WestConnex

Australian Government

BUILDING OUR FUTURE

NSW GOVERNMENT

M4-M5 Link

Environmental Impact Statement

August 2017

Appendix T

Volume 2I

Since finalisation of the Environmental Impact Statement, the project has been declared by Ministerial Order to be State significant infrastructure and critical State significant infrastructure under sections 115U (4) and 115V of the *Environmental Planning and Assessment Act 1979*. The Ministerial Order also amended Schedule 5 of *State Environmental Planning Policy (State and Regional Development) 2011*. The project remains subject to assessment under Part 5.1 of the *Environmental Planning and Assessment Act 1979* and requires the approval of the Minister for Planning.

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Publication number: RMS 17.372
ISBN: 978-1-925659-56-6

Volume 2I

Appendix

T .... Technical working paper: Groundwater

WestConnex

Appendix T

Technical working paper: Groundwater

WestConnex

Roads and Maritime Services

WestConnex – M4-M5 Link

Technical working paper: Groundwater

August 2017

Client: Roads and Maritime Services

ABN: 76 236 371 088

Prepared by

AECOM Australia Pty Ltd
Level 21, 420 George Street, Sydney NSW 2000, PO Box Q410, QVB Post Office NSW 1230, Australia
T +61 2 8934 0000 F +61 2 8934 0001 www.aecom.com
ABN 20 093 846 925

AECOM in Australia and New Zealand is certified to ISO9001, ISO14001 AS/NZS4801 and OHSAS18001.

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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
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
BoM	Bureau of Meteorology
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
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
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

Term	Definition
DECC	(NSW) Department of Environment, Climate Change
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
DPI-Fisheries	NSW Department of Primary Industries – Fisheries. State agency responsible for managing fisheries
DPI-Water	NSW Department of Primary Industries – Water. State agency responsible for managing groundwater and surface 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
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
Ecology	The study of the relationship between living things and the environment
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
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)

Term	Definition
Ephemeral	Existing for a short duration of time
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)
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
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)
Groundwater 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
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
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
Hydrocarbon	Any organic compound – gaseous, liquid or solid – consisting only of carbon and hydrogen
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
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

Term	Definition
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)
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
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
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

Term	Definition
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
SMC	Sydney Motorway Corporation
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 and aquifer thickness. In an unconfined aquifer the storativity is known as the specific yield
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
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
THR	Total recoverable hydrocarbons
Transient conditions	During transient flow conditions the magnitude and direction of flow change with time in accordance with impacts imposed within the model domain
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
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 WestConnex M4-M5 Link (the project), which would comprise a new, tolled multi-lane road link between the M4 East Motorway at Haberfield and the New M5 Motorway at St Peters. The project would also include an interchange at Lilyfield and Rozelle (the Rozelle interchange), including connections to the surface road network, a tunnel link to Victoria Road (the Iron Cove Link), and civil construction of connections to and parts of the proposed future Western Harbour Tunnel and Beaches Link project.

Approval is being sought under Part 5.1 of the *Environmental Planning and Assessment 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 will form part of the EIS 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 3 March 2016 and revised on 9 November 2016 and 3 May 2017. 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):

- Twin mainline motorway tunnels between the M4 East at Haberfield and the New M5 at St Peters
- A new interchange at Lilyfield and Rozelle (the Rozelle interchange)
- Civil construction only of connections to and parts of the proposed future Western Harbour Tunnel and Beaches Link project, including tunnels that would allow for underground mainline connections between the M4 East and New M5 motorways and the proposed future Western Harbour Tunnel and Beaches Link
- Twin tunnels that would connect Victoria Road near the eastern abutment of Iron Cove Bridge and Anzac Bridge (the Iron Cove Link). Underground entry and exit ramps would also provide a tunnel connection between the Iron Cove Link and the New M5 / St Peters interchange (via the M4-M5 Link mainline tunnels and the Inner West subsurface interchange)
- Tunnel ventilation systems, including ventilation supply and exhaust facilities, axial fans, ventilation outlets and ventilation tunnels.

The tunnels are to be constructed to depths up to 60 metres below the ground surface with the deepest tunnel sections being at the proposed Rozelle interchange and beneath Newtown along the mainline tunnel. Tunnelling is expected to commence in 2018 and be completed by 2023. The majority of the tunnels are to be constructed below the water table predominately within the Hawkesbury Sandstone but also within the Ashfield Shale and alluvium.

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

During operation of the project, groundwater would be directed to water treatment plants at Darley Road, Leichhardt (part of the Darley Road motorway operations complex (MOC1)), and within the Rozelle Rail Yards site, Rozelle (part of the Rozelle East motorway operations complex (MOC3)). Treated water from the Darley Road treatment plant would be discharged via the stormwater system and Hawthorne Canal into Iron Cove. At Rozelle, treated water would be discharged via a constructed wetland and upgraded Easton Park drainage into Rozelle Bay. Undrained or tanked tunnel sections are to be constructed where the tunnel intersects unconsolidated saturated alluvium at Rozelle.

The project is designed to achieve a maximum inflow of one litre 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 membrane may need to be applied combined with shotcrete to undrained or tanked sections of tunnel. Water proofing 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 over 200 geotechnical boreholes and the construction of 58 monitoring wells. During the drilling program, 220 packer tests were conducted in 94 boreholes to assess the hydraulic conductivity of the lithologies intersected. Core samples were collected and submitted to the laboratory to measure the hydraulic conductivity and porosity of the Hawkesbury Sandstone and Ashfield Shale. A monthly groundwater monitoring program commenced in June 2016 to monitor groundwater levels and groundwater quality to characterise the hydrogeology within the three aquifers identified, these being the alluvium, including palaeochannel sediments, Ashfield Shale and Hawkesbury Sandstone.

The hydraulic parameters identified within the field investigation were used to support the development of a three dimensional numerical groundwater model. The model domain extends over an area of approximately 11 x 11 kilometres, with the northern boundary represented by the central channel of Sydney Harbour/Parramatta River and includes the footprint of the New M5 and M4 East projects. The MODFLOW model was developed by HydroSimulations 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 for the other WestConnex projects. The following three scenarios were modelled:

- Scenario 1: A 'Null' run (as per Barnett *et al* 2012) consists of no WestConnex impacts but does include the existing drained M5 East tunnels
- Scenario 2: The 'Null' run in Scenario 1, plus the approved WestConnex tunnel projects (M4 East and New M5)
- Scenario 3: The 'Null' run in Scenario 1, plus the approved WestConnex tunnel projects (M4 East and New M5) in Scenario 2, and the M4-M5 Link project.

Construction impacts

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

- Groundwater along the project footprint is present within the fill, alluvium (including palaeochannel sediments), Ashfield Shale and Hawkesbury Sandstone
- The majority of the tunnels are to be constructed within the competent Hawkesbury Sandstone, and below the water table
- Alluvium is to be intersected by the tunnels beneath the Rozelle Rail Yards, within the Whites Creek palaeochannel
- The Ashfield Shale is to be intersected by the tunnels to the south of the project alignment at Alexandria and at St Peters interchange
- The majority of tunnels would be constructed as drained tunnels with design criterion of a maximum of one litre per second per kilometre for any kilometre length of tunnel; of on-going groundwater leakage into each tunnel during operations. The tunnels have been designed to not

intersect the palaeochannels by diving beneath Hawthorne Canal and tanking the tunnel through the Whites Creek palaeochannel alluvium to minimise groundwater inflow. 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, such as where the project footprint passes close to watercourses and/or where higher than expected inflows are experienced. 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. At Rozelle tunnel lengths that intersect the alluvium are to be tanked.

- At the end of construction of the project (2023), the drawdown on the water table is expected to be up to 42 metres with major drawdown centred over the Rozelle interchange. Drawdown extends up to 500 metres either side of the tunnel corridor, with the widest areas being mid-way along the M4-M5 Link mainline tunnels around Newtown and at the interchanges
- At dive structures and shafts, groundwater flow within unconsolidated sediments, fill, alluvium and weathered shale or sandstone would be restricted by the construction of retaining walls such as secant pile, sheet pile walls or diaphragm walls founded in good quality Ashfield Shale or Hawkesbury Sandstone
- A review showed that tunnel inflows in 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 range from 0.6 to 1.7 litre per second per kilometre. At the adjoining New M5 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 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. Captured water from the tunnels would also have a high turbidity and pH due to the influence of tunnel grouting and would require treatment prior to discharge. Water captured during construction, would be tested and treated at construction water treatment plants prior to reuse or discharge, or disposal offsite if 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 operations phase of the project are as follows:

- After the commencement of operations in 2023 the estimated long term inflows into the motorway tunnels are predicted to be 0.47 litres per second per kilometre initially, reducing to 0.25 litres per second per kilometre in 2100
- The predicted long term tunnel inflow or ‘take’ (from the combined motorway tunnels and ventilation tunnels) is estimated to vary from 1.74 megalitres per day (635.1 megalitres per year) in 2023 reducing to 0.99 megalitres per day (361.4 megalitres per year) in 2100

- The predicted long term tunnel inflows represent a small percentage of the Long Term Average Annual Extraction Limit as outlined in the water sharing plan (LTAAEL) for the Sydney Basin Central which range from 0.7 per cent to 1.3 per cent
- 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
- A review of the Greater Metropolitan Water Sharing Plan within five kilometres of the project footprint did not identify any priority groundwater dependent ecosystems (GDEs). Consequently, no priority groundwater dependent ecosystems are likely to be impacted by groundwater level decline associated with the long term impacts of the project
- Only one bore (GW110247) located in the University of Sydney grounds, registered for domestic use, is predicted to have a drawdown in excess of two metres that is directly attributable to the M4-M5 Link project. This 210-metre deep bore is located at Sydney University and is registered for domestic use. The piezometric head in the Hawkesbury Sandstone is predicted to be drawn down by about 2.4 metres by the end of the long term simulation in the year 2100.
- Although the Botany Sands are not proposed to be intersected by the tunnels, the model outcomes show that there is some hydraulic connection with the Ashfield Shale and Botany Sands. Groundwater modelling indicates the drawdown propagation into the Botany Sands at St Peters is minimal, resulting in a negligible change in natural groundwater flow direction within the Botany Sands. Therefore, groundwater take from the Botany Sands aquifer due to tunnelling is minimal
- Groundwater baseflow to creeks represents the occasions when groundwater reaches the ground surface and enters the drainage system, and is predicted to be reduced by between seven and 83 per cent due to the project. Although the baseflow component of Whites Creek and Hawthorne Canal would be substantially reduced, the overall reduction in river flow is small as baseflow only represents a small percentage of total stream flow in these two systems. . There is no impact on the baseflow of other major creeks along the broader WestConnex alignment including Cooks River, Wolli Creek and Bardwell Creek due 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 along the shoreline with more saline tidal water.

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) developed by the operations contractor. 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:

- 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 would consider the characteristics of the discharge and receiving waterbody, any operational constraints or practicalities and associated environmental impacts and be developed in accordance with *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (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

- 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, derived from groundwater with elevated natural concentrations of iron
- The groundwater aggressivity assessment indicates that some of the groundwater to be intersected is corrosive towards concrete and steel due to naturally low pH and elevated concentrations of sulfate and chloride. A more detailed aggressivity assessment should be undertaken by the tunnel 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, building on the dataset collected in this assessment. 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. 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.
- In accordance with the AIP, if the performance of bore (GW110247) 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, for example, lowering the pump in the borehole or providing an alternative water supply
- The groundwater and surface water quality monitoring program would continue throughout the construction phase and continue for at least 12 months after the completion of construction. 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), DPI-Water and the Inner West and City of Sydney councils. Monitoring locations from the existing groundwater and surface water monitoring networks would form the basis of this monitoring program.

Cumulative impacts

The groundwater model was set up to predict cumulative impacts for the M4-M5 Link project, the New M5 project and M4 East project during the construction and operation phases. Once the full extent of the WestConnex projects is operational, groundwater drawdown due to the cumulative impact of the three tunnel projects is not expected to be greater than in any one section of the overall project footprint. This is because the tunnel projects do not overlap but are adjoining and thus the sum of impacts are similar to a continuous tunnel.

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 that 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 three tunnels.

The Sydney Metro City and Southwest rail link is to be constructed as undrained (tanked) tunnels that will cross the M4-M5 Link project alignment near St Peters. As the twin Sydney Metro tunnels are to be constructed as tanked tunnels, there will be negligible impacts on groundwater draw down. The station boxes are to be constructed and operated as drained shafts and will extract groundwater from the local hydrogeological regime over time. The closest drained structure is proposed at Marrickville Station which is about 2.5 kilometres west of the M4-M5 Link, which is considered a sufficient distance not to substantially cumulatively impact groundwater drawdown.

1 Introduction

NSW Roads and Maritime Services (Roads and Maritime) is seeking approval to construct and operate the WestConnex M4-M5 Link (the project), which would comprise a new multi-lane road link between the M4 East Motorway at Haberfield and the New M5 Motorway at St Peters. The project would also include an interchange at Lilyfield and Rozelle (the Rozelle interchange) and a tunnel connection between Anzac Bridge and Victoria Road, east of Iron Cove Bridge (Iron Cove Link). In addition, construction of tunnels, ramps and associated infrastructure to provide connections to the proposed future Western Harbour Tunnel and Beaches Link project would be carried out at the Rozelle interchange.

Together with the other components of the WestConnex program of works and the proposed future Sydney Gateway, the project would facilitate improved connections between western Sydney, Sydney Airport and Port Botany and south and south-western Sydney, as well as better connectivity between the important economic centres along Sydney's Global Economic Corridor and local communities.

Approval is being sought under Part 5.1 of the *Environmental Planning and Assessment 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.

1.1 Overview of WestConnex and related projects

The M4-M5 Link is part of the WestConnex program of works. Separate planning applications and assessments have been completed for each of the approved WestConnex projects. Roads and Maritime has commissioned Sydney Motorway Corporation (SMC) to deliver WestConnex, on behalf of the NSW Government. However, Roads and Maritime is the proponent for the project.

In addition to linking to other WestConnex projects, the M4-M5 Link would provide connections to the proposed future Western Harbour Tunnel and Beaches Link, the Sydney Gateway (via the St Peters interchange) and the F6 Extension (via the New M5).

The WestConnex program of works, as well as related projects, are shown in **Figure 1-1** and described in **Table 1-1**.

Table 1-1 WestConnex and related component projects

Project	Description	Status
WestConnex program of works		
M4 Widening	Widening of the existing M4 Motorway from Parramatta to Homebush.	Planning approval under the EP&A Act granted on 21 December 2014. Open to traffic.
M4 East	Extension of the M4 Motorway in tunnels between Homebush and Haberfield via Concord. Includes provision for a future connection to the M4-M5 Link at the Wattle Street interchange.	Planning approval under the EP&A Act granted on 11 February 2016. Under construction.
King Georges Road Interchange Upgrade	Upgrade of the King Georges Road interchange between the M5 West and the M5 East at Beverly Hills, in preparation for the New M5 project.	Planning approval under the EP&A Act granted on 3 March 2015. Open to traffic.
New M5	Duplication of the M5 East from King Georges Road in Beverly Hills with tunnels from Kingsgrove to a new interchange at St Peters. The St Peters interchange allows for connections to the proposed future Sydney Gateway project and an underground connection to the M4-M5 Link. The New M5 tunnels also include provision for a future connection to the proposed future F6 Extension.	Planning approval under the EP&A Act granted on 20 April 2016. Commonwealth approval under the *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth) granted on 11 July 2016. Under construction.

Project	Description	Status
M4-M5 Link (the project)	Tunnels connecting to the M4 East at Haberfield (via the Wattle Street interchange) and the New M5 at St Peters (via the St Peters interchange), a new interchange at Rozelle and a link to Victoria Road (the Iron Cove Link). The Rozelle interchange also includes ramps and tunnels for connections to the proposed future Western Harbour Tunnel and Beaches Link project.	The subject of this EIS.
Related projects		
Sydney Gateway	A high-capacity connection between the St Peters interchange (under construction as part of the New M5 project) and the Sydney Airport and Port Botany precinct.	Planning underway by Roads and Maritime and subject to separate environmental assessment and approval.
Western Harbour Tunnel and Beaches Link	The Western Harbour Tunnel component would connect to the M4-M5 Link at the Rozelle interchange, cross underneath Sydney Harbour between the Birchgrove and Waverton areas, and connect with the Warringah Freeway at North Sydney. The Beaches Link component would comprise a tunnel that would connect to the Warringah Freeway, cross underneath Middle Harbour and connect with the Burnt Bridge Creek Deviation at Balgowlah and Wakehurst Parkway at Seaforth. It would also involve the duplication of the Wakehurst Parkway between Seaforth and Frenchs Forest.	Planning underway by Roads and Maritime and subject to separate environmental assessment and approval.
F6 Extension	A proposed motorway link between the New M5 at Arncliffe and the existing M1 Princes Highway at Loftus, generally along the alignment known as the F6 corridor.	Planning underway by Roads and Maritime and subject to separate environmental assessment and approval.

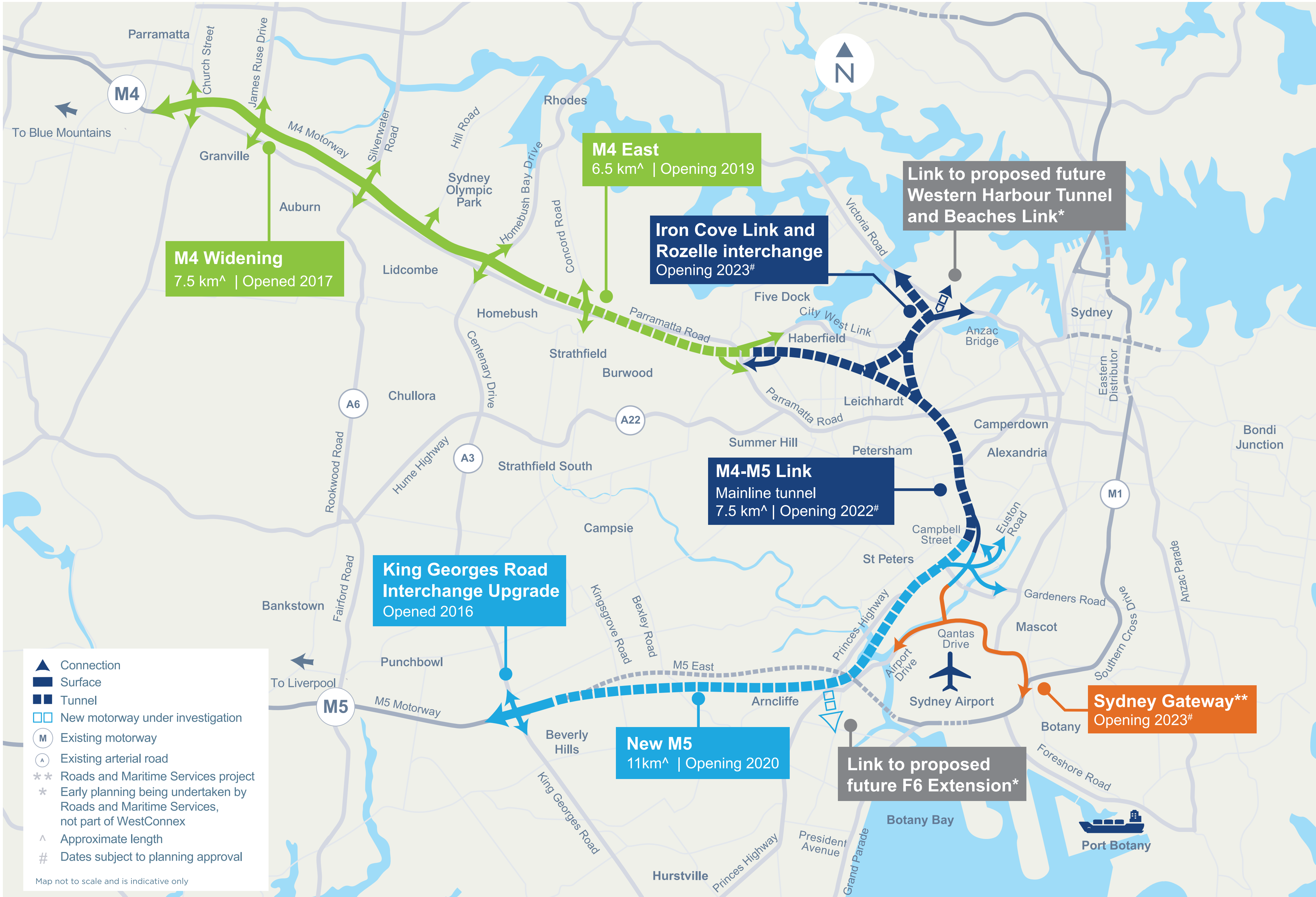

Figure 1-1 Overview of WestConnex and related projects

1.2 Purpose of this report

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 groundwater impacts during construction and operational phases
- Assess the 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.

1.3 SEARs and Agency comments

The SEARs were issued for the project by the NSW Department of Planning and Environment on the 3 March 2016, and revised on 9 November 2016 and 3 May 2017. The SEARs relating to hydrogeological impacts and where these requirements have been addressed in this report are summarised 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 been undertaken during the preparation of this report and will continue as the design is further progressed.

Table 1-2 How SEARs have been addressed in this report

SEARs	
10. Water - Hydrology	
Requirement	**Section where addressed in report**
1. The Proponent must describe (and map) the existing hydrological regime for any surface and groundwater resource (including reliance by users and for ecological purposes) likely to be impacted by the project, including stream orders, as per the Framework for Biodiversity Assessment (FBA).	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 Q** (Technical working paper: Surface water and flooding) and **Appendix S** (Technical working paper: Biodiversity) of the EIS.
2. The Proponent must prepare a detailed water balance for ground and surface water including the proposed intake and discharge locations, volume, frequency and duration for both the construction and operational phases of the project.	**Section 5.9** Construction and **section 6.9** Operation. The surface water balance is outlined in sections 5.2.1, 5.2.2 and 6.3 of **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS.

SEARs	
3. The Proponent must assess (and model if appropriate) the impact of the construction and operation of the project and any ancillary facilities (both built elements and discharges) on surface and groundwater hydrology in accordance with the current guidelines, including: (a) natural processes within rivers, wetlands, estuaries, marine waters and floodplains that affect the health of the fluvial, riparian, estuarine or marine system and landscape health (such as modified discharge volumes, durations and velocities), aquatic connectivity and access to habitat for spawning and refuge;	Construction and operational impacts are outlined in **Chapters 5** and **6** and cumulative impacts in **Chapter 7**, as informed by numerical modelling **section 3.3.3**) and Annexure H. Impacts to surface water features including water courses, groundwater dependent ecosystems are discussed in **sections 5.4.2** and **6.3.5**). Existing surface water features are outlined for: water courses, estuaries and fluvial systems) (**section 4.4.1**) Marine waters and floodplains (**section 4.4.2**), groundwater dependent ecosystems (**section 4.4.3**) and wetlands (**section 4.4.4**) aquatic habitat (**section 4.4.5**)
(b) impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, barriers to flows, implications for groundwater dependent surface flows, ecosystems and species, groundwater users and the potential for settlement;	Impacts to temporary and permanent groundwater flow are outlined for construction and operation in **Chapters 5** and **6**. In particular, extent of drawdown (**sections 5.4** and **6.3**), ancillary infrastructure (**sections 5.6** and **6.5**) barriers to flows (**section 6.6**), implications for groundwater dependent surface flows (**sections 5.4.2** and **6.3.5**), groundwater dependent ecosystems (**sections 5.4.1** and **6.3.3**) and groundwater users (**sections 5.4.3** and **6.3.4**) and settlement (**sections 5.8** and **6.3.6**) are assessed.
(f) water take (direct or passive) from all surface and groundwater sources with estimates of annual volumes during construction and operation.	Groundwater take has been modelled (Annexure H) for the construction and operational phases and is discussed in **Chapters 5** and **6**. Surface water take is outlined in **Appendix Q** of the EIS.
5. The assessment must include details of proposed surface and groundwater monitoring.	Proposed groundwater monitoring is outlined in **Sections 5.5.7, 6.4.5, 8.1,** and **8.2**. Surface water monitoring is outlined **in section 4.16** and in more detail in **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS.
6. The proposed tunnels should be designed to prevent drainage of alluvium in the palaeochannels.	**Sections 5.4.2** and **6.2**. The project tunnels have been designed to avoid palaeochannels where possible. At the Rozelle Rail Yards tunnels intersecting the alluvium are to be fully lined to prevent direct inflow of groundwater from the alluvium.

SEARs	
11. Water Quality	
1. The Proponent must: i) identify proposed monitoring locations, monitoring frequency and indicators of surface and groundwater quality.	**Sections 3.3.2, 4.9, 4.13** and **4.14** outline the field investigations and groundwater monitoring undertaken to inform groundwater modelling for the project. These sections also outline the proposed groundwater monitoring for the project. Surface water monitoring is described in **Chapter 15** (Soil and water quality) of the EIS.
13. Soils	
4. 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, 5.5.6** and **6.4.3**.
5. The Proponent must assess the impacts of the project on soil salinity and how it may affect groundwater resources and hydrology.	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**.
7. The Proponent must assess the impact of any disturbance of contaminated groundwater and the tunnels should be carefully designed so as to not exacerbate mobilisation of contaminated groundwater and/or prevent contaminated groundwater flow.	An assessment of the potential for the tunnels to intercept contaminated groundwater is included in **sections 5.5.2** and **6.4.1**.

Table 1-3 How agency comments been addressed in this report

Agency comments	Where addressed in the EIS
NSW Department of Primary Industries (Water)	
Summary of requirements	**Section(s) addressed in report**
• Tunnels should be designed to prevent drainage of alluvium in the palaeochannels • The potential of the intersection of polluted groundwater should be considered in the assessment • The tunnels should be designed so contaminated groundwater is not mobilised. Consider impacts on Zone 2 of the Botany Sands Source Management Zone • The EIS should include an assessment of the drainage volumes from of the groundwater resource in the Sydney Basin Central zone and the details of groundwater levels and potentiometric pressures • The EIS should assess the potential impacts on existing registered groundwater users due to the project • The groundwater assessment within the EIS should include a discussion on the following details: – The highest water table along the alignment – The works that would likely intersect, connect or infiltrate the groundwater resources – Any proposed groundwater extraction including purpose, location and annual extraction volumes – A description of the hydrogeological regime including groundwater pressures, flow directions physical and chemical properties	• **Sections 5.4.2** and **6.2** • **Sections 5.5.2** and **6.4.1** • **Sections 6.2.2** and **6.3.1** • **Sections 4.10**, **4.10.1** and **6.2** • **Sections 4.10**, **5.4.3**, **6.3.4**, **8.1** and **8.2** • **Section 4.9** • **Section 4.7** • **Sections 5.5.2**, **6.2**, **6.3.1**, **6.8** and **6.9** • **Sections 4.9**, **4.11** and **4.13** • **Sections 4.9** and **4.13** • **Section 6.7** • **Sections 4.4**, **4.10**, **5.4.3**, **6.3.4**, **8.1** and **8.2** • **Sections 4.13**, **5.5** and **6.4** • **Sections 4.14**, **5.5.2**, **6.4.1**, **8.1**,and **8.2** • **Sections 4.4**, **5.4.1**, **6.1**,

Agency comments	Where addressed in the EIS
– Groundwater baseline monitoring for groundwater quantity and quality sufficient to describe temporal and spatial variations – The predicted impacts of any final landform on the groundwater regime – The existing groundwater users along the alignment (including the environment), any potential impacts on these users and measures to mitigate impacts – An assessment of groundwater quality, its beneficial use classification and prediction of any impacts on groundwater quality – An assessment of groundwater contamination along the alignment outlining potential impacts and mitigation measures during the construction and operations phases – An assessment of groundwater dependent ecosystems including wetlands, recharge characteristics, potential impacts and mitigation measures during the construction and operations phases – Proposed methods of waste water collection and disposal – Outcomes of the groundwater model predictions.	**6.3.3**, **8.1**, and **8.2** • **Sections 4.13.8**, **5.5.2**, **6.8**, **8.1** and **8.2** • **Chapters 5** and **6**, **Annexure H**
Marrickville Council	
Requirement	**Section(s) addressed in report**
• The proposal may have a permanent impact on groundwater flow patterns and affect groundwater dependent ecosystems • The potential for the interception of contaminated groundwater from previous industrial sites via tunnel seepage should be considered. There is also a requirement for on-going monitoring, treatment and disposal of seepage including potential reuse that should be outlined. The seepage collection and treatment infrastructure should be described, outlining water quality objectives.	• **Sections 4.4**, **5.4.1**, **6.1**, **6.3.3**, **8.1** and **8.2** • **Sections 4.14**, **5.5.2**, **6.4.1**, **8.1**, and **8.2**

1.4 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 proposed 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 proposed 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 location

The project would be generally located within the City of Sydney and Inner West local government areas (LGAs). The project is located about two to seven kilometres south, southwest and west of the Sydney central business district (CBD) and would cross the suburbs of Ashfield, Haberfield, Leichhardt, Lilyfield, Rozelle, Annandale, Stanmore, Camperdown, Newtown and St Peters. The local context of the project is shown in **Figure 2-1**.

2.2 Overview of the project

Key components of the project are shown in **Figure 2-1** and would include:

- Twin mainline motorway tunnels between the M4 East at Haberfield and the New M5 at St Peters. Each tunnel would be around 7.5 kilometres long and would generally accommodate up to four lanes of traffic in each direction
- Connections of the mainline tunnels to the M4 East project, comprising:
  - A tunnel-to-tunnel connection to the M4 East mainline stub tunnels east of Parramatta Road near Alt Street at Haberfield
  - Entry and exit ramp connections between the mainline tunnels and the Wattle Street interchange at Haberfield (which is currently being constructed as part of the M4 East project)
  - Minor physical integration works with the surface road network at the Wattle Street interchange including road pavement and line marking
- Connections of the mainline tunnels to the New M5 project, comprising:
  - A tunnel-to-tunnel connection to the New M5 mainline stub tunnels north of the Princes Highway near the intersection of Mary Street and Bakers Lane at St Peters
  - Entry and exit ramp connections between the mainline tunnels and the St Peters interchange at St Peters (which is currently being constructed as part of the New M5 project)
  - Minor physical integration works with the surface road network at the St Peters interchange including road pavement and line marking
- An underground interchange at Leichhardt and Annandale (the Inner West subsurface interchange) that would link the mainline tunnels with the Rozelle interchange and the Iron Cove Link (see below)
- A new interchange at Lilyfield and Rozelle (the Rozelle interchange) that would connect the M4-M5 Link mainline tunnels with:
  - City West Link
  - Anzac Bridge
  - The Iron Cove Link (see below)
  - The proposed future Western Harbour Tunnel and Beaches Link
- Construction of connections to the proposed future Western Harbour Tunnel and Beaches Link project as part of the Rozelle interchange, including:
  - Tunnels that would allow for underground mainline connections between the M4 East and New M5 motorways and the proposed future Western Harbour Tunnel and Beaches Link (via the M4-M5 Link mainline tunnels)
  - A dive structure and tunnel portals within the Rozelle Rail Yards, north of the City West Link / The Crescent intersection
  - Entry and exit ramps that would extend north underground from the tunnel portals in the

  - Rozelle Rail Yards to join the mainline connections to the proposed future Western Harbour Tunnel and Beaches Link
  - A ventilation outlet and ancillary facilities as part of the Rozelle ventilation facility (see below)
- Twin tunnels that would connect Victoria Road near the eastern abutment of Iron Cove Bridge and Anzac Bridge (the Iron Cove Link). Underground entry and exit ramps would also provide a tunnel connection between the Iron Cove Link and the New M5 / St Peters interchange (via the M4-M5 Link mainline tunnels)
- The Rozelle surface works, including:
  - Realigning The Crescent at Annandale, including a new bridge over Whites Creek and modifications to the intersection with City West Link
  - A new intersection on City West Link around 300 metres west of the realigned position of The Crescent, which would provide a connection to and from the New M5/St Peters interchange (via the M4-M5 Link mainline tunnels)
  - Widening and improvement works to the channel and bank of Whites Creek between the light rail bridge and Rozelle Bay at Annandale, to manage flooding and drainage for the surface road network
  - Reconstructing the intersection of The Crescent and Victoria Road at Rozelle, including construction of a new bridge at Victoria Road
  - New and upgraded pedestrian and cyclist infrastructure
  - Landscaping, including the provision of new open space within the Rozelle Rail Yards
- The Iron Cove Link surface works, including:
  - Dive structures and tunnel portals between the westbound and eastbound Victoria Road carriageways, to connect Victoria Road east of Iron Cove Bridge with the Iron Cove Link
  - Realignment of the westbound (southern) carriageway of Victoria Road between Springside Street and the eastern abutment of Iron Cove Bridge
  - Modifications to the existing intersections between Victoria Road and Terry, Clubb, Toelle and Callan streets
  - Landscaping and the establishment of pedestrian and cycle infrastructure
- Five motorway operations complexes; one at Leichhardt (MOC1), three at Rozelle (Rozelle West (MOC2), Rozelle East (MOC3) and Iron Cove Link (MOC4)), and one at St Peters (MOC5). The types of facilities that would be contained within the motorway operations complexes would include substations, water treatment plants, ventilation facilities and outlets, offices, on-site storage and parking for employees
- Tunnel ventilation systems, including ventilation supply and exhaust facilities, axial fans, ventilation outlets and ventilation tunnels
- Three new ventilation facilities, including:
  - The Rozelle ventilation facility at Rozelle
  - The Iron Cove Link ventilation facility at Rozelle
  - The Campbell Road ventilation facility at St Peters
- Fitout (mechanical and electrical) of part of the Parramatta Road ventilation facility at Haberfield (which is currently being constructed as part of M4 East project) for use by the M4-M5 Link project
- Drainage infrastructure to collect surface and groundwater for treatment at dedicated facilities. Water treatment would occur at
  - Two operational water treatment facilities (at Leichhardt and Rozelle)
  - The constructed wetland within the Rozelle Rail Yards
  - A bioretention facility for stormwater runoff within the informal car park at King George Park at

Rozelle (adjacent to Manning Street). A section of the existing informal car park would also be upgraded, including sealing the car park surface and landscaping

- Treated water would flow back to existing watercourses via new, upgraded and existing infrastructure
- Ancillary infrastructure and operational facilities for electronic tolling and traffic control and signage (including electronic signage)
- Emergency access and evacuation facilities, including pedestrian and vehicular cross and long passages and fire and life safety systems
- Utility works, including protection and/or adjustment of existing utilities, removal of redundant utilities and installation of new utilities. A Utilities Management Strategy has been prepared for the project that identifies management options for utilities, including relocation or adjustment. Refer to **Appendix F** (Utilities Management Strategy) of the EIS.

The project does not include:

- Site management works at the Rozelle Rail Yards. These works were separately assessed and determined by Roads and Maritime through a Review of Environmental Factors under Part 5 of the EP&A Act (refer to **Chapter 2** (Assessment process) of the EIS)
- Ongoing motorway maintenance activities during operation
- Operation of the components of the Rozelle interchange which are the tunnels, ramps and associated infrastructure being constructed to provide connections to the proposed future Western Harbour Tunnel and Beaches Link project.

Temporary construction ancillary facilities and temporary works to facilitate the construction of the project would also be required.

2.2.1 Staged construction and opening of the project

It is anticipated the project would be constructed and opened to traffic in two stages (as shown in **Figure 2-1**).

Stage 1 would include:

- Construction of the mainline tunnels between the M4 East at Haberfield and the New M5 at St Peters, stub tunnels to the Rozelle interchange (at the Inner West subsurface interchange) and ancillary infrastructure at the Darley Road motorway operations complex (MOC1) and Campbell Road motorway operations complex (MOC5)
- These works are anticipated to commence in 2018 with the mainline tunnels open to traffic in 2022. At the completion of Stage 1, the mainline tunnels would operate with two traffic lanes in each direction. This would increase to generally four lanes at the completion of Stage 2, when the full project is operational.

Stage 2 would include:

- Construction of the Rozelle interchange and Iron Cove Link including:
  - Connections to the stub tunnels at the Inner West subsurface interchange (built during Stage 1)
  - Ancillary infrastructure at the Rozelle West motorway operations complex (MOC2), Rozelle East motorway operations complex (MOC3) and Iron Cove Link motorway operations complex (MOC4)
  - Connections to the surface road network at Lilyfield and Rozelle
  - Construction of tunnels, ramps and associated infrastructure as part of the Rozelle interchange to provide connections to the proposed future Western Harbour Tunnel and Beaches Link project
- Stage 2 works are expected to commence in 2019 with these components of the project open to traffic in 2023.

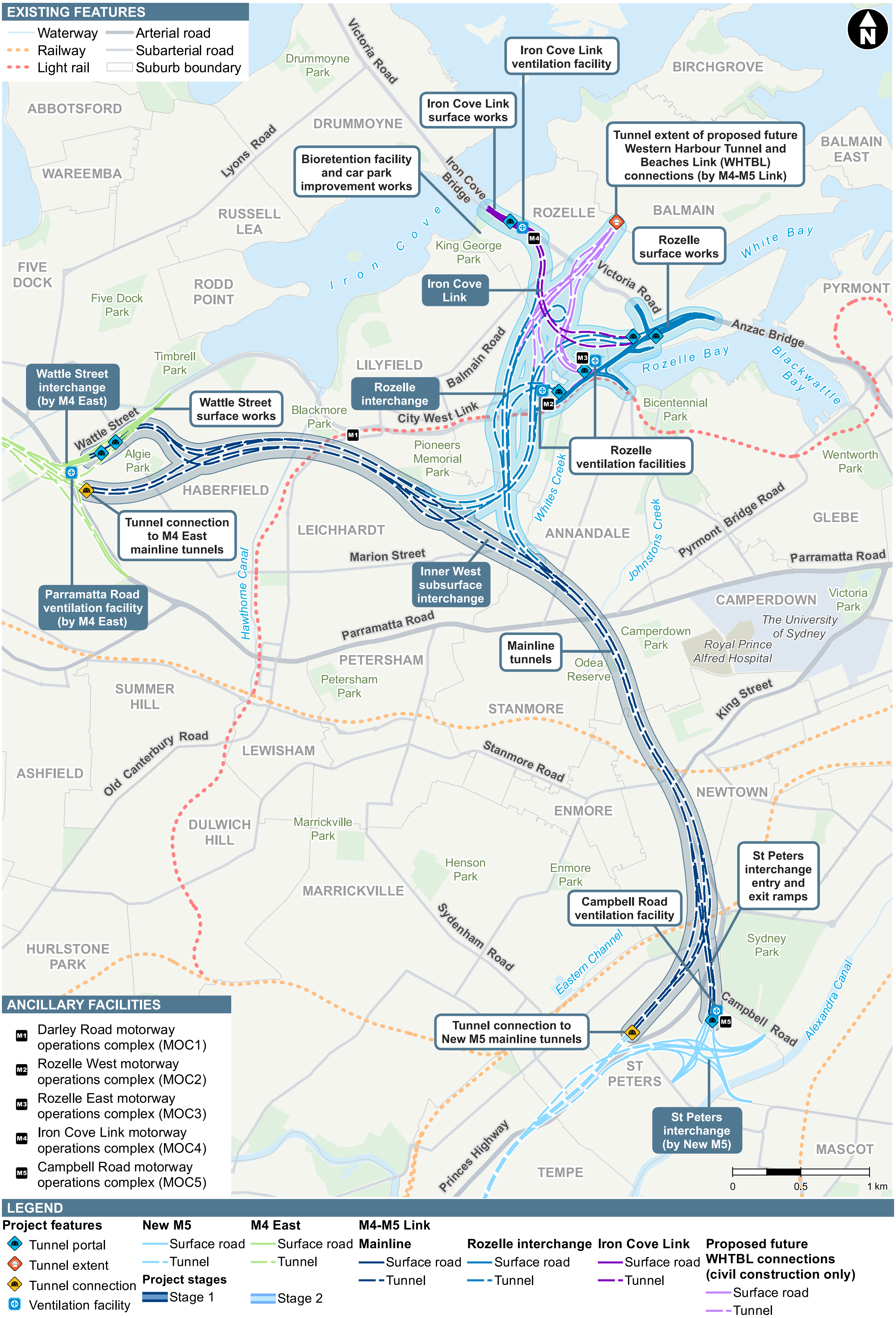

Figure 2-1 Overview of the project

2.3 Construction activities

An overview of the key construction features of the project is shown in **Figure 2-2** and would generally include:

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

A more detailed overview of construction activities is provided in **Table 2-1**.

Table 2-1 Overview of construction activities

Component	Typical activities
Site establishment and enabling works	• Vegetation clearing and removal • Utility works • Traffic management measures • Install safety and environmental controls • Install site fencing and hoarding • Establish temporary noise attenuation measures • Demolish buildings and structures • Carry out site clearing • Heritage salvage or conservation works (if required) • Establish construction ancillary facilities and access • Establish acoustic sheds • Supply utilities (including construction power) to construction facilities • Establish temporary pedestrian and cyclist diversions
Tunnelling	• Construct temporary access tunnels • Excavation of mainline tunnels, entry and exit ramps and associated tunnelled infrastructure and install ground support • Spoil management and haulage • Finishing works in tunnel and provision of permanent tunnel services • Test plant and equipment
Surface earthworks and structures	• Vegetation clearing and removal • Topsoil stripping • Excavate new cut and fill areas • Construct dive and cut-and-cover tunnel structures • Install stabilisation and excavation support (retention systems) such as sheet pile walls, diaphragm walls and secant pile walls (where required) • Construct required retaining structures • Excavate new road levels

Component	Typical activities
Bridge works	• Construct piers and abutments • Construct headstock • Construct bridge deck, slabs and girders • Demolish and remove redundant bridges
Drainage	• Construct new pits and pipes • Construct new groundwater drainage system • Connect drainage to existing network • Construct sumps in tunnels as required • Construct water quality basins, constructed wetland and bioretention facility and basin • Construct drainage channels • Construct spill containment basin • Construct onsite detention tanks • Adjustments to existing drainage infrastructure where impacted • Carry out widening and naturalisation of a section of Whites Creek • Demolish and remove redundant drainage
Pavement	• Lay select layers and base • Lay road pavement surfacing • Construct pavement drainage
Operational ancillary facilities	• Install ventilation systems and facilities • Construct water treatment facilities • Construct fire pump rooms and install water tanks • Test and commission plant and equipment • Construct electrical substations to supply permanent power to the project
Finishing works	• Line mark to new road surfaces • Erect directional and other signage and other roadside furniture such as street lighting • Erect toll gantries and other control systems • Construct pedestrian and cycle paths • Carry out earthworks at disturbed areas to establish the finished landform • Carry out landscaping • Closure and backfill of temporary access tunnels (except where these are to be used for inspection and/or maintenance purposes) • Site demobilisation and preparation of the site for a future use

Twelve construction ancillary facilities are described in this EIS (as listed below). To assist in informing the development of a construction methodology that would manage constructability constraints and the need for construction to occur in a safe and efficient manner, while minimising impacts on local communities, the environment, and users of the surrounding road and other transport networks, two possible combinations of construction ancillary facilities at Haberfield and Ashfield have been assessed in this EIS. The construction ancillary facilities that comprise these options have been grouped together in this EIS and are denoted by the suffix a (for Option A) or b (for Option B).

The construction ancillary facilities required to support construction of the project include:

- Construction ancillary facilities at Haberfield (Option A), comprising:
  - Wattle Street civil and tunnel site (C1a)
  - Haberfield civil and tunnel site (C2a)

- Northcote Street civil site (C3a)

- Construction ancillary facilities at Ashfield and Haberfield (Option B), comprising:
  - Parramatta Road West civil and tunnel site (C1b)
  - Haberfield civil site (C2b)
  - Parramatta Road East civil site (C3b)
- Darley Road civil and tunnel site (C4)
- Rozelle civil and tunnel site (C5)
- The Crescent civil site (C6)
- Victoria Road civil site (C7)
- Iron Cove Link civil site (C8)
- Pyrmont Bridge Road tunnel site (C9)
- Campbell Road civil and tunnel site (C10).

The number, location and layout of construction ancillary facilities would be finalised as part of detailed construction planning during detailed design and would meet the environmental performance outcomes stated in the EIS and the Submissions and Preferred Infrastructure Report and satisfy criteria identified in any relevant conditions of approval.

The construction ancillary facilities would be used for a mix of civil surface works, tunnelling support, construction workforce parking and administrative purposes. Wherever possible, construction sites would be co-located with the operational footprint to minimise property acquisition and temporary disruption. The layout and access arrangements for the construction ancillary facilities are based on the concept design only and would be confirmed and refined in response to submissions received during the exhibition of this EIS and during detailed design.

2.3.1 Construction program

The total period of construction works for the project is expected to be around five years, with commissioning occurring concurrently with the final stages of construction. An indicative construction program is shown in **Table 2-2**.

Groundwater modelling predictions for the project have been based on an earlier project program and not the program in **Table 2-2**. The current indicative program shows construction of the mainline tunnels starting in Q3 2018 and finishing in Q4 2022 and the Rozelle interchange starting in Q4 2018 and finishing in Q3 2023. This change has no material impact on the findings of the groundwater assessment.

Table 2-2 Construction program overview

Construction activity	Indicative construction timeframe																							
	2018				2019				2020				2021				2022				2023			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Mainline tunnels																								
Site establishment and establishment of construction ancillary facilities			■	■	■	■	■	■	■	■														
Utility works and connections			■	■	■	■	■	■																
Tunnel construction				■	■	■	■	■	■	■	■	■	■											
Portal construction				■	■	■	■	■																
Construction of permanent operational facilities												■	■	■	■	■								
Mechanical and electrical fitout works														■	■	■								
Establishment of tolling facilities															■	■								
Site rehabilitation and landscaping																■	■	■	■					
Surface road works																	■	■	■					
Demobilisation and rehabilitation																			■	■				
Testing and commissioning																■	■	■	■	■				
Rozelle interchange and Iron Cove Link																								
Site establishment and establishment of construction ancillary facilities				■	■	■	■	■	■															
Utility works and connections and site remediation				■	■	■	■	■																
Tunnel construction									■	■	■	■	■	■	■	■	■	■						
Portal construction						■	■	■	■															
Construction of surface road works						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Construction of permanent operational facilities						■	■	■	■	■	■	■	■	■	■	■								
Mechanical and electrical fitout works													■	■	■	■	■	■	■	■				
Establishment of tolling facilities																		■	■					
Site rehabilitation and landscaping																			■	■	■			
Demobilisation and rehabilitation																						■	■	
Testing and commissioning																			■	■	■	■	■	

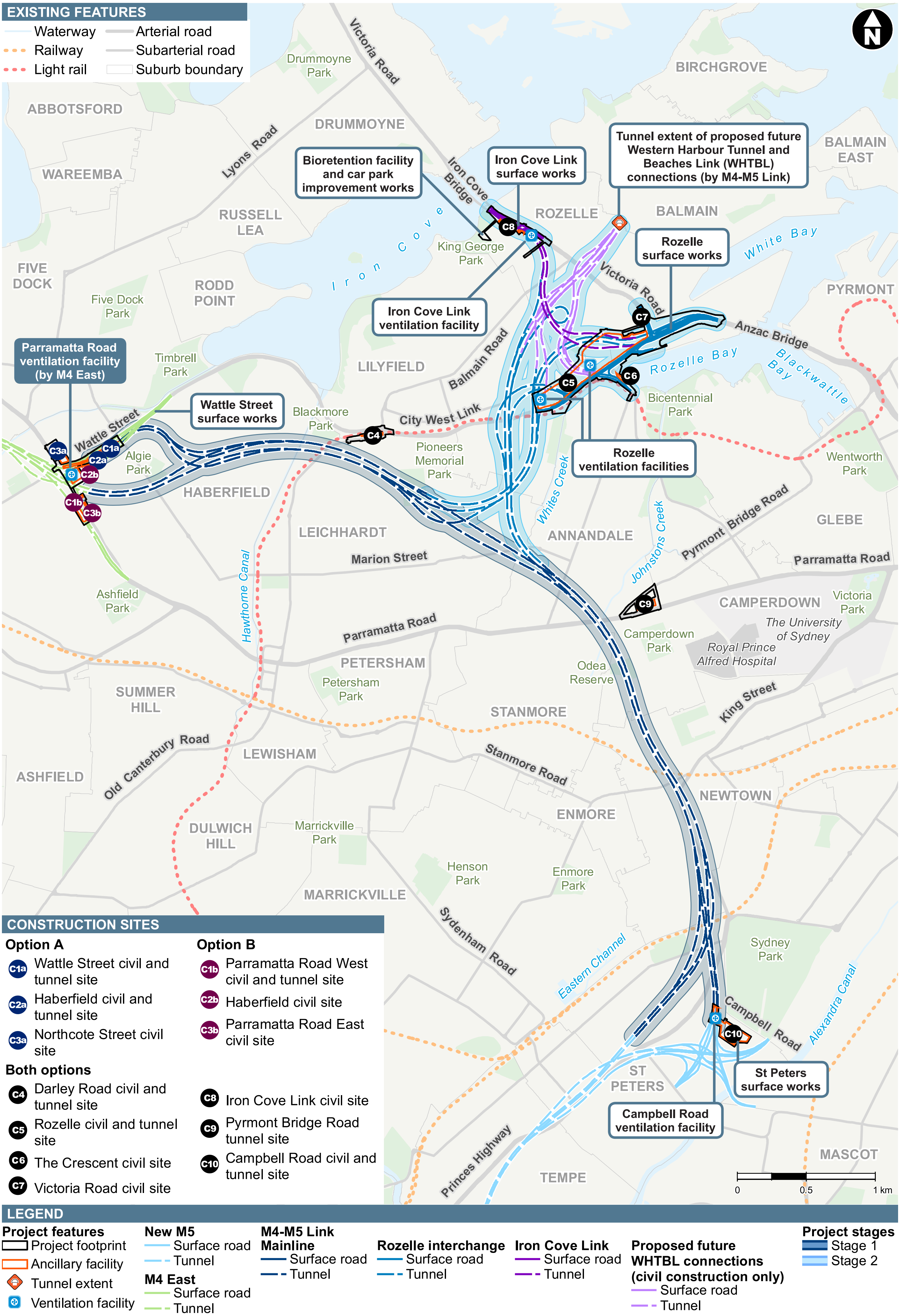

Figure 2-2 Overview of project footprint and ancillary facilities

2.3.2 Other project specific aspects

Construction program for M4 East and New M5

The construction programs for the M4 East and New M5 as outlined in their respective EIS's commenced in 2016 and are planned for completion in 2019 and 2020 respectively as outlined in **Table 2-3** and **Table 2-4**. These construction programs overlap with the M4-M5 Link construction program and have been included in the groundwater model to assess cumulative construction impacts.

Table 2-3 M4 East Construction program overview

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

Source: WestConnex Delivery Authority 2015

Table 2-4 New M5 Construction program overview

Construction Activity	Indicative construction timeframe			
	2016	2017	2018	2019
Site establishment and establishment of construction ancillary facilities				
Landfill closure works				
Construction of western surface works				
Tunnel construction				
Construction of St Peters Interchange				
Portal construction				
Construction of local road upgrades				
Construction of permanent operational facilities				
Mechanical and electrical fitout works				
Establishment of tolling facilities				
Demobilisation and rehabilitation				

Source: Roads and Maritime 2015

Tunnel lining

The project is designed predominately as a drained tunnel. That is, the tunnel would allow groundwater to seep into the tunnel with the water being collected in the tunnel drainage system, draining to sumps where the water is pumped to the surface for treatment. Drained tunnels are typically constructed in competent rock such as the Hawkesbury Sandstone and are typically constructed 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. It is intended that the waterproofing and drainage requirements for the M4-M5 Link tunnels would be consistent, as far as possible, the adjoining New M5 and M4 East tunnels. The exception is that at that tunnels intersecting alluvium beneath the Rozelle Rail Yards are to be constructed as tanked (undrained) tunnels to prevent alluvial groundwater inflow to the tunnels.

Where the tunnels or cut-and-cover sections intersect alluvium, or deeply weathered sandstone, groundwater inflows are likely to exceed inflow from the sandstone without the use of water proofing. To restrict groundwater inflow and potentially contaminated groundwater inflow into the tunnels, driven tunnel sections and cut-and-cover sections excavated within the alluvium and poor quality sandstone are to be tanked. Cut-and-cover sections through the alluvium would be constructed with diaphragm walls or secant pile walls, for example. This approach of restricting groundwater flow from the alluvium to minimise any contaminant migration is in accordance with the recommendations of DPI-Water.

The decision whether to tank parts of the tunnel or to construct an undrained tunnel is based on the lithology intersected, and whether to restrict potentially large groundwater inflows to mitigate potential impacts. Other considerations as to whether or not to tank the tunnels are to compare the two options through a whole of life cost assessment. Under a tanking scenario, the construction costs are substantially higher but ongoing maintenance and operation costs associated with corrosion of drainage and treatment systems are reduced. Conversely in a predominately un-tanked scenario, the construction costs would be lower but the ongoing maintenance costs of water collection and ongoing treatment and disposal of groundwater would be higher.

Based on the current design, the total length of tunnel sections, including ventilation shafts, for the Rozelle interchange, Iron Cove Link, Western Harbour Link stub tunnels and mainline tunnels is

47,943 metres. Of this total 44,951 metres are drained tunnels and 2,992 metres are undrained tunnels as summarised in **Table 2-5** The tunnel sections at Rozelle outlining lengths of drained tunnels, tanked tunnels, cut and cover sections, trough structures and ventilation tunnels is shown on **Figure 2-3**. The design, and subsequent length of tunnel sections, may change during detailed design. A detailed groundwater model will be developed by the construction contractor.

The tunnel lengths for the mainline tunnel and Rozelle interchange are summarised in **Table 2-5**. In the Rozelle interchange, the percentage of tanked tunnel (6.2 per cent) is higher than along the mainline tunnel (1.8 per cent) due to the presence of alluvium associated with the Whites Creek palaeochannel at Rozelle.

Table 2-5 Indicative tunnel lengths along the mainline tunnel and Rozelle interchange

Tunnel elements	Mainline tunnel (m)		Rozelle interchange (m)		Total
	Drained	Undrained	Drained	Undrained	
Motorway tunnel length	19,556	2,006	19,504	986	42,052
Other tunnel length (ventilation tunnels and construction access tunnels)	1,248	-	4,643	-	5,891
Total	**20,804**	**2,006**	**24,147**	**986**	**47,943**
Total drained					**44,951**
Total undrained					**2,992**

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 undrained 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 drainage system.

There are some parts of the tunnel that would intersect fractured shale and secondary geological structural features such as 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 Wattle Street interchange, portal cut-off walls would be required to reduce groundwater ingress from the alluvium. Similarly, at the Rozelle interchange, the cut-and-cover approaches from the west and some portals would be constructed within saturated alluvium and would require excavation support options such as diaphragm walls or a cut-off wall option (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 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 the use of shotcrete and grout. Various construction methodologies would be required to reduce groundwater ingress to below the limit of one litre per second across any given kilometre of tunnel. The methods to reduce groundwater ingress would be confirmed during detailed design and potentially include the option of installation of tunnel lining progressively as the roadheaders advance.

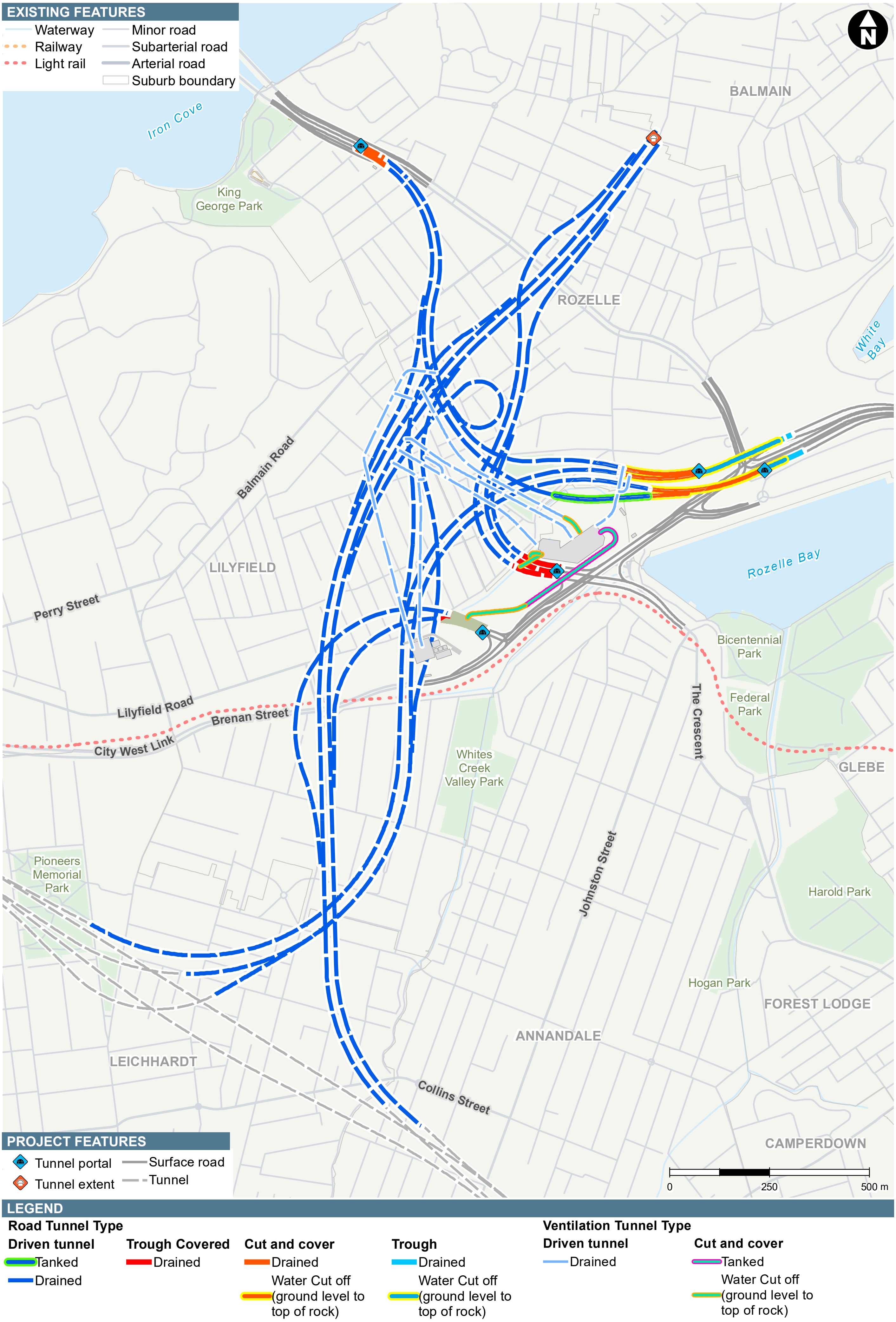

Figure 2-3 Indicative extent of drained and undrained tunnel sections at Rozelle

During operation of the tunnel, groundwater management would be controlled under low and medium groundwater inflow conditions (AECOM 2016f). For tunnel sections with low groundwater inflows and where water ingress is observed, strip drains at regular spacing and/or across the roof of the tunnel may be incorporated within a permanent tunnel drainage system. If required, the strip drains would be incorporated in the shotcrete lining. A similar detail would apply to the tunnel walls.

Groundwater inflows are more likely to be higher in tunnel sections with non-localised inflows from discontinuities such as shear zones or faults, or where the drainage capacity of strip drains is exceeded. In this instance, full coverage by a waterproof geomembrane from the tunnel crown to the invert level, for example, may be required to be incorporated with the permanent tunnel drainage system. The tunnel structure would be designed as ‘drained' allowing the external groundwater to flow into the tunnel void and prevent the build-up of hydrostatic pressure. The waterproof membrane would be incorporated between the initial shotcrete layer and the final shotcrete or cast *in situ* concrete lining. In general, the waterproof membrane would be either a spray-applied membrane or pre-formed sheets or geo-membranes fixed to the tunnel excavation.

Fully tanked tunnels are required in areas where the estimated groundwater inflow is expected to exceed the design criterion of one litre per second per kilometre for any kilometre length of tunnel) due to high ground mass permeability and high groundwater levels. 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’ tunnel. In this case the undrained tunnel is designed for the exterior hydrostatic pressure.

Groundwater collection and treatment system

During construction, groundwater inflows would be directed behind the roadheader and collected via a temporary tunnel drainage system and pumped to the surface for water quality treatment prior to discharge. Water treatment would address a series of analytes as outlined in the Construction Environment Management Plan (CEMP), to reduce turbidity, salinity and identified contamination.

During construction, the wastewater generated in the tunnel would be captured, tested and treated at a construction water treatment plant (if required) prior to reuse or discharge, or disposal offsite if required (refer to **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS).

Monitoring of groundwater flows and water quality would be undertaken during construction in accordance with a Construction Soil and Water Management Plan (CSWMP) which would form part of the CEMP and would address groundwater management and monitoring. The monitoring would be used to inform the operators of the water treatment plant of water quality.

The primary features of the drainage design for the collection of groundwater during operation of the tunnels include:

- Provide for the collection of sub-surface water seepage
- Collect water from ventilation shafts and tunnels
- Allow for cleaning and maintenance of the drainage system.

The operational tunnel design would incorporate a permanent drainage system and sumps at low points to capture groundwater ingress. The proposed water infrastructure for the operation of the project includes constructed wetlands and water treatment facilities for the management of surface and groundwater. Groundwater is to be treated at the permanent water treatment plants to be construction at the Darley Road motorway operations complex (MOC1) in Leichhardt, and at the Rozelle East motorway operations complex (MOC 3).

Water treatment and the advantages of discharge to the proposed wetlands at Rozelle are discussed further in sections 2.4.2, 6.3.3 and 9.2 of **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS.

Tunnel design

The M4-M5 Link project has been designed primarily as a drained tunnel. The design of the project has had consideration to minimising water inflow into the tunnels whereby:

- The vertical alignment of the proposed tunnels would dive beneath palaeochannels where possible to reduce groundwater and surface water inflows into the tunnels. Where the project footprint intersects palaeochannels, the tunnels would be tanked to prevent groundwater inflow in these areas
- 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.

Undrained (tanked) tunnels

Undrained or tanked tunnels limit the groundwater ingress into the tunnel to small inflows (typically resulting in minor seepage into the tunnel) by the installation of a structural lining which can resist the groundwater pore pressure, combined with a waterproofing system.

Undrained (tanked) tunnels are typically specified to achieve one or more of the following objectives:

- Limit drawdown of the water table to mitigate:
  1) Loss of baseflow to creeks that may adversely affect sensitive groundwater dependent ecosystems (GDEs)
  2) Reduction in groundwater levels in registered boreholes used for water supply
  3) Damage to existing infrastructure due to the settlement of compressible soils
  4) Reduction in surface subsidence due to groundwater drawdown.
- Limit groundwater ingress into the tunnel to mitigate:
  1) Corrosion which may damage internal tunnel assets, drainage and treatment systems due to corrosive groundwater
  2) Blockage of tunnel drainage systems and high maintenance requirements due to sludge precipitating from groundwater with high natural iron and manganese concentrations
  3) Treatment and discharge of potentially saline or low pH groundwater.

Ground conditions within the project footprint are expected to have similar hydrogeological conditions to those experienced by other major Sydney drained tunnels that have been successfully constructed. Other WestConnex tunnels including the New M5 are to be constructed as drained (un-tanked) tunnels. With the exception of Lane Cove Tunnel and the Cross City Tunnel, long term monitored groundwater inflows along other tunnels (Eastern Distributor, M5 East Motorway, Epping to Chatswood Rail, Northside storage tunnel, Cross City Tunnel) have averaged below one litre per second per kilometre.

In general, NSW DPI-Water does not support an activity that causes perpetual inflow volumes, so as to protect the sustainability of the natural resource. To minimise groundwater impacts within the alluvium beneath the Rozelle Rail Yards, sections of the tunnel are to be tanked. Within this EIS, the potential impacts of the drained (un-tanked) tunnels on the natural and built environments are fully assessed. Alteration of the tunnel design from a drained tunnel to an undrained (fully tanked) tunnel is feasible, however would potentially prohibitively increase project construction costs.

3 Assessment methodology

3.1 Relevant guidelines and policies

Groundwater in NSW is managed by DPI-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 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 DPI-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** 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 footprint 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 NoW 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 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 impacts are specifically addressed in **section 9.2**.

The project footprint flanks the Botany Sands aquifer, an alluvial and coastal sand bed located to the east of the project footprint near St Peters, extending to the north and south along the coastal fringe. The aquifer is managed under Zone 2 of the Botany Sands Groundwater Source Management Zone. Although the tunnels do not intersect the Botany Sands, it is possible the project could impact the hydrogeological regime of the Botany Sands due to hydraulic connection with the Ashfield Shale or 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 DPI-Water despite the considerable contamination and groundwater extraction embargos due to this contamination. Consequently, the highly productive minimal impact considerations of the AIP with respect to coastal aquifer water sources apply. The location of the Groundwater Management Areas relative to the WestConnex projects is shown on **Figure 3-1**.

Developments conducted on waterfront land, such as adjacent to Sydney Harbour 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 includes waterfront land as defined by the guidelines, as it is within 40 metres of Rozelle Bay and Iron Cove. Controlled activities on waterfront land are administered by DPI-Water and include removal of vegetation, earthworks and construction of temporary detention basins. A controlled activity approval must be obtained from DPI-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**.

Figure 3-1 Groundwater management areas (from HydroSimulations 2017)

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) *2000* 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)
- *WestConnex Sustainability Strategy* (SMC 2015)

- *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.*

3.2 Key assumptions

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

- A worst case inflow rate to the tunnels of one litre per second per kilometre for any kilometre length of tunnel has been assumed, 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 June 2016) satisfies the conditions of the AIP. Additional time series groundwater monitoring data from the edges of the project footprint from the M4 East and New M5 WestConnex projects has been collated for this impact assessment. At the time of groundwater modelling calibration, nine months of transient water level data was available
- 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
- Surface water in the Parramatta River, Rozelle Bay and Sydney Harbour would control groundwater levels in the study area and prevent large scale lowering of the water table
- The M4-M5 Link mainline 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 and the proposed M4 East and New M5 tunnels which are under construction
- A qualitative assessment on the cumulative impacts for future and current tunnel projects has been considered, including Sydney Metro, and the proposed future Western Harbour Tunnel and Beaches Link and F6 Extension projects.

3.3 Assessment 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 (steady state and transient models) 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 changes to groundwater quality due to potential saltwater intrusion

- Qualitative assessment of design refinements made post groundwater modelling, including assessment of the EIS construction “Option B” at Haberfield, which proposes construction access tunnelling at Parramatta Road rather than at Wattle Street, and the proposed bifurcation of the proposed Inner West subsurface interchange located underground at Leichhardt and Annandale
- 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
- Assess cumulative impacts of the project on the local hydrogeological regime taking into account the construction and operation of other infrastructure including the New M5, M4 East, 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 Desktop assessment

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

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

3.3.2 Field investigation

A field program was conducted by AECOM to construct a groundwater monitoring network and collect baseline data as follows:

Monitoring well installation

The M4-M5 Link geotechnical drilling program was undertaken between May 2016 and May 2017. During the drilling program, 58 selected boreholes were converted to monitoring wells. The locations of monitoring wells constructed throughout this investigation are presented on **Figure 3-2**. Monitoring well location selection was based on the initial project design and subsequent changes to during design development. Consequently, some monitoring wells have become redundant as the alignment has changed during the development of the concept. 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. A schematic diagram of the monitoring well construction is shown on **Figure 3-3**. Monitoring wells were constructed with bentonite seals either side of the well screen 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 majority of monitoring wells targeted the Hawkesbury Sandstone (39). Eight wells targeted the Ashfield Shale, one targeted the Mittagong Formation and ten intersect the alluvial sediments flanking creeks and canals. Monitoring wells have been constructed within the Botany Sands aquifer as part of the New M5 project and would be monitored during the New M5 and M4-M5 Link construction phases. All monitoring wells were completed with a three metre well screen installed opposite the expected tunnel zone to depths up to 59 metres (RZ_BH60, Rozelle interchange). Monitoring well construction details are summarised in Table B1, **Annexure B** and project borelogs are presented in **Annexure F**.

Packer tests

Packer tests or *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 within the borehole up to 10 metres thick with inflatable packers 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 flow of water into the test section with the measured water inflow being proportional to the hydraulic conductivity. The packer test results were interpreted in accordance with the British Standards and Houlsby (1976).

Laboratory testing of hydraulic conductivity and porosity

Selected HQ core samples (63.5 millimetre diameter) about 0.25 metres long were collected during the field program for laboratory testing of vertical hydraulic conductivity (K_v) and porosity. The data was used to support the groundwater modelling. The packer test data provided horizontal hydraulic conductivity (K_h) data. Laboratory testing was undertaken by Macquarie Geotech at their National Association of Testing Authorities (NATA) accredited Alexandria laboratory in accordance with Australian Standards. Hydraulic conductivity testing was conducted by the constant head method using a flexible wall permeameter AS1289 6.7.3. Porosity testing was conducted by the saturation and calliper techniques AS4133 2.1.1.

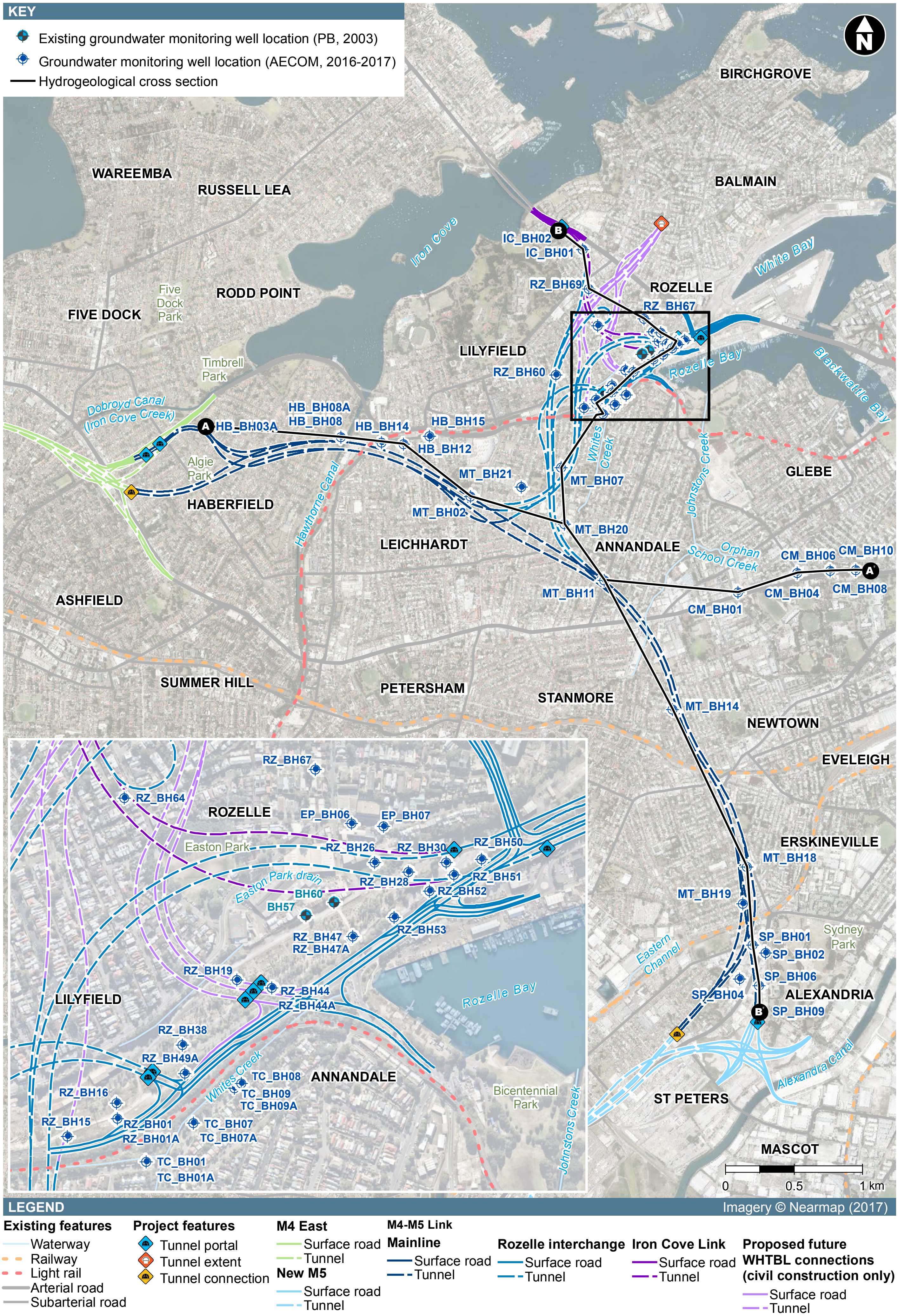

Figure 3-2 Location of monitoring wells

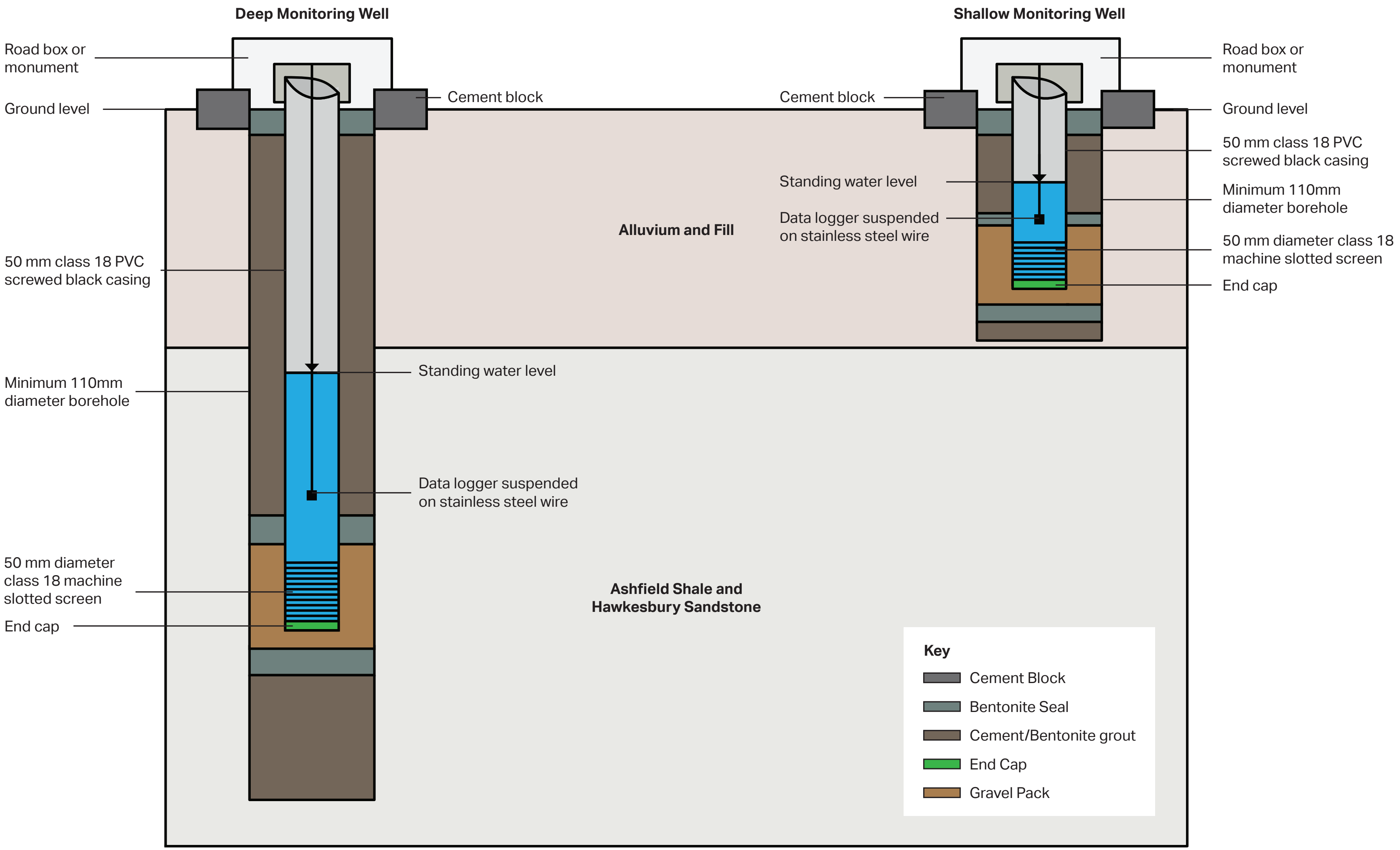

Figure 3-3 Monitoring well construction - schematic diagram

Groundwater gauging

Groundwater gauging was conducted throughout the field program, measuring standing water levels manually with an electronic dipper monthly since July 2016. Data loggers were installed in each of the monitoring wells after well development. The data loggers were installed to measure groundwater level fluctuations automatically 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 network for laboratory analysis (AECOM 2016c,e, AECOM 2017c,e) 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), total recoverable hydrocarbons (TRH), benzene, toluene, ethylbenzene, xylene and naphthalene (BTEXN), polycyclic aromatic hydrocarbons (PAHs), inorganics (including major anions and cations, alkalinity, electrical conductivity, ionic balance, total dissolved solids, pH and hardness), organochlorine pesticides (OCPs), organophosphate pesticides (OPPs), semi volatile organic hydrocarbons (SVOCs) and volatile organic compounds (VOCs).

The monitoring wells were sampled monthly using low flow sampling or a double valve stainless steel bailer. Sampling was typically scheduled for the middle of the month. During groundwater sampling, discharge water was directed through a flow cell to measure the field parameters including dissolved oxygen, electrical conductivity, pH, temperature and redox conditions.

3.3.3 Groundwater numerical modelling

A three-dimensional numerical groundwater model was developed to simulate existing groundwater conditions, project footprint, caverns and associated subsurface ancillary infrastructure. The model domain extends over a study area of 121 square kilometres, with the northern boundary represented by the central channel of Sydney Harbour/Parramatta River. The active domain is centred on the project, and partially includes neighbouring M4 East and New M5 projects. The model domain is shown on **Figure 3-4**. The groundwater model was used to predict future groundwater conditions and potential impacts related to the project. Both steady state and transient models were developed and calibrated.

The groundwater model was prepared by HydroSimulations (HydroSimulations 2017). The groundwater modelling report, which describes the model design, parameters, grid, hydraulic boundaries and assumptions, is provided in **Annexure H**. The groundwater model was peer reviewed in accordance with Australian Groundwater Modelling Guidelines (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
- 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 is the most widely used code for groundwater modelling and is presently considered an industry standard. MODFLOW applies a series of 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 for the M4 East and New M5 groundwater impact assessments.

MODFLOW-USG represents a major revision of the MODFLOW code, in that it uses a different underlying numerical scheme: control volume finite difference (CVFD), rather than traditional MODFLOW's finite difference (FD) scheme. 'USG' is an acronym for unstructured grid, meaning that MODFLOW-USG supports a variety of structured and unstructured model grids, including those based on cell shapes including prismatic triangles, rectangles, hexagons, and other cell shapes. In accordance with Barnett *et al* 2012 the model has been constructed as a Confidence Level 2 (Class 2) model.

The model domain is discretised into eight layers with the upper three layers representing fill, alluvium, Botany Sands (layer 1), upper Ashfield Shale (layer 2), lower Ashfield Shale/Mittagong Formation (layer 3). The lower five 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 was 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 (HydroSimulations 2017) presented in **Annexure H**.

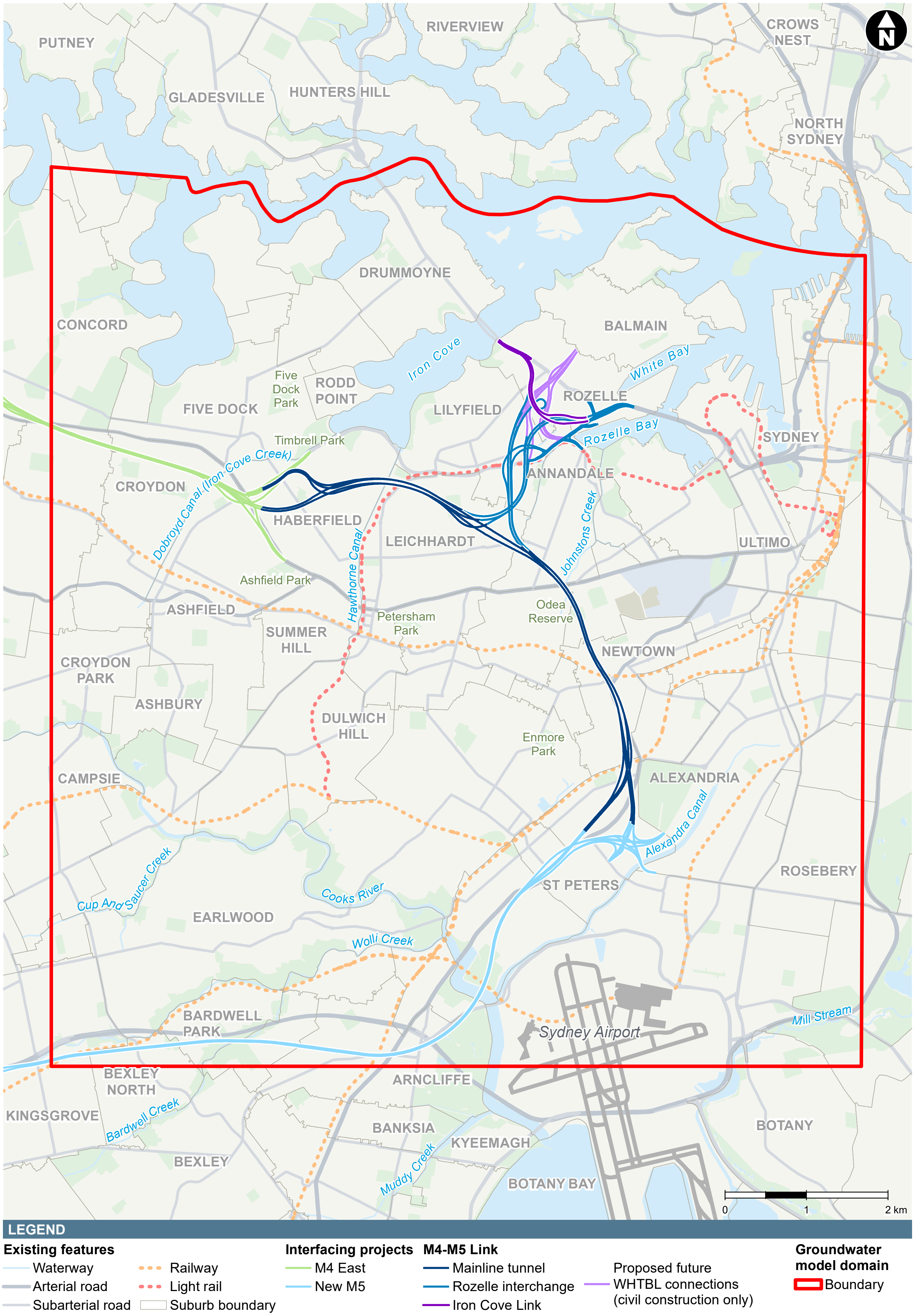

Figure 3-4 Groundwater model domain

Model assumptions

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

- Surface water in Alexandra Canal, Parramatta River, Rozelle Bay, Whites Bay, Iron Cove, and Sydney Harbour would control groundwater levels and prevent large scale lowering of the water table
- Groundwater inflows to the tunnel are based on the project design criterion of no more than one litre per second per kilometre for each kilometre length of tunnel
- The hydrogeological properties used in the model are based on bulk average hydrogeological properties derived from desktop analysis and packer test data
- 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 base of the model is assumed to be horizontal at an elevation of -100 metres Australian Height Datum (AHD)
- The proposed M4-M5 Link main 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 constant rate
- A model has been prepared and calibrated and run in steady state and transient modes
- Other major existing tunnel infrastructure that may influence groundwater levels and quality including the M5 East Motorway tunnels, and New M5 and M4 East tunnels have been simulated in the model
- The model domain does not include the Cross City Tunnel, Eastern Distributor and the Cooks River Tunnel. It was deemed not necessary to simulate the Airport Rail Tunnel as this tunnel is fully tanked. These tunnels were excluded as they are not considered close enough to the areas of interest and inclusion of these features would have increased model uncertainty.

Detailed model limitations are outlined in (HydroSimulations 2017).

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 Motorway and the New M5 and M4 East tunnels which are under construction. The model objectives were to:

- Predict groundwater drawdown due to drainage into the tunnel during construction and long term operations
- Predict potential impacts on nearby registered groundwater users and groundwater dependent ecosystems, in terms of groundwater drawdown and groundwater quality, in accordance with the AIP
- 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 operations groundwater impacts of the project as follows:

- **Scenario 1:** A ‘Null’ run (as per Barnett *et al* 2012), which does not include any WestConnex projects but does include the existing drained M5 tunnels

- **Scenario 2:** The ‘Null’ run plus the current approved WestConnex tunnel projects (M4 East and New M5), with construction scheduling included as per **Table 2-3** and **Table 2-4**, ie Scenario 1 plus the M4 East and New M5 projects
- **Scenario 3:** The ‘Null’ run plus the approved WestConnex projects (M4 East and New M5) and the proposed project (M4-M5 Link), with construction scheduling as per **Table 2-2**, ie Scenario 2 plus the M4-M5 Link project.

The impacts of the M4-M5 Link project were computed by the model by subtracting the Scenario 3 impacts from those of Scenario 2.

4 Existing environment

4.1 Infrastructure

4.1.1 Existing infrastructure

The project footprint transects an urban environment that consists of established industrial, commercial, recreational and residential areas. In some areas, there is major existing or proposed infrastructure that has deep foundations that may influence the project or the local hydrogeological regime. This includes the Alexandria landfill, Rozelle Rail Yards, White Bay redevelopment precinct and parks. These features are described further below and shown on **Figure 4-1**.

Sydney Park is located north of the St Peters interchange (part of the New M5 project) and the project footprint would flank the western park perimeter. The park is a former quarry where weathered shale and clay was excavated for brickmaking. The former quarry was infilled with municipal waste and then capped to create the current parkland. Sydney Park consists of open recreation spaces, playing fields and wetlands.

King George Park is a foreshore park in Rozelle located next to Iron Cove Bridge and Rozelle Bay. The park has a range of sporting facilities, picnic areas and playgrounds.

Easton Park is a public park located in Rozelle to the north of the Rozelle Rail Yards. The park has a range of sporting facilities established trees and picnic areas and playgrounds.

Rozelle Rail Yards is located in Lilyfield and Rozelle, north and west of Rozelle Bay, flanked by Lilyfield Road to the north and the Inner West Light Rail line to the south. In the 1900s, the wetland valley was covered with fill during reclamation works associated with the formation of the Rozelle Rail Yards. Excavation of sandstone along the northern boundary may have been a source of some of this fill. Once established, the rail yards were used for the storage and loading and unloading of various goods transported by rail until the late 1990s. After this, the rail yards fell into disrepair and were used for industrial purposes and the storage of disused railway wagons.

Bicentennial Park is located on the Glebe foreshore and was formed on reclaimed land. The swampy land and shallow marshes were infilled indiscriminately over the years. For the majority of the 20th century, the land was owned by the Maritime Services Board and leased to timber companies and, after their decline, the land was converted to parklands and playing fields in 1988.

Existing tunnels – major existing tunnels in Sydney are described as follows:

- **The Cross City Tunnel**: a 2.1 kilometre twin drained road tunnel oriented east–west and located about three kilometres south-east of the proposed Rozelle interchange
- **The Eastern Distributor**: a 1.7 kilometre three lane double deck drained road tunnel oriented north–south and parallel to the proposed M4-M5 Link, around 3.3 kilometres to the east of the proposed M4-M5 Link project footprint
- **The M5 East Motorway tunnels**: are a pair of undrained 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 fully 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.

Surface roads and rail – The proposed tunnels are cross-cut by major road and rail infrastructure on the surface. The major roads include the Princes Highway, Parramatta Road, Victoria Road, City West Link and the Western Distributor, parts of which are to be upgraded or partially bypassed by the project. Heavy rail crosses the project footprint at Newtown (Inner West Line) and Sydney Park

(Bankstown Line). The Inner West Light Rail line travels above the project footprint at Haberfield and Lilyfield.

4.1.2 Other proposed and approved infrastructure projects

A number of other proposed and approved infrastructure projects in the vicinity of the proposed M4-M5 Link project have the potential to cause cumulative impacts on the local environment. These projects are outlined as follows:

New M5 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 interchange is to be constructed at Arncliffe to link the proposed southern extension tunnels (the F6 Extension) that would extend through Rockdale and Brighton-Le-Sands. The twin mainline tunnels would consist of three traffic lanes, in each direction. The M4-M5 Link project would join the New M5 at the St Peters interchange. Construction of the New M5 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.

Proposed future Sydney Gateway is a proposed project consisting of ungraded roads and new infrastructure that will link the New M5 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 subject to a separate environmental impact assessment and approval process.

Proposed future F6 Extension is a proposed project linking the F6 Motorway to the New M5 at Arncliffe. The design is yet to be finalised and may include twin drained tunnels emanating from the Arncliffe interchange. The F6 Extension project 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 Rozelle interchange at the Rozelle Rail Yards 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 is a proposed rail alignment linking the north-west region to the Sydney CBD and further south to Bankstown. The Chatswood to Sydenham portion of the project was approved in early January 2017. The alignment would consist of 15.5 kilometre twin railway tunnels extending from Chatswood, beneath Sydney Harbour to Sydenham. Rail tunnels and some cross passages and underground stations would be fully tanked and consequently any groundwater ingress would be negligible. Construction is expected to commence in late 2018. The Metro tunnels emerge to ground surface at Sydenham Station located west of Sydney Park.

White Bay Power Station Redevelopment is a disused heritage precinct, covering 38,000 square metres in White Bay at Rozelle, which is located on the edge of the proposed M4-M5 Link project footprint between the Rozelle interchange and Anzac Bridge. The State government owned site is proposed for redevelopment in accordance with The Bays Precinct master plan. Redevelopment of the site may include the provision of a transport interchange, including an underground rail line and platforms.

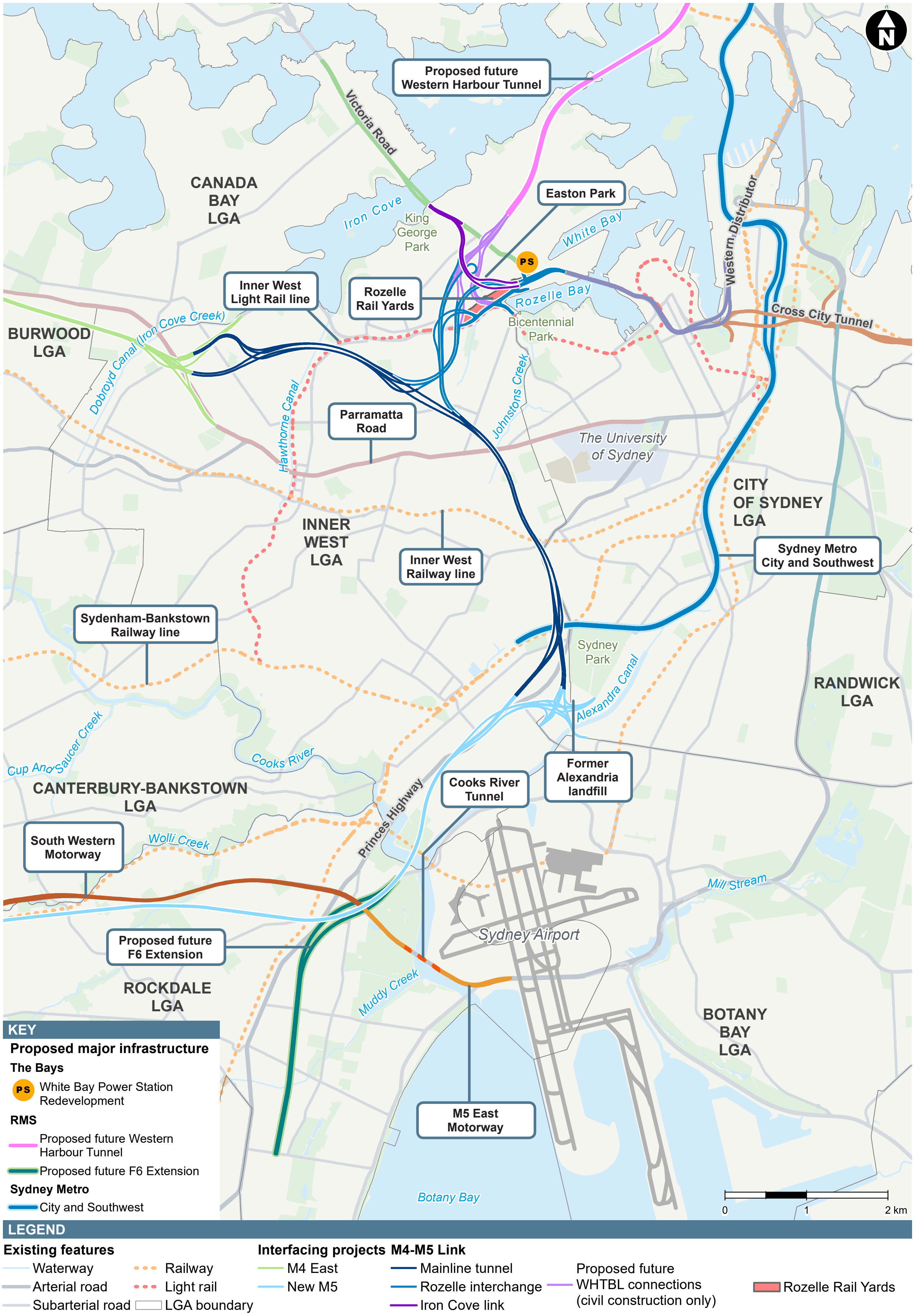

Figure 4-1 Existing and proposed major infrastructure

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 66062 located at Sydney Observatory Hill near the north-eastern fringe of the project footprint. Rainfall has been measured at this station since 1858. 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 (Station 66062)

Month	Rainfall mean (mm)	Rainfall 2016 (mm)	Rainfall difference (mm)	Evaporation (mm)
January	7	249.8	147.3	160
February	117	25.8	-91.2	110
March	129.6	193.2	63.6	140
April	119.2	155	35.8	110
May	133	7.2	-125.8	70
June	97.1	305	207.9	55
July	81.1	104.6	23.5	70
August	68.4	151.4	83	90
September	76.7	70	-6.7	110
October	76.4	31.4	-45	160
November	83.8	27.2	-56.6	180
December	77.6	65	-12.3	180
Total	**1162.4**	**1385.6**	**223.2**	**1500**

Note:

Rainfall averages from 1858 to 2016

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 2016 monthly rainfall from the Sydney Observatory are shown in **Figure 4-2**.

Mean monthly rainfall (since 1858) has been compared to the recorded 2016 monthly rainfall. Overall 2016 was a wetter year with 1385.6 millimetres recorded compared to a mean annual rainfall of 1161.3 millimetres, a difference of 224.3 millimetres. January and June were very wet months with rainfall exceeding the monthly average by 143.7 millimetres and 208 millimetres respectively. Conversely, the latter part of the year was drier than average with the months of September, October, November and December being in deficit in comparison to the monthly averages by 6.7 millimetres, 45.0 millimetres, 56.6 millimetres and 12.3 millimetres respectively.

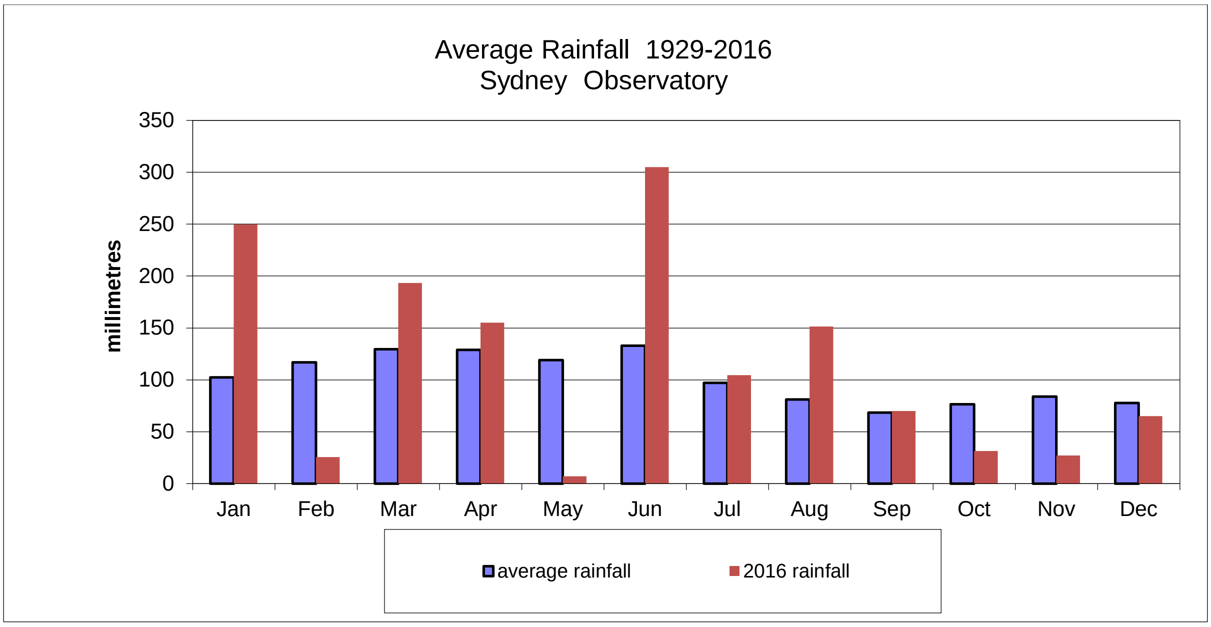

Figure 4-2 Average monthly rainfall compared to 2016 rainfall at Sydney Observatory

The long term data has been collated to calculate a cumulative residual rainfall analysis 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 Observatory for the period 1860 to the end of 2016 is presented as **Figure 4-3**.

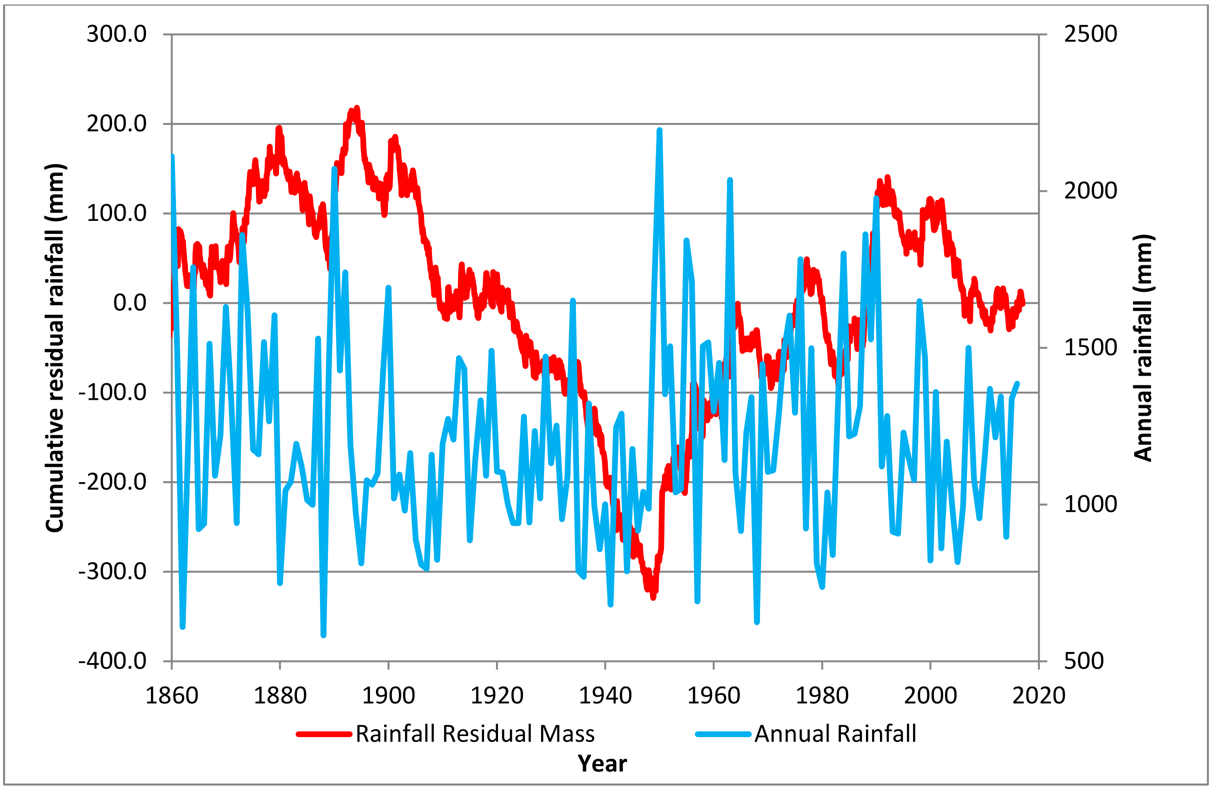

Figure 4-3 Sydney rainfall residual mass – Sydney Observatory 1860 to 2016

The rainfall residual mass curve shows Sydney was subjected to relatively wet years from 1860 to the 1890s followed by a relatively dry period until the late 1940s. The period between the 1940s and 1980s was a relatively wet period followed by a dry period. Following the millennium drought (2001–

2009) the rainfall residual mass has approximated average conditions suggesting natural groundwater levels during this period (2010 to present) would approximate long term average conditions.

4.3 Physiography

The project would be generally located within the City of Sydney Council and Inner West Council local government areas (LGAs). The project is located about two to seven kilometres south, southwest and west of the Sydney central business district (CBD) and would cross the suburbs of Ashfield, Haberfield, Leichhardt, Lilyfield, Rozelle, Annandale, Stanmore, Camperdown, Newtown and St Peters.

The project footprint extends from the M4 East in Haberfield through proposed interchanges at Rozelle emerging at the St Peters interchange. The topography of the project footprint is relatively flat and low lying, ranging from sea level, adjacent to Sydney Harbour and Rozelle Bay, up to 33 metres AHD in Lilyfield where the Hawkesbury Sandstone outcrops. Areas of physiographical interest along the project footprint are the Rozelle Rail Yards and Alexandria Landfill. At the Rozelle Rail Yards, the sandstone cutting is about six metres high but is not considered an escarpment for the purposes of Part 9 Rule 41 of the Greater Metropolitan Region Groundwater Sources Water Sharing Plan since the cliffs are artificial and do not form a water shed.

The Rozelle Rail Yards are highly disturbed and have the potential to contain contaminated soil and groundwater due to previous land-use practices. The Rozelle Rail Yards are located in Lilyfield and Rozelle and are generally bordered by City West Link, Victoria Road and Lilyfield Road. Some of the ramps and tunnels for the proposed Rozelle interchange are to be constructed beneath the former Rozelle Rail Yards and a large proportion of the tunnelling is to be to the north within the sandstone.

The Alexandria Landfill is a former brickworks quarry that after its closure in 1988 was converted to a landfill. The landfill is unlined and generates leachate that requires treatment prior to off-site discharge. The former landfill is the location of the proposed St Peters interchange which is being constructed as part of the New M5 project. As part of the WestConnex construction program, a cut-off wall is being constructed as part of the New M5 to reduce leachate generation in addition to landfill capping to reduce rainfall infiltration. Leachate capture and treatment will be on-going. The Alexandria Landfill is located at Albert Street in St Peters, adjacent to Alexandra Canal.

4.4 Existing surface water features

4.4.1 Watercourses

Surface water features along the project footprint are detailed in **Appendix Q** of the EIS (Technical working paper: Surface water and flooding) and relevant details are summarised as follows:

The majority of the project footprint is located in a heavily urbanised area and is drained by the stormwater network. The primary surface water features in the project footprint are the creeks, infilled creeks and canals. The project footprint is covered by five catchments that are drained by canals and creeks into Sydney Harbour and Botany Bay as shown in **Figure 4-4**. The creeks and canals are heavily modified, which impacts discharge volumes, durations and velocities. These processes are discussed for each catchment in in **Appendix Q** of the EIS (Technical working paper: Surface water and flooding).

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

Major watercourses within or in close proximity to the project footprint including Dobroyd Canal, Hawthorne Canal, Whites Creek, Easton Park drain, Johnstons Creek, Iron Cove Creek and Alexandria Canal are either first or second order streams. The project footprint is within 40 metres of Hawthorne Canal, Whites Creek, Easton Park drain and Johnstons Creek. Alexandra Canal is the main waterway downstream of the project footprint to the south within the Cooks River catchment. The canal, originally a natural watercourse named Sheas Creek, flows into the Cooks River near the north-western corner of Sydney Airport. Sediments in the canal are contaminated and it has been declared a remediation site by the NSW EPA.

Patches of coastal saltmarsh occur along the edge of Rozelle Bay and Johnstons Creek. To the south the suburbs of Newtown, Enmore and St Peters are drained by the lined Eastern Channel that discharges to the Cooks River. Wolli Creek, Bardwell Creek and Mill Stream are unlined and are outside the immediate project footprint, though are included in the groundwater model domain.

Despite the majority of the creeks and canals in the model domain being concrete lined, the alluvium beneath the channels is saturated with groundwater. In the concrete lined creeks, seepage to groundwater is limited to water flowing through fractures within the concrete lining, and along unlined stretches or naturalised areas. Lower reaches of the concrete lined channels are expected to leak more where the channels are tidally influenced and receive more water than the upper reaches. Sydney Water is in the process of naturalising some creeks and canals by replacing the concrete lining with a natural permeable stream base, planting natural vegetation and recontouring river banks. Parts of the Cooks River have been naturalised and it is proposed to naturalise parts of Johnstons Creek, Iron Cove Creek and Whites Creek in the near future. The groundwater model modelled the creeks as being lined as at the time of modelling the proposed naturalisation projects were in the concept design phase. Should the creeks be naturalised it is expected the groundwater recharge would increase and the impact of groundwater drawdown due to tunnel leakage would slightly decrease.

At a macro scale, surface water and groundwater in the Central Sydney Basin is described in the Water Sharing Plan, Greater Metropolitan Regional Groundwater Sources Background Document (NoW 2011). Within the porous rock aquifer, the level of connection between groundwater and surface water is stated as low to moderate with the estimated travel time between groundwater and unregulated rivers being in the order of years to decades.

Fluvial groundwater systems are located up gradient from the alluvial systems flanking the natural creek systems. The distinction between the two systems is minor as they are part of the same aquifer system. The water quality in these systems is slightly brackish and would sustain salt tolerant flora species. These creeks would receive base flow when the natural groundwater level is higher than the creek stage. Under natural conditions recharge to fluvial systems would be also received via floodwaters from floodplains, however the discharge volumes, duration and velocities are altered due to the modified urban environment. Typically the floodwaters would flow into the fluvial systems more quickly due to the increased run-off caused by paved areas and concrete lined drains.

4.4.2 Riparian corridors

A riparian corridor is a transition zone between the land and a river or watercourse or aquatic environment and is discussed in more detail in to **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS. 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 FBA (OEH 2014). The Parramatta River is defined as an estuary which has implications when assessing the biodiversity offsets policy for major projects. Refer to **Appendix S** (Technical working paper: Biodiversity) of the EIS for additional information on the biodiversity assessment carried out for the project in accordance with the FBA.

The lower reaches of Parramatta River, Iron Cove, Rozelle Bay and Whites Bay 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.

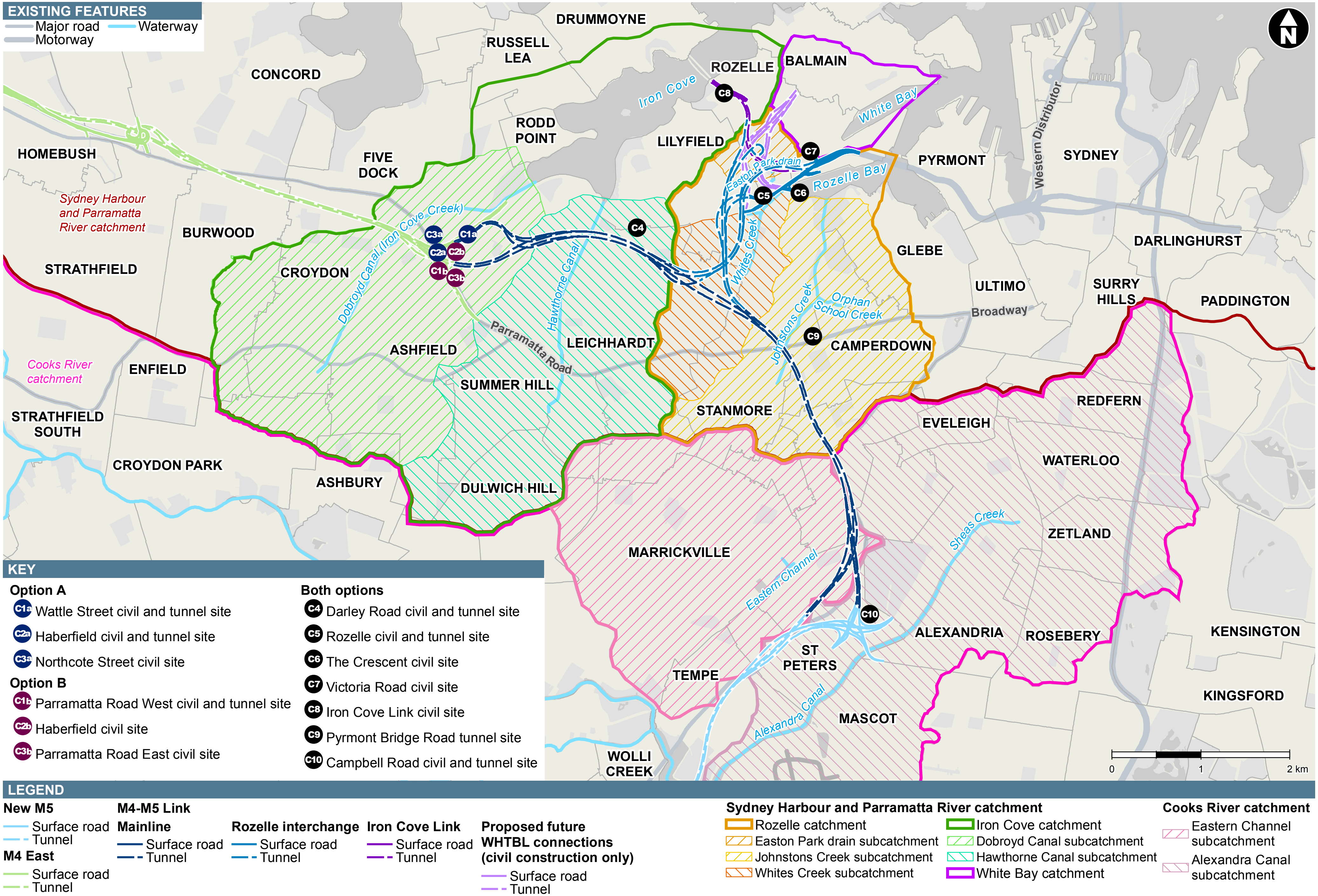

Figure 4-4 Catchments and watercourses within the project footprint

As the Rozelle Rail Yards is within a topographic low, it receives runoff from relatively steep contributing catchments to the north and west. This, combined with the limited capacity of the local drainage network, means that the existing site functions as a floodway for overland flow and provides a significant area for floodwater storage. Floodways are areas of the floodplain where a significant discharge of water occurs during floods. They are areas that, even if only partially blocked, would cause a significant redistribution of flood flow or a significant increase in flood levels. The existing flood behaviour in the various catchments intersected by the project footprint is discussed in detail in **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS. **Appendix S** (Technical working paper: Biodiversity) of the EIS indicates that sections of the riparian buffer zone of Whites Creek and Rozelle Bay are located within the surface works area at Rozelle and a small portion of the riparian buffer of Iron Cove touches the western edge of the surface works area at Iron Cove. No other construction ancillary facilities or operational areas of the project are within riparian corridors.

An assessment of compliance with the FBA, in accordance the water sharing plan and potential impacts on the riparian corridor is outlined in **section 9.4**.

4.4.3 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. The presence or absence of GDEs within or near to the project footprint has been determined 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 (Australian Bureau of Meteorology).

Review of these resources (viewed 22 August 2016) indicated there are no high priority groundwater dependent ecosystems within the project footprint. The nearest high priority wetlands (as defined in the Water Sharing Plan) are the Botany Wetlands and Lachlan Swamps within the Botany Sands, located in Centennial Park about five kilometres east of the project footprint, outside of the model area domain.

With reference to the BoM Atlas, the closest GDEs to the M4-M5 Link are a series of wetlands associated with Wolli Creek at Turrella, located about 1.5 kilometres west of the St Peters interchange. Potential groundwater impacts on these GDEs were considered in the New M5 EIS, (Roads and Maritime, 2015) and the cumulative impacts are outlined in **Chapter 7**.

Appendix S (Technical working paper: Biodiversity) of the EIS states that waterways in or adjacent to the proposed works are not suitable habitat for threatened fish species and there are no SEPP 14 wetlands in the study area. It is also unlikely that there is valuable or specific aquatic habitat for threatened aquatic/estuarine species, populations or communities listed under the *Fisheries Management Act 1994* (NSW), *Threatened Species Conservation Act 1995* (NSW) or *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth) present within the project footprint. It is possible some species may opportunistically pass through the estuarine bays within the study area (Whites Bay, Rozelle Bay and Iron Cove) given the connectivity to the broader harbour and coastal habitats, but the species are unlikely to depend on the habitat adjacent to the project footprint.

4.4.4 Wetlands

Reference to the Directory of Important Wetlands of Australia (DIWA) and SEPP 14 wetland data indicates no natural wetlands have been identified within the project footprint. However the waterways of Hawthorne Canal, Rozelle Bay and saltmarshes flanking Rozelle Bay near the confluence with Johnstons Creek are recognised as sensitive areas. A man-made wetland was constructed in Annandale in 2002, located upstream adjacent to Whites Creek and discharges into Rozelle Bay. The wetland covers an area of 1200 square metres and consists of five ponds and a settling pond.

No natural springs have been identified within the project footprint, which is attributed to the relatively flat topography. Groundwater periodically flows from the sandstone cutting at the Rozelle Rail Yards following large rainfall events but no groundwater dependent ecosystems were identified within

Appendix S (Technical working paper: Biodiversity) of the EIS. Flora within the Rozelle Rail Yards was described as being dominated by exotic vegetation or disturbed tolerant species within a highly disturbed and degraded environment.

4.4.5 Aquatic habitat

Rozelle Bay, Iron Cove, White Bay, Alexandra Canal and downstream portions of Dobroyd Canal and Hawthorne Canal have been mapped as Class 1 Major key fish habitat, as defined in the *Fisheries Policy and Guidelines for Fish Habitat Conservation and Management* (Fairfull 2013). The project's receiving waters are marine environments which include the intertidal and subtidal ecosystems of the harbour and its estuarine tributaries. Within these environments there are no weirs or fish barriers. Marine vegetation includes mangroves, seagrasses and marine microalgae which provide an important habitat for spawning and refuge. **Appendix S** (Technical working paper: Biodiversity) of the EIS states that waterways in or adjacent to the proposed works are not suitable habitat for threatened fish species.

Aquatic habitats of catchments, watercourses and surface water bodies are outlined in **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS and are summarised as follows:

- Dobroyd Canal (Iron Cove Creek) is mapped as key fish habitat downstream of Ramsay Street, Haberfield
- Hawthorne Canal is mapped as key fish habitat downstream of Marion Street, Leichhardt
- Whites Creek is mapped as a first order stream
- Easton Park drain is mapped as a first order stream
- Johnstons Creek is mapped as a first order stream
- Rozelle Bay is mapped as key fish habitat and is an estuarine environment
- Iron Cove is a bay within the Parramatta River estuary mapped as key fish habitat
- White Bay is mapped as key fish habitat and is an estuarine environment
- Alexandra Canal is a constructed canal originally a natural watercourse named Sheas Creek and is a second order stream.

4.5 Soils

Soils within the project footprint are identified from the Soil Landscapes of the Sydney 1:100,000 Sheet (Chapman, G.A and Murphy, C.L. 1989) and are presented on **Figure 4-5**. Six major soil profiles have been identified along the project footprint as follows:

- The **Blacktown (bt)** soil landscape is a red and brown podzolic soil that covers the majority of the project footprint. It represents a residual soil profile overlying the Wianamatta Group and Hawkesbury Sandstone
- The **Gymea (gy)** soil profile outcrops around the edge of the harbour near the Rozelle Rail Yards. This unit is an erosional soil profile consisting of yellow earths and earthy sands overlying the Hawkesbury Sandstone
- Along the south-eastern shores of Iron Cove, the **Hawkesbury (ha)** soil landscape unit flanks the harbour. The Hawkesbury unit is shallow and is composed of yellow earths and some yellow podzolic soils sometimes with sandstone outcropping
- In the eastern part of the project footprint at Alexandria, the **Tuggerah (tg)** soil profile outcrops over Botany Sands. The aeolian soil profile is deep
- The **Birrong (bg)** soil profile flanks the upper reaches of Hawthorne Canal and Johnstons Creek. The fluvial unit drains the Wianamatta Shale and is composed of yellow soils that are seasonally waterlogged
- **Disturbed terrain (xx)** is common in low lying areas adjacent to the harbour due to the historic indiscriminate infilling of wetlands. Often the original soil has been removed and the fill is capped with a clay layer to form sports grounds and parks.

A search of the Australian Soils Resource Information System indicated that the majority of the project footprint has a low to extremely low probability of occurrence of acid sulfate soils. Land adjacent to watercourses, namely Hawthorne Canal, Johnstons Creek, Whites Creek and Alexandra Canal were identified as having a high probability of being potential acid sulfate soils (PASS). In addition, estuarine soils were sampled above bedrock but below the fill at the Rozelle Rail Yards were shown to be PASS (AECOM 2016a). These areas correspond to land identified as containing Class 1, 2 and 3 acid sulfate soils. 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 in **Figure 4-6**. The disturbance of acid sulfate soil has the potential to generate acidic groundwater that would require treatment prior to discharge. Consequently, procedures for the management of acid sulfate soils would be required during construction works. Site specific acid sulfate soil investigations undertaken at the Rozelle Rail Yards are discussed further in **section 4.14**.

Salinity hazard mapping for Western Sydney (NSW Department of Infrastructure, Planning and Natural Resources 2002) extends as far east as Homebush Bay but does not extend into the project footprint such as Whites Creek near Rozelle Bay. However, many of the mapped geological and soil units in Western Sydney extend into the project footprint. The salinity potential mapping is based on soil salinity, topography, geometry of the landscape geology and soil and groundwater settings. The majority of the project footprint is underlain by Hawkesbury Sandstone which is considered to have a very low salinity potential. Areas underlain by the Wianamatta Shale on which the Blacktown soil unit has developed are considered to have a moderate salinity potential. There is a high salinity potential within the alluvium flanking creeks in low lying areas. Along the project footprint there are no known salt scald occurrences suggesting that if saline soils are present, the salts have not reached the ground surface.

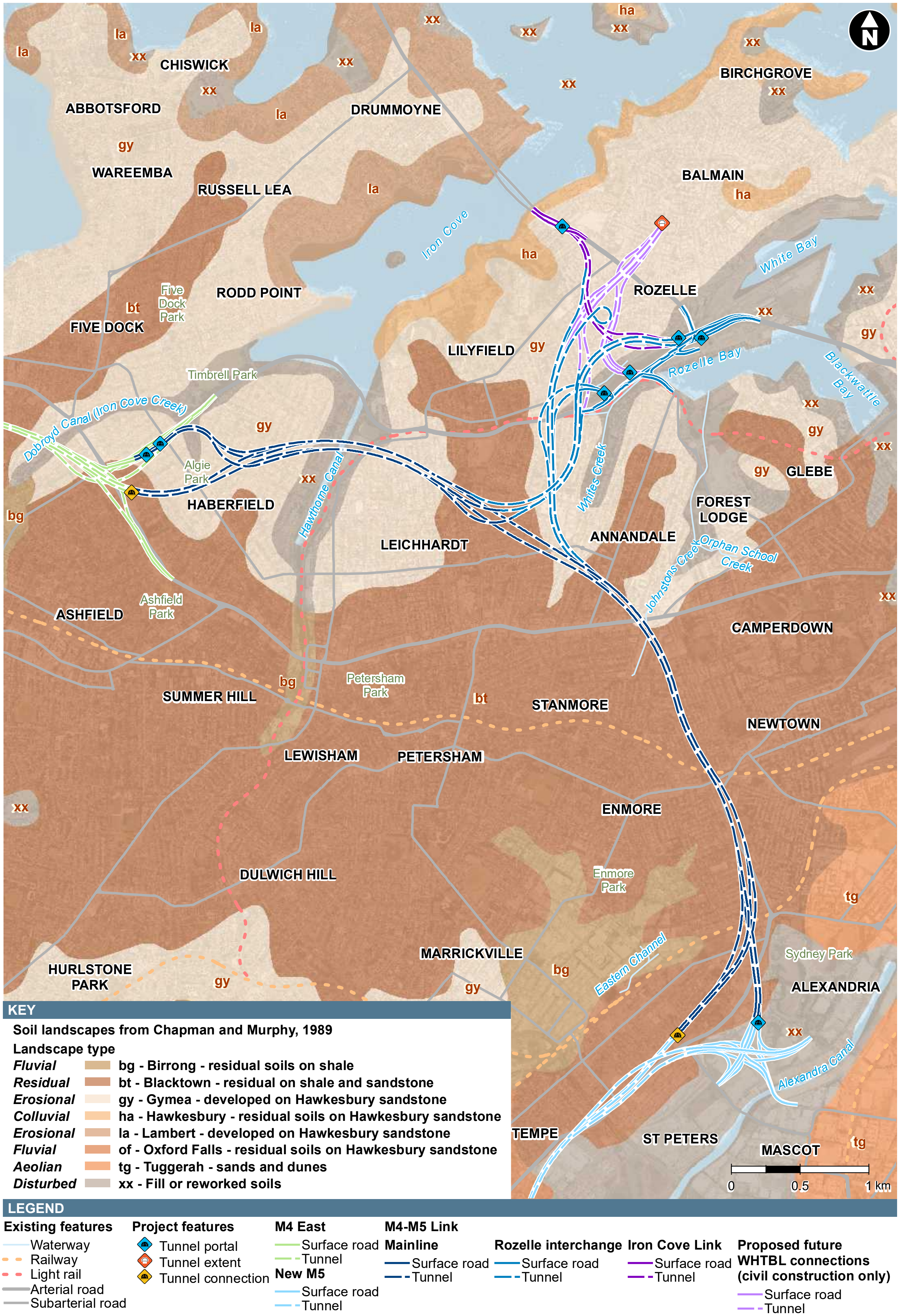

Figure 4-5 Soils within the project corridor

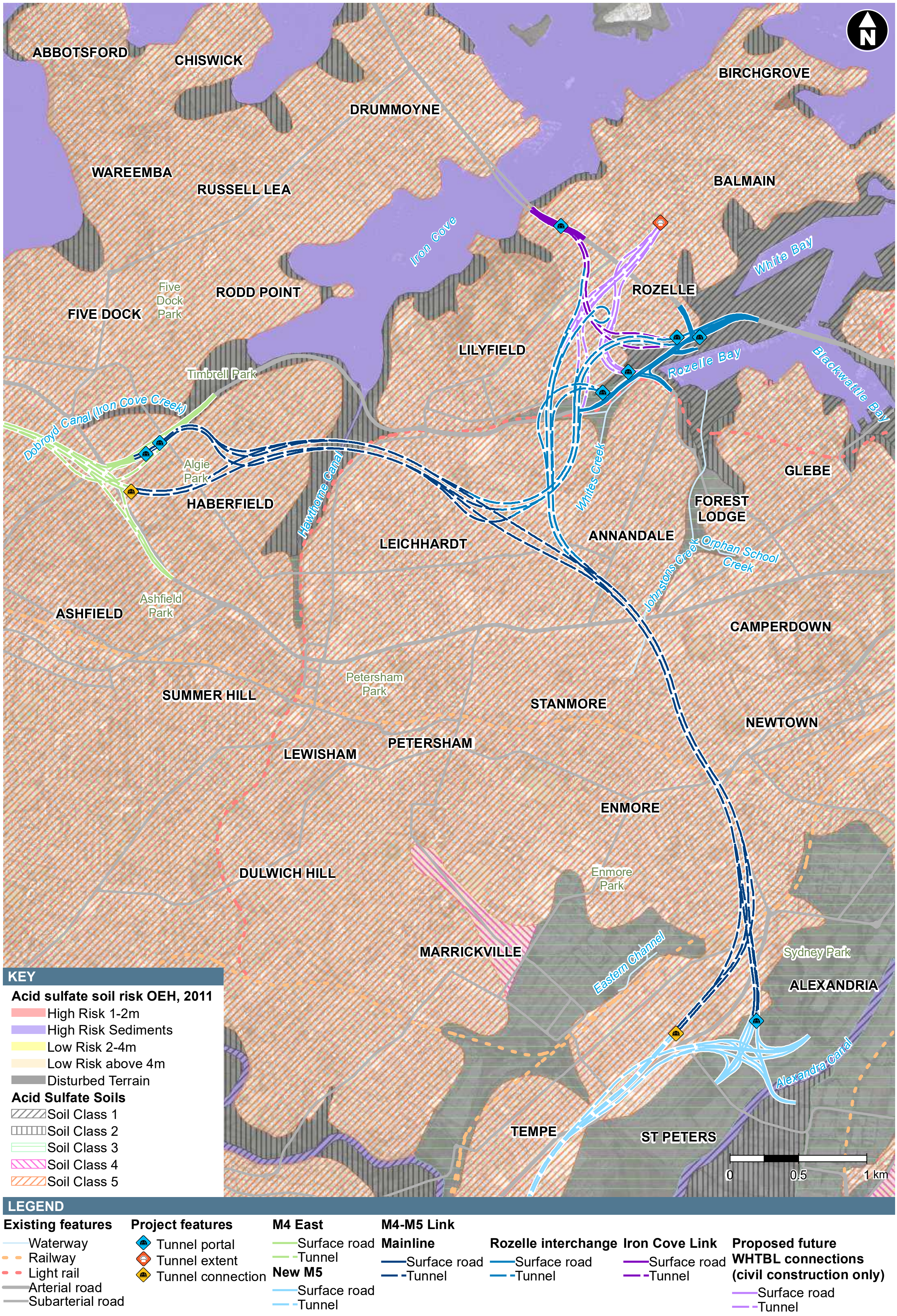

Figure 4-6 Acid sulfate soil risk map

4.6 Geology

4.6.1 Geological setting

Regionally, the study area is located within the Permo-Triassic Sydney Basin that is characterised by sub-horizontal lying sedimentary sequence, mainly sandstone and shale. The published 1:100,000 series geological map for Sydney, Sheet 9130 (Herbert 1983) indicates that the proposed M4-M5 Link project footprint is underlain by two main geological units, the Ashfield Shale and the Hawkesbury Sandstone (**Figure 4-7**). The Ashfield Shale and Hawkesbury Sandstone are sometimes separated by the transitional Mittagong Formation. To the east of the project footprint, the unconsolidated Quaternary-aged Botany Sands onlap the basin and unconformably overlie the bedrock.

The main stratigraphic units that have been encountered along the project footprint comprise of the following from youngest to oldest:

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

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). These alluvial infilled deeply incised palaeochannels of Pleistocene age are carved into the sandstone and shale bedrock to depths up to 25 metres. At the edge of the harbour, alluvium and colluvium is present along with man-made fill. Beneath the major drainage lines discharging into Rozelle Bay, deep alluvium up to 20 to 25 metres below ground level is present as palaeochannels. Also at the edge of the harbour, wetlands and swamps have historically been infilled to ‘reclaim’ the land to create parks and playing fields.

The geology of the project footprint is presented in more detail in the geotechnical preliminary reference design report (AECOM 2017d).

4.6.2 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 consists of locally excavated and imported materials.

More substantial filling has occurred along low lying areas such as reclamation works associated with the perimeter of Rozelle Bay and Iron Cove, Rozelle Rail Yards, Hawthorne Canal and Alexandra Canal. Fill materials typically consist of locally dredged material and imported rubble and waste. Compaction levels may range from uncompacted associated with reclamation works to engineered and certified fill at development sites. Unconsolidated man-made fill has been placed periodically over the years around Rozelle Bay up to three to four metres thick.

The most substantial fill deposits are at the Alexandria Landfill which has been infilled with uncompacted waste to depths of 35 to 40 metres.

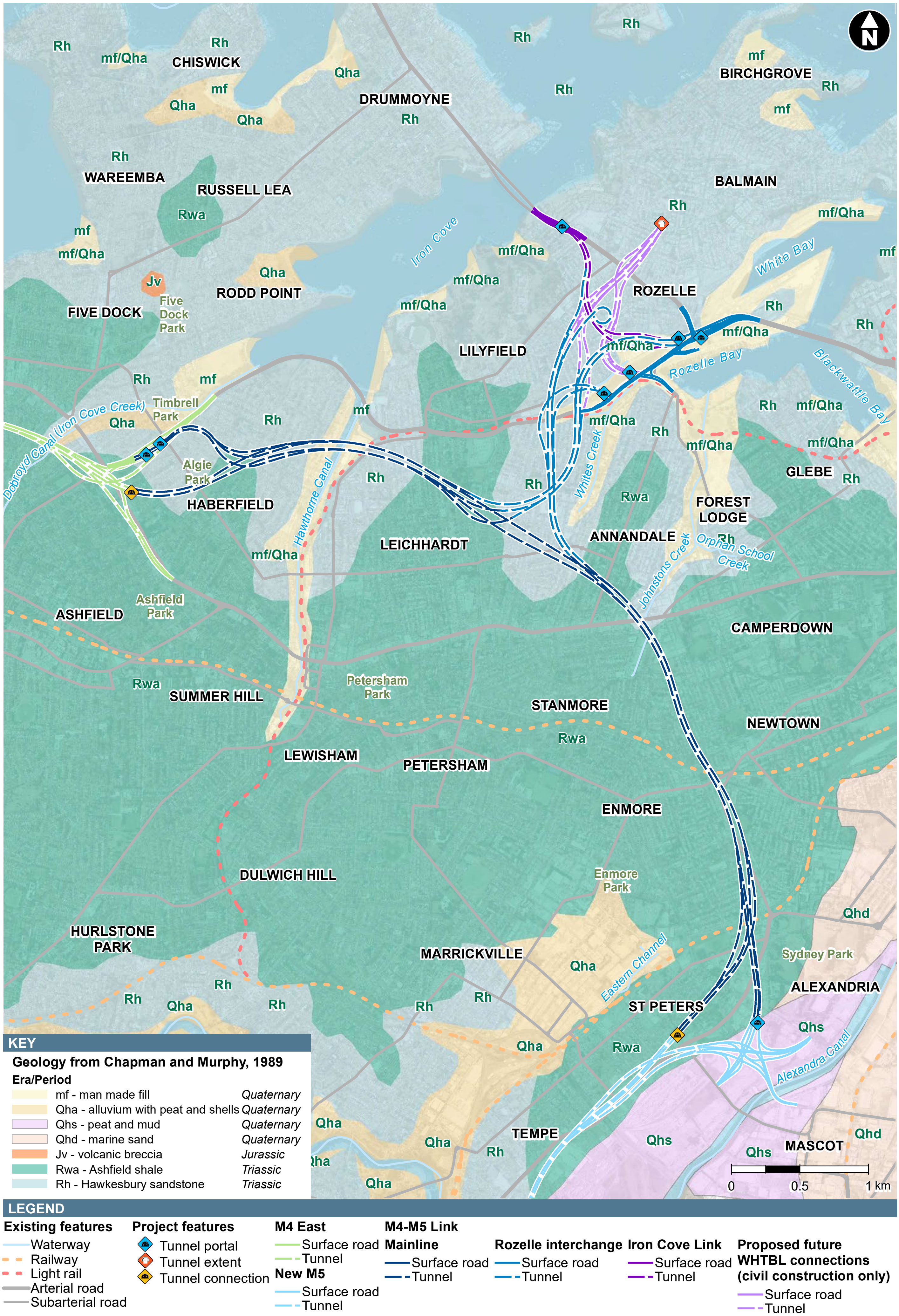

Figure 4-7 Geology of the project footprint

4.6.3 Alluvium

Deposits of alluvial and fluvial sediments are located beneath fill around Rozelle Bay, White Bay and Iron Cove and flank the major creeks and gullies including Hawthorne Canal, Johnstons Creek and Whites Creek. Often these alluvial sediments are overlain by reclamation fill. The alluvial sediments consist of sand, silt, clay, gravels and some peat with a basal clay occasionally defining the base of the sequence. Some of the alluvium contains shells and marine muds. The thickness of the alluvium is variable and can be up to 25 metres deep within palaeochannels such as beneath Hawthorne Canal and Whites Creek. Fill and alluvium at the Rozelle Rail Yards potentially contaminated from previous light industrial land-uses, identified during contaminated land investigations, remains at the site.

4.6.4 Botany Sands

The Botany Sands occur along the eastern perimeter of the project footprint in the eastern part of the Alexandria Landfill at the proposed St Peters interchange. The alluvial, aeolian and estuarine deposits of the Botany Sands onlap the Ashfield Shale in the project footprint, and extend along the eastern coastal strip of Sydney. Inland extensions of the Botany Sands estuarine deposition along valleys are considered as palaeochannel deposits. Lithologically the Botany Sands consists of unconsolidated clayey sand, silty sand, and muds with occasional gravel (Hatley 2004). 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.

4.6.5 Palaeochannels

Deeply incised palaeochannels have carved out narrow drainage channels into the sandstone and shale bedrock associated with a network of ancient river channels. These palaeochannels are infilled with up to 25 metres of saturated sediments comprised of alluvium, estuarine and marine deposits. The depth of some of the palaeochannels is unknown. The palaeochannels typically underlie alluvium associated with structural features such as rivers or gullies and drain to the north into Sydney Harbour.

Palaeochannels have been identified within the project footprint at the following locations:

- Hawthorne Canal
- Whites Creek
- Johnstons Creek
- Rozelle Rail Yards
- Alexandra Canal.

4.6.6 Volcanic intrusions

Intrusive volcanic dykes of Jurassic age intrude and cross-cut the bedrock shale and sandstone 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 dykes are of variable width ranging from less than three metres, up to 16 metres wide such as the Great Sydney Dyke (Davies 2002). The Great Sydney Dyke extends from Centennial Park, through Sydney's southern CBD to the Balmain area. The dykes are typically variably weathered and in some cases are altered to white kaolinitic clay to a depth of some 10 to 20 metres below ground level. Elsewhere, swarms of dykes can occur that may represent stringers or off-shoots from a main intrusion. Within the project footprint three to four dykes parallel to the Great Sydney Dyke have been identified within the Rozelle Rail Yards. One single north–south trending dyke has been identified at the Wattle Street ramps, Haberfield. Similarly a 12 metre wide dyke intruding the Hawkesbury Sandstone was identified 10 metres below ground level at Iron Cove in monitoring well IC_BH02.

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, although the distance between dykes may vary from less than 20 metres to in excess of 500 metres. The host rock adjacent to the dyke may be fractured and metamorphosed for a distance of up to two metres from the dyke interface. Where the dyke has intruded into the sandstone, there is commonly a metamorphosed aureole that can be more resistant to weathering than the surrounding sandstone or shale.

4.6.7 Ashfield Shale

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 project footprint only intersects the lowest member of this unit, the Ashfield Shale. The Ashfield Shale outcrops in the southern portion of the project footprint between St Peters and Camperdown, and again capping the higher topographic areas of Annandale and Leichhardt. 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.

The Ashfield Shale unit is about 60 to 70 metres thick and consists of four siltstone and laminate members, from youngest to oldest as follows:

- Mulgoa Laminite
- Regentville Siltstone
- Kellyville Laminite
- Rouse Hill Siltstone.

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, bedding planes and displays slickensided (evidence of geological faulting) features along some surfaces. Where exposed, the Ashfield Shale weathers to a stiff to hard clay with medium to high plasticity. The shale weathered profile typically extends to a depth of three to 10 metres, although within the former brick pits at the Alexandria Landfill the weathered clay has extended to depths in excess of 40 metres.

4.6.8 Mittagong Formation

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 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. Across the Sydney Basin the Mittagong Formation has largely been eroded, rarely outcrops and within the project footprint is not known to extend beyond a thickness of 10 metres. The Mittagong Formation has been identified in boreholes across most of the project footprint but is not known to outcrop.

4.6.9 Hawkesbury Sandstone

The Hawkesbury Sandstone is the dominant lithology across the project footprint and is present beneath the entire length of the proposed M4-M5 Link project footprint, albeit at depth in the southern portion, beneath the Ashfield Shale. 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 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 Geological features along the project footprint

4.7.1 Mainline tunnels

The twin mainline tunnels are about 7.5 kilometres in length extending from Haberfield under Leichhardt, Annandale, Newtown and emerging at St Peters. Ramp tunnels would provide surface connections to St Peters interchange, Rozelle interchange, Iron Cove Link and the M4 East interchange at Wattle Street, Haberfield. The shallow ramp tunnels would intersect a combination of weathered Hawkesbury Sandstone, Mittagong Formation, Ashfield Shale and residual and alluvial soil profiles depending on the location.

The mainline tunnels are to be generally constructed in good quality Hawkesbury Sandstone with the project footprint remaining predominately below the Ashfield Shale. Groundwater within the unconsolidated saturated sediments beneath creek crossings at Johnstons Creek, Iron Cove Creek, Whites Creek and Hawthorne Canal would be managed by the tunnels diving beneath the underlying palaeochannels and remaining within the competent Hawkesbury Sandstone. Within the Whites Creek palaeochannel at the Rozelle Rail Yards the tunnels would be tanked to limit groundwater ingress from the alluvium.

4.7.2 New M5 interface (St Peters interchange)

St Peters interchange forms the interface between the New M5 and M4-M5 Link projects and consists of two tunnels, northbound and southbound. There is also a surface interface between the New M5 project and the north facing ramps of the M4-M5 Link project at the northern corner of the St Peters interchange.

The ground conditions at St Peters are dominated by thick residual clay soils over weathered shale. The St Peters interchange has been approved to be constructed at the former Alexandria Landfill, a former brickworks quarry that was excavated to a depth of about 35 metres to near the top of the Hawkesbury Sandstone and subsequently infilled with uncontrolled waste material. The proposed M4-M5 Link project footprint commences in weathered shale exposed in the western wall of the former brickpit and descends through shale and sandstone to the main project footprint.

Near Canal Road, the Mittagong Formation is encountered which has a higher siltstone content than the Hawkesbury Sandstone but groundwater inflows are expected to be similar. During excavation of the TransGrid Cable tunnel (AECOM 2016f) a joint swarm trending 040 (parallel to Mitchell Road) was encountered. The width and extent of this joint swarm is not known, but extrapolated north, the joint swarm may intersect the ramps. The presence of joints can act as a conduit for groundwater flow directing groundwater along the lineament impacting groundwater flow patterns.

Groundwater levels at St Peters interchange are influenced locally by leachate pumping from the former Alexandria Landfill, which is hydraulically connected to the shale. Although the former landfill is to be rehabilitated as part of the St Peters interchange construction, it would still require ongoing leachate pumping during operation of the interchange.

4.7.3 Rozelle interchange

The Rozelle interchange is a complex major project feature forming the interface for the mainline tunnels of the M4-M5 Link project with City West Link and Anzac Bridge, Victoria Road, via the Iron Cove Link, and stub tunnels for the future connection with the proposed future Western Harbour Tunnel and Beaches Link project. The majority of the proposed Rozelle interchange would be constructed beneath the ground surface within the Hawkesbury Sandstone, with invert levels at a maximum of 60 metres below ground level.

The ground conditions at the Rozelle interchange are predominately good quality Hawkesbury Sandstone beneath the residential area of Rozelle. The geology beneath the adjacent Rozelle Rail Yards is complex as it is underlain by a deep palaeochannel sequence that is composed of saturated sand, silts and clay. Several basalt dykes trending to the north-west have been mapped cross-cutting the sandstone and outcropping in the sandstone cutting north of the Rozelle Rail Yards. Minor seepage has been observed (particularly after rainfall events) from fractures and bedding planes within these sandstone cliffs.

4.7.4 Iron Cove Link

The proposed Iron Cove Link would consist of twin two lane, one kilometre long tunnels extending from the Rozelle interchange beneath Easton Park linking with Victoria Road south of Iron Cove Bridge. At Iron Cove, ramps and tunnel portals would be excavated from the shallow Hawkesbury Sandstone that would transition into cut-and-cover tunnels before diving into the twin tunnels to the south.

The Iron Cove Link tunnels are to be constructed in good quality saturated Hawkesbury Sandstone. The soil profile is thin and typically less than two metres thick. At the Iron Cove Link portal there is up to five metres of fill overlying the Hawkesbury Sandstone that is likely to contain minor perched water at the interface with the sandstone. At Iron Cove, a basalt dyke was intersected in borehole IC_BH02 at 11 metres below ground level.

4.7.5 M4 East interface and ramps (Wattle Street interchange)

The Wattle Street interchange and associated ramps at Haberfield are being constructed as part of the M4 East project. The eastbound and westbound cut-and-cover structures would extend over 150 and 280 metres respectively before diving deep into the sandstone.

The ground conditions at the Wattle Street interchange are challenging with a palaeovalley located 100 metres east of the proposed driven tunnel portals. The top of rock in the base of the palaeovalley is up to eight metres below ground level while the crown of the tunnels are located less than eight metres below ground. The palaeovalley is infilled with a combination of soft estuarine clays and firm, water saturated clayey sands which are alluvial in origin.

Around 150 metres to the east of the palaeovalley, a dolerite dyke crosses the project footprint which is about 12 metres thick. The dyke can act as either a barrier to groundwater flow or a conduit for flow depending on the hydraulic properties of the weathered dolerite. The remainder of the tunnel intersects good quality sandstone at depth.

4.8 Hydrogeological setting

The majority of the project footprint, caverns and associated tunnel 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 units:

- Alluvium around the edges of Rozelle Bay, White Bay and Iron Cove
- Palaeochannels beneath creeks
- Ashfield Shale and 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.

Groundwater flow through the Ashfield Shale and Hawkesbury Sandstone is variable with the majority of groundwater flowing along secondary structural features rather than the primary matrix. The hydraulic conductivity of the sandstone tends to be higher than the shale due to the increased number of saturated fractures, joints and fissures. The fill and alluvium form an unconfined highly permeable aquifer. Groundwater quality within the Ashfield Shale is typically brackish and aggressive due to its marine origin. The underlying Hawkesbury Sandstone is typically of lower salinity but immediately below the Ashfield Shale the salinity within the sandstone can be elevated due to leakage from the shale. Groundwater within the alluvium and fill is typically of low salinity in the upper reaches of the creeks although becomes more saline down gradient with increased tidal influences and mixing.

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 Parramatta River and Sydney Harbour is recharged daily by tidal fluctuations.

4.8.1 Quaternary alluvium

Modern alluvium outcrops around the edge of the harbour at Rozelle Bay and is present beneath fill and infilling palaeochannels forming an unconfined aquifer. The alluvium surrounding creeks is generally of high permeability. 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. As the alluvium is hydraulically connected to the creeks the groundwater levels are shallow and typically within one metre of ground level Hawthorne Canal, Whites Creek and Johnstons Creek are concrete lined limiting the hydraulic connection between surface water and groundwater. Recharge to the alluvium is via direct rainfall recharge and runoff or surface water inflow.

The palaeochannels that occur beneath some of the major creeks or valleys and extend to depths of up to 25 metres are saturated with groundwater. Groundwater quality within the palaeochannels is typically saline due to recharge from the Ashfield Shale and leakage from tidally flushed rivers and tributaries. The alluvium infilling the palaeochannels is highly transmissive due to the coarse 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 and Alexandria Canal. The Botany Sands aquifer naturally contains moderately low salinity groundwater (generally less than 2000 milligrams per litre) and is moderately acidic but in many areas has been contaminated by industrial activities, most notably in the southern portion of the aquifer near the Botany Industrial Park where groundwater use has been embargoed 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, Sydney Harbour and associated canals.

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. DPI-Water advise that the whole Botany Sands hydrogeological unit is over allocated and to extract groundwater a water allocation must be bought on the open market. Since 2007 residents are no longer allowed to extract groundwater for domestic use in the ‘Zone 2 area’ adjacent to the project footprint due to extensive groundwater contamination.

While the Botany Sands are not intersected by the project footprint, groundwater from the Botany Sands may be hydraulically linked with the drained tunnels. The residual alluvial clay that separates the sands from the underlying bedrock forms a hydraulic seal or aquitard that would reduce vertical leakage restricting groundwater drawdown due to the project. Lateral groundwater flow to the Ashfield Shale is also expected to be low due to the poor water transmitting properties of the Ashfield Shale.

4.8.3 Ashfield Shale

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

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 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. Recharge is via rainfall infiltration on fractured outcrop and through leakage from the Ashfield Shale, soil profile and alluvium. Discharge is via seepage to cuttings such as the exposed quarried sandstone at the Rozelle Rail Yards, creeks and evapotranspiration.

Groundwater within the Hawkesbury Sandstone is generally acidic but of low salinity, however the salinity of the upper part of the aquifer can be elevated due to leakage from the Ashfield Shale. 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 cross-cut by a number of structural features including dykes, joint swarms and limited faults that may impact groundwater flow. Increased groundwater ingress to tunnels is typically associated with major fractures or fault zones, although not all structural features are saturated and hence transmissive. Increased tunnel inflows can result from a higher hydraulic conductivity associated with the structure. Increased tunnel inflows can also result because of a reduced hydraulic conductivity, as the structure can act as a barrier causing higher heads on one side of the structure. When intersected by a tunnel, the higher hydraulic head on the other side of the structure could result in higher inflows than were occurring before the structure was intersected. During construction, water-bearing fractures and faults can release groundwater initially, which declines as the storage is depleted. Fractures, faults and dykes within the project footprint are typically oriented between 090 degrees and 120 degrees and between 005 degrees and 035 degrees which influences the predominant groundwater flow directions within the Hawkesbury Sandstone.

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 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 or limited flow to the tunnel where the sandstone is not fractured. 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-sections

Two hydrogeological cross-sections A-A’ and B-B’ based on boreholes and monitoring wells constructed during the investigation are presented as **Figure 4-8** and **Figure 4-9** respectively. The cross-sections present the simplified geology, the water table or potentiometric surface, monitoring wells showing the screened intervals and the project footprint. The cross-section transects are shown on **Figure 3-2**.

Cross-section A-A’ is east–west oriented extending from Haberfield through Leichhardt and Annandale to Camperdown. The tunnel is shown diving beneath Hawthorne Canal and extending as far as Camperdown at MT_BH11 after which the tunnel is oriented southwards. Cross-section A-A’ primarily intersects the Hawkesbury Sandstone with Ashfield Shale capping higher elevation areas at Leichhardt (MT_BH02) and to the east outcropping at Camperdown. A thin veneer of unsaturated soil and colluvium covers the majority of the cross-section, although the alluvium contains significant groundwater within the Hawthorne Canal palaeochannel. The Hawthorne Canal palaeochannel extends to an elevation of -11.6 metres AHD (HB_BH8d) and is interpreted to be about 400 metres wide. The piezometric head within the alluvium at Hawthorne Canal is shown at similar elevations to the potentiometric head within the Hawkesbury Sandstone. To the east the potentiometric head within the Hawkesbury Sandstone and Ashfield Shale becomes deeper as the topography increases.

Cross-section B-B’ is north–south oriented extending from the Iron Cove Link at Iron Cove and Rozelle extending along the Main Line Tunnel through Annandale, Camperdown, Newtown to the St Peters interchange near Alexandria. Cross-section B-B’ primarily intersects the Hawkesbury Sandstone with Ashfield Shale outcropping to the south at Newtown and St Peters. Adjacent to Iron Cove a dolerite dyke has been intersected 10 metres below ground level. Beneath the Rozelle Rail Yards the White Creek palaeochannel has been intersected and extends to a depth of -17.8 metres AHD. Groundwater levels are represented as a piezometric head within the alluvium and a potentionmetric head with in the sandstone and shale. The piezometric head within the alluvium is shown at a slightly lower elevation than the potentiometric head confirming the upward pressure head from the Hawkesbury Sandstone. The tunnels are shown as being below the water table indicating that the sandstone and alluvium intersected would be saturated.

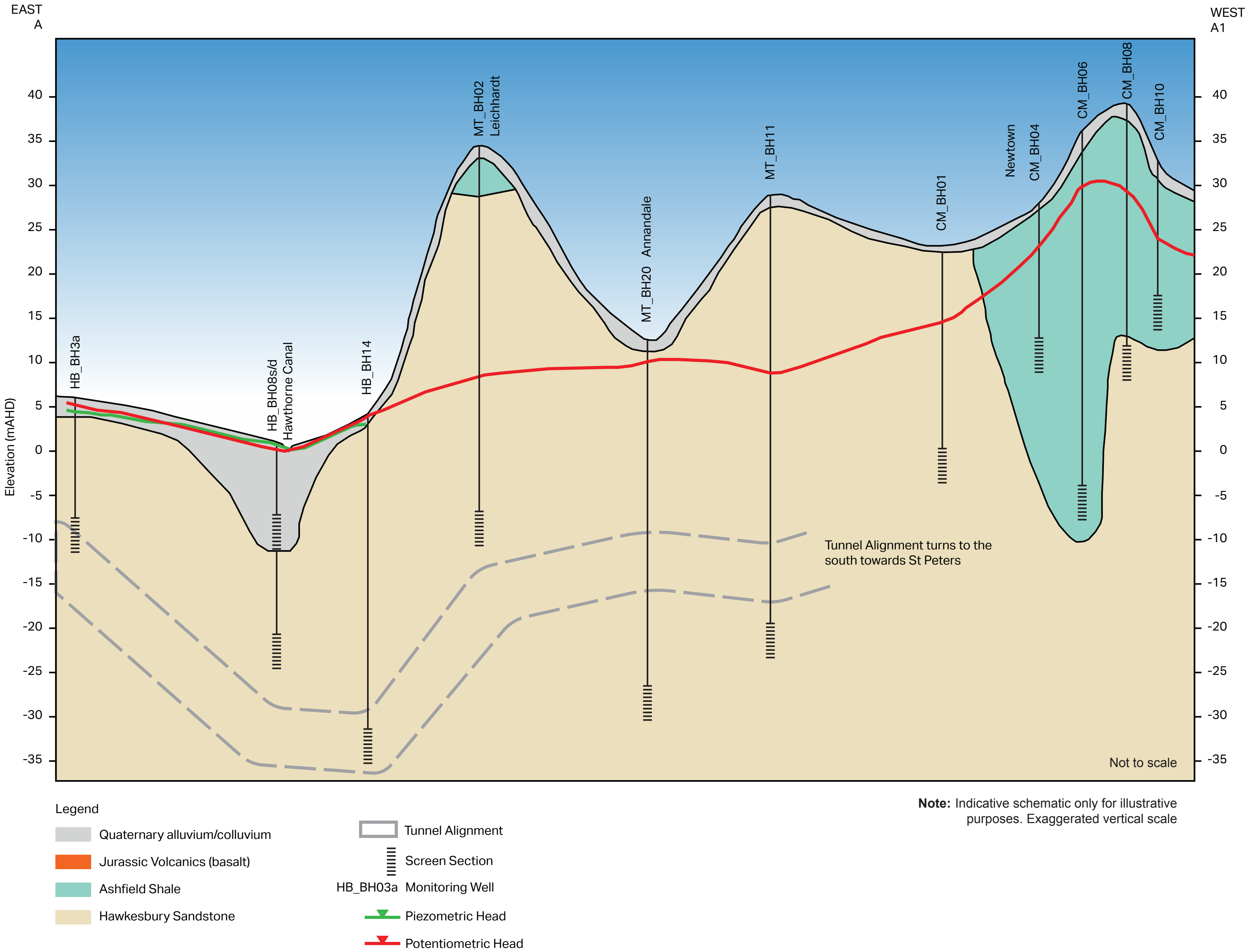

Figure 4-8 Hydrogeological cross section A-A'

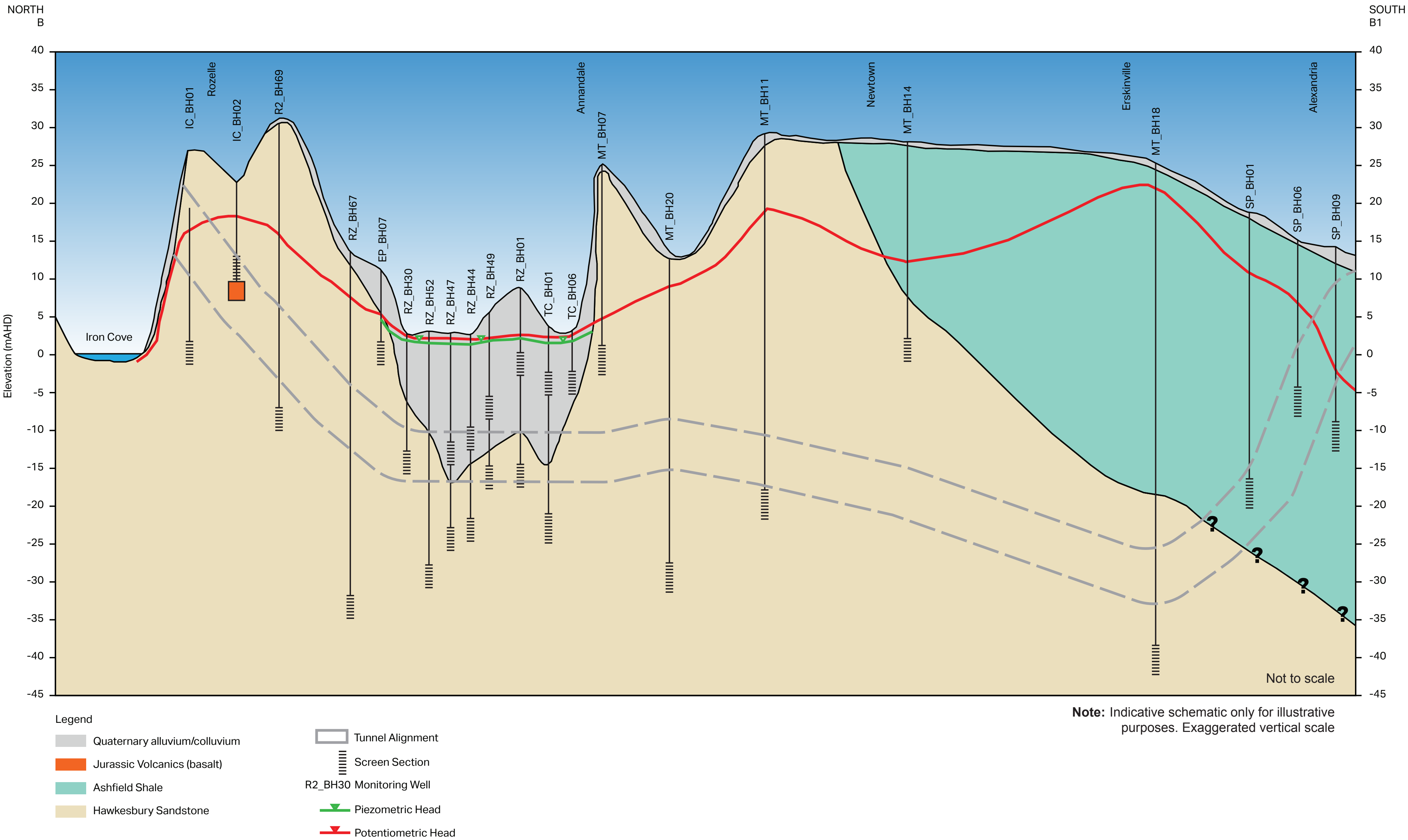

Figure 4-9 Hydrogeological cross section B-B’