnels in the model were controlled by the geometry of the system and by the spatial distribution of hydraulic conductivities (both horizontal and vertical) between the rivers and project tunnels across the model domain. Simulated groundwater levels and volumetric flows were calibrated by a combination of trial and error process against the observed data and by applying the Parameter Estimation (PEST) module. Model calibration was undertaken under steady state and transient conditions to historical groundwater levels.

The modelling methodology is outlined in more detail in the Groundwater Modelling Report (RPS 2018) presented in **Annexure F**.

Model assumptions

The following assumptions were made in preparing the numerical groundwater model:

- The project joins into the New M5 Motorway stub tunnels at Arncliffe and is a fully draining tunnel at connection
- The project alignment at the exit/entry ramps at President Avenue and part of the Rockdale construction access decline is to be constructed as a undrained (tanked) structure
- All drained (untanked) trafficable tunnels are allowed to inflow up to 1 L/sec/km for any kilometre length of tunnel to represent the operational scenario, except where the tunnel is tanked (undrained) and assigned zero inflow. At the Rockdale construction access decline, an inflow of up to 2 L/sec/km for any kilometre length of tunnel is assumed (Bamser 2018)
- The Airport Rail Link is fully lined tunnel and therefore is not included in the model, assuming groundwater flows around the tunnel
- Timing of the New M5 Motorway construction is between July 2017 to December 2020
- Timing of the construction for the project is based on quarterly time intervals as outlined in **Figure 2-3**. Tunnelling will be completed in Q1 2023
- M5 East tunnel inverts are inferred to be comparable to the New M5 Motorway
- The hydrogeological properties used in the model are based on bulk average hydrogeological properties derived from desktop analysis, packer test data and previously calibrated models
- The vertical hydraulic conductivity within the Hawkesbury Sandstone (Kv) is considerably lower than the horizontal hydraulic conductivity (Kh), typically by between one and two orders of magnitude, due to the horizontal bedding being more developed than vertical defects
- Prescribed head and no flow boundaries were assumed on model boundaries
- The proposed mainline tunnels are mostly below sea level and therefore groundwater gradients from the surface waterbodies would be towards the tunnels
- Rainfall recharge has been applied to the upper most model layer at a variable rate depending on the outcropping lithology and whether the area is paved or un-paved based on pre-construction conditions

- Other major existing tunnel infrastructure that may influence groundwater flows, levels and quality including the M5 East, New M5 Motorway and M4-M5 Link motorway tunnels have been simulated in the model.

Detailed model limitations are outlined in RPS 2018, **Annexure F**.

Modelling objectives

The numerical groundwater model was developed and calibrated to simulate the existing hydrogeological regime within the alluvium associated with the creeks and palaeochannels, Botany Sands, Ashfield Shale and Hawkesbury Sandstone and existing infrastructure including the M5 East, New M5 Motorway and M4-M5 Link tunnels. The model process is to:

- Develop a hydrogeological conceptual model based on a literature review and previous tunnelling projects including M5 East, New M5 Motorway, M4 East and M4-M5 Link motorways
- Develop a numerical model in accordance with Barnett *et al.,* 2012
- Calibrate the model in steady state and transient conditions.

The model objectives are to:

- Predict tunnel inflows and check compliance with regulatory constraints
- Predict groundwater drawdown due to drainage into the tunnels during construction and long term operations in accordance with the NSW AIP
- Predict potential impacts on nearby registered groundwater users and groundwater dependent ecosystems, in terms of groundwater drawdown and groundwater quality, in accordance with the NSW AIP
- Qualitatively predict the impacts on water quality from salt intrusion within the drawdown impact zones.

Modelling scenarios

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

- **Scenario 1:** A 'Null' run (as per Barnett *et al.,* 2012), which does not include current approved WestConnex tunnel projects (M4 East, New M5 Motorway and M4-M5 Link) projects but does include the existing drained M5 tunnels
- **Scenario 2:** The 'Null' run plus the current approved WestConnex tunnel projects (M4 East, New M5 Motorway and M4-M5 Link), with construction scheduling included as per Figure 3.3. i.e. Scenario 1 plus the M4 East, New M5 Motorway and M4-M5 Link projects
- **Scenario 3:** Scenario 2 plus the project.

Project specific impacts are calculated by Scenario 3 minus Scenario 2.

Cumulative impacts are the outcomes of Scenario 3.

4 Existing Environment

4.1 Infrastructure

4.1.1 Existing infrastructure

The project transects an urban environment that consists of established industrial, commercial, recreational and residential areas. Key features of the area include Kogarah Golf Course and other recreational reserves, surface roads, Sydney Airport and industrial and commercial precincts as outlined on **Figure 4-1**.

Kogarah Golf Course and reserves

The Kogarah Golf Course is an 18 hole course (temporarily 15 hole during the New M5 Motorway construction works) located at 19 Marsh Street, Arncliffe that has been operating as a golf course since 1928. The course is bounded by Marsh Street to the north, Cooks River to the east and the M5 motorway to the south and west. The course has numerous shallow ponds and the green and gold bell frog has previously been identified at some of these ponds.

There are many playing fields and reserves along the project footprint that have been developed adjacent to natural and altered wetlands. These reserves include Barton Park, south of Kogarah Golf Course, Ador Avenue reserve, McCarthy Reserve and Rockdale Bicentennial Park.

Surface roads and railway lines

The M5 East Motorway twin two lane tunnels extend 3.2 kilometres from west of Bexley Road Kingsgrove, under Wolli Creek Valley to emerge at Marsh Street, Arncliffe, next to Kogarah Golf Course. The drained (untanked) tunnels are constructed within Hawkesbury Sandstone.

Other major surface roads oriented approximately parallel to the project footprint is the Princes Highway to the west and General Homes Drive to the east. Three major east-west oriented roads including Bestic Street, Bay Street and President Avenue cross the project footprint.

The above ground Illawarra Railway Line runs approximately parallel to the project and is located between 200 and 750 metres to the west. Serving the local area are the Arncliffe, Banksia, Rockdale and Kogarah Railway Stations. Immediately to the north of the project is the underground Airport Link railway line joining the CBD with Sydney Airport.

Sydney Airport

Sydney's major airport, Kingsford Smith Airport (Sydney Airport) is located immediately north-east of the project footprint and will be serviced by the new infrastructure. The airport consists of a domestic and international terminal and three main runways.

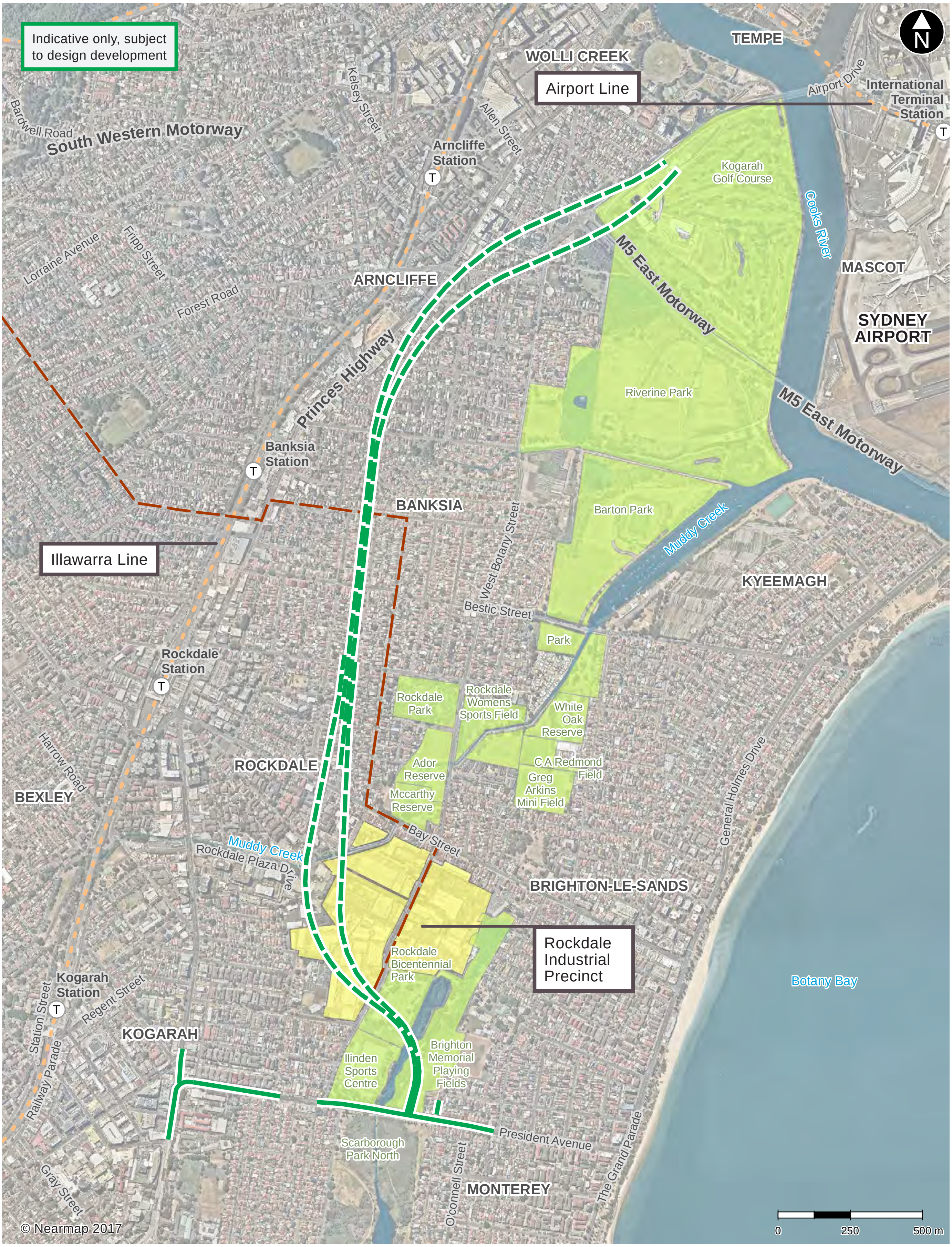
Industrial and commercial precincts

At the southern portion of the alignment, between Bay Street and President Avenue there are numerous industrial buildings which cover large surface areas and may have deep foundations. Rockdale Plaza, and several other high-rise structures located north of President Avenue are likely to have deep foundations that could be impacted by tunnelling.

Existing tunnels

Major existing tunnels in the vicinity of the project are:

- The M5 East Motorway tunnels: are a pair of drained (untanked) twin road tunnels located beneath Arncliffe (between Bexley Road in Bexley North) to the western side of Sydney Airport (about four kilometres in length), with a shorter tunnel (about one kilometre in length) beneath the Cooks River at Arncliffe
- The Airport Link rail tunnel: consists of four kilometres of tunnel in rock and another six kilometres of tunnel in soft ground. The undrained (tanked) tunnel extends from Green Square Station in the north, and passes beneath the domestic and international terminals at Sydney Airport, beneath the Cooks River and eventually joining the above ground rail system near Wolli Creek Station. Beneath Cooks River the tanked tunnel is situated within Cooks River Palaeochannel sediments which is supported by concrete lining.



LEGEND

- The project in tunnel
- The project on surface
- Permanent power supply line
- Rockdale industrial precinct
- Parks and recreation
- Waterway
- Waterbody
- Railway line
- Railway station

Figure 4-1 Existing major urban infrastructure and development

4.1.2 Other proposed and approved infrastructure

A number of other proposed and approved infrastructure projects in the vicinity of the project have the potential to cause cumulative impacts on the local hydrological environment. These projects are outlined as follows:

- **New M5 Motorway** 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. An underground interchange is to be constructed at Arncliffe linking with the F6 Extension Stage 1 New M5 Motorway, at Arncliffe, to President Avenue, at Kogarah. The twin mainline tunnels will consist of three traffic lanes, in each direction. Construction of the New M5 Motorway project has commenced and is due for completion in 2020
- **M4 East** will extend from the widened M4 Motorway at Homebush to Haberfield consisting of 5.5 kilometres of three lane twin drained tunnel. The M4 East would join the M4-M5 Link at Wattle Street, Haberfield. Interchanges are being constructed at Concord Road, North Strathfield, and Wattle Street, Haberfield. The twin mainline tunnels would consist of three traffic lanes, in each direction and would join the M4-M5 Link at Haberfield. Construction of the M4 East project has commenced and is due for completion in 2019
- **M4-M5 Link** will extend from the M4 East at Haberfield to the New M5 Motorway at St Peters and include underground interchanges at Lilyfield and Rozelle. The twin motorway tunnels are to be constructed at depths up to 60 metres below the ground surface. The project consists of 42.1 kilometres of motorway tunnel and 5.9 kilometres of ventilation and access tunnels. Tunnelling is expected to commence in 2018 and be completed by 2023. The majority of the tunnels are to be drained and constructed within the Hawkesbury Sandstone
- **Proposed future Sydney Gateway** is a proposed project consisting of ungraded roads and new infrastructure that would link the New M5 Motorway at St Peters interchange with Sydney Airport and the Port Botany precincts. The new infrastructure may include new bridges across Alexandra Canal that may require temporary dewatering during construction. Sydney Gateway is part of the WestConnex program of works but is subject to a separate environmental impact assessment and approval process
- **Proposed future Western Harbour Tunnel and Beaches Link** project would direct traffic from the proposed M4-M5 Link Rozelle interchange to the north and north-west through tunnels beneath the Balmain peninsula and Sydney Harbour. If approved, it is expected that the tunnels for the future Western Harbour Tunnel and Beaches Link project would be constructed predominately within the Hawkesbury Sandstone. The project is subject to a separate environmental impact assessment and approval process
- **Sydney Metro – South West** is a proposed rail alignment linking the north-west region to the Sydney CBD and further south to Bankstown. The Sydenham to Bankstown portion of the project consists of 13 kilometre upgrade of the existing Bankstown Line to the light rail metro line. Station boxes along the alignment are to be drained which would extract groundwater from the system. The nearest station to be upgraded is Marrickville located some 3.6 kilometres to the north.

4.2 Rainfall and climate

Sydney's climate is characterised as temperate, having no dry season with a slight predominance of rainfall throughout the autumn and winter months. Rainfall data has been obtained from BoM Station 66037 located at Sydney Airport near the north-eastern fringe of the project footprint. Rainfall has been measured at this station since 1929. Evaporation data is derived from the BoM website that presents Australia's open pan evaporation on a detailed contoured map based on data collected between 1975 and 2005. Monthly rainfall, evaporation and the rainfall difference is summarised on **Table 4-1**. The monthly rainfall difference is the deficit or surplus difference between monthly rainfall and the combined results is representative of the long term average.

Table 4-1 Summary of monthly rainfall and average evaporation (millilitres)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall mean[1]	95.4	111.6	117.1	108.8	96.9	124.2	69.6	78.6	59.7	69.7	80.4	73.6	1085.6
Rainfall 2017	48.4	158.0	229.2	94.4	32.4	113.6	18.0	27.2	0.2	59.6	38.4	52.0	871.4
Rainfall difference	-47.0	46.4	115.1	-14.4	-64.5	-10.6	-51.6	-51.4	-59.5	-10.1	-42.0	-21.6	-211.2
Evaporation	160	110	140	110	70	55	70	90	110	160	180	180	1435

Notes:
1 Rainfall averages from 1929 to 2017

Mean rainfall is highest during late summer and early autumn peaking in March and May. The lowest average rainfall is in late winter and early spring. Evaporation is highest in November and December and lowest in June, and exceeds mean rainfall for the months of February, April, May, June and July. Average monthly rainfall and recorded 2017 monthly rainfall from the Sydney Observatory are shown in **Figure 4-2**.

Mean monthly rainfall (since 1927) has been compared to the recorded 2017 monthly rainfall. Overall 2017 was a drier year with 874.4 millimetres recorded compared to a mean annual rainfall of 1085.6 millimetres, a difference of 211.2 millimetres. February and March were very wet months with rainfall exceeding the monthly average by 46.4 millimetres and 115.1 millimetres respectively. Conversely, the remainder of the year was drier than average.

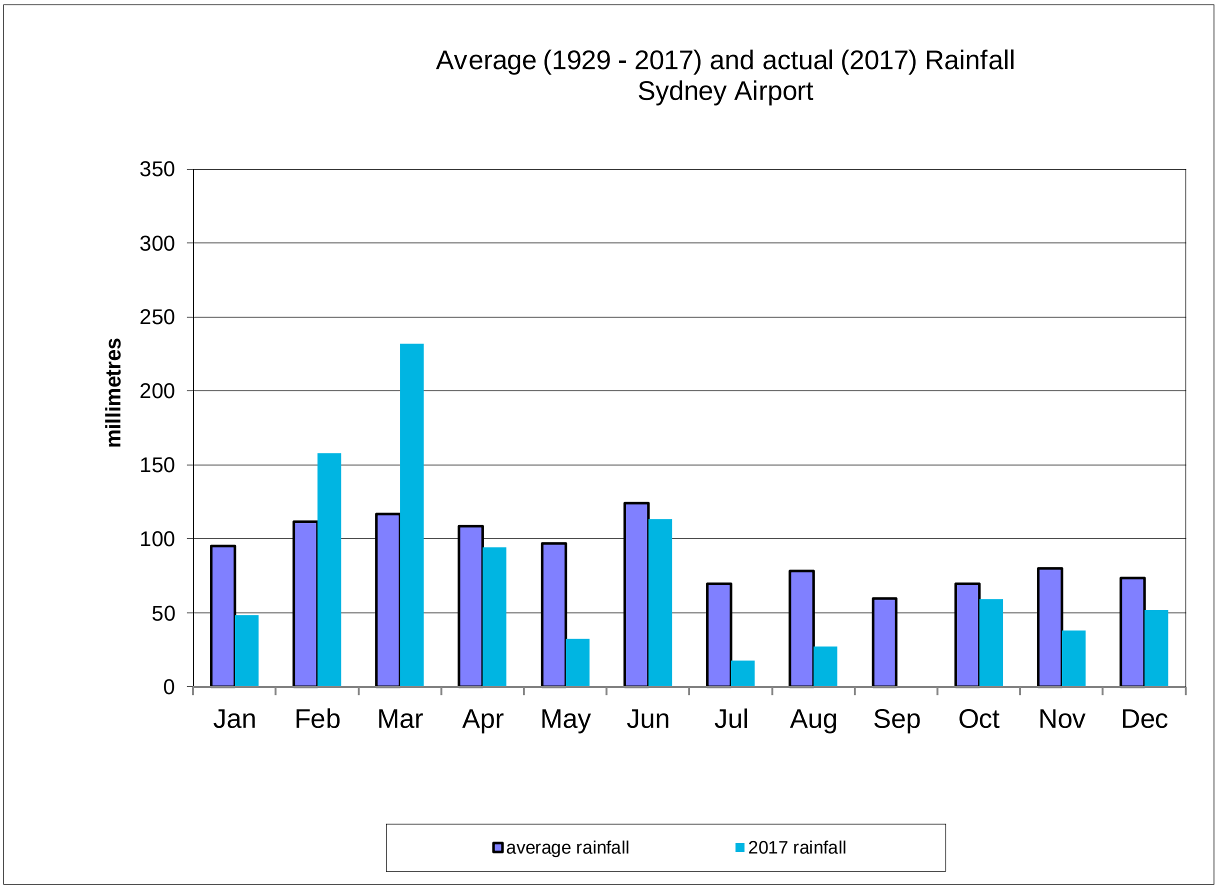


Figure 4-2 Average monthly rainfall compared to 2017 rainfall at Sydney Airport

The long term data has been collated to calculate a cumulative residual rainfall mass to assist in the identification of rainfall trends. Time series graphs of cumulative residual rainfall allow long term rainfall patterns to be assessed, with periods of above average rainfall indicated by upward trends and periods of below average rainfall by downward trends. A plot of rainfall residual mass from the Sydney Airport for the period 1929 to the end of 2017 is presented as **Figure 4-3**.

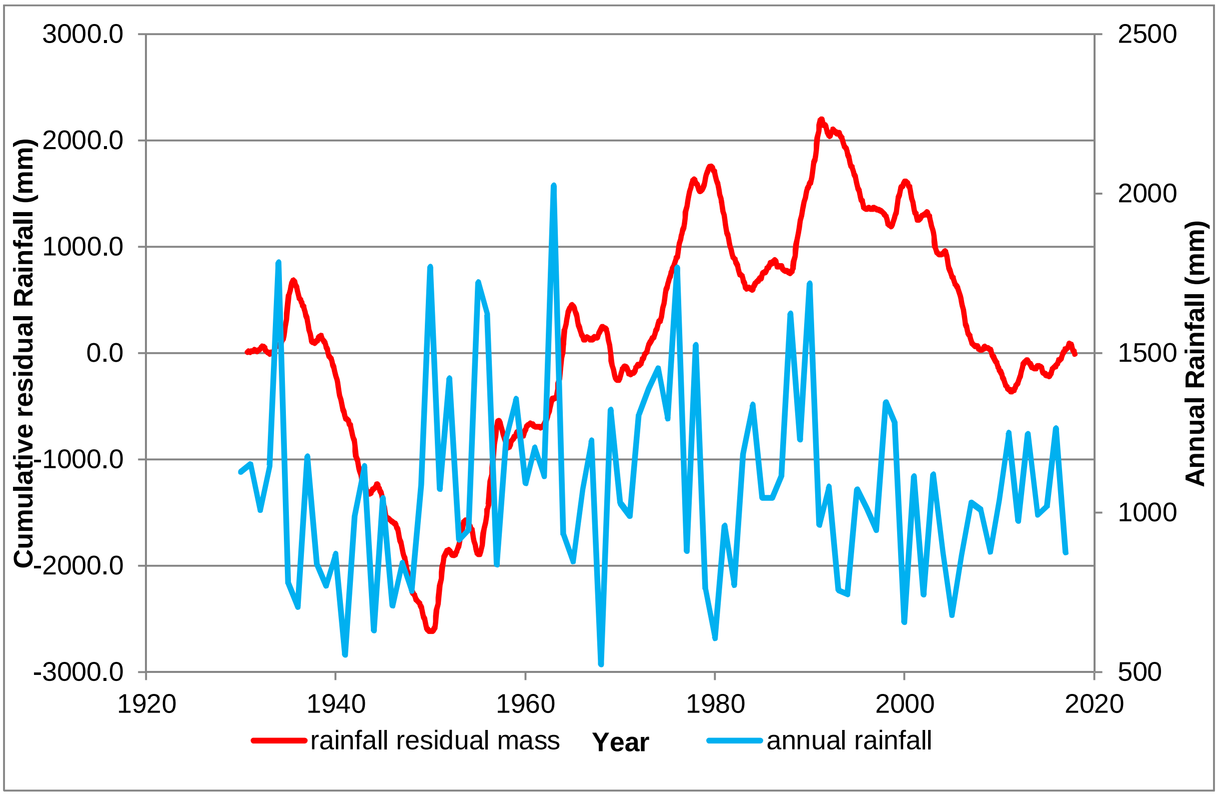


Figure 4-3 Sydney rainfall residual mass – Sydney Airport 1929 to 2017

The rainfall residual mass curve shows Sydney was subjected to significantly wet years in the 1930's and 1940's. The period between 1950and the mid-1980s was a relatively wet period followed by a dry period to about 1990. Following the millennium drought (2001–2009) the rainfall residual mass has approximated average conditions suggesting natural groundwater levels during this period would approximate long term average conditions.

4.3 Physiography

The project footprint extends from Arncliffe to Kogarah, and crosses undulating terrain from the New M5 Motorway to President Avenue.

Wolli Creek and its southern tributary, Bardwell Creek, have incised gullies through a subterranean (under the surface) Hawkesbury Sandstone plateau, which is higher in elevation than in other parts of the Sydney basin. Wolli Creek flows to the east to join the Cooks River which is to the north of the project. The Wolli Creek and Cooks River valleys widen as they approach Botany Bay and the incised valley floors have been filled with alluvial sediment to create flat alluvial plains.

The more elevated ground (about RL+10 m AHD to RL+30 metres AHD) is generally underlain by shallow Hawkesbury Sandstone. Low areas (about RL+3 metres AHD to RL+10m AHD) generally cross Quaternary Alluvium.

Low lying areas include:

- Intersection of the project with M5 East at Kogarah Golf Club
- South of Rockdale.

Elevated areas include:

- Arncliffe from Wickham Street to Spring Street
- Tabrett Street to the vicinity of Bay Street.

Topography across the study area has been input into the groundwater model at a one metre contour interval based on LiDAR data, sourced from the Australian government.

4.4 Existing surface water features

The project footprint is located within the Cooks River catchment, which covers an area of around 10,200 hectares. Wolli Creek is a major waterway and tributary of Cooks River, located to the immediate north of the project that is tidal in its lower reaches. The main surface water features in the project footprint are the Cooks River and its tributaries, the Marsh Street and Eve Street Wetlands the Landing Lights Wetland at Arncliffe and Kings Wetland and Rockdale Wetlands at Kogarah. Beyond the project study area is the Towra Point Wetlands, a Ramsar listed (global environment agreement) site to the south-east, across Botany Bay. Key surface water features within the project study area are shown on **Figure 4-4.**

The majority of the project footprint is located in a heavily urbanised area and is drained by a stormwater network. The project footprint is covered by five catchments that are drained by canals and creeks into Botany Bay as shown in **Figure 4-5**. Surface water features along the project footprint are presented in **Appendix L** of the EIS (Surface water technical report) and relevant details are summarised in the following sections.

4.4.1 Watercourses

The Cooks River flows for about 23 kilometres from Graf Park in Bankstown to Botany Bay at Kyeemagh (Cooks River Alliance 2016). The major tributaries of the Cooks River include Coxs Creek, Cup and Saucer Creek, Wolli Creek, Bardwell Creek, Alexandria Canal and Muddy Creek. The tidal limit of the Cooks River is estimated to be adjacent to Sando Reserve, Croydon Park (Manly Hydraulics Laboratory (MHL) 2005).

The Cooks River and its tributaries within the project study area are located in topographically low lying areas and are generally gaining streams, whereby groundwater discharges from the aquifer into the creek maintaining as baseflow.

The project footprint is located within a highly urbanised area and has been impacted over many years by intensive land use ranging from residential use to light and heavy industry. Consequently the majority of the Cooks River and its tributaries are artificially modified by dredging, widening, realignment and armouring such as concrete linings and rock revetments. Impacts of urbanisation have also caused degradation of the catchment resulting in very little remaining natural bushland and a degraded waterway.

Muddy creek is the only major tributary of the Cooks River within the project study area. The creek flows in a north-easterly direction extending approximately 4.3 kilometres from Forest Road in Hurstville to its confluence with the Cooks River, draining the suburbs of Hurstville, Allawah, Carlton, Kogarah, Bexley, Rockdale, Brighton Le Sands and Kyeemagh. Its main tributary is the Spring Street Drain. As for the Cooks River, Muddy Creek drains a highly urbanised catchment and is degraded because of the intense urbanisation. In addition, Muddy Creek has been highly modified and consists of a series of concrete and brick lined channels and closed box culvert structures. Sydney Water plan to naturalise Muddy Creek between West Botany Street and Bestic Street, however the timing of the works is currently unknown.

Wolli Creek flows east-north-easterly through the Wolli Creek Valley and Wolli Creek Regional Park. The creek extends for approximately six kilometres from Beverly Hills to the west joining the Cooks River at Arncliffe. The upper reaches of 3.5 kilometre length at Bexley Road, Bexley is a concrete channel where the water course flows through a box culvert and the stream bed becomes naturalised.

The major waterways of Cooks River, Muddy Creek, Wolli Creek, Bardwell Creek and Spring Street Drain are all first or second order streams.

4.4.2 Riparian corridors

A riparian corridor is a transition zone between the land and a river or watercourse or aquatic environment and are discussed in more detail in to **Appendix H** of the EIS (Biodiversity development assessment report). Calculation of the riparian zone and vegetated buffer from an activity is required to assess compliance with controlled activities on water front land (DPI 2012) and the framework for biodiversity assessment (OEH 2014).

The lower reaches of Cooks River and Muddy Creek are infilled with saline marine water. These creek systems in the riparian zone are tidal, causing the groundwater within the alluvium to mix with saline tidal water. The mixing process is influenced by the tides, currents and seasonal variation within the marine waters and the quality and volume of water entering the alluvium via groundwater. On a daily basis there is a tidal prism which moves the saline water within the alluvium in accordance with tidal movements. The movement of saline water within the alluvium is also subject to seasonal fluctuations where the saline prism is forced downstream following heavy rainfall events and the influx of low salinity runoff and groundwater flowing within the alluvium. The water salinity varies due to climatic conditions, becoming less saline following high rainfall events and low salinity runoff.

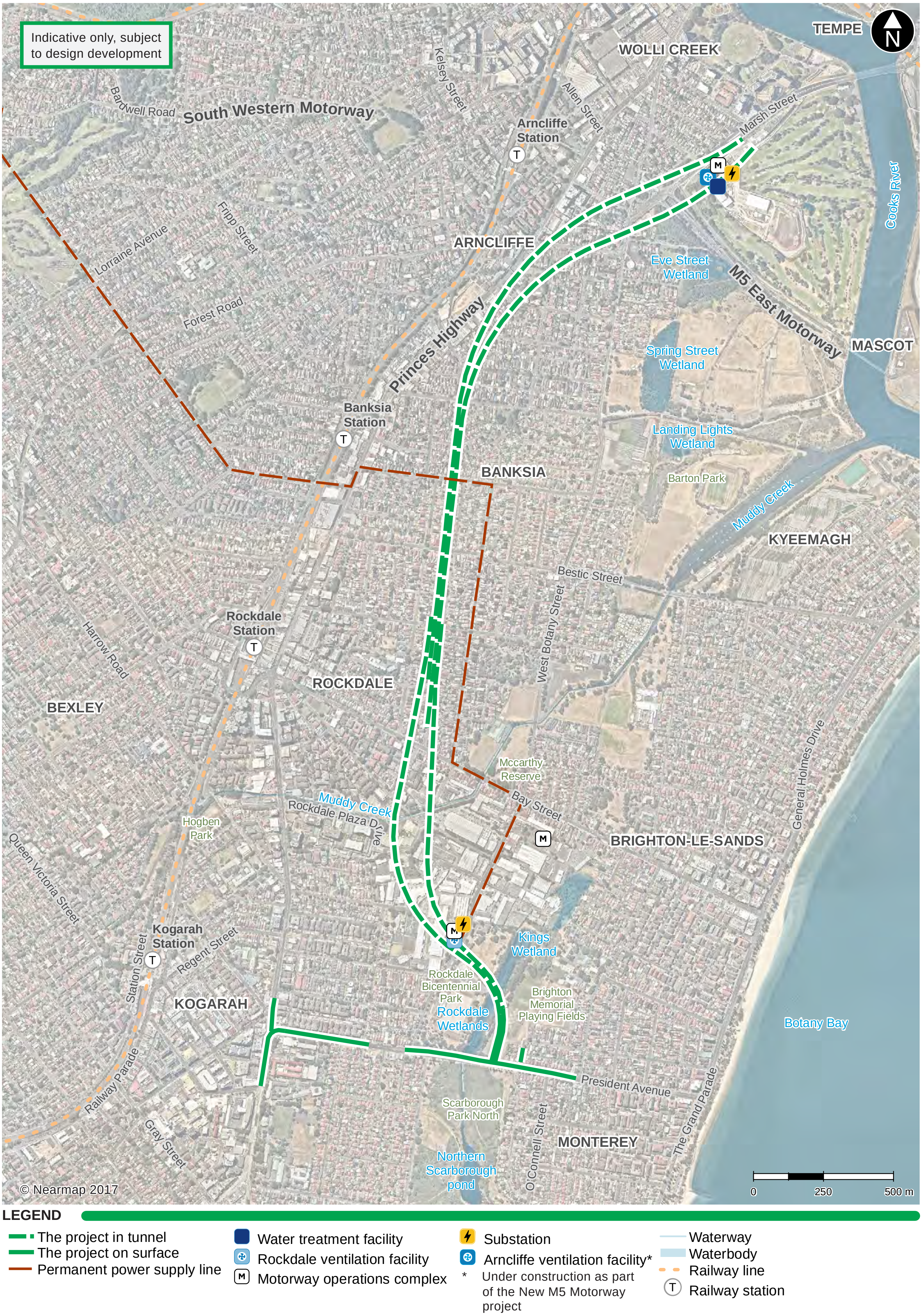


Figure 4-4 Key surface water features within the study area

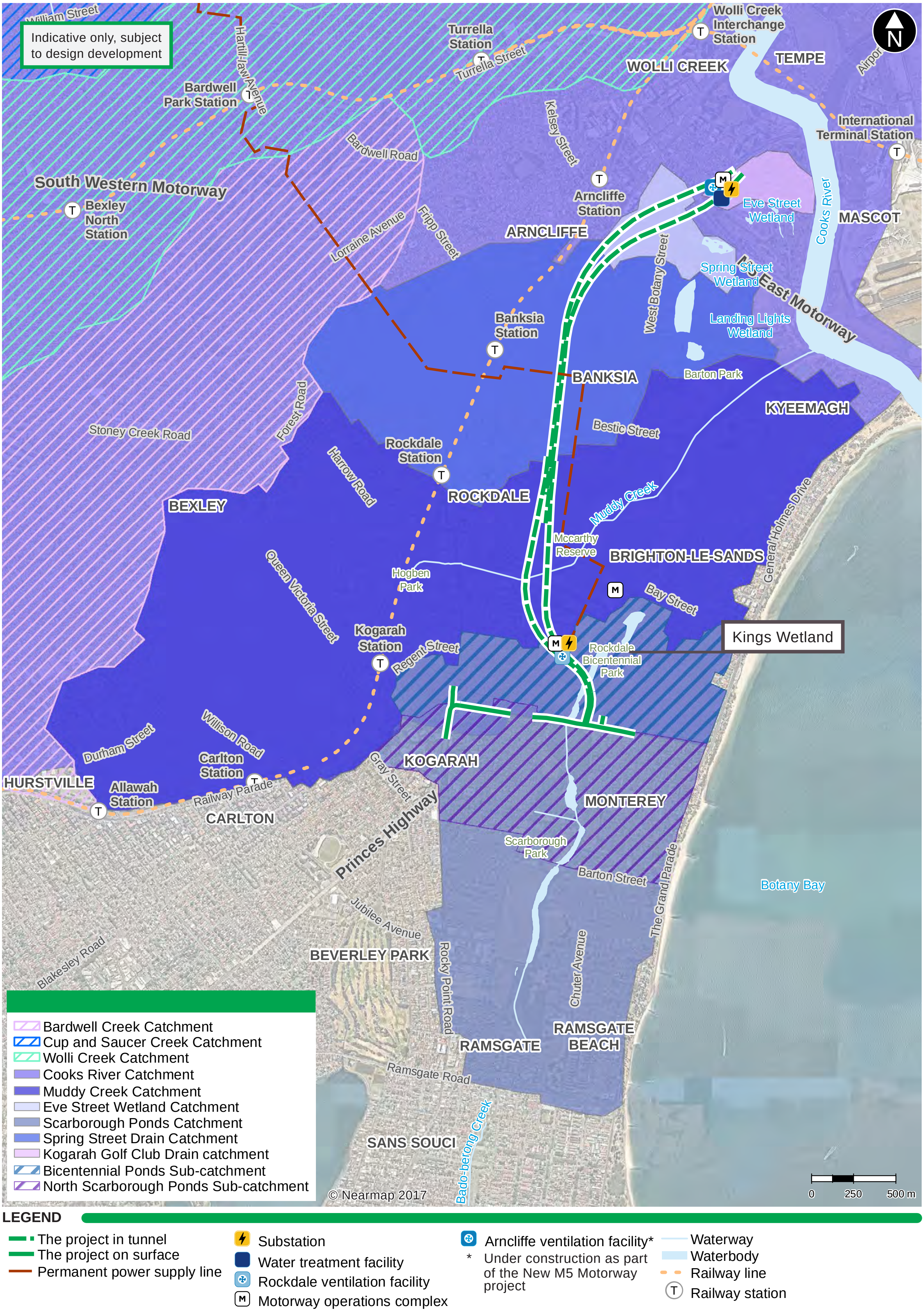


Figure 4-5 Catchments and water courses within the project footprint

4.4.3 Wetlands

The Rockdale wetlands and recreation corridor form an almost continuous link from the Cooks River in the north to the Georges River in the south. From north to south the corridor consists of the Marsh Street Wetland, Eve Street Wetland, Spring Street Drain, Landing Lights Wetland, Rockdale Wetlands (including Kings Wetland, Rockdale Bicentennial Park Wetland) and Scarborough south of President Avenue, consisting of Patmore Swamp and Scott Park Wetland. The mainline tunnel runs parallel to the Rockdale wetlands approximately 500 metres to the west.

These tidal and freshwater wetlands are a remnant of a once more extensive complex of wetlands along the western shore of Botany Bay. In more recent times the wetlands have been drained and filled to create artificial lakes. The lakes are impacted by urban development and partially infilled or raised by illegal dumping and use as landfill sites or modified to form stormwater detention basins. Despite this degradation, the wetlands remain an important part of the local environment providing a habitat for a variety of native animals and migratory birds. The surrounding low lying open space is important recreational areas, having been developed into parklands and playing field for the public. The wetlands are described in this section and in more detail in **Appendix L** of the EIS (Surface water technical report).

The Marsh Street Wetland is located south west of the Kogarah Golf Course, and has developed within the Botany Sands aquifer. There are also a series of ponds within the Kogarah Golf Course. The Marsh Street wetland was impacted by the M5 East Motorway, and only remnants of the wetland remain. Historically the wetlands have provided a habitat for the Green and Golden Bell Frog along with other frogs (**Appendix H of** the EIS (Biodiversity development assessment report)). To mitigate the impacts of the New M5 Motorway on the Marsh Street Wetlands purpose built breeding ponds were constructed near the golf course (known as the 'RTA ponds'). The RTA ponds are supplied by stormwater and are unlikely to be dependent on groundwater as the shallow ponds are constructed on locally elevated ground.

The Spring Street Drain flows easterly for approximately two kilometres from Forest Road in Rockdale to its confluence with Muddy Creek and comprises a concrete lined channel. A sub-branch of the Spring Street Drain runs in a north-easterly direction and joins the main channel approximately 160 metres upstream of West Botany Street. This sub-branch comprises a series of channel and culvert reaches, ending in a concrete lined channel where it discharges into Spring Street Drain (Lyall and Associates 2017).

Eve Street Wetland is located on the southern side of the M5 Motorway within the suburb of Arncliffe, about two kilometres west of Sydney Airport. The wetland covers about two hectares and is situated on a low lying coastal floodplain and is subject to brackish tidal flows twice a day. It is identified as a marine and coastal wetland comprising of intertidal mud, sand or salt flats as well as intertidal marshes. The marsh is listed on the directory of important wetlands of Australia that provides habitat for uncommon saltmarsh communities and migratory birds.

Landing Lights Wetland is located at Spring Street, Arncliffe, approximately 600 metres south of Eve Street Wetland and 400 metres west of Cooks River. The wetland is a tidal, saline salt marsh that are periodically flushed with saline water from Cooks River and fresh water runoff following large rainfall events. The marshes also receive fresh to brackish water. There is likely to be some leakage of groundwater from the alluvium into the underlying Hawkesbury Sandstone. As for the Eve Street Wetland, the Landing Lights Wetland provides a habitat for many migratory and native birds and contains some of the last remaining saline wetlands on the Cooks River, including Coastal Saltmarsh.

The Rockdale Wetlands consist of elongated north-south oriented wetlands extending north from President Avenue, Kogarah. The wetlands consist of Kings Wetland and the Rockdale Bicentennial Park wetland. The wetlands are surrounded by a large amount of open space consisting of parklands and playing fields. Little monitoring of pond levels is known although **Appendix L** of the EIS (Surface water technical report) describes the pond levels naturally fluctuating by around 0.5 metres in sympathy with groundwater level fluctuations. The ponds are:

- Kings Wetland, adjacent to Kings Road Kogarah, a pond that covers an area of around 200 m^2

- Rockdale Bicentennial Park Pond (BP Pond), situated to the north of President Avenue and is a highly modified, freshwater system. BP Pond is approximately 1.2 to 2.0 metres deep (Storm Consulting 2005) and functions as a stormwater detention system. It is developed within the Botany Sands aquifer and maintains shallow water levels of approximately 1 metre AHD to 1.5 metres AHD suggesting the pond is groundwater fed and represents a groundwater window. The water quality within the Rockdale Bicentennial Park pond is likely to be degraded due to contaminated groundwater leaching into the pond from former landfills located immediately to the east and west.

The Scarborough Ponds are located south of President Avenue and are hydraulically linked to the Rockdale wetlands via a weir. The elongated north south oriented ponds extend from President Avenue in the north to Ramsgate Road to the south, with surface water flowing southward. The ponds include

- The Northern Scarborough Pond, located south of President Avenue is stratified between fresh and saline water and receives fresh water inflow from Rockdale Bicentennial Park Pond. The Northern Scarborough Pond drains to the Southern Scarborough Pond via five 1050 mm diameter culverts beneath Barton Road. The Southern Scarborough Pond forms a tidal creek at its southern end which provides important habitat for fish in Botany Bay. It is permanently stratified with fresh water overlying saline tidal waters
- Scott Park is a salt marsh in Sans Souci south of the project study area on the western side of Bodo-berong Creek that has been rehabilitated.

The Towra Point Wetlands is a Ramsar listed site. The estuarine complex comprises of a mixture of spits, bars, mudflats, dunes and beaches are located on the southern shores of Kurnell. The Towra Point wetland is located approximately three kilometres east of the project across Botany Bay.

4.4.4 Groundwater dependent ecosystems

Groundwater dependent ecosystems (GDEs) are communities of plants, animals and other organisms whose extent and life processes are dependent on groundwater, such as wetlands and vegetation on coastal sand dunes. Most wetland communities and many river systems have some degree of dependence on groundwater. GDEs within or near to the project footprint have been identified following a review of:

- *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011* (the Plan). Schedule 4 of the Plan identifies high priority GDEs and Appendix 2 identifies GDEs
- National Atlas of Groundwater Dependent Ecosystems (Bureau of Meteorology 2018).

Botany Wetlands or Lachlan Swamps located in Centennial Park is identified as a high priority GDE in the Plan and the Botany Sands Groundwater Source extends to these wetlands. However, these wetlands are located approximately eight kilometres north east of the project and the potential impacts due to WestConnex tunnelling were assessed in the New M5 Motorway EIS (Roads and Maritime 2015).

The Groundwater Dependent Ecosystem Atlas (Bureau of Meteorology 2015) identifies the Cooks River as being highly likely to have an inflow dependence on groundwater, meaning that the Cooks River estuary receives groundwater passively through its bed. Some of this groundwater may flow beneath the Kogarah Golf Course at Arncliffe, which could be intercepted during tunnelling. The volume and rate of groundwater flow into the Cooks River is unknown; however WestConnex tunnelling as part of the New M5 Motorway indicates a strong hydraulic connection with the new tunnels and the alluvium flanking the Cooks River via fractures in the Hawkesbury Sandstone (Golder 2017). Impacts to the Cooks River Castlereagh Ironbark Forest GDE and Cooks River GDE were assessed in the New M5 Motorway EIS which identified moderate and low impacts to the GDEs respectively. Potential impacts to these GDEs due to the project are assessed in **sections 5.4.1** and **6.3.3**.

Salt Pan Creek is also identified as a high priority GDE, which is located around eight kilometres to the west of the project footprint.

The search of the National Atlas of Groundwater Dependent Ecosystems (Australian Bureau of Meteorology) also identified the presence of additional GDEs within or near to the project footprint:

- Hinterland sandstone gully forest with moderate to high potential for groundwater dependence at Bardwell Valley Parkland and Broadford Street Reserve, located 2.0 kilometres to the west of the project
- Coastal sandstone ridgetop woodland with moderate potential for groundwater dependence at Stotts Reserve at Bexley North, located 3.8 kilometres to the west of the project
- Estuarine fringe forest and mangrove forest with low to moderate potential for groundwater dependence between the southern bank of Wolli Creek and the railway line west of Wolli Creek station, located 1.0 kilometres to the north of the project.

Potential impacts to these GDEs were assessed as part of the New M5 Motorway EIS (Roads and Maritime 2015), which determined that there would be low impacts from that project to the Hinterland sandstone gully forest and Estuarine fringe forest GDEs and, moderate impacts to the Coastal sandstone ridgetop woodland GDE.

The Rockdale Wetlands are potentially dependent on groundwater. There is likely to be some connection between groundwater and the wetlands, through a direct hydraulic connection, and via the roots of wetland vegetation. In particular, there are some small patches of mapped Coastal Freshwater Swamp Forest and Coastal Flats Swamp Mahogany Forest at Rockdale Bicentennial Park, north of President Avenue. These vegetation communities have a moderate potential to be reliant on the subsurface connections to groundwater in the unconsolidated Botany Sand aquifer.

4.5 Soils

Soils within the project footprint are identified from the Soil Landscapes of Sydney 1:100,000 sheet, (Chapman, G.A. and Murphy, C.L. 1989) and are presented on **Figure 4-6**. The project will intersect a diverse range of soil types most of which will be excavated through due to the cut and cover and tunnelling construction methods. The soils within low-lying parts of the project study area consist principally of estuary and coastal deposits, comprising sands, freshwater peat, silts and muds. Relatively shallow colluvium and residual soils have formed from the weathering of the Hawkesbury Sandstone and may be encountered in areas that are more elevated. These soils will typically consist of clays and sandy clays of medium and high plasticity and stiff to hard consistency.

The soils and their description are presented in **Table 4-2.**

Table 4-2 Soil landscape across the study area

Soil type	Description
Birrong (bg)	Deep (greater than 0.25 m) yellow podzolic soils and Yellow solodic Soils on older alluvial terraces; (deep - greater than 0.25 m) solodic soils and yellow solonetz on current floodplain. The fluvial unit drains the Wianamatta Shale that is seasonally waterlogged.
Disturbed terrain (xx)	Turfed fill areas commonly capped with up to 0.4 metres of sandy loam or up to 0.6 metres of compacted clay over fill or waste materials. The unit is common in low lying areas adjacent to Botany Bay, the Cooks and Georges Rivers due to the historic indiscriminate infilling of wetlands.
Gymea (gy)	Shallow to moderately deep (0.3 to 1.0m) yellow earths and earthy sands on crests and inside of benches; shallow (greater than 0.2 m) siliceous sands on leading edges of benches; localised gleyed podzolic soils and yellow podzolic soils on shale lenses; shallow to moderately deep (greater than 1.0m). Siliceous sands and leached sands along drainage lines. This erosional unit overlies the Hawkesbury Sandstone.
Hawkesbury (ha)	Shallow (greater than 0.5 m), discontinuous lithosols/siliceous sands associated with rock outcrop; earthy sands, yellow earths and some yellow podzolic soils on inside of benches and along joints and fractures; localised yellow and red podzolic soils associated with shale lenses; siliceous sands and secondary yellow earths along drainage lines. The Hawkesbury unit is shallow, sometimes with sandstone outcropping.

Soil type	Description
Newport (np)	Shallow (greater than 0.5 m), well sorted Siliceous Sands overlying moderately deep (greater than 1.5 m) buried sands including yellow podzolic soils with sandy topsoils on crests and gentle slopes; deep (greater than 2.0 m) podzols on steep slopes, lower slopes and in depressions. The aeolian soil profile is developed over the Botany Sands.
Tuggerah (tg)	Deep (greater than 2.0 m) podzols on dunes and podzols/humus podzol intergrades on swales. The deep aeolian soil profile is developed over the Botany Sands.
Warriewood (wa)	Deep (greater than 1.5 m), well sorted, sandy humus podzols and dark, mottled siliceous sands, overlying buried acid peats in depressions; deep (greater than 2.0 m) podzols and pale siliceous sands on sandy rises. The swamp deposits are located along the former marshes of the Rockdale wetlands.

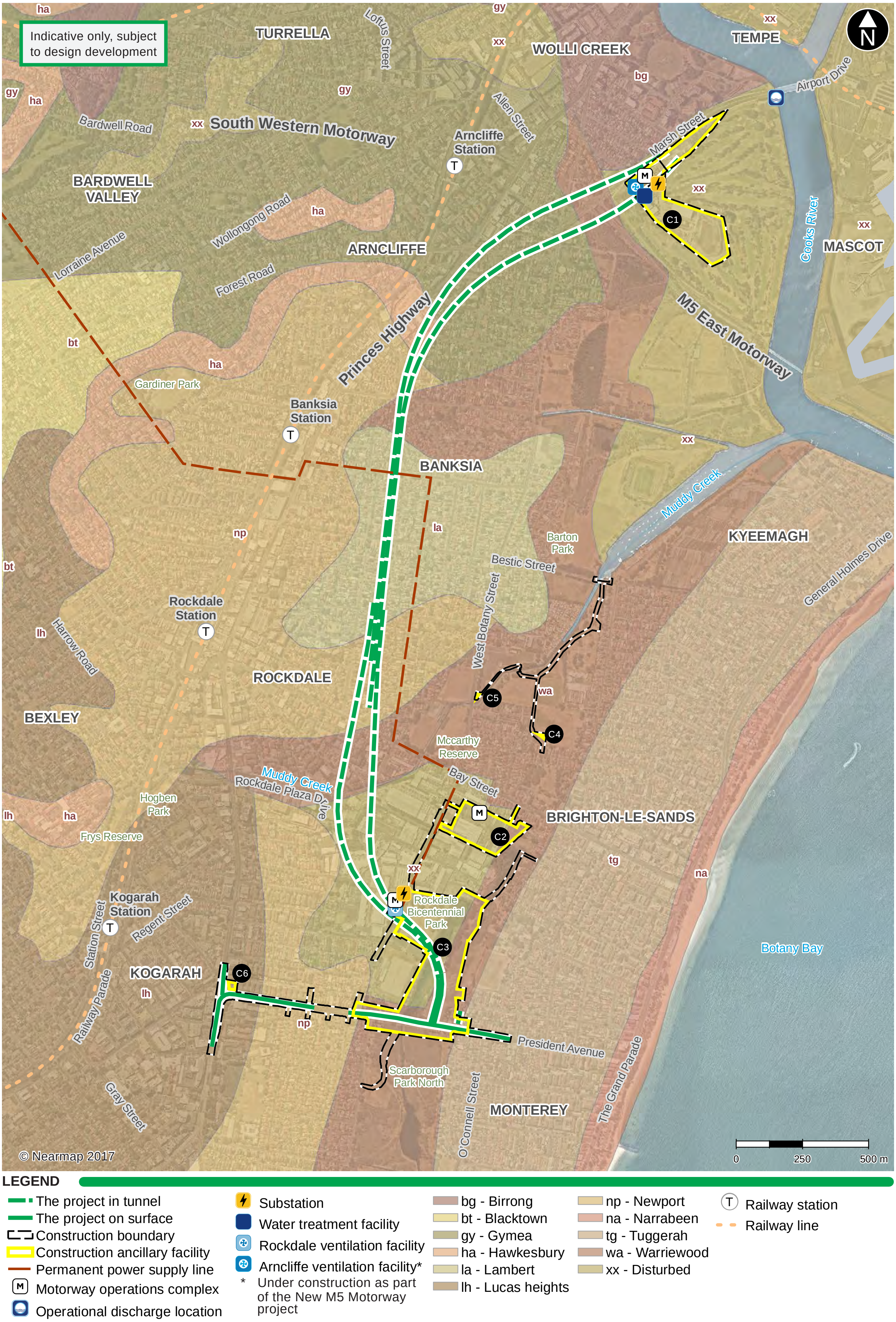


Figure 4-6 Soil types around the project footprint

4.6 Acid sulfate soils

Acid sulfate soils is the common name given to naturally occurring sediments and soils containing iron sulphides, the most common being pyrite. The exposure of the sulphide in these soils to oxygen by drainage or excavation can lead to the generation of sulphuric acid. The release of sulphuric acid from ASS often mobilises metals such as aluminium, iron and magnesium at toxic levels from otherwise stable soil matrices. Elevated concentrations of metals in site runoff may result in changes which are potentially detrimental to receiving water bodies and associated aquatic organisms.

The majority of acid sulfate sediments were formed by natural processes during the Holocene geological period (the last 10,000 years), when formation conditions for acid sulfate soils were optimum. These conditions exist in mangrove flats, salt marshes, tea tree swamps vegetation or tidal areas, and at the base of coastal rivers and lakes.

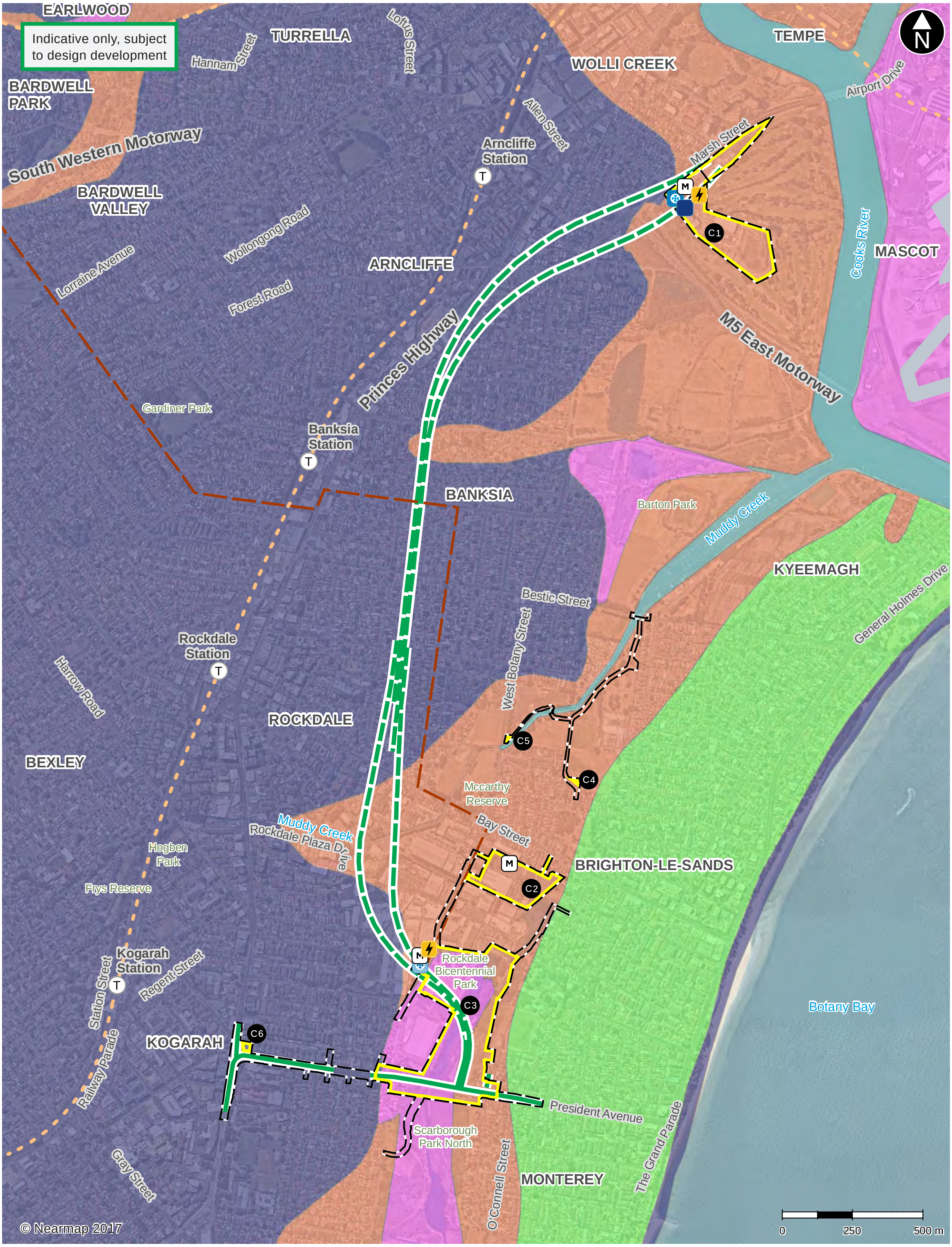
Acid sulfate soils which formed on coastal lowlands are generally found less than 2.5 to 3 metres above sea level. Where encountered in civil works, acid sulfate soils can affect durability of steel and concrete in contact with the ground and can prevent the growth of vegetation. NSW regulatory requirements assume that all coastal soils less than 5 metres AHD likely to be disturbed by excavation or water table draw-down be assessed for their acid sulfate soil properties. Where their presence is identified, a management plan for minimising impacts must be developed. The plan may include lime treatment to neutralise or prevent the formation of acids before they can be re-used on site or disposed off-site.

A search of the Australian Soils Resource Information System indicated that the majority of the project footprint has a low probability of occurrence of acid sulfate soils. Land adjacent to watercourses, namely Muddy Creek and the southern section of the Rockland Wetlands were identified as having a high probability of being potential acid sulfate soils (PASS). Areas within the project footprint showing a high and low probability of occurrence of acid sulfate soils, extracted from the *NSW Department of Land and Water Conservation Acid Sulfate Soil Risk Map for Botany Bay,* are presented on **Figure 4-7**.

In summary there is a high probability that acid sulfate soils will be encountered:

- Near Kogarah Golf Course
- Between Spring Street and Chestnut Drive, Banksia
- Between Bay Street and Rockdale Plaza Drive, Rockdale
- Near President Avenue, Kogarah.

The disturbance of acid sulfate soil has the potential to generate acidic surface water or groundwater that would require treatment prior to discharge. Consequently, procedures for the management of acid sulfate soils would be required during construction works and are discussed further in **section 4.16.**



LEGEND

- The project in tunnel
- The project on surface
- Permanent power supply line
- Construction boundary
- Construction ancillary facility
- Motorway operations complex
- Substation
- Water treatment facility
- Rockdale ventilation facility
- Arncliffe ventilation facility*
- * Under construction as part of the New M5 Motorway project
- Class 1 No known ocurrance
- Class 2 Disturbed terrain
- Class 3 High probability of occurance
- Class 4 Low probability of occurance
- Class 5 Low risk
- Railway line
- Railway station

Figure 4-7 Acid sulphate soil risk map

4.7 Geology

4.7.1 Geological setting

Regionally, the study area is located within the Permo-Triassic Sydney Basin that is characterised by sub-horizontal lying sedimentary sequence of mainly sandstone and sandstone interbedded with shale. The published 1:100,000 series geological maps for Sydney, Sheet 9130 (Herbert 1983) and Wollongong and Port Hacking, Sheets 9029 and 9129 (Sherwin and Holmes 1985) indicate that the project is underlain primarily by the Hawkesbury Sandstone and some complex Quaternary sediments (**Figure 4-8**).

The main geological units that have been encountered along the project footprint comprise of the following from youngest to oldest are summarised in **Table 4-3**.

Table 4-3 Summary of geological units

Map code	Geological unit	Lithology	Depositional/intrusive environment
mf	Anthropogenic Fill	Dredged estuarine sand and mud, demolition rubble, industrial and household waste	Estuarine and sub-aerial
Qhs	Quaternary Alluvium	Peat, sandy peat, and mud	Freshwater swamp
Qha	Quaternary Alluvium	Silty to peaty quartz sand, silt, and clay. Ferruginous and humic cementation in places. Common shell layers.	Stream alluvial and estuarine sediment
Qd	Quaternary Alluvium	Medium to fine grained marine sand and podsols.	Transgressive dunes
Qhbr	Quaternary Alluvium	Quartz sand, minor shell content, inter-dune (swale) silt and fine sand.	Beach ridge system (Outer Barrier)
Jv	Jurassic volcanics	Basalt, dolerite, volcanic breccia	Cross cutting igneous intrusions
TRh	Triassic Hawkesbury Sandstone	Medium to coarse grained quartz sandstone, very minor shale and laminate lenses.	Braided alluvial channel fill

The project footprint is located within the central part of the Sydney Basin commonly known as the Fairfield Basin where the greatest thicknesses of sediments are encountered. Regionally, the sediments gently dip to the west, typically less than five degrees.

Large scale penetrative faulting is rare in the Sydney Basin (AECOM 2017d). Structurally there are major faults oriented north-north-east to south-south-west that cross-cut the basement rocks. These fault zones are represented as zones of increased joint frequency that are referred to as joint swarms.

Palaeovalleys or palaeochannels have also been mapped in the project footprint (Och *et al.,* 2009) and (Albani et al., 2015). These alluvial, infilled, deeply incised palaeochannels of Pleistocene age are carved into the sandstone bedrock to depths up to 25 metres. To the south of the project footprint at Sans Souci and at Sydney Airport much of the land and reclaimed land is composed of man-made fill. Beneath parts of the Rockdale wetlands alluvium and colluvium is present along with man-made fill where wetlands and swamps have historically been infilled to 'reclaim' the land to create parks and playing fields.

The engineering properties of the geology along the project footprint are presented in more detail in the geotechnical interpretative report (AECOM 2018).

4.7.2 Fill materials

As the project footprint is located within an urban environment, fill materials are common and range from minor landscaping to extensive fill for construction of major buildings and infrastructure. The fill typically consists of locally excavated and imported materials.

More substantial filling has occurred along low lying areas such as reclamation works associated with the partial infilling of the Rockdale wetlands foreshore areas. Fill materials within the Rockdale wetlands consist of uncontrolled and illegally dumped rubbish; waste and putrescible material. Fill along foreshore areas of Botany Bay and the Cooks River and Georges River typically consist of locally dredged material and possibly imported waste. Compaction levels may range from uncompacted associated with reclamation works to engineered and certified fill at development sites.

4.7.3 Alluvium

Deposits of alluvial and fluvial sediments flank major rivers and creeks including the Cooks River, Georges River and Muddy Creek. The alluvial and fluvial sediments (Qha) consist of sand, silt, clay, gravels and some peat with a basal clay occasionally defining the base of the sequence. Some of the alluvium deposited in an estuarine environment contains shells and marine muds. Beneath the Rockdale Wetlands swamp deposits consisting of peat, sandy peat and mud (Qhs) outcrop or have been covered by fill.

4.7.4 Botany Sands

The Botany Sands occur along the eastern edge of Botany Bay between the beach sand and swamp deposits. The alluvial, aeolian and estuarine deposits of the Botany Sands are beach ridge systems (Qhbr) composed of quartz sand, minor shell content, inter-dune silt and fine sand and transgressive dune systems (Qd) composed of medium to fine grained marine sand and podzols. Inland extensions of the Botany Sands estuarine deposition along valleys are considered as palaeochannel deposits. At the base of the Botany Sands there is a residual alluvial clay that separates the sands from the underlying bedrock, restricting groundwater leakage to or from the bedrock (Hatley 2004).

4.7.5 Palaeochannels

Deeply incised palaeochannels have carved out drainage channels into the Hawkesbury Sandstone bedrock and are associated with a network of ancient river channels. These palaeochannels have then been infilled with up to 25 metres of saturated sediments comprised of alluvium, estuarine and marine deposits. The palaeochannels typically underlie alluvium associated with structural features such as rivers or gullies but can also be unrelated to the current drainage network. Three main palaeochannels including the Cooks River (No 1), Georges River (No 2) and Towra River (No 3) have been mapped by Albani et al. (2015) as shown on **Figure 4-9**. These palaeochannels flow north-easterly and south-easterly discharging into Botany Bay.

The project is impacted by the Cooks River palaeochannel system that extends from the Cooks River in the north to Sans Souci in the south. Branches of this palaeochannel have resulted in low bedrock levels in the vicinity of Kogarah Golf Course, Spring Street and President Avenue. The palaeochannels along the project alignment have been mapped in more detail based on drilling data obtained during the EIS field investigation (AECOM 2018). Stratigraphic data collected during the drilling program Indicates that monitoring wells BH1300, BH1303, BH1314, BH1315, BH1316, BH1143, BH1212, WCX-BH61a and WCX-BH63a are located within the palaeochannel (see **section 4.9**).

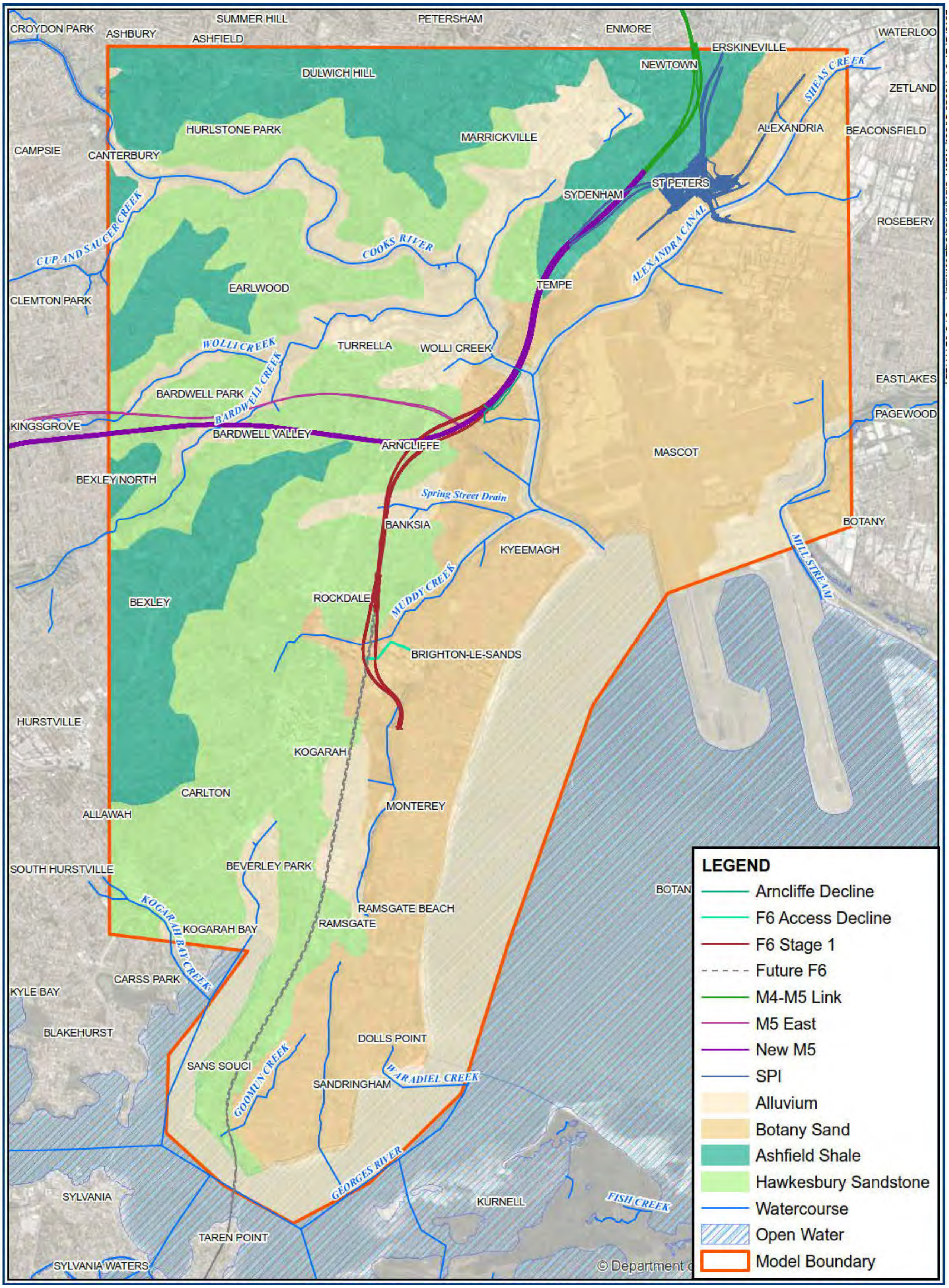


Figure 4-8 Geology of the project footprint (from RPS 2018)

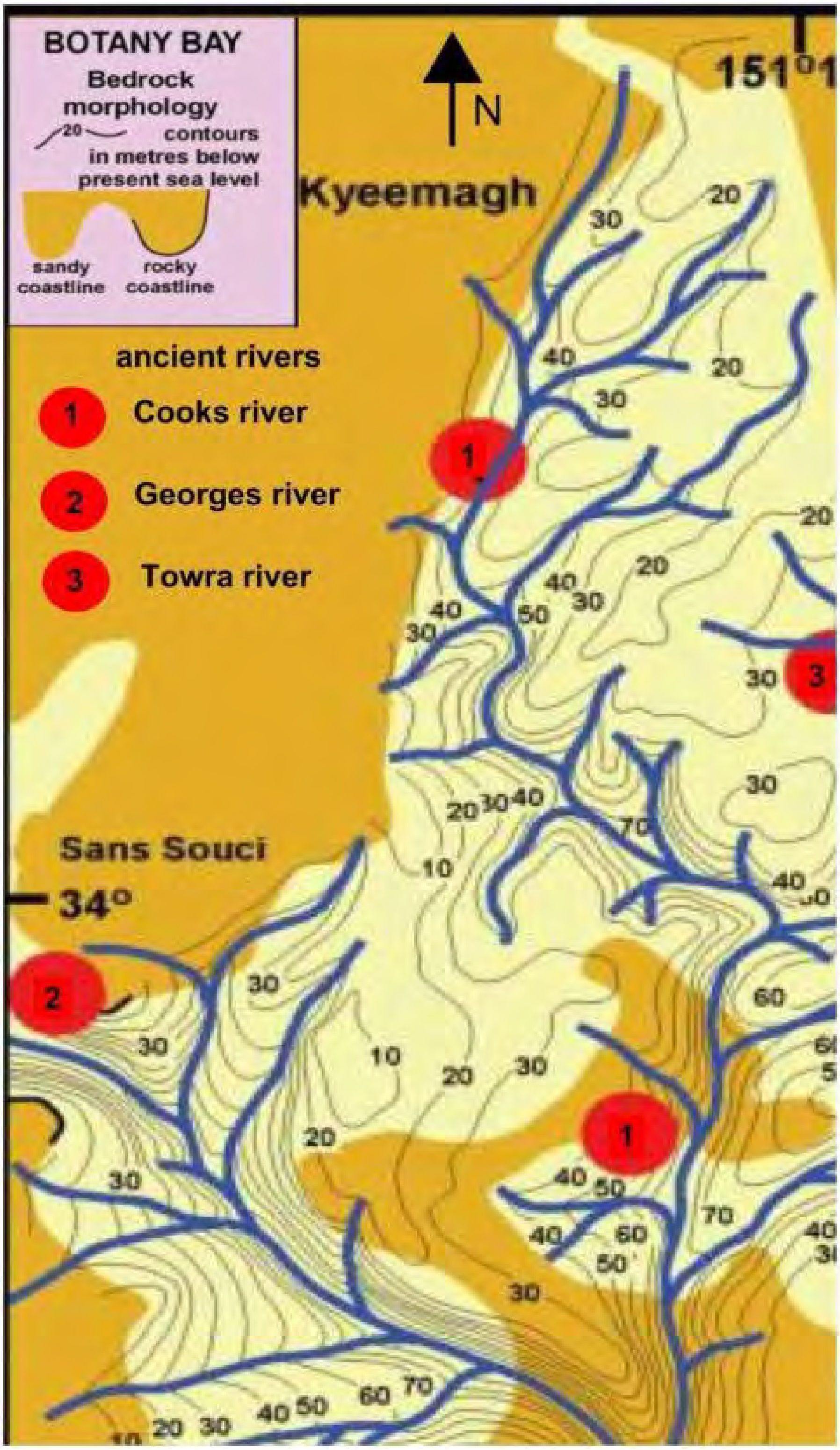


Figure 4-9 Mapped palaeochannels of Botany Bay from Albani *et al.* (2015)

4.7.6 Volcanic intrusions

Intrusive volcanic dykes of Jurassic age intrude and cross-cut the sandstone bedrock of the Sydney Basin. The dykes are basaltic and are typically oriented between 090 degrees and 120 degrees and between 005 degrees and 035 degrees, which is consistent with the dominant orientation of faults and joints within the Sydney Basin. The Sydney 1:100,000 Geological Sheet shows two east-west oriented dykes close to the project footprint to the south west that could potentially intersect the project tunnels. A dyke located to the immediate north of the tunnel alignment was intersected in eight boreholes during the construction of the west dive structure at Cooks River for the M5 East (Golder 2016), and could also intersect the project tunnels.

The dykes are of variable width ranging from less than three metres, up to 16 metres wide such as the dyke adjacent to the Cooks River (Golder 2016). The dykes are typically variably weathered and in some cases are altered to white kaolinitic clay to variable depths. Elsewhere, swarms of dykes can occur that may represent stringers or off-shoots from a main intrusion. The frequency of the occurrence of dykes along a linear feature is difficult to assess due to the difficulty in mapping poorly defined outcrops in an urban environment. Based on the geological mapping along coastal exposures in the Botany Basin, the dyke frequency within the project footprint could be expected to be one in every 150 to 200 metres.

4.7.7 Ashfield Shale

The Ashfield Shale does not outcrop along the project alignment and is not expected to be intersected by the tunnels, however it does occur within the model domain to the north at Tempe and St Peters and to the west at Bexley and Carlton. The Ashfield Shale is the lowest member of the Wianamatta Group of sedimentary rocks that also consists of the Bringelly Shale and Minchinbury Sandstone. The shale is a marine deposited sequence consisting of fine grained particles including clay, silt and sand that has undergone minor deformation and developed into a laminated shale.

Lithologically the Ashfield Shale is a dark grey to black siltstone/mudstone or laminate (thin alternating layers of siltstone and sandstone) that is sometimes carbonaceous with variable silt and clay particles throughout. The shale grades upwards into partly carbonaceous silty shale with siderite nodules and ironstone bands. Structurally the unit is laminated but still retains bedding planes at some locations. The rock structure also contains faulting, fracturing, shears and bedding.

4.7.8 Mittagong Formation

As for the Ashfield Shale the Mittagong Formation is not expected to be intersected by the tunnels along the alignment but occurs within the model domain beneath the Ashfield Shale. The Mittagong Formation represents the transition unit from the fluvial/terrestrial environment of the Hawkesbury Sandstone deposition to the marine delta depositional environment of the Ashfield Shale. The formation is composed of a series of interbedded dark shale and sandstone of variable thicknesses. The shale beds are lithologically similar to those of the Ashfield Shale but are typically no more than 0.5 metres thick. The fine to medium grained sandstone beds are up to five metres thick but contain more silt than the Hawkesbury Sandstone giving the sandstone a more ‘dirty’ appearance.

4.7.9 Hawkesbury Sandstone

The Hawkesbury Sandstone is the dominant lithology across the study area and is present beneath the entire length of the mainline tunnel alignment, although at depth where the Cooks River palaeochannel is incised. Lithologically the Hawkesbury Sandstone is described as a medium to coarse grained quartzose sandstone. The formation extends across the whole Sydney Basin and is up to 290 metres thick. The sandstone has been deposited in a fluvial environment and consists of three main depositional environments, namely massive sandstone facies, cross-bedded or sheet facies, and shale/siltstone interbedded facies. The dip of the sandstone bedding is to the north at approximately 5 degrees with cross beds dipping up to 20 degrees (Golder 2016).

The Hawkesbury Sandstone displays bedding but also contains secondary structural features such as joints, fractures and faults. The sandstone weathers to a clayey sand residual skeletal soil profile typically one to two metres deep. Within the upper 10 metres of the profile, a duricrust can sometimes be present where iron cementation has caused the development of ferricrete or coffee rock, or silica cementation has caused the development of silcrete. Iron staining is characterised by deep orange and red colouration throughout the rock mass that can be concentrated along water bearing fractures.

4.7.10 Geological faults

Reference to the Sydney 1:100,000 scale Geological Sheet indicates there are no faults mapped near the project footprint. However extrapolation of the Woolloomooloo Fault from the Sydney CBD as mapped by Och et al. (2009) has the fault running sub-parallel to the alignment and intersecting the alignment to the south near President Avenue. Golder (2016) mapped a relatively complex faulting system based on geotechnical borehole data as part of the New M5 Motorway and concluded that the identified faulting was associated with the Woolloomooloo Fault in Arncliffe. Extrapolation of these structures would result in faulting potentially being encountered at the western edge of the Kogarah Golf Course.

4.8 Hydrogeological setting

The majority of the project tunnels and associated infrastructure are to be constructed beneath the water table within the saturated rock mass. Groundwater across the project footprint is present in the following three broad hydrostratigraphic units:

- Alluvium around the edges of Muddy Creek, Cooks River and the Rockdale Wetlands
- Cooks River palaeochannel
- Hawkesbury Sandstone.

Across the project footprint, the water table generally reflects a subdued shape of the topography the groundwater being deeper beneath hills and shallowest beneath creeks or gullies. Groundwater along the project footprint is recharged by infiltration of rainfall and runoff. Perched groundwater may be encountered within fill and natural soils in more elevated areas. In lower lying areas tidal influences are typically experienced within close proximity to the foreshore. Seasonal variations in groundwater levels can be expected in response to natural climatic variation.

The project is located in an urbanised part of Sydney where rainfall recharge has been reduced by hard stand captured runoff and roof runoff being directed to stormwater. The majority of groundwater recharge occurs in parks, gardens and bushland. Alluvium flanking the Cooks River, Muddy Creek and Botany Bay is recharged daily by tidal fluctuations.

4.8.1 Quaternary alluvium

Modern alluvium outcrops around the flanks of Cooks River and Muddy Creek forming an unconfined aquifer which is generally of high permeability. Groundwater flow within the shallow alluvium associated with the Rockdale Wetlands is southward discharging into the Georges River. Typical hydraulic conductivity values are between 0.01 and 1 metre per day and the horizontal hydraulic conductivity (K_h) is typically higher than the vertical hydraulic conductivity (K_v) due to sub-horizontal bedding. Groundwater within the alluvium can be a source of either recharge or discharge to the creeks depending on whether upward or downward hydraulic gradients are present. Measured shallow groundwater levels within the alluvium associated with the Rockdale Wetlands suggest the wetlands intersect the water table forming a groundwater window. Recharge to the alluvium is via direct rainfall recharge and runoff or surface water inflow. Groundwater baseflow to creeks is restricted where the natural system has been modified and the creeks concrete lined.

The palaeochannels of the Cooks, Georges and Towra Rivers (Albani et al. 2015) extend to depths of up to 25 metres are saturated with groundwater. In contrast to the surficial alluvium groundwater flow within the deeper palaeochannels is eastward discharging into Botany Bay. Groundwater quality within the palaeochannels is expected to be saline due to leakage from tidally flushed rivers and tributaries. The alluvium infilling the palaeochannels is highly transmissive due to the coarse sands and gravels present and a low clay content.

4.8.2 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. The Botany Sands aquifer naturally contains moderately low salinity groundwater (generally less than 2000 milligrams per litre – mg/L) and is moderately acidic but is vulnerable to contamination because of the unconfined nature of the aquifer and overlying urban environment. Most notably, to the north the aquifer near the Botany Industrial Park has been embargoed for groundwater use due to contamination.

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

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

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

The extent of Botany Sands aquifer as mapped in the Water Sharing Plan (NOW 2011) includes the palaeochannel sediments as part of the available groundwater resource (**Figure 4-10**). The groundwater resource is managed under two management zones as shown in **Figure 4-10**. The project alignment is within Management Zone 2 on the north western edge of Botany Bay where commercial extraction has been embargoed but the groundwater is still used for industrial and domestic purposes.

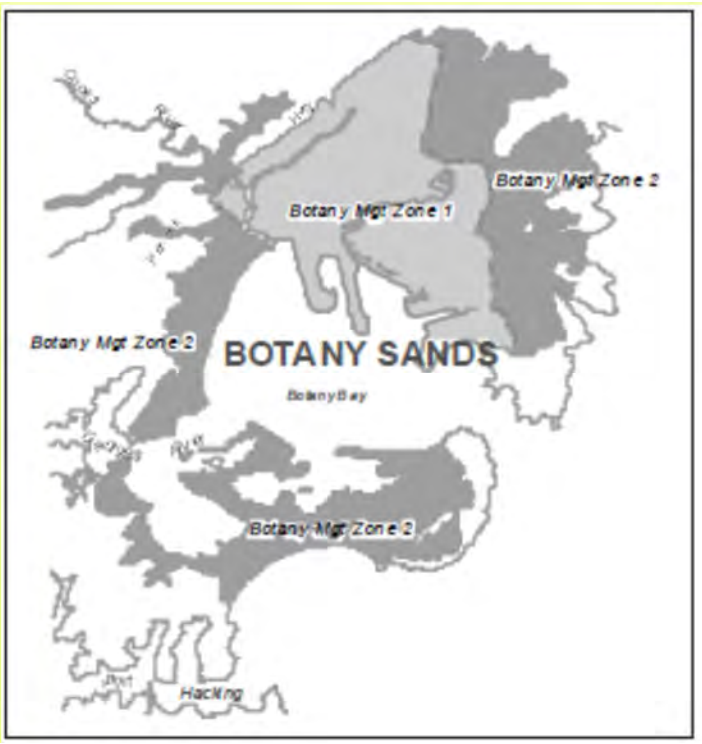


Figure 4-10 Extent of the Botany Sands Aquifer (NOW 2011)

4.8.3 Ashfield Shale

Although the Ashfield Shale does not outcrop along the project alignment and is not expected to be intersected by the tunnels, it is described because it occurs within the model domain. 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 forms an aquitard reducing groundwater infiltration to the underlying Mittagong and Hawkesbury Sandstone Formations. Groundwater quality within the shale is highly variable but is typically brackish or saline, due to the marine salts contained within the shale. The shale aquifer is characterised by low yields, limited storage and poor groundwater quality. Due to elevated salinity, low pH and the presence of sulphides the groundwater can be corrosive to the tunnel and associated infrastructure. Recharge to the shale is via direct rainfall recharge and runoff in elevated areas where the shale outcrops.

4.8.4 Mittagong Formation

Although the Mittagong Formation does not outcrop along the project alignment and is not expected to be intersected by the tunnels, it is described because it occurs within the model domain. 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. Recharge is via leakage from the Ashfield Shale or direct rainfall infiltration where the formation outcrops.

4.8.5 Hawkesbury Sandstone

The tunnel alignment is designed to allow the majority of the tunnels to be excavated within the Hawkesbury Sandstone as the engineering properties of the sandstone are suited to tunnelling. The Hawkesbury Sandstone is characterised as a dual porosity aquifer whereby 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. The hydraulic conductivity of the Hawkesbury Sandstone is low in the order of 10^{-3} to 10^{-1} metres per day and fracture related storage is less than two per cent although unconfined matrix storage can be higher. 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 fractures.

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

Groundwater within the Hawkesbury Sandstone is generally acidic but of low salinity. A basin wide salinity map (Russell 2007) indicates that groundwater within the Hawkesbury Sandstone in the study area is of much poorer quality water than in other areas of the basin. Elevated concentrations of dissolved iron and manganese naturally occur within the Hawkesbury Sandstone which can cause staining when discharged and oxidised. In tunnels groundwater ingress becomes oxidised causing the dissolved iron and manganese to precipitate forming sludge in drainage lines.

4.8.6 Structural features

The solid geology along the project footprint is expected to be cross-cut by dykes and possibly faults. Fault zones can have a significant impact on rock mass permeability and groundwater flow causing preferential flow paths, although not all structural features are saturated and hence transmissive. During construction, water-bearing fractures and faults can release groundwater initially when intersected, which will decline as the storage is depleted. Test pumping conducted during the construction of the WestConnex New M5 Motorway tunnels at Arncliffe has shown that fractures located beneath the Cooks River Palaeochannel are highly transmissive and interconnected which without grouting could yield unacceptably large volumes of groundwater into the tunnels (Yim *et al.* 2017).

The intersection of dykes during tunnel construction can either increase or decrease groundwater ingress to the tunnel depending on the weathering of the dyke and what units or structures it cross-cuts. Unweathered and non-fractured dykes or dykes that have been weathered to kaolinite can create a vertical or sub-vertical hydraulic barrier impeding groundwater flow. This can cause differential groundwater pressure across the dyke and potential groundwater ingress to the tunnel through the fractured sandstone. A fractured dyke cross-cutting water bearing structural features can provide a conduit for groundwater to flow directly into the tunnel.

4.8.7 Hydrogeological cross-section

A north-south oriented hydrogeological cross-section extending from St Peters to Sans Souci and Georges River to the south is presented on **Figure 4-11**. The section is based on boreholes and monitoring wells constructed during the investigation and shows the monitoring wells, screen intervals and nine model layers. The cross-section also presents the simplified geology, the water table and tunnel alignment for the project and New M5 Motorway.

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

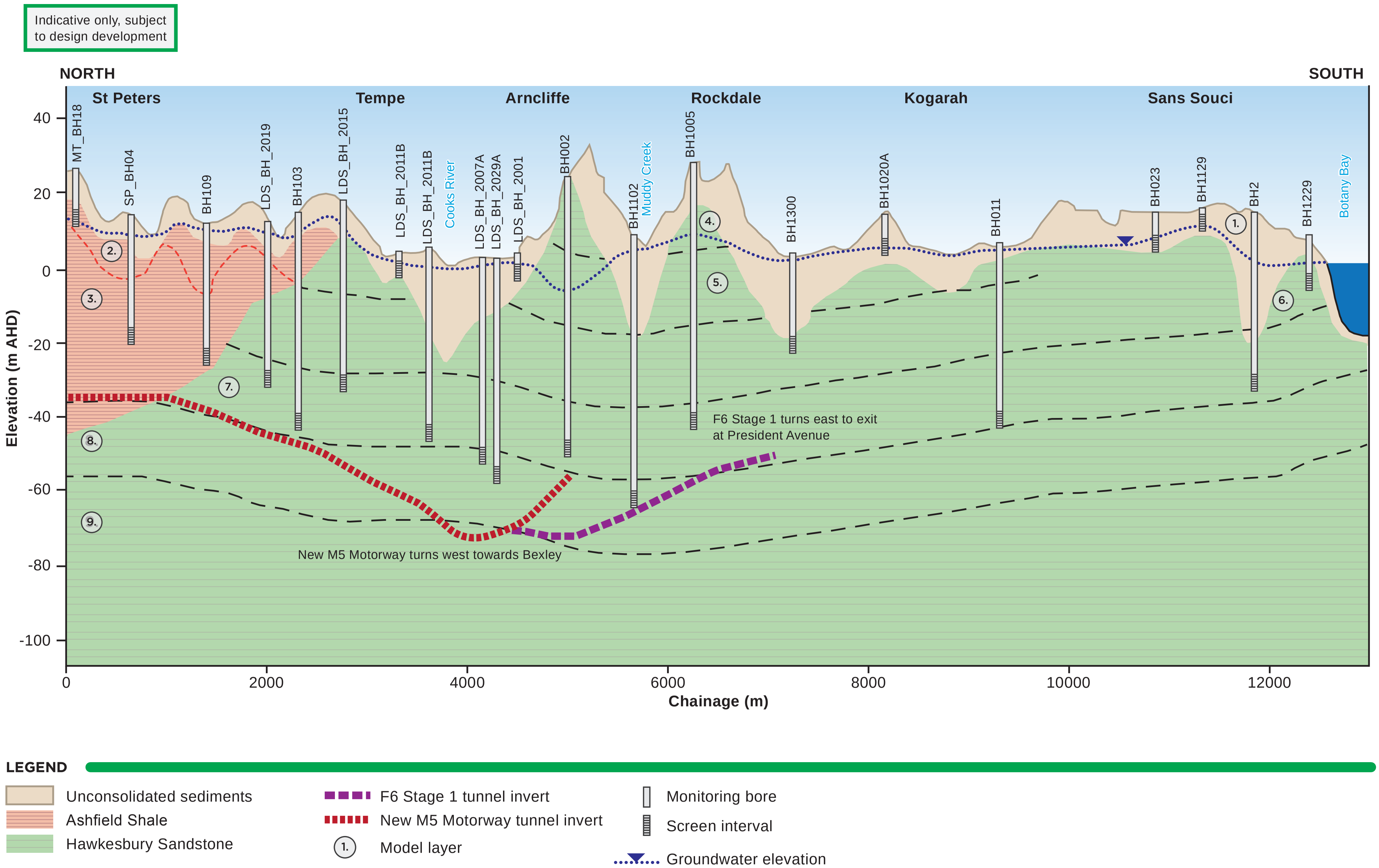


Figure 4-11 Hydrogeological cross section

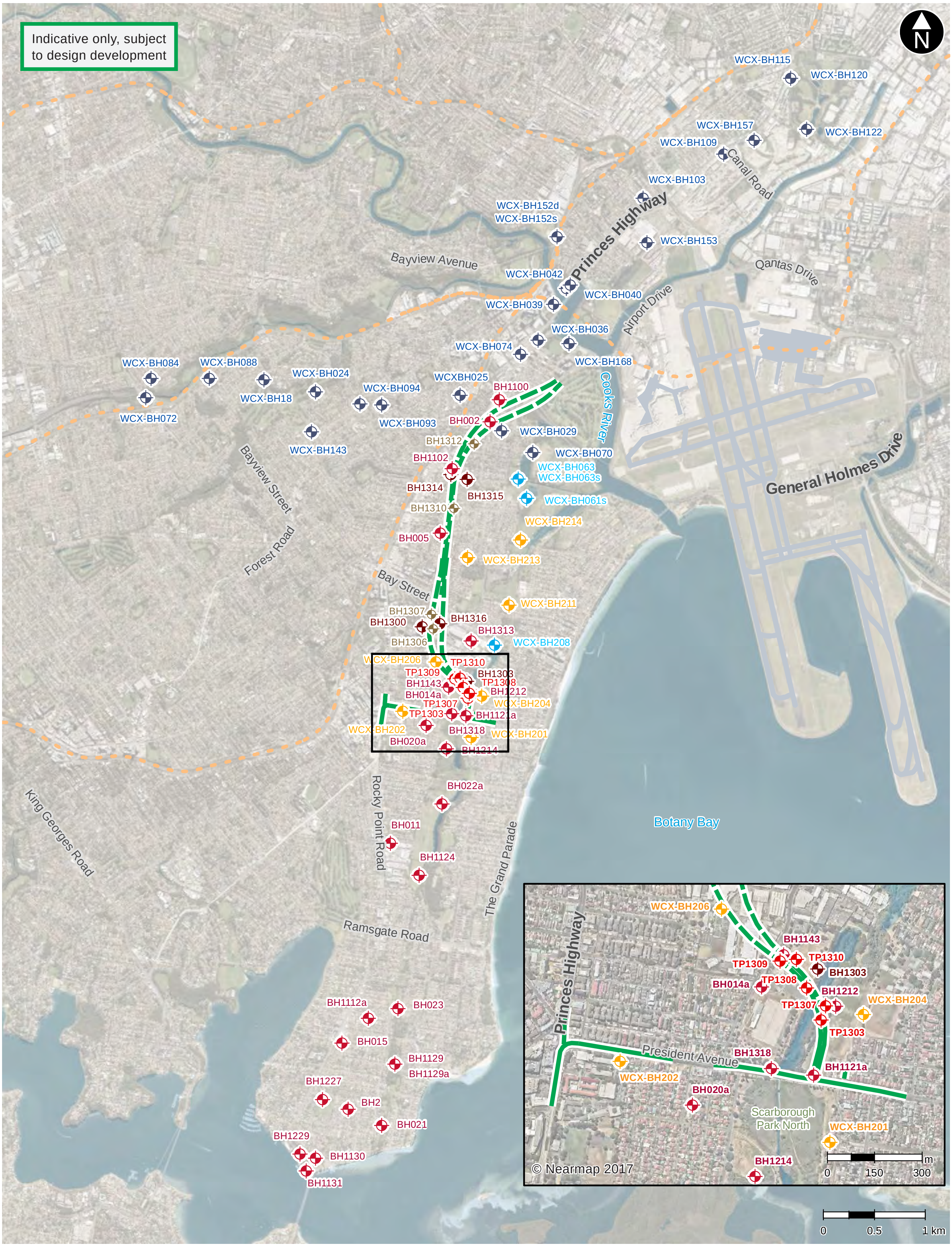
4.9 Groundwater monitoring network

Baseline groundwater monitoring has been conducted in a network of monitoring wells along the alignment and in the modelling domain as summarised in Table B1, **Annexure B**. Project borelogs are provided online as **Annexure G**. The location of monitoring wells is shown on **Figure 4-12**. The majority of monitoring wells have been constructed as open wells screened to intersect groundwater from the alluvium, Botany Sands, alluvium, Ashfield Shale and Hawkesbury Sandstone. This construction approach allows for groundwater level and groundwater quality monitoring to be undertaken. Monitoring well construction details are outlined in **section 3.3.3**.

The majority of wells are screened within the sandstone as this is the dominant rock formation intersected by the tunnels. Forty monitoring locations are constructed in the BH series of wells and piezometers (SMEC 2017 and 2018a). An additional 37 wells in the WCX series of wells were constructed along the New M5 Motorway alignment and within the model domain as part of the baseline monitoring for the New M5 Motorway project (Roads and Maritime 2015). Five wells (BH1315, BH1316,BH1112a BH1313 and BH1318a) constructed for the project by SMEC are screened across the alluvium and underlying sandstone (SMEC 2017 and 2018c). Monitoring well BH1303 is screened within the alluvium across the 10 to 13 metre and 16 to 19 metre intervals. All other wells were constructed with one screened interval that is generally three metres long.

The baseline monitoring consists of groundwater level monitoring and groundwater quality monitoring. Groundwater level monitoring was undertaken in monitoring wells manually with an electronic dip-meter and automatically as time-series data with dataloggers. Groundwater level monitoring is described further in **section 4.10**. Groundwater quality monitoring is discussed in **section 4.11**.

Vibrating wire piezometers were constructed in four boreholes (BH1306, BH1307, BH1310 and BH1312), inclined at 60º (SMEC 2018c) as shown on **Figure 4-12**. Sensors to monitor pore pressures within the Hawkesbury Sandstone were installed at corrected depths between 66.40 and 99.96 metres as outlined in Table B1, **Annexure B.** The piezometers were installed between December 2017 and February 2018, Groundwater elevations and pore pressures measured in these piezometers between December 2017 and March 2018 (SMEC 2018d) are presented in **Appendix C**. With the exception of BH1312, pore pressures have remained constant, while groundwater level elevations have shown variable declines from 0.000 metres (BH1307) to 5.0 metres (BH1312).



LEGEND

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

Figure 4-12 Location of monitoring wells

4.10 Groundwater levels and movement

Natural groundwater levels are influenced by topography, creeks, rainfall, recharge, evapotranspiration and man-made structures. Groundwater levels are related to the position of a well in the landscape, with the groundwater table typically being deeper beneath higher topographical areas and shallower in low lying areas. Groundwater flow directions and gradients are typically a subdued reflection of the surface topography, although groundwater flow within palaeochannels can be completely independent of the surface expression.

Locally, the water table can be impacted by infrastructure including groundwater resource pumping, localised temporary dewatering or passive pumping such as on-going groundwater ingress to drained tunnels along the M5 East and New M5 Motorway. Conversely, in some areas the local water table may be elevated above natural conditions due to irrigation at parks and golf courses. Deep subsurface structures that intersect the watertable such as building foundations can restrict or alter groundwater flow causing localised groundwater mounding.

Groundwater levels along the alignment and across the model domain have been collated from a variety of sources over various timeframes since 2015 and are summarised in Table B1, **Annexure B**. Despite the potential for seasonal variations to influence groundwater levels over time, the use of groundwater levels from different time periods between 2015 and 2017 is considered acceptable to provide a good estimation of piezometric and potentiometric heads across the model domain. It should be noted that the rainfall residual mass (**Figure 4-3**) is relatively stable indicating that there was little climatic variation over this period. Groundwater levels have been compiled from the WestConnex New M5 Motorway monitoring wells for the period November 2014 to October 2015 (Roads and Maritime 2015) with selected groundwater monitoring wells along the project alignment compiled for the period November 2014 to April 2017 (AECOM 2017a). Groundwater levels monitored from August 2016 to September 2017 were compiled from eleven wells along the project alignment (SMEC 2017), and for levels monitored from October to December 2017 in a further five wells, located in Banksia, Rockdale and Kogarah (SMEC 2018a).

The depth to groundwater, groundwater flow directions, the distribution of piezometric and potentiometric heads for each aquifer is discussed in more detail in **sections 4.10.2** to **4.10.4**. Historical standing water levels within the groundwater monitoring network are summarised in Table B2, **Annexure B**.

4.10.1 Regional groundwater flow

Groundwater flow within the Sydney Basin is complex and is controlled by many geological features including lithology, structural features and basin morphology. Regionally, groundwater flow within the Hawkesbury Sandstone and the Wianamatta Group is predominately fracture controlled. Flow is directed towards the central part of the basin that is generally beneath Sydney Harbour and the Sydney CBD (McKibbin and Smith 2000). Thus in general, the regional groundwater flow direction through the project footprint is expected to be northwards or north easterly with groundwater ultimately discharging offshore into the Pacific Ocean. On a more localised scale, groundwater movement is controlled by the elevation of the water table (hydraulic head), potentiometric heads and the hydraulic gradient which is a subdued expression of the topography.

The Hawkesbury Sandstone is a series of sandstone layers interbedded with low permeability shales and siltstones that form a series of partially confined or confined localised aquifers rather than a massive 300 metre thick sandstone unit. Groundwater can flow between these layers via fractures and joints hydraulically linking these sub-aquifers, however the degree of connectivity is variable with different sandstone layers exhibiting different hydraulic heads throughout the whole sandstone sequence. The groundwater within the upper unconfined layer of the sandstone is known as the water table, whereas the lower partially confined sub-aquifers with variable hydraulic heads are more correctly known as the potentiometric surface. Groundwater movement is anisotropic due to the groundwater flow being dominated by vertical flow rather than horizontal flow due to the fracture controlled systems.

Along the project footprint, alluvium flanks the creeks and underlies the Rockdale Wetlands. Within the shallow alluvium flanking creeks, groundwater is typically unconfined and flowing parallel to the creek. In the deeper palaeochannels, groundwater flow is independent of the upper surficial alluvium and flows along the axis of the palaeochannel, discharging into the ocean. Groundwater flow within the Botany Sands aquifer located east of the tunnel alignment is mainly eastward towards Botany Bay with minor components of flow to the Cooks and Georges Rivers (Hatley 2004).

4.10.2 Alluvium

Groundwater levels within the alluvium are primarily controlled by local recharge and discharge conditions. Shallow alluvium flanks the major waterways and underlies the Rockdale Wetlands. Alluvium also infills the palaeochannels as part of the Botany Sands and the Botany Sands outcrop to the east adjacent to Botany Bay.

Groundwater levels have been monitored in the Botany Sands and palaeochannels in ten wells and for this discussion are considered together. The measured groundwater levels are shallow, ranging between 0.77 mAHD (WCX-BH61s) to 2.72 mAHD (BH1314) with one exception. This exception is a groundwater level of 4.75 mAHD (BH1314) which is slightly higher than other water levels because this well is located towards the western edge of the palaeochannel where the underlying bedrock is slightly elevated. Groundwater flow within the palaeochannels is along the axis of the channel, discharging into Botany Bay.

Groundwater levels measured in a nested well intersecting the Botany Sands and Hawkesbury Sandstone at the Eve Street Wetland (WCX-BH61s Table B1 **Appendix B**) differ by only 0.06 metres indicating there is little difference in hydraulic head between the sandstone and overlying Botany Sands.

Fourteen monitoring wells are constructed across the project study area within the shallow alluvium as distinct from the Botany Sands. With one exception, groundwater levels are shallow, ranging from 0.53 mAHD (BH22a) to 1.49m AHD, similar to the Botany Sands. The exception is BH020a (4.47 mAHD) which is located towards the western edge of the alluvium where the underlying bedrock becomes higher. The shallow alluvium is typically low lying as it is connected to surface water within the creeks or wetlands. In areas of widespread filling, such as parts of the Rockdale wetlands, there may be some perched groundwater within the fill, however discharge of perched groundwater would be controlled by local drainage zones that are likely to respond to rapid, short term, rainfall events.

Groundwater flow within the shallow alluvium is southward following the axis of the Rockdale wetlands, discharging into some of the wetlands or further south into the Georges River. In contrast, groundwater flow within the deeper palaeochannel and Botany Sands either follows the axis of the channel or follows the hydraulic gradient and flows eastward discharging into Botany Bay.

Groundwater contours within the alluvium based on December 2017 measured groundwater levels have been interpolated by and are presented in **Figure 4-13**.

4.10.3 Hawkesbury Sandstone

Groundwater level elevations within the Hawkesbury Sandstone across the project alignment and model domain are highly variable, ranging from -27.46 mAHD (BH1100) at Arncliffe to 28.15 mAHD (WCX-BH094a), also located at Arncliffe. This large variation is attributed to the complex and interconnected fracture network within the various layers of the sandstone. Based on December 2017 measured groundwater levels, groundwater contours within the Hawkesbury Sandstone have been interpolated and are presented in **Figure 4-14**.

Review of the groundwater level contours shows that the dominant groundwater flow direction is easterly towards Botany Bay. Elevated groundwater levels are centred on Bexley and Bardwell Park, with low levels below 0 mAHD at Arncliffe and Wolli Creek. Locally, groundwater levels within the Hawkesbury Sandstone are depressed along the M5 East alignment due to groundwater leakage into the M5 East tunnels.

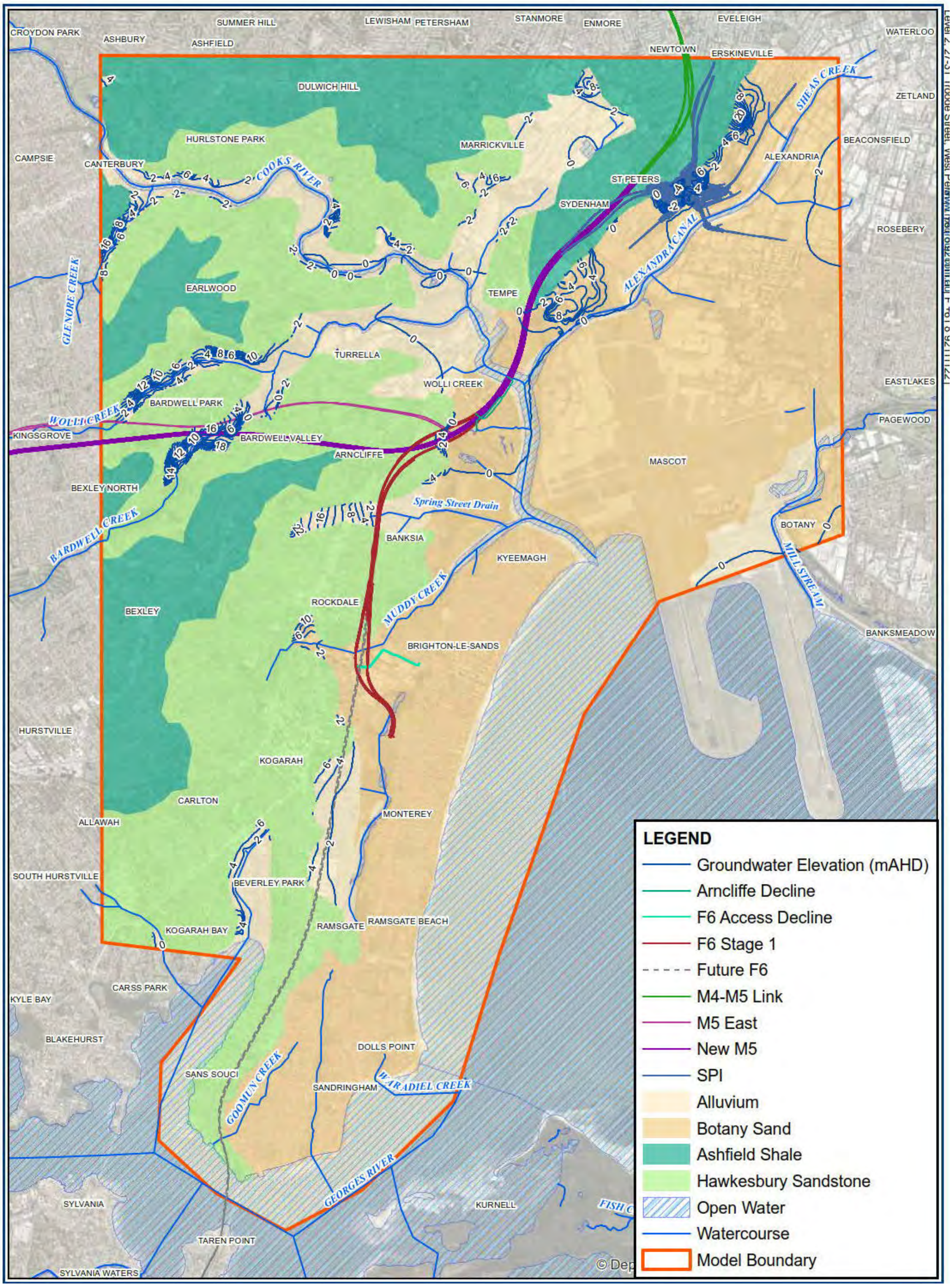


Figure 4-13 Groundwater contours in the Botany Sands and alluvium (RPS 2018)

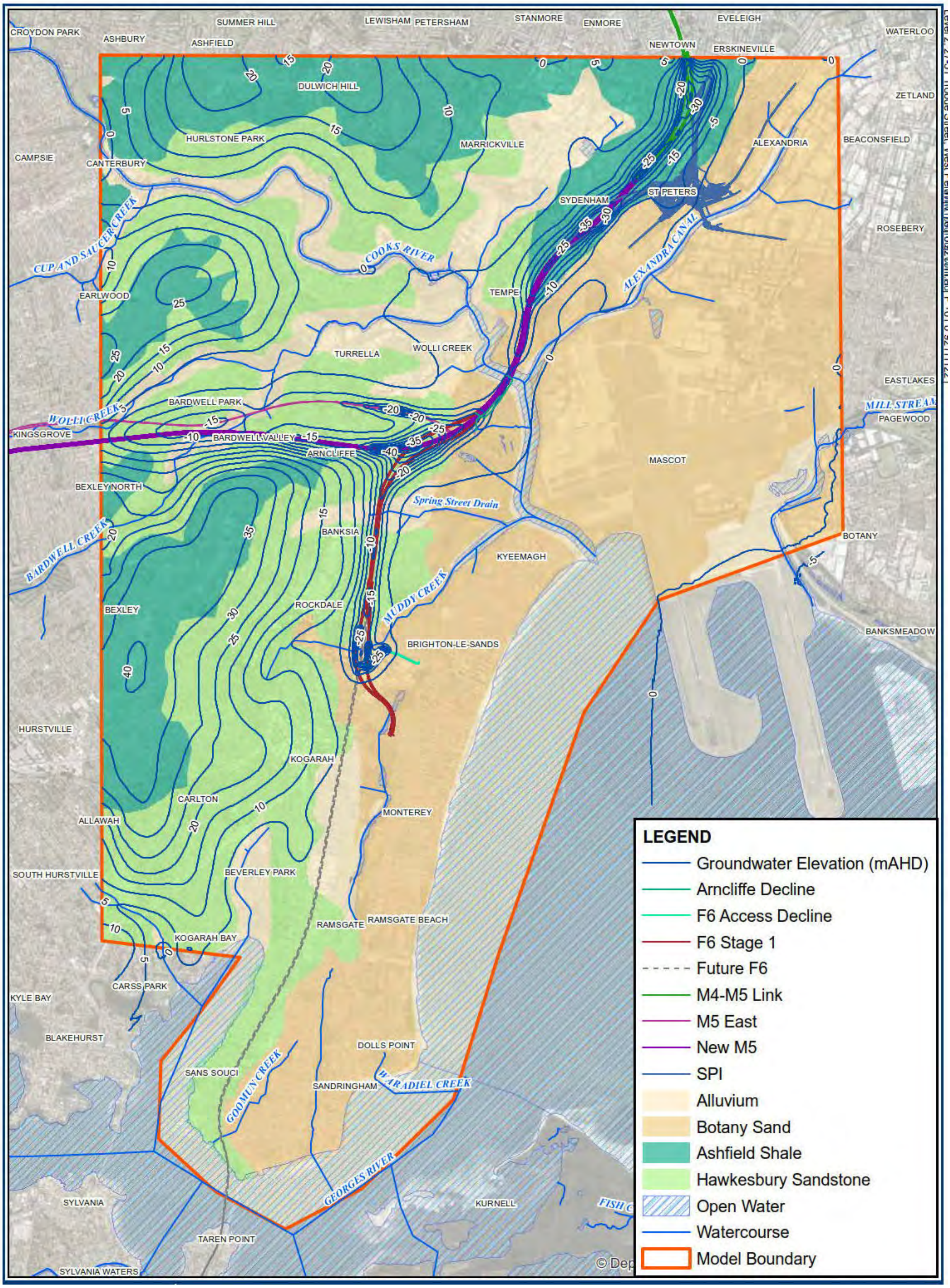


Figure 4-14 Groundwater contours in the Hawkesbury sandstone (RPS 2018)

4.10.4 Time series groundwater level trends

Groundwater levels have been automatically monitored on an hourly basis by data loggers in selected wells in the groundwater monitoring network as outlined in **section 4.9**. The data has been corrected for barometric pressure effects and plotted as hydrographs relative to metres AHD. The resultant hydrographs displaying groundwater level trends within the alluvium, Ashfield Shale and Hawkesbury Sandstone are compared to rainfall and are presented in **Annexure C**. Hydrographs are presented for the New M5 Motorway series of wells from October 2014 through to November 2015 (Roads and Maritime 2015) with the wells along the project alignment extending from October 2014 to April 2017 (AECOM 2018). Hydrographs developed from the BH series of monitoring wells, constructed as part of the F6 Extension project field investigation, monitor groundwater levels from August 2016 to March 2018 (SMEC 2018b).

Review of the hydrographs indicates there are at least three natural processes that influence the plots:

- Diurnal fluctuations due to tidal or barometric pressure fluctuations
- Short term response to specific rainfall events
- Long term trends related to the departure of rainfall trends from average conditions.

No anthropogenic features such as impacts due to irrigation, pumping or passive discharge to unlined subsurface structures were detected.

Groundwater level fluctuations within the alluvium are monitored in three monitoring wells from the New M5 Motorway series and ten monitoring wells in BH series. The hydrographs show that the groundwater levels fluctuating in the alluvium respond to tidal activity, and levels rise quickly following significant rainfall. For example at BH201 located at Scarborough Park, Monterey, groundwater levels fluctuated over an amplitude of 1.0 metre between November 2014 and April 2017. Superimposed over the climatic and seasonal fluctuations are variable tidal fluctuations ranging from 1 to 2 millimetres. Similarly at BH020a located at Oakdale Avenue, Kogarah, west of Rockdale Wetlands, the groundwater level has varied over an amplitude of 2.2 metres, responding rapidly to rainfall. The water level trend follows the monthly rainfall residual mass trend suggesting the watertable responds to climatic variation.

Groundwater level fluctuations within the Ashfield Shale have been monitored in four monitoring wells (WCX_BH109, WCX_BH115, WCX_BH122 and WCX_BH157) located to the north of the project alignment at Alexandria and St Peters. The hydrographs produced between November 2014 and October 2015 indicate that the water levels within the shale vary over a similar amplitude to the alluvium, in the order of 1 to 1.5 metres, and are also influenced by tidal fluctuations. Groundwater recharge is slower within the shale than in the alluvium as shown in WCX_ BH122, located at St Peters, where high rainfall in excess of 240 mm over three days in April 2015 took several days for groundwater levels to reach their highest point.

The majority of hydrographs prepared monitor groundwater fluctuations within the Hawkesbury Sandstone along the project alignment and within the model domain. Review of these hydrographs indicates that the majority are influenced by tidal oscillations and that the water level generally rises rapidly after rainfall and declines following periods of low rainfall. The amplitude of water level fluctuations measured in the BH series between July 2016 and August 2017 varies from 0.6 metres (BH1130) and 1.2 metres (BH1102). Similar groundwater level trends were identified in the WCX series monitored between March 2015 and April 2017 with the groundwater level amplitude varying from 0.7 metres (WCX_BH211) to 1.6 metres (WCX_BH202). There does not seem to be any other external influences such as pumping or localised dewatering affecting the levels in the aquifer. The relatively small groundwater level amplitude indicates that the Hawkesbury Sandstone groundwater system is in equilibrium with the components of the hydrogeological regime, whereby recharge (primarily rainfall infiltration) and discharge (primarily discharge to creeks and evapotranspiration) are balanced. The groundwater level trends within the Hawkesbury Sandstone tends to follow the rainfall residual mass curve indicating that groundwater levels fluctuate in accordance with long term climatic variation.

4.11 Groundwater quality monitoring

Groundwater quality monitoring results along the alignment have been collated from routine monitoring conducted for the project (SMEC 2017 and 2018) and earlier monitoring conducted as part of the New M5 Motorway project (Roads and Maritime 2015). Routine water quality monitoring commenced in March 2015 in the WestConnex New M5 Motorway monitoring wells and continued throughout 2016 and 2017 in the F6 Extension monitoring network. Monitoring will continue during construction and for at least one year into the operations phase or as directed by project approvals. Groundwater contamination monitoring undertaken as part of this investigation along the alignment is discussed in **section 4.16**.

The groundwater quality sampling program included the following analytes:

- Field parameters (temperature, dissolved oxygen, electrical conductivity, pH and redox conditions)
- Major ions (calcium, magnesium, sodium, potassium, chloride, sulfate, carbonate and bicarbonate)
- Metals (arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, zinc, manganese and iron)
- Nutrients (nitrite as N, nitrate as N, reactive phosphorous and ammonia).

The purpose of the groundwater quality monitoring program is to:

- Characterise the existing hydrogeochemistry in the alluvial and sandstone aquifers along the project footprint
- Establish the environmental value and beneficial use of groundwater along the project footprint under existing conditions
- Develop a groundwater quality baseline dataset along the project footprint to inform the EIS
- Characterise the potential aggressiveness of the native groundwater to the building material used to construct the project infrastructure
- Obtain a preliminary understanding of the groundwater and surface water treatment requirements required prior to discharge during the construction and operation phases.

4.11.1 Groundwater assessment criteria

The groundwater quality criteria have been developed in accordance with guidelines from the Australian and New Zealand Environment Conservation Council (ANZECC 2000). For highly disturbed receiving environments such as those that could be impacted by the project, ANZECC (2000) recommends that suitable guidelines for groundwater quality trigger values can be derived from a local reference data set for nutrients, dissolved oxygen and pH. For toxicants (such as heavy metals or organic chemical compounds), the water quality requirements should be consistent with the 95 per cent protection level for freshwater ecosystems (Table 3.4.1, 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. The adopted guideline values are presented in Table B5, **Annexure B**.

To assess the potential impacts of groundwater to building materials, dissolved sulfate, chloride and pH values are assessed against the aggressivity criteria outlined in the exposure classification criteria for concrete and steel piles presented in Australian Standard (2010).

4.11.2 Field parameters

Groundwater field parameters monitored throughout the field programs are summarised in Table B3, **Annexure B**. Measured groundwater temperatures varied over a narrow range between 19.6 and 22.1°C. Seasonally, groundwater temperatures are expected to vary by one or two degrees, although there was no variation between aquifers. Redox conditions were also variable along the project footprint ranging from -196mv in the sandstone (BH1300) through to 140 mv in the alluvium (BH1314).

Measurement of the electrical conductivity within the alluvium was variable ranging from 254 microsiemens per centimetre (µS/cm) (BH1314) to 17,100 µS/cm (WCX_BH201). Elevated electrical conductivity values in excess of 10,000 µS/cm in wells BH1303 (12,780 µS/cm), WCX_BH201 and (17,100 µS/cm) is attributed to tidal mixing with groundwater. The groundwater in the remainder of the alluvial wells is generally below 3000 µS/cm suggesting the alluvium is recharged by rainfall infiltration with minimal tidal interaction. Electrical conductivity values measured within the Hawkesbury Sandstone are similar to those measured within the alluvium ranging from 516 µS/cm (WCX_BH063) to 10,400 µS/cm (WCX_BH202). As for the alluvium the range of results is attributed to the degree of tidal mixing with rainfall infiltration and leakage from the overlying alluvium.

Measured values of pH in the alluvium and the Hawkesbury Sandstone range from 5.07 (BH1314) to 12.4 (WCX_BH202). Some elevated pH levels in excess of ten have been recorded in monitoring wells, which are attributed to cement grout entering the well screen through the bentonite seal that had not formed a sufficient hydraulic seal. In most cases, additional well development was successful in reducing pH levels. Natural pH levels within the Hawkesbury Sandstone are mildly acidic, generally ranging from pH 5 to 6.5.

4.11.3 Major ions

Major cations (calcium, magnesium, sodium and potassium) and major anions (chloride, sulfate, carbonate and bicarbonate) have been routinely sampled and are tabulated in Table B4, **Annexure B**. The data has also been plotted on Piper diagrams for each aquifer to assess the hydrogeochemical distribution of major ions to determine if there are any temporal or spatial variations. Piper diagrams for the alluvium, Hawkesbury Sandstone and wells intersecting both aquifers are presented in **Annexure E**. Each plot has been compared to the composition of seawater and in each case there is little correlation, indicating that the tidal influences on the groundwater hydrogeochemistry are minor.

The distribution of major cations and anions within the alluvial groundwater is presented in Figure F1 in **Annexure E**. Analysis of the results indicate the groundwater is low in magnesium and sulfate with variable proportions of calcium, sodium, potassium, carbonate, bicarbonate and chloride. The variable proportion of calcium is attributed to variable amounts of shells within the alluvial sands. Similarly the variable proportions of sodium and chloride is attributed to the variable mixing of tidal waters with groundwater. At monitoring wells BH1303 and BH1314 sampling was repeated in November and December 2017 and in WCX_BH63a in March and November 2015. Analysis of these results indicates there is considerable variation between monitoring events, indicating natural variation.

The distribution of major cations and anions within the Hawkesbury Sandstone groundwater is presented in Figure F2 in **Annexure E**. Analysis of the results indicate the groundwater is dominated by sodium and chloride which is attributed tidal influences and interaction with sea water. As for the alluvium the groundwater in the Hawkesbury Sandstone has low proportions of magnesium and sulfate. In monitoring wells WCX_BH063 and BH1300 analyses were duplicated in March and November 2015 and November and December 2017 respectively. Analysis of these duplicated results indicate very little natural seasonal variation.

The distribution of major cations and anions in groundwater for four wells intersecting the alluvium and Hawkesbury Sandstone is presented in Figure F3 in **Annexure E**. Analysis of these results indicate that although the majority of the well screens intersect the alluvium the groundwater hydrochemistry is dominated by the Hawkesbury Sandstone type waters rather than the alluvium.

4.11.4 Heavy metals

Groundwater has been monitored monthly for 10 dissolved metals including arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc in the alluvial and Hawkesbury Sandstone aquifers. The analytical results are presented in Table B5 in **Annexure B** along with the adopted groundwater guidelines. Since groundwater discharges into the Cooks River and the lower lying areas are tidal, the ANZECC 2000 guidelines for freshwater (95 per cent level of protection) are considered the most appropriate.

Within the alluvial groundwater, measured background metals concentrations have exceeded the adopted groundwater concentration guideline for As, Fe, Pb, Mn, and Zn. In most cases the guidelines have been marginally exceeded, indicating that background levels are naturally elevated. However the alluvial groundwater consistently has elevated iron, manganese and zinc.

Within the groundwater derived from the Hawkesbury Sandstone, natural measured metals concentrations have exceeded the guideline concentration value for As, Cr, Cu, Fe, Pb, Mn, Ni and

Zn. Cr, Cu, Fe, Pb, Mn, Ni and Zn. In most cases the guidelines have been marginally exceeded however the concentrations of manganese, iron and zinc are consistently elevated. Dissolved iron and manganese in groundwater are known to be elevated within the Hawkesbury Sandstone, McKibbin and Smith (2000) and often cause red-brown or black staining or sludge when the groundwater becomes oxidised and the metals precipitate. Sources of iron include siderite (iron carbonate) and iron oxyhydroxides and oxides (McLean and Ross 2009). The consistent exceedance of dissolved zinc across the model domain suggests the elevated dissolved zinc concentrations are at background levels.

4.11.5 Nutrients

Nutrients including nitrite as N, nitrate as N, ammonia and reactive phosphorous have been measured in the alluvial and Hawkesbury Sandstone aquifers. The analytical results are presented in Table B4 in **Annexure B.**

Within the alluvium, nitrite and nitrate concentrations ranged from below detection limits to 0.19 and 1.9 mg/L respectively. In comparing these results to the amended *Australian Drinking Water Guidelines* (NHMRC 2015) nitrite and nitrate concentrations are below the health criteria of three and 50 mg/L indicating background nutrient levels are low. Reactive phosphorous as P concentrations ranged from below detection limits to 0.4 mg/L indicating phosphorous levels are also low. Ammonia concentration values in the alluvium range from 0.01 to 63 mg/L exceeding the guideline value of 0.91 mg/L. Elevated dissolved ammonia recorded at BH014 (63 mg/L) may be due to a former landfill located nearby in Banksia. Similarly, elevated ammonia concentrations were identified in BH1300 (1.1 mg/L), BH1303 (2 mg/L), BH1313 (7.4 mg/L) and BH1318 (33 mg/L) located within Rockdale Bicentennial Park where former landfilling activities have occurred. In contrast, elevated dissolved ammonia recorded at WCX_BH063a is attributed to natural decaying vegetation associated with the Eve Street Wetland. The use of fertilisers in parklands constructed over the alluvium and infilled wetlands is also likely to impact dissolved nutrient concentrations.

Dissolved nitrite and nitrate concentrations in groundwater derived from the Hawkesbury Sandstone range from below detection limits to 0.05 and 1.7 mg/L respectively. In comparing these results to the *Australian Drinking Water Guidelines* (NHMRC 2015) nitrite and nitrate are below the health criteria of 3 and 50 mg/L indicating nutrient levels are low. In comparison to the overlying alluvium, nitrite and nitrate concentrations in the Hawkesbury Sandstone are significantly lower. Ammonia values are relatively consistent ranging from 0.039 to 1.96 mg/L. Phosphorous as P ranged from below detection limits to 0.08 mg/L indicating phosphorous levels are very low.

4.11.6 Groundwater aggressivity

An assessment of groundwater aggressivity has been conducted to better understand the corrosive nature of the natural groundwater intersected to assist in selecting building materials to minimise corrosive impacts on the tunnel and its infrastructure. The corrosion assessment applies to infrastructure to be constructed with concrete and steel below the water table. The assessment has been conducted by collating the major ion chemistry and hydrogeochemical parameters including pH, resistivity, sulfate and chloride concentrations by application of the exposure classification in the Australian Standard AS2159-2009 (AS2159-2009) for piling. The calculated groundwater aggressivity to concrete in the alluvium and sandstone is presented in Table B6 in **Annexure B** and for aggressivity to steel in Table B7 in **Annexure B**.

By application of the water classification for concrete piles in AS2159-2009 and applying the values from Table B6, **Annexure B** groundwater aggressiveness has been assessed and the results are summarised in **Table 4-4** for the alluvium and Hawkesbury Sandstone. The aggressivity assessment indicates that groundwater within the alluvium and Hawkesbury Sandstone is mildly aggressive with respect to average chloride, pH and sulfate to concrete piles.

The aggressivity of groundwater to steel piles has also been assessed by application of the water classification for steel piles in AS2159-2009. With reference to the values from Table B7, **Annexure B** the groundwater within the alluvium and Hawkesbury Sandstone as summarised in

Table 4-4 is non aggressive with respect to chloride and pH, however the groundwater is severely aggressive to steel with respect to resistivity.

Further assessment would be required at locations where project infrastructure sensitive to groundwater is to be constructed.

Table 4-4 Groundwater aggressivity assessment

Aquifer aggressivity	Cement grout			Steel		
	Chloride	pH	Sulfate	Chloride	pH	Resistivity
Alluvium	Mild	Mild	Mild	Non-aggressive	Non-aggressive	Severe
Hawkesbury Sandstone	Mild	Mild	Mild	Non-aggressive	Non-aggressive	Severe

4.12 Groundwater extraction

A review of bores registered with DI-Water accessed through the Bureau of Meteorology (10 January 2018) and the PINNEENA groundwater database identified 373 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 DI-Water. The distribution of registered boreholes extracted from the database is shown on Figures D1 to Figure D13 in **Annexure D** and are tabulated and presented in Table D1 in **Annexure D**. The majority of registered bores are shallow spearpoints intersecting alluvium of the Botany Sands aquifer (362). Two bores intersected the Hawkesbury Sandstone. For the remaining nine bores the lithology was not recorded. The groundwater extracted is generally described as good quality with an average yield of between 0.5 and 1 L/sec recorded by drillers.

The purpose for each bore is recorded in the database and is summarised in **Table 4-5**. The majority of bores are shallow spearpoints constructed for domestic purposes with others constructed for monitoring, irrigation and industrial purposes.

Table 4-5 Summary of DI-Water registered bores within two kilometres of the project footprint

Purpose	Number of bores	Predominant lithology	Standing water level min1	Standing water level max1	Bore depth min1	Bore depth max1
Domestic	345	Alluvium	1.22	7.30	2.0	15.0
Recreation/irrigation	15	Alluvium	0.70	14.0	4.5	90.5
Monitoring	9	Alluvium	1.24	1.80	3.5	17.5
Test bore	2	Sandstone	1.83	4.0	4.6	162
Unknown	2					
Total	373					

Notes:
1 Metres below ground level

The two deepest bores GW072161 and GW111316 at depths of 90.5m and 162.0 metres both intersect Hawkesbury Sandstone. At GW111316 37 metres of sand overlies the Hawkesbury Sandstone.

The groundwater modelling has been applied to quantify potential impacts on these registered bores due to the project (see **Chapters 5** and **6** for further information).

Groundwater usage within the Botany Sands aquifer is relatively high because groundwater can be extracted at no cost (other than borehole establishment and pumping costs) for domestic purposes. The water is typically used to water lawns and gardens. In contrast, groundwater quality within the Hawkesbury Sandstone is generally good but usage is low along the project footprint because the groundwater is more difficult to extract when compared to access to reticulated water.

The project does not propose to extract groundwater during the construction or operational phases for project purposes. Groundwater reuse will be considered in accordance with policies of sustainable water use of DI-Water (National Water Quality Management Strategy 2006).

4.12.1 Groundwater extraction entitlements

At a macro scale, the project footprint is located within Sydney Basin Central as part of the Greater Metropolitan Region Groundwater Resources Water Sharing Plan (NoW 2011). The Botany Sands aquifer intersects the project footprint to the east and has been included in the discussion as the aquifer is likely to be impacted by the project. Within the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources, groundwater is to be extracted from the Sydney Basin Central and the Botany Sands aquifer as outlined in **Table** 5-1. The AIP (NoW 2012) is addressed in **sections 9.1** and **9.2.**

The Sydney Basin Central Water Source covers an area of 3,758 square kilometres, receives an annual rainfall of 3,820,386 megalitres per year and, with an estimated infiltration rate of six per cent, the estimated average annual rainfall recharge is 229,223 megalitres per year (Table 7, NoW 2011). Based on water that is potentially available for extraction, NoW (2011) assessed that the sustainability of groundwater extraction from the Sydney Basin Central is of moderate environmental risk.

By contrast, the Botany Sands Water Source covers an area of 91 square kilometres, receives an annual rainfall of 101,413 megalitres per year and, with an estimated infiltration rate of thirty per cent, the estimated average annual rainfall recharge is 30,424 megalitres per year (Table 7, NoW 2011). The sustainability of groundwater that is potentially available for extraction within the Botany Sands groundwater resource has been assessed as to be of moderate environmental risk. Within the Botany Sands aquifer in Management Zone 2 (**Figure 4-10**) on the north western edge of Botany Bay commercial extraction has been embargoed but the groundwater can still be used for industrial and domestic purposes.

Based on the estimated recharge and the existing groundwater extraction licences at the commencement of the water sharing plan (July 2011), the long term average annual extraction limits (LTAAEL) have been calculated by NoW and are presented in **Table 4-6**. The LTAAEL is an estimated sustainable extraction limit for each of the groundwater sources, based on the annual rainfall recharge that may be sustainably released for use.

Table 4-6 Groundwater extraction and entitlement limit

Groundwater source	Entitlement (ML/ year)	LTAAEL (ML/yr)	Approximate number of existing licences[1]
Sydney Basin Central	2,592	45,915	120
Botany Sands	11,156	14,684	80

Notes:
1 Based on the commencement of the water sharing plan (July 2011)

4.13 Regional hydraulic parameters

The hydraulic properties across the project footprint within the Sydney Basin have been collated from previous investigations and published data. Realistic hydraulic parameters are required for input into the numerical groundwater modelling and then these are refined as the model is calibrated. The hydraulic properties of the various hydrogeological units are discussed below and the model ranges are presented in **Annexure F**. Site specific hydraulic conductivity tests by slug testing was conducted for the project (SMEC 2018).

4.13.1 Alluvium and fill

Alluvium flanking rivers and creeks and infilling palaeochannels are composed of silts and clays weathered from the Hawkesbury Sandstone and Ashfield Shale. 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 10 metres per day for sandy alluvium. Five slug tests were conducted along the alignment within the alluvium with the hydraulic conductivity results ranging from 0.08 to 12.4 m/day. Similarly the hydraulic conductivity of alluvium in a similar depositional environment associated with Wolli Creek is noted to be between 0.2 and 0.8 metres per day based on slug tests (CDM Smith 2016).

4.13.2 Wianamatta Group Shale

The bulk hydraulic conductivity range of the Wianamatta Group Shale varies from 0.0001 to 0.01 metres per day for fresh rock, increasing to 0.0001 to 0.1 metres per day for weathered shale (Hewitt 2005). Russell *et al.* 2009 indicates there is a general lack of hydrogeological permeability data for the Ashfield Shale possibly due to the unit having poor resource potential. Laboratory investigations of drill core undertaken during the M4-M5 Link hydrogeological investigations measured the porosity of the shale as 5.6 precent (Roads and Maritime, 2017a).

4.13.3 Hawkesbury Sandstone

The hydraulic properties of the Hawkesbury Sandstone are reasonably well known because it has been investigated over the years due to its high resource potential. The hydraulic conductivity within the Hawkesbury Sandstone is related to defect characteristics which are influenced by depth and *in situ* stress conditions. Hydraulic conductivity tends to decrease with depth mainly due to decreasing sub-horizontal defect apertures (Tammetta and Hewitt,2004). An analysis of packer test data for the Hawkesbury Sandstone confirms the relationship of a reduction in geometric mean hydraulic conductivity with depth (Tammetta and Hawkes 2009). More recently, groundwater resource investigations initiated by the Millennium Drought and centred on the Hawkesbury Sandstone have identified structurally deformed areas which have bore yields up to 30 litres per second (Ross 2014).

Hewitt (2005) estimates the hydraulic conductivity of the Hawkesbury Sandstone ranges from 0.1 metres per day at ground surface decreasing to around 0.001 metres per day at a depth of around 50 metres. McKibbin and Smith (2000) quote a hydraulic conductivity range for the Hawkesbury Sandstone between 0.01 and1 metre per day and note that values in excess of 0.1 metres per day are probably associated with fracture permeability. Values of hydraulic conductivity within the State Government database may be on average higher as quoted hydraulic parameters are often associated with resource works which are typically higher yielding.

Regionally there is a hydraulic conductivity anisotropy where the horizontal (K_h) is typically greater than the vertical (K_v) by up to two orders of magnitude or more. An analysis of laboratory testing and packer tests undertaken during the M4-M5 Link groundwater investigation confirmed that K_h exceeded K_v by two orders of magnitude (Hawkes, 2017). In addition porosity within the Hawkesbury Sandstone was measured between 11.3 and 19.2 percent. Literature values for specific storage range from $1x10^{-5}$ to $1x10^{-4}$ m^{-1} (Hawkes, Ross and Gleeson 2009) and $3.7x10^{-3}$ to $1x10^{-1}$ m^{-1} (Tammetta and Hewitt, 2004).

4.13.4 Hydraulic conductivity testing

In situ water pressure (packer) testing was undertaken in selected boreholes to assess hydraulic conductivity of the Hawkesbury Sandstone within the project footprint in both field programs. The packer tests also give an indication where groundwater inflows into the tunnels could be expected. *In situ* hydraulic conductivity results predominately represent horizontal water movement (K_h) through the aquifer. The water pressure testing was carried out in accordance with established procedures set out in Fell *et al*. (2005) or using the Burgess/Snowy Method as detailed in Burgess et al, 1983, *In situ* Permeability Testing in Soil and Rock. Packer tests are conducted by the drilling contractors by 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.

Packer testing was performed over selected intervals using a single stage pneumatic HQ packer and calibrated flow meters provided by the drilling contractor. Water pressure testing was carried out in 40 boreholes (uncased as distinct from monitoring wells) with multiple tests performed in each borehole as shown in **Figure 4-15**. Each test was typically carried out in five different pressure stages (three increasing and two decreasing stages), at the nominated test interval (typically about three, six, nine or 12 metres). Where inclined holes were tested, the test section was corrected to represent the vertical depth interval.

The packer test results provide a bulk hydraulic conductivity for the intervals measured including horizontal and vertical features and the rock matrix. The defects tend to decrease with depth as the surficial pressure influences decrease as shown in **Figure 4-16**.

The hydraulic conductivity has been measured by conducting 56 packer tests in 40 boreholes. The location of boreholes where packer tests were conducted is shown on **Figure 4-15**.

The packer test results are presented in Tables B8 and B9, **Annexure B**. Results of the packer tests are expressed as lugeon units where a lugeon (L) is equivalent to a hydraulic conductivity of $1x10^{-7}$ metres per second ($8.8x10^{-3}$ metres per day).

Figure 4-15 Location of packer tests along the alignment

The distribution of hydraulic conductivity results and the 10 point geometric mean plotted against depth are presented in **Figure 4-16**. The plot shows a wide variation in hydraulic conductivity values, with the overall trend of decreasing hydraulic conductivity with depth. The large scatter is caused by the variation in defect spacing which tends to decline with depth due to an increased influence of overburden pressure.

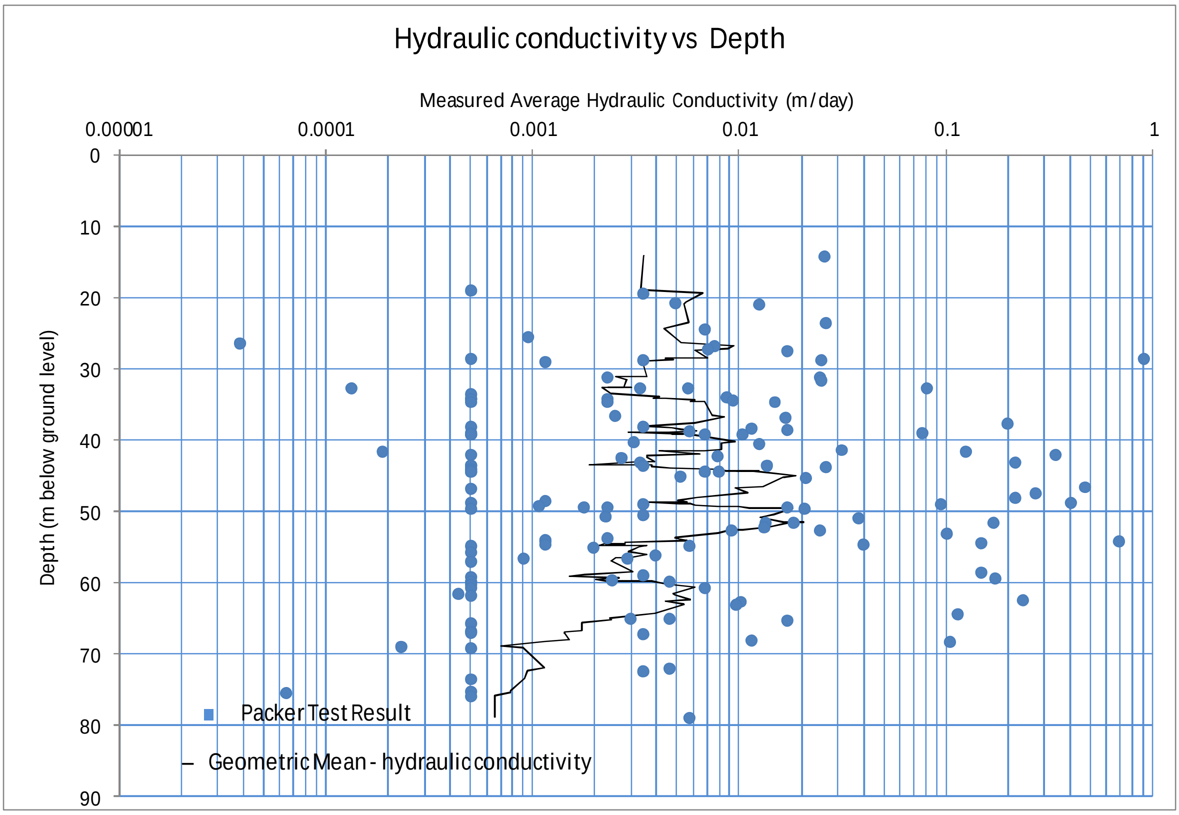


Figure 4-16 Hydraulic conductivity value and depth from packer tests

As part of the New M5 Motorway design and construct program test pumping of the Hawkesbury Sandstone was conducted at the Kogarah Golf Course, next to Marsh Street, to assess the hydraulic conductivity and assess the degree of connectivity between the alluvium and Hawkesbury Sandstone (Golder 2017). The site was selected because the area was known to contain highly transmissive fractures beneath Cooks River Palaeochannel. Two constant rate pumping tests were conducted at separate pumping wells in March and July 2016. In March 2016 a pumping bore was pumped for 4.5 days at 2 L/sec. In July 2016 two separate wells were pumped concurrently for 15 days at rates between 2 L/sec and 6 L/sec. The high pumping rates indicate the fractures are highly transmissive due to the high flow rates that could be sustained. Groundwater monitoring demonstrated drawdown of up to four metres within the alluvium indicating substantial connectivity between the sandstone and alluvium. Drawdown within the alluvium, however, was variable which was interpreted to reflect the lithological variability of interbedded sand and clay within the alluvium. As an outcome of the test pumping program it was concluded that the interbedded alluvium near Marsh Street underlying the Kogarah golf course did not contain a basal clay unit as is present further to the east.

The hydraulic conductivity and storativity parameters calculated in this investigation are discussed in **section 4.14**.

4.14 Hydrogeological conceptual model

A hydrogeological model has been prepared to form the background for the numerical groundwater modelling. The majority of the conceptual aspects are discussed in more detail in this report and the groundwater model report (RPS 2018) but are summarised in this section.

4.14.1 Climate

Sydney is located within the Zone 5 – warm temperate climatic zone of Australia. Rainfall measured at Sydney Airport (BOM Station 66037) indicates that the mean annual rainfall is 1085.6 mm. Mean rainfall is highest during late summer and early autumn peaking in March and May. Potential evaporation (PE) for the region is approximately 1220 mm/a, while actual evapotranspiration (AE) for the region is up to approximately 620 mm/a (BoM 2009). Applied evapotranspiration was input to the model via the ET or EVT modules.

The climate and rainfall of the project alignment have been discussed in more detail in **section 4.2**.

4.14.2 Hydrostratigraphic units

There are three main hydrostratigraphic units across the model domain that includes the alluvium including the Botany Sands, palaeochannel sediments and the regolith, Ashfield Shale including the Mittagong Formation and the Hawkesbury Sandstone. The geology and hydrogeology of these units are described in more detail in **sections 4.7** and **4.8** respectively. The groundwater model has split these units into nine layers base on lithological variations with average thicknesses ranging from 6.4 metres (Layer 2 - Upper Ashfield Shale) to 22.9 metres (Layer 4 – Hawkesbury Sandstone).

4.14.3 Hydraulic conductivity

Values of hydraulic conductivity have been compiled from field investigation results undertaken as part of this EIS (**section 4.13.4**) and from previous investigations and modelling reports including the New M5 Motorway, M4 East and M4-M5 Link WestConnex investigations. These results have been used to compile a table of values of horizontal (K_h) and vertical (K_v) hydraulic conductivity (RPS 2018) that have been refined for each layer during the groundwater model calibration process.

Within the groundwater model K_h values range from 18.5 m/day in the Botany Sands to 9.0×10^{-4} m/day in the Hawkesbury Sandstone. Similarly K_v values range from 18.0 m/day in the Botany Sands to 1.0×10^{-4} m/day in the Hawkesbury Sandstone.

4.14.4 Storage parameters

Values of specific yield (Sy) and specific storage (Ss) have been collated from the New M5 pump test investigation in the Hawkesbury Sandstone (Golder 2017) and from modelling reports for the New M5 Motorway, M4 East and M4-M5 Link WestConnex investigations. Storage parameters adopted for the groundwater model were based on these values and refined through the calibration process and are tabulated in **Annexure F**. Values of Sy adopted in the model range from 2.0×10^{-1} (alluvium and Botany Sands) to 1.0×10^{-1} (Regolith, Ashfield Shale and Hawkesbury Sandstone). Similarly values of Ss adopted in the model range from 2.0×10^{-4} (alluvium and Botany Sands) to 2.0×10^{-6} m-^{1} (Hawkesbury Sandstone).

4.14.5 Recharge and discharge

Groundwater recharge is applied to the groundwater model by applying a percentage of annual rainfall. The percentage is variable and depends on the lithology outcropping and whether the area is paved or unpaved. For example recharge values applied to the model range from 1.8 percent (shale unpaved) to 25.5 percent (Botany Sands unpaved). In the groundwater model recharge is applied by the recharge (RCH) module. Recharge is also applied to the model via the interaction with surface water via inflows from creeks and tidal interaction. At the boundaries of the model recharge is applied to the model from up-gradient groundwater flow via the model boundary conditions such as the general head (GHB) or constant head boundaries (CHB).

Groundwater discharge across the model domain is complex. Under natural conditions groundwater discharges to Botany Bay; to rivers when there are downward hydraulic gradients; through pumping from Alexandria landfill and domestic bores, and via evaporation and evapotranspiration. During and post construction there would also be groundwater discharge from tunnel leakage for the project and the M5 East, New M5 Motorway and M4-M5 Link tunnels. In the groundwater model regional groundwater discharge is simulated by the GHB. In tidal areas discharge is simulated by constant head discharge and tunnel leakage is simulated by the drainage (DRN) module.

4.14.6 Surface water interaction

Groundwater naturally interacts with surface water in ponds, rivers, streams and tidal regions including the Scarborough Ponds, Botany Bay and the Georges River. This interaction can result in groundwater being recharged or discharged depending on the hydraulic gradients. In tidal regions, groundwater recharge is simulated in the groundwater model by the use of a constant head boundary set at 1m AHD which is the annual tide level.

Watercourses across the model domain are simulated by establishing river cells in model layer 1 which can either recharge or discharge groundwater depending on the hydraulic gradients. In the case where drainage channels are concrete lined, such as parts of Cooks River, Spring Creek Dain and Muddy Creek, the streams are simulated as drains with a low stream bed conductance.

4.15 Groundwater inflow in other tunnels

Within the Hawkesbury Sandstone water inflow is dependent upon the number and aperture of saturated secondary 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 project. These inflow rates are considered long term flow rates throughout the operational life of the infrastructure, and are summarised in **Table 4-7** (after Hewitt 2005).

Drainage inflow as summarised in **Table 4-7** varies from 0.6 litres per second per kilometre to up to 1.7 litres per second per kilometre.

Table 4-7 Measured drainage rates from other Sydney Tunnels

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

Notes:
1 Litres per second per kilometre of tunnel
2 Measured inflow in Lane Cove Tunnel varied from 1.7 L/sec/km (2001 – mid-2004) to 0.6 L/s/km (2011)

Predicted inflows to the proposed M4 East and New M5 Motorway tunnels have been calculated by numerical modelling published in the respective environmental impact statements. For the New M5 Motorway, groundwater modelling predicted an average inflow rate over the full length of the tunnel of 0.63 L/sec along the eastbound tunnel and 0.67 L/sec along the westbound tunnel (CDM Smith 2015).

Similarly, for the M4 East, groundwater modelling was undertaken to predict inflows to the drained tunnels. The M4 East tunnels extend over a combined length of 17 kilometres. Groundwater modelling predicted inflow rates between 0.3 and 0.9 litres per second per kilometre of tunnel (WestConnex Delivery Authority 2015).

Groundwater inflows to the M4-M5 Link tunnels were predicted to be below the 1L/sec/km criterion for any kilometre of tunnel.

4.16 Contamination

An assessment of contaminated land risk is provided in **Appendix J** of the EIS (Contamination technical report). The assessment along the project footprint is based on historical and present land-use practices that may have impacted the soil and groundwater. Previous and current land-uses along the alignment that could impact groundwater quality include:

- Market gardens and associated pesticides and herbicides
- Service stations and associated fuel storage
- Fire station and associated fire-fighting foam residues
- Smash repairs and mechanics and the use of oils and solvents
- Waste management and storage
- Light industrial including the use of solvents and manufacturing.

These land-use practices have the potential to impact groundwater with the following compounds:

- Heavy Metals
- Poly Aromatic Hydrocarbons (PAH)
- Total Recoverable Hydrocarbons (TRH)
- Polychlorinated Biphenols (PCBs)
- Chlorinated Hydrocarbons
- Volatile Organic Compounds (VOCs)
- Semi Volatile Organic Compounds (SVOCs)
- Pesticides and Herbicides
- Polyfluoroalkyl Substances (PFAS)
- Nutrients (ammonia, nitrate, nitrite and phosphorous).

Groundwater sampling undertaken as part of this investigation for the above analytes is summarised in Table B10, **Annexure B**. A search of the NSW EPA records indicated that there were no sites currently regulated by the NSW EPA under Section 60 of the CLM Act 1997 within 500 metres of the tunnel alignment.

Groundwater analytical results were assessed against three criteria as follows:

- National Environment Protection Measure (NEPM) Table 1C Groundwater Investigation Levels (GILs) for Marine Waters, National Environment Protection Council (NEPC, 2013 as amended)
- NEPM Table 1A (4) Groundwater Health Screening Levels (HSLs) for vapour intrusion 8m+ (NEPC, 2013 as amended)
- Australia New Zealand Environment Conservation Council (ANZECC, 2000) Recreational water quality and activities.

Key sites investigated related to the project are discussed in the following sections.

4.16.1 Mainline tunnel alignment

The mainline tunnel alignment would extend from Kogarah Golf Course in Arncliffe passing through Banksia and Rockdale emerging at Rockdale Bicentennial Park via ramps at President Avenue.

Groundwater contamination sampling was conducted in five monitoring wells (BH1300, BH1303, BH1314, BH1315, BH1316) installed along the alignment where areas of former historical landfilling took place. Despite there being many land-uses along the alignment that could impact groundwater quality such as light industry, market gardens and mechanical workshops there was only one groundwater exceedance detected along the alignment. The exceedance was detected in BH1303 where dissolved arsenic (55 µg/L) exceeded the assessment criteria of 50 µg/L (ANZECC 2000).

4.16.2 Arncliffe construction ancillary facility (C1)

The Arncliffe construction facility (C1) is to be located on the site of the New M5 Motorway Arncliffe construction compound, which was formerly part of Kogarah Golf Course (**Figure 2-3**). The Arncliffe construction ancillary facility (C1) would be used to support tunnelling; including loading of spoil and spoil removal. There is potential for groundwater contamination to be present due to the historical use of pesticides and herbicides at market gardens and golf course and areas of historical landfilling nearby.

The New M5 Motorway Arncliffe construction compound would be handed over to the F6 project contractor at completion of the New M5 Motorway construction works at Arncliffe. The permanent facility consisting of New M5 Motorway building, New M5 Motorway water treatment plant, exhaust vent building and supply vent building will have been completed. The Arncliffe construction ancillary facility has previously been assessed by the New M5 Motorway EIS and in particular, in Volume 2F, Appendix O Technical Working Paper: Contamination New M5 Environmental Impact Statement (RMS 2015). The findings in this report have been used to inform the contamination assessment for the project.

Nearby monitoring wells were constructed within the sandstone (WCX_BH029 and WCX_BH063) and one well was constructed within the Botany Sands (WCX_BH063a). Collected groundwater samples were analysed for TRH, BTEX, heavy metals, SVOCs, VOCs, cations and anions. With the exception of zinc, all analysed analytes were below the adopted assessment criteria. Concentrations of zinc exceeded the ANZECC (2000) 95 per cent trigger level for marine ecosystems in the three wells (0.036 to 0.046 mg/L).

Two monitoring wells located within the Kogarah Golf Course (LDS-BH-2005 and LDS-BH-2001) were screened within the Hawkesbury Sandstone and alluvium respectively (Golder 2017). Monitoring well LDS-BH-2005 was sampled for dissolved heavy metals, TRH, BTEX, PAHs, OCPs, OPPs, phenols, volatile hydrocarbons, PFOA, PFOS, PCBs and nutrients. Concentrations of dissolved arsenic (8 µg/L, chromium (1 µg/L), copper (6 µg/L) and zinc (14 µg/L) exceeded the adopted assessment criteria. Monitoring well LDS-BH-2001 identified elevated concentrations of ammonia (1.2 mg/L) and dissolved methane (8.8 mg/L).

4.16.3 Rockdale construction ancillary facility (C2)

The Rockdale construction ancillary facility (C2) is located at West Botany Street, Rockdale, south of Bay Street (**Figure 2-3**). This construction ancillary facility is to be constructed above and below ground and would require 1.2 hectares of the existing Roads and Maritime maintenance depot. Rockdale construction ancillary facility (C2) would be used to support tunnelling, including loading of spoil and spoil removal. The site is currently used for warehousing and car parking.

A summary of the site history (**Appendix J** of the EIS (Contamination technical report) indicates there is potential for groundwater contamination to be present due to the historical use of pesticides and herbicides for agricultural purposes and former, current and surrounding industrial properties used for chemical manufacturing.

One borehole GW107531, identified in the State government groundwater database is present at the site and indicates the groundwater level within the Botany Sands aquifer is shallow (less than two metres below the ground surface) however no groundwater quality sampling has been undertaken (SMEC, 2018a). The water quality within the database was recorded as ‘good’. Other bores are noted within 100 metre radius of Rockdale construction ancillary facility (C2) that are used for industrial and domestic purposes.

Groundwater quality monitoring was conducted in January 2018 in monitoring well BH1313 located at the Roads and Maritime Rockdale Depot at 400 West Botany Street and screened within the alluvium. The groundwater is shallow at 1.4 metres below the ground surface. The groundwater was analysed for a series of targeted analytes including metals, nutrients, TPH/BTEX, monocyclic hydrocarbons (MAH) and chlorinated hydrocarbons. The only exceedance was ammonia which exceeded the NEPM marine guidelines.

4.16.4 President Avenue construction ancillary facility (C3) and construction site

The President Avenue construction ancillary facility site (C3) is around 15 hectares in area and comprises parts of the Rockdale Bicentennial Park and Rockdale Bicentennial Park Esat, and sections of President Avenue, leading to the intersection with Princes Highway to the west (**Figure 2-3**). Current and historical land-use at the proposed intersection includes recreational parklands and sports fields, residential housing and the historical use of market gardens. Up-gradient service stations, motor and mechanical businesses have the potential to impact groundwater quality.

A search of groundwater bores identified in the State government groundwater database indicated that two bores are located within the site of the proposed ancillary facility: GW107531 for industrial purposes in the north, and GW026647 for private use in the centre of the site. Recorded information indicates that groundwater within the Botany Sands aquifer at this location is shallow (2 to 3 metres bgl). The shallow watertable is consistent with shallow water levels in the adjacent Rockdale ponds and wetlands.

Various groundwater investigations have been undertaken to assess groundwater contamination at the President Avenue construction ancillary facility site (C3). These investigations and outcomes are summarised in **Table 4-8**. In summary, groundwater sampling at the President Avenue construction ancillary facility footprint indicated that the adopted groundwater guidelines for arsenic, copper, nickel, zinc and ammonia were exceeded. Low concentrations of various hydrocarbons were detected but did not exceed the adopted groundwater guidelines.

Table 4-8 Summary of groundwater contamination investigations at the President Avenue construction ancillary facility site

Borehole ID	Location	Summary
BH014A	Rockdale Bicentennial Park (to the south and outside the ancillary facility boundary)	• Alluvium monitoring well (7 to 10 metres bgl) • Concentrations of copper, nickel, zinc and ammonia in groundwater exceeded the marine and freshwater GILs • Low concentrations of TRH, BTEX, chlorobenzene, cyclohexane, isopropylbenzene and n-propylbenzene were detected above the LOR but below the assessment criteria
BH1143	Rockdale Bicentennial Park	• Alluvium screened monitoring well (16.4 to 18.4 metres bgl) • Concentrations of nickel and zinc in groundwater exceeded the marine and freshwater GILs • Low concentrations of chloroform was detected above the LOR but below the assessment criteria
BH1121A	Rockdale Bicentennial Park East	• Alluvium screened monitoring well (7 to 10 metres bgl) • No sampling for contamination assessment
BH1303	Rockdale Bicentennial Park	• Concentrations of arsenic in groundwater exceeded the freshwater GIL and concentrations of ammonia and zinc exceeded the marine GILs • Low concentrations of TRH, xylene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, chloroform and manganese detected above the LOR but below the assessment criteria
BH1318	Rockdale Bicentennial Park	• Groundwater monitoring well installed and screened 5.8 to 8.8 metres bgl in alluvium • Groundwater level 2.06 metres below top of casing (b toc)
TP1303	Rockdale Bicentennial Park East	• Groundwater monitoring well installed and screened 2 to 4 metres bgl in fill • Groundwater level 2.89 metres below top of casing (b toc) (21 December 2017)
TP1307	Rockdale Bicentennial Park East	• Groundwater monitoring well installed and screened 2 to 4 metres bgl in alluvium • Groundwater level 2.04 metres below toc (21 December 2017)

Borehole ID	Location	Summary
TP1308	Rockdale Bicentennial Park	• Dual groundwater and gas monitoring well installed and screened from 1.5 to 6 metres bgl in fill • Groundwater level 2.67 metres below toc (21 December 2017) • Hydrocarbon sheen in groundwater
TP1309	Rockdale Bicentennial Park	• Dual groundwater and gas monitoring well installed and screened from 2 to 4 metres bgl in fill • Groundwater level 3.32 metres below toc (21 December 2017)
TP1310	Rockdale Bicentennial Park	• Dual groundwater and gas monitoring well installed and screened from 1 to 5 metres bgl in fill • Groundwater level 2.46 metres below toc (21 December 2017) • Hydrocarbon sheen in groundwater

4.16.5 Shared pedestrian and cycle path

A shared pedestrian and cycle path is to be constructed from Bestic Street, Brighton-le-Sands, south to Civic Avenue, Kogarah through the reinstated Rockdale Bicentennial Park. The shared pedestrian and cycle path intersects with several existing and proposed east-west paths. As part of the corridor, a dedicated shared overpass would be built over President Avenue.

The Shared cycle and pedestrian pathway construction ancillary facility east (C5) includes the southern portion of 310 West Botany Street, Rockdale, Rockdale Women's Sports fields. The Shared cycle and pedestrian pathways construction ancillary facility west (C4), is within southwest portion of Redmond Field. The general alignment of the shared pedestrian and cycle path and the location of the facilities are shown on (**Figure 2-3**). The current land uses of the Shared pedestrian and cycle pathways construction ancillary facilities (C4 and C5) includes part of Bestic Street and recreational open space including Whiteoak Reserve, C A Redmond Field, Rockdale Women's Sportsfields and Greg Atkins Mini Field.

No groundwater contamination investigations have been conducted in the Shared cycle and pedestrian pathway construction ancillary facilities (C4 and C5) areas. Groundwater within the Botany Sands is expected to be shallow and less than two metres below the ground surface. Groundwater flow is eastward towards Muddy Creek ultimately discharging into the Cooks River. A historical review indicates that previous agricultural use may have introduced pesticides, herbicides and fertilisers and there may be areas of uncontrolled fill along Muddy Creek that may influence groundwater quality.

4.17 Surface water monitoring

Surface water quality monitoring as part of the New M5 Motorway investigations has been compiled from Cooks River, Muddy Creek and Rockdale Wetlands as outlined in **Appendix L** of the EIS (Surface water technical report). In general, the concentrations for nutrients including total nitrogen, total phosphorous, reactive phosphorous and ammonia, metals including arsenic, cadmium and nickel and ammonia are elevated above the ANZECC (2000) 95% species protection level (95% SPL).

Further surface water monitoring including water quality and surface level monitoring is proposed to be conducted for a period of 12 months prior to and during construction to further the characterisation of baseline conditions. The monitoring will be conducted at Rockdale Bicentennial Park Pond. Surface water quality monitoring locations monitored as part of this EIS are shown on **Figure 4-17**.

LEGEND

- The project in tunnel
- The project on surface
- New M5 Monitoring Program
- F6 SW Quality Monitoring Program
- Rockdale Water Quality Monitoring Study 2012-2013
- Scarborough and Bicentennial Ponds and Tonbridge Creek Water Quality Monitoring Study
- Railway station
- Railway line

Figure 4-17 Surface water quality monitoring locations

5 Assessment of construction impacts

A numerical groundwater model as outlined in **section 3.3.4** has been developed to quantify potential groundwater impacts. Groundwater levels and/or quality within the project footprint during construction and operation could be impacted due to the project. Mitigation measures and management strategies to eliminate, reduce or manage potential impacts are outlined in **Chapter 8.**

The potential impacts on the hydrogeological regime during construction of the project are:

- Reduced groundwater recharge
- Loss of groundwater due to inflows to the tunnels
- Localised groundwater drawdown
- Reduction in groundwater quality due to tunnelling related activities.

Each of these potential impacts is discussed in the following sections, with specific discussion regarding identified environmentally sensitive areas outlined in **Chapter 4**.

5.1 Reduced groundwater recharge

Ground disturbance at the surface due to construction of the project would include the establishment of paved construction ancillary facilities, and the excavation and sealing of cut-and-cover tunnel sections which could temporarily alter or reduce groundwater recharge. The construction ancillary facilities (in particular the Arncliffe construction ancillary facility (C1)) would create additional temporary impervious surfaces during construction. However, the impacts of these surfaces are temporary and considered minor since their construction would not substantially reduce groundwater recharge during construction. In many instances, construction ancillary facilities would be located on existing impervious surfaces and would therefore not substantially 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. Stockpiling areas will be required for the new cuttings and embankments along President Avenue which would temporarily reduce groundwater recharge, if run-off is directed off-site to stormwater. These impacts are considered minimal, as the affected areas are small, and temporary and the various construction structures and compounds would be removed at the end of the construction phase.

5.2 Tunnel inflow

The short term inflow of groundwater during construction would be dependent upon a number of factors including tunnelling progress, tunnelling construction methodology (including the success of pre-grouting), fractured zones intersected, localised groundwater gradients and storativity. Initial inflows to tunnels during construction can be large, because of the large hydraulic gradients that initially develop near the tunnel walls, however these gradients will reduce in time as drawdown impacts extend to greater distances from the tunnels and inflows approach steady state conditions. Higher inflow rates are likely from zones of higher permeability, where saturated geological structural features are intersected by the tunnels. The tunnel construction program for the New M5 at Arncliffe has experienced higher than anticipated groundwater inflows due to fractured sandstone beneath the Cooks River Palaeochannel (Golder 2017). Based on the geotechnical investigations and packer tests conducted as part of the New M5 investigation (Golder 2017), higher groundwater inflows are expected between chainages 1,650 and 1,750 at the northern ends of the mainline tunnels. During construction these high inflow zones are to be grouted to reduce the inflow rate to below the one litre per second per kilometre for any kilometre length of tunnel criterion.

Groundwater inflow from the Hawkesbury Sandstone is expected to be highest during construction, as hydraulic gradients would be at their highest and would then decline as equilibrium is reached. Groundwater modelling has predicted groundwater inflows to the tunnels (after grouting) and access declines during construction to range between 0.1414 megalitres per day (51.11 ML/yr) in 2021 and 0.55 megalitres per day (200 ML/yr) in 2023 as predicted in the groundwater modelling construction phase.

Tunnel inflow from the Botany Sands aquifer also occurs during construction, as leakage into the Hawkesbury Sandstone. Over the construction period, tunnel inflow from the Botany Sands is predicted to range from 0.03 ML/day (2020) to 0.22 ML/day (2022). Project specific extraction due to dewatering during the construction of the Rockdale access decline and Arncliffe construction access decline is discussed in **section 5.2.1**.

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

During construction, long term water management solutions would be implemented such as the installation of water proofing membranes or undrained (tanked) tunnels. Groundwater inflows would be collected via a temporary drainage system collecting water from the road header or tunnel boring machine and pumping it to the surface for treatment and discharge. Water inflows, treatment and discharge would be managed in accordance with a water management plan that would form part of the CEMP.

To reduce long term groundwater inflows, pre-excavation pressure grouting may be undertaken, to allow groundwater inflows to be more easily managed. This technique is undertaken by drilling a pattern of holes in advance of the excavation to conduct packer tests and calculate the hydraulic conductivity. Grout is then injected at a pre-determined pressure to reduce the bulk rock mass permeability. The implementation of this technique is dependent upon the local geology, in particularly the orientation and density of water bearing rock defects. Another option to reduce the bulk rock mass permeability and long term inflows is the installation of water proofing membranes during construction.

5.2.1 Dewatering during construction

Groundwater extraction via dewatering from the Botany Sands alluvium would be required during the construction of the cut-off walls for the President Street ramps. Extracted groundwater from the Botany Sands would be directed into a pre-treatment basin, treated in the construction water treatment plant and discharged into the stormwater network as outlined in the **Appendix L** (Surface water technical report) of the EIS.

The Rockdale access decline (0.40 kilometres) and the Arncliffe construction access decline (1.0 kilometres) are being constructed as drained tunnels with a long term inflow criteria of 2L/sec/km and 1L/sec/km respectively (Bamser 2018). At the completion of the project the Arncliffe construction access decline is to be backfilled.

Groundwater modelling has predicted that groundwater inflows to the Rockdale access decline would be around 0.07 ML/day during construction. Similarly, predicted inflows to the Arncliffe construction access decline would range from 0.07 to 0.06 ML/day during construction.

5.2.2 Water take from the Metropolitan Regional Groundwater Resources

The predicted maximum annual water take from the Greater Metropolitan Regional resource during construction is 248 ML/year (Year 2023) due to tunnel inflows. Of this extraction 76.7 ML is due to extraction from the Botany Sands aquifer during the Rockdale access decline excavation.

These maximum predicted inflows for each aquifer is compared to the LTAAEL and is summarised in **Table 5-1**. Comparison of predicted tunnel inflows indicates the reduction in the groundwater availability within the Botany Sands during construction is predicted to be reduced by 0.52 per cent of the LTAAEL. Similarly the predicted reduction in the groundwater availability during construction will be reduced by 171 ML/year or 0.37 per cent of the LTAAEL for the Sydney Basin Central groundwater resource.

Once the temporary dewatering is complete, the take from the Botany Sands will be reduced and will continue to decline during the operation of the project as discussed in **section 6.2.1**.

Table 5-1 Groundwater extraction from the Metropolitan Regional Groundwater Resources during construction

Aquifer	LTAAEL	Water take (year 2023)	Percentage of LTAAEL
units	ML/year	ML/year	(%)
Botany Sands	14,684	76.77	0.52
Sydney Basin Central	45,915	171.3	0.37

Source: NoW 2011 and RPS 2018

5.3 Predicted groundwater level decline

Groundwater modelling has been used to predict groundwater level drawdown as a result of the project at the end of the construction period within the alluvium and Hawkesbury Sandstone. Along the alignment, the groundwater levels are predicted to drawdown where there is good hydraulic connection with the Hawkesbury Sandstone within the alluvium or unconsolidated sediments (**Figure 5-1**). Specifically, at the end of construction, drawdown within the alluvium at Spring Street Drain is estimated to be about two metres, indicating a hydraulic connection between the alluvium and sandstone at this location. Elsewhere there is minor drawdown of up to 0.1 metres within the Botany Sands.

Conversely, at the end of construction, drawdown within the Hawkesbury Sandstone is predicted to be up to 24 metres at Arncliffe where the tunnel is deepest (**Figure 5-2**). To the south, where the access decline joins into the mainline tunnel and tunnel ingress is up to 2L/sec/km for any kilometre length of the decline, groundwater drawdown in the sandstone is predicted to be 33 metres at the end of construction. At the end of construction, the drawdown to the two metre drawdown contour extends to around 250 metres either side of the tunnel alignment. The two metre drawdown contour is significant because groundwater induced drawdown in excess of two metres exceeds the minimal impact consideration threshold of the AIP.

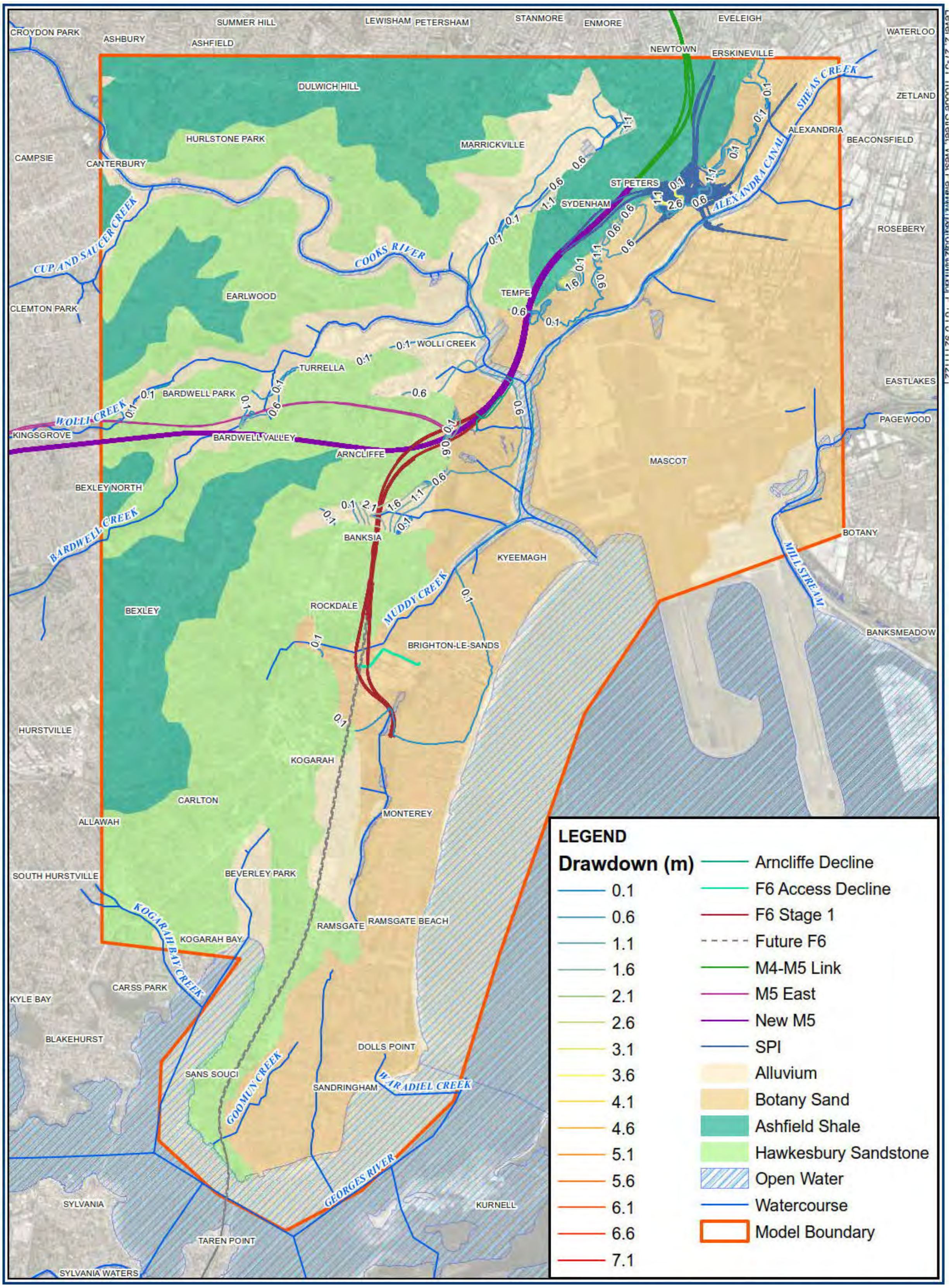


Figure 5-1 Predicted drawdown in the alluvium after construction –– 2024 - from RPS 2018

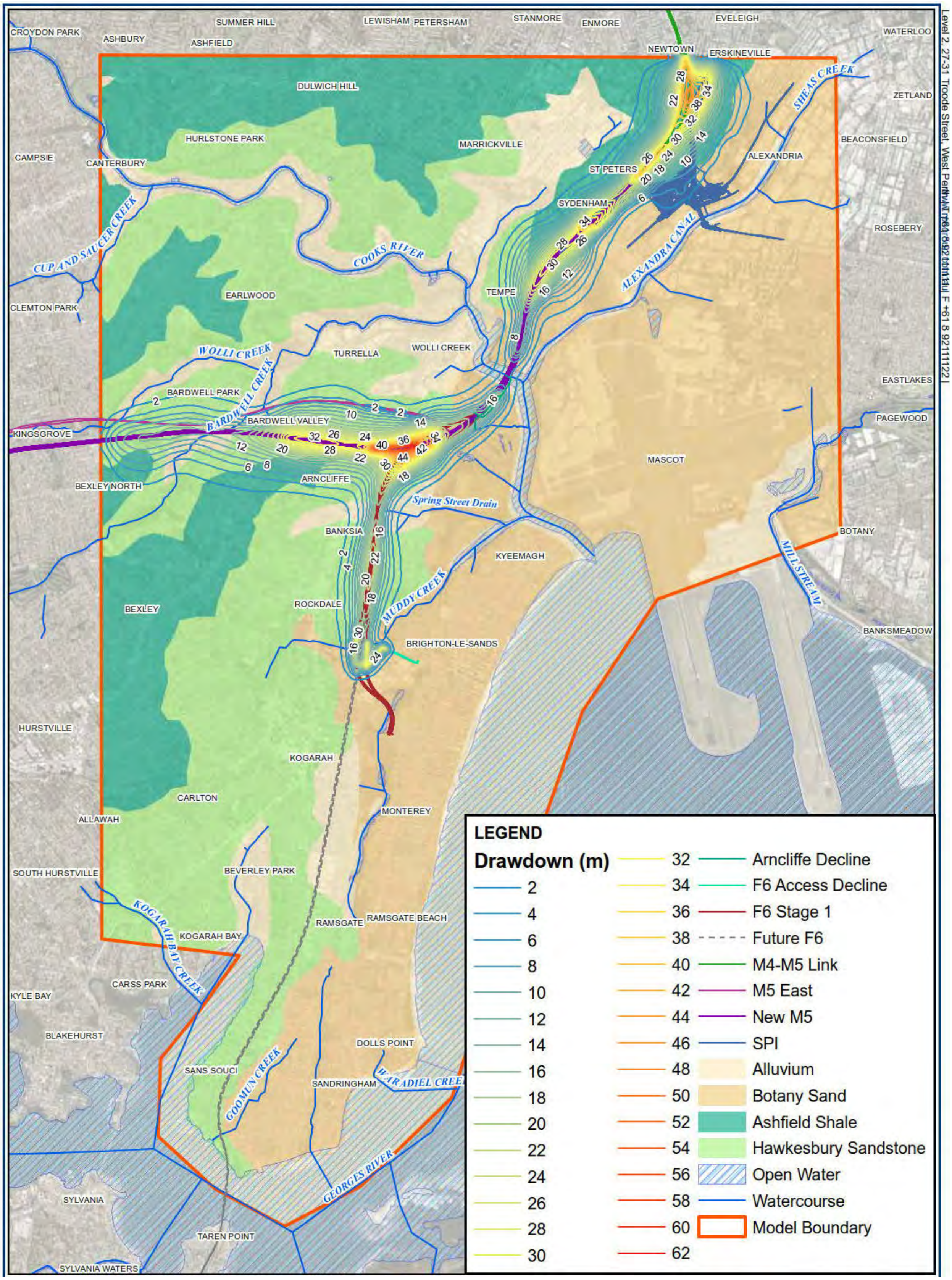


Figure 5-2 Predicted drawdown in the Hawkesbury Sandstone after construction –– 2024 - from RPS 2018

5.4 Groundwater level drawdown

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

During construction, the regional extent of drawdown impacts due to tunnel construction would be minimal even though groundwater inflows are high. This is due to groundwater storage depletion within the sandstone from the immediate vicinity of the tunnel restricting the lateral extent of drawdown and the relatively short construction timeframe. As construction continues, the inflows are predicted to decrease but the depressurisation caused by the tunnel inflows would propagate to the surface causing the water table to decline and the cone of depression would extend outwards to progressively greater distances until steady state conditions are reached.

Grouting will be undertaken throughout the construction program to reduce groundwater inflows and hence limit the groundwater level decline. Groundwater levels would be monitored throughout the construction phase in accordance with a CSWMP to be developed as part of the CEMP. Additional groundwater modelling will be required to be undertaken during the construction program, using measured tunnel inflow rates and monitored groundwater drawdown, to re-calibrate the model and refine post-construction model predictions.

5.4.1 Potential impacts on groundwater dependent ecosystems

Groundwater dependent ecosystems across the project footprint are discussed in **section 4.4.4**. In accordance with the AIP, groundwater drawdown must be within an allowable range of up to 10 per cent of natural variation 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 in Centennial Park around eight kilometres north-east of the project footprint. These wetlands are at a sufficient distance from the project footprint to not be impacted by construction of the project.

Within the study area, the Rockdale wetlands are considered to have some degree of groundwater dependence and groundwater modelling has predicted that groundwater drawdown at the end of construction would be between 0.02 and 0.19 metres at this location. However the drawdown is not expected to decline as far as predicted because during construction treated water extracted from the President Avenue ramps dewatering is to be discharged into the Rockdale Wetlands partially maintaining water levels.

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

An assessment of the impacts to natural processes as a result of the operational discharges which may affect the health of the fluvial, riparian and estuarine systems and landscape health within the project study area is provided in **Appendix L** of the EIS (Surface water technical report). These natural processes are outlined in **section 4.4**.

5.4.2 Potential impacts on surface water and baseflow

Surface water features within or in proximity to the project footprint are described in **section 4.4**. There is unlikely to be any direct surface water inflow to the tunnels from the alluvium as the tunnels are to be undrained (tanked) and cut and cover sections are to be constructed by diaphragm walls, preventing direct inflow from the alluvium. Elsewhere along the alignment, the tunnels are designed to dive beneath the palaeochannels. Since the majority of the creeks and drains are concrete lined, the risk for surface water from creeks or drains to seep into the tunnels via leakage to the alluvium is considered low. There may be some seepage from the creeks due to cracks in the aged concrete.

Surface water quality would be monitored throughout the construction phase in accordance with a surface water management plan (SWMP) to be developed as part of the CEMP. The Sydney Water proposal to naturalise sections of Muddy Creek is likely to increase groundwater recharge and may partially increase the baseflow to the creek. Surface water monitoring is discussed in more detail in **section 4.17** and in **Appendix L** of the EIS (Surface water technical report).

Surface water can only flow to the groundwater system as leakage 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. Under conditions when groundwater levels are higher than surface water levels and creeks are not concrete lined, groundwater would naturally discharge as baseflow into Muddy Creek or Cooks River. For the purposes of modelling, baseflow is considered to be the groundwater that discharges to a creek or river and is simulated in the model only when groundwater reaches the ground surface and enters the drainage system.

Predicted impacts of construction of the project on baseflow/leakage for major creeks has been modelled (**Annexure F**). Changes in baseflow calculated by the model are relative to the model as there is no gauging data to calibrate against to determine absolute values. Prior to the commencement of construction of the project, there is likely to be some existing reduction in baseflow due to influence of the New M5 Motorway construction program. Calculated initial baseflow, project baseflow and the reduction in baseflow as a result of construction of the project are summarised in **Table 5-2**.

Table 5-2 Predicted changes in baseflow at the end of construction (2024)

2024 (m^3/day)	Muddy Creek	Spring Street Drain	Cooks River	Wolli Creek	Bardwell Creek
Base case	29.9	198.8	10.6	106.6	126.1
Project baseflow	26.5	142.4	10.6	106.6	126.1
Baseflow reduction*	3.4	56.4	0.0	0.0	0.0
% Reduction*	11.5	28.4	0.0	0.0	0.0

Note: *reduction is due to the project

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

5.4.3 Impacts on existing groundwater users

A review of current groundwater use has been conducted to identify registered groundwater users and the environment (GDEs) within a two kilometre buffer of the project footprint. In accordance with the AIP, existing groundwater bores impacted by the lowering of groundwater levels in excess of two metres due to the project would be protected by 'make good' provisions. This would require the project to restore supply to pre-development levels. The measures taken to 'make good' 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, for example. A review of existing users within and adjacent to the project footprint is summarised in **section 4.12**.

The groundwater model has been used to assess the potential groundwater level drawdown at sensitive areas, and at bores owned by registered groundwater users.

The groundwater modelling predicts that one registered well (GW072161) would be drawn down in excess of two metres during the construction phase. This bore, located in Arncliffe is registered as a recreation bore drawing water from the Hawkesbury Sandstone. Drawdown is expected to be in excess of 65 metres at this location at the end of construction as the bore is situated within the line of the New M5 Motorway tunnels, however it is expected that this bore may be destroyed during construction of that project.

Groundwater drawdown is expected to be less during the construction phase than during the operational phase, since long term groundwater levels would continue to decline until steady state conditions are reached. These impacts are discussed in **Chapter 6**.

5.5 Groundwater quality

Risks to groundwater quality during construction include the potential to contaminate groundwater 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 due to previous industrial land use. Contaminants within soil beneath former and current industrial sites and within former landfill sites could be mobilised due to altered groundwater flow paths during construction. As groundwater drawdown increases due to tunnel inflows there is the potential for tidal waters to be drawn towards the tunnels causing saltwater intrusion from tidal watercourses or at the edge of Botany Bay. Groundwater quality would be monitored throughout the construction phase in accordance with a CSWMP to be developed as part of the CEMP and would address groundwater management and monitoring. The monitoring outcomes would be used to inform the water treatment plant operation. These potential risks to groundwater quality are discussed further in the following sections.

5.5.1 Spills and incidents

There is potential to contaminate groundwater through spills and incidents within the construction compounds from the inappropriate storage of hazardous materials or during refuelling of plant and machinery. 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, palaeochannel or fractured sandstone. Unmanaged stockpiling of construction materials may also introduce contaminants to the groundwater of the project footprint by the leaching of contaminants followed by run-off and accession to the water table.

The risks to groundwater as a result of such incidents would be managed through standard construction management procedures in accordance with site specific CEMP developed for the project. Further, emergency spill kits would be available on site during construction and staff would be trained in their use. All liquid dangerous goods and hazardous chemicals would be appropriately stored, for example within a bunded storage container or spill tray to avoid contamination of the groundwater. Similarly, where possible, refuelling of vehicles or plant equipment would take place on hardstand or bunded areas to contain potential leaks and spills.

Runoff from high rainfall events that occur during construction would be managed in accordance with the protocols outlined in **Appendix L** to the EIS (Surface water technical report) and the surface water management plan to be prepared as part of the CEMP. Following high rainfall events groundwater quality impacts would be reduced, as the majority of run-off would discharge to receiving waters.

5.5.2 Intercepting contaminated groundwater

A number of sites with the potential for existing groundwater contamination due to various current and historical land-uses are located along the project footprint as outlined in **section 4.16** and in **Appendix J** to the EIS (Contamination technical report). A potential contamination risk associated with these sites would be associated with the migration of potentially contaminated groundwater plumes towards the tunnels.

The majority of the tunnels are to be constructed within the Hawkesbury Sandstone at depths greater than 20 metres and up to 62 metres at the northern end of the alignment where the project joins the New M5 Motorway tunnel stubs, limiting the risk of shallow groundwater contamination being intersected during construction.

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 cut-off walls such as diaphragm walls or secant piled walls.

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

Limited groundwater contamination investigations have been conducted as part of EIS investigations and have identified some areas where contaminated groundwater may occur, such as beneath former and current industrial sites in the southern part of the alignment, former landfill sites around the central wetlands and former and current market gardens to the north of the alignment. Large portions of the Botany Sands are known to be contaminated from a variety of sources primarily related to previous industrial land-use, however the groundwater in the study area has generally low levels of contamination compared to the groundwater within Botany Management Zone 1, north and east of the project. If contaminated groundwater enters the tunnels during construction it will be treated at one of the water treatment plants prior to discharge. It is not considered feasible to estimate the concentration of contaminants with any certainty due to significant variabilities and uncertainties associated with the contamination. An approach which is consistent with previous road tunnelling projects is to provide management measures and treatment to control pollutants. Potential pollutants identified in the contamination investigations include heavy metals, PFAS compounds, hydrocarbons, nutrients pesticides and herbicides.

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

5.5.3 Groundwater treatment

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

Where appropriate, 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, for example. Groundwater reuse would be undertaken in accordance with the policies of sustainable water use of DPI-Water (National Water Quality Management Strategy 2006). The volume of recycled water required for beneficial use will be variable and dependent on site conditions and will be likely be driven by a demand for beneficial use water. The estimated total volume of water required during construction is not available at this stage of the project and will be determined during detailed design. It is expected that there will be a water surplus during construction and recycled water for operational purposes would be used in preference to potable water where possible.

Based on the knowledge gained from the adjoining WestConnex tunnelling projects (M4 East, New M5 Motorway and M4-M5 Link) it is likely that the water treatment plants would be required to include pH correction as well as the ability to reduce concentrations of iron, manganese, suspended solids, ammonia, nitrate and hydrocarbons. The results collected as part of this EIS investigation as outlined in **sections 4.11** and **4.16** confirm that groundwater may require treatment for these compounds in addition to total nitrogen and total phosphorous. Other metals including copper, chromium, lead, nickel and zinc were also recorded at elevated levels on a limited number of occasions. The type, arrangement and performance of the construction of water treatment facilities will be developed and finalised during detailed design.

The receiving waterways and ambient water quality of Muddy Creek and Botany Bay are all disturbed receiving environments. The discharge quality criteria will be provided in the project conditions of approval but given the nature of the receiving waterways and temporary nature of the construction phase the ANZECC 90 per cent protection level for discharge is considered appropriate. The 99 per cent protection level would apply to analytes that bio-accumulate such as heavy metals.

The assessment of the potential impacts of the quality of water discharged from the water treatment plants during construction is discussed in **Appendix L** of the EIS (Surface water technical report).

5.5.4 Acid sulfate soils

Potential acid sulfate soils (PASS) have been identified within locally derived fill that is associated with the palaoechannel beneath the southern part of the alignment near Bay Street (AECOM 2018). The majority of the tunnels would be deep and extend below the areas where PASS may be expected to be found. The excavation of low-lying natural soil for the President Avenue Ramps, however, may uncover PASS which will require treatment and removal under the CEMP. When exposed to air, the iron sulphides (commonly pyrite) within acid sulfate soils can oxidise, producing sulphuric acid. The soils become exposed to air by either excavation or dewatering.

Parts of the project that could be impacted by acid sulfate soils if excavated during construction are:

- Temporary and permanent surface infrastructure including building foundations, roads and stormwater drainage structures
- Vent and access shafts through soils such as at the Roads and Maritime depot in West Botany Street and the vent shafts that are being considered from this site to the main tunnel alignment and ramp alignments.
- Bridge and portal structures penetrating soils
- Soft ground tunnels.

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

5.5.5 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. Typically salt concentrations within soils derived from the Hawkesbury Sandstone are low. However concentrations of salts within alluvium can be extremely variable depending on the origin of the alluvium. Salt concentrations within marine derived alluvium or is tidally influenced would be high, whereas fluvial sediments deposited in a fresh water creek system would be expected to have low salt concentrations. Under shallow groundwater conditions, saline groundwater may be drawn to the ground surface 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 study area over 150 years ago, a new equilibrium has been established and the removal of any further remaining trees on the new equilibrium would not be substantial. The development of urban salinity may cause corrosion of building materials, degrade surface water quality or prevent the growth of all but highly salt tolerant vegetation.

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

5.5.6 Saltwater intrusion

Saltwater intrusion would commence as soon as the drawdown cone of depression reaches the edge of nearby tidal surface waterbodies and starts to impact groundwater close to the shoreline. The nearest tidal water bodies are Cooks River, Muddy Creek, and Botany Bay located 450 metres, 700 metres and 1000 metres east respectively of the alignment. During construction, saline groundwater would not inflow to the tunnels from tidal areas because the tidal surface waterbodies are a considerable distance from the tunnels and the calculated groundwater travel times from these waterbodies are too long for saline water to reach the tunnels. The modelling predicts average travel times for saline water to enter the tunnels ranges between 46 years (Spring Street Drain) and 150 years (Wolli Creek). Close to the shoreline, groundwater quality would become more saline during the construction period due to saltwater intrusion; however the slight salinity increase is unlikely to impact on the environment since the groundwater along the tidal fringe is naturally saline due to tidal mixing. In addition, there are no registered water supply wells or priority groundwater dependent ecosystems along this tidal fringe.

5.5.7 Groundwater monitoring

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

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

Groundwater would be monitored in the alluvium and Hawkesbury Sandstone. The construction groundwater monitoring network would use a sub-set of the current monitoring wells identified in this EIS. 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 (nitrate, nitrite, Total Kjeldahl Nitrogen (TKN), ammonia and total phosphorous)
- Major cations (sodium, potassium, calcium, magnesium) and anions (chloride, sulfate, carbonate, bi-carbonate).

The analytes to be sampled and the frequency and type of reporting will be confirmed prior to construction.

The monitoring program would be developed in consultation with the NSW EPA, DPI-Fisheries, DI-Water and Bayside Council and documented in the CSWMP.

5.6 Construction of ancillary infrastructure and facilities

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

- Tunnel portals
- Ventilation systems
- Cut and cover sections.

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

5.7 Utility adjustments

Utilities and services located within close proximity to the project would need to be protected, relocated or realigned during construction. . The majority of the utility adjustments would occur in new utility service corridors along President Avenue and along the cut and cover sections linking the tunnels with the President Avenue ramps. The utilities to be impacted include:

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

The relocation of utilities is discussed in more detail in **Chapter 14** (Property and land use) of the EIS. These works would involve excavating utility trenches to varying depths and are likely to intersect the shallow water table within the alluvium. During trench excavations, sheet piling (or similar) 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. The location of existing utility services and any changes required would be confirmed by the construction contractor during the detailed design of the project, in consultation with the relevant utility providers. These works will be undertaken in accordance with the CEMP and the CSWMP.

5.8 Ground movement (settlement)

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

When groundwater levels are drawn down, the unconsolidated sediments hosting the groundwater are subjected to an increase in effective stress. The increase in stress is analogous to additional load being applied to sediment, and the sediment would experience settlement. The magnitude of the resulting settlement can induce damage to structures within the groundwater drawdown zone of influence. Settlement associated with groundwater drawdown is different from settlement associated with construction tunnelling. Settlement associated with construction tunnelling occurs within a shorter timeframe compared to settlement associated with groundwater drawdown, which occurs over a longer timeframe.

Residual soil profiles developed on the weathered sandstone are typically relatively thin, stiff and of low compressibility. The risks associated with water table drawdown and associated dewatering induced settlement is dependent upon the amount of drawdown within the alluvium and geotechnical properties. Settlement within the Hawkesbury Sandstone would be expected to be less than that within the alluvium due to the competent nature and geotechnical properties of the sandstone.

Since ground settlement is more likely to occur within the alluvium, design measures have been instigated to minimise settlement at those locations. The tunnels have been designed to dive beneath the majority of the Cooks River Palaeochannel to reduce groundwater ingress to the tunnels from the alluvium and hence reduce settlement. Where tunnels rise to the ground surface in the southern part of the alignment, the alluvium will be intersected. Tunnel sections intersecting the alluvium will be undrained (tanked) to minimise groundwater ingress. Cut and cover sections forming part of the President Avenue Ramps will be constructed with diaphragm walls socketed into the sandstone to reduce tunnel groundwater ingress. Elsewhere along the alignment, the bulk hydraulic conductivity of the sandstone will be decreased by grouting, decreasing groundwater inflow and hence reducing settlement.

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

Although the groundwater model has predicted groundwater drawdown within the alluvium and Botany Sands, during construction, 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. Detailed settlement modelling would be required to be undertaken during the detailed design phase where the water table within alluvium may be drawn down.

Monitoring of settlement throughout the construction program would be included as part of the CEMP and may include the installation of settlement markers or inclinometers. Pre-construction condition surveys of property and infrastructure that could be impacted by settlement would be undertaken before the commencement of construction activities. If high risk areas are identified, management measures such as appropriate support and stabilisation structures would be implemented to minimise settlement impacts on property and infrastructure. 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. Environmental management measures to control groundwater inflows (which influence groundwater drawdown and therefore ground movement) during construction are outlined in **section 8.**

5.8.1 Consolidation of the soil profile

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

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

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

With the exception of the palaeochannels, groundwater drawdown caused by the tunnel is expected to be generally confined to bedrock and not induce consolidation in the soils overlying the bedrock. On this basis, surface settlement due to drawdown of groundwater is expected to be negligible along the tunnel alignment other than at the palaeochannels in the vicinity of Spring Street, Bay Street and President Avenue. Preliminary estimates of the ground settlements at these locations are provided in **Table 5-3**.

Table 5-3 Preliminary estimates for ground settlements overlying palaeochannels

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

5.8.2 Muddy Creek constructed channel

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

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

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

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

5.9 Water balance

The simulated water balance calculated for the end of construction (year 2024) is summarised in **Table 5-4** based on the water balance presented in the groundwater modelling report for Scenario 3 (M5 East, New M5 Motorway, M4-M5 Link and the project).

Table 5-4 Simulated groundwater balance – construction (2024)

Water component (Unit)	Inputs (recharge)	Output (discharge)
	ML/day	
Rainfall infiltration (Rf)	4.92	0.00
Evapotranspiration (Et)	0.00	4.22
GW Extraction* (Pw)	0.00	0.03
River inflow/outflow (Ri/Ro)	3.233	1.5858
Tunnels (M5 East, New M5 and M4-M5 Link) (T)	0.00	0.9999
Regional boundary flow (RBi/RBo)	0.34	1.15
Tidal seepage (TSi/TSo)	0.15	1.666
Storage (Si/So)	3.233	2.244
TOTAL	11.8686	11.8686

Note: * Extraction from Alexandria Landfill

The groundwater balance confirms that the major water inflows to the model during the construction phase would be derived from rainfall infiltration, river leakage and storage. Conversely, the major outflows are via evapotranspiration, river baseflow and regional flow with additional water being extracted as the tunnels progress. The net loss in storage of 1.06 ML/day indicates the tunnel is draining water from the local hydrogeological system.

In summary the water balance can be summarised as follows:

Inputs = Outputs; where

Rf + Ri + RBi + TSi + Si + RO = Et + Ro + T + Pw + RBo + Tso + So + SWo

6 Assessment of operational impacts

Potential impacts on groundwater due to the operation of the project are discussed in this chapter and mitigation measures to eliminate or manage impacts are outlined in **Chapter 8**. The potential impacts include reduced groundwater recharge, groundwater drawdown and reduction in groundwater quality. Each of these potential impacts is discussed, with specific reference to environmentally sensitive areas where applicable.

6.1 Altered groundwater recharge

The alluvium along the Rockdale wetlands and recreation corridor is recharged by direct rainfall recharge and leakage from the Rockdale wetlands. A new pavement drainage system to accommodate the President Avenue widening would direct runoff into water quality basins before discharge into either Rockdale Bicentennial Park Pond or North Scarborough Pond. Although the runoff to the ponds is likely to marginally increase due to the higher volumes of captured run-off, groundwater recharge should remain the same as the leakage factor will remain constant.

The development of impervious surfaces along the alignment such as the President Avenue road widening and intersection would increase the volume and rate of runoff, locally reducing groundwater recharge.

Elsewhere across the project footprint there are areas where buildings and paved areas are to be temporarily used for construction within the construction ancillary facilities. If during operation of the project these areas no longer contain buildings or structures or are no longer paved, then groundwater recharge is likely to be enhanced.

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

6.2 Tunnel inflow

Inflow to the drained tunnel is influenced by the geology, structural geology and hydrogeological parameters of the intersected lithologies. These parameters include the bulk hydraulic conductivity, storativity and hydraulic connectivity of water bearing structural features to the tunnel. Groundwater inflow from the Hawkesbury Sandstone is expected to be low along the majority of the alignment due to low bulk hydraulic conductivity values of typically 0.008 metres per day (**Table 4-7**).

The project tunnels are to be excavated from the Hawkesbury Sandstone with some sections transitioning through the Mittagong Formation and alluvium. To reduce groundwater inflow, the tunnels are designed to minimise intersecting the alluvium by diving beneath the Cooks River Palaeochannel and being excavated from the less transmissive Hawkesbury Sandstone. Where the tunnels rise to the surface at the President Avenue Ramps it is not possible to avoid the alluvium so the tunnels will be undrained (tanked) to reduce groundwater inflow.

Conservative estimates of tunnel inflows can be made by assuming a maximum uniform groundwater inflow rate of one litre per second per any kilometre along the whole drained tunnel length during operation of the project plus two litres per second along the 0.4 kilometres of the Rockdale access decline per any kilometre of that decline. The total tunnel length including motorway and ventilation tunnels is around 8,460 metres. The total tunnel length of drained tunnel is around 6,840 metres. Assuming a worst case scenario of the above inflow rates a groundwater inflow of around 77.04 litres per second (0.6 megalitres per day) would be expected. This approach is a conservative inflow estimate as the operational tunnels are designed to restrict groundwater inflow to below one litre per second per kilometre for any kilometre length of tunnel.

Long term groundwater inflows have been modelled and vary over time as local conditions change. After the commencement of operations in 2025, the estimated long term inflows into the motorway tunnels are predicted to be 0.54 ML/day (197 ML/year), reducing to 0.52 ML/day (190 ML/year) in 2100.

The regional impact of long term groundwater inflow (or 'take') as a result of the project on the Sydney Basin Central has been estimated by comparing the annual recharge with the modelled long term inflow. Annual rainfall recharge to Sydney Basin Central is 229,223 ML (NoW 2011). The predicted long term tunnel inflow or 'take' (from the combined motorway tunnels, Rockdale access decline and ventilation tunnels) is estimated to vary from 220 megalitres per year (2025) reducing to 215 megalitres per year in 2100. Consequently the long term groundwater 'take' due to groundwater inflow to the tunnels represents 0.48 per cent of the annual recharge across the Central Sydney Basin in 2025 reducing to 0.47 per cent in 2100. Although the groundwater 'take' from the local hydrogeological system is considerable in terms of volume, when compared with regional recharge across Sydney Basin Central, the groundwater 'take' is less than 0.1 per cent of the annual rainfall recharge.

Groundwater modelling (**Annexure F**) has predicted inflows over the four kilometre length of the existing M5 East tunnels. Modelling Scenario 1 presents the base case and predicts the inflow to the M5 East tunnels to be 0.92 litres per second per kilometre (2016), gradually declining to 0.19 litres per second per kilometre (2100). These results are consistent with the long term inflow of 0.8 to 0.9 litres per second per kilometre reported by Hewitt (2005) confirming the model accurately predicts tunnel groundwater inflow. It should be noted that while groundwater inflows are calculated as accurately as possible within the model confines, the inflows are averages along the alignment and actual inflow rates could be highly variable and dependent upon local geological features and the success of grouting during construction. Consequently the long term inflow rates should not be used for the purpose of planning water management during construction or operation.

The predicted long term water take from each of the Greater Metropolitan Regional resources due to tunnel inflows and compared to the LTAAEL is summarised in **Table 6-1**. Comparison of predicted tunnel inflows indicates that the long term reduction in the groundwater availability within the Botany Sands over the life of the project will vary from 00.2 ML/dayday (73 ML/year in 2025) to 0.14ML/day (51 ML/year in 2100) which represents 0.35 to 0.50 per cent of the LTAAEL. Annual rainfall recharge to the Botany Sands Aquifer is 30,424 megalitres (NoW 2011). Therefore the predicted groundwater 'take' from the Botany sands represents between 0.17 and 0.244 percent of the available recharge.

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

Table 6-1 Long term groundwater extraction from the Metropolitan Regional Groundwater Resources

Aquifer	LTAAEL (megalitres per year)	Water take – Year 2025 (megalitres per year)	Water take – Year 2100 (megalitres per year)	Percentage of LTAAEL
Botany Sands	14,684	66	51	0.35 to 0.50
Sydney Basin Central	45,915	220	215	0.7 to 0.48

Source: NoW 2011 and RPS 2018

6.2.1 Botany Sands

The alignment intersects the Botany Sands Source Management Zone 2 (**Figure 4-10**) however there would be no direct inflow of groundwater from the Botany Sands into the tunnels because the sections of tunnels intersecting the alluvium are to be undrained (tanked). There are however likely to be indirect inflows from the Botany Sands aquifer, as the Hawkesbury Sandstone is likely to be hydraulically connected to the Botany Sands aquifer. Hydraulic connection would however be limited where the basal residual alluvial clay layer (reducing vertical flow) is present. Where the basal clay has been eroded (as suggested by Golder 2017 (**section 4.13.4**)) there is potential for groundwater from the Botany Sands aquifer to enter the tunnel via fractured rock due to downward leakage induced by drawdown in the underlying Hawkesbury Sandstone. This downward leakage of groundwater from the Botany Sands to the Hawkesbury Sandstone could potentially occur anywhere within the area of drawdown extent in the Hawkesbury Sandstone where the sandstone is overlain by the Botany Sands.

6.2.2 Alluvium and surface water

As with the Botany Sands aquifer, alluvium flanking and underlying creeks, drains and wetlands are partly saturated. Since the alluvium is hydraulically connected to surface waterbodies, water can potentially leak from the wetlands, ponds and creeks via the alluvium and fractured sandstone into the project footprint. Although the majority of the creeks and drains are concrete lined, there remains good hydraulic connection with the groundwater and alluvium outside the main channels and within Scarborough Ponds and Rockdale Bicentennial Park Wetlands. Cut-and-cover sections that intersect the saturated alluvium are to be constructed with cut-off walls, such as diaphragm walls, to restrict long term tunnel leakage from the alluvium. There is no direct inflow to the tunnels from the alluvium since the tunnels are designed as undrained (tanked) where the alluvium is intersected.

Leakage from surface water channels due to the project has been modelled. The modelling demonstrated that an increase in leakage from the creeks occurs when the drawdown due to tunnelling lowers the groundwater elevation to below the creek stage. The leakage would impact groundwater in tidal creeks where saline water replaces better quality groundwater. Modelled changes in leakage from the main creeks and channels is summarised for the end of construction and the long term impact (Year 2100) in **Table 6-2**.

Table 6-2 Predicted changes in leakage at the end of construction (2024) and long term (2100)

(m^3/day)	Muddy Creek	Spring Street Drain	Cooks River	Wolli Creek	Bardwell Creek
Base case	2.6	1.0	0.8	1.4	39.1
Leakage increase (2024)	0.0	0.0	0.0	0.0	0.0
Leakage increase (2100)	0.1	3.3	0.0	0.0	0.0
% increase*	2.8	308.9	0.0	0.0	0.0

Note: *increase is due to the tp at 2100

At the end of construction there is predicted to be no change in leakage from Muddy Creek and Spring Street Drain, suggesting that the localised drawdown does not reduce groundwater levels below the channel stage. Longer term drawdown in the Spring Street Drain alluvium results in a long term leakage of 309%. The drawdown in the alluvium in Muddy Creek is much less with a predicted 2.8% increase in leakage. Although Bardwell Creek is non-tidal there is no predicted increase in leakage due to the project.

Where the channels are concrete lined, groundwater would be expected to flow within the alluvium surrounding the channel, discharging downstream directly into Muddy Creek. However, if groundwater levels are lowered, due to tunnel inflows, then groundwater flow could be reduced 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 catchment, any groundwater loss from the creek to groundwater via leakage is unlikely to degrade groundwater quality as the surface water would be of lower salinity.

6.2.3 Dykes

Dykes such as those discussed in **section 4.7.6** cross-cut the Hawkesbury Sandstone. The dykes may affect tunnel drainage in the short term as competent (fresh) dykes or dykes weathered to clay can form natural hydraulic barriers. Conversely the metamorphosed zone around the volcanic intrusion within the sandstone or shale can be fractured causing a conduit for preferred groundwater flow. Several dykes have been identified along the project footprint.

6.2.4 Management of groundwater inflows during operation

Groundwater inflows to the tunnel are influenced by the geology intersected and the water bearing structural features encountered. Once constructed, the drained tunnels would behave as longitudinal drains at atmospheric pressure, allowing groundwater leakage into the tunnels. Groundwater intersected during the operations phase would be the primary source of wastewater, with surface water inflow being a minor component. The wastewater management system has been designed to treat and discharge groundwater as well as stormwater and other intersected water streams.

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

6.3 Groundwater level decline

6.3.1 Long term groundwater inflow

Previous tunnelling in the Hawkesbury Sandstone in the Sydney region has shown that groundwater inflow is typically highest during construction and then steadily reduces as the cone of drawdown expands and an equilibrium or steady state conditions are reached. This equilibrium is achieved when the tunnel inflow is matched by rainfall recharge via infiltration and/or surface water inflows. Long term groundwater inflow to the tunnels is influenced by the geology intersected and the tunnel construction method used to reduce the bulk hydraulic conductivity. The gradual 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, and as inflow rates are directly proportional to the hydraulic gradient, inflow rates decline. Water is derived from storage depletion and potentially surface water interaction but will be partly offset by recharge, both in the short term and long term.

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

Groundwater modelling has calculated inflows for the construction and operations phases of the project. At project opening (2025) tunnel inflows are estimated to be 241 megalitres per year, declining to 212 megalitres per year at the end of the model simulation in 2100. As observed in other Sydney tunnels, inflow is likely to decrease with time. This is primarily due to the groundwater levels drawing down and inducing flow towards the tunnels from an increasingly broader region, as the cone of depression expands over time. Inflows would also decline over time as groundwater pressures around the tunnel decline as the storages of higher inflow features are drained. Similarly, siltation, chemical induration and organic slimes that accumulate in the tunnel defects may reduce the surrounding rock mass permeability, further reducing inflows.

6.3.2 Predicted groundwater drawdown

Construction of drained tunnels beneath the water table is expected to cause long term ongoing groundwater inflow to the tunnels, inducing groundwater drawdown along the project footprint during its operation.

There are two main mechanisms that influence groundwater drawdown: the actual water table drawdown and the hydraulic pressure drawdown. Actual groundwater drawdown of the water table would be dependent on a number of factors including hydraulic parameters and proximity to the project footprint. Immediately after tunnelling is completed, groundwater inflows would be at their highest. With time, groundwater inflow to the tunnel will decrease while the water table would gradually decline until equilibrium is reached. In zones where the inflow rates are likely to exceed the inflow criterion, the fractured lithology would be pre-treated or have waterproof membranes installed (for example) to reduce permeability during construction to reduce on-going groundwater inflow and drawdown in the operations phase. Groundwater movement is naturally restricted in some areas as the Hawkesbury Sandstone is interbedded with shale lenses that locally act as aquicludes or aquitards.

Groundwater drawdown within the palaeochannels and river alluvium within the project footprint would be minimal as the hydraulic heads within saturated sediments are in part maintained by direct hydraulic continuity with surface water, supported by a reduction in stream baseflow (refer to **section 5.4.2**).

The predicted drawdown beneath surface water bodies including creeks, drains, wetlands and ponds varies depending on local geology, presence or absence of aquicludes and saturated fractures, horizontal distance from the tunnel, depth to the tunnel and tunnel design. The tunnels have been designed so there would be no direct inflow from the alluvium as outlined in **sections 5.2** and **6.2**.

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

Groundwater drawdown due to the F6 Extension Stage 1 New M5 Motorway, at Arncliffe, to President Avenue, at Kogarah has been calculated by subtracting the results of modelling Scenario 3 (the project, M5 East, M4 East, New M5 Motorway and M4-M5 Link) from Scenario 2 (M5 East, New M5 Motorway and M4-M5 Link). Calculated long term (Year 2100) drawdown for the project within the alluvium and Hawkesbury Sandstone is presented in **Figure 6-1** and **Figure 6-2**, respectively.

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

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

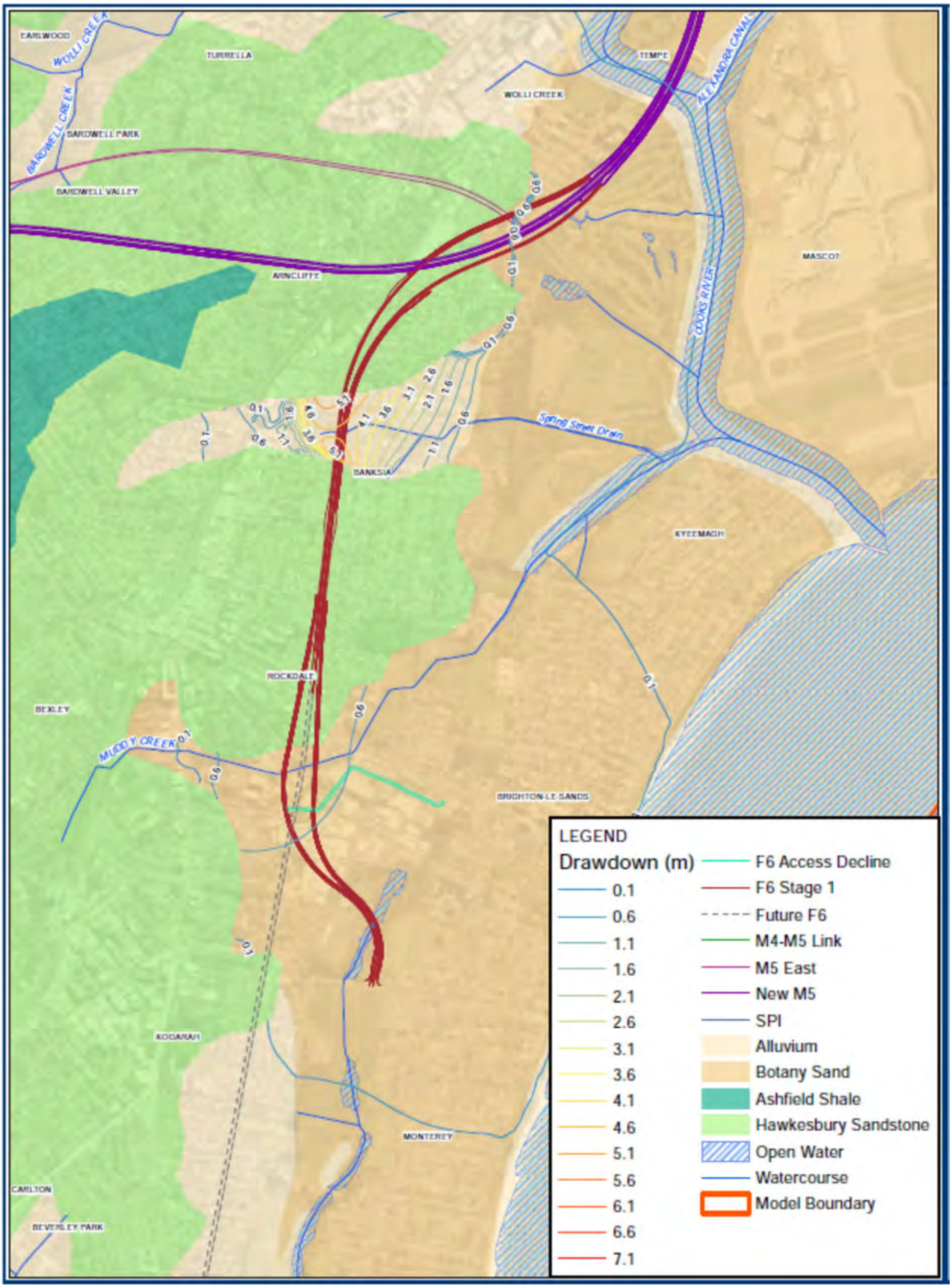


Figure 6-1 Predicted long term (Year 2100) drawdown in the alluvium for the project (RPS 2018)

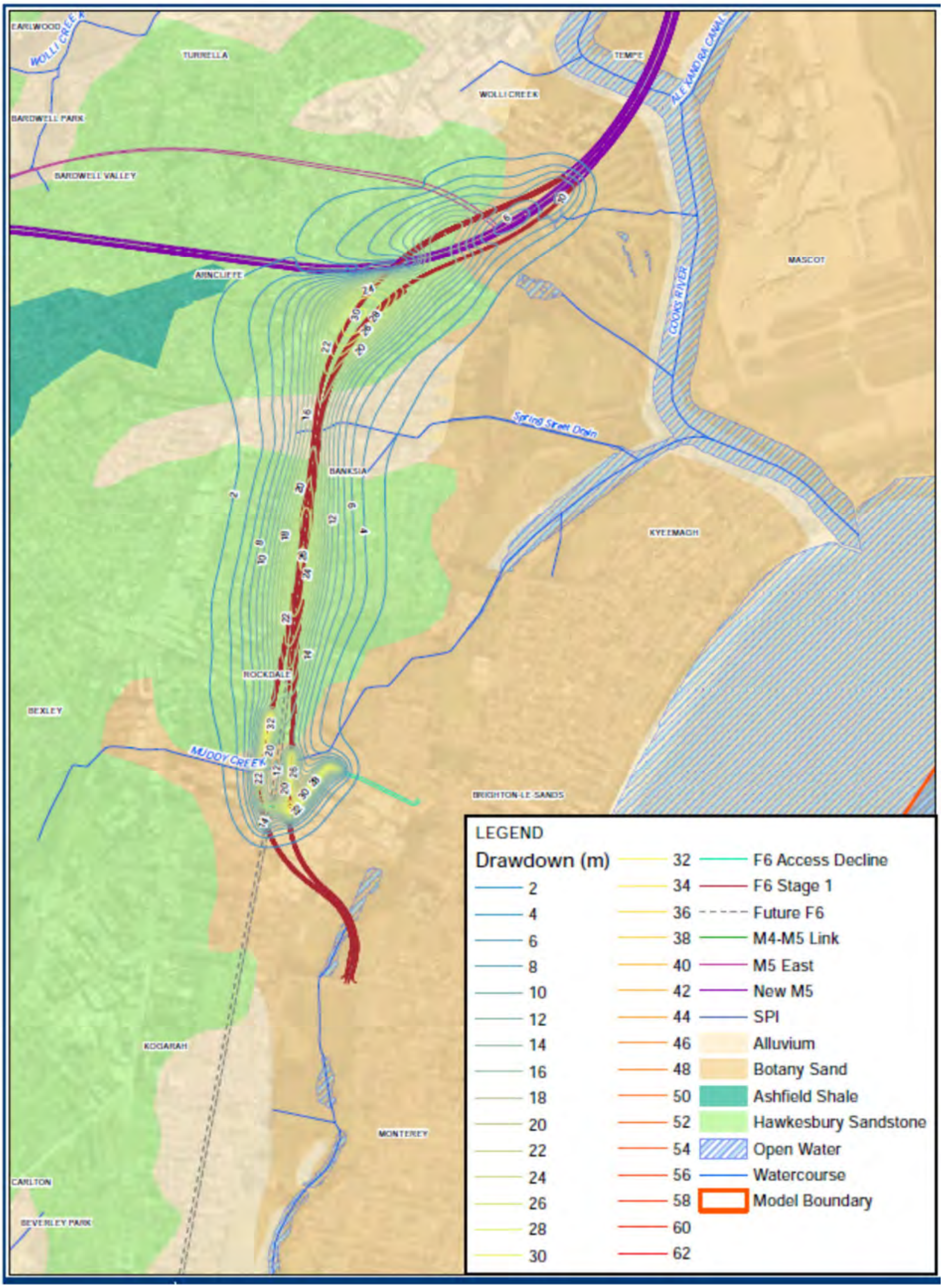


Figure 6-2 Predicted long term (Year 2100) drawdown in the Hawkesbury Sandstone for the project (RPS 2018)

6.3.3 Potential impacts on groundwater dependent ecosystems

The closest priority GDEs are the Botany Wetlands and Lachlan Swamps within the Botany Sands, located in Centennial Park around eight kilometres north-east of the project footprint. These wetlands are at a sufficient distance from the project footprint to not be impacted. Groundwater dependent ecosystems across the project footprint are discussed in **section 4.4.4** and in **Appendix H** to the EIS (Biodiversity development assessment report).

Under the AIP a predicted drawdown of greater than 10% of natural variation will require adaptive management for high priority GDEs. Although little is known about water level fluctuations within the Rockdale wetlands the natural variation has been estimated at 0.5 metres (**section 4.4.3**). Consequently according to this criteria a predicted drawdown in excess of 0.05 metres would require adaptive management. Wetlands within the project study area that in accordance with the BOM GDE Atlas do not have any groundwater dependence include Landing Lights, Eve Street, Spring Street, King Street and Marsh Street Wetlands. Drawdown in excess of the seasonal variation of 0.05 metres is predicted at these wetlands with long term drawdown predicted to vary from 0.28 metres at Landing Lights Wetland to 0.47 metres at the Marsh Street Wetland. These predicted drawdowns are not considered to be of concern because of the limited groundwater dependence of these wetlands.

Long term drawdown predicted at the Rockdale Wetlands ranges from 0.28 metres to 0.32 metres. Similarly long term drawdown at the Scarborough Ponds is predicted to be between 0.11 and 0.12 metres. In both cases these predicted drawdowns are not considered substantial because the wetlands are not classified as high priority and in fact are highly modified to act as flood mitigation basins. Consequently the predicted groundwater drawdown will be less than predicted because of the continual inflow of stormwater and floodwaters.

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

Post tunnel construction, groundwater would be available for partially groundwater dependent flora as the vadose (unsaturated) zone would not be affected by the project as flora would continue to receive rain infiltration. Shallow perched water pooled over shale lenses within the sandstone (recharged by rainfall) is expected to be present irregularly along the alignment. The perched groundwater could partially sustain surface ecosystems, if any exist, however they would be mainly dependent upon rainfall recharge and moisture within the vadose zone. In low lying areas, the project is not expected to substantially change the availability of water for plants due to the low permeability of the clayey soils in combination with frequent rainfall events and higher recharge than elevated sites.

An assessment of the impacts to natural processes as a result of the operational discharges which may affect the health of the fluvial, riparian and estuarine systems and landscape health within the study area is provided in **Appendix L** of the EIS (Surface water technical report). These natural processes are outlined in **section 4.4.** In summary, no wetlands, marine waters or natural floodplain systems are considered to be substantially impacted by the project. Impacts to aquatic connectivity and habitat are considered in **Appendix H** of the EIS (Biodiversity development assessment report).

6.3.4 Potential impacts on existing groundwater users

Existing groundwater use and extraction is outlined in **section 4.12**. Long term tunnel drainage could impact existing groundwater users registered with DI-Water. A review of the DI-Water groundwater database indicates that of the registered bores within two kilometres of the project footprint, the majority are shallow bores extracting groundwater from the Botany Sands for domestic use. A total of 360 boreholes within a two kilometre radius of the project footprint are registered for water supply or irrigation. The majority of these are shallow spearpoints extracting water from the Botany Sands for domestic use.

Groundwater modelling has been used to predict drawdown at the location of registered bores across the project footprint. In accordance with the AIP, a predicted drawdown of greater than two metres will require adaptive management. Only five bores are predicted to be impacted by a long term drawdown in excess of two metres that is directly attributable to the project. These bores are shallow water supply wells as summarised in **Table 6-3** with a maximum predicted long term drawdown of around 3.8 metres (GW024062).

Two additional bores (GW072161 and GW107993) outside the project boundary are expected to be drawn down in excess of two metres due to the cumulative impacts of the project and WestConnex tunnels. Impacts and mitigation measures for these wells are discussed in RMS, 2015.

Table 6-3 Predicted long term drawdown in registered bores in excess of two metres

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

6.3.5 Potential impacts on baseflow

Losses to stream flows can occur either as a reduction in baseflow, or as streambed leakage that are dependent on the hydraulic connection between the stream channel and alluvium, the underlying sandstone and the relative water levels of the creek and groundwater. Baseflow within the alluvial sediments beneath creeks and drains can be hydraulically connected to the tunnels via saturated secondary structural pathways within the Hawkesbury Sandstone. Conversely stream bed leakage occurs only when the water table elevation is below the creek bed level and groundwater seeps into the underlying lithologies. The concrete lining of creeks reduces stream bed leakage and baseflow.

Predicted impacts on baseflow of major non-tidal creeks within the project footprint during the operations phase has been modelled (**Annexure F**). Baseflow, as simulated in the model, only represents the occasions when groundwater reaches the ground surface or the streambed and enters the drainage system. Changes in baseflow calculated by the model are relative to the model as there is no gauging data to calibrate against to determine absolute values. Predicted long term changes in baseflow as a result of the project are summarised in **Table 6-4**.

Although the baseflow component of surface flow is reduced in several of the water courses, the volumes are small and it is possible that the overall contribution to river flow from groundwater input is even smaller due to the waterways being mostly lined channels, including Muddy Creek. It has not been possible to quantify the proportion of stream flow that is baseflow due to the lack of gauging data, however it is likely that the majority of stream flow would be derived from stormwater runoff.

Table 6-4 Predicted long term changes in baseflow (Year 2100)

2100 (m^3/day)	Muddy Creek	Spring Street Drain	Cooks River	Wolli Creek	Bardwell Creek
Base case	36.6	139.8	14.1	55.6	103.7
Project baseflow	29.2	83.2	14.1	55.6	103.7
Baseflow reduction*	7.4	56.6	0.0	0.0	0.0
% Reduction*	20.4	40.5	0.0	0.0	0.0

Note: *reduction is due to the project

Muddy Creek and Spring Street Drain are the only streams or channels in the study area that are expected to experience a long term reduction in baseflow. However since both channels are predominately concrete lined and tidally influenced, the baseflow contribution to the total streamflow us expected to be a negligible proportion. The majority of stream flow would be derived from surface run-off and tidal waters at low elevation. Of this small proportion, there is a predicted long term 20% and 40% reduction in baseflow. Further afield but within the model domain there are no predicted impacts on Wolli Creek and Bardwell Creek during operation of the project.

The Rockdale wetlands and Scarborough Ponds are unlined and in hydraulic connection with the underlying alluvium. Any decline in water levels in these waterbodies is likely to be in part balanced with diverted stormwater and floodwaters in the engineered flood mitigation scheme.

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

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

6.4 Ground movement (settlement)

Ground movement induced by tunnel excavation is anticipated to be predominately settlement or subsidence and is discussed in **section 5.8.** 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.

Residual soil profiles developed on the weathered sandstone bedrock are typically relatively thin, stiff and of low compressibility and as such would be less susceptible to ground settlement. The risks associated with water table drawdown within the alluvium beneath the Spring Street Drain and Muddy Creek and associated dewatering induced settlement is dependent upon the amount of groundwater drawdown within the alluvium and the geotechnical properties of the soil. The tunnels have been designed to reduce groundwater drawdown within the unconsolidated sediments by constructing tanked (undrained) tunnel sections through the alluvium which would also minimise settlement in these areas.

A geotechnical model of representative geological and groundwater conditions would be prepared during the detailed design phase prior to the commencement of tunnelling. The model would be used to assess predicted settlement impacts and ground movement during the construction and operation of the project.

Environmental management measures to control groundwater inflows (which influence groundwater drawdown and therefore ground movement) during the operation of the project are outlined in **section 8.2.**

As with construction, settlement monitoring would be undertaken during operation at buildings and infrastructure where exceedances of the settlement criteria are predicted. Settlement monitoring may include the installation of settlement markers or inclinometers. In the event that settlement criteria are exceeded for property and infrastructure during operation, measures would be taken to 'make good' the impact. These measures would be included as part of the OEMP.

6.5 Groundwater quality

6.5.1 Intercepting contaminated groundwater

There is a risk that contaminated groundwater within the project footprint (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 construction and hydraulic gradient changes may locally cause existing contaminant plumes (if present) to migrate towards the project footprint. During the operational phase these risks would be managed as outlined in **section 8.2**.

Leachate and elevated concentrations of ammonia are generated from landfills and historical illegal dumping sites such as those beneath the Rockdale Bicentennial Park playing fields within the Botany Sands. The risk of leachate contaminated groundwater directly entering the tunnels is considered low, since the tunnels within the alluvium are to be undrained (tanked) or cut and cover sections are to be constructed with cut-off walls to prevent groundwater inflow into the tunnels.

Contamination generated within the project tunnels during operations 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 water treatment process prior to discharge.

Beneath the Rockdale Industrial precinct (**Figure 4-1**), there is a risk that alluvial groundwater is contaminated from a variety of previous industrial activities. The risk of intersecting shallow contaminated groundwater during operation of the project is considered to be low because the tunnels intersecting the alluvium are to be tanked. However there may be hydraulic connection between the Hawkesbury Sandstone and alluvium, through which potentially contaminated groundwater could enter the unlined section of the tunnel.

Captured contaminated groundwater through tunnel inflows will be treated in the Arncliffe water treatment plant in accordance with the discharge criteria. Groundwater quality of tunnel inflows will be monitored throughout the operation phase in accordance with the OEMP to detect changes in water quality and treat as needed.

6.5.2 Groundwater treatment

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

Groundwater quality monitoring (**section 4.11**) indicates the groundwater is brackish with elevated metals and nutrients recorded during groundwater sampling. In order to prevent adverse impacts on downstream water quality within the Cooks River, treatment facilities would be designed so that the effluent would be of suitable quality for discharge to the receiving environment.

The tunnel operation water treatment facilities would be designed such that effluent would be of suitable quality for discharge to the receiving environment. Thus the ANZECC (2000) marine' default trigger values for 95 per cent level of species protection are considered the most appropriate guideline with reference to the NSW Water Quality Objectives. The 99 per cent protection level would apply to analytes that bio-accumulate such as heavy metals. Details of the adopted guideline values are provided in **Appendix L** of the EIS (Surface water technical report).

Water treatment may involve, for example:

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

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

In tunnels, iron or manganese sludges are formed naturally where there is elevated dissolved iron and manganese in the groundwater. These sludges are often a residue accumulated by bacteria that develops as the bacteria dies. The growth of iron bacteria such as *Crenothrix*, *Gallionella* and *Leptothrix* thrive best in low light conditions with little or no oxygen but with considerable carbon dioxide and dissolved iron. Iron commonly precipitates as a red-brown ferric (Fe^{3+}) deposit in oxic conditions. Similarly manganese bicarbonate precipitates as a black sooty deposit. These precipitates have the potential to block internal drainage infrastructure within the tunnel. The water treatment process is discussed in more detail in **Appendix L** of the EIS (Surface water technical report).

6.5.3 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 of Cooks River with more saline tidal water. In some locations, saline intrusion could cause saline water to reach the tunnels.

A capture zone analysis has been undertaken as part of the groundwater modelling to investigate the movement of saline water. From this analysis it is not possible to quantify accurate volumes or concentrations of saline water entering the tunnels so consequently the following discussion is qualitative. Backward particle tracking analysis has been used via MODPATH3DU to determine the capture zone of the tunnels during operation and the potential for water to be drawn from the tidal regions into the tunnels.

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

Travel times for tidal water to enter the tunnels in the project study area have been computed by the groundwater model and the average timeframes range from 46 years at Spring Street Drain to 127 years from the Botany Sands from the project mainline tunnels.

Early saline inflows would occur when water in the alluvium directly above and adjacent to the proposed tunnels rapidly drain into the tunnels. Initially, 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, although it will always be a minor component of total inflow.

Even though at Bardwell Creek for example the first saline groundwater is modelled to enter the interchange after year nine, this represents an extremely small inflow which will slowly become a larger proportion of flow over time. Thus 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, infrastructure and the environment in this timeframe. Similarly there is the potential to increase the salinity in registered bores due to saltwater intrusion however the slow progress is expected to have a minimal impact on these bores over a period of 100 years due to the slow groundwater movement.

Under natural conditions within the Hawkesbury Sandstone, a low salinity water lens towards the top of the aquifer is often present, unless there is nearby leakage from the typically more saline Ashfield Shale. Shallow rooted plants may have a partial dependency on the low salinity groundwater lens however it is expected that the plants would be sustained primarily through rainfall recharge and soil moisture within the vadose zone. In a coastal environment, the relationship between the depth of the fresh/saltwater interface is defined approximately by the Ghyben-Herzberg Principle which is dependent upon water density contrast and thickness of fresh groundwater above sea level. In summary, the Principle indicates that for every metre of freshwater in an unconfined aquifer above sea level there would be about 40 metres of fresh water in the aquifer below sea level. Thus as groundwater levels decrease over time so would the fresh water lens decrease but would be in part balanced by rainfall recharge.

In accordance with the OEMP, groundwater quality and inflow will be routinely monitored and treated as required prior to discharge.

6.5.4 Groundwater aggressivity

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

The aggressivity assessment (**section 4.11.6**) indicates that groundwater within the alluvium and Hawkesbury Sandstone is mildly aggressive to concrete piles with respect to chloride, pH and sulfate. For steel piles, groundwater within the alluvium and Hawkesbury Sandstone is non aggressive with respect to chloride and pH but is severely aggressive with respect to resistivity.

6.5.5 Groundwater monitoring

The groundwater monitoring program prepared and implemented during construction (**section 5.5.7**) 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.

The exact nature and frequency of the ongoing groundwater monitoring during operation would be determined by the project operator in consultation with the NSW EPA, DPI-Fisheries, DI-Water and the Bayside Council and documented in the OEMP or EMS.

6.6 Impacts due to ancillary infrastructure and facilities

Ancillary infrastructure constructed to support the project is outlined in **section 5.6**. The following ancillary infrastructure may impact groundwater during operation of the project:

- Tunnel portals
- Ventilation tunnels and systems
- Cut and cover tunnel sections.

Options for the construction of tunnel portals and cut-and-cover structures include secant piled walls or diaphragm walls socketed into the underlying bedrock to prevent the long term ingress of alluvial or perched groundwater into the tunnels. The construction of these structures would potentially alter local groundwater flow directions and could create groundwater mounding if the structures behave as barriers to groundwater flow. Mitigation measures such as the installation of drainage blankets to direct groundwater around these barriers would be explored during the detailed design phase. These impacts are discussed further in **section 5.4** and potential impacts to the final landform are discussed in **section 6.3.**

Ventilation tunnels are likely to be constructed as drained tunnels. This infrastructure has been included in the groundwater model so consequently long term impacts, such as groundwater drawdown and groundwater ingress due to tunnel seepage, is considered in the model discussions. Impacts to the hydrogeological regime due to additional drained tunnels are likely to slightly increase groundwater inflows and the lateral extent of groundwater drawdown.

The water treatment facilities are to be constructed to enable captured groundwater and surface water that enters the tunnels to be treated and discharged within the appropriate guideline concentration values. The water treatment plant is not expected to impact groundwater since it will be above ground level and have no interaction with the water table. Utility corridors, drainage channels and wetland areas are unlikely to be constructed at a depth to impact groundwater. Potential impacts due to discharge are discussed in **Appendix L** of the EIS (Surface water technical report).

6.7 Barriers to groundwater flow

Below ground infrastructure such as a tunnel below the water table can create physical barriers causing temporary or permanent interruptions to groundwater flow. Temporary impacts may occur after heavy rainfall, with infiltration to the water table and lateral flow being slowed due to the barrier, creating a groundwater mound behind the barrier. Permanent impacts may be caused by the compartmentalisation of an aquifer caused by the construction of a barrier boundary impacting groundwater flow patterns.

In the case of the operation of the project tunnels, there are unlikely to be physical barriers to groundwater flow created for a number of reasons. Firstly the majority of the tunnels are designed to be drained, allowing groundwater to seep into the tunnel and thus not creating a physical barrier to groundwater flow. Secondly, only limited sections of the tunnels are to be undrained (tanked), and not allowing groundwater ingress. These sections of the tunnels are to be constructed within alluvium and are unlikely to create a physical barrier as the tunnels would not fully penetrate the alluvium allowing groundwater to flow around (above or below) the tunnel. Grouting of highly permeable zones to reduce the bulk hydraulic conductivity and tunnel inflows are unlikely to create hydraulic barriers to regional flow, as the grouting would be localised and not applied through the full thickness of the aquifer, thus allowing groundwater to continue to flow through the ungrouted part of the aquifer.

Although the proposed 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 the lowering of groundwater levels centred on the project footprint and in some cases as a result of locally reversing the groundwater flow direction. Permanent drawdown around the drained tunnels for the project is likely to occur and the impacts are discussed in **sections 5.4** and **6.3**. The creation of this groundwater sink would occur along the project footprint and extend to a depth beneath the tunnel invert. Below this depth, there will be no discernible lowering of groundwater pressures and the groundwater flow pattern would remain unchanged. The groundwater model prepared for the project has simulated the effects of the hydraulic barrier due to tunnel seepage, allowing potential impacts on be predicted.

At tunnel portals or cut-and-cover sections such as the President Avenue ramps, the potential interruption of groundwater and possible groundwater mounding caused by the installation of cut-off walls would be avoided by the inclusion of drainage blankets or drains in the detailed design. The installation of pumps to periodically lower groundwater levels or to reduce hydrostatic pressures would not be recommended due to continued maintenance requirements.

6.8 Impacts to the final landform

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

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

Induced groundwater drawdown may impact the environment or groundwater users. The environment may be impacted by reducing the base flow to creeks or restricting flow to high priority groundwater dependent ecosystems as discussed in **sections 5.4.1** and **6.3.3** respectively. Lowering potentiometric heads may result in a reduced registered bore capacity as described in **section 6.3.4**.

6.9 Water balance

A groundwater balance for the long term operational phase for Scenario 3 (Year 2100) of the groundwater model has been conducted by for the project (**Annexure F**). The simulated water balance has been averaged from the beginning of the operations phase through to 2100, and is summarised in **Table 6-5**.

The water balance confirms that the major model inputs are rainfall infiltration and river leakage. The key output parameters are evapotranspiration, river leakage and discharge to tidal areas. The net storage loss confirms the tunnels are increasingly draining water from the system. The total recharge and discharge components match within an acceptable margin of error, indicating that the water components of the model balance.

Table 6-5 Estimated water balance – operational phase

Water component	Inflow (ML/day)	Outflow (ML/day)
Rainfall infiltration (Recharge)	5.12	0.00
Evapotranspiration (Et)	0.00	3.45
GW Extraction* (Pw)	0.00	0.01
River inflow/outflow (Ri/Ro)	1.10	1.27
Regional groundwater flow	0.17	1.38
Tidal seepage (TSi/TSo)	0.12	0.91
Tunnels (M5 East, New M5 Motorway, M4-M5 Link, F6) (T)	0.00	0.61
Storage (Si/So)	0.41	0.29
Total	6.82	6.92

Note: * Extraction from Alexandria Landfill

6.10 Groundwater management

During tunnel construction higher groundwater inflows would be reduced by a combination of pre-grouting and the installation of waterproof membranes. Strip drains or similar would be installed behind wall panels to assist in dissipating groundwater with tunnel drainage and treatment infrastructure designed to accommodate groundwater ingress. Groundwater is to be drained from south to north and collected at a sump at Arncliffe and pumped to the Arncliffe water treatment plant.

The beneficial reuse of the treated water during operation of the project would also be considered, the most likely reuse option being the irrigation of golf courses, parks and playing fields. Groundwater reuse would be in accordance with DPI-Water policies for sustainable water use.

Groundwater monitoring would be conducted periodically during the operations phase in accordance with OEMP as outlined in **section 6.5.5**. Additional groundwater monitoring wells are likely to be required once the tunnels are constructed. Their location, depth and purpose would be decided in consultation with DPE and DI-Water.

6.11 Climate change

The effects of climate change that may impact the groundwater regime are generally accepted as increased rainfall, increased rainfall intensity and sea level rises. DECC (2007) suggests values of sea level rises of 0.4 metre (Year 2050) and 0.9 metre (Year 2100). This is in general accordance with Anderson, 2017 who states that there will be a 0.38 to 0.66 metre median rise in sea level by 2090, relative to 1990. Similarly for the 200 year and 500 year average recurrence interval (ARI) rainfall intensities are predicted to represent 10 per cent or 30 per cent increase in 2016 (present day) rainfall intensities, respectively. Anderson (2017) however states that mean recharge in the southern part of Australia is more likely to decrease.

Increased rainfall and rainfall intensity would ultimately add more water to the hydrogeological system via increased rainfall recharge. This would result in slightly more water available for tunnel inflows but conversely with additional recharge the effects of groundwater drawdown would be slightly reduced.

Increased sea level rises would alter hydraulic gradients slowing groundwater discharge and river base flow to Muddy Creek, Spring Street Drain and Cooks River. The sea level rises would also alter groundwater salinity in tidal zones causing the displacement of low salinity groundwater up gradient with more saline water derived from tidal zones. No registered water supply bores have been identified in this tidal area that could become more saline. Any impacts to travel times for saline intrusion would be negligible.

Increased rainfall across the project footprint due to climate change would cause more freshwater recharge to the aquifers which may slightly improve groundwater quality although the impacts would be negligible.

The proposed impacts of climate change could result in outcomes that are greater than the current climate variability. These outcomes could include occasional increases in tunnel inflows due to increased rainfall but are expected to be in part balanced with extended periods of lower than average rainfall. Increases in tunnel inflows due to increased rainfall is not expected to increase the depth or extent of groundwater drawdown within the Hawkesbury Sandstone or alluvium because the additional inflows will not cause a depletion in aquifer storage. Consequently the climate impact changes are not expected to alter the proposed mitigation and management measures.

7 Assessment of cumulative impacts

7.1 Requirement for an assessment of cumulative impacts

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

Where drawdown occurs, for example, the drawdown cone of depression from a tunnel section may intersect with a drawdown cone from a neighbouring tunnel section or neighbouring activity such as the New M5 Motorway, M5 East or M4-M5 Link tunnels. The cumulative effect of overlapping drawdown cones results in a greater overall total drawdown, which may increase impacts on groundwater dependent receptors in the areas of overlap or increase settlement in key areas. Similarly, cumulative effects to groundwater quality may occur where the groundwater has been impacted by previous or current land use practices and/or saltwater intrusion.

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

7.2 Qualitative cumulative impact assessment for the F6 Extension Stage 1, New M5 Motorway, at Arncliffe, to President Avenue, at Kogarah and WestConnex projects

The groundwater model (**Annexure F**) has been used to quantify cumulative impacts of the WestConnex projects on the hydrogeological regime. The modelling scenario runs were as follows:

- Scenario 1 – Null Run (includes existing M5 East tunnel)
- Scenario 2 – Null run, plus M4 East, New M5 Motorway and M4-M5 Link
- Scenario 3 – Scenario 2 plus the project.

Scenario 3 minus Scenario 2 represents the cumulative impact assessment for the project.

The groundwater model has been used to predict groundwater inflows to the WestConnex tunnels at the end of construction (Year 2024) and throughout the operations phase (to Year 2100) for the three scenarios. The maximum calculated inflow rates are summarised in **Table 7-1.**

Cumulative inflow rates for the project and the portions of the WestConnex tunnels simulated in the model design are predicted to peak in 2023 at a rate of 1.52 ML/day or 0.62 L/sec/km over a tunnel length of 27.7 kilometres. Note that the 27.7 kilometre length of tunnel represents the project plus the length of WestConnex tunnels simulated in the model domain. The inflow rate declines over time to 1.38 ML/day or 0.56 L/sec/km in Year 2100. The declining inflow rate over time indicates that the modelled recharge does not supply enough water to the system to maintain the initial flow rates and groundwater storage is depleted. The predicted tunnel inflows remain below the overall project and WestConnex tunnel inflow criterion of one litre per second per kilometre for any kilometre length of tunnel.

Table 7-1 Predicted maximum cumulative project and WestConnex* tunnel inflows

Tunnel scenario	Combined tunnel length	Max inflow		
	(km)**	Year	ML/day	L/sec/km
1.M5 East (pre project)	4.00	2016	0.32	0.92
2. F6 Extension	7.9	2023	0.68	0.99
3. New M5 Motorway and M4-M5	20.8	2020	0.9	0.65

Tunnel scenario	Combined tunnel length	Max inflow		
	(km)**	Year	ML/day	L/sec/km
Link				
4. The project and WestConnex	23.9	2021	1.32	0.64

Note* represents the portion of New M5 Motorway and M4-M5 Link tunnelling included in the current model
** represents tunnelling in both directions.

Cumulative impacts during construction are impacts caused by the groundwater being extracted by the tunnelling process plus groundwater leakage into the WestConnex drained tunnels from the M5 East, New M5 Motorway and M4-M5 Link. These potential impacts are an increased groundwater 'take', increased drawdown and a reduction in groundwater quality due to increased saltwater intrusion.

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

Cumulative groundwater drawdown for the WestConnex and project tunnels in the alluvium, and Hawkesbury Sandstone at the end of construction (2024) is presented on **Figure 7-1** and **Figure 7-2** respectively. Specifically the modelling predicts an increase in drawdown of 0.5 metres (total drawdown of 4.1 metres) within the palaeochannel sediments beneath Spring Street Drain due to the cumulative tunnelling with the nearby New M5 Motorway tunnelling in September 2024. There is expected to be negligible drawdown within the sediments to the south. Drawdown of up to 0.7 metres is predicted within the alluvium flanking the Cooks River, although more than 0.5 metres of this drawdown is attributed to the New M5 Motorway tunnelling. Cumulative drawdown within the Hawkesbury Sandstone at the end of construction (**Figure 7-2**) is predicted to reach 61 metres to the invert of the tunnel at the connection with the New M5 Motorway at Arncliffe although the drawdown will also be influenced by the New M5 Motorway tunnelling. The drawdown extent beyond two metres extends a maximum of 350 metres either side of the project tunnels.

Long term cumulative groundwater drawdown for the project and WestConnex tunnels in the alluvium, and Hawkesbury Sandstone in Year 2100 is presented in **Figure 7-3** and **Figure 7-4** respectively. Within the alluvium long term cumulative drawdown reaches a maximum of 7.5 metres beneath the Spring Street Drain. To the south towards the President Street Ramps the long term drawdown in the alluvium is not impacted by cumulative drawdown, with drawdown remaining at about 0.6 metres. Long term cumulative drawdown in the Hawkesbury Sandstone (**Figure 7-4**) is predicted to reach a maximum of 62 metres at Arncliffe where the project joins the New M5 Motorway. The cumulative extent (to the two metre drawdown contour) extends up to 650 metres either side of the tunnel with the widest drawdown extent south if the New M5 Motorway in the Arncliffe/Bardwell Valley area.

The groundwater modelling has predicted that five registered bores would be drawn down in excess of two metres due to the project and two additional bores would be impacted due to the cumulative impacts of the WestConnex tunnels. Groundwater drawdown due to the project at the Rockdale Bicentennial Park and Scarborough Parks wetlands has been predicted by the model as 0.32 and 0.12 metres respectively. No additional drawdown at these wetlands is predicted due to the cumulative impacts with the WestConnex project works.

Baseflow reduction due to the project during construction and operations is discussed in **sections 5.4.2** and **6.3.5**. During long term operations baseflow reduction in Muddy Creek and Spring Street Drains is predicted to be 20.4% and 40.5% increasing to 20.8% and 56.0% respectively with cumulative impacts from the WestConnex tunnels. It should be noted that although these baseflow inflows are substantial the proportion of stream flow is small since the baseflow predictions are based on when the groundwater elevation is higher than the river stage.

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

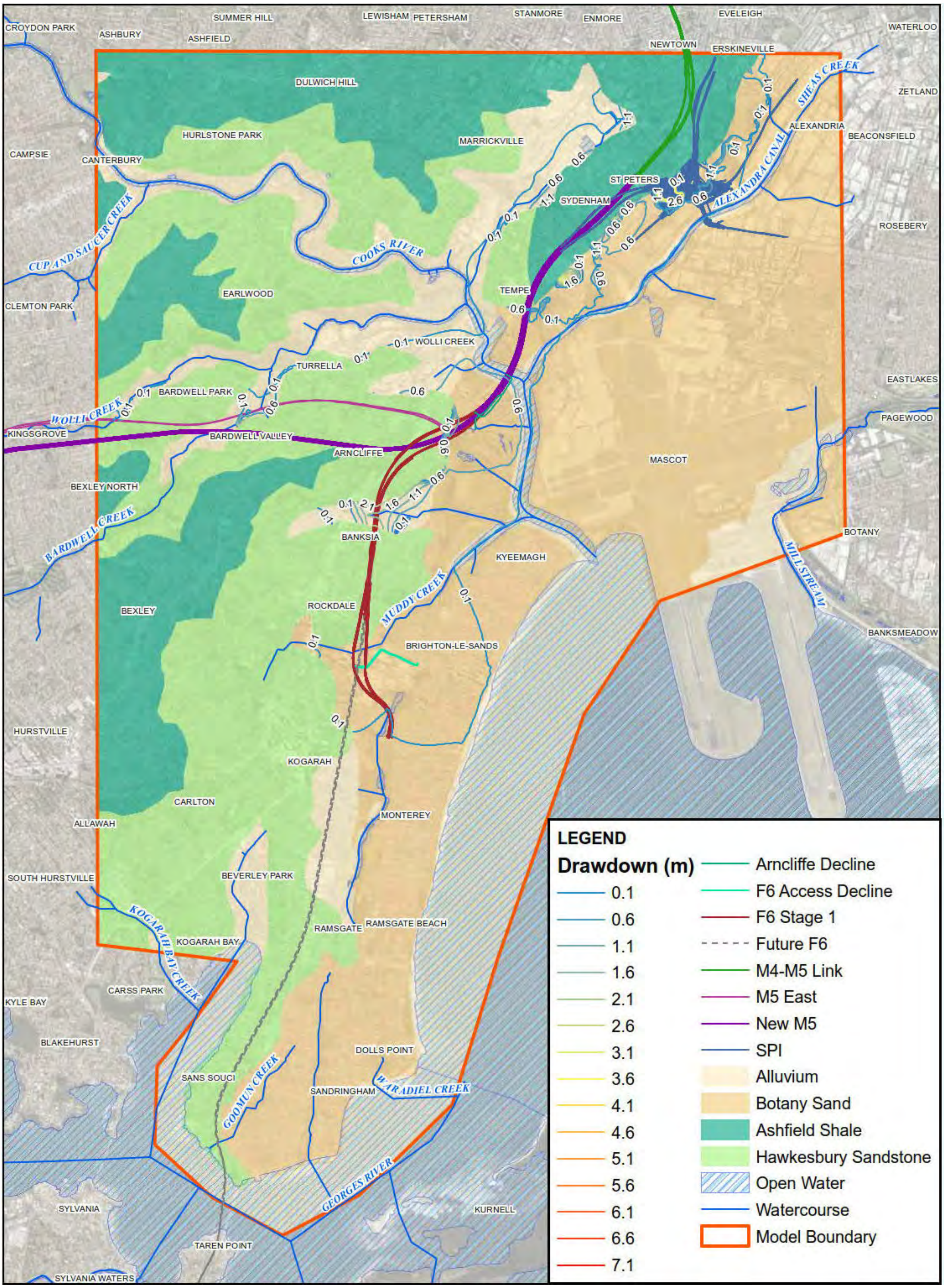


Figure 7-1 Cumulative drawdown in the alluvium following construction (2024) – from RPS 2018

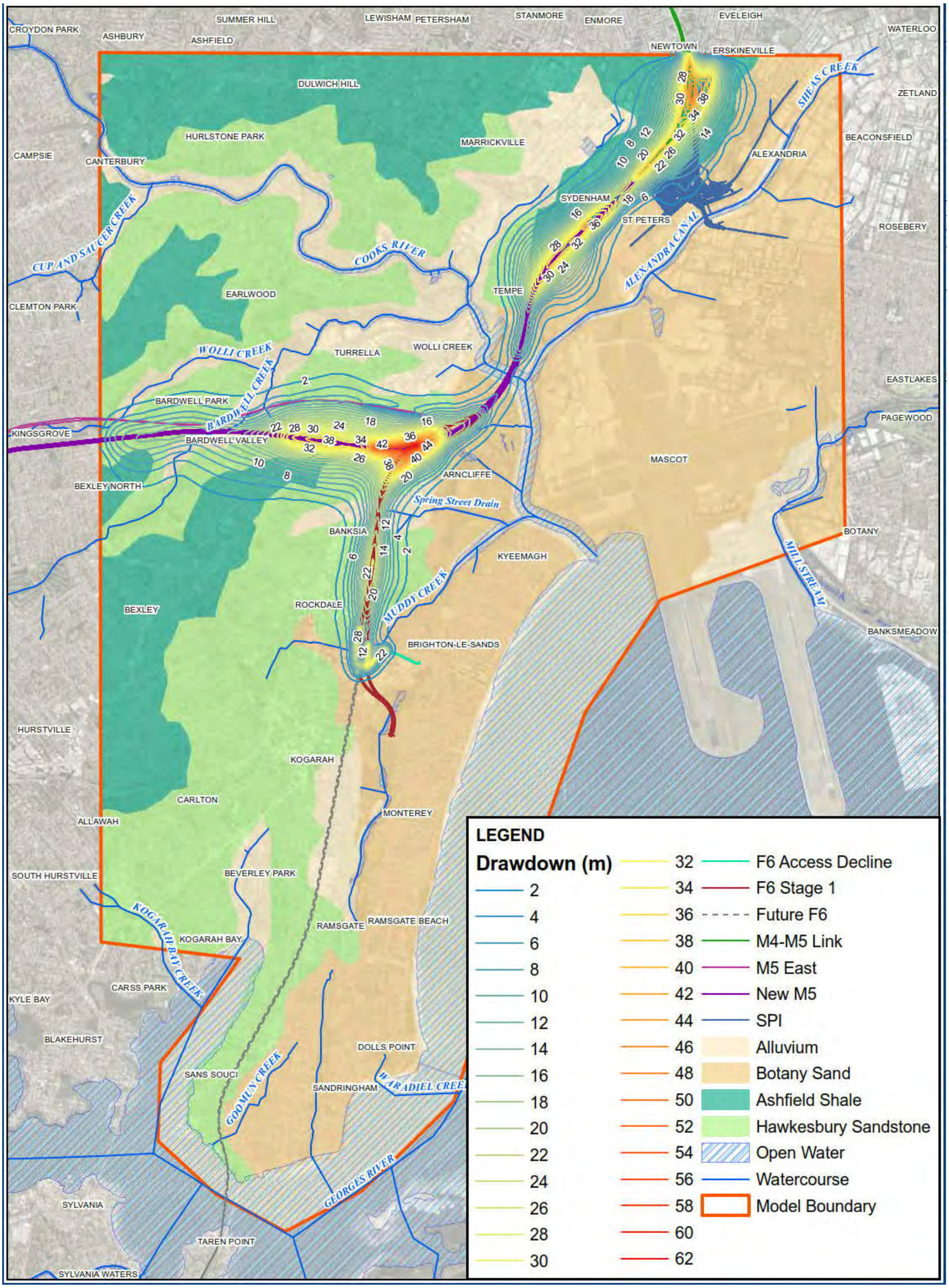


Figure 7-2 Cumulative drawdown in the Hawkesbury Sandstone following construction (2024) - from RPS 2018

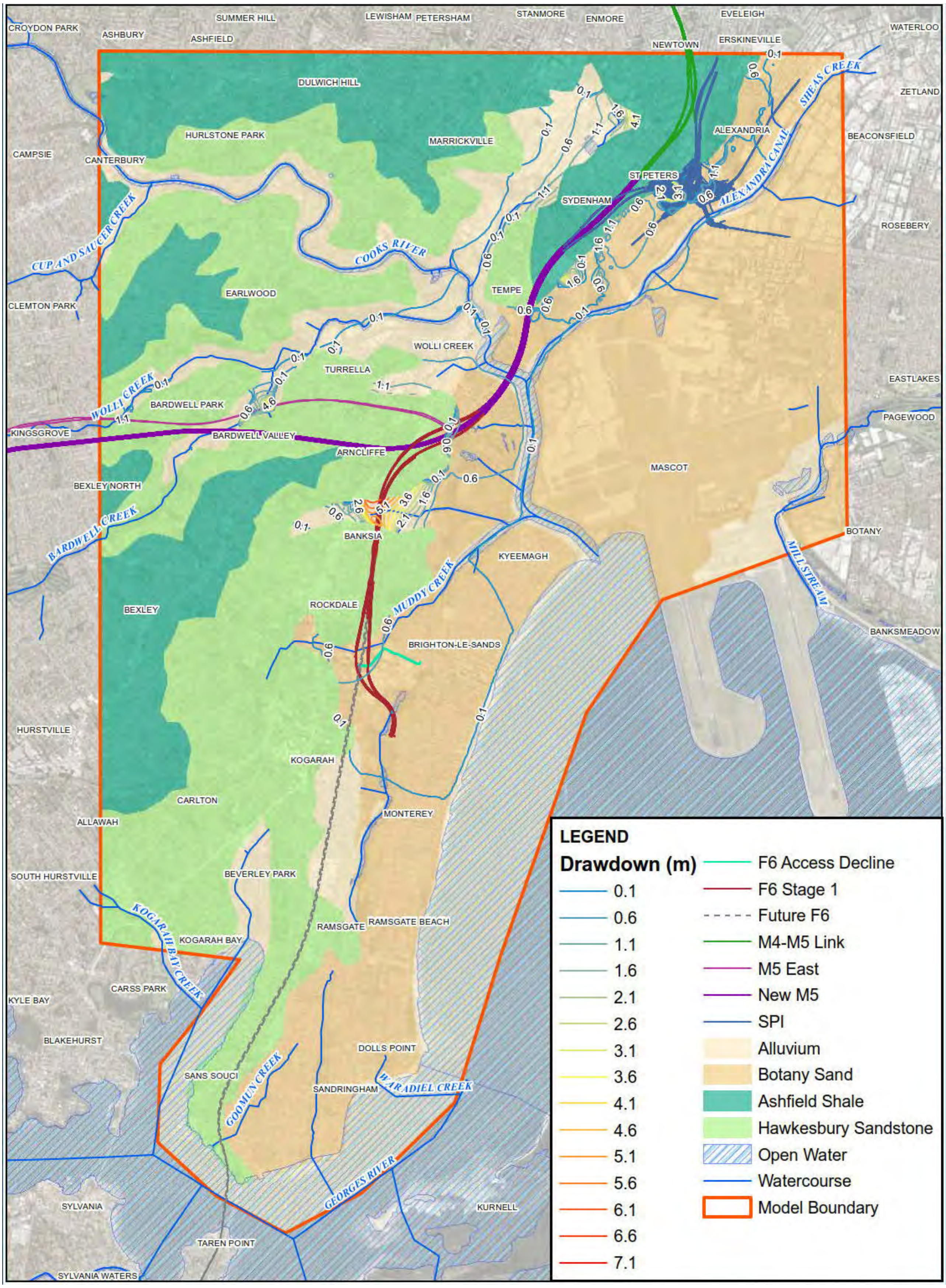


Figure 7-3 Long term cumulative drawdown in the alluvium (2100) - from RPS 2018

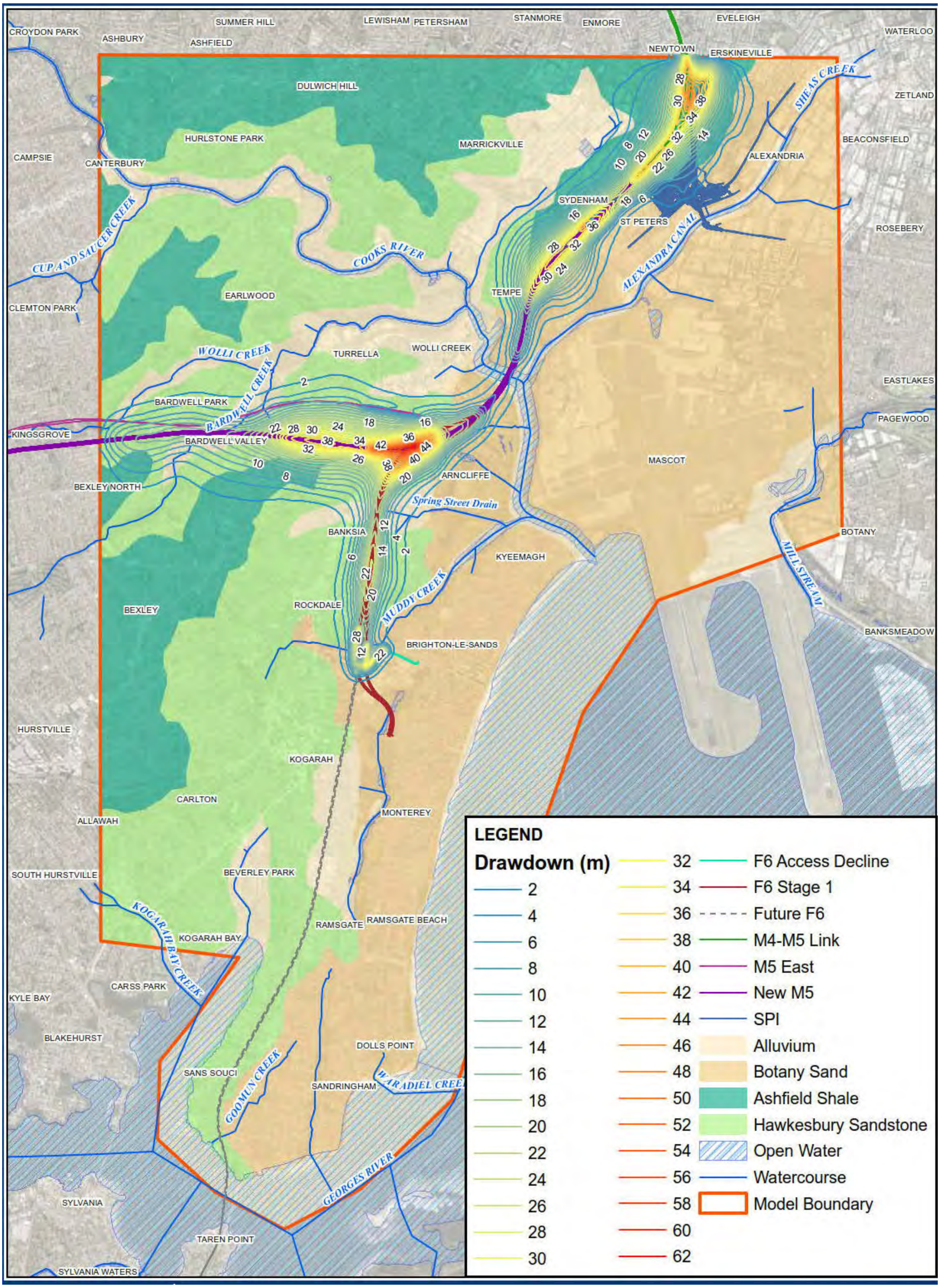


Figure 7-4 Long term cumulative drawdown in the Hawkesbury Sandstone (2100) - from RPS 2018

7.3 Quantitative assessment of other proposed major tunnel infrastructure projects

At the time of preparing this groundwater impact assessment there were two other major tunnel infrastructure projects proposed for the Sydney region. These projects are:

- the Sydney Metro City and Southwest, a proposed rail alignment Sydney's north-western suburbs to the Sydney CBD and continuing further south to Bankstown
- the future Western Harbour Tunnel and Beaches Link, a potential future motorway that would link to the WestConnex tunnels at the Rozelle interchange, extending beneath Sydney Harbour to the northern suburbs and northern beaches.

These tunnels are located north of the study area adjoining the M4-M5 Link WestConnex tunnels and consequently are not likely to cause cumulative impacts with the project. Cumulative impacts for these tunnels and the project were outlined and discussed in the M4-M5 Link EIS, (Roads and Maritime 2017a). The proposed future Sydney Gateway project has not been included in the groundwater cumulative impact assessment as the updated road infrastructure is to be constructed along the ground surface and is unlikely to substantially impact groundwater.

7.4 Summary

A cumulative impact assessment has been conducted to assess the cumulative groundwater impacts of the project with other tunnelling projects such as WestConnex including the M5 East, New M5 Motorway and M4-M5 Link tunnels. The groundwater model predicts the combined groundwater impacts of these projects during the construction (to Year 2024) and long term operations phase (to Year 2100). Other WestConnex projects including the M4 widening and King Georges Road Interchange Upgrade were not included in this assessment because these works do not impact the groundwater during operation. The M4 East was not included because it was too far from the project alignment and outside the model domain. The groundwater cumulative impacts for other major tunnel infrastructure projects including the Sydney Metro City and South-west (Chatswood to Sydenham section) and the proposed future Western Harbour Tunnel and Beaches Link and proposed future Project have been considered qualitatively since there was insufficient publically available information available for inclusion in the project's groundwater model.

During construction, cumulative impacts on groundwater would be greatest at the northern extremity of the project near the confluence with the New M5 Motorway at Arncliffe. Once the full extent of the WestConnex projects are operational, groundwater drawdown due to the cumulative impact of the four tunnel projects is not expected to be greater than in any one section of the overall project footprint. Long term cumulative groundwater tunnel inflows due to the project and WestConnex tunnel projects may cause groundwater salinity to increase due to surface water from tidal reaches being drawn into or towards the tunnels. Initially, the saline water would be a small fraction of total tunnel ingress but this is expected to increase over time as water is drawn from further afield, although it would always be a minor component of total inflow. The groundwater modelling has predicted that five registered bores would be drawn down in excess of two metres due to the project and two additional bores would be impacted due to the cumulative impacts with the WestConnex tunnels. No additional cumulative impacts are expected at the Rockdale Bicentennial Park and Scarborough Park wetlands.

8 Management of impacts

The following mitigation measures are proposed, to reduce or eliminate the risk posed by potential impacts on the existing groundwater regime from the construction and operation of the project. Environmental mitigation measures including management, engineering solutions and monitoring and have been developed to minimise impacts on the local hydrogeological regime.

8.1 Management of construction impacts

Mitigation measures to manage potential impacts on the existing hydrogeological regime during construction are outlined in **Table 8-1**.

Table 8-1 Construction mitigation and management measures

Potential impact	Mitigation and management measures
Groundwater	
Tunnel inflows higher than expected which may exceed the inflow criteria of 1 L/sec/km for any kilometre length of tunnel.	Groundwater inflows within the tunnels will be minimised by designing the final tunnel alignment to dive beneath known palaeochannels and alluvium where possible. Tunnel sections intersecting the alluvium at the President Ave ramps are to be tanked to minimise groundwater inflows from the alluvium. Where fractured Hawkesbury Sandstone is intersected, a combination of techniques will be used to reduce the bulk hydraulic conductivity that will include pre-excavation pressure grouting, pressure grouting at the tunnel face, shotcrete and the installation of waterproof membranes. Post grouting may also be required to further reduce groundwater inflows.
	Appropriate waterproofing measures will be identified and included in the detailed design to reduce the inflow into the tunnels. A target of one litre per second per kilometre for any kilometre length of the tunnel during operation will be adopted.
	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. These measures could include but are not limited to retaining walls such as secant pile or diaphragm walls founded in good quality Hawkesbury Sandstone.
Corrosion of building materials by sulfate reducing bacteria	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.
Groundwater drawdown impacting a water supply well water level by more than two metres	In accordance with the AIP, impacts on water supply bores will be 'made good' as soon as practicable. Where water supply bores cannot be made good, alternate measures are to be implemented to replace supply. 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.
Alteration of groundwater flows and levels due to the installation of subsurface project components	Measures to reduce potential impacts to groundwater flows due to subsurface components of the project will be identified and included in the detailed construction methodology and the detailed design as relevant.
Poor water management could lead to adverse impacts on the environment	A CEMP will be developed to manage potential impacts on groundwater and soil. The CEMP will be a 'live' document with the capacity to be updated if conditions are different to those expected. As part of the CEMP a CSWMP will prepared by the contractor to manage soil and water impacts during construction, identifying potential impacts and recommending mitigation measures to eliminate or reduce the identified risks.

Potential impact	Mitigation and management measures
	The CSWMP will outline the groundwater monitoring plan that will include: • Groundwater levels (manual monitoring and automatic monitoring by data loggers) • Groundwater quality (within key boreholes and tunnel inflows) • Groundwater inflow volumes to the tunnels. The program will identify groundwater monitoring locations, performance criteria in relation to groundwater inflow and levels, and potential remedial actions that will be considered to address potential impacts. As a minimum, the program will include monthly manual groundwater level and quality monitoring and weekly monitoring of inflow volumes and quality. Trigger levels would be established that if exceeded would instigate mitigation measures. Water quality trigger levels will be based on the ANZECC 2000 marine and non-marine guidelines in accordance with the 90 percent level of protection during construction. The monitoring will be used to inform the operators of the water treatment plant which contaminants require treatment. Temporary water treatment plants are to be constructed to treat water prior to discharge in accordance with the adopted groundwater quality guidelines. The CSWMP would also manage the following potential groundwater impacts: • Spill prevention and response procedures • Management measures for the storage and stockpiling of materials, fuel and wastes during construction to contain spills and reduce the risk of contaminating groundwater • A protocol for the management of acid sulfate soils during bulk earthworks that will include the types of treatment required for acid sulfate soils, leachate, bunding and treatment pond requirements. • A protocol to address unexpected contaminated finds or unforeseen contamination issues during surface works and tunnelling. This will consider approaches to remove the source of contamination by excavation, or an engineering solution to prevent the migration of contaminated groundwater into the tunnels.
Actual groundwater inflows and drawdown in adjacent areas exceed expectations	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. Groundwater inflow 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 detailed groundwater model will be updated based on the results of the monitoring as required and proposed management measures to minimise potential groundwater impacts adjusted accordingly to ensure that groundwater inflow performance targets are met. Groundwater quality monitoring will be conducted throughout the construction program.
Potential impacts on existing buildings and infrastructure due to settlement	Groundwater drawdown may induce ground settlement and impact existing and future infrastructure. Detailed settlement modelling will be carried out during detailed design. If excessive settlement is predicted then construction methodologies would be revised to minimise impacts. Settlement monitoring would be undertaken in accordance with the protocols developed in the CEMP and may include the installation of settlement markers or inclinometers. Before the commencement of tunnelling, dilapidation assessments would be undertaken on buildings and structures which may be impacted by settlement. A post construction inspection will also be conducted to identify any building defects that could be attributed to the project so make good provisions could be initiated.
Geology (ground movement)	
Ground movements may cause impacts to structures on the surface.	A geotechnical model of representative geological and groundwater conditions would be prepared by the construction contractor during the detailed design phase prior to the commencement of tunnelling. The model would be used to assess predicted settlement impacts and ground movement during the construction and operation of the project.

Potential impact	Mitigation and management measures
	Further assessment of potential settlement impacts, including numerical geotechnical modelling will be undertaken prior to excavation and tunnelling to assess the cumulative predicted settlement, ground movement, stress redistribution and horizontal strain profiles caused by excavation and tunnelling, including groundwater drawdown and associated impacts, on adjacent surface and sub-surface structures. Criteria for surface and sub-surface structures at risk will be determined in consultation with the owner(s) of the structures. Where modelling predicts exceedances of these criteria, an instrumentation and monitoring program will be implemented to measure settlement, distortion or strain as required. Appropriate mitigation measures will be identified and implemented in consultation with the owner(s) prior to excavation and tunnelling works to where possible not exceed the settlement criteria.

Based on these mitigation and management measures it is considered that potential groundwater impacts that may arise during the construction phase can be effectively managed for the project.

8.2 Management of operational impacts

Mitigation measures to manage potential impacts on the existing hydrogeological regime during the operation phase are outlined in **Table 8-2**.

Table 8-2 Operational mitigation and management measures

Potential impact	Mitigation and management measures
Impacts to groundwater quality, groundwater levels or groundwater flows	A groundwater monitoring program will be prepared and implemented to monitor groundwater inflows in the tunnels, groundwater levels and groundwater quality in the alluvium and Hawkesbury Sandstone at the commencement of the operations phase. The monitoring will be a continuation of the construction monitoring program. The monitoring program will be developed in consultation with the EPA, DPI-Fisheries, DI-Water and the Bayside Council.
	The program will identify groundwater monitoring locations, performance criteria in relation to groundwater inflow and groundwater quality and potential remedial actions that would manage or mitigate any non-compliances with performance criteria. In addition the monitoring program will include the manual and automatic (using dataloggers) groundwater level monitoring and groundwater quality monitoring from selected monitoring wells intersecting groundwater from the alluvium and Hawkesbury Sandstone. The monitoring frequency is likely to be six monthly for three years or as stated in the conditions of project approval.
Poor water management could lead to adverse impacts on the environment	An OEMP will be developed by the tunnel operators to manage potential impacts to groundwater. The OEMP will be a 'live' document with the capacity to be updated if conditions are different to those expected. As part of the OEMP the following will be addressed: • Groundwater management and monitoring • Surface water management and monitoring • Drainage system maintenance, e.g. to remove build-up of precipitated iron (slimes) and silt and sand due to slaking of the sandstone. • Settlement monitoring which may include the installation of settlement markers or inclinometers

Potential impact	Mitigation and management measures
Adverse impacts on the local hydrogeological regime due to groundwater discharge	Long term groundwater inflows will be pumped to the surface and transferred to the operational water treatment plant within Arncliffe Motorway Operations Complex (MOC1), and treated water will be discharged into the Cooks River. The tunnel operation water treatment facilities would be designed such that effluent will be of suitable quality for discharge to the receiving environment. The level of treatment will 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 to 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 EPA.
Corrosive groundwater could adversely impact the tunnel and associated infrastructure	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.
Groundwater drawdown due to the project may exceed two metres in registered bores or at other receptors	In accordance with the AIP, measures will be taken to 'make good' the impact to 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.
Treated groundwater may be discharged to stormwater without consideration to a suitable sustainable use.	Sustainable water re-use options will be reviewed for treated groundwater during operations. Re-use options may include the irrigation of open space along the project alignment or discharge into Rockdale wetlands. Groundwater reuse will be undertaken in accordance with the policies of sustainable water use of DI-Water.

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

8.3 Management of cumulative impacts

As noted in **section 7.4**, once the full extent of the WestConnex projects is operational, groundwater drawdown due to the cumulative impact of the M5 East, New M5 Motorway, M4-M5 Link and F6 Extension Stage 1 projects is not expected to be greater than in any one project footprint.

The tunnels and associated lining would be designed and constructed to comply with the groundwater inflow criterion of one litre per second per kilometre for any kilometre length of tunnel. Consequently the groundwater inflows along the tunnels would vary within a known range. A comprehensive groundwater monitoring program would be required for each project to confirm the actual inflows do not exceed the criterion and drawdown does not exceed predictions. Provided that each project includes relevant monitoring and management measures into their respective CEMPs and OEMPs there is limited potential for increases in impacts due to the cumulative construction and operation of the four tunnels.

9 Policy compliance

9.1 Aquifer interference policy

The *Water Act 1912* (NSW) has been replaced by the (WM Act) and does not apply to areas of the state where water sharing plans are in place. Groundwater and surface water within the project footprint are covered by the Groundwater Metropolitan Region Groundwater Sources and the Greater Metropolitan region Unregulated River Water Sources.

The AIP explains the requirements of the WM Act. It clarifies the requirements for licences for aquifer interference activities and establishes the considerations required for assessing potential impacts on key water dependent assets. Any potential impact on local aquifers would be assessed under this policy.

Under this policy, a controlled activity approval (such as a water access licence or aquifer access licence) and/or an aquifer interference approval is required for any activity that results in interference to an aquifer. Under section 91F of the WM Act, approval is required for aquifer interference activities. These activities include the taking of groundwater. The policy applies to all aquifer interference activities, but has been developed to address a range of high risk activities.

Road authorities including Roads and Maritime are exempt (under Schedule 5, Part 1, clause 2 of the Water Management (General) Regulation 2011) from the requirement to hold a water access license to access water during the construction and operational phases including major tunnelling projects.

9.2 Minimal impact assessment

The AIP outlines minimal impact considerations that must be met as a result of the project. The minimal impact considerations are dependent upon the impacted aquifer type (alluvial, coastal, fractured rock or special cases such as the Great Artesian Basin) and whether the aquifer is 'highly productive' or 'less productive groundwater'. The impacts on be considered are to groundwater levels (or water pressure in artesian basins) and water quality as follows:

- **Water table** (drawdown) – impact is considered to be minimal where there is less than a cumulative two metre decline at any water supply work. If the impact is greater than two metres than make good provisions apply
- **Water table** (receptors) – impact is considered to be minimal where the water table change is less than 10 percent of the cumulative variation in the water table 40 metres from any high priority GDE or high priority culturally significant site listed in the water sharing plan
- **Water pressure** – impact is considered to be minimal where the cumulative decline in head is less than two metres at any water supply work
- **Water quality** – impact is considered to be minimal where the change in groundwater quality is within the current beneficial use category of the groundwater beyond the 40 metres of the activity.

If the predicted impacts are less than Level 1 minimal impact considerations (as defined in the AIP) then these impacts are considered acceptable. If, however, the impacts are assessed as greater than Level 1 but these predicted impacts exceed the Level 1 thresholds by no more than the accuracy of a robust model, the project would be accepted as suitable with appropriate monitoring during operation. To reduce the impacts, mitigation measures such as make good provisions may be required to protect a resource or receptors. Where the groundwater impacts are deemed not acceptable the project may have to be modified to reduce the groundwater impacts on an acceptable level.

The majority of the project footprint is considered to be within a 'Less Productive Groundwater Source' within fractured rock, based on the low number of registered bores in the area. In outlining the Minimal Impact Considerations (Table 1, AIP) the policy considers porous and fractured rock water resources together. The groundwater is administered under the *Greater Metropolitan Regional Groundwater Sources Groundwater Water Sharing Plan 2012*.

The tunnels pass through the Botany Sands but in these areas they are constructed as either undrained (tanked) or as cut and cover sections reducing the direct inflow of groundwater from the Botany Sands. However alluvial groundwater would be extracted from the Rockdale access decline and through hydraulic connectivity with the Hawkesbury Sandstone. Potential impacts of the project to the Botany Sands were assessed in this assessment. The groundwater within the Botany Sands is considered to be in a 'Highly Productive Groundwater Source' despite the groundwater in some areas being highly contaminated.

A minimal impact assessment has been conducted for the groundwater potentially impacted by the project in accordance with the NSW Aquifer Interference Policy Step by Step Guide,(NoW, 2013b). The minimal impact considerations for 'less productive groundwater' in a fractured rock aquifer are presented in **Table 9-1**. The minimal impact considerations for 'Highly productive groundwater' in a coastal aquifer are presented in **Table 9-2.**

Table 9-1 Minimal impact considerations for a 'less productive fracture rock aquifer'

Minimal impact considerations	Response
Water Table – Level 1 Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic 'post water sharing plan' variations, 40 metres from any: High priority groundwater dependent ecosystem; or High priority culturally significant site listed in the schedule of the relevant water sharing plan, or A maximum of a 2 metres decline cumulatively at any water supply work.	There are no high priority groundwater dependent ecosystems listed under Schedule 4 of the Greater Metropolitan Regional Groundwater Sources Water Sharing Plan that are within the Hawkesbury Sandstone. No culturally significant sites were identified within the Greater Metropolitan Regional Groundwater Water Sharing Plan. Groundwater modelling has indicated there is one registered bore within a 2 kilometre radius of the tunnels registered for water supply purposes (domestic) that extracts groundwater from the Hawkesbury Sandstone where the long term drawdown is predicted to exceed two metres. The approach to minimising impacts is outlined below.
Water Table – Level 2 If more than 10% cumulative variation in the water table, allowing for typical climatic 'post water sharing plan' variations, 40 metres from any: High priority groundwater dependent ecosystem; or High priority culturally significant site; listed in the schedule of the relevant water sharing plan, if appropriate studies demonstrate to the Minister's satisfaction that the variation will not prevent the long term viability of the dependent ecosystem or significant site. If more than a 2 metres decline cumulatively at any water supply work then make good provisions should apply.	The predicted long term drawdown in water supply bore GW023194 is 2.51 metres or a predicted cumulative drawdown with other WestConnex projects (Year 2100) of 4.47 metres. The approach to 'make good' the supply to predevelopment levels would be adopted. This approach would commence with discussions with the bore owner about 'make good' options. Mitigation options would include deepening the bore, lowering the pump or providing an alternative water supply (such as mains water).
Water Pressure – Level 1 A cumulative pressure head decline of not more than a two metre decline, at any water supply work.	Mitigation measures have been recommended for one domestic bore (GW023194) located at West Botany Street Arncliffe where it has been predicted that the long term drawdown exceeds a water level decline of more than two metres.
Water Pressure – Level 2 If the predicted pressure head decline is greater than condition 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	The predicted groundwater level decline will not prevent the long term viability of the bore and make good provisions are proposed.

Minimal impact considerations	Response
Water Quality – Level 1 Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	Groundwater within the study area has limited beneficial use potential due to the variable water quality and presence of a Sydney Water reticulated water supply across the project study area. Groundwater from the Hawkesbury Sandstone is used for limited domestic and irrigation purposes. Groundwater modelling predicts there is likely to be saline water ingress from Cooks River, Muddy Creek and the Spring Street Drain to the project footprint over time (sections 5.5.6 and 6.5.3), which may increase the salinity of groundwater between the project footprint and impacted tidal areas. Given the low level of groundwater use, elevated metals and ongoing pollution potential within an urban environment, the lowering of the aquifer system beneficial use category is unlikely.
Water Quality – Level 2 If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long term viability of the dependent ecosystem, significant site or affected water supply works.	Level 2 does not apply as Level 1 criteria are not exceeded.

Table 9-2 Minimal impact considerations for a 'highly productive coastal aquifer'

Minimal impact considerations	Response
Water Table – Level 1 Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic 'post water sharing plan' variations, 40 metres from any: High priority groundwater dependent ecosystem; or High priority culturally significant site listed in the schedule of the relevant water sharing plan; or A maximum of a 2 metres decline cumulatively at any water supply work.	The closest high priority ecosystems listed under Schedule 4 of the Greater Metropolitan Regional Groundwater Sources Water Sharing Plan are the Botany Wetlands including the Lachlan Swamps, Mill Pond, Mill Stream and Engine Pond located within the Botany Sands. These ecosystems are located more than eight kilometres from the project footprint. Groundwater modelling conducted as part of this investigation indicates that the water table at these wetlands is unlikely to be impacted by the project or undergo a water level decline of more than 2 metres (section 6.3.3). No culturally significant sites were identified within the Greater Metropolitan Regional Groundwater Water Sharing Plan. Groundwater modelling predicted that four registered bores within a two kilometre radius of the tunnels intersecting the alluvium are likely to be drawn down long term by more than two meters. The approach to minimising impacts is outlined below.
Water Table – Level 2 If more than 10% cumulative variation in the water table, allowing for typical climatic 'post water sharing plan' variations, 40 metres from any: High priority groundwater dependent ecosystem; or High priority culturally significant site; listed in the schedule of the relevant water sharing plan, if appropriate studies demonstrate to the Minister's satisfaction that the variation will not prevent the long term viability of the dependent ecosystem or significant site. If more than a 2 metres decline cumulatively at any water supply work then make good provisions should apply.	The predicted long term drawdown in water supply bores GW0224062, GW108295, GW108438 and GW110735 is between 2.07 and 3.78 metres or a predicted cumulative drawdown with other WestConnex projects (Year 2100) of between 2.42 and 4.14 metres. These bores are located close to the Spring Street Drain in Banksia. The approach to 'make good' the supply to predevelopment levels would be adopted. This approach would commence with discussions with the bore owner about 'make good' options. Mitigation options would include deepening the bore, lowering the pump or providing an alternative water supply (such as mains water).

Minimal impact considerations	Response
Water Pressure – Level 1 A cumulative pressure head decline of not more than a 2 metres decline, at any water supply work.	Mitigation measures have been recommended for the four potentially impacted bores (GW0224062, GW108295, GW108438 and GW110735) located near Spring Street Drain Banksia where it has been predicted that the long term drawdown exceeds a water level decline of more than two metres.
Water Pressure – Level 2 If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	The predicted groundwater level decline will not prevent the long term viability of the bores and make good provisions are proposed.
Water Quality – Level 1 Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	Groundwater within the project study area has limited beneficial use potential due to the water quality and since the study area has a reticulated water supply provided by Sydney Water. The Botany Sands aquifer contains a significant groundwater resource under natural conditions, however due to contamination, DI-Water has embargoed domestic groundwater use under the Metropolitan Water Sharing Plan. Consequently any alteration of the groundwater beneficial use is unlikely.
Water Quality – Level 2 If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.	Level 2 does not apply as Level 1 criteria are not exceeded.

9.3 Water extraction licensing

An aquifer interference approval under the WM Act is required if the project intersects a groundwater source. The AIP documents the NSW Government's intention to implement the requirement for the approval of 'aquifer interference activities' under the WM Act. Although the project would affect a groundwater aquifer, the requirement for an aquifer interference approval has not yet commenced. As such, this approval is not required.

In general DI-Water does not support an activity that causes perpetual inflow volumes, although in the case of constructing important major infrastructure exemptions can be granted. Ongoing tunnel inflows are designed to be less than one litre per second per kilometre for any kilometre length of tunnel. Currently road authorities are exempt (under Schedule 5, Part 1, clause 2 of the Water Management (General) Regulation 2011) from the requirement to hold a water access license to access water during the construction and operations phases including major tunnelling projects.

9.4 Compliance with the Water Sharing Plan

The project is covered by the Water Sharing Plan (WSP) for the Greater Metropolitan Region Groundwater Sources 2011, which applies to 13 groundwater sources. The WSP outlines a series of rules for granting access licences (Part 7), managing access licences (Part 8), water supply works approvals (Part 9), access licence dealings (Part 10) and mandatory conditions (Part 11). A summary of relevant rules and an assessment of project compliance are provided in **Table** 9-3.

Table 9-3 Project compliance with the Water Sharing Plan

Minimal impact considerations	Response
Part 7 – Rules for granting access licences	Road authorities are exempt (under Schedule 5, Part 1, clause 2 of the Water Management (General) Regulation 2011) from the requirement to hold a water access licence to access water during the construction and operation of projects.
Part 8 – Rules for managing access licences	Refer to the assessment for Part 7.
Part 9 – 39 Distance restrictions to minimise interference between supply works	As outlined in section 3.1 under the WM Act road authorities are not exempt for the requirement of obtaining a water supply work approval. An approval would be required for this project for the water ingress to the drained tunnels.
Distance restriction from the property boundary is 50 metres	The drained tunnels would in many cases be within 50 metres of property boundaries and hence the project would not comply with this rule. However this non-compliance is considered acceptable since the tunnels are at depth in a highly urbanised area with a reticulated water supply and limited water supply works in the immediate vicinity of the project footprint. Settlement has also been considered (section 6.4) and mitigation measures outlined in section 8.
Distance restriction from an approved water supply work is 100 metres	Over10 registered boreholes have been identified within 100 metres of the project footprint and hence the project would not comply with this rule. However this non-compliance is considered acceptable since only five of these bores are predicted to be drawn down long term by more than two metres. Under the AIP this drawdown triggers the 'make good' condition which will be undertaken as described in sections 5.4.3 and 6.3.4.
Distance restriction from a Department observation bore is 200 metres	There are no DI-Water observation bores within 200 metres of the project footprint.
Distance restriction from an approved work nominated by another access license is 400 metres	There are no water supply works nominated by another access licence within 400 metres of the project footprint.
Distance restriction from an approved water supply work nominated by a local water utility or major utility access licence is 1000 metres	There are no local or major water supply works within 1000 metres of the project footprint.
Part 9 – 40 Rules for water supply works located near contaminated sources	Contaminated groundwater has been identified within the alluvium beneath the Rockdale Wetlands and is suspected beneath former and current market gardens. To minimise the migration of contaminated groundwater, the tunnels, portals and cut-and-cover sections within the alluvium are to be tanked preventing groundwater ingress to the tunnels.

Minimal impact considerations	Response
Part 9 – 41 Rules for water supply works located near sensitive environmental areas	The project footprint is located outside the required distance for the following sensitive environmental areas: 200 metres of a high priority groundwater dependent ecosystem 500 metres of a karst groundwater dependent ecosystem 40 metres from a lagoon or escarpment. The project footprint is not located outside the required distance of the following sensitive environmental areas: 40 metres from third order streams or above. The non-compliance of the third order streams as discussed in section 4.4.1 is considered acceptable since the creeks are concrete lined and the tunnels are to be excavated within the Hawkesbury Sandstone.
Part 9 – 42 Rules for water supply works located near groundwater dependent culturally significant sites	The project footprint is not located near a groundwater dependent culturally significant site.
Part 9 – 44 Rules for water supply works located within distance restrictions	There are no water supply works that are located within restricted distances along the project footprint.
Part 10 – Access dealing rules	Refer to the assessment for Part 7.

10 Conclusion

This groundwater impact assessment has been prepared to support the EIS for the project and was prepared in accordance with NSW water policy under the WM Act, administering water policy under the AIP and the *Greater Metropolitan Region Groundwater Source Water Sharing Plan.* The objectives of the groundwater impact assessment are outlined in the SEARs issued on 23 January 2018 which, in summary, must address the following:

- Extent of drawdown
- Impacts on groundwater quality
- Volume of groundwater that would be taken (including inflows)
- Discharge requirements
- Location and details of groundwater management and implications for groundwater dependent surface flows
- Groundwater-dependent ecological communities
- Groundwater users
- Proposed groundwater monitoring
- Cumulative impacts from adjacent WestConnex projects.

The methodology to conduct the groundwater impact assessment included outlining the existing environmental conditions from available reports, maps and databases. A field investigation was conducted to investigate the geology along the tunnel alignment, assess the hydraulic conductivity by packer tests, laboratory testing of porosity, install monitoring wells along the tunnel alignment and conduct monthly hydrogeochemical sampling and groundwater gauging to establish background conditions. Test pumping results were collated from the Arncliffe area that were collected during the New M5 WestConnex groundwater investigation program. Data loggers have been installed in many of the monitoring wells to monitor long term groundwater levels. A three dimensional numerical groundwater model (using MODFLOW-USG) has been developed to simulate existing groundwater conditions. By simulating the project footprint the groundwater model has been used to predict future groundwater conditions and impacts related to the project. Estimation of these impacts has allowed mitigation measures to be developed during the construction and operational phases of the project.

The tunnels would be excavated predominately through competent Hawkesbury Sandstone with parts of the tunnels intersecting unconsolidated alluvium. The majority of the tunnels would be constructed as drained (untanked) tunnels that allows groundwater to drain passively into the tunnel from the sandstone. During construction groundwater would be directed into the drainage system, pumped to temporary water treatment plants in construction compounds and discharged into the Rockdale Wetlands, eventually discharging into the Cooks River. Long term during operations, groundwater is to be collected and pumped to the Arncliffe water treatment plant, treated and discharged to the Cooks River. Undrained (tanked) tunnel sections would be constructed where the tunnels intersect unconsolidated saturated alluvium to the south of the alignment as the tunnels emerge to the surface at the President Street Ramps. The project is designed achieve a maximum groundwater inflow of one litre per second per kilometre for any kilometre length of tunnel during its operation. Allowable maximum inflows of 2L/sec/km for any kilometre length of tunnel from the Botany Sands are designed for the access ramps in the south of the project study area. To achieve this design criterion, water proofing may be required in parts of the tunnels to reduce the bulk rock permeability. Waterproofing options will ultimately be selected by the tunnel construction contractor but may include shotcrete, installation of waterproof membranes, advance pressure cementing or grouting at the tunnel face.

10.1 Potential impacts

Potential impacts due to the construction and operation of the project have been identified. Impacts during construction are likely to include:

- Reduced groundwater recharge, caused by the temporary construction of paved ancillary facilities

- Tunnel inflows and associated groundwater drawdown. Tunnel inflows and drawdown have been predicted by groundwater modelling. Peak tunnel inflows from the Hawkesbury Sandstone occur in 2023 at 0.55 megalitres per day (200 ML/year). Peak tunnel inflows from the Botany Sands will occur in 2022 at 0.22 megalitres per day (80ML/year).
- Groundwater drawdown associated with tunnel inflows. Drawdown within the Botany Sands at the end of construction at Spring Street Drain is estimated to be about two metres and elsewhere there is predicted to be minor drawdown up to 0.1 metres. Conversely drawdown within the Hawkesbury Sandstone at the end of construction is predicted to be up to 24 metres at Arncliffe where the tunnel is deepest. The predicted drawdown extent will be approximately 250 metres either side of the tunnel to the two metre drawdown contour.
- Degradation of groundwater quality during the tunnel construction program as a result of:
  - The intersection of acid sulfate soils during excavation works that could cause the generation of acidic groundwater
  - The spilling of hazardous materials such as fuels and oils
  - The intersection of contaminated groundwater during tunnelling that could further spread the contamination
  - The natural groundwater may be aggressive to tunnel building materials and cause corrosion of the tunnel structures.

Operational impacts are likely to include:

- Tunnel inflows and associated groundwater drawdown. Tunnel inflows are limited by the design criterion of one litre per second per kilometre for any kilometre length of tunnel or two litres per second per kilometre for any kilometre length at the Rockdale access decline. At project opening (2025) tunnel inflows are estimated to be 241 megalitres per year, declining to 222 megalitres per year at the end of the model simulation in 2100.
- Long term drawdown is likely to eventually extend to the tunnel invert extending to depths of up to 33 metres to the north within the Hawkesbury Sandstone. The drawdown for the project within the Hawkesbury Sandstone is elongated along the alignment extending approximately 350 metres from the alignment. Drawdown within the Botany Sands is centred on Spring Street Drain and Muddy Creek with a maximum predicted drawdown of 5.3 metres. The drawdown extent to the 2.0 metre drawdown contour extends approximately 200 metres either side of the drain.
- Groundwater drawdown that impacts the natural environments
- No substantial impacts on groundwater dependent ecosystems were identified
- Potential impacts on river or stream baseflow
- Only five bores are predicted to impacted by a long term drawdown in excess of two metres that is directly attributable to the project
- Groundwater quality could be degraded through:
  - Intersection of contaminated groundwater
  - Saltwater intrusion
  - Natural groundwater aggressivity to tunnel building materials that could cause corrosion of the tunnel structures
  - Drainage lines within the tunnel could become blocked due to the natural iron and manganese oxidising within the drains causing sludges
  - Tunnel inflows could include leachate derived from the former illegal landfills near the Rockdale wetlands
- Barriers to groundwater flow. caused by ancillary infrastructure extending into the water table and the groundwater sinks created by tunnel drainage induced drawdown
- Long term cumulative groundwater drawdown or groundwater inflows due to the WestConnex tunnel projects are minimal as the tunnel projects do not overlap spatially but are adjoining and thus the sum of impacts are similar to a continuous tunnel

- The cumulative impacts on groundwater drawdown or groundwater inflows due to the WestConnex tunnel projects are minimal in terms of the timing of the projects overlapping since construction is staged with the maximum cumulative impact occurring at the end of construction in 2024.

10.2 Mitigation and management measures

To mitigate and manage the potential impacts during construction, the following measures may be implemented:

- Preparation and implementation of a CEMP by the contractors that addresses the hazards associated with soil and groundwater contamination and groundwater management. The CEMP will include a CSWMP that addresses:
  - Groundwater management and monitoring
  - Surface water management and monitoring
  - Acid sulfate soils
- Management measures for the storage and stockpiling of materials, fuel and wastes during construction including spill prevention and response procedures
- Waterproofing would be installed during construction in areas identified that could have potential higher inflows. Post- grouting may also be required to further reduce groundwater inflows if monitoring indicates excessive inflows
- During construction water from within the tunnels would be collected and treated prior to discharge at temporary water treatment plants located within the construction compounds prior to discharge to the Rockdale wetlands and ultimately into the Cooks River
- Long term groundwater will be pumped to the Arncliffe water treatment plant, treated and discharged to the Cooks River
- Building materials that are resistant to aggressive groundwater conditions would be selected
- A groundwater monitoring program is to be prepared and implemented to monitor groundwater quality impacts during construction. The program shall be developed in consultation with the NSW EPA, DPI-Fisheries, DI-Water and the Bayside Council. Strategies would be developed and implemented to reduce adverse impacts on groundwater quality due to construction activity if they are identified by the monitoring program. The monitoring program would include groundwater inflows, groundwater quality and groundwater levels.

To mitigate and manage potential operational impacts the following measures may be implemented:

- Groundwater monitoring (in monitoring wells) would be conducted in accordance with the OEMP and project consent conditions to monitor the groundwater drawdown, and inflows
- Groundwater quality would be monitored in monitoring wells in accordance with the OEMP within the expected drawdown zone, and trigger mitigation measures if required. Mitigation measures to be considered may include retrofitting tunnel lining to reduce groundwater tunnel inflows, or increased monitoring in key areas
- To reduce the impacts of groundwater level decline in existing water supply wells mitigation measures would be taken to ‘make good’ the impact by restoring the water supply to pre-development levels. The measures taken would be dependent upon the location of the impacted bore but could include, deepening the bore, providing a new bore or providing an alternative water supply.

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