WestConnex

Australian Government
BUILDING OUR FUTURE

NSW
MAKING IT HAPPEN

New M5

Environmental Impact Statement

Technical working paper: Groundwater

Appendix Q

November 2015

WestConnex

WestConnex The New M5

Technical Working Paper: Groundwater

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

20-Nov-2015

Job No.: 60327128

Quality Information

Document	WestConnex The New M5
Ref	60327128
Date	20-Nov-2015
Prepared by	Graham Hawkes
Reviewed by	Brad Eismen
Authorised by	Caitlin Bennett

Executive Summary

Roads and Maritime Services (Roads and Maritime) is proposing the construction and operation of the New M5 (the project); which would comprise a new, tolled multi-lane road link between the M5 East Motorway east of King Georges Road and St Peters. The project would also include an interchange at St Peters and connection to the existing road network.

Approval is being sought under Part 5.1 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The project is declared to be State significant infrastructure (SSI) under section 115U(2) of the EP&A Act by reason of the operation of clause 14 and Schedule 3 of the *State Environmental Planning Policy (State and Regional Development) 2011*. Accordingly, the project is subject to assessment under Part 5.1 of the EP&A Act and requires the approval of the Minister for Planning. An environmental impact statement (EIS) is therefore also required. This technical working paper presents the groundwater impact assessment for the project .

The project would include nine kilometres of twin tunnels between the existing M5 East Motorway at Beverly Hills and St Peters. The western portals along the project would be located east of King Georges Road, and the eastern portals at St Peters would be located in the vicinity of the Princes Highway and Canal Road.

The majority of the tunnels are to be constructed below the water table predominately within the Hawkesbury Sandstone but also within the Ashfield Shale, Mittagong Formation and Botany Sands. The project is designed as a drained tunnel; that is to allow groundwater to flow into the tunnel and be collected in the drainage system to be treated and discharged into the Cooks River.

Waterproofing would be required to reduce the bulk rock permeability to meet the groundwater inflow criterion in sections of the tunnels. The New M5 tunnel inflow design criterion is one litre per second per kilometre averaged over every kilometre of tunnel. As such, approach to the control of water ingress into the tunnel consists of a suite of options, ranging from areas where no waterproofing would be required to areas where a membrane may need to be applied.

The findings of the groundwater impact assessment are as follows:

- Groundwater along the alignment is within fill, Botany Sands, palaeochannel sediments, Ashfield Shale, Mittagong Formation and Hawkesbury Sandstone;
- The majority of the tunnel is to be constructed within the competent Hawkesbury Sandstone;
- After tunnelling is completed groundwater inflows would be at their highest but there would be minimal impact on the water table. With time groundwater inflow to the tunnel decreases while the water table gradually declines until an equilibrium is reached. Groundwater modelling has predicted that the drawdown is centred on the Bexley and Tempe areas and it would attain a maximum depth of around 40 metres. The maximum lateral extent of the plot is 500 metres from the alignment between Banksia and Arncliffe which reduces considerably in width further to the west. Drawdown decreases to the west in the western part of the alignment due to the water table already being depressed due leakage into the existing M5 East Motorway tunnel.
- There is potential to impact contaminated groundwater during construction and during long term operations. Groundwater is to be collected, treated and discharged into the Cooks River and Alexandra Canal during construction. Construction water treatment plants would be used during construction at five locations. An operational water treatment plant at Arncliffe motorway operations complex would treat groundwater inflows. The drainage system has been designed to capture groundwater and surface water inflows to the tunnels separately via different drainage networks to streamline the treatment process. In addition groundwater would be collected separately east and west of the sump as groundwater in the east is more likely to be contaminated.
- There is potential for groundwater quality to be impacted due to tunnel inflow from the Cooks River via the alluvium. It is assessed that any changes in water quality by increased salinity would be minimal as the groundwater in the alluvium and Hawkesbury Sandstone is already brackish due to hydraulic continuity with the Cooks River. Groundwater quality in the upper reaches of the catchment is not expected to change as recharge would continue to be dominated by rainfall infiltration.
- Groundwater modelling (CDM Smith, 2015) predicted model inflows of 1,115 cubic metres per day into the project tunnels. Over a modelled length of 20 kilometres an inflow rate of 0.63 litres per second along every

kilometre of east bound (shallower) tunnel and 0.67 litres per second along every kilometre of the westbound (deeper) tunnel was predicted.

- Groundwater is to be collected treated and discharged in accordance with the surface water requirements. The project discharge requirements have been developed in accordance with ANZECC, (2000) for a highly disturbed ecosystems, which cannot feasibly be returned to a ‘slightly to moderately disturbed’ condition. The selection of 80th and/or 20th percentile values from the reference dataset is recommended since the objective for the receiving environment is to improve water quality.
- Landing Lights Wetland, Eve Street Wetland and Marsh Street Wetland are located in alluvium, on the fringe of an area where there may be water table decline when steady state has been reached. The presence of a low permeability organic layer beneath the alluvium would restrict groundwater leakage from the alluvium. Groundwater modelling has predicted that groundwater drawdown at Tempe Wetlands located close to Alexandra Canal to be negligible. Similarly groundwater drawdown beneath Wolli Creek and Bardwell Creek and the estuarine fringe forest and mangrove forest between Wolli Creek and Wolli Creek Railway Station are predicted to be less than one metre and the impacts are unlikely to impact any GDEs that may be present. The Stotts Reserve is directly above the tunnel alignment and groundwater modelling has predicted that drawdown could be in excess of 10 metres. Trees that are partially dependent on groundwater could show signs of stress in prolonged dry periods, however the community should recover following sufficient rainfall.
- Beneath creeks groundwater and creek water could enter tunnels directly where saturated secondary structural features are hydraulically connected to the creek and aquifer through the saturated alluvium or palaeochannel sediments. Surface water can only flow to the groundwater system when the groundwater levels are lower than the surface water levels or when the alluvial water table falls below the surface water level in the creeks. In the lower catchment reaches if brackish water from the Cooks River or Wolli Creek replaces groundwater lost from the alluvium the groundwater quality may be degraded. This groundwater quality degradation is considered unlikely to be influenced by the project as the groundwater is already in hydraulic connection with the brackish tidal surface water. Higher up in the catchments any groundwater loss from the creeks to groundwater via leakage should not impact groundwater quality as the surface water would be of low salinity.
- A review of NSW DPI (Water) groundwater database within a one kilometre radius of the tunnel alignment identified 61 registered users of which half are used for water supply and irrigation. Groundwater modelling predicts that eleven bores would draw down in excess of two metres due to tunnel induced drainage. Of these wells only four are registered for water supply. In the event that groundwater users are impacted by the project by a decline in groundwater levels in existing bores, in excess of two metres, provisions are to be implemented to ‘make good’ the supply by restoring the water supply to pre-development levels. The measures taken would be dependent upon the location of the impacted bore and would be confirmed during detailed design in consultation with the affected licence holder. Measures could include, deepening the bore, providing a new bore, lowering the pump, providing an alternative water supply or appropriate monetary compensation.
- A groundwater and surface water quality monitoring program is to be prepared and implemented to monitor groundwater and surface water impacts during tunnel operations on groundwater quality and wetlands. The program shall be developed in consultation with the EPA, DPI (Fisheries), DPI (Water) and relevant councils. The existing groundwater monitoring network will be utilised.
- At Alexandria Landfill leachate is continually being generated and has the potential to leak into the tunnel infrastructure. A new leachate treatment plant would be commissioned as part of the project. Operation of the pumping system would cause groundwater to flow into landfill away from the tunnel infrastructure reducing the risk of water entering the tunnel infrastructure. A backup leachate pumping system should also be installed to increase margin of safety. Installation of a cut-off wall around the southern perimeter of the landfill and capping of the landfill will reduce leachate generation.

Table of Contents

List of Tables

List of Figures

This page has been left blank intentionally.

Glossary of Terms

Term	Definition
Aeolian	Clays, silts and sands that have been deposited by wind
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.
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.
Arterial roads	The main or trunk roads of the State road network.
Australian Height Datum (AHD)	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.
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.
Catchment	The area from which a surface watercourse or a groundwater system derives its water.
Clearing	The removal of vegetation or other obstacles at or above ground level.
Construction Environmental Management Plan	A site specific 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.
Cumulative impacts	Combination of individual effects of the same kind due to multiple actions from various sources over time.
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.
Drainage	Natural or artificial means for the interception and removal of surface or subsurface water.
Earthworks	Operations involved in loosening, excavating, placing, shaping and compacting soil or rock.
Ecology	The study of the relationship between living things and the environment.
Ecologically sustainable development (ESD)	As defined by the *Protection of the Environment Administration Act 1991*, 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).

Term	Definition
Ecosystem	As defined in the *Environment Protection and Biodiversity Conservation Act 1999*, an ecosystem is a 'dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.'
Endangered ecological community (EEC)	An ecological community identified by the *Threatened Species Conservation Act 1995* 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.
Electrical Conductivity (EC)	A unit of measurement for water salinity. One EC equals one micro –Siemen per centimetre (µS/cm) measured at 25^{o}C
Emission	The discharge of a substance into the environment.
Environmental Management Plan (EMP)	A plan used to manage environmental impacts during each phase of project development. It is a synthesis of proposed mitigation, management and monitoring actions, set to a timeline with defined responsibilities and follow up actions.
Environmental management system (EMS)	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 Protection & Assessment Act, 1979*, all aspects of the surroundings of humans, whether affecting any human as an individual or in his or her social groupings.
Ephemeral	Existing for a short duration of time.
Environment Protection Licence	Environment Protection Licences (EPLs) are issued by EPA under the *Protection of the Environment Operations Act 1997*. EPLs with respect to scheduled development work or scheduled activities or non-scheduled activities may regulate all forms of pollution (including water pollution) resulting from that work or those activities. EPLs authorising or controlling an activity carried on at any premises may also regulate pollution resulting from any other activity carried on at the premises to which the licence applies. .
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.
Groundwater	Water located within an aquifer, that is, held in the rocks and soil in interconnected pores located beneath the water table .
Groundwater Dependent Ecosystems (GDEs)	Groundwater dependent ecosystems are communities of plants, animals and other organisms whose extent and life processes are dependent on groundwater.
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).

Term	Definition
Groundwater Treatment Plant	A treatment plant to treat groundwater for the operational phase of the project. This differs from the water treatment plants which will be temporary during the construction phase and treat captured surface water and groundwater.
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
Hydrocarbon	Any organic compound — gaseous, liquid or solid — consisting only of carbon and hydrogen.
Hydraulic conductivity	The rate at which water of a specified density and kinematic viscosity can move through a permeable medium (notionally equivalent to the permeability of an aquifer to fresh water)
Hydraulic gradient	The change in total groundwater head with a change in distance in a given direction, which yields a maximum rate of decrease in head.
Hydrogeology	The study of subsurface water in its geological context.
Hydrology	The study of rainfall and surface water runoff processes.
Impact	Influence or effect exerted by a project or other activity on the natural, built and community environment.
Local road	A council controlled road which provides for local circulation and access.
Perched Water	Unconfined groundwater held above the water table by a layer of impermeable rock or sediment.
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.
Portal	Entrance to a tunnel.
Project Area	Shown on Figure 1
Proposed development	The WestConnex New M5 project as described in Chapter 5 and Chapter 6 of the environmental impact statement.
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.
Reference Design	The Project design and alignment as outlined by WestConnex at the commencement of the impact assessment prior to the acceptance of the preferred Tenderers Design.
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.
Run-off	The portion of water that drains away as surface flow.

Term	Definition
Salinity	The concentration of ~~sodium chloride or~~ 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.
Sensitive receiver	A location where a person works or resides, including residential, hospitals, hotels, shopping centres, play grounds, recreational centres or similar.
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.
Surface water	Water flowing or held in streams, rivers and other wetlands in the landscape.
Tributary	A river or stream flowing into a larger river or lake.
Tunnel portal	The entry / exit structures at each end of a tunnel.
Vulnerable	As defined under the *Threatened Species Conservation Act 1995*, a species that is facing a high risk of extinction in New South Wales in the medium-term future.
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 natural or artificially regulated (not necessarily permanent).

Acronyms

Acronym	Term/ Definition
AECOM	AECOM Australia Pty Ltd
AHD	Australian Height Datum
AIP	Aquifer Interference Policy, 2012
ALS	Australian Laboratory Services
ANZECC	Australian and New Zealand and Conservation Council
ASS	Acid Sulfate Soil
ASSMP	Acid Sulfate Soil Management Plan
BoM	Bureau of Meteorology
BTEXN	Benzene, Toluene, Ethylbenzene, Xylene, Naphthalene
CBD	Central Business District.
CEMP	Construction Environmental Management Plan
DADI	Dial a Dump Industries Pty Ltd
DLWC	NSW Department of Land and Water Conservation, precursor to DPI (Water)
DPI	Department of Primary Industries, which contains a number of division including the DPI (Water).
DPI (Water)	Department of Primary Industries (Water), formerly NSW Office of Water
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	Environmental Protection Authority
EPL	Environmental Protection License
ESA	Environmental Site Assessment
GDEs	Groundwater Dependent Ecosystems
GGBF	Green and Golden Bell Frog
GWTP	Groundwater Treatment Plant

Acronym	Term/ Definition
LCMP	Landfill closure management plan
LGA	Local Government Area.
NATA	National Association of Testing Authorities
NSW EPA	NSW Environment Protection Authority
NoW	NSW Office of Water, now DPI (Water)
OEH	NSW Office of Environment and Heritage
OEMP	Operations Environmental Management Plan
O&M	Operations and Maintenance
PAH	Hydrocarbons – Poly Aromatic Hydrocarbons
PASS	Potential Acid SulfateSoil
POEO	Protections of the Environment Operations Act (1997)
RH	Road Header
SEARs	Secretary's Environmental Assessment Requirements
SWTC	Scope of Works and Technical Criteria
SEPP	State Environment Planning Policy.
SMPO	Sydney Motorways Project Office.
SWL	Standing Water Level
TBM	Tunnel Boring Machine
TDS	Total Dissolved Solids
TPH	Total Petroleum Hydrocarbons
TRH	Total Recoverable Hydrocarbons
TWA	Trade Waste Agreement
WDA	WestConnex Delivery Authority
WTP	Water Treatment Plant

1.0 Introduction

Roads and Maritime Services (Roads and Maritime) is proposing the construction and operation of the New M5 (the project); which would comprise a new, tolled multi-lane road link between the M5 East Motorway east of King Georges Road and St Peters. The project would also include an interchange at St Peters and connection to the existing road network. The project is shown in Figure 1-1.

Approval is being sought under Part 5.1 of the Environmental Planning and Assessment Act 1979 (EP&A Act). The project is declared to be State significant infrastructure (SSI) under section 115U(2) of the EP&A Act by reason of the operation of clause 14 and Schedule 3 of the *State Environmental Planning Policy (State and Regional Development) 2011*. Accordingly, the project is subject to assessment under Part 5.1 of the EP&A Act and requires the approval of the Minister for Planning. An environmental impact statement (EIS) is therefore also required.

Roads and Maritime is seeking the project to be declared by the Minister for Planning as State significant infrastructure and critical State significant infrastructure under sections 115U(4) and 115V of the EP&A Act.

On 11 August 2015, the Commonwealth Minister for the Environment determined that the project has the potential to significantly impact on a matter of national environmental significance and is therefore a ‘controlled action’. This means that approval of the project will be required from the Commonwealth Minister for the Environment in addition to environmental and planning approvals required under State legislation.

Under the Bilateral Agreement relating to environmental assessment (February 2015) between the Commonwealth Government and the NSW Government, this EIS has been adopted for the purpose of meeting the assessment requirements of both the Commonwealth EPBC Act and the NSW EP&A Act.

This technical working paper identifies and assesses the potential groundwater impacts associated with construction and operation of the project and supports the EIS for the project.

1.1 Overview of WestConnex

WestConnex is a 33 kilometre motorway that is intended to link Sydney’s west with the airport and the Port Botany precinct. The component projects of the WestConnex program of works are:

- M4 Widening – Pitt Street, Parramatta to Homebush Bay Drive, Homebush (planning approval granted on 21 December 2014 and under construction)
- M4 East – Homebush Bay Drive, Homebush to Parramatta Road and City West Link (Wattle Street) at Haberfield (planning application lodged and subject to planning approval)
- New M5 – (the subject of this EIS)
- King Georges Road Interchange Upgrade (planning approval granted on 3 March 2015 and under construction)
- M4-M5 Link – Haberfield to St Peters (undergoing concept development and subject to planning approval)
- Sydney Gateway (is the subject of further investigations by the NSW Government and would be subject to separate planning approval).

Separate planning applications have or will be lodged for each component project. Each project will be assessed separately, but the impact of each project will also be considered in the context of the wider WestConnex program of works.

A proposed Southern extension from Arncliffe to Kogarah is currently being investigated by the NSW Government, and would connect the New M5 to the southern and bayside suburbs of Sydney, and the proposed F6 motorway.On 1 October 2015 the transfer of the project delivery functions of WDA to Sydney Motorway Corporation (SMC) was finalised, forming a single decision-making entity to finance and deliver the WestConnex program of works. SMC is a private corporation, the shareholders of which are the Minister for Roads, Maritime and Freight and the Treasurer, with a majority independent board of nine directors.

Roads and Maritime is the Government client agency for the WestConnex program of works. In that capacity Roads and Maritime will enter into contractual arrangements with SMC subsidiary entities which will design, build, own and operate the motorway on behalf of Roads and Maritime. Roads and Maritime and SMC are working together to manage the planning approval process for the project. However, for the purpose of the planning application for the project, Roads and Maritime is the proponent.

1.2 Overview of the project

Key components of the project would include:

- Twin motorway tunnels between the existing M5 East Motorway (between King Georges Road and Bexley Road) and St Peters. The western portals along the M5 East Motorway would be located east of King Georges Road, and the eastern portals at St Peters would be located in the vicinity of the Princes Highway and Canal Road. Each tunnel would be about nine kilometres in length and would be configured as follows:
    - Between the western portals and Arncliffe, the tunnels would be built to be three lanes but marked for two lanes as part of the project. Any change from two lanes to three lanes would be subject to future environmental assessment and approval
    - Between the Arncliffe and St Peters, the tunnels would be built to be five lanes but marked for two lanes as part of the project. Any change from two lanes to any of three, four or five lanes would be subject to future environmental assessment and approval
- The western portals along the M5 East Motorway would be located east of King Georges Road, and the eastern portals at St Peters would be located in the vicinity of the Princes Highway and Canal Road
- Tunnel stubs to allow for a potential future connection to the M4-M5 Link and a potential future connection to southern Sydney
- Surface road widening works along the M5 East Motorway between east of King Georges Road and the new tunnel portals
- A new road interchange at St Peters, which would initially provide road connections from the main alignment tunnels to Campbell Road and Euston Road, St Peters
- Two new road bridges across Alexandra Canal which would connect St Peters interchange with Gardeners Road and Bourke Road, Mascot
- Closure and remediation of the Alexandria Landfill site, to enable the construction and operation of the new St Peters interchange
- Works to enhance and upgrade local roads near the St Peters interchange
- Ancillary infrastructure and operational facilities for electronic tolling, signage (including electronic signage), ventilation structures and systems, fire and life safety systems, and emergency evacuation and smoke extraction infrastructure
- A motorway control centre that would include operation and maintenance facilities
- New service utilities and modifications to existing service utilities
- Temporary construction facilities and temporary works to facilitate the construction of the project
- Infrastructure to introduce tolling on the existing M5 East Motorway
- Surface road upgrade works within the corridor of the M5 South West Motorway and M5 East Motorway.

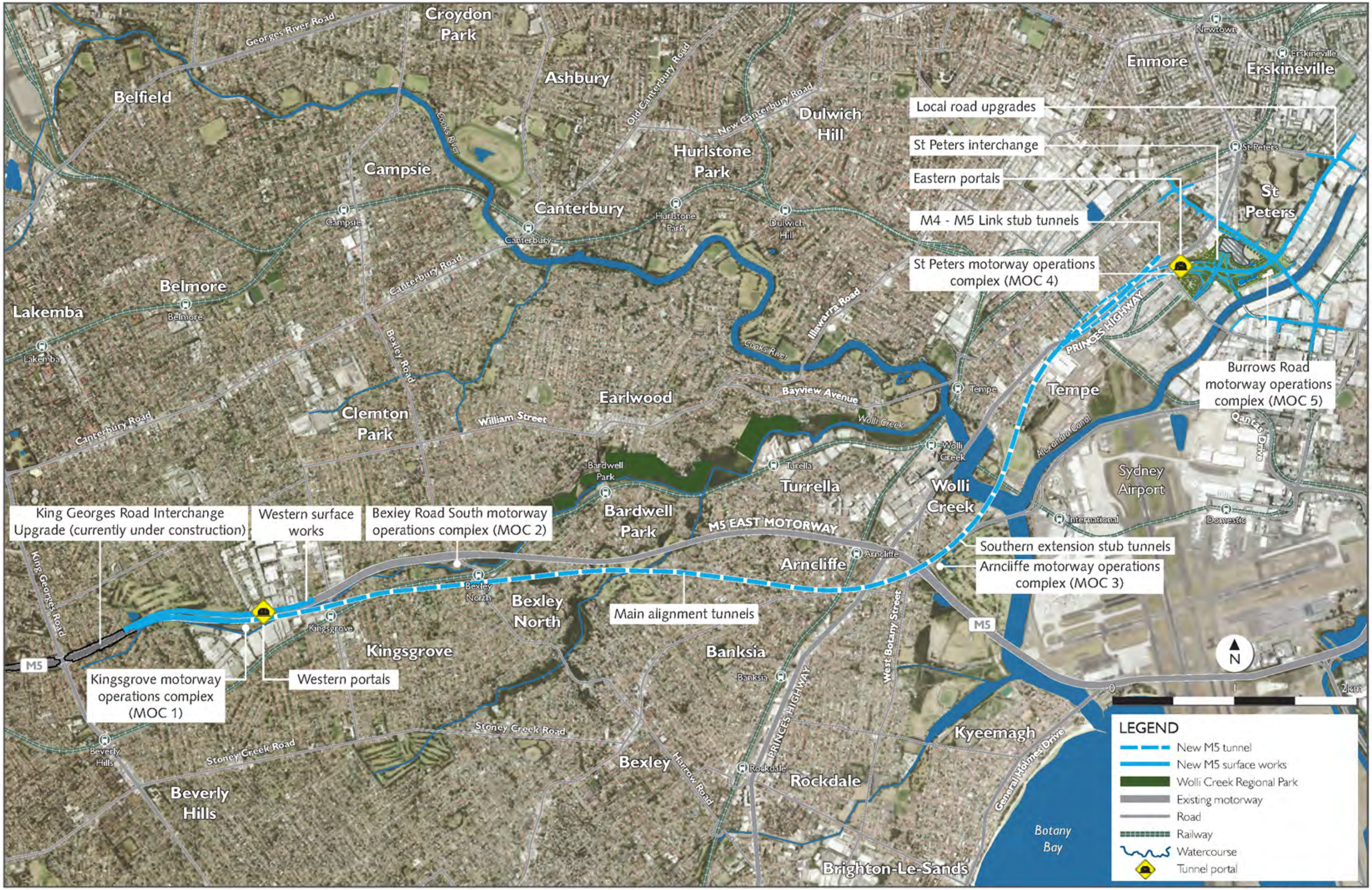


Figure 1-1 Key features of the project

Construction activities associated with the project would generally include:

- Commencement of enabling and temporary works, including construction power, water supply, ancillary site establishment, demolition works, property and utility adjustments and public 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 control centre and ancillary operations buildings
- Upgrades to surface roads and construction of bridges
- Implementation of environmental management and pollution control facilities for the project.

Subject to the project obtaining environmental planning approval, construction of the project is anticipated to commence around mid-2016 and is expected to take around three years to complete.

The M5 Motorway corridor (the M5 East Motorway and the M5 South West Motorway) is the main passenger, commercial and freight corridor between Port Botany, Sydney Airport and south-west Sydney. Traffic demands on the M5 East Motorway currently exceed the design capacity of the roadway, and as a result, present a bottleneck to the M5 Motorway corridor with motorists experiencing heavy congestion and unreliable journey times. The project is needed to provide additional capacity along the M5 Motorway corridor, and would allow for a more robust and reliable transport network.

1.3 Project location

The project would be located within the Canterbury, Hurstville, Rockdale, Marrickville, Sydney and Botany Bay local government areas. The project corridor is located from about five to twenty kilometres to the south and south-west of the central business district of Sydney. The project would traverse the suburbs of Beverly Hills, Kingsgrove, Bexley North, Earlwood, Bardwell Park, Bardwell Valley, Arncliffe, Wolli Creek, Tempe, Sydenham, St Peters, Alexandria and Mascot.

1.4 Secretary’s Environmental Assessment Requirements

The Secretary’s Environmental Assessment Requirements (SEARs) were issued for the project by the NSW Department of Planning and Infrastructure on the 5 March 2015, and re-issued on 26 August 2015.The SEARs relating to hydrogeological impacts and where these requirements have been addressed in this report are summarised in Table 1.

Table 1 Relevant Secretary's Environmental Assessment Requirements

Secretary’s Environmental Assessment Requirement	Section addressed
Soil, Water and Hydrology	
An assessment of groundwater impacts (including ancillary facilities such as the tunnel control centre and any deluge systems), considering local impacts along the length of the tunnels and impacts on local and regional hydrology including consideration of any Water Sharing Plan and impacts on groundwater flow. The assessment must consider: - Extent of drawdown; - Impacts to groundwater quality; - Volume of groundwater that will be taken (including inflows); - Discharge requirements; - Location and details of groundwater management and implications for groundwater dependent surface flows; - Groundwater-dependent ecological communities; - Groundwater users.	Chapter 6 (construction) and Chapter 7 (operation)

Secretary's Environmental Assessment Requirement	Section addressed
Soil, Water and Hydrology	
The assessment must include details of proposed surface and groundwater monitoring and be prepared having consideration to the requirements of the *NSW Aquifer Interference Policy*.	Chapter 9 (Management and mitigation measures)
Contaminated Sites	
An assessment of the potential intersection of contaminated bed sediments in the Alexandra Canal and interception of contaminated water from the Botany Sand Beds aquifer	Chapter 6 (construction) and Chapter 7 (operation)

1.5 Study area

For the purposes of this technical working paper, the project corridor is defined by the alignment of the project with a buffer of one kilometre.

1.6 Groundwater legislation and policy framework

Groundwater in NSW is managed by the Department of Primary Industries (Water) (DPI (Water)) under the *Water Act 1912* and the *Water Management Act 2000*. The *Water Management Act 2000* is gradually replacing the planning and management frameworks in the *Water Act 1912* although some provisions of the *Water Act 1912* remain in operation. The *Water Management Act 2000* regulates water use for rivers and aquifers where water sharing plans have commenced, while the *Water Act 1912* continues to operate in the remaining areas of the State. The *Aquifer Interference Policy* (NoW, 2012) explains the process of administering water policy under the *Water Management Act 2000*.

The project corridor 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 corridor is subject to the rules of the Sydney Basin Central and Botany Sands. Of particular interest to the project, the rules of Sydney Basin Central Groundwater Source and Botany Sands Groundwater Source outline the management 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 Botany Sands Groundwater Source rules also refer to exclusion zones around contaminated industrial areas (Management Zone 1) where groundwater is prohibited to be pumped, although these are not in the vicinity of the project corridor.

The *NSW Government Groundwater Policy Framework Document* (Framework Document) (Department of Land and Water Conservation (DLWC), 1997) aims to manage the State's groundwater resources to sustain their environmental, social and economic uses. The policy has three component parts:

- The *NSW Groundwater Quality Protection Policy* (DLWC, 1998)
- The *NSW Groundwater Dependent Ecosystems Policy* (DLWC, 2002)
- The *NSW Groundwater Quantity Management Policy* (DLWC, undated).

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

- ANZECC/ARMCANZ National Water Quality Management Strategy Australian Guidelines for Fresh and Marine Water Quality.
- NSW Government. *Protection of the Environment Operations Act No 156.* 1997.
- *Water Management Act 2000*
- NSW *Aquifer Interference Policy*.

Minimum impact considerations as required under the *Aquifer Interference Policy* are outlined in Chapter 9 of this hydrogeological assessment.

1.7 Report Structure

This report is structured as follows:

- **Chapter 1 – Introduction**.
- **Chapter 2 – Methodology**. This chapter describes the methodology undertaken for the impact assessment.
- **Chapter 3 – Existing environme**nt. This chapter describes the existing environment prior to project commencement.
- **Chapter 4 – Field investigations**. This chapter describes the field investigation methodologies and observations.
- **Chapter 5 – The project**. This chapter describes the project and the components that relate to groundwater.
- **Chapter 6 – Impact assessment (construction)**. This chapter describes the potential impacts to groundwater inflow, groundwater drawdown and groundwater quality resulting from the proposed project, during the construction.
- **Chapter 7– Impact assessment (operation)**. This chapter describes the potential impacts to groundwater inflow, groundwater drawdown and groundwater quality resulting from the proposed project, during the on-going operations.
- **Chapter 8 – Mitigation and management measures**. This chapter provides a summary of environmental safeguards, mitigation, management and monitoring responsibilities in relation to groundwater impacts for the project.
- **Chapter 9 – NSW Aquifer Interference Policy Considerations**. This chapter describes how the project complies with the NSW Aquifer Interference Policy.
- **Chapter 10 – Conclusions**. This chapter summarises the outcomes of the groundwater impact assessment.
- **Chapter 11 – References**.

1.8 Limitations

AECOM Australia Pty Ltd does not represent that the information or interpretation contained in this report addresses all of the existing features, as-built construction, subsurface conditions or ground behaviour on the subject site. This is because the ground is a product of continuing natural and man-made processes and therefore exhibits characteristics and properties which vary from place to place and can change with time. A hydrogeological assessment involves the gathering and assimilating of the limited facts about these characteristics and properties in order to better understand or predict the behaviour of the hydrogeological regime on a particular site for certain conditions.

The facts reported in this document may have been obtained by inspection, excavation, probing, sampling, testing or other means of investigation. They are directly relevant only to the hydrogeological unit at the place where and time when the investigation was carried out and are believed to be reported accurately. Any interpretation or recommendation given in this report is based on judgement and experience and not on greater knowledge of the facts than the reported investigation may imply.

2.0 Methodology

This chapter outlines the methodology for the hydrogeological impact assessment as presented in this technical working paper.

This assessment has been prepared as follows:

- Identification of the existing environment based on a desktop assessment of existing studies and data relevant to the project corridor, including:
  - Database searches conducted as part of the assessment;
  - Review of previous studies.
- A review of field investigations completed for the project to further inform the impact assessment, which included the collection of:
  - Historical and existing groundwater levels;
  - Groundwater quality;
  - Hydraulic conductivity;
  - Storativity.
- Development of a three dimensional calibrated numerical groundwater model to calculate groundwater inflow to the tunnels and caverns and predict groundwater drawdown along the project alignment.
- An impact assessment that includes:
  - Assessment of predicted groundwater inflows during the construction and operation of the project.
  - Assessment of groundwater drawdown during the construction and operation of the project within one kilometres radius of the project, and the associated potential impacts on registered groundwater bores and groundwater dependent ecosystems.
  - Assessment of the impact of the tunnel on nearby surface water features as a result of impacts to groundwater
- An outline of appropriate mitigation and management measures to eliminate or reduce the risk posed by the potential impact to the groundwater regime.
- Presentation of a proposed future groundwater monitoring framework with consideration of the requirements of the *NSW Aquifer Interference Policy*.

2.1 Desktop assessment

2.1.1 Database searches

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

- Australian Soils Resource Information System acid sulfate soils, accessed May 2015;
- BoM 2015 Australian Groundwater Explorer, (formerly DPI (Water) groundwater database) accessed 2 June 2015 and Pinneena Groundwater Database, version 10.1, dated October 2014;
- Appendix 4 of the Greater Metropolitan Regional groundwater Sources Water Sharing Plan;
- BoM 2015 Atlas of Groundwater Dependent Ecosystems, accessed May 2015;
- BoM 2015 On-line climate data, accessed 30 April 2015;
- NSW EPA Contaminated Land Record;
- M5 East Motorway development;
- Environmental and re-development projects at Alexandria Landfill;
- New Southern Railway Project.

2.1.2 Review of previous studies

In preparing the back ground for this report data were extracted from the following reports:

- AECOM, 2014; The New M5 State significant infrastructure application report. Prepared for WestConnex Delivery Authority, dated November 2014.
- AECOM, 2015a; WestConnex Stage 2: M5 Geotechnical Investigation – Report of Completed Work. Report – WCX2-00-2000-GT-009, Prepared for WestConnex Delivery Authority, dated 27 March 2015
- AECOM, 2015b, WestConnex Stage 2 M5 Hydrogeological Investigation – Groundwater Drilling and preliminary Monitoring Progress Report – WCX2-00-2000-GT-010A, 27 March 2015.
- AECOM, 2015c, WestConnex Stage 2 M5 Landfill Closure Plan – Groundwater Drilling and preliminary Monitoring Progress Report – WCX2-00-2000-GT-010A, 27 March 2015.
- Chapman and Murphy, 1989; Soil Landscapes of the Sydney 1:100,000 Sheet report, Department of Conservation and Land Management, Sydney.
- Chapman GA, Murphy CL, Tille PJ, Atkinson G and Morse RJ (2009) Ed. 4, Soil Landscapes of the Sydney 1:100,000 Sheet map. Department of Environment, Climate Change and Water, Sydney.
- Coffey Geotechnics (2012). Geotechnical Interpretative Report. North West Rail Link. Transport for NSW. Dated 18 May.
- Cooks River Alliance (2014) Cooks River Alliance Annual Report 2012-2013. http://cooksriver.org.au/wp-content/uploads/Annual-Report-2012_2013_final v2.pdf. Accessed 27 August 2014
- Hem J.D., 1992; Study and Interpretation of the Chemical Characteristics of Natural Water. United States Geological survey Water-Supply Paper 2254. Third Edition.
- Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition. Geological Survey of New South Wales, Sydney.
- Woodward Clyde, 1997; Further Investigations, Albert Street Disposal Depot, St Peters. AGC Woodward Clyde Pty Ltd, July 1997.

2.2 Field investigation

A field program was conducted by AECOM to collect baseline data as follows:

Monitoring well installation

The New M5 drilling program was conducted between September 2014 and March 2015. During the geotechnical drilling program, 28 selected boreholes were converted to monitoring wells. 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.

To construct the monitoring wells a three metre screen was installed opposite the interval of interest and graded gravel installed in the annulus around the screen, extending to one metre above and below the screen. One metre thick bentonite seals were installed either side of the gravel pack and at the ground surface to reduce the risk of surface water ingress. The remainder of the borehole annulus was infilled with grout. In some cases the base of the borehole was infilled with grout up to two metres below the level that the well screen was to be installed. 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.

Packer tests

Packer tests or in-situ water pressure tests were conducted on selected boreholes to calculate the average hydraulic conductivity of the tested interval during the drilling program. The packer testing involves hydraulically isolating an interval up to ten 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 analysis is based on the flow of water into the isolated section being proportional to the hydraulic conductivity. The packer test results were interpreted in accordance with the British Standards and Houlsby (1976).

Groundwater gauging

Groundwater gauging was conducted throughout the field program measuring standing water levels manually with an electronic dipper on various dates since November 2014. Data loggers were installed in each of the 39 monitoring wells after well development. The data loggers were installed to measure groundwater level fluctuations automatically on a two hour interval. The loggers were suspended in each borehole at a depth of approximately five metres below the standing water level. Once collated the data are presented in hydrographs and compared to daily rainfall measured at Sydney Airport (Appendix D).

Groundwater sampling and hydrogeochemical analysis

Groundwater samples were collected from 22 monitoring wells for laboratory analysis (AECOM, 2015d). Analytes included: heavy metals and metalloids (arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel and zinc), total recoverable hydrocarbons (TRH), benzene, toluene, ethylbenzene, xylene and naphthalene (BTEXN), polycyclic aromatic hydrocarbons (PAHs), inorganics (including major anions and cations, alkalinity, ammonia, electrical conductivity, ionic balance, total dissolved solids, pH and hardness), organochlorine pesticides (OCPs), organophosphate pesticides (OPPs), semi volatile organic hydrocarbons (SVOCs) and volatile organic compounds (VOCs).

The monitoring wells were sampled using low flow sampling or a hydrasleeve™. A hydrasleeve™ was used where the groundwater level was too deep for low flow sampling. During low flow sampling water discharge water was directed through a flow cell and was sampled once the field parameters being monitored had stabilised to within five per cent. Field parameters of dissolved oxygen, electrical conductivity, pH, temperature and redox conditions were measured during sampling. A hydrasleeve™ is a no purge groundwater sampling device that was installed in each monitoring well opposite the screen and allowed to equilibrate for a week prior to retrieving and sampling. All groundwater sampling followed well development conducted at least one week prior to sampling.

2.2.1 Groundwater monitoring network

A groundwater monitoring network was constructed as part of the WestConnex hydrogeological investigations between October 2014 and March 2015 (AECOM, 2015a). Twenty eight (28) monitoring wells were constructed at selected locations along the New M5 alignment. The majority of monitoring wells target the Hawkesbury Sandstone (21). Five wells target the Wianamatta Shale (Ashfield Shale, Rouse Hill Siltstone and Regentville Siltstone), one targets alluvial and estuarine sediments and one targets a basalt dyke. The location of the monitoring wells is shown on Figure 2-1. All monitoring wells were completed with a three metre well screen installed opposite the expected tunnel zone to depths up to 85 metres (BH143, Bardwell Valley). Monitoring well construction details are summarised in Table A1.

Groundwater data have also been drawn from other sources and major developments in the area including:

- Registered groundwater bore information was obtained from the NSW Department of Natural Resources, NSW Natural Resource Atlas online database (http://www.nratlas.nsw.gov.au/)
- Environmental and re-development projects at Alexandria Landfill
- M5 East Motorway
- Sydney Airport Line.

Collectively, this information has been used to identify the following:

- Existing groundwater levels and changes with time
- Groundwater quality
- Hydraulic conductivity.

A summary of these results is presented in Chapter 4

2.3 Groundwater numerical modelling

A three dimensional numerical groundwater model has been developed to simulate existing groundwater conditions. By simulating the proposed tunnel alignments the groundwater model has also been used to predict future groundwater conditions and impacts related to the project.

The groundwater model has been prepared by CDM Smith Australia Pty Ltd (CDM Smith, 2015). The groundwater modelling report describing the model design, parameters, grid, hydraulic boundaries and assumptions is provided in Appendix A. A summary of the groundwater model development is provided below.

2.3.1 Groundwater model development methodology

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

- 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 modelling plan
- Development of a hydrogeological conceptual model
- Model development including setting model boundaries, layers, model discretisation and selection of interfaces to simulate surface water bodies and the interaction with groundwater
- Model calibration
- Sensitivity analysis
- Model predictions.

The numerical groundwater model was developed using MODFLOW-USG released in 2012. This version of MODFLOW was selected as it allows local grid refinement and is suited to simulating linear features such as tunnels. The model was developed in steady state conditions rather than transient analysis. As a result the predictions of inflows and drawdowns are those that would apply in the long term, after equilibrium has been established. That is once the new equilibrium is reached water is flowing through the system from boundary to boundary without taking water from storage. It is not known how long it would take for steady state conditions to be established.

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

The groundwater model for the project applied:

- Prescribed head boundary conditions at the coastline and along tidal rivers.
- Drain boundary conditions (with conductances) for tunnels.
- Evapotranspiration (ET or EVT) boundary conditions along drainage lines.
- Horizontal and vertical hydraulic conductivities for alluvium, shale and sandstone.

Rates of flow from rivers to project tunnels in the model is 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. The hydraulic conductivity values were estimated during the process of model calibration by a combination of trial and error and applying the Parameter Estimation (PEST) module.

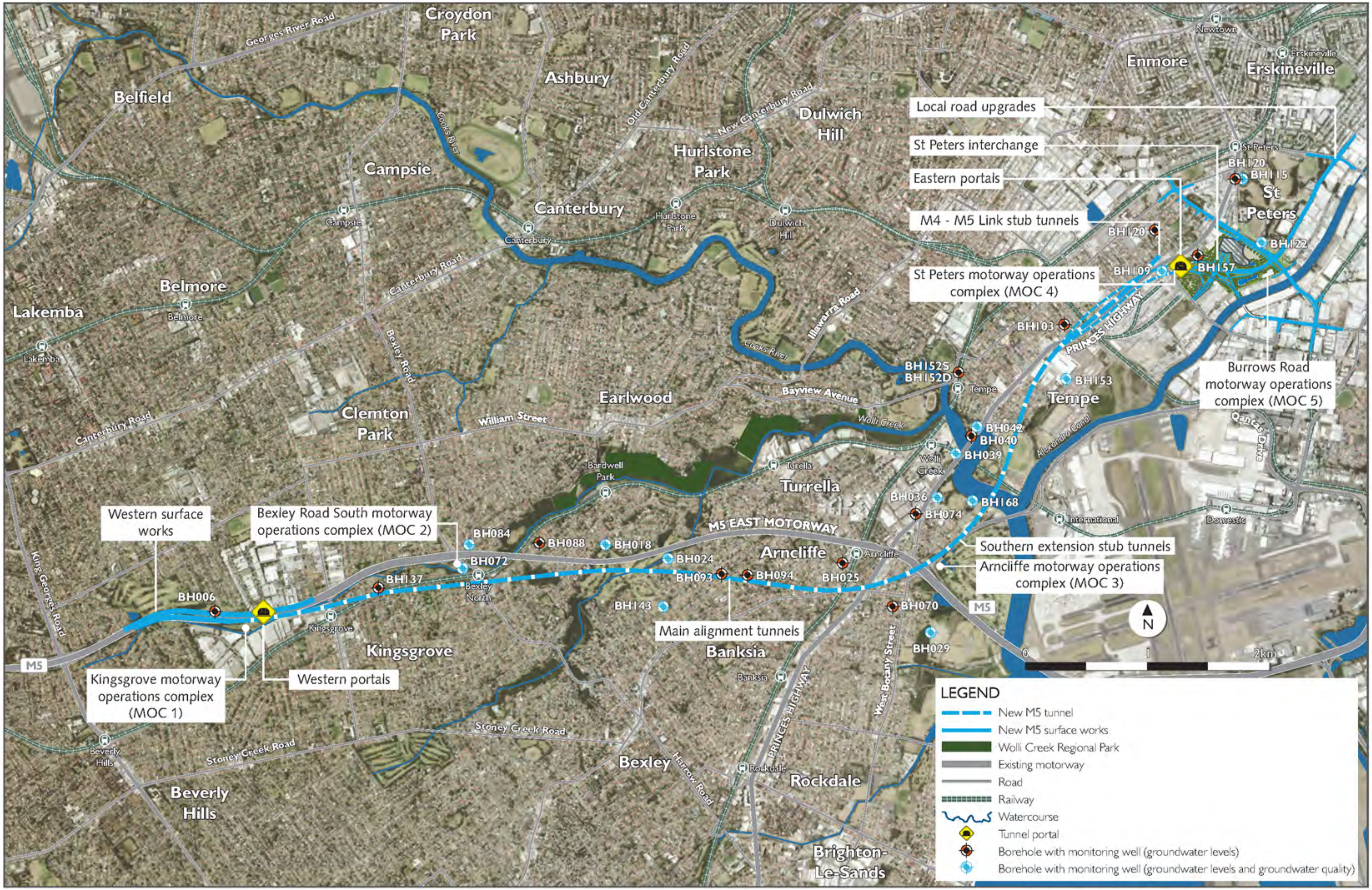


Figure 2-1 Groundwater monitoring network

2.3.2 Assumptions

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

- Surface water in the Cooks River, Alexandra Canal and Wolli Creek would control groundwater levels and prevent large scale lowering of the water table
- The hydrogeological properties used in the model are based on bulk average hydrogeological properties derived from desktop properties and packer test data
- The vertical hydraulic conductivity within the Hawkesbury Sandstone (K_v) is considerably lower than the horizontal hydraulic conductivity (K_h) typically by between one and four orders of magnitude due to the horizontal bedding
- 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 AHD
- The New M5 main alignment tunnels are mostly below sea level and thus groundwater gradients from the surface water bodies will be towards the tunnels
- Rainfall recharge has been applied to the upper most layer at a constant rate
- The model has been prepared primarily as a steady state model
- Other major existing tunnel infrastructure that may influence model simulations including the Sydney Airport Line tunnel and the M5 East Motorway tunnels have been simulated in the model
- The New M5 tunnels have been simulated as strings of contiguous cells of approximately the same diameter as the tunnel, linked through the tunnel centreline
- Groundwater drawdown and inflows were induced by prescribing a target head and conductance above the tunnel and using K_h data from the packer test data.
- In the tunnel zone between Bexley North and Arncliffe where the tunnels would be duplicated by the existing M5 East Motorway groundwater inflows will be restricted due to drainage loss to the M5 East Motorway.

2.3.3 Modelling objectives

The numerical groundwater model has been developed and calibrated to simulate the existing hydrogeological regime within the alluvium associated with the creeks and rivers, Botany Sands, Ashfield Shale and Hawkesbury Sandstone and infrastructure including the Sydney Airport Line and existing M5 East Motorway tunnels.

The modelling objectives are to:

- Predict groundwater inflow into the tunnel during construction and long term during the operations phase;,
- Predict groundwater drawdown around the tunnel due to drainage into the tunnel during construction and long term during the operations phase
- Predict the impacts to nearby registered groundwater users and groundwater dependent ecosystems.

3.0 Existing Environment

This chapter provides an overview of the existing natural and built environment within the project corridor based on the desktop assessment.

3.1 Existing major infrastructure

The project corridor transects an urban environment that consists of established industrial, commercial, recreational and residential areas. In some areas land-uses have changed over the years as the city has expanded or former industrial sites have been re-zoned. Consequently there is major infrastructure that has deep foundations that may influence the project or local hydrogeological regime. This includes the Alexandria Landfill, M5 East Motorway tunnels, the Sydney Airport Line tunnels and golf courses. These features are described further below and shown on Figure 3-1.

Alexandria Landfill

The Alexandria Landfill is a former quarry where weathered shale and clay was excavated for brickmaking. During the quarry development the Botany Sands were intersected as the quarry expanded to the south which caused groundwater to flow into the quarry. The landfill located at 10-16 Albert Road St Peters extends over an area of 15.7 hectares and is excavated to a maximum base level of around -31 metres AHD. The former quarry has operated as a landfill since 1988 and as a recycling and as a recycling and waste transfer station to date. Leachate is generated within the Site and is collected and treated via the existing onsite leachate management system prior to off-site discharge to sewer in accordance with the requirements outlined in the existing trade waste agreement (TWA). Surface water accumulating within the operational areas in the eastern portion of Alexandria Landfill drains to stormwater drains (with sediment control). Surface water that accumulates within the active filling area of the Alexandria Landfill collects in the leachate pond which is transferred to the leachate treatment system and is subsequently discharged to the trade waste system (sewer). Leachate is pumped daily from the internal leachate collection system from a herringbone drainage network at the base of the landfill. The leachate is pumped from a located sump in the eastern part of the site to a water treatment plant and then discharged to sewer under a trade waste agreement. The volume of leachate treated is variable and dependent on rainfall conditions. In 2015 average daily volumes of treated leachate varied from 100 kilolitres to 600 kilolitres following heavy rainfall. Groundwater was pumped from the Botany Sands from two groundwater extraction points (BS1 and BS2) to reduce leachate generation. Areas of the Alexandria Landfill that have been capped discharge to the stormwater system to nearby Alexandra Canal. The infrastructure at Alexandria Landfill is shown on Figure 3-2.

Tempe Landfill

Tempe Landfill located at 634 – 726 Princes Highway, Tempe is located around 700 metres east of the project corridor on the western side of Alexandra Canal. The former landfill is capped and closed but still generates leachate and has elevated concentrations of ammonia. Groundwater and leachate flows in a south easterly direction towards Alexandra Canal where a soil bentonite mix cut-off wall and leachate extraction and treatment system is in place to protect water quality within Alexandra Canal. A shallow ground gas interception trench and venting system is present in the north-western section of the Tempe Landfill site.

Sydney Airport

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

M5 East Motorway

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

Sydney Airport Line

The Sydney Airport Line formerly known as the New Southern Railway extends from Prince Alfred Park Redfern, for four kilometres through sandstone and then six kilometres through soft alluvial beneath Cooks River surfacing at Wolli Creek. Beneath Cooks River the tanked tunnel is situated within Cooks River palaeochannel sediments. The 10 metres diameter tunnel is supported by concrete lining through the alluvial clay and sand sediments.

Golf courses

Canterbury Golf Course, Bardwell Valley Golf Course and Kogarah Golf Course are located above the project corridor.

3.2 Rainfall and climate

Rainfall data have been obtained from Bureau of Meteorology (BoM) Station 66037 located at Sydney Airport near the eastern fringe of the project area. Rainfall has been measured at this station since 1929. Evaporation data are 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 and evaporation is summarised on Table 2. Climate data has been obtained from the hyperlink address.
http://www.bom.gov.au/jsp/ncc/climate_averages/evaporation/index.jsp

Table 2 Summary of Average Monthly Rainfall and Evaporation (mm) (Station 66037)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Rainfall	94.0	111.9	115.4	106.5	98.7	122.8	69.9	77.0	60.2	70.7	81.5	74.1	1083.7
Evaporation	160	110	140	110	70	55	70	90	110	160	180	180	1500

Rainfall is highest during late summer and early autumn peaking in February/March and lowest in winter and early spring. Evaporation is highest in November and December and lowest in June and evaporation exceeds rainfall for all months except May and June.

3.3 Topography

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

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

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

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

3.4 Surface water features

The main surface water features in the project area are the Cooks River and its tributaries, the Marsh Street and Eve Street Marsh wetlands and Landing Lights Wetland at Arncliffe. Beyond the project area is the Towra Point Wetlands, a Ramsar listed (global environmental agreement) site.

The project corridor is located within the Cooks River catchment, which covers an area of about 10,200 hectares and flows for about 23 kilometres from Graf Park in Bankstown into Botany Bay at Kyeemagh (Cooks River Alliance 2013). Wolli Creek and Alexandra Canal / Sheas Creek sub-catchments are also located within the project corridor.

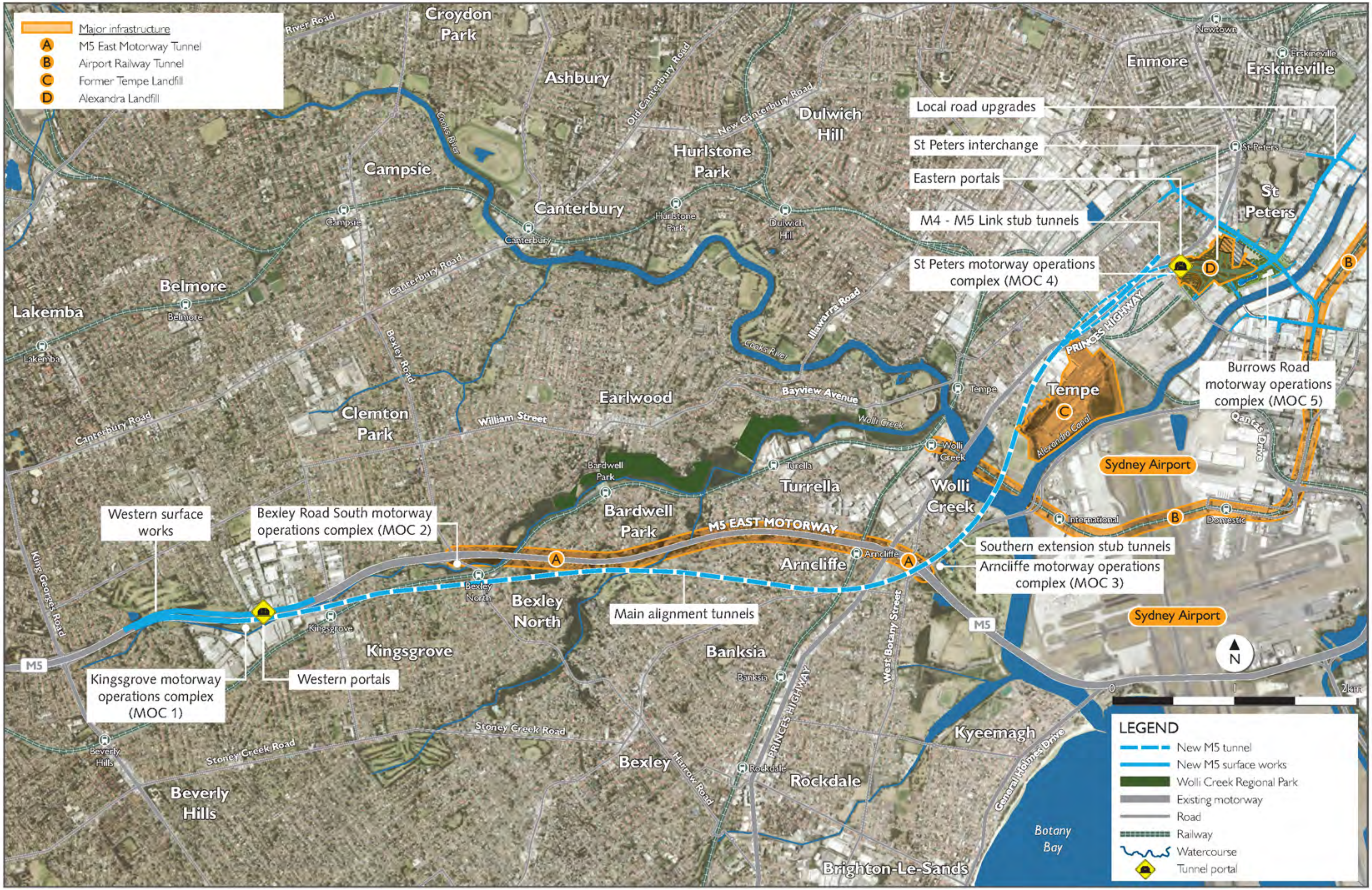


Figure 3-1 Existing major infrastructure

This page has been left blank intentionally.

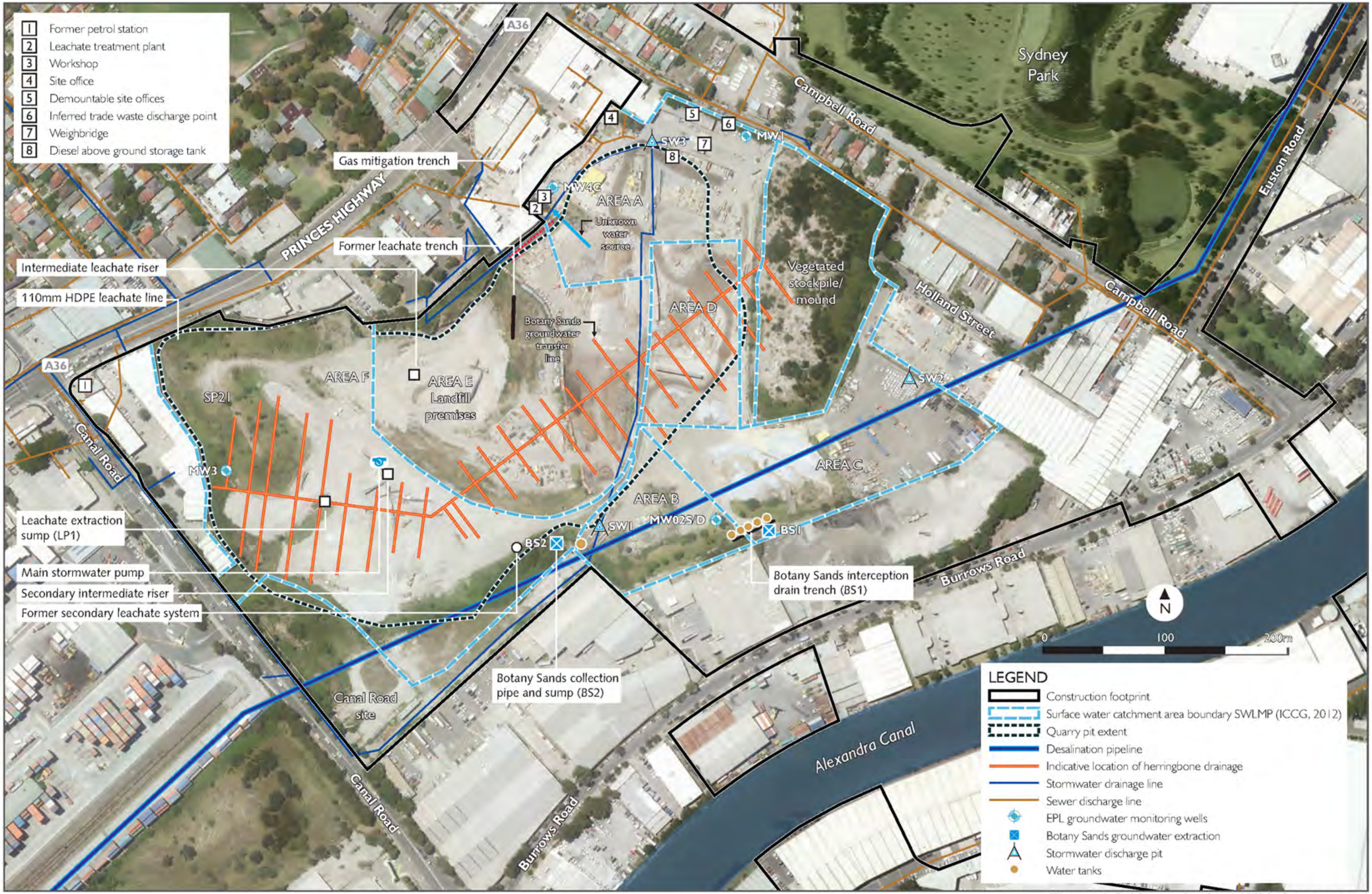


Figure 3-2 Alexandra Landfill infrastructure

3.4.1 Cooks River and tributaries

Cooks River was stripped of its natural vegetation during early European settlement and has been subject to long term anthropogenic degradation. The landscape and natural function of the catchment has been impeded by dredging and artificial channel modifications, including re-alignment.

The eight tributaries of the Cooks River are:

- Greenacre Creek.
- Cox's Creek.
- Cup and Saucer Creek.
- Fresh Water Creek.
- Bardwell Creek.
- Wolli Creek.
- Muddy Creek.
- Sheas Creek / Alexandra Canal.

Wolli Creek and Alexandra Canal / Sheas Creek sub-catchments are located within the project corridor. Wolli Creek is the largest tributary of the Cooks River. The creek runs through the Wolli Creek Valley in a north-easterly direction from Kingsgrove in the west, joining the Cooks River near Tempe.

Wolli Creek is a concrete channel for 3.5 kilometres, from its westernmost extent in the vicinity of the King Georges Road interchange to Bexley Road in the east, where the watercourse flows through a box culvert. East of Bexley Road, Wolli Creek comprises a natural streambed, which flows through Wolli Creek Valley and Wolli Creek Regional Park. Wolli Creek is joined by the Bardwell Creek tributary within Wolli Creek Regional Park on the northern side of the passenger rail line at Bardwell Park, before reaching its confluence with the Cooks River south of Wentworth Park, Wolli Creek.

Alexandra Canal is an adapted artificial waterway (formerly known as Sheas Creek), which extends for about four kilometres from Huntley Street, Alexandria in the north-west to its confluence with the Cooks River at Tempe. Alexandra Canal was built during the 1890s to provide access for water transport for the delivery of cargo (Heritage Branch 2014).

The Cooks River and its tributaries across the majority of the project area in the lower topographic areas are generally gaining streams; that is groundwater discharges from the aquifer into the stream or creek. In the upper reaches of the catchment such as Bardwell Park and Bardwell Valley the creeks are likely to be losing streams; that is water from the creeks discharges to the underlying aquifer via primary and secondary porosity features.

3.4.2 Wetlands

Marsh Street wetland was impacted by the M5 East Motorway, and remnants of the wetland remain. There is a key population of Green and Golden Bell Frogs at Arncliffe in areas within and adjacent to the Kogarah Golf Course. To mitigate the impacts of the M5 East Motorway on Marsh Street wetland, which provided habitat for the species, purpose built breeding ponds were constructed against to the golf course (known as the 'RTA ponds'). The RTA ponds are fed by stormwater and are not dependent upon groundwater.

Eve Street wetland is situated within the project corridor west of the Cooks River at Arncliffe, about two kilometres west of Sydney Airport. The marsh is listed on the directory of important wetlands in Australia and covers an area of about two hectares. The Eve Street wetland is situated on a low lying coastal floodplain and is subject to brackish tidal flows twice a day. It is identified as a marine and coastal wetland comprising intertidal mud, sand or salt flats as well as intertidal marshes. The Eve Street wetland is located in an that was once an extensive brackish marsh and is considered to be an important wetland as it is one of the first Australian examples of a rehabilitated tidal marsh that provides habitat for uncommon saltmarsh communities and for migratory wading birds and resident birds.

Landing Lights Wetland (also known as Riverine Park) is located at Spring Street Arncliffe. The wetland is around 600 metres south of the Eve Street Wetland and 400 metres west of Cooks River. The wetland is a salt marsh and is one of the remaining saline wetlands along the Cooks River that provides a habitat for many migratory birds.

The saline marshes are tidal and are periodically inundated with saline water from Cooks River and fresh water following large rainfall events. The saline nature of the marshes indicates that tidal flushing is the major water input to the marshes. The marshes are groundwater discharge areas for the alluvium. There is likely to be some leakage of saline water from the alluvium to the underlying Hawkesbury Sandstone.

The Towra Point Wetlands is an estuarine complex comprising a mixture of spits, bars, mudflats, dunes and beaches located around 6.8 kilometres south of the project corridor. The Towra Point Wetlands are a sufficient distance and across Botany Bay from the project corridor to be outside the range of impact and would not be considered further in the impact assessment.

3.5 Soils

Soils within the project corridor are identified from the Soil Landscapes of the Sydney 1:100,000 Sheet (Chapman, G.A and Murphy, C.L., 1989). The Gymea soil landscape covers the majority of the project corridor in the west, with smaller areas of the Hawkesbury, Blacktown, Birrong, Warriewood and Oxford Falls soil landscapes. The eastern extent of the project corridor is largely covered by land identified as being disturbed terrains, associated with Alexandra Canal and industrial land uses.

A search of the Australian Soils Resource Information System indicated the majority of the project corridor has a low to extremely low probability of occurrence of acid sulfate soils (ASS). Land adjacent to watercourses, namely the Cooks River, Wolli Creek and Alexandra Canal were identified as having a high probability of being potential acid sulfate soils (PASS). These areas correspond to land identified as containing Class 1, 2 and 3 acid sulfate soils. Areas 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* is presented on Figure 3-3. The disturbance of ASS has the potential to generate acidic groundwater that would require treatment prior to discharge.

3.6 Geological setting

Regionally the project area is located within the Permo-Triassic Sydney Basin that is characterised by sub-horizontal lying sediments mainly sandstone and shale. To the east the unconsolidated Quaternary aged Botany Sands onlap the basin and unconformably overlie the bedrock. The geology is published on the 1:100,000 series geological map for Sydney, Sheet 9130 (Herbert, 1983) and is presented on Figure 3-4. A geological cross section is presented in Figure 3-5. This cross section is based on boreholes that were constructed during the investigation and highlights the vertical alignment diving beneath the palaeochannels under the Bardwell Valley and Cooks River.

The main stratigraphic units that are expected to be encountered will 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 corridor 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. Structurally there are major faults oriented north-north-east to south-south-west that cross cut the basement rocks. Two major faults known as the Luna Park Fault Zone and the Woolloomooloo Fault Zone are projected to cross cut the central and eastern ends of the project alignment (Och et al, 2009). There are two dominant joint sets known within the Sydney Basin. The common trends for faults and joints are between 090° and 120° and between 005° and 035° (Parsons Brinckerhoff, 2010). Intrusive dykes cross cut the basement rocks. Two major dykes identified in the project area are the Cooks River Bexley Dyke and the Eveleigh Dyke. The width of the dykes can vary from less than three metres to in excess of sixteen metres (Davies, 2002). Palaeovalleys or palaeochannels have also been mapped in the project area (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 50 metres.

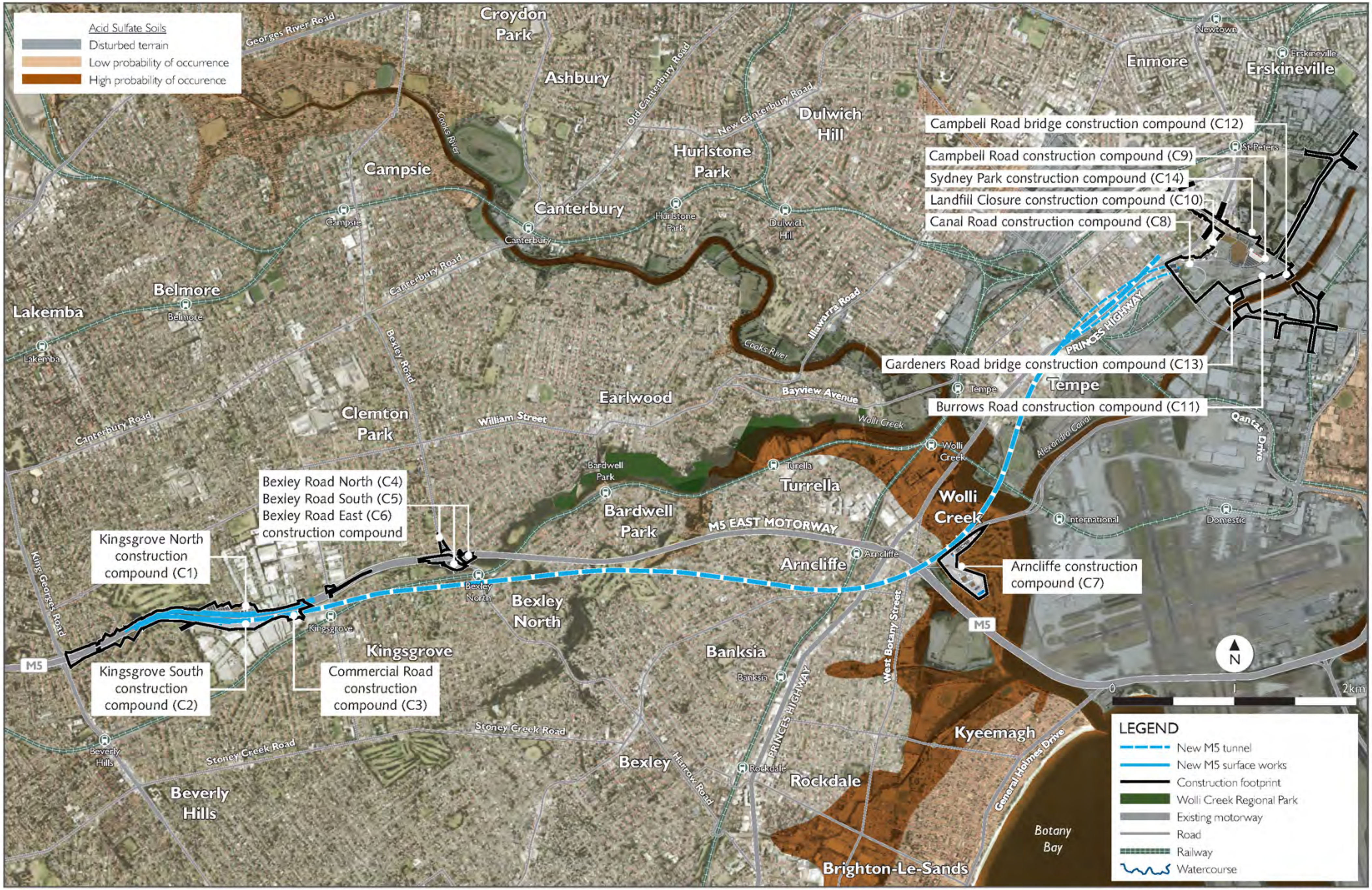
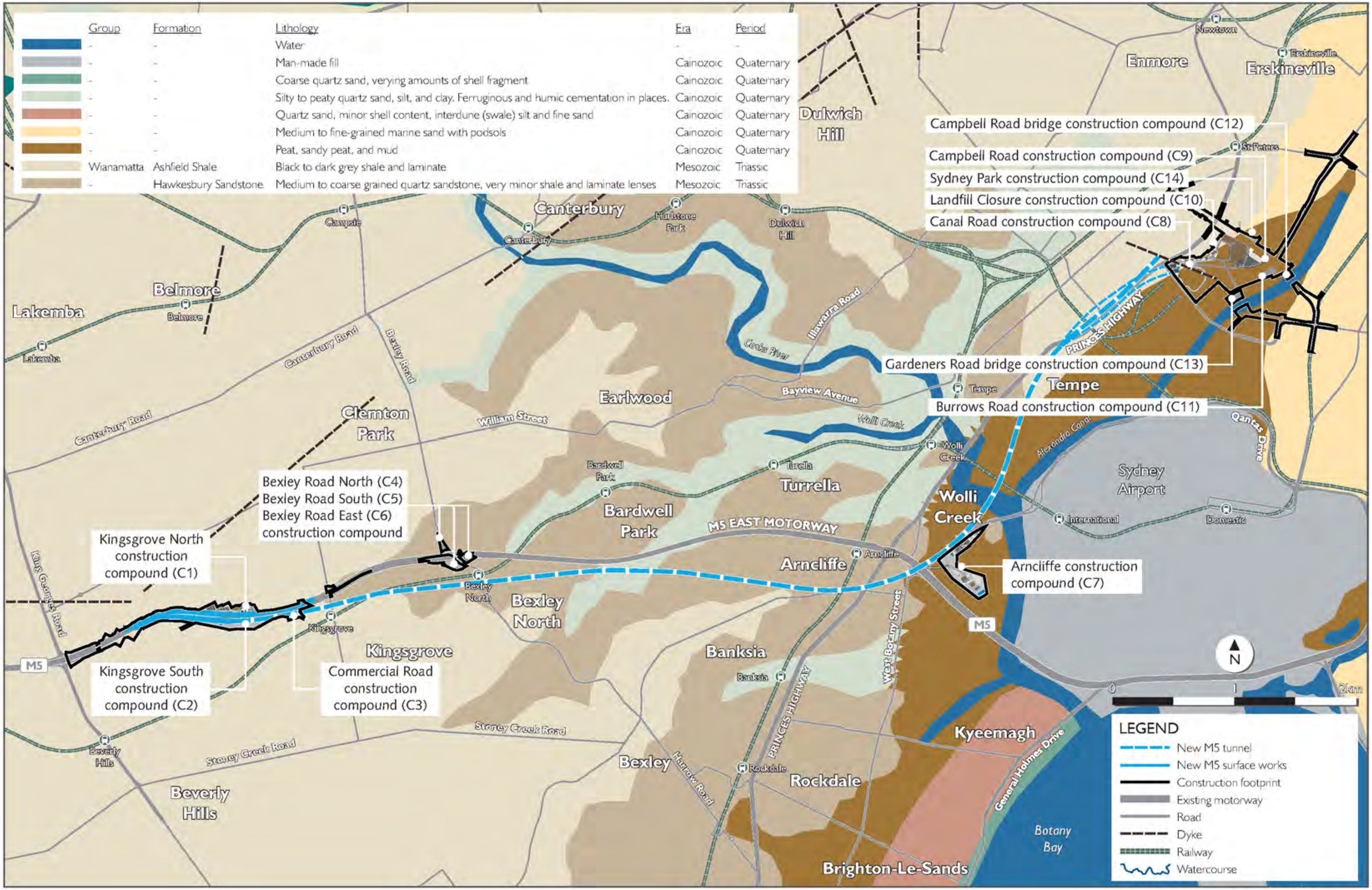


Figure 3-3 Acid sulfate soil risk map

This page has been left blank intentionally.



Group	Formation	Lithology	Era	Period
-	-	Water	-	-
-	-	Man-made fill	Cainozoic	Quaternary
-	-	Coarse quartz sand, verying amounts of shell fragment	Cainozoic	Quaternary
-	-	Silty to peaty quartz sand, silt, and clay. Ferruginous and humic cementation in places.	Cainozoic	Quaternary
-	-	Quartz sand, minor shell content, interdune (swale) silt and fine sand	Cainozoic	Quaternary
-	-	Medium to fine-grained marine sand with podsols	Cainozoic	Quaternary
-	-	Peat, sandy peat, and mud	Cainozoic	Quaternary
Wianamatta	Ashfield Shale	Black to dark grey shale and laminate	Mesozoic	Triassic
-	Hawkesbury Sandstone	Medium to coarse grained quartz sandstone, very minor shale and laminate lenses	Mesozoic	Triassic

Figure 3-4 Geology of the project

This page has been left blank intentionally.

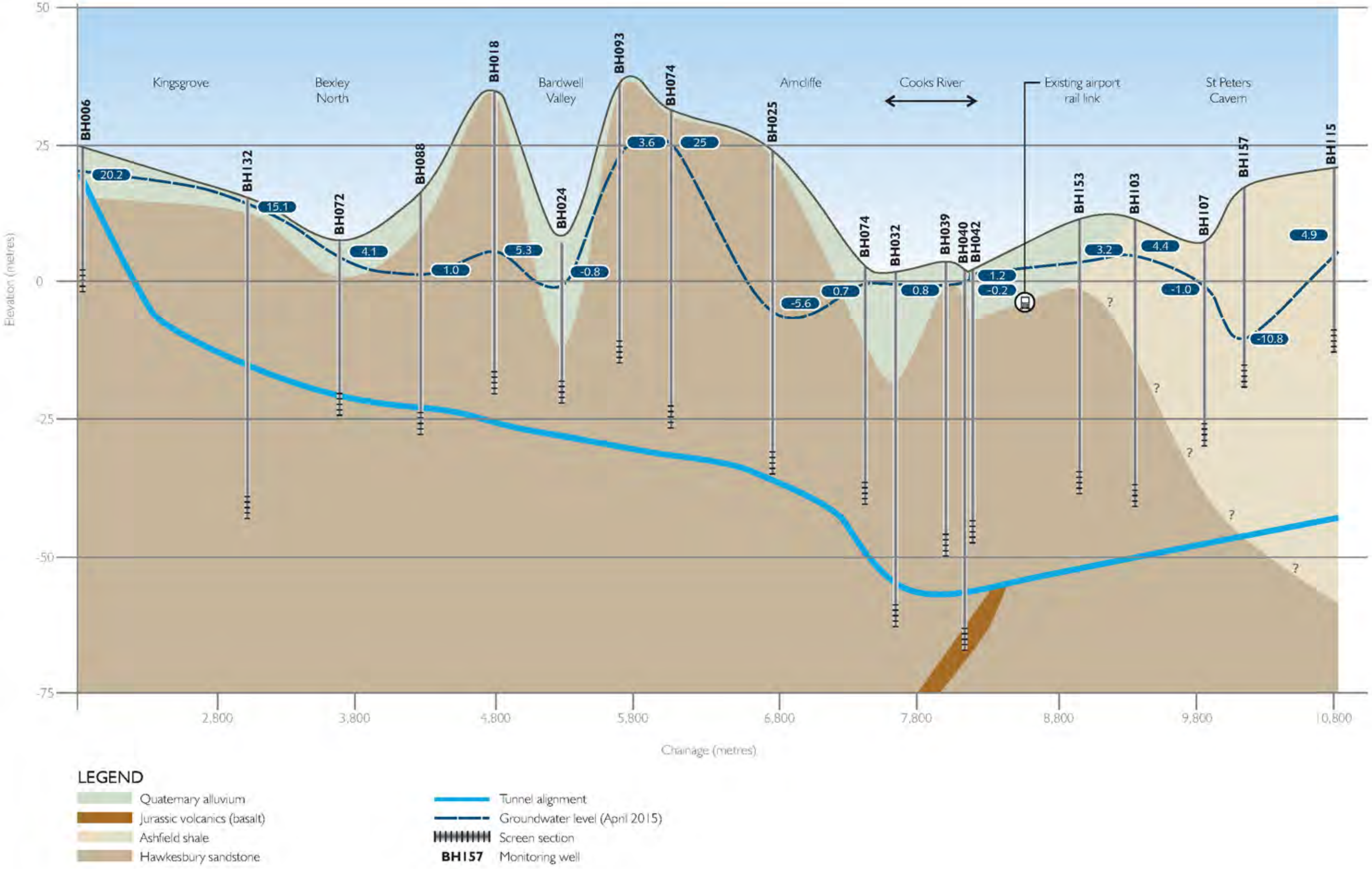


Figure 3-5 Geological cross section

This page has been left blank intentionally.

3.6.1 Fill Materials

As the project corridor is located within an urban environment, it is expected that fill materials would be common along the alignment ranging from minor landscaping to extensive fill for construction of major buildings and infrastructure. The fill is likely to consist of locally excavated materials and imported materials.

More substantial filling has occurred along low lying areas such as reclamation works associated with the Cooks River and Alexandra Canal, Tempe Recreational Reserve, Kogarah Golf Course and Sydney Airport. Fill materials are expected to consist of local dredged material and possibly landfill. Compaction levels may range from uncompacted associated with reclamation works to engineered and certified fill at the Sydney Airport and other development sites.

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

The Ashfield Shale is the primary geological unit at the Alexandria Landfill. The Mittagong Formation and Hawkesbury Sandstone are present few metres beneath the quarry floor (Woodward Clyde, 1997). The weathered shale and clay in the Alexandria Landfill was formerly quarried to an approximate maximum depth of -32 metres AHD for use in brick manufacturing. A former Holocene shoreline runs through the centre of the Site, in an orientation parallel to the current Alexandra Canal (McNally and Branagan, 1998). These alluvial and aeolian sediments, known as the Botany Sands are only present in the eastern part of the landfill with a thickness of approximately ten metres. Prior to 1972 the landfill accepted general waste and putrescible waste. Since 1972 to closure in February 2015 the landfill was licensed to accept general solid waste and asbestos (AECOM, 2014b). The fill has since been classified as general solid, restricted and hazardous waste (AECOM, 2015d).

3.6.2 Alluvium

Deposits of alluvial sediments flank the major rivers, creeks and gullies including the Cooks River and Alexandra Canal. 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.

3.6.3 Botany Sands

The Botany Sands occur along the eastern perimeter of the project corridor in the eastern part of the Alexandria Landfill in the north and extending to the airport in the south. The Kogarah Golf Course is also underlain by Botany Sands. The alluvial, aeolian and estuarine deposits of the Botany Sands on-lap the Hawkesbury Sandstone and Ashfield Shale and extend along the eastern coastal strip. Lithologically the Botany Sands consists of unconsolidated clayey sand, silty sand, muds with occasional gravel (Hatley, 2004). The upper most unit is fine to medium grained sand of aeolian origin and is commonly interbedded with discontinuous layers of peat and clay. Occasionally the peat is interlayered or transgresses into peat rich sand layers. The Botany Sands aquifer named by Bish, et al., 2000 has been divided into four stratigraphic layers. Underlying the Aeolian sequence are alluvial and estuarine deposits which can contain peat layers formed from swamp deposits. Abundant shell layers are common throughout the estuarine sands. Also associated with the estuarine sands, but not always is a thin layer of iron indurated sand known as Waterloo Rock.

At Alexandria Landfill a former Holocene shoreline runs through the centre of the Site, in an orientation parallel to the current Alexandra Canal (McNally and Branagan, 1998). Deposits of the Botany Sands are exposed along the south-eastern boundary of the former quarry. The Holocene sediments in the eastern half of the Alexandria Landfill site have been described to consist of the following unconsolidated layers (from ground surface):

- Fine sand, yellow and grey with shell and charcoal fragments
- Shell band, with quartz sand and carbonised wood
- Sand with abundant fine shell fragments
- Sand increasing with clay content with depth
- Clay, dark grey with yellow staining
- Discontinuous peat beds (0.2 – 0.3 metres thick)
- Cay, grey-blue, plastic, slightly sandy.

Since the unconsolidated Botany Sands outcrop at Alexandria Landfill and Kogarah Golf Course shallow tunnel infrastructure such as dive structures and ventilation shafts would require shoring to stabilise the excavations and prevent groundwater inflow.

3.6.4 Palaeochannels

Deeply incised palaeochannels have carved out narrow drainage channels associated with a network of ancient river channels into the sandstone and shale bedrock. These palaeochannels are infilled with up to 50 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 east towards Botany Bay. The palaeochannels are older than the Botany Sands.

The following palaeochannels have been identified within the project area:

- Wolli Creek Palaeochannel
- Bardwell Valley Palaeochannel
- Upper Cooks River Palaeochannel
- Marrickville Palaeochannel
- Arncliffe Park Palaeochannel
- Arncliffe Station Palaeochannel
- Alexandra Canal Palaeochannel
- Lower Cooks River Palaeochannel.

3.6.5 Volcanic Intrusions

Volcanic dykes of Jurassic age intrude 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 thickness ranging from less than three metres up to 16 metres wide. In some areas, such as the M5 East Motorway tunnel, swarms of dykes can occur. This may represent stringers or off-shoots from a main intrusion.

The frequency of the occurrence of dykes along a linear feature is difficult to assess due to the difficulty in mapping poorly defined outcrops in an urban environment. Based on the geological mapping along coastal exposures in the Botany Basin the dyke frequency within the project corridor 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.

The following major known volcanic intrusions have been identified within the project area:

- Bexley Dyke – Bardwell Valley Golf Course (possibly 5 metres to 15 metres wide)
- M5 East Motorway – Bexley (dyke swarms from 0.2 metres to 5 metres wide)
- M5 East Motorway – west of Cooks River Crossing (16 metres wide)
- Sydney Airport domestic terminal station (1.2 metres wide);
- Mascot Station (six metres wide)
- Tempe Dyke – north of Cooks River (unknown width)

3.6.6 Wianamatta Group

The Wianamatta Group of rocks consists of the Bringelly Shale, Minchinbury Sandstone and Ashfield Shale. The project alignment only intersects the lowest member of this unit, the Ashfield Shale. The Ashfield Shale caps ridgelines over the majority of the alignment outcropping west and north of Sydney Airport with the shale extending to a depth of up to 50 metres. The shale is a marine deposited sequence consisting of fine grained particles including clay, silt and sand that has undergone minor deformation and developed into a laminated shale.

The Ashfield Shale is composed of the following four discrete siltstone and laminate sub-group members, from youngest to oldest:

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

In general 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 ten metres, although within the former brick pits the weathered clay has extended to depths in excess of 40 metres.

3.6.7 Mittagong Formation

The Mittagong Formation is a transition unit between the Ashfield Shale and underlying Hawkesbury Sandstone. 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.

Within the project area the Mittagong Formation is not known to extend beyond a thickness of ten metres. Across the Sydney Basin the Mittagong Formation is quite a thin unit and consequently rarely outcrops. The Mittagong Formation has been identified where the contact between the Ashfield Shale and Hawkesbury Sandstone has been observed at the far eastern and western ends of the alignment.

3.6.8 Hawkesbury Sandstone

The Hawkesbury Sandstone is the dominant lithology across the project area and the majority of the tunnel will be constructed through this competent sandstone. Lithologically the Hawkesbury Sandstone is described as a medium to coarse grained quartzose sandstone. The formation extends across the whole Sydney Basin and is up to 290 metres thick. The 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 ten 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.

3.7 Hydrogeological setting

Groundwater across the project corridor is present in three broad units consisting of alluvium associated with modern river valleys and ancient palaeovalleys, the Botany Sands aquifer and the Triassic shale and sandstone. The tunnels and caverns are to be constructed beneath the water table within the saturated rock mass. Across the project corridor, 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 alignment is recharged by infiltration of rainfall and runoff.

3.7.1 Quaternary alluvium

Modern alluvium underlies and flanks Cooks River and its tributaries forming an unconfined aquifer. Groundwater is also present within localised alluvium in some gullies. Groundwater quality within the alluvium is variable but typically of low salinity in the upper reaches and becoming brackish in the lower reaches due to tidal influences and mixing. The river alluvium is generally of high permeability and the groundwater within the alluvium and can be a source of either recharge or discharge depending on whether upward or downward hydraulic gradients are present. Typical hydraulic conductivity values are between 0.01 and 1 m/day and the horizontal hydraulic conductivity (K_h) is typically higher by a factor of ten than the vertical hydraulic conductivity (K_v). As the alluvium is hydraulically connected to the rivers the groundwater levels are shallow and typically within one metre of ground level. That is whether the stream is a losing or gaining stream.

The palaeochannels that occur beneath some of the major creeks or valleys extend to depths of up to 50 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 (Parsons Brinckerhoff, 2010).

3.7.2 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. Groundwater levels within the Botany Sands between Alexandria Landfill and Alexandra Canal range from -2 to 1 mAHD and are influenced locally by two groundwater extraction schemes, the leachate pumping system and discharge to the landfill and Alexandra Canal. Natural groundwater fluctuations can increase the water table by up to 0.5 metres following a high rainfall event and can also be influenced by tidal fluctuations and seasonal variations. The water table depth is also influenced by other local factors such as distance from recharge and discharge areas, local development and dewatering. Recharge is via direct rainfall and local run-off in green spaces such as Centennial Park, golf courses, parks and gardens. Groundwater recharge has typically decreased as the degree of urbanisation has increased due to enhanced runoff from hardstand areas directing stormwater to Botany Bay.

The Botany Sands aquifer naturally contains low salinity groundwater (generally less than 2000 milligrams per litre which 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. Variations in the native groundwater quality in the Botany Sands aquifer can be attributed to a number of factors including:

- Proximity to recharge;
- Presence of ponds and other wetlands (either enhanced recharge or enhanced evaporation loss);
- Presence of peaty sediments (elevated sulphide concentrations); and
- Industrial development (variety of chemical compounds).

The Botany Sands aquifer is used beneficially for a number of purposes including irrigation, watering market gardens and domestic use. Groundwater is typically extracted from shallow 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.

Prior to Alexandria Landfill, natural groundwater levels within the Botany Sands would be expected to be slightly above sea level with the natural hydraulic gradient flowing towards Botany Bay or locally towards Alexandra Canal. Natural groundwater quality is good and of low salinity. A groundwater divide has been inferred within the Botany sands between the landfill and Alexandra Canal (Woodward Clyde, 1998). Recent groundwater investigation results at the Alexandria Landfill are consistent with the presence of a groundwater divide (AECOM, 2015g). Groundwater to the north of the divide flows towards the landfill and groundwater to the south of the divide flows to the canal. The presence of a groundwater divide indicates there is no groundwater flow between the landfill and Alexandra Canal. There is however hydraulic connection between the landfill and canal as evidenced by minor tidal influences on data logger traces within the Botany Sands (Appendix D). A perched groundwater table is present within the overlying adjacent Botany sands.

3.7.3 Ashfield Shale

Groundwater flow within the Ashfield Shale is poor 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 reduce groundwater flow locally. 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. Salinities typically range from 5,000 mg/L to 12,000 m/L TDS but may be up to 40,000 mg/L causing the groundwater to be corrosive to building materials.

3.7.4 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} m/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. 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 the soil profile. Discharge is via seepage to cliffs and creeks and evapotranspiration.

The 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. Elevated concentrations of dissolved iron and manganese naturally occur within the Hawkesbury Sandstone which can cause staining when discharged and oxidised. In tunnels the inflow of the groundwater causes the iron and manganese to oxidise forming sludge in drainage lines.

The hydrogeological properties of the Mittagong Formation are similar to those of the Hawkesbury Sandstone as their lithologies are similar. Groundwater quality within the Mittagong Formation tends to be poorer and more saline than the Hawkesbury Sandstone due to the higher clay content.

3.7.5 Structural features

The solid geology along the alignment is cross cut by a number of structural features including dykes, joint swarm and faults that may impact groundwater flow. Increased groundwater flow to tunnels is typically associated with major fractures or fault zones, although not all fault zones are transmissive. During construction water bearing fractures and faults can release groundwater initially which declines as the storage is exhausted. Fractures, faults and dykes within the Project area are typically oriented between 090 degrees and 120 degrees and between 005 degrees and 035 degrees which influencers the predominant groundwater flow directions within the Hawkesbury Sandstone.

The intersection of dykes during tunnel construction can increase or decrease groundwater flow into the tunnel depending on the weathering of the dyke and what units or structures it cross-cuts. Where un-weathered and non-fractured dykes cross cut saturated secondary structural features within the sandstone a hydraulic barrier can be created impeding groundwater flow. This can cause differential groundwater pressure across the dyke and potential inflow 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.

When a fractured dyke cross-cuts the shale and is intersected by the tunnel the fractured dyke may provide a conduit for increased groundwater flow into the tunnel from the Ashfield Shale.

3.8 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. GDEs within or near to the project corridor have been identified following a review of:

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

Botany Wetlands is identified as a high priority GDE in the Plan and the Botany Sands Groundwater Source extends to these wetlands. The wetlands are located around two kilometres to the east of the project corridor. Adjacent to Alexandria Landfill groundwater flow from the Botany Sands to Alexandra Canal indicates this is a groundwater discharge area for the sand deposits. However the canal is tidal and is unlikely to have any dependency on groundwater.

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

The Plan also identifies Cooks River/Castlereagh Ironbark Forest Endangered Ecological Community (EEC). A 1.8 hectare area of the EEC has been identified to the north of the M5 East Motorway at Kingsgrove and within the project corridor. The presence of Melaleuca and Casuarina species suggests possible groundwater dependence.

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

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

3.9 Existing Groundwater Users

A review of bores registered with the DPI (Water) and accessed through the Bureau of Meteorology (extracted 18 August 2015) and the Pinneena Groundwater Database has identified 61 boreholes within a one kilometre radius of the project alignment. There may also be other private bores present within the project radius that have not been registered with DPI (Water). The results of this search are summarised in Table B2, Appendix B. The locations of boreholes are shown in Appendix C and geographical distribution shown on Figure 3-6 to Figure 3-9.

The geographical distribution of the boreholes falls within three general populations as follows.

1) West of Arncliffe along existing M5 East Motorway (three)
2) At and near the Kogarah Golf Course (15)
3) At Tempe, St Peters and Alexandria (43)

A summary of the registered borehole details is provided in Table 3.

Figure 3-6 Registered boreholes surrounding the project - Western surface works

This page has been left blank intentionally.

Figure 3-7 Registered boreholes surrounding the project - Bexley surface works

This page has been left blank intentionally.

Figure 3-8 Registered boreholes surrounding the project - Arncliffe surface works

This page has been left blank intentionally.

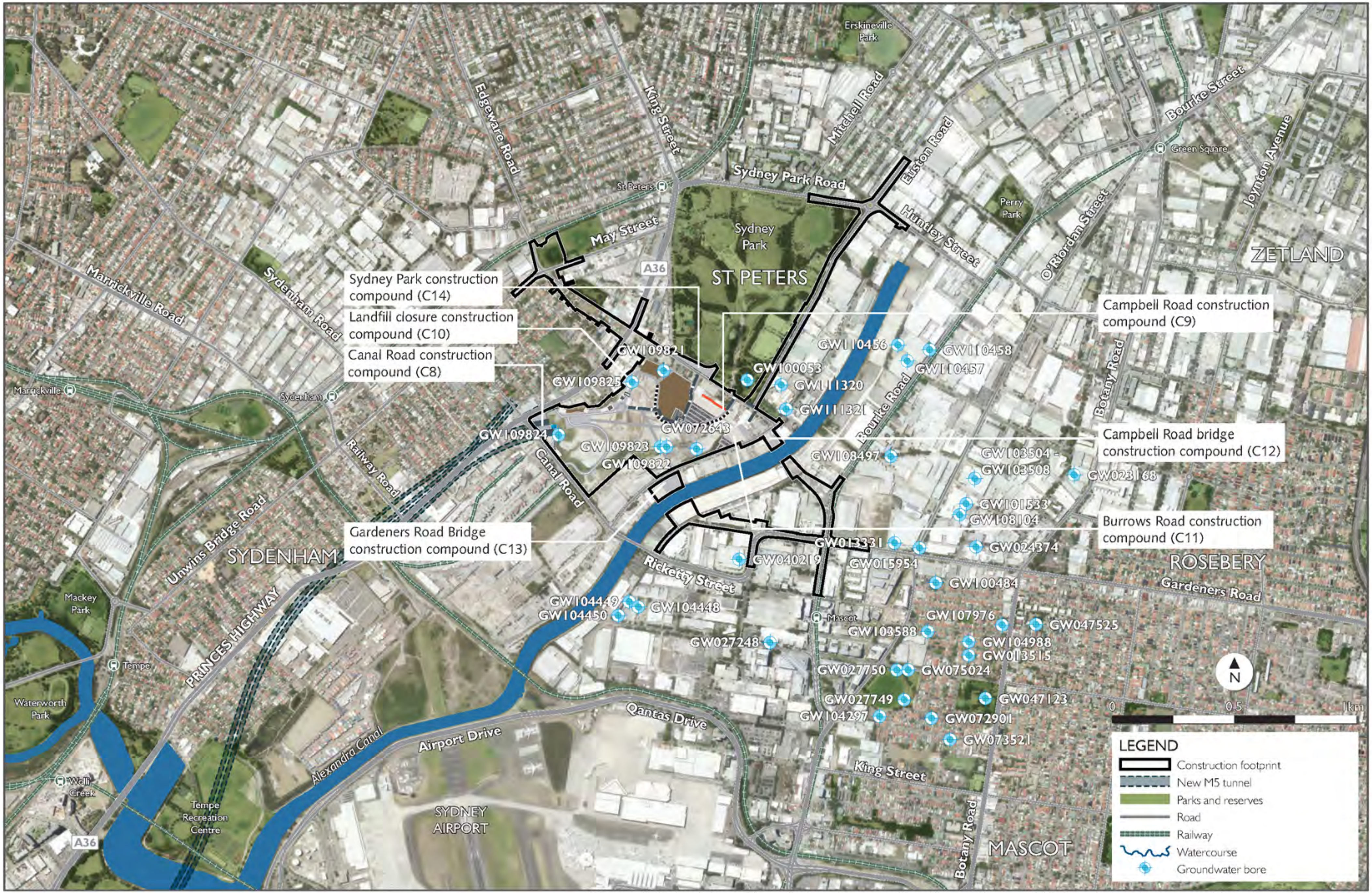


Figure 3-9 Registered boreholes surrounding the project - St Peters interchange and local road upgrades

This page has been left blank intentionally.

Table 3 Summary of DPI (Water) registered bores within one kilometre of the project corridor

Purpose	Number of bores	Predominant lithology	SWL min (mbtoc**)	SWL max (mbtoc**)	Bore depth min (m)	Bore depth max (m)
Water Supply	31	Sand	0.3	8.22	3	108
Monitoring	20	Sand	0.16	37	2.8	162
Other	10	Sand	0.7	10.97	3.5	186

Note: SWL = Standing Water Level (metres below ground level) mbtoc = metres below top of casing

Review of the lithological data indicates the majority of boreholes are shallow (less than 10 metres) and extract groundwater from the sand. Only 11 of the 61 bores intersect the sandstone (eight) or shale (three).

Along the M5 East Motorway there is a low density of bores intersecting the Hawkesbury Sandstone. South of the M5 East Motorway, there is a cluster of shallow wells that extract groundwater from the Botany Sands aquifer for domestic water supply or irrigation.

At the eastern end of the project corridor near St Peters, the borehole density is low as the Ashfield Shale is a poor aquifer and is generally not exploited. Registered bores in eastern end of the project corridor are typically related to monitoring wells associated with groundwater monitoring at the Alexandria and Tempe Landfill.

Registered bores within the Hawkesbury Sandstone are scattered across the project corridor and report a variety of purposes with the most common purposes being monitoring and domestic use. The borehole depth within the Hawkesbury Sandstone is deeper and up to 186 metres. In contrast bores in the shale are much shallower and attain a maximum depth in the project area of 35 metres at Alexandria Landfill.

Even though groundwater quality is generally good, groundwater use across most of the in the project corridor is low as bore yields are low and the area has access to reticulated water. Registered boreholes are constructed for many purposes including monitoring wells, groundwater extraction for domestic, irrigation, recreation purposes and exploration test bores. Borehole depths range from two metres to 186 metres intersecting clay, sandstone and shale. The distribution of registered boreholes, summary of borehole details and borehole logs extracted from the database are in Appendix C.

At Alexandria Landfill there are many monitoring wells that have not been registered with DPI (Water). Leachate is pumped from the base of the Alexandria Landfill, treated on-site and discharged to sewer under a trade waste agreement.

3.10 Groundwater inflow in existing Sydney tunnels

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

Drainage inflow as summarised in Table 4 varies from 0.6 litres per second per kilometre to less than 1.7 litres per second per kilometre.

Table 4 Measured Drainage Rates from other Sydney Tunnels

Tunnel	Type	Width (m)	Length km	Drainage inflow (L/sec/km)	Reference
Eastern Distributor	3 lane road	12 (Double deck)	1.7	1	Hewitt, 2005
M5 East Motorway	Twin 2 lane road	8 (twin)	3.8	0.9	Tammetta and Hewitt, 2004
Epping to Chatswood	Twin rail	7.2	13	0.9	Best and Parker, 2005
Lane Cove	Twin 3 lane road	9 (twin)	3.6	0.6/1.7*	Coffey, 2012
Northside Storage	Sewer storage	6	20	0.9	Coffey, 2012

Note: * measured inflow in Lane Cove Tunnel varied from 1.7 L/s/km (2001 – mid 2004) to 0.6 L/s/km (2011)

3.11 Contamination

3.11.1 Areas of Known Contamination

An assessment of contaminated land risk is provided in Technical Working Paper: Contamination (AECOM, 2015h). Contamination reports undertaken along the project corridor include a Phase 1 and Phase 2 reports at and nearby Alexandria Landfill (AECOM, 2014b, 2015d and 2015e). Areas located above the project tunnel alignment have not been assessed in detail due to the generally low likelihood of significant contamination being encountered at depth in bedrock. Key sites that are relevant to this assessment is provided below.

Alexandria Landfill is located within the project corridor at St Peters, which continues to generate leachate that is pumped from the former quarry, treated and discharged to sewer under a trade waste agreement. Groundwater inflow from the Botany Sands aquifer has been observed at the landfill (AECOM, 2015g). To the south-west of the landfill at the 5 Canal Road site groundwater is contaminated with lead and hydrocarbons due to past site usage.

The Botany Sands aquifer is highly vulnerable to contamination. Botany and its surrounding suburbs have been heavily used by industry for more than 100 years, including tanneries, metal platers, service stations and depots, landfills, dry cleaners and wool scourers. Industrial activity has been undertaken in this area largely before any environmental protection controls were in place, and as a result, hydrocarbons, heavy metals including chromium, nickel, lead and arsenic may have contaminated the aquifer.

Some of these industrial uses have led to contamination of the groundwater within the aquifer. Because of known or potential contamination, the NSW Government has taken a precautionary approach to ensure public health is not put at risk from exposure to potentially contaminated groundwater. Under the precautionary approach, the Botany Sands aquifer is divided into four management zones; the known contaminated Orica exclusion area, and three other management zones. Domestic groundwater use is banned within all four management zones in order to minimise the risk to bore users and prevent the spread of contamination through pumping. Industrial bore users within all management zones are required to test their bore water annually and report the results of testing to the DPI (Water) and OEH. There has been an embargo in place since August 2003 on the acceptance of new licence applications to extract groundwater.

The Tempe landfill, located at 634-726 Princes Highway, Tempe is a closed landfill with elevated ammonia and a remediation system that consists of a soil-bentonite cut-off wall and leachate extraction and treatment system (AECOM, 2015h). The site is located south east of the project corridor.

3.11.2 Areas of Potential Contamination

There are a number of current and former land uses within the project corridor which may have resulted in contamination such as service stations and industrial facilities. The bed of Alexandra Canal is declared as a remediation site under the *Contaminated Land Management Act 1997*. The bed sediments of Alexandra Canal have been identified as containing chlorinated hydrocarbons, including organochloride pesticides (chlordane, total DDT and dieldrin), polychlorinated biphenyls (PCBs) and metals. The contamination of the bed sediments is sufficiently impacted to warrant regulation (NSW EPA, 2000).

A Phase 1 ESA (AECOM, 2015h) along the alignment identified potential groundwater contamination associated with historical land uses as follows:

- Leachate associated within former brick works quarries in Sydney Park, Camdenville Park and Alexandria Landfill at St Peters Interchange;
- Groundwater contamination in an area known as the St Peter Local Roads area (located between Campbell Street, Euston Road and Bourke Road in the suburbs of Alexandria, Mascot and St Peters) where manufacturing and workshops were identified as potential sources of contamination;
- Groundwater contamination consisting of elevated dissolved hydrocarbons and metals at 5/5A Canal Road, St Peters due to historical uses on site including a metal smelter and battery storage and migration from the adjacent Alexandria Landfill;
- Elevated dissolved hydrocarbon contamination at 6A Huntley Street, Alexandria due to leaks from above ground and underground storage tanks (PAHs, total petroleum hydrocarbons (TPHs));
- Groundwater beneath the Kogarah Golf Course has the potential to be contaminated by fertilizers, pesticides and herbicides due to its former use as market gardens and current use as a golf course.

Golf courses and parks

Several golf courses and major parks are located within or close to the project corridor. These parks and gardens can be potential sources of impacts to groundwater due to the use of fertilisers and pesticides and groundwater extraction for irrigation. From west to east, this includes:

- Canterbury Golf Course
- Bardwell Valley Golf Course
- Kogarah Golf Course
- Barton Park
- Tempe Recreational Reserve
- Sydney Park, also a former landfill at St Peters.

This page has been left blank intentionally.

4.0 Field investigations

As detailed in **Section 2.2.1**, a groundwater monitoring network was constructed as part of the WestConnex geotechnical investigations (AECOM, 2015a). Twenty eight monitoring wells were constructed at selected locations along the project alignment. This chapter presents the findings of this investigation with respect to:

- Existing groundwater levels
- Groundwater quality
- Hydraulic conductivity.

4.1 Existing groundwater levels

Groundwater levels are influenced by topography, creeks, rainfall, recharge and manmade structures. Natural groundwater levels are expected to generally reflect a subdued reflection of the topography, with the groundwater table generally displaying gentler gradients but similar flow directions to the surface topography. Locally the water table is impacted by infrastructure such as pumping or along the alignment of the M5 East Motorway tunnel which is a drained tunnel. Conversely in some areas the local water table may be elevated above natural conditions due to irrigation such as at the Kogarah Golf Course or subsurface structures such as infrastructure or building foundations that inhibit groundwater flow causing localised groundwater mounding.

Groundwater levels have been monitored within the 28 monitoring wells constructed as part of investigations for the New M5 project design development and environmental impact assessment. The highest groundwater levels occur in high topographic areas, up to 25 metres AHD at Arncliffe, and are some 50 to 60 metres above the reference design tunnel invert level. Measured groundwater levels and reduced groundwater levels (m AHD) are presented in Table B3, Appendix B.

Groundwater levels have been assessed for each lithology and in relation to their topographic position. Five monitoring wells (BH109, BH115, BH120, BH122 and BH157) were screened in the Wianamatta Shale (Ashfield Shale, Rouse Hill Siltstone and Regentville Siltstone), in Alexandria and St Peters. Groundwater levels within the Ashfield Shale were variable ranging from 3.1 metres to 25.9 metres below ground level and from -9.1 metres to 12.1 metres AHD. As expected groundwater levels within the Botany Sands and alluvium are shallow ranging from 0.3 metres to 2.6 metres below ground level and from -0.2 metres to 1.2 metres AHD. The monitoring well intersecting basalt (BH040) adjacent to Cooks River has a standing water level at 1.7 metres below ground level (-0.21 metres AHD) and may be hydraulically connected to the river.

The majority of groundwater wells intersect the Hawkesbury Sandstone. All monitoring wells are constructed with a three metre screen interval which varies in depth between 19 and 85 metres below ground level. The groundwater elevation is highly variable and dependent upon the topographical expression. Groundwater levels within the Hawkesbury Sandstone vary from 1.5 metres to 35 metres below ground level and from -1.0 to 24.2 metres AHD. Large vertical gradients are apparent in topographically high areas around Bardwell Park and Kingsgrove.

Monitored groundwater levels in and around Alexandria Landfill within the Botany Sands and Ashfield Shale are influenced by the leachate pumping system that causes groundwater to flow towards the centre of the landfill. This radial flow pattern prevents contamination from the landfill dispersing into the Ashfield Shale and Botany Sands.

At Tempe Railway Station adjacent to Cooks River the alluvium is 23 metres deep (BH152). Nested monitoring wells constructed into the river alluvium and Hawkesbury Sandstone demonstrate the standing water levels in the alluvium measured in April 2015 (0.63 metres AHD) are lower than the Hawkesbury Sandstone (1.38 metres AHD) suggesting there is an upward groundwater pressure to the alluvium. This is consistent with groundwater levels measured at Arncliffe (April 2015) in nested wells within the Botany sands (-3.36 metres AHD) and underlying Hawkesbury Sandstone (0.70 metres AHD). At this location the standing water level in the Botany sands is lower than in the Hawkesbury Sandstone suggesting there is an upward groundwater pressure from the Hawkesbury Sandstone. This upward pressure gradient may not be indicative of the whole Hawkesbury Sandstone as the Hawkesbury Sandstone is often compartmentalised due to stratigraphy confining layers and structural defects creating different hydraulic conditions throughout the aquifer. Hence at this location the upward pressure indicates groundwater from the Hawkesbury Sandstone may be discharging into the alluvium, and the alluvium is not losing groundwater to the underlying sandstone.

Groundwater level fluctuations as monitored with the data loggers as presented on hydrographs (Appendix D) indicate the fluctuations for most monitoring wells are less than one metre suggesting that the Hawkesbury Sandstone groundwater system is in equilibrium. That is the components of hydrogeological regime including recharge (primarily rainfall infiltration) and discharge (primarily discharge to creeks and evapotranspiration) are balanced. There are clear correlations with rainfall with the groundwater level rising following a rainfall event generally in excess of 10 millimetres although there is a lag time of typically between 24 and 48 hours.

4.2 Groundwater Quality

An understanding of the groundwater quality within the various hydrogeological units intersected by the tunnels and its infrastructure is important for the Project for a number of reasons. The groundwater quality has been characterised prior to development to establish background conditions. This dataset will be used for comparison for post development groundwater quality monitoring. The natural groundwater quality is also required to meet discharge requirements and design any water treatment requirements. Groundwater can also be corrosive to building materials depending on a number of hydrogeochemical factors including salinity, pH, sulfateand chloride concentrations. Understanding the corrosive nature of the natural groundwater intersected assists in selecting building materials to minimise corrosive impacts to the tunnel and its infrastructure.

At Alexandria landfill leachate is generated by the continual decomposition of waste within the landfill interacting with native groundwater and rainfall infiltration. The leachate quality has been characterised through on-going monitoring programs in accordance with the EPL conditions. The leachate typically has elevated concentrations of ammonia and minor hydrocarbon contamination. Concentrations of total dissolved solids measured quarterly since 1996 range from 2030 to 6450 mg/L total dissolved solids. The leachate is collected through a herringbone drainage network at the base of the landfill and pumped to an on-site treatment plant and discharged to sewer under a trade waste agreement. Leachate collection, treatment and discharge will continue after the construction of St Peters Interchange is a new purpose built water treatment plant.

Groundwater quality within the Hawkesbury Sandstone is typically of low to moderate salinity with electrical conductivity generally ranging between 500 µS/cm and 2000 µS/cm. The pH is typically acidic ranging from 4 to 6.5 pH units. The sandstone tends to have elevated dissolved iron and manganese concentrations that results in precipitation of brown ferric hydroxide or black manganese rich sludge and/or staining when exposed to air. Groundwater quality within the Mittagong Formation is similar to that of the Hawkesbury Sandstone, although often has a higher salinity due to the higher clay and silt content. Bacteria are a common natural occurrence within the fractured rocks of the Sydney Basin. Under favourable conditions, typically seepage points within tunnels the bacteria grow as a colony forming a sludge that can block pump intakes of submerged pumps.

Groundwater quality within the Ashfield Shale is of poorer quality with salinities typically ranging from 5,000 mg/L to 12,000 m/L but may be up to 40,000 mg/L causing the groundwater to be corrosive to building materials. The groundwater within the Hawkesbury Sandstone underlying the Ashfield Shale generally has higher salinity concentrations due to leakage of poor quality water from the Ashfield Shale.

Groundwater quality within the alluvium associated with the rivers is variable but typically of low salinity in the upper reaches and becoming brackish in the lower reaches due to tidal influences and mixing. The Botany Sands aquifer contains good quality, moderately acidic groundwater but in many areas has been contaminated by industrial activities or the impacts of urban development. Groundwater within infilled quarries and landfills can also be contaminated, the degree of contamination dependent on the refuse type deposited.

Groundwater analytical results along the alignment have been assessed for 14 representative samples within the, Ashfield Shale (3) and Hawkesbury Sandstone (11). During the sampling program a series of contaminants of concern, identified based on previous site history were submitted for laboratory analysis. Despite the considerable industrial activity that has historically occurred along the alignment little dissolved contamination was identified with almost all analytes being below the adopted groundwater screening criteria (AECOM, 2015b). Some heavy metals moderately exceeded the site criteria but these exceedances are attributed to elevated background concentrations. The results of statistical analysis for some key hydrogeochemical parameters are presented in **Table 5**. Analytical results for major anions and cations, iron, manganese, pH, electrical conductivity and nutrients are summarised in Table B4 Appendix B).

Table 5 **Summary of average major hydrogeochemical parameters**

Constituent	Units	Ashfield Shale	Hawkesbury Sandstone
pH	pH Units	6.2	7.5^
TDS*(Salinity)	mg/L	4250	3190
Chloride (Cl)	mg/L	1310	975
Sulfate (SO_4)	mg/L	75	272
Total Iron (Fe)	mg/L	10	5.0
Manganese	mg/L	-	0.44
Number (n)		3	11

Note: * TDS – Total dissolved Solids ^ Some field results not available

The TDS and pH results of the Ashfield Shale and Hawkesbury Sandstone indicate the salinity of the groundwater within the shale is higher than that within the Hawkesbury Sandstone and the pH is neutral. Chloride and sulfate concentrations do not appear related to each other Sulfate concentrations are attributed to the sulphide mineralisation within the parent rock which is highly variable whereas chloride concentrations are related to its marine origin. Both the Ashfield Shale and Hawkesbury Sandstone contain elevated concentrations of dissolved iron which precipitate as described above.

The major ion chemistry is shown on the trilinear Piper Diagram and compared to seawater (Hem, 1992) is presented on Figure 4-1. The groundwater within the sandstone has higher concentrations of calcium and sulfate which is attributed to enrichment of these ions due to the development of secondary mineralisation. In contrast the shale is depleted in sodium, potassium and chloride.

4.3 Hydraulic conductivity

In-situ water pressure (packer) testing was undertaken along the alignment in selected boreholes to assess hydraulic conductivity. The packer tests also give an indication where groundwater inflows into the tunnels could be expected. The water pressure testing was carried out in accordance with established procedures set out in Fell, MacGregor, Stapledon and Bell, 2005. Packer tests or water pressure tests are conducted by the drilling contractors by injecting water under pressure into a rock mass interval and measuring the water ingress over a given time period. The amount of water injected is proportional to the hydraulic conductivity.

Packer testing was performed in selected cored sections using a single stage pneumatic HQ packer and calibrated flow meters provided by the drilling contractor. Water pressure testing was carried out in 35 boreholes (as distinct from monitoring wells) with up to seven tests performed in each borehole. Each test was typically carried out in five different pressure stages (three stages upward and two stages downward), at the nominated test interval (typically around three, six, nine or 12 metres). When possible, the packer testing was continuous in the bottom half of the hole. In selecting intervals to be tested the more fractured sections in boreholes were targeted to provide an upper limit of hydraulic conductivity.

The packer test results provide a bulk hydraulic conductivity for the intervals measured including horizontal and vertical features and the rock matrix. Horizontal and sub-horizontal permeability is expected to be higher than vertical permeability because the horizontal defects tend to be more extensive, numerous and wider in the Hawkesbury Sandstone and Ashfield Shale. The defects tend to decrease with depth as the surficial pressure influences decrease.

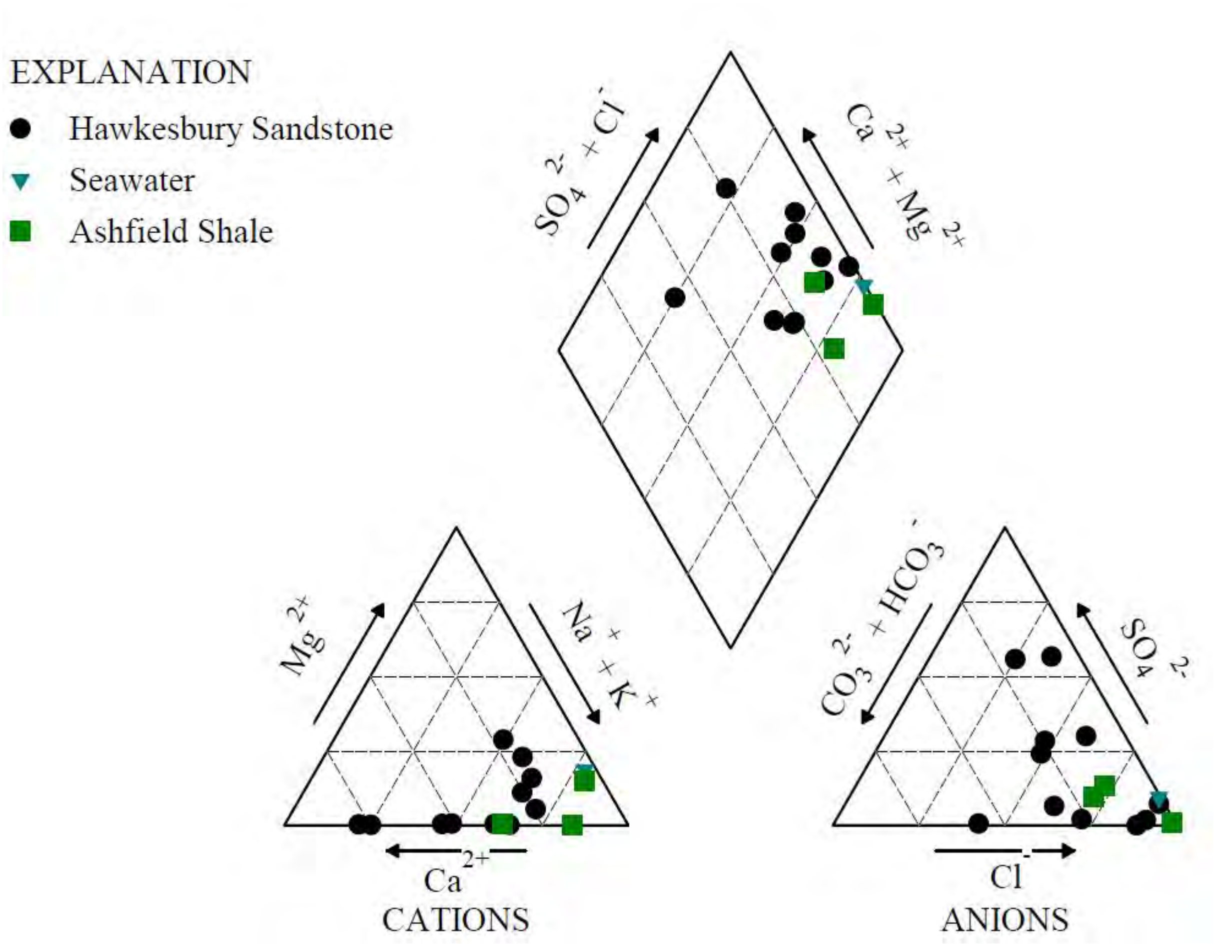


Figure 4-1 Piper Diagram displaying major ion chemistry

The hydraulic conductivity has been measured by conducting 158 packer tests in 35 boreholes as shown on Figure 4-2. The packer test results are summarised in Table B5, Appendix B. Results of the packer tests are expressed as Lugeon units where a 1µL is equivalent to a hydraulic conductivity of $1x10^{-7}$ m/s ($8.8x10^{-3}$ m/day). The distribution of packer test results for all lithologies are presented in Table 6 and show the majority of the rock mass results are classified as of low hydraulic conductivity, suggesting that inflows rates would be low.

Table 6 Distribution of rock mass permeability

Relative Permeability	Permeability Range	Measurements
Low	< 1 Lugeon	112
Moderate	1 to 5 Lugeons	20
High	5 to 20 Lugeons	14
Very High	20 to 50 Lugeons	7
Extremely High	> 1 Lugeons	5
Total		158

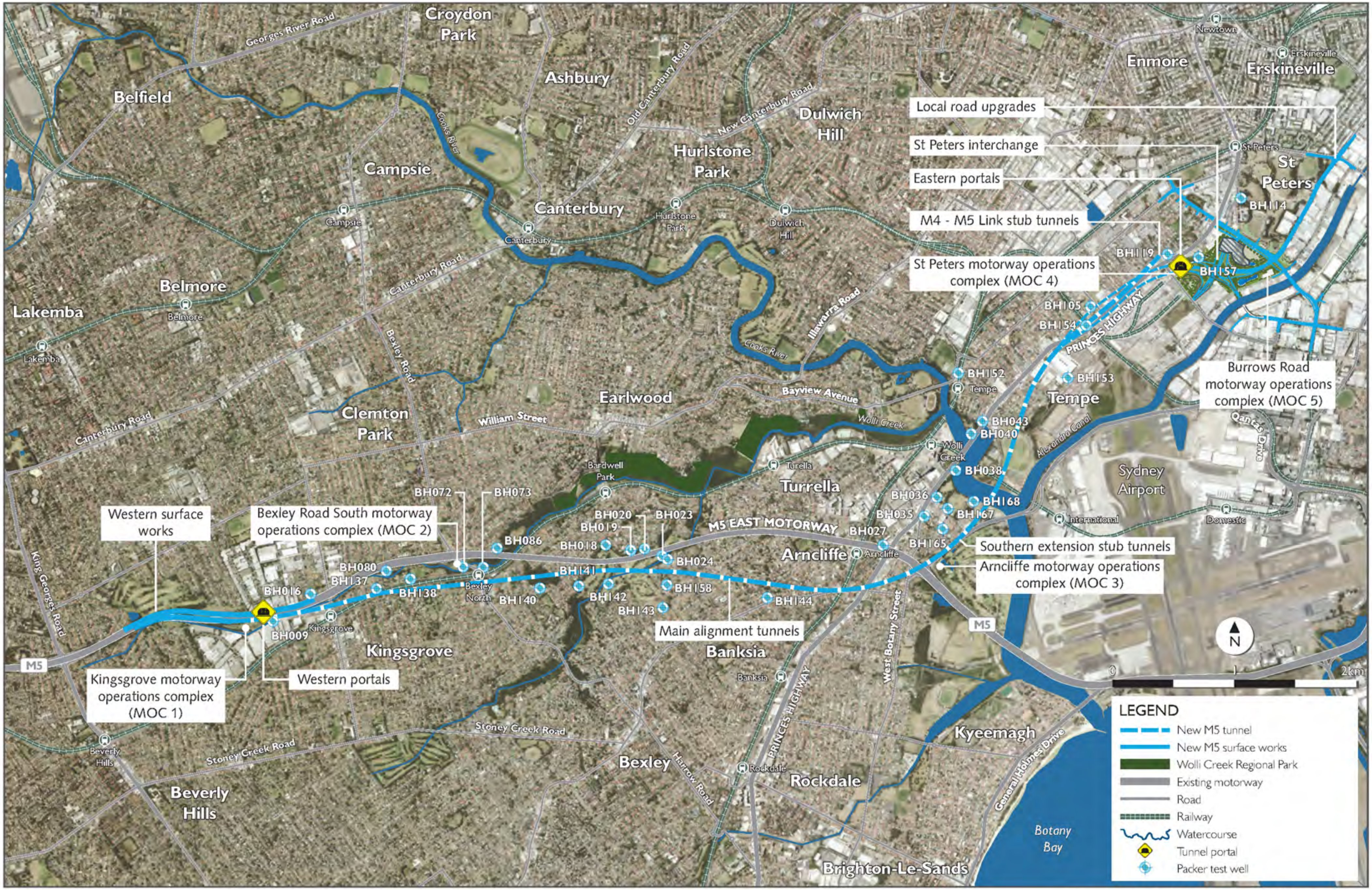


Figure 4-2 Packer test borehole locations

This page has been left blank intentionally.

To provide an understanding of the hydraulic conductivity within each lithology the statistics are presented in Table 7. The majority (90 per cent) of packer tests were conducted within the Hawkesbury Sandstone. For comparison hydraulic conductivity values within the Hawkesbury Sandstone across the whole Sydney Basin were compiled by McKibbin and Smith, 2000 ranging between 0.01 and 0.15 metres per day. This range is higher than the packer test data as the data is typically derived from test pumping data, obtained from successful production bores that intersects faults and fractures.

Table 7 Rock mass permeability for each lithology (metres per day)

Relative Permeability	Basalt	Ashfield Shale	Mittagong Formation	Hawkesbury Sandstone
Average	0.02	0.02	0.1	0.08
Minimum	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Maximum	0.04	0.07	0.9	4.3
median	0.02	0.003	0.01	0.003
n	2	6	10	205

The distribution of hydraulic conductivity results and the 15 point geometric mean plotted against depth are presented in Figure 4-3. The plot shows a wide variation in hydraulic conductivity values with the overall trend of decreasing hydraulic conductivity with depth. The log-average hydraulic conductivity varies from about 0.01 metres per day at 23 metres to 0.003 metres per day at a depth of 80 metres. The large scatter is caused by the variation in defect spacing which tends to decline with depth due to an increased influence of overburden pressure.

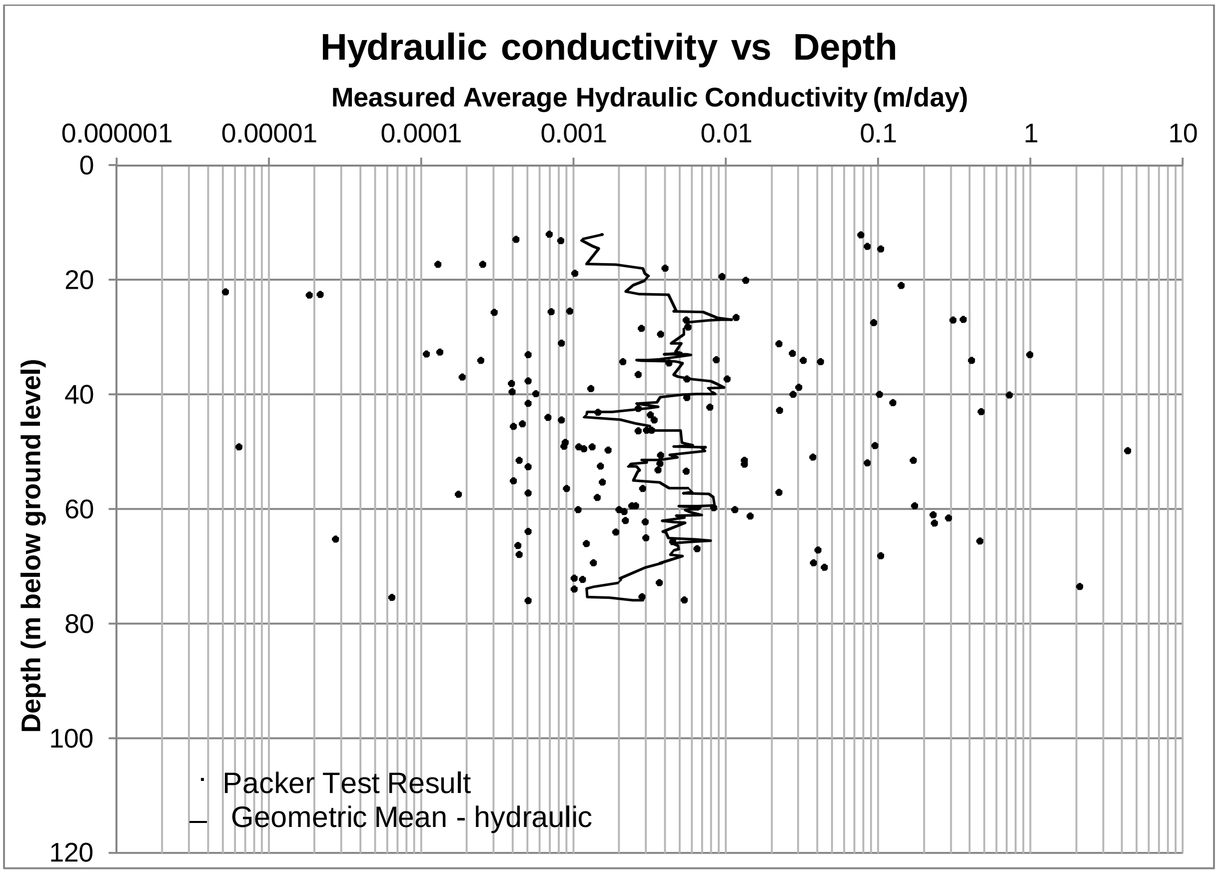


Figure 4-3 Hydraulic conductivity value from packer tests versus depth

Although the majority of packer test results were classified as having a low hydraulic conductivity there were four that were classified as being of extremely high hydraulic conductivity where there is potential for higher groundwater inflows.

- Bexley North: at BH072 (31.5-34.5 metres). The extremely high permeability is due to variable cross bedding and thin grey laminations across this small zone. The hydraulic conductivity for the remaining six packer tests at this location were classified as high (10.0 – 18.1 metres) and low (18-27.1 metres and 34.6-64.5 metres).
- Bexley North: at BH073 (34 – 46 metres). The extremely high permeability is due to variable cross bedding and thin grey laminations similar to the zone intersected in nearby BH072. The hydraulic conductivity for the remaining six packer tests at this location were classified as low, moderate and very high suggesting there may be an increased amount of water bearing defects in this area.
- Bardwell Valley: at BH141 (103.7 – 115.9 metres). The extremely high permeability is due to laminations and wisps within a carbonaceous medium to coarse grained sandstone. The hydraulic conductivity above 94 m was classified as low. Thus should the tunnels at this location not extend beyond 103 m depth (a likely scenario) then tunnel inflows are expected to be low.
- Tempe: at BH043 (72.0 -75.0 metres). The lithology intersected by the packer test which reported extremely high permeability was laminations and wisps within a carbonaceous medium to coarse grained sandstone, similar to what was intersected in BH141 at Bardwell Valley. The other packer tests were classified at very high between 57 and 67.5 metres and of low hydraulic conductivity below 57 metres. Clearly the hydraulic conductivity at this location increases at depth below 57 metres and increased groundwater inflows are likely if the tunnel exceeds 57 metres depth.

High groundwater inflows may be expected at the above locations where highly permeable saturated lithologies are intersected.

Due to horizontal nature of bedding in sedimentary rocks, the vertical hydraulic conductivity of Hawkesbury Sandstone is typically lower that the horizontal hydraulic conductivity. Hawkesbury Sandstone typically has a vertical hydraulic conductivity at most one tenth the value of horizontal hydraulic conductivity.

The Ashfield Shale generally has a lower hydraulic conductivity than the Hawkesbury Sandstone. The weathered soil profile of the Ashfield Shale is clay and silty clay with a reduced bulk hydraulic conductivity which can restrict recharge to the underlying shale and sandstone.

The hydraulic conductivity of the Botany Sands is variable and ranges from 15 to 50 metres per day and 1.5 to five metres per day where clay is present (Jankowski et al, 1997).

5.0 The project

5.1 Project overview

The project would comprise a new, tolled multi-lane road link between the M5 East Motorway east of King Georges Road and St Peters, and would include an interchange at St Peters and connections to the existing road network. Key components of the project would include:

Key components of the project would include:

- Twin motorway tunnels between the existing M5 East Motorway (between King Georges Road and Bexley Road) and St Peters. The western portals along the M5 East Motorway would be located east of King Georges Road, and the eastern portals at St Peters would be located in the vicinity of the Princes Highway and Canal Road. Each tunnel would be about nine kilometres in length and would be configured as follows:
    - Between the western portals and Arncliffe, the tunnels would be line marked for two lanes as part of the project, and built with the provision to be widened to three in the future, subject to additional assessment and approval
    - Between the Arncliffe and St Peters, the tunnels would be line marked for two lanes as part of the project, and built with the provision to be widened to five in the future, subject to additional assessment and approval.
- The western portals along the M5 East Motorway would be located east of King Georges Road, and the eastern portals at St Peters would be located in the vicinity of the Princes Highway and Canal Road
- Tunnel stubs to allow for a potential future connection to the future M4-M5 Link and a potential future connection to southern Sydney
- Surface road widening works along the M5 East Motorway between east of King Georges Road and the new tunnel portals
- A new road interchange at St Peters, which would initially provide road connections from the main alignment tunnels to Campbell Road and Euston Road, St Peters
- Two new road bridges across Alexandra Canal which would connect St Peters interchange with Gardeners Road and Bourke Road, Mascot
- Closure and remediation of the Alexandria Landfill site, to enable the construction and operation of the new St Peters interchange
- Works to enhance and upgrade local roads near the St Peters interchange
- Ancillary infrastructure and operational facilities for electronic tolling, signage (including electronic signage), ventilation structures and systems, fire and life safety systems, and emergency evacuation and smoke extraction infrastructure
- A motorway control centre that would include operation and maintenance facilities
- New service utilities and modifications to existing service utilities
- Temporary construction facilities and temporary works to facilitate the construction of the project
- Infrastructure to introduce tolling on the existing M5 East Motorway
- Surface road upgrade works within the corridor of the M5 East Motorway.

Construction activities associated with the project would generally include:

- Commencement of enabling and temporary works, including construction power, water supply, ancillary site establishment, demolition works, property and utility adjustments and public 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 control centre and ancillary operations buildings
- Upgrades to surface roads and construction of bridges
- Implementation of environmental management and pollution control facilities for the project.

Further detail on the key features of the project, as relevant to hydrogeological impacts are detailed below.

5.2 Project features

5.2.1 Main tunnel alignment

The eastern end of the tunnels would terminate underground at St Peters in the form of stub tunnels, providing a potential future connection to the M4-M5 link. An overview of the project is shown in Figure 1-1.

The project has been design to connect to the surrounding road network at four locations:

- To the King Georges Road interchange and M5 South West Motorway via the western portals.
- To the St Peters interchange and local surface road network via the eastern portals.
- To the possible future southern extension via stub tunnels at the southern extension caverns near the Kogarah Golf Course.
- To the possible future M4-M5 Link via stub tunnels at the St Peters caverns near the St Peters interchange.

The main alignment tunnels include two vehicular cross passages at Bexley and Arncliffe to allow for emergency traffic switching, as well as pedestrian cross passages spaced at a maximum of 120 metres and emergency pedestrian egress between tunnels in the event of an emergency. An emergency breakdown bay would also be provided. The depth of the main alignment tunnels would vary depending on geological constraints. The lowest section of the tunnels would be about 60 metres below the ground surface below Kogarah Golf Course (Chainage 7850) with shallower sections on the approach to the western and eastern tunnel portals. The lowest point has been selected at this location as it is a natural low point beneath the Cooks River Palaeochannel. The deepest section of the tunnels is beneath the Arncliffe at a depth of around 80 metres beneath ground surface.

Tunnel excavations would be carried out with roadheaders. Blasting would be used in some areas of the tunnel excavation to improve the efficiency of excavation activities and shorten the overall excavation program.

Cut and cover structures would be constructed for the project at the western and eastern portals, as well as the structure beneath Campbell Road as part of the potential future connection of the St Peters Interchange with the M4-M5 Link.

The tunnel cross section would be a relatively flat arched profile. The arch profile would vary slightly depending on the local geology. Indicative dimensions of the main alignment tunnels (without fit-out) are summarised in Table 8. The arched tunnel profile has several advantages, including the prevention of ponding of groundwater in the strip drains that direct groundwater to the drainage systems along the sides of the tunnels.

Table 8 Indicative tunnel dimensions (metres)

Tunnel section	Width (tunnel floor)	Width (arched tunnel roof)	Height (metres)
From the western portals to the southern extension caverns.	12.4	14.1	6.5
From the southern extension caverns to the St Peters caverns.	17.9	20.6	7.9
M4-M5 Link and Southern extension stub tunnels.	12.4	14.1	6.5
Areas with breakdown bays.	22.5	24.7	8

Note: Indicative tunnel dimensions are within Hawkesbury Sandstone and without tunnel fit-out. Widths and heights may vary locally along the length of the project due to geological constraints, and areas where additional tunnel features are present.

5.2.2 Construction Compounds

A number of construction compounds are proposed to support the construction of the project. A limited number would include tunnel support at which roadheaders would be launched. These are:

- The Kingsgrove North construction compound (C1).
- The Kingsgrove South construction compound (C2).
- The Bexley Road North construction compound (C4).
- The Bexley Road South construction compound (C5).
- The Arncliffe construction compound (C7).
- The Canal Road construction compound (C8).
- The Campbell Road Construction Compound (C9).

5.2.3 Tunnel Ventilation System

The ventilation system for the project would include ventilation facilities and emergency smoke extraction facilities at the following locations

- The Kingsgrove motorway operations complex (MOC1).
- The Bexley Road South motorway operations complex (MOC2) (emergency smoke extraction only).
- The Arncliffe motorway operations complex (MOC3).
- The St Peters motorway operations complex (MOC4).

The facilities would be constructed utilising shafts used for the tunnelling works at the Bexley Road South and Arncliffe construction compounds. Precast concrete wall panels would be used for shaft structure stability.

5.2.4 Tunnel lining and groundwater collection system

The majority of the tunnel alignment would be located within Hawkesbury Sandstone. There would be some smaller areas in shale and underneath geological secondary structural features such as faults, joint sets, dykes and shear zones, which would likely include a higher water inflow and more fractured rock.

The project would be construction to limit groundwater inflow along the tunnel length to no greater than one litre per second across any given kilometre of tunnel. In areas of high local hydraulic conductivity zones, the natural rock mass permeability may have to be reduced, such as the use of shotcrete and grout, to achieve one litre per second across any given kilometre of tunnel.

To limit groundwater inflow, tunnel lining would be installed progressively as the roadheaders advance. Two types of lining would be used for the project, depending on the local geology. Different types of waterproofing would be applied depending on the inflow type and rate. Should the inflow be expected to exceed the inflow criteria set in the long term, grouting would be carried out to reduce the inflow to an acceptable inflow rate. This approach is to limit groundwater extraction during construction by maintaining groundwater inflow to below the project criterion of one litre per second per kilometre.

During construction and operation, groundwater inflows would be collected via the tunnel drainage system and pumped to the surface for treatment prior to discharge. Treatment would be undertaken during construction and operation prior to discharge.

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

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

The groundwater would be treated and discharged in accordance with the surface water guidelines. The potential impacts associated with the discharge of treated groundwater is addressed in Technical Working Paper: Surface Water (AECOM, 2015i).

5.3 Geological features along the project corridor

As noted in **Section 5.2.1** the majority of the tunnel alignment would be located within Hawkesbury Sandstone. There would be some smaller areas in shale and underneath geological secondary structural features such as faults, joint sets, dykes and shear zones, which would likely include a higher water inflow and more fractured rock.

5.3.1 Western surface works

Construction of the western portal would be by cut and cover techniques to provide access for the road headers. The portal would intersect fill and rubble associated with the current M5 East Motorway underlain by alluvium near Wolli Creek, weathered shale and then Hawkesbury Sandstone. Groundwater is expected to be encountered at the base of the alluvium, at the approximate level of Wolli Creek.

5.3.2 Main tunnel alignment between western surface works and Southern extension caverns

The main tunnel alignment that would connect to the western portal is constructed completely within Hawkesbury Sandstone. The project would be constructed in sandstone with the overlying rock cover varying from 20 to 30 metres in the west and 70 metres to 115 metres beneath the Bardwell Park plateau.

The sandstone is expected to be of good quality with a low density of structural features and hence groundwater inflows are expected to be minimal with the following exceptions:

- Possible joint swarms and Luna Park Fault Zone beneath Bardwell Valley
- Localised siltstone may be encountered throughout.

5.3.3 Southern extension cavern

The future Southern extension stubs would be located in Arncliffe where the tunnel alignment passes below the Cooks River Palaeochannel.

The cavern is located completely within Hawkesbury Sandstone with approximately 70 to 75 metres of rock cover. There is potentially a fault intersecting the cavern.

5.3.4 Bexley Road surface works

The Bexley Road surface works, which would include the Bexley Road South construction compound and the Bexley Road South motorway operations complex, is located on the northern bank of Wolli Creek.

The Bexley Road East construction compound would provide access to the main alignment tunnels (position around -45 metres AHD) via a shaft. The geology at this site is complex with an incised palaeochannel expected beneath Wolli Creek which is almost certain to contain large volumes of groundwater within the saturated sediments. In addition sub-vertical dolerite dykes have been encountered which are expected to be highly fractured and possibly act as a conduit for groundwater flow.

5.3.5 Arncliffe motorway operations complex

The Arncliffe motorway operations complex would be located at the western corner of Kogarah Golf Course. As detailed earlier, the permanent air intake and smoke extraction facility would utilise the shaft used for the tunnelling works.

The golf course is underlain by fill, alluvial Holocene aged sands to around -5 metres AHD, Pleistocene aged sands and clays to around -20 metres AHD which is underlain by Hawkesbury Sandstone. Groundwater levels within the alluvial sediments are shallow, between one and two metres below ground level. Consequently the shaft would be constructed with retaining walls (reinforced soil walls) and water proofing in the upper parts to prevent groundwater inflow.

5.3.6 Tunnel between Southern extension cavern and St Peters caverns

The majority of the main alignment tunnel between the southern extension stubs and the St Peters caverns would be constructed in Hawkesbury Sandstone with around 55 metres to 70 metres of overlying rock cover. The sandstone is expected to be of good quality with a low density of structural features and hence with minimal groundwater inflows with the following exceptions:

- Possible faulting beneath Kendrick Park in Tempe;
- Palaeochannels have been mapped beneath Cooks River and Cahill Park and at these locations there may be only 19 metres of rock cover above the tunnel;
- Faulting within the sandstone and a palaeochannel have been mapped beneath Alexandra Canal;
- At Cooks River, Kendrick Park, Cahill Park and Alexandra Canal structural features are present within the sandstone below the mapped paleaochannels and the joints and fractures may act as a conduit for groundwater flow into the tunnels.

5.3.7 St Peters caverns

The St Peters caverns are located in Tempe close to the Princes Highway with around 70 metres of rock cover and represent the confluence of the main tunnel alignment with the M4-M5 Link stub tunnels and the on and off ramps connecting to the St Peters interchange.

5.3.8 M4-M5 Link stub tunnels

The M4-M5 Link stub tunnels would be constructed in good quality Hawkesbury Sandstone with around 50 metres to 70 metres of rock cover. Limited faulting has been identified suggesting tunnel inflows would be limited. 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. The stub tunnels would link with the project and would extend to an elevation of – 38 metres AHD.

5.3.9 On and off ramps, St Peters interchange

The on and off ramps would link the St Peters caverns to the eastern portals at St Peters interchange. The ramps transition through the Mittagong Formation and into the Ashfield Shale. In this area there is a thick sequence of weathered shale as evidenced at the former Alexandria Landfill.

5.3.10 St Peters interchange

The St Peters interchange is an above ground structure that would traverse the footprint of the Alexandria Landfill. As part of this project, the landfill would be closed and remediated to enable the construction and operation of the interchange. As part of these works, up to ten metres of fill would be excavated to accommodate the proposed road infrastructure. The excavated fill would to be retained on-site where possible in accordance with the Landfill closure management plan (LCMP).

Groundwater flow at the landfill is radial towards the centre of the site due to the current leachate management system which pumps leachate from a central sump for treatment on-site before discharge to sewer. The landfill is unlined and receives groundwater inflow from the Botany Sands and Ashfield Shale. The landfill also receives rainfall recharge as the majority of the landfill is un-capped. The leachate pumping system and leachate treatment plant would continue to operate throughout the construction and operation phases to maintain groundwater levels below the cutting.

As part of this project, a leachate collection system and an upgraded leachate treatment plant would be constructed at the end of the construction phase for on-going leachate treatment during the operation phase. The interchange is to be constructed to minimise groundwater inflow from the Botany sands to minimise leachate generation. On-going pumping from the leachate pumping system would maintain groundwater levels below the road level in the early operational stages.

Treated leachate would continue to be discharged to sewer under a trade waste agreement. On-going water management would be required at the landfill following construction of St Peters interchange. Rainfall infiltration would be reduced following the capping of the landfill, however groundwater inflow would continue to generate leachate. Groundwater inflow to the former landfill will be from the Ashfield Shale and Botany Sands. Inflow from the Ashfield Shale would be minor and naturally flow into the landfill as it is unlined. The most groundwater inflow to the landfill currently is from the Botany Sands. To minimise inflow from the Botany Sands a cut-off wall socketed into the Ashfield Shale that broadly encircles the southern part of the landfill would be installed as part of the project. The cut-off wall restricts groundwater flow into the landfill and reverses groundwater gradients so groundwater discharges into Alexandra Canal.

5.4 Justification for a drained tunnel

The project is designed as a drained tunnel and is to be constructed predominately through sandstone with sections of shale. Local grouting may be required to reduce the bulk rock permeability to meet the groundwater inflow criterion in sections of the tunnels. As such, the approach to control of water ingress into the tunnel consists of a suite of options, ranging from areas where no waterproofing may be required to areas where a membrane may need to be applied to divert water into the drainage system and grouting may be required.

The design of the project has also had consideration to minimising groundwater inflow with:

- The vertical alignment would dive beneath palaeochannels that could otherwise provide elevated inflows into the tunnels.
- The horizontal alignment maximising the extent of the tunnel alignment within competent Hawkesbury Sandstone and minimising the alignment traversing beneath sensitive environmental areas, creeks and wetlands.

This assessment of potential groundwater impacts has included the potential impacts due to the construction and ongoing operational impacts and provided management or mitigation measures to minimise the impacts on existing users and the environment.

5.4.1 Undrained tunnels

Undrained tunnels limit the groundwater inflows into the tunnel to very small flows (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 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; and
    3) Damage to existing infrastructure due to the settlement of compressible soils.
- Limit inflow of groundwater into the tunnel to mitigate:
    4) Corrosion which may damage internal tunnel assets, drainage and treatment systems due to corrosive groundwater;
    5) Blockage of tunnel drainage systems and high maintenance requirements due to sludge precipitating from groundwater with high natural iron and manganese concentrations; and
    6) Treatment and discharge of potentially saline of low pH groundwater.

5.4.2 Why construct drained tunnels

The option to construct drained tunnels rather than lined undrained tunnels can have a large impact on the project outcomes and economic feasibility. The decision is either driven by mitigation of potential impacts from issues 1 and 3 above or from the outcomes of a whole of life cost assessment in consideration of issues 4 to 6 above (i.e. capital cost versus operational cost).

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

Typically drained tunnel sections that extend beneath creeks are grouted to reduce the risk of increased tunnel inflow. There are many other drained tunnels excavated in sandstone and shale throughout the Sydney Basin and very few undrained tunnels, in part due to the competent nature of the bedrock. The few known undrained tunnels are the North West Rail Link (NWRL) and City East Cable Tunnel, both of which were designed as undrained structures as part of a whole of life cost assessment, and to mitigate maintenance and operation issues associated with items 4 to 6 above.

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

There are potential environmental, sustainability, social and safety impacts associated with excavating larger tunnels, to accommodate a liner which includes moving more spoil, and transporting and disposing of more materials for tunnels. In addition, these factors contribute to a higher capital cost, but there would be an off-setting reduction in operating costs. On-going operating costs for a drained tunnel would include the collection, treatment and discharge of groundwater. In the absence of any indication for potential impacts associated with items 1, 2 and 3 above, it was therefore considered reasonable to specify a groundwater control (in the form of an inflow limit) instead of an undrained requirement.

5.4.3 Inflow rate of 1 L/sec/km

The New M5 tunnel inflow design criterion is one litre per second per kilometre averaged over every kilometre of tunnel. This criterion is more stringent that other Sydney tunnels where the inflow criterion is typically one litre per second per kilometre averaged over the length of tunnel. The design criterion is broadly based on inflows experienced in other Sydney tunnels within similar geological and hydrogeological conditions as summarised in Section 3.10.

The majority of groundwater inflow into the New M5 tunnels is expected to be derived from the Hawkesbury Sandstone. The Hawkesbury Sandstone is a dual porosity aquifer where groundwater enters the tunnel via the rock matrix voids (primary porosity) and saturated joints fractures, shear zones, dykes and solution cavities (secondary porosity). The majority of groundwater inflow from the Hawkesbury Sandstone entering a major tunnel such as the New M5 is via saturated vertical or sub-vertical structural features, however during construction major inflow zones are to be grouted to reduce tunnel inflow and maintain inflow rates below the design inflow criterion.

This page has been left blank intentionally.

6.0 Impact assessment – Construction

Groundwater along the alignment during construction could be impacted. Potential impacts are discussed and mitigation measures to eliminate or manage potential impacts are discussed in Section 8.1. The potential impacts identified are reduced groundwater recharge impacts, drawdown impacts and groundwater quality impacts. Each of these potential impacts is discussed below with specific discussions about identified environmentally sensitive areas.

6.1 Potential groundwater inflow

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

The tunnels are to be constructed predominately through the competent Hawkesbury Sandstone and to a lesser extent the Mittagong Formation and Ashfield Shale. The tunnel alignment is designed to not intersect the palaeochannels beneath Cooks River and Bardwell Valley by diving below these features. There is potential for the palaeochannels to extend deeper than expected (based on current information) and consequently there is a low risk that the alignment could intersect a palaeochannel.

Groundwater inflow from the Hawkesbury Sandstone is expected to be low due to low bulk hydraulic conductivity values typically 0.008 metres per day (Table 6). The Ashfield Shale overlying the Hawkesbury Sandstone typically has a lower hydraulic conductivity in the order of 1×10^{-3} to 1×10^{-2} m/day (Hewitt, 2005) indicating groundwater inflow is expected to be lower. Higher hydraulic conductivity values are expected along major structural features within the sandstone and shale such as joints, fractures and shear zones where higher inflows are expected. Other potential problem areas related to the intersected lithology have been identified that may affect tunnel drainage including dykes, Botany Sands, alluvium and palaeochannels.

During construction, routine advance drilling would inform the geological conditions that would encountered during tunnel excavation and inform the required waterproofing. This includes in the event that a palaeochannel is intersected by the project.

Botany Sands

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

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

Alluvium

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

Palaeochannels

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

Dykes

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

6.1.1 Predicted groundwater inflows

Groundwater modelling (CDM Smith, 2015) predicted model inflows of 1,115 cubic metres per day into the project tunnels. Over a modelled length of 20 kilometres an inflow rate of 0.63 litres per second along every kilometre of east bound (shallower) tunnel and 0.67 litres per second along every kilometre of the westbound (deeper) tunnel was predicted. These results are consistent with the results reported by the contractor calculated using the Heuer method.

Groundwater modelling is based on well-established scientific principles, but has limitations because of the difficulty of inferring the properties of an extensive aquifer based on a relatively small number of measurements. From a groundwater modelling point of view, an estimate of 0.6 L/sec/km is equivalent to an estimate of 1 L/sec/km. In this case, the fact that the model predicts a lower value for the New M5 tunnels than for the existing tunnels means that geometry (depth of tunnels and hydrostratigraphy) and spatial variability in vertical and horizontal hydraulic conductivities combine to suggest smaller flows into the New M5 tunnels.

The modelling has not predicted inflow rates during construction, but rather has predicted long term steady state inflows that would only apply once equilibrium has been reached (that is the long term operational inflow rates). It is difficult to predict the evolution of inflows during construction, mainly because the short term tunnel inflows are influenced by local fracturing and storage of water in nearby fracture networks (CDM Smith, 2015). The model also predicts average inflow rates. Higher inflow rates are likely from zones of higher permeability, where saturated geological structural features are intersected. During construction these high inflow zones are to be grouted to reduce the inflow rate below one litre per second per kilometre. However the potential for higher inflow rates has been considered in the assessment, and the consideration of mitigation and management measures.

Initial inflows to tunnels during construction can be large, because of the large hydraulic gradients that develop near the walls, however these gradients dissipate in time as inflows approach a steady state. That is during construction relatively large inflows can be experienced for a short duration as the confined storage from water bearing fractures is released due to water expanding slightly as pressure drops. After the initial confined storage is released inflow rates decline as storage is depleted and groundwater levels begin to decline. Eventually a steady state equilibrium is reached where rainfall recharge is balanced with groundwater inflow to the tunnels and the groundwater levels no longer decline due to tunnel inflows. The higher construction inflow rates would be expected to decline in the order of days rather than weeks.

Ventilation tunnels in sandstone and shafts from the surface to those tunnels would also have the potential to induce leakage. The impact of the ventilation tunnels are expected to have a minor impact compared to the main alignment tunnels because they are relatively short and adjacent to the main tunnel alignments, so that the effects of the project would already be taken into account (CDM Smith, 2015).

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

It is recognised that high groundwater inflow during excavation is possible in faulted or fractured zones or other water bearing geological features such as beneath the Cooks River palaeochannels or beneath Wolli Creek. During construction, the hydraulic gradients near the exterior surface of the tunnel would be steep causing initial rates of inflow to be greater than at later stages. To reduce groundwater inflows, pre-excavation pressure grouting would be undertaken to allow groundwater inflows to be more easily managed. This technique is undertaken by drilling a pattern of holes in advance of the excavation to conduct packer tests. Once the hydraulic conductivity is calculated grout is injected at a pre-determined pressure to reduce the bulk rock mass permeability. The implementation of this technique is dependent upon the local geology.

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

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

6.2 Groundwater drawdown impacts

Groundwater drawdown due to construction activities and temporary dewatering could impact the local water table or surface water features where there is hydraulic connectivity. As the tunnels are drained structures, the tunnels could impact the natural groundwater system and potentially alter regional hydrogeological conditions. Inflows from the Hawkesbury Sandstone and Ashfield Shale are expected to be highest during construction as hydraulic gradients will be at their highest and then would decline as equilibrium is reached.

Groundwater drawdown impacts during operation are discussed in Chapter 7.0. During construction the drawdown impacts due to tunnel construction would be minimal even though groundwater inflows are high due to high hydraulic gradients. That is during tunnelling there is initially no drawdown of the water table, but eventually over time and certainly within tens of years the effects of depressurisation at depth would impact the water table causing a water tabledecline (CDM Smith, 2015). .

The longer term impacts would be greater as steady state conditions are reached as discussed in Section 7.2.

6.3 Reduced groundwater recharge impacts

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

The majority of the project is below ground surface and is unlikely to directly impact groundwater recharge during construction. The risks during the construction would be that access roads, tracks and the isolation of areas for stockpiling of construction materials, groundwater recharge could be altered, moderately reducing recharge. These impacts are considered minimal and temporary.

Alexandria Landfill would be capped to reduce recharge and surface water run-off from the cap and road infrastructure would be directed off-site. Construction impacts at Alexandria Landfill are discussed in Section 6.7.

6.4 Impacts on existing users

A review of current groundwater use has been conducted to identify registered groundwater users and the environment within a one kilometre buffer of the project corridor. In the event that groundwater users are impacted by the project by a decline in groundwater levels in existing bores, in excess of two metres, provisions are to be implemented to ‘make good’ the supply by restoring the water supply to pre-development levels. The measures taken would be dependent upon the location of the impacted bore but could include, deepening the bore, providing a new bore or providing an alternative water supply, or alternatively providing appropriate monetary compensation. A review of existing users within and adjacent to the project corridor is summarised in Section 3.9.

A three dimensional numerical groundwater model has been developed to assess the potential groundwater level drawdown at sensitive areas and where the impacts are expected to be in excess of minimal impact considerations as specified in the Aquifer Interference Policy, mitigation measures have been recommended. The impacts on existing users during construction are the potential drawdown in monitoring wells due to the extraction of groundwater during tunnelling.

The drawdown is expected to be less in the construction than during the operational phase, since groundwater levels would continue to decline until steady state conditions are reached. These impacts are discussed in Chapter 7.

There is potential for groundwater extracted from the alluvium to become more saline due to inducing saline water from tidal rivers towards the bore. It is however likely that alluvial groundwater hydraulically connected to the tidal rivers are already saline so the potential impact to reduce water quality is considered low.

6.5 Impacts to the environment

6.5.1 Drawdown beneath creeks

Surface water features along the project alignment are described in Section 3.4. Beneath creeks groundwater and creek water could enter tunnels directly where saturated secondary structural features are hydraulically connected to the creek and aquifer through the saturated alluvium or palaeochannel sediments. In these environments a risk to the tunnel integrity is posed as the groundwater inflows combined with stream losses could exceed one litre per second per kilometre and large drawdowns within the Hawkesbury Sandstone could occur. Losses to stream flows are dependent on the hydraulic connection between the stream channel and alluvium the underlying sandstone or shale and the relative water levels of the creek and groundwater.

Surface water can only flow to the groundwater system when the groundwater levels are lower than the surface water levels or when the alluvial water table falls below the surface water level in the creeks. In the lower catchment reaches if brackish water from the Cooks River or Wolli Creek replaces groundwater lost from the alluvium the groundwater quality may be degraded. Typically groundwater levels would be higher than surface water levels almost all of the time. Therefore, the flow direction would be from the groundwater to the Cooks River and Wolli Creek. However, if the groundwater levels are lowered, then flow could be reversed. Therefore, there is potential for groundwater quality to decline as a result of the groundwater drawdown, although the natural groundwater is likely to be brackish due to interaction with the surface water during periods of climatic variation. Higher up in the catchments any groundwater loss from the creeks to groundwater via leakage should not impact groundwater quality as the surface water would be of low salinity.

Long term predictions for groundwater drawdown indicated that along the alignment west of Arncliffe drawdown is expected to be less than elsewhere along the alignment, presumably due to existing drawdown caused by the existing M5 East Motorway tunnel, which is a drained tunnel. The predicted extent of lateral drawdown varies from around 500 metres in the western part of the alignment to approximately one kilometre elsewhere. The lateral footprint of drawdown within the alluvium has been shown as being variable but less than the extent within the bedrock. Drawdown within the sandstone has not extended to the top of the tunnel due to the interbedded sandstone and shale layers above the tunnel behaving as aquicludes restricting groundwater drawdown combined with recharge.

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

6.5.2 Groundwater Dependent Ecosystems

An assessment of potential impacts on GDEs due to groundwater drawdown is discussed in Section 7.6 as the potential operational impacts would have a longer term impact on these communities. During tunnelling there would be no immediate effect on GDEs as discussed in Section 6.1.1 and Section 6.2.

6.6 Groundwater quality impacts

The risks from construction activities to adversely impact groundwater quality include the potential to contaminate groundwater from fuel, oil and other chemical spills and the captured groundwater intersected during tunnelling. There is also potential to intersect acid sulfate soils and contaminated groundwater such as lead impacted groundwater adjacent to Alexandria Landfill (AECOM 2015e).

6.6.1 Spills and incidents

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

The risks to groundwater as a result of such incidents would be managed through standard construction management procedures. Further, emergency spill kits would be kept on site during construction and staff would be trained in their use. All liquid dangerous goods and hazardous chemicals would be stored within a bunded storage container or spill tray within the construction compounds.

6.6.2 Intercepting contaminated groundwater

A number of sites with the potential for contamination are located along the project main tunnel alignment due to various current and historical land-uses as outlined in Section 3.11 and assessed in Technical Working Paper: Contamination (AECOM, 2015h). A potential contamination risk to the tunnels and caverns would be associated with the migration of contaminated groundwater plumes towards the tunnels.

The majority of the tunnels are to be constructed within the Hawkesbury Sandstone at depths greater than 20 metres at the western and eastern ends and around 80 metres beneath Arncliffe. Given these combined factors of the depth, location of the tunnel in relation to the contaminant source and low inflow rates, the risk of intercepting contaminated groundwater is considered low.

There is potential to intersect contaminated groundwater during construction while excavating the portals and dive structures that are constructed from the top down.

At Arncliffe, groundwater beneath the site is shallow and impacted by a variety of historical land uses including market gardens (pesticides and herbicides), dredged sediments from the Cooks River (with ASS) and sewage disposal and landfilling (leachate). Leachate and elevated ammonia concentrations have been reported in the groundwater within former landfills in the southern part of the golf course. Groundwater flow within the alluvium and fill beneath the golf course is towards the Cooks River and also influenced the Cooks River palaeochannel. The main alignment tunnels are not expected to be impacted by the shallow contaminated groundwater as the tunnel would be deep within the Hawkesbury Sandstone. However during ground excavation works associated with the tunnel access decline (which would be repurposed for ventilation purposes), shallow groundwater is likely to be encountered and would require management during construction.

Potential contaminated groundwater inflows could be derived from industrial sites that overlie the tunnels at Alexandria and St Peters where the tunnels are relatively shallow but constructed within the Ashfield Shale. At 316 Princes Highway there is former service station where the underground fuel tanks remain and petroleum hydrocarbon impacts may be present. Near this location the cut and cover northern ramp portals are to be constructed. Again the risk is considered low because the tunnel is constructed within the Ashfield Shale where the hydraulic conductivity and groundwater leakage would be low (AECOM, 2015h).

Leachate and elevated concentrations of ammonia are associated with the Alexandria Landfill. Geotechnical drilling as part of the project did not identify localised faulting or fracturing which could provide leachate conduits. Immediately south of the Alexandria Landfill at the Canal Road site contaminated lead has been identified (AECOM, 2015e). However, the cut-off wall that would be constructed at the Alexandria Landfill would be designed to prevent un-impacted groundwater from the Botany Sands from flowing into the landfill and generating leachate. Installation of the cut-off wall would also capture the lead and hydrocarbon impacted groundwater to the south west of the landfill and direct it to the landfill where it would be extracted and treated prior to discharge to sewer.

6.6.3 Groundwater management

The volume of groundwater and treatment requirements would differ depending on the depth of the tunnel to be constructed, and the geological units through which it passes. Captured groundwater and surface water as a result of tunnelling are likely to be contaminated with suspended solids and increased pH due to tunnel grouting activities.

It would comprise of around 65 percent of water captured would be groundwater as a result of tunnelling activities with the remaining 35 percent resulting from imported construction water.

These flows would be captured and treated prior to discharge via water treatment plants located at Kingsgrove, Bexley North, Arncliffe and St Peters. The assessment of the potential impacts from the quality of water discharged from the groundwater treatment plant is discussed in Technical Working Paper: Surface Water (AECOM, 2015). and is not discussed further in this technical working paper.

6.6.4 Acid Sulfate Soils

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

PASS and/or ASS may be intersected at Arncliffe construction compound, near Alexandra Canal and at Alexandria Landfill. This is discussed further in Chapter 16 of the environmental impact statement.

At Arncliffe, the disturbance of PASS may occur during the construction earthworks. Treatment of PASS may be required as part of any re-contouring or excavation works at the golf course.

Near Alexandra Canal the project would be constructed at the ground surface with bridge crossings of the canal. Excavation of PASS may occur during road construction works, the construction of bridge footings or dewatering.

Based on historical quarrying records at Alexandria Landfill, PASS is most likely present in the southern and eastern areas of the site outside the areas that have been subject to quarrying. ASS could be excavated during earth moving works and/or acidic groundwater could be pumped during construction dewatering.

In general, acid sulfate soils could be disturbed by the project and may cause the generation of acidic runoff and/or the increased acidity of groundwater. To manage these risks, a Construction Soil and Water Quality Management Program (CSWQMP) would be prepared in accordance with *NSW Acid Sulfate Soils Manual* (Stone et al., 1998). The CSWQMP would include water quality monitoring and acid sulfate soil management.

6.6.5 Groundwater Aggresivity

An understanding of the major ion chemistry as outlined in Section 4.2 is important as the groundwater can be corrosive to building materials depending on a number of hydrogeochemical factors including salinity, pH, sulfate and chloride concentrations. Understanding the corrosive nature of the natural groundwater intersected assists in selecting building materials to minimise corrosive impacts to the tunnel and its infrastructure.

Tunnel infrastructure including the construction of interchanges and installation of water proofing will be mostly located below the water table and subjected to corrosion due to interaction with groundwater. There are a number of factors that contribute to corrosion, which may be due to groundwater aggresivity. The average primary parameters of groundwater aggresivity are presented in Table 5. The presence of dissolved chloride and sulfate in groundwater is one of the main factors contributing to corrosion potential of concrete and steel. By application of the exposure classification in the Australian Standard AS2159-2009 for piling – design and installation and referring to the average values from Table 5 the water for all lithologies is mildly aggressive to concrete for average chloride and non-aggressive for average sulfate.

Along the alignment groundwater quality intersected by the tunnel would be variable as different water bearing fractures are intersected. Assessment of the groundwater quality data indicates the groundwater with the highest aggresivity based on elevated electrical conductivity and sulfate and chloride concentrations will be in the northern part of the alignment around St Peters interchange where the Ashfield Shale outcrops. In addition aggressive groundwater is also expected within the Hawkesbury Sandstone in the Tempe Arncliffe area near Cooks River. The piling standards also state that the exposure classification for piles intersecting domestic waste and industrial waste would be severe and very severe which are likely to impact the piles to be constructed to stabilise the road to be constructed through the Alexandria Landfill.

Long term the tunnels are designed to be drained and will require groundwater seepage, tunnel wash or deluge system water to be collected, treated and discharged. Water treatment may be required to reduce salinity and turbidity and adjust pH. The discharge would likely be into a local watercourse, such as Wolli Creek, the Cooks River or Alexandra Canal. This could depend on the discharge volumes and the point of discharge. Water is to be discharged under the same conditions as surface water.

6.7 Alexandria Landfill

Although the Alexandria Landfill has ceased commercial operations, leachate is still being generated due to rainfall infiltration and groundwater seepage. Leachate management is subject to the requirements of Environment Protection Licences, which includes a requirement for on-going pumping and monitoring with annual reporting.

A landfill closure management plan (LCMP) has been developed to manage leachate generation and treatment during and after construction (AECOM, 2015c). On-going leachate pumping would be required during the construction of the St Peters interchange to maintain groundwater levels below the finished road level and foundations and to maintain radial groundwater inflow into the landfill to prevent leachate from migrating into the shale. In addition the portal and the cut and cover sections of the interchange would be below the natural groundwater level. Within Alexandria Landfill or the Botany Sands it is possible that there is shallow perched contaminated groundwater present. Where this contaminated groundwater is intersected, treatment is likely to be required prior to discharge.

Consequently a groundwater management system is required. This includes measures to reduce the generation of leachate during and after the construction of the interchange, as well as the collection and treatment of leachate.

Leachate generation can be reduced by reducing rainfall infiltration and/or groundwater inflow.

Rainfall infiltration would be reduced by the installation of the road drainage network and capping of the landfill as part of the LCMP. As part of the project, the final capping layer would include a low permeability capping layer, subsoil drainage connected to stormwater and a revegetated layer at the surface.

Groundwater inflow is primarily from the Botany Sands aquifer and would be reduced by the installation of a soil bentonite or cement bentonite cut-off wall. Groundwater extraction from the Botany Sands and discharge to stormwater is not in accordance with the policy of the NSW Office of Environment and as such, a cut-off wall has been proposed as the preferred groundwater management option. The design specifications of the cut-off wall would be around 1000 metres in length around the southern perimeter of the landfill, with a thickness of 0.8 metres and hydraulic conductivity of 10^{-8} metres per second.. This will locally reverse groundwater gradients away from the landfill and towards Alexandra Canal restoring pre-quarry hydrogeological conditions.

Capping the landfill and construction of the cut-off wall is designed to reduce rainfall infiltration to the Botany Sands inside the cut-off wall. As such, groundwater recharge inside the cut-off wall would be reduced, which would ultimately reduce the volume of leachate being generated. Consequently the leachate generated post-construction is likely to contain a higher concentration of contaminants pre-construction, which would require treatment. Outside the cut-off wall groundwater recharge is unlikely to be significantly impacted as this area would not be capped although the paved area is likely to increase due to the construction of the road infrastructure. Groundwater quality within the Botany Sands outside the wall is likely to be improved due to the groundwater contaminated with lead associated with the Canal Road site being captured by the cut-off wall.

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

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

A long term groundwater and leachate management system would also be constructed during the construction of the interchange. This is designed as a long term management system to minimise groundwater seepage into the landfill to reduce leachate generation. During construction, leachate collected by the leachate management system would be collected and treated via the existing leachate treatment plant. The existing leachate treatment system is currently being upgraded in accordance with an effluent improvement program agreed with Sydney Water. It is understood the upgraded system would be fully operational and compliant by the end of 2015. It would treat a minimum 100 kilolitres per day of raw leachate and remain operational until 2017 until the new leachate treatment plant is operational. The new leachate treatment plant would have a maximum treatment capacity of 200 kilolitres per day. The construction of the leachate treatment plant is proposed to commence in 2016 for completion in 2017.

North-west of the landfill, beneath Canal Road, the M4-M5 Link stub tunnels extend to an elevation of -38 metres AHD, below the base of the landfill. Given the off-set for the stub tunnels is around 140 metres horizontally from the landfill within Hawkesbury Sandstone the risk of migration of leachate through the Ashfield Shale into the Hawkesbury Sandstone and tunnels is considered low.

The desalination pipeline is located south of the landfill and is likely to be partly inside the cut-off wall and subject to dewatering due to the installation of the cut-off wall. Risks to the pipeline and required mitigation would be confirmed during detailed design..

7.0 Impact assessment – Operational

Following construction and implementation of mitigation strategies, there could be long term residual impacts to groundwater. Potential impacts are discussed in this chapter and mitigation measures to eliminate or manage potential risks are discussed in Chapter 8. The potential impacts identified are reduced groundwater recharge impacts, drawdown impacts and groundwater quality impacts. Each of these potential impacts is discussed below with specific discussion of environmentally sensitive areas.

An Operational Environmental Management Plan (OEMP) would be developed outlining the management measures for groundwater inflows, treatment and discharge.

7.1 Potential groundwater inflow

Long term groundwater inflows to the tunnels would be influenced by the geology intersected as outlined in the construction groundwater inflows (Section 6.1) although the flows are likely to be lower than the construction inflows. Based on groundwater inflows to other drained Sydney tunnels (Section 3.10) and the results of groundwater modelling (Section 2.3 and Appendix A) the long term inflow is expected to be below the one litre per second per kilometre criterion on average. Specific zones capable of higher rates of inflow identified during construction would be treated to reduce inflow rates to below the criterion.

While the evolution of tunnel inflows during construction has not been calculated by the model it is discussed qualitatively. Inflows to the M5 East Motorway are important due to the proximity of the tunnel to the project. During the construction of the M5 East Motorway no grouting was reported to control groundwater inflows. Localised inflows of two to three litres per second were reported, reducing to 1.5 litres per second within two to three weeks of construction (Best and Parker, 2005). Inflows during construction could not be calculated due to because the short term tunnel inflows are influenced by local fracturing and storage of water in nearby fracture networks. Initial inflows to tunnels can be large, because of the large hydraulic gradients that develop near the walls, however these gradients dissipate in time, as inflows approach a steady state. Immediately after tunnelling, the rate of inflow to a tunnel is as large as it ever becomes, but the effect on the water table is zero. With time, the rate of inflow to the tunnel decreases, while the effect at the water table gradually increases. At some time after the water table starts to decline, the rate of inflow into the tunnel would be almost balanced by the rate of change of storage at the water table.

Groundwater modelling predicts the overall groundwater inflow to achieve less than one litre per second per kilometre as high inflow zones are grouted during construction. Groundwater inflow is dependent upon the final construction methodology and water proofing solutions as determined during detailed design. As discussed in Section 6.1.1, the predicted average groundwater inflow along the 20 kilometre of tunnels is an inflow rate of 0.63 litres per second along every kilometre of east bound (shallower) tunnel and 0.67 litres per second along every kilometre of the westbound (deeper) tunnel.

7.2 Groundwater drawdown

Previous tunnelling in the Hawkesbury Sandstone in the Sydney region has shown that groundwater inflow is typically highest during construction and then is reduced as the cone of drawdown expands and an equilibrium or steady state conditions are approached. This equilibrium is achieved when the tunnel inflow is matched by rainfall recharge via infiltration. Groundwater drawdown within the palaeochannels and river alluvium would be minimal or not likely to occur as the hydraulic heads within saturated sediments are maintained by direct hydraulic continuity with surface water, supported by a slight reduction in river baseflow. Immediately after tunnelling is completed groundwater inflows would be at their highest but there would be at that stage no impact on the water table. With time groundwater inflow to the tunnel would decrease while the water table would gradually decline until an equilibrium is reached.

Construction of the drained tunnels beneath the water table may cause long term on-going groundwater inflow inducing groundwater drawdown along the tunnel alignment. There are two main mechanisms that influence groundwater drawdown, the actual water table drawdown and the hydraulic pressure drawdown. Actual groundwater drawdown of the water table would be dependent on proximity to the tunnel alignment.

In zones where the inflow rates are likely to exceed one litre per second per kilometre, water bearing fractures/rock defects would be grouted to reduce groundwater inflow. This grouting would also reduce drawdown impacts. The Hawkesbury Sandstone is also interbedded with shale lenses that locally act as aquicludes or aquitards restricting vertical groundwater movement. Shallow perched water over shale lenses (recharged by rainfall) also occurs, which potentially sustains surface ecosystems. To the west of the alignment the deeper water table within the Hawkesbury Sandstone is already influenced by drawdown induced by the existing drained M5 East Motorway tunnels. Localised groundwater drawdown could also be expected around existing shafts and portals that extend below the water table.

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

Long term dewatering caused by tunnel drainage could lower the water table within the Hawkesbury Sandstone and reduce the amount of groundwater available for shallow rooted plants. The minimum depth of the water table underlying the majority of the alignment is on average two metres below ground surface and the flora is unlikely to be completely dependent on groundwater. This would not change as the unsaturated zone is influenced by rain infiltration. In low lying areas the low permeability of the clayey soils in combination with frequent rainfall events and higher recharge due to surface water concentration is not expected to change availability of water for plants. The predicted drawdown at the various creeks varies depending on local geology, horizontal distance from the tunnel and depth to the tunnel. Typical drawdown within alluvium is estimated to be negligible as it is recharged by rainfall infiltration and will continue to discharge to surface water. In upper reaches of the catchment the water table can be more than 30 metres below ground level.

Long term dewatering could also impact existing groundwater users registered with NSW DPI (Water). A review of the NSW DPI (Water) groundwater database indicates that of the registered bores within one kilometre of the project alignment approximately half are registered as being used for water supply or irrigation. The majority of these registered bores are shallow (no greater than 10 metres in depth) located within the Botany Sands, Wolli Creek and Cooks River alluvium. Groundwater drawdown at these locations due to drainage into the project tunnels is expected to be minimal due to the hydraulic connection of the alluvium with the surface water in Wolli Creek and Cooks River. A clay aquitard typically underlies the Botany Sands reducing hydraulic continuity between the alluvium and underlying sandstone. In the event that the drawdown in a water supply bore or irrigation bore exceeds two metres (as outlined in the Aquifer Interference Policy), measures would be taken to ‘make good’ the impact by restoring the water supply to pre-development levels. The measures taken will be dependent upon the location of the impacted bore but could include, deepening the bore, drilling a new bore or providing an alternative water supply.

Groundwater modelling has been used to predict potential impacts on the natural systems and the water table. Output from the groundwater model shows predicted water table elevations after completion of the project (Figure 7-1) and drawdown caused by the project (Figure 7-2).

The groundwater elevation as shown in Figure 7-1shows an elongated cone of depression that is predicted to develop along the tunnel alignment, especially to the west of Cooks River. The blue and black shaded contours indicate the steady state groundwater elevation would extend to below sea level. The water table is predicted to remain relatively high near Bardwell Creek which is attributed to the presence of deep alluvium along this drainage line.

Long term steady state drawdown of the water table is presented on Figure 7-2. Drawdown is predicted in two elongated sections above the tunnel alignment east and west of Cooks River. West of Cooks River the maximum drawdown is at Arncliffe extending from the M5 East Motorway, beneath Princes Highway to the edge of Bardwell Park. The drawdown extends to a maximum depth of 40 metres below the ground surface. The edge of the drawdown plot has been defined as the two metre drawdown contour. The maximum lateral extent of the plot is around 500 metres from the alignment between Banksia and Arncliffe which reduces considerably in width further to the west. The reduction in width of the drawdown zone is attributed to the water table in the western part of the alignment already being depressed due to inflows into the existing M5 East Motorway tunnel.

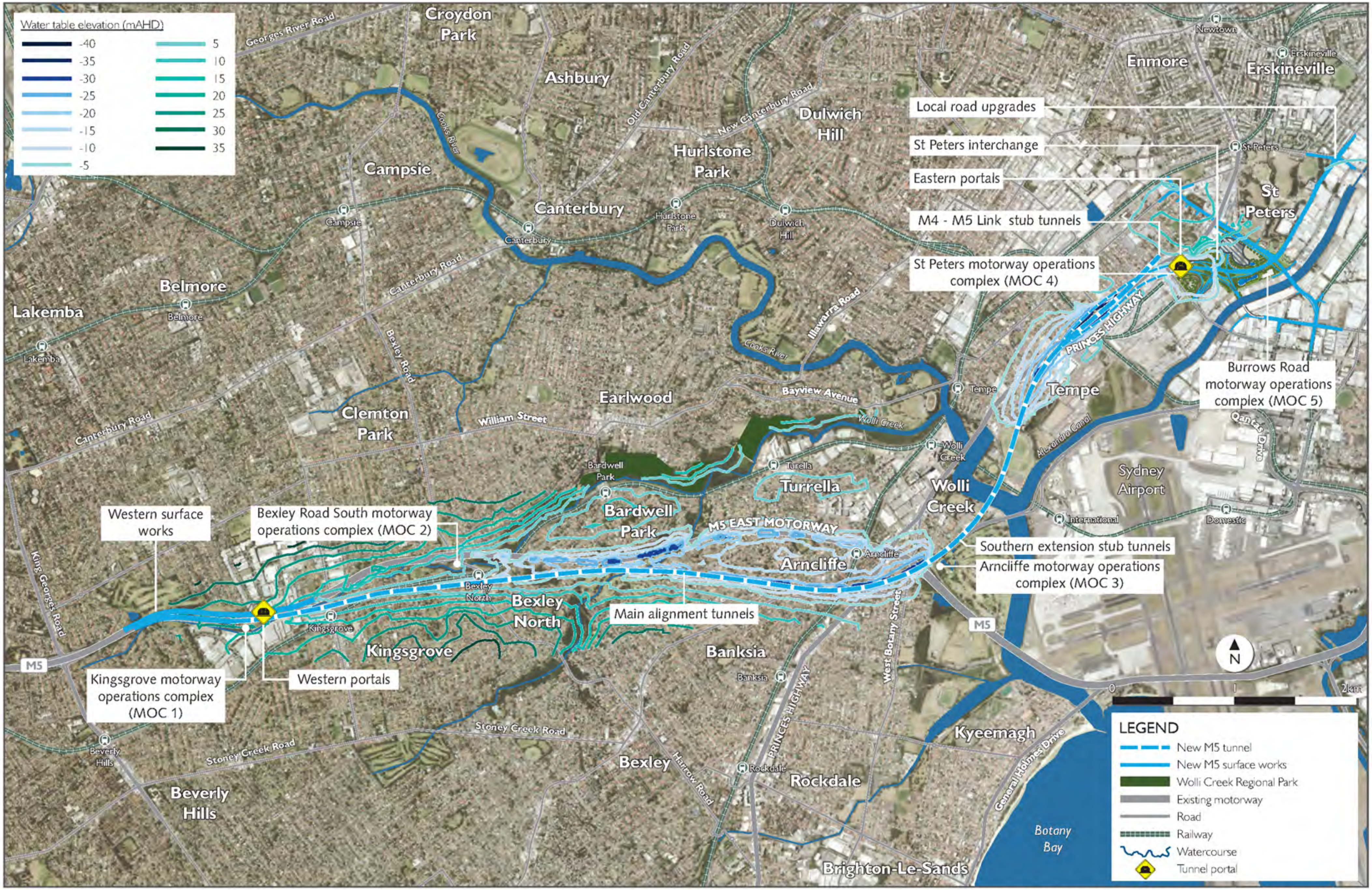


Figure 7-1 Predicted watertable elevations at steady state conditions

This page has been left blank intentionally.

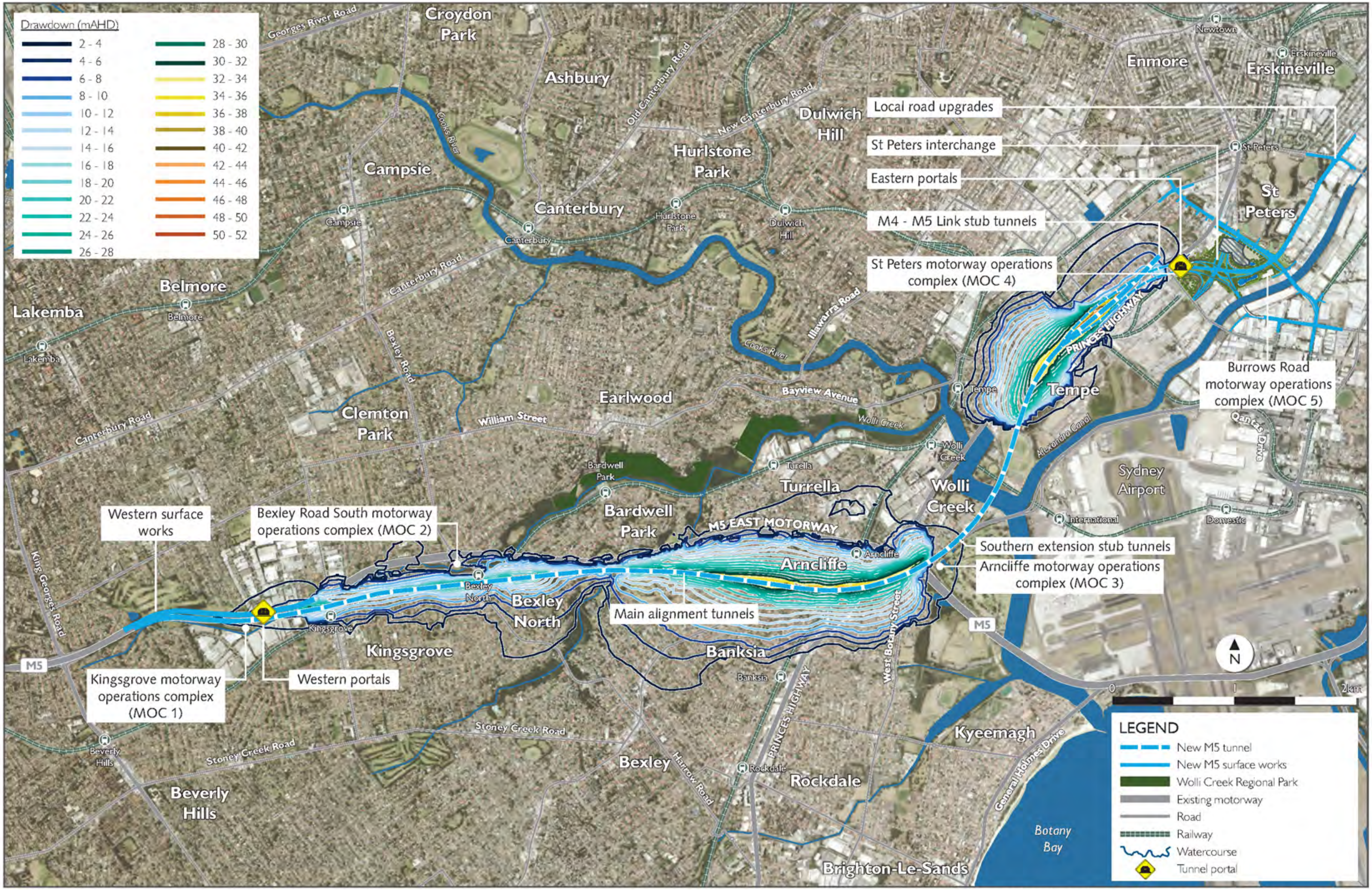


Figure 7-2 Predicted drawdown at steady state conditions

This page has been left blank intentionally.

To the east of Cooks River, heading eastwards from the edge of the alluvium, the predicted drawdown increases quickly. The sudden change in drawdown as the alignments approach St Peters appears to be due to the tunnel transitioning from sandstone into shale. The maximum depth of predicted drawdown is around 45 metres immediately south of the Alexandria Landfill. The extend of the two metre drawdown contour from the alignment is variable ranging from less than 100 metres to the east up to 500 metres to the west. The minimal extent of drawdown to the east is attributed to existing drawdown caused by leachate pumping at Alexandria Landfill.

Little groundwater drawdown has been predicted within the Botany Sands aquifer in the vicinity of Cooks River because this unit is able to transmit water (due to its higher hydraulic conductivity) with relatively flat hydraulic gradients. Groundwater modelling predicts the project would not have additional impacts in the area of the Alexandria Landfill.

Being connected to the ocean, the river can supply water to the tunnels below, without affecting levels in the river. A gradient would develop, however, from the river in both westerly and easterly directions. It has previously been observed that higher inflows to tunnels beneath palaeovalleys may be an effect of valley bulging, and enhanced hydraulic conductivities due to fracturing. The model suggests that higher inflows can also be explained by availability of water and rapid transfer of water to alluvium over underlying rock.

7.3 Groundwater management

Long term groundwater inflows are to be reduced through design, by the installation of waterproofing where higher inflows are identified during tunnelling. However, the project would allow ongoing groundwater seepage into the tunnels which flows into the drainage system via gravity to the sump near the Arncliffe motorway operations complex. The groundwater is to be pumped to the surface, treated and discharged to the Cooks River via stormwater drains. The drainage system would separate groundwater and surface water collected via pits, drains and sumps. There is potential for groundwater to require additional treatment and the separating of these waters may decrease long term treatment requirements. Stormwater and groundwater are to be pumped to the surface from the low point sumps to the water treatment plants via rising mains. Operational environmental measures would be prepared as part of the Operational Environmental Management Plan, which contains response plans to manage on-going monitoring and reporting requirements, spillages or incidents. Monitoring parameters are likely to include groundwater levels, groundwater quality including field parameters, laboratory analytes and sample frequency.

Options are to be explored for the beneficial re-use of treated inflow water, rather than discharge to stormwater.

7.3.1 Alexandria Landfill

On-going groundwater management would be required at the former Alexandria Landfill at the completion of the St Peters interchange.

Leachate generation would continue albeit reduced due to the landfill being capped and the installation of a cut-off wall to reduce groundwater inflows from the Botany Sands into the landfill. Leachate would be collected via the existing herringbone drainage network at the base of the landfill and pumped to the surface via a leachate riser. The leachate would be transferred to a leachate treatment plant and pumped to sewer under a Sydney Water trade waste agreement. The upgraded treatment plant will biologically treat the raw leachate to remove the high concentrations of ammonia which are typically found in landfill leachate wastewaters. The upgraded leachate treatment plant is to be located in the western portion of the landfill site and would have an approximate maximum leachate treatment capacity of 200 kilolitres per day.

Operation of the leachate pumping system would maintain natural groundwater levels below the road infrastructure at St Peters Interchange. This would be achieved by a reduction in groundwater inflow and rainfall infiltration into the landfill as discussed in Section 6.7. Capping the landfill would reduce rainfall infiltration causing rainfall to be captured in the drainage systems, treated and discharged off-site. Continual leachate pumping would dewater and depressurise the groundwater in the Ashfield Shale and maintain groundwater levels below the road systems. In addition the construction of a cut-off wall broadly around the southern perimeter of the landfill would cut-off the majority of groundwater inflow from the Botany Sands, further reducing groundwater inflow into the landfill. The proposed alignment of the cut-off wall is shown in Figure 7-3.

A groundwater and leachate monitoring program would be prepared and implemented in accordance with a revised EPL to be issued by the EPA. The program is expected to be an upgraded version of the existing EPL requirements and would include the monitoring of leachate volumes treated and discharged, groundwater levels and groundwater and leachate quality (field parameters and laboratory analytes). The technical details of the required monitoring program will be included in the Operational Environmental Management Plan.

A water treatment plant is to be permanently established at the site of the Arncliffe motorway operations complex to treat groundwater from dewatering of the tunnel along with stormwater and system deluge water captured in the tunnel. The assessment concerning the treatment and discharge of treated groundwater can be found in the Technical Working Paper: Surface Water (AECOM, 2015) for the New M5.

7.4 Groundwater quality impacts

Road runoff can contain pollutants associated with vehicular movement and normal use due to leaks, spills and accidents. Expected contaminants from groundwater within the region indicate that contaminants will include iron, hydrocarbons (petrol, diesel, oil and grease), metals and suspended solids. Discharge water is to be directed to sumps via gravity drainage within the tunnels and pumped to a operational water treatment plant to be constructed at the Arncliffe motorway operations complex.

In the event of a hydrocarbon spill within the tunnels water and fuel would be pumped to the surface and stored in holding ponds for off-site treatment and discharge. The drainage system has been designed to capture groundwater and surface water inflows to the tunnels separately via different drainage networks to streamline the treatment process. In addition groundwater will be collected separately east and west of the sump. The rationale is that groundwater to the east of the sump that collects groundwater from St Peters, Alexandria and Tempe is more likely to be contaminated than groundwater collected west of Kogarah Golf Course. Sources would be from former and current industrial areas of St Peters, Alexandria and Tempe. The risk is considered low due to the depth of the tunnel and where contaminated groundwater is identified waterproofing would be undertaken to reduce inflows of contaminated groundwater. Groundwater leakage calculated into the project tunnels adjacent to Alexandria Landfill would consist of 86 per cent background water and 14 per cent leachate impacted groundwater.

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

The assessment concerning the treatment and discharge of treated groundwater can be found in Technical Working Paper: Surface Water (AECOM, 2015). Induced drawdown caused by tunnel drainage may cause saline water to be drawn into the tunnels due to the connection with the Cooks River or Alexandra Canal. The Cooks River is in hydraulic connection with alluvium and has the capacity to supply saline water to the alluvium, potentially degrading groundwater quality of the alluvium. As the alluvium directly overlies the sandstone and may be in hydraulic connection there is potential for saline water to enter the sandstone. However groundwater beneath the Cooks River is likely to be already to have elevated salinity and consequently the project is unlikely to adversely impact groundwater quality beneath the river.

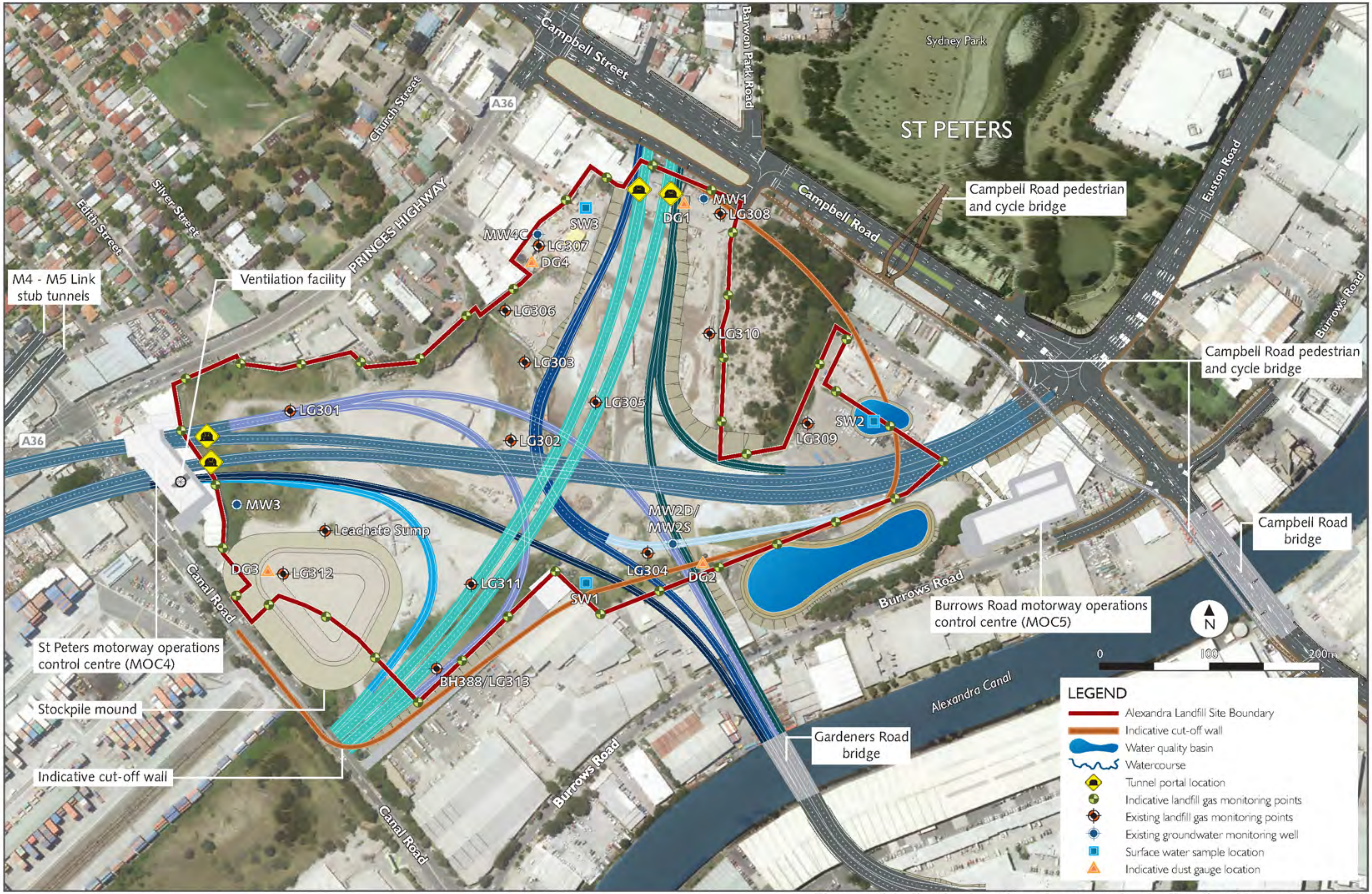


Figure 7-3 Indicative location of proposed cut-off wall at Alexandra Landfill

7.5 Impacts to existing users

A review of NSW DPI (Water) groundwater database within a one kilometre radius of the tunnel alignment identified 61 registered users of which half are used for water supply and irrigation. The majority of these bores are shallow (no greater than 10 metres in depth) and are located within the Wolli Creek and Cooks River alluvium and Botany Sands. Groundwater drawdown at these locations related to the project tunnels is not expected to be large due to the hydraulic connection of the alluvium with the surface water in Wolli Creek and Cooks River. Beneath the Botany Sands there is an extensive clay aquitard that would reduce groundwater leakage from the alluvium into the underlying sandstone.

In some registered boreholes in hydraulic connection with the tidal reaches of the Cooks River and its tributaries there is potential for the salinity to increase as river water may be drawn towards a borehole due to drawdown caused by tunnel inflows. That is the fresh water lens overlying the saline groundwater in a Ghyben-Herzberg system may mix with the saline groundwater increasing shallow groundwater salinity. This potential groundwater salinity increase would be in part be balanced by ongoing groundwater rainfall recharge. Should the increase in salinity cause the extracted groundwater to be unsuitable for its intended purpose, a groundwater impact assessment would be conducted and mitigation measures outlined. Mitigation measures would be site specific and may include targeting a deeper aquifer, mixing with fresher water to reduce salinity or replacing the water source with a reticulated water supply. Overall registered boreholes are considered to be of low risk to receiving hydrocarbon and metals contamination as a result of the installation of the tunnel infrastructure as during the operations phase potentially contaminated road run-off is to be collected and treated prior to discharge.

The drawdown in registered bores has been predicted by the groundwater model and the results are presented in Table 9. Their location in mapped on Figure 7-4 and 7-5 and shows the purpose for each bore. The modelling predicts that eleven bores would drawdown in excess of two metres due tunnel induced drainage. The modelled drawdown in the registered bores varies from 2.2 metres to 11.5 metres. Of these wells only four are used for water supply – domestic (two) and industrial (two). The remaining wells are classified as either monitoring wells, test bore or other.

Three of the water supply wells where the drawdown is predicted in excess of two metres are shallow bores intersecting sand where the water table is expected to be drawn down below the base of the bore. In these cases it may be possible to extend the wells to intersect deeper groundwater. The fourth bore is constructed for industrial purposes within the Hawkesbury Sandstone to a depth of 186 metres. In this bore the water table is at a depth of 93 metres and the drawdown is predicted to be 5.7 metres. Depending on the depth of the pump inlet setting in this bore a mitigation measure may be to lower the pump deeper into the bore. Should deepening the bore be the appropriate course of action, a groundwater impact assessment would be conducted.

In the event that groundwater users are impacted by the project by a decline in groundwater levels in existing bores, in excess of two metres, provisions are to be implemented to ‘make good’ the supply the impact by restoring the water supply to pre-development levels. The measures taken would be dependent upon the location of the impacted bore and would be confirmed during detailed design but could include, deepening the bore, providing a new bore, lowering the pump, providing an alternative water supply or appropriate monetary compensation.

Table 9 Predicted drawdown in registered wells in excess of two metres

Bore ID	Lithology	Depth (m)	Water table depth metres below ground level	Purpose	Predicted drawdown (m)
GW023191	Sand	4.9	3.3	Water supply - domestic	6.7
GW023194	Sand	2.1	2.1	Water supply - domestic	2.2
GW027664	Sand	6.1	0.7	Industrial	2.4
GW107993	Sandstone	13.6	1.95	Monitoring	11.5

Bore ID	Lithology	Depth (m)	Water table depth metres below ground level	Purpose	Predicted drawdown (m)
GW108406	Sand	8	Not available	Monitoring	2.4
GW108588	Sand	8	Not available	Test bore	2.7
GW109191	Sandstone	186	93	Industrial	5.7
GW109963	Sand	8	Not available	Other	2.7
GW109964	Sand	8	Not available	Monitoring	2.8
GW109965	Sand	8	Not available	Monitoring	2.4
GW109966	Sand	3	Not available	Monitoring	4.5

7.6 Impacts to the environment

Existing groundwater dependent ecosystems and wetlands are described in Sections 3.8 and 3.4.2 respectively.

Drawdown beneath these sensitive wetlands is considered negligible due to hydraulic connectivity with the Cooks River and lower Wolli Creek and continual recharge or tidal flushing. Although replacement of alluvial groundwater with brackish river water would introduce salinity into the alluvial aquifers the groundwater within the alluvium is already of high salinity in these areas due to tidal flushing and hydraulic connection with the brackish surface water. Consequently replacement of groundwater in the alluvial aquifer with brackish river water is considered unlikely to degrade the alluvial groundwater any further. Other wetlands within the alluvium are likely to be sustained because drawdown in the alluvium is low.

Landing Lights Wetland, Eve Street Wetland and Marsh Street Wetland are located in alluvium, on the fringe of an area where there may be water table decline when steady state has been reached. The presence of a low permeability organic layer beneath the alluvium would restrict groundwater leakage from the alluvium. In addition groundwater drawdown at the wetlands may be less than predicted by the groundwater model as recharge over the alluvium is likely to be higher than the 40 millimetre per year set for the whole regional model. Furthermore predicted drawdown may be less than calculated due to a phenomenon known as induced recharge. That is as the water table declines the vegetation takes less water (evapotranspiration is reduced), such that the difference between and evapotranspiration (net recharge to the water table) increases. Thus by this mechanism the predicted drawdown is less than actual. Oren et. al (2013) notes that water loss in wetlands by a reduction in evapotranspiration in a non-arid environment is not a major contributing factor in plant degradation.

Groundwater modelling has predicted that groundwater drawdown at Tempe Wetlands located close to Alexandra Canal to be negligible (CDM Smith, 2015). This is because the Cooks River and Alexandra Canal are tidal, with water levels controlled by the sea.

The majority of the Cooks River/Castlereagh Ironbark Forest at Kingsgrove would be cleared as a result of the project. For vegetation that is not cleared, groundwater modelling indicates that any groundwater drawdown would be less than two metres and would be unlikely to stress the community. This is because a drawdown of less than two metre is within natural seasonal variation.

The Stotts Reserve is directly above the tunnel alignment and groundwater modelling has predicted that drawdown could be in excess of 10 metres. Trees that are partially dependent on groundwater could show signs of stress in prolonged dry periods, however the vegetation community should recover following sufficient rainfall.

Groundwater modelling has shown that groundwater drawdown beneath the estuarine fringe forest and mangrove forest between Wolli Creek and Wolli Creek Railway Station is likely to be low (less than one metre) and unlikely to impact the forest.

Similarly groundwater drawdown beneath the upper reaches of Wolli Creek and Bardwell Creek are predicted to be less than one metre and the impacts are unlikely to impact any GDEs that may be present. The depth to groundwater is likely to be in excess of ten metres based on deep monitoring wells constructed nearby in the Hawkesbury Sandstone. Hence the water table is well below the ground surface and drawdown is unlikely to impact vegetation. In periods of low run-off, the baseflow often sustains riparian vegetation, however in the upper reaches of these creeks the water table is too low to provide baseflow.

Groundwater quality is unlikely to be impacted by any leakage from the creeks in the upper reaches as the surface water is dominated by rainfall recharge and is consequently of low salinity.

There is limited potential for groundwater drawdown to impact trees near watercourses. The majority of the project alignment has a water table below about two metres depth and below the growth zone. Trees are not completely dependent on the water table, drawing water from the soils and rocks in the unsaturated zone Impacts to flora is discussed further in the ecological impact report. This would not change as the unsaturated zone is influenced by rain infiltration. In low lying areas the low permeability of the clayey soils in combination with frequent rainfall events and higher recharge due to surface water concentration is not expected to change availability of water for plants. The predicted drawdown at the various creeks varies depending on local geology, horizontal distance from the tunnel and depth to the tunnel. Groundwater modelling suggests typical groundwater drawdown beneath the creeks is estimated to be negligible due to hydraulic connectivity with the creeks or in the upper reaches the water table is already naturally depressed.

The potential impacts to ecological values of GDEs is provided in the Technical Working Paper: Biodiversity (Eco Logical Australia, 2015).

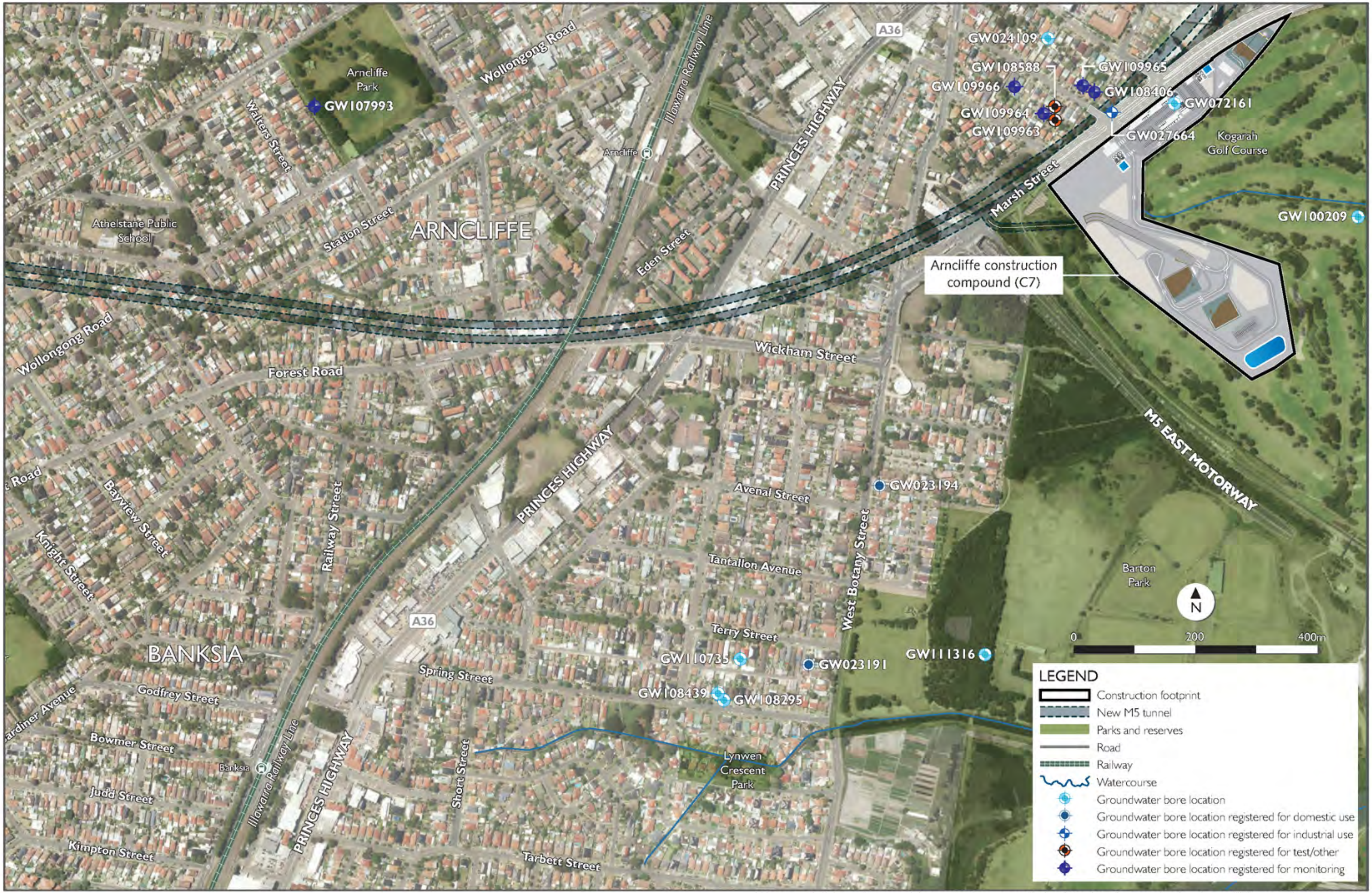


Figure 7-4 Registered boreholes predicted to be impacted - Arncliffe surface works

This page has been left blank intentionally.

Figure 7-5 Registered boreholes predicted to be impacted - Bexley surface works

This page has been left blank intentionally.

8.0 Mitigation and management measures

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

8.1 Construction

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

- A tunnelling waterproofing procedure would be implemented that outlines the methodology to determine when and what type of waterproofing is required to be installed during construction.
- Appropriate waterproofing measures would be implemented to permanently reduce the inflow to an acceptable quantity where the project alignment passes close to watercourses and/or where higher than expected inflows are experienced. This may include spray on membrane, grouting or the installation of a sheet membrane. In the unlikely event that a palaeochannel was intersected by the alignment water proofing would be installed to reduce groundwater inflow.
- Pre-excavation pressure grouting would be used in locations that could produce substantial inflows to reduce groundwater inflows to an acceptable level. Post-excavation grouting may also be required to further reduce groundwater inflows, and would occur shortly following the excavation of that area.
- Additional rock support would be installed where saturated faults and fractures are intersected by the project to ensure tunnel stability.
- A Construction Soil and Water Quality Management Plan implemented during construction, which would also manage groundwater impacts during construction due to disturbances at the surface. This is to include:
    - An acid sulfate soil management plan is to be prepared prior to the commencement of bulk earth works where PASS is expected. The plan would include the types of treatment required for ASS, bunding and requirement for treatment ponds
    - Management measures for the storage and stockpiling of materials, fuel and wastes during construction
    - Spill prevention and response procedures.
- A protocol to address unexpected contaminated finds or unforeseen contamination issues during surface works and tunnelling. This would include approaches to remove the source of contamination by excavation, or an engineering solution to prevent the migration of contaminated groundwater into the tunnels.
- Shallow perched groundwater within Alexandria Landfill or Botany Sands would be directed to the leachate treatment plant or the construction water treatment plant prior to discharge, depending on the characteristics of this groundwater. Elsewhere, collection and treatment options would be considered and releases made under relevant discharge criteria.
- Treated waste water would be stored and re-used for project purposes wherever possible. Groundwater reuse would be in accordance with the policies of sustainable water use of the DPI (Water), such as dust suppression and earthworks.
- A groundwater soil and salinity report, which would be prepared detailing the outcomes of geotechnical investigations to determine the presence, extent and severity of soil salinity along the alignment. The report is to be prepared in consultation with Office of Environment and Heritage and NSW DPI (Water). Measures would be outlined to minimise impacts on groundwater systems and other receiving environments;
- A groundwater monitoring program is to be prepared and implemented to monitor groundwater impacts during construction on groundwater quality. The program shall be developed in consultation with the DPI (Water) and relevant councils. If adverse impacts to groundwater quality are identified by the monitoring program due to construction activity, strategies would to be developed and implemented to reduce the impacts.

- Contingency measures to address leachate management at the Alexandria Landfill during construction and prior to the commissioning of the leachate treatment plant would be explored during detailed design. Identified measures would be detailed in the Construction Environmental Management Plan and implemented during construction.
- Contingency measures would be implemented in the event that of interaction with contaminated groundwater during construction within the Alexandria Landfill.
- Building materials that are resistant to aggressive groundwater conditions would be selected.
- In the event that the drawdown in a water supply bore or irrigation bore exceeds two metres (in accordance with the Aquifer Interference Policy) measures will be taken to 'make good' the impact by restoring the water supply to pre-development levels. The measures taken will be dependent upon the location of the impacted bore but could include, deepening the bore, providing a new bore or providing an alternative water supply.

8.2 Operation

Following construction and implementation of mitigation strategies, there could be residual impacts to groundwater throughout the long term operational phase. Operational environmental measures will be prepared as part of the Operational Environmental Management Plan (OEMP), which contain response plans to manage on-going monitoring and reporting requirements, spillages or incidents. Potential risks and associated impacts to the local hydrogeological regime that could result during the long term operations are presented in Table 10 along with mitigation and/or management measures.

Table 10 Potential risks and proposed mitigation measures during operation

Mitigation and management measures
An OEMP is to be prepared and implemented that would outline management measures for groundwater inflows, treatment and discharge and protocols for spillages or incidents.
A groundwater and surface water quality monitoring program is to be prepared and implemented to monitor groundwater and surface water impacts during tunnel operations on groundwater quality and wetlands. The program will be developed in consultation with the EPA, DPI (Fisheries), DPI (Water) and relevant councils. Monitoring parameters may include groundwater levels, groundwater quality including field parameters, laboratory analytes and sample frequency. At least three monitoring wells or vibrating wire piezometers should be constructed as close as possible to the tunnel centrelines to approximately five to ten metres above the top of the tunnel crown to allow for groundwater drawdown monitoring in the Hawkesbury Sandstone. Six monthly groundwater monitoring should occur for three years after the tunnel becomes operational after which the requirement for on-going monitoring will be assessed. Corrosion and other associated impacts of high aggressivity on the tunnel infrastructure would be monitored during regular inspections outlined within the OEMP.
Groundwater inflow to the tunnel may cause the groundwater to decline by more than two metres or adversely impact the groundwater quality at some bores. Mitigation measures would be confirmed in detailed design and in consultation with the affected bore licence holder and may include providing an additional water source, deepening a borehole, lowering a pump in a borehole or alternatively providing appropriate monetary compensation.
The drainage system would be regularly maintained in accordance with the OEMP to remove build-ups of precipitated iron (slimes) and silt and sand due to slaking of the sandstone.

Mitigation and management measures
At Alexandria Landfill a new leachate water treatment plant would be commissioned and would treated leachate would be discharged to sewer. Operation of the pumping system would. Operation of the pumping system will cause groundwater to flow into landfill away from the tunnel infrastructure reducing the risk of water entering the tunnel infrastructure. A backup leachate pumping system should also be installed to increase margin of safety. Installation of a cut-off wall around the southern perimeter of the landfill and capping of the landfill will reduce leachate generation.
Options are to be explored for the beneficial re-use of treated inflow water, rather than discharge to stormwater.

This page has been left blank intentionally.

9.0 NSW Aquifer Interference Policy – minimal impact considerations

9.1 Aquifer Interference Policy

The *Water Act 1912* has been replaced by the *Water Management Act 2000* and does not apply to areas of the state where water sharing plans are in place. Groundwater and surface water within the project area are covered by the *Groundwater Metropolitan Region Groundwater Sources* and the *Greater Metropolitan region Unregulated River Water Sources*.

The *NSW Aquifer Interference Policy 2012* explains the requirements of the *Water Management Act 2000.* It clarifies the requirements for licences for aquifer interference activities and establishes the considerations required for assessing potential impacts to key water dependent assets. Any potential impact to local aquifers will be assessed under this policy.

Under this policy, a controlled activity approval (such as a water access licence or aquifer access licence) and/or an aquifer interference approval is required under the *Water Management Act 2000* for any activity that results in interference to an aquifer.

An aquifer interference approval under the *Water Management Act 2000* if construction requires intersection of a groundwater source. The *NSW Aquifer Interference Policy* documents the NSW Government's intention to implement the requirement for the approval of 'aquifer interference activities' under the *Water Management Act 2000*. Although the project would affect a groundwater aquifer, the requirement for an aquifer interference approval has not yet commenced. As such, this approval is not required.

9.2 Minimal impact assessment

The *Aquifer Interference Policy 2012* (Department of Primary Industries, 2012) outlines minimal impact considerations that must be met as a result of the proposal. The minimal impact considerations are dependent upon the impacted aquifer type (alluvial, coastal, fractured rock or special cases such as great Artesian Basin) and whether the aquifer is "highly productive" or "less productive groundwater". The impacts to be considered are to groundwater levels (or water pressure in artesian basins) and water quality.

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

The groundwater within the Botany Sands is considered to be in a "Highly Productive Groundwater Source."

The minimal impact considerations for "less productive groundwater" in a fractured rock aquifer are presented in Table 11. The minimal impact considerations for "Highly productive groundwater" in a coastal aquifer are presented in Table 12.

Table 11 Minimal Impact Considerations for a "Less Productive Fractured Rock Aquifer"

Minimal Impact Considerations	Response
Water Table – Level 1 Less than or equal to 10 per cent cumulative variation in the water table, allowing for typical climatic "post water sharing plan" variations, 40 metres from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site listed in the schedule of the relevant water sharing plan, or A maximum of a two metre decline cumulatively at any water supply work.	There are no high priority groundwater dependent ecosystems listed under Schedule 4 of the *Greater Metropolitan Regional Groundwater Sources Water Sharing Plan* that are within the Hawkesbury Sandstone or Ashfield Shale No culturally significant sites were identified within the *Greater Metropolitan Regional Groundwater Water Sharing Plan*. Groundwater modelling has indicated that there are two registered bores within a one kilometre radius of the tunnel that intersect the fractured sandstone where the drawdown is predicted to be more than two metres. Only one of these bores is registered for water supply purposes (industrial). The approach to minimising impacts are outlined below.
Water Table – Level 2 If more than 10% cumulative variation in the water table, allowing for typical climatic "post water sharing plan" variations, 40m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan, if appropriate studies demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than a two metre decline cumulatively at any water supply work then make good provisions should apply.	The predicted long term drawdown in industrial bore GW107993 is 5.7 metres. The bore is 186 metres deep with water table depth recorded at 93 metres. Groundwater will not be drawn down to 93 metres as this is below the tunnel at this location. It is considered unlikely that drawdown in the borehole due to the tunnel will impact the sustainability of the borehole.
Water Pressure – Level 1 A cumulative pressure head decline of not more than a two metre decline, at any water supply work.	The groundwater modelling has included the cumulative impacts of the existing M5 East Motorway tunnel. Mitigation measures have been recommended for the bores where it has been predicted that the drawdown exceeds a water level decline of more than two metres.
Water Pressure – Level 2 If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	Mitigation measures have been recommended as above.

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

Table 12 Minimal Impact Considerations for a "Highly Productive Coastal Aquifer"

Minimal Impact Considerations	Response
Water Table – Level 1 Less than or equal to 10 per cent cumulative variation in the water table, allowing for typical climatic "post water sharing plan" variations, 40 metres from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site listed in the schedule of the relevant water sharing plan, or A maximum of a two metre decline cumulatively at any water supply work.	There are no high priority groundwater dependent ecosystems listed under Schedule 4 of the *Greater Metropolitan Regional Groundwater Sources Water Sharing Plan*. There are two wetlands within the project corridor at Tempe known as the Eve Street Wetland and Landing Lights Wetland. Groundwater modelling conducted as part of this investigation indicates that the water table at these wetlands is unlikely to undergo a water level decline of more than 2m. No culturally significant sites were identified within the Greater Metropolitan Regional Groundwater Water Sharing Plan Groundwater modelling predicted that eight water supply bores within a one kilometre radius of the tunnels that intersect alluvium are likely to be drawn down by more than two metres. Three of these bores are registered for water supply purposes, the remaining being categorised as monitoring wells or other, Mitigation measures are outlined below.
Water Table – Level 2 If more than 10% cumulative variation in the water table, allowing for typical climatic "post water sharing plan" variations, 40m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan, if appropriate studies demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than a two metre decline cumulatively at any water supply work then make good provisions should apply.	The approach to "make good" the supply to predevelopment levels within these alluvial wells is limited by the aquifer depth. Discussions with the bore owners should be held to make good the supply. Options include drilling deeper holes (where the aquifer is deeper), lowering the pump, providing an alternative water supply (such as mains water) or providing appropriate monetary compensation.

Minimal Impact Considerations	Response
Water Pressure – Level 1 A cumulative pressure head decline of not more than a two metre decline, at any water supply work.	The groundwater modelling has included the cumulative impacts of the existing M5 East Motorway tunnel. Mitigation measures have been recommended for the three water supply bores where it has been predicted that the drawdown exceeds a water level decline of more than two metres. The mitigation measures include drilling deeper bores at these locations or if not possible connect to the reticulated water supply and provide monetary compensation.
Water Pressure – Level 2 If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	Mitigation measures are outlined above
Water Quality – Level 1 Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity.	The beneficial use category of groundwater will not be changed beyond 40m of the tunnel.
Water Quality – Level 2 If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.	Level 2 does not apply as Level 1 criteria are not exceeded.

10.0 Conclusions

The groundwater impact assessment has been prepared in accordance with NSW groundwater policy under the *Water Management Act, 2000*, administering water policy under *the Aquifer Interference Policy2012* and the *Greater Metropolitan Region Groundwater Source Water Sharing Plan.* The objectives of the groundwater impact assessment are outlined in the SEARs for the project.

The methodology to conduct the groundwater impact assessment included outlining the existing environmental conditions from available reports, maps and databases. The primary database searches consulted were DPI (Water) groundwater database, Australian Soils Resource Information System for acid sulfate soils, BoM Atlas of Groundwater Dependent Ecosystems and NSW EPA contaminated land record. A field investigation was conducted to investigate the geology along the alignment, assess the hydraulic conductivity by packer tests, install monitoring wells along the alignment, conduct hydrogeochemical sampling and groundwater gauging to establish background conditions. Data loggers are installed in each of the 28 monitoring wells to monitor groundwater levels before and after the construction program. A three dimensional numerical groundwater model (using MODFLOW-USG) has been developed to simulate existing groundwater conditions. By simulating the proposed tunnel alignments the groundwater model has also been used to predict future groundwater conditions and impacts related to the project.

The St Peters interchange is an above ground structure that would traverse the footprint of the Alexandria Landfill. As part of this project, the landfill would be closed and remediated to enable the construction and operation of the interchange. As part of these works, up to ten metres of fill would be excavated to accommodate the proposed road infrastructure. Leachate is generated at the landfill from rainfall infiltration and groundwater inflow, primarily from the Botany Sands. A leachate collection system and an upgraded leachate treatment plant would be constructed at the end of the construction phase for on-going leachate treatment during the operation phase. Ongoing pumping of the Botany Sands groundwater via leachate extraction or external pumping systems is not in accordance with the policies of the NSW DPI (Water). As a cut-off wall would be installed that broadly encircles the southern part of the landfill. The cut-off wall would restrict groundwater flow into the landfill and reverses groundwater gradients so groundwater discharges into Alexandra Canal.

The project is designed as a drained tunnel, that is to allow groundwater to leak into the tunnel and be collected in the drainage system to be treated and discharged into the Cooks River. Waterproofing would be required to reduce the bulk rock permeability to meet the groundwater inflow criterion in sections of the tunnels. The New M5 tunnel has been designed to achieve one litre per second per kilometre averaged over every kilometre of tunnel. As such, approach to the control of water ingress into the tunnel consists of a suite of options, ranging from areas where no waterproofing may be required to areas where a membrane may need to be applied.

Impacts during construction may include:

- Intersection of acid sulfate soils during excavation works that could cause the production of acidic groundwater
- Degradation of groundwater quality by the spilling of hazardous materials such as fuels and oils.
- Tunnel inflows may exceed the design criterion of one litre per second per kilometre.
- The intersection of contaminated groundwater during tunnelling could further spread the contamination;
- The natural groundwater may be aggressive to tunnel building materials and cause corrosion of the tunnel structures.
- Groundwater quality could be degraded during the tunnel construction program.
- Tunnelling could cause drawdown in a water supply bore in excess of two metres.

Following construction and implementation of mitigation strategies, there could be residual impacts to groundwater throughout the long term operational phase. Impacts during operations may include:

- Long term impacts to groundwater quality, wetlands or groundwater levels may be experienced;
- Long term inflow to the tunnel may cause the groundwater to decline by more than two metres in existing water supply bores;
- Drainage lines within the tunnel could become blocked due to the natural iron and manganese oxidising within the drains causing sludges.

- At Alexandria Landfill leachate is continually being generated and has the potential to leak into the tunnel infrastructure.
- Groundwater drawdown directly above the tunnel crown could be up to 40 metres.

To mitigate and manage the potential impacts of the project on groundwater, the following measures would be implemented:

- Preparation and implementation of a CEMP that addresses the hazards associated with exhuming landfill waste or alluvium and the hazards posed by soil and groundwater contamination. The CEMP should also include an Acid Sulfate Soil Management Plan (ASSMP) that outlines the measures and monitoring to be undertaken where PASS is expected;
- Management measures for the storage and stockpiling of materials, fuel and wastes during construction including spill prevention and response procedures;
- Waterproofing would be installed during construction in areas identified that could have potential higher inflows. This may include spray on membrane, grouting or the installation of a sheet membrane. Pre-excavation pressure grouting would be used in locations that could produce substantial inflows to reduce groundwater inflows to an acceptable level. Post grouting may also be required to further reduce groundwater inflows.
- Waste water intersected would be collected and treated prior to discharge at four temporary water treatment plants. Shallow perched groundwater within Alexandria Landfill or Botany Sands would be directed to the leachate treatment plant or the construction water treatment plant prior to discharge, depending on the characteristics of this groundwater.
- Building materials that are resistant to aggressive groundwater conditions would be selected
- A groundwater monitoring program is to be prepared and implemented to monitor groundwater impacts during construction on groundwater quality. The program shall be developed in consultation with the DPI (Water) and relevant councils. If adverse impacts to groundwater quality are identified by the monitoring program due to construction activity, strategies would to be developed and implemented to reduce the impacts.
- In the event that the drawdown in a water supply bore or irrigation bore exceeds two metres measures will be taken to ‘make good’ the impact by restoring the water supply to pre-development levels. The measures taken would be dependent upon the location of the impacted bore but could include, deepening the bore, providing a new bore or providing an alternative water supply. This would be confirmed during detailed design and in consultation with the affected bore licence holder.

Mitigation and management measures during operations may include:

- A groundwater and surface water quality monitoring program is to be prepared and implemented to monitor groundwater and surface water impacts during tunnel operations on groundwater quality and wetlands. The program shall be developed in consultation with the EPA, DPI (Fisheries), DPI (Water) and relevant councils;
- To reduce the impacts of water level decline in existing monitoring wells mitigation measures may include providing an additional water source, deepening a borehole, lowering a pump in a borehole or alternatively providing appropriate monetary compensation.
- The drainage system would be regularly maintained in accordance with the OEMP to remove build-ups of precipitated iron (slimes) and silt and sand due to slaking of the sandstone.
- At Alexandria Landfill a new leachate water treatment plant would be commissioned and would treated leachate would be discharged to sewer. Operation of the pumping system would cause groundwater to flow into landfill away from the tunnel infrastructure reducing the risk of water entering the tunnel infrastructure. A backup leachate pumping system should also be installed to increase margin of safety. Installation of a cut-off wall around the southern perimeter of the landfill and capping of the landfill will reduce leachate generation.
- Re-use options for groundwater would be explored during detailed design. The feasibility and appropriateness of any options would be discussed with DPI (Water) during detailed design.

11.0 References

AECOM, 2014a; The New M5 State significant infrastructure application report. Prepared for WestConnex Delivery Authority, dated November 2014.

AECOM, 2014b. Phase 1 ESA Phase 1 Environmental Site Assessment, Alexandria Landfill Acquisition Area, St Peters, NSW . Draft, 14 August.

AECOM, 2015a; WestConnex Stage 2: M5 Geotechnical Investigation – Report of Completed Work. Report – WCX2-00-2000-GT-009, Prepared for WestConnex Delivery Authority, dated 27 March 2015

AECOM, 2015b, WestConnex Stage 2 M5 Hydrogeological Investigation – Groundwater Drilling and preliminary Monitoring Progress Report – WCX2-00-2000-GT-010A, 27 March 2015.

AECOM, 2015c, WestConnex Stage 2 M5 Landfill Closure Plan – Groundwater Drilling and Preliminary Monitoring Progress Report – WCX2-00-2000-GT-010A, 27 March 2015.

AECOM, 2015d; Phase 2 Environmental Site Assessment. Alexandria Landfill, 10-16 Albert Street, St Peters, NSW, dated 6 May 2015, Draft Report.

AECOM, 2015e; Phase 2 Environmental Site Assessment, 5 and 5A Canal Road, St Peters, NSW, dated 5 May 2015, Draft Report.

AECOM, 2015f; Alexandria Landfill. Landfill Closure Management Plan. Draft Report 60327128_RPT_0120150515_A, dated 15 May 2015.

AECOM, 2015g; Alexandria Landfill Closure. Hydrogeological Assessment Draft Report, dated 31 August2015.

AECOM, 2015h. Phase 1 ESA Phase 1 Environmental Site Assessment, WestConnex New M5 Project. dated72 July.

AECOM, 2015i, The New M5. Surface Water Impact Assessment. Prepared for the WestConnex Delivery Authority, dated 13 August.

Australian Drinking Water Guidelines Paper 6, National Water Quality Management Strategy. NHMRC National Resource Management Ministerial Council (NRMMC), Commonwealth of Australia, Canberra Version 2.0, December, 2013. (NHMRC, 2013).

Australian and New Zealand guidelines for fresh and marine water quality. Agriculture and Resource Management Council of Australian and New Zealand Environment and Conservation Council, 2000.

Australian Bureau of Meteorology (2015) On-line climate data, Accessed 30 April 2015. http://www.bom.gov.au/climate/data/index.shtm

Australian Standard 2159 (2009) Piling – Design and Installation. Standards Australia.

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

Best, R.J. and Parker, C.J., (2005). Groundwater in Sydney – tunnel inflows and settlement – theory and experience, 12th Australian tunnelling conference, Brisbane, 5-3.

Bish S, Realica S and Wischusen J, 2000; Botany Sand Beds (GWMA018), Botany Basin, NSW – Northern, Southern and Western Zones, Status Report No 2. NSW Department of Land and Water Conservation, Sydney South Coast Region, March

CDM Smith, 2015; West Connex Stage 2 New M5 Groundwater Modelling Report. Prepared for AECOM, dated 28.September.

Chapman GA and Murphy CL, 1989; Soil Landscapes of the Sydney 1:100,000 Sheet report, Department of Conservation and Land Management , Sydney.

Chapman GA, Murphy CL, Tille PJ, Atkinson G and Morse RJ (2009) Ed. 4, Soil Landscapes of the Sydney 1:100,000 Sheet map. Department of Environment, Climate Change and Water, Sydney.

Coffey Geotechnics (2012). Geotechnical Interpretative Report. North West Rail Link. Transport for NSW. Dated 18 May.

Cooks River Alliance (2014) Cooks River Alliance Annual Report 2012-2013. http://cooksriver.org.au/wp-content/uploads/Annual-Report-2012_2013_finalv2.pdf. Accessed 27 August 2014.

Davies, P.R. (2002) Case Study of Retaining Walls at the M5 East Cooks River Crossing. Proc. 5th ANZ Young Geotechnical Professionals Conference, Rotorua, New Zealand.

DPI, 2012; NSW Aquifer Interference Policy. Department of Primary Industries – Office of Water, dated September.

Fell, R., MacGregor, P., Stapledon, D., and Bell, G., (2005) “Geotechnical engineering of dams”, A.A. Balkema, Rotterdam, 2005 (Section 5.14.4.1).

Friebel, E. & Nadebaum, P., 2011. Health Screening Levels for Petroleum Hydrocarbons in Soil and Groundwater.

Geoscience Australia (2009) Groundwater Quality in Australia and New Zealand: A literature review. http://www.ga.gov.au/corporate_data/71401/71401.pdf. Accessed 27 August 2014.

GoodmanR, Moye D, Schalkwyk A, and Javandel I (1965); Groundwater inflow during tunnel driving, Engineering Geology, 2:39.

Hatley, 2004; Hydrogeology of the Botany Basin. Australian geomechanics Vol 39 No 3 pp73-91, dated September.

Hem J.D., 1992; Study and Interpretation of the Chemical Characteristics of Natural Water. United States Geological survey Water-Supply Paper 2254. Third Edition.

Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition. Geological Survey of New South Wales, Sydney.

Hewitt P (2005); *Groundwater control for Sydney rock tunnels*, AGS AUCTA Mini-symposium: Geotechnical aspects of tunnelling for infrastructure projects, Sydney, 1-12,

Heuer RE (1995); Estimating rock tunnel water inflow. Proceedings of the rapid Excavation and Tunnelling Conference, Society for Mining, Metallurgy and Exploration, Colorado, p41-60.

Houlsby, A. (1976). Routine Interpretation of the Lugeon Water-Test. Q. J. Eng. Geol. Vol. 9, pp. 303-313.

Ivkovic, K.M., Marshall, S.K., Carey, H., Morgan, L.K., Sundaram, B., Dixon-Jain, P, Caruana, L., Garlapati, N., and Werner,A.D. (2013), *A national-scale vulnerability assessment of seawater intrusion: Coastal aquifer typology*. Record 2013/04. Geoscience Australia, Canberra, and National Centre for Groundwater Research and Training, Adelaide, http://www.ga.gov.au/corporate_data/74648/Rec2013_004.pdf, accessed September 2014.

Jankowski J 1997; Vertical Heterogeneity in the Botany Sands Aquifer, Sydney, Australia. In Chilton J Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham UK 21-27 September 1997.

McKibbin and Smith (2000); Sandstone Hydrogeology of the Sydney Region. 15th Australian Geological Convention. Sandstone City University of Technology, Sydney, July 2000.

McNally, G.H & Branagan, DF (1998) The St Peters Brickpits: Their Geology, Operations and Reclamation, and the Adjacant Quaternary Shoreline. Environmental Geology of the Botany Basin- the Geological Society of Australia, and Conference Publications, Collected Case Studies in Engineering Geology, Forth Series.

NSW EPA, 2014; List of Licences Under Schedule 1 of the Protection of the Environment Operations Act 1997. http://www.epa.nsw.gov.au/prpoeo.licences.htm. Accessed 13 May 2015.

NSW EPA, 2014; Contaminated Land – record of Notices, Under Section 58 of the Contaminated Land Management Act, 1997. http://www.epa.nsw.gov.au/prclmapp/searchregister.aspx. Accessed 13 May 2015.

NUDLC, 2012; Minimum Construction Requirements for Water Bores in Australia. National Uniform Drillers Licensing Committee. ISBN 978-0-646-56917-8. pp134.

Och DJ, Offler R, Zwingmann, Braybrooke J, Graham IT; 2009; Timing of brittle faulting and thermal events, Sydney region: association with the early stages of extension of East Gondwana. Australian Journal of Earth Sciences, 56:7, 873-887.

Parsons Brinckerhoff (2010); M5 East Expansion Geotechnical Management Dradt Desktop Study Report. Roads and Traffic Authority, Report No 2161023A PP_0131 Rev 01, dated November.

Shelef O, Gross A, and Rachmilevich S; 2013; Role of Plants in a Constructed Wetland: Current and New Perspectives. *Water* 2013, 5, 405-419.

Stone Y, Ahem, CR and Blunden, 1998. Acid Sulfate Soils Manual 1998. *Acid Sulfate Soils Management Advisory Committee (ASSMAC), Wollongbar, NSW. Australia.*

Tammetta, P., and Hewitt, P., (2004). Hydrogeological properties of Hawkesbury Sandstone in the Sydney region, Australian Geomechanics. 39(3), 93-108.

WHO Petroleum Products in Drinking Water (2008). *World Health Organisation. Report WHO/SDE/05.08/123. http://www.who.int/water_sanitation_health/dwq/chemicals/petroleumproducts_2add_june2008.pdf?ua=1*
WHO, (2011) Guidelines for Drinking Water Quality. World Health Organisation, Fourth Edition. ISBN 978 92 4 154815 1.

Woodward Clyde, 1997; Further Investigations, Albert Street Disposal Depot, St Peters. AGC Woodward Clyde Pty Ltd, July 1997.

This page has been left blank intentionally.

Appendix A

Groundwater Modelling Report

Appendix A Groundwater Modelling Report

AECOM

WestConnex Stage 2 New M5 Groundwater Modelling Report

AECOM

WestConnex Stage 2 New M5 Groundwater Modelling Report

28 September 2015

CDM Smith Australia Pty Ltd
ABN 88 152 082 936
11/300 Rokeby Road
Subiaco
WA 6008
Tel: +61 8 9381 8855
Fax: +61 8 9381 8822

Table of Contents

List of Figures

List of Tables

Appendices

Document History and Status

Revision	Date Issued	Reviewed By	Approved By	Date Approved	Revision Type
Rev A	29 July 2015	Rikito Gresswell	Lloyd Townley	29 July 2015	Draft
Rev 0	20 August 2015	Rikito Gresswell	Lloyd Townley	20 August 2015	Draft
Rev 1	6 September 2015	Rikito Gresswell	Lloyd Townley	5 September 2015	Draft
Rev 2	28 September 2015	Rikito Gresswell	Lloyd Townley	28 September 2015	Final

Distribution of Copies

Version	Date Issued	Quantity	Electronic	Issued To
Rev A	29 July 2015	1	PDF	Graham Hawkes
Rev 0	20 August 2015	1	PDF	Graham Hawkes
Rev 1	6 September 2015	1	PDF	Graham Hawkes
Rev 2	28 September 2015	1	PDF	Graham Hawkes

Printed:	30 September 2015
Last Saved:	30 September 2015 03:45 PM
File Name:	CDMSmith_BWS150016_RPT_AECOM_WestConnexGroundwaterModelling_Rev2.docx
Author:	Lloyd Townley, Rikito Gresswell
Project Manager:	Lloyd Townley
Client:	AECOM
Document Title:	WestConnex Stage 2 New M5 Groundwater Modelling Report
Document Version:	Final
Project Number:	PWS150016.01

Executive Summary

A regional scale groundwater flow model has been developed to support the Technical Working Paper: Groundwater (AECOM, 2015) in order to satisfy the Secretary's Environmental Assessment Requirements (SEARs).

The model has been developed using MODFLOW-USG (free groundwater modelling software developed by the United States Geological Survey) and a graphical user interface known as GMS. The primary advantage of MODFLOW-USG is its ability to represent local features like tunnels with fine discretisation, in the middle of a region with larger cells.

The model has been developed using methods consistent with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012). This report describes assimilation and analysis of data, the development of a conceptual model of regional scale groundwater flow, calibration of a model including the M5 East Motorway, and prediction of the combined potential impacts of the M5 East Motorway and the New M5 tunnels.

The model shows that when the water table reaches steady state, there will be an elongated cone of depression along each pair of twin tunnels. The depth of the cone of depression cannot be predicted with accuracy, largely because there are insufficient measurements of water table elevation above the M5 East Motorway for the model to be calibrated well. The water table is about 5 metres below sea level near the portals at each end of the M5 East Motorway. One observation bore near the middle of the M5 East Motorway shows that the water table is 0.84 metres below sea level, but this observations is 65 metres away from the nearest tunnel centreline, horizontally, and it is not known whether the water table will decline further.

Where the New M5 tunnels pass beneath Cooks River and the adjacent alluvium, inflows to the tunnel will ultimately have a salinity approaching that of sea water. If the water table along other parts of the tunnel draws down to below sea level, there would be a tendency for further migration of seawater from tidal boundaries towards the main tunnel alignments, perhaps more from rivers rather than from Botany Bay.

The model has been calibrated to predict inflows to the M5 East Motorway tunnels of less than one litre per second per kilometre, so it is not surprising that the model also predicts inflows to the New M5 tunnels that are also less than this rate.

The model does not explicitly represent surface water flows. The upper reaches of Wolli Creek and Bardwell Creek are not represented as drain boundaries. The water table is predicted to be below land surface along these drainage lines because depth-dependent removes water beneath these drainage lines. It is believed that surface runoff is unlikely to be affected. Any ponding of water following runoff events may lead to slightly increased recharge along these drainage lines.

Groundwater-dependent ecosystems (GDEs) such as Tempe Wetlands, Landing Lights Wetland, Eve Street Wetland and Marsh Street Wetland are not explicitly represented in the model. Tempe Wetlands are very unlikely to be affected, because of their proximity to Cooks River and Alexandra Canal. The other three wetlands are in contact with alluvium, and are also unlikely to be affected because groundwater flows in the alluvium are likely to allow redistribution of water as needed.

Sixty-one licensed bores have been identified within one kilometre of the main tunnel alignments, and predictions of drawdown have been tabulated. Potential impacts near these bores, and near other sensitive locations, may be over-estimated in the model, and may be less if processes such as induced recharge lead to increased recharge as the water table declines.

Section 1 Introduction

1.1 Preamble

NSW Roads and Maritime Services (Roads and Maritime) is seeking approval to construct and operate the New M5 (the project), which would comprise a new, tolled multi-lane road link between the existing M5 East Motorway, east of King Georges Road, and St Peters. The project would also include an interchange at St Peters and connections to the existing road network.

WestConnex is a 33 kilometre motorway that is intended to link Sydney's west with the airport and the Port Botany precinct. The WestConnex program of works is proposed to be delivered as a series of projects, each of which would be subject to a standalone planning assessment and approvals process in accordance with the requirements of the *Environmental Planning and Assessment Act 1979* (EP&A Act) and other relevant legislation. The project forms part of WestConnex Stage 2, which also includes the King Georges Road interchange upgrade project.

Approval for the project is being sought under Part 5.1 of the EP&A Act. The project is declared to be State significant infrastructure (SSI) under section 115U(2) of the EP&A Act by reason of the operation of clause 14 and Schedule 3 of the State Environmental Planning Policy (State and Regional Development) 2011. Accordingly, the project is subject to assessment under Part 5.1 of the EP&A Act and requires the approval of the Minister for Planning. An environmental impact statement (EIS) is therefore also required.

1.2 The Project

The project would comprise the following key features:

- Twin motorway tunnels between the existing M5 East Motorway (between King Georges Road and Bexley Road) and St Peters. The western portals along the M5 East Motorway would be located east of King Georges Road, and the eastern portals at St Peters would be located in the vicinity of the Princes Highway and Canal Road. Each tunnel would be about nine kilometres in length and would be configured as follows:
    - Between the western portals and Arncliffe, the tunnels would be built to be three lanes but marked for two lanes as part of the project. Any change from two lanes to three lanes would be subject to future environmental assessment and approval
    - Between the Arncliffe and St Peters, the tunnels would be built to be five lanes but marked for two lanes as part of the project. Any change from two lanes to any of three, four or five lanes would be subject to future environmental assessment and approval.
- Tunnel stubs to allow for a potential future connection to the M4-M5 Link and a potential future connection to southern Sydney.
- Surface road widening works along the M5 East Motorway between east of King Georges Road and the new tunnel portals.
- A new road interchange at St Peters, which would initially provide road connections from the main alignment tunnels to Campbell Road and Euston Road, St Peters.
- Two new road bridges across Alexandra Canal which would connect St Peters interchange with Gardeners Road and Bourke Road, Mascot.

- Closure and remediation of the Alexandria Landfill site, to enable the construction and operation of the new St Peters interchange.
- Works to enhance and upgrade local roads near the St Peters interchange.
- Ancillary infrastructure and operational facilities for electronic tolling, signage (including electronic signage), ventilation structures and systems, fire and life safety systems, and emergency evacuation and smoke extraction infrastructure.
- A motorway control centre that would include operation and maintenance facilities.
- New service utilities and modifications to existing service utilities.
- Temporary construction facilities and temporary works to facilitate the construction of the project.
- Infrastructure to introduce tolling on the existing M5 East Motorway.
- Surface road upgrade works within the corridor of the M5 South West Motorway and M5 East Motorway.

The project does not include ongoing motorway maintenance activities during operation. These would be subject to separate assessment and approval as appropriate.

Construction activities associated with the project would generally include:

- Commencement of enabling and temporary works, including construction power, water supply, ancillary site establishment, demolition works, property and utility adjustments and public 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 control centre and ancillary operations buildings.
- Upgrades to surface roads and construction of bridges.
- Implementation of environmental management and pollution control facilities for the project.

Subject to the project obtaining environmental planning approval, construction of the project is anticipated to commence around mid-2016 and is expected to take around three years to complete.

A detailed description of the project is provided in Chapter 5 (Project description) and Chapter 6 (Construction work) of the Environmental Impact Statement (AECOM, 2015).

1.3 Secretary's Environmental Assessment Requirements

In preparing this report, the Secretary's environmental assessment requirements (SEARs) issued for the New M5 project (SSI 6788) on 5 March 2015, and subsequently revised, have been addressed. The key matters raised by the Secretary for consideration in this report are as follows:

An assessment of groundwater impacts (including ancillary facilities such as the tunnel control centre and any deluge systems), considering local impacts along the length of the tunnels and impacts on local and regional hydrology including consideration of any Water Sharing Plan and impacts on groundwater flow. The assessment must consider:

- *Extent of drawdown;*
- *Impacts to groundwater quality;*
- *Volume of groundwater that will be taken (including inflows);*
- *Discharge requirements;*
- *Location and details of groundwater management and implications for groundwater dependent surface flows;*
- *Groundwater-dependent ecological communities; and*
- *Groundwater users.*

1.4 Objectives

The objective of this report is to support the Technical Working Paper: Groundwater (AECOM, 2015) in order to satisfy the SEARs.

The objectives of modelling are to:

- Predict groundwater inflow into the tunnel during construction and operation;
- Predict the groundwater drawdown around the tunnel due to groundwater inflow to the tunnel; and
- Predict impacts on nearby registered groundwater users and groundwater dependent ecosystems (GDEs).

The following sensitive environmental receivers have been identified: Cooks River, Alexandra Canal, Wolli Creek, Tempe Wetlands, Landing Lights Wetland, Eve Street Wetland and Marsh Street Wetland.

The first objective has not been fully met, partly because a schedule for tunnel development was not provided, and also because of the difficulty of representing the gradual advancement of each tunnel face using currently available modelling software. The evolution of tunnel inflows during construction is discussed qualitatively.

1.5 Technical Challenges

The project has been designed with a criterion that the maximum allowable inflow to the main alignment tunnels would be one litre per second per kilometre. The design includes measures to reduce inflows if unmitigated inflows exceed this rate. For the purposes of this report, it is assumed that this constraint applies for each kilometre of each of the twin motorway tunnels.

Groundwater flow models predict inflows to tunnels by representing regional and local hydrostratigraphy, the hydrogeological properties of hydrostratigraphic units (HSUs), and boundary conditions such as nearby rivers and streams, recharge at the land surface, and conditions along the tunnels. The air pressure inside a tunnel is effectively atmospheric pressure. Piezometric head[1] at any location on the exterior surface of a tunnel[2] is therefore equal to elevation. The exterior surface of a tunnel acts as a seepage face boundary, such that groundwater can flow into the tunnel, in principle from all directions.

A challenge for regional scale groundwater flow models is that it is impossible to represent the exterior surface of a tunnel in sufficient detail to set different values of head around the exterior surface of the tunnel. In this report, as in other studies at regional scale, it is assumed that tunnel inflows can be predicted with sufficient accuracy by representing each section of tunnel by a single cell, 10 metres square in plan, with an appropriate thickness based on the thickness of HSUs at that location. A single value of head has been assigned to each such cell, equal to the elevation of the tunnel centreline at that location.

Using the elevation of the tunnel centreline is a compromise. Consider a cross-section through and orthogonal to a circular tunnel located in rock deep below the land surface and the regional water table. From the moment the tunnel is constructed, groundwater will tend to flow towards the tunnel, because heads around the exterior surface of the tunnel are lower than the water table above. The lowest head in the cross-section is at the bottom of the tunnel, and long flow paths will quickly develop drawing water from the water table, at some distance away from the tunnel centreline, to elevations well below the tunnel invert and finally upwards towards the tunnel invert. However the shortest distance from the water table to the tunnel is directly above the tunnel, from the water table to the crown. The rate of groundwater flow along any flow path depends on hydraulic or piezometric gradients at all points along all flow paths. The gradient is the difference between heads at two points along a flow line divided by the distance between them. While the lowest head in the system attracts flow towards that point, flow paths towards that point are longer. A larger proportion of inflows to a tunnel comes from above, towards the crown. If the single elevation chosen to represent the tunnel was the lowest point in the tunnel cross section, gradients would be slightly larger, but if the water table was predicted to be lowered to this level, this would be too low in the deeper parts of the tunnel. Setting head equal to the elevation of the tunnel centreline is believed to be a reasonable compromise at regional scale. Estimates of tunnel inflows are far more sensitive to values of hydraulic conductivities, and these are known with much less certainty.

---

[1] Piezometric head (sometimes called potentiometric head) is equal to the sum of elevation above datum and pressure head. Pressure head a measure of ambient water pressure at the location where piezometric head is measured. Pressure head is the height of a column of water, at ambient density, such that the weight of that column exerts a pressure on the bottom of the column equal to the ambient pressure.

[2] The exterior surface of a tunnel, whether circular or with some other geometry, includes the roof, walls and floor of the tunnel. The top half of a tunnel is often called the crown, while the bottom half is called the invert.

Predicting inflows to tunnels is also difficult in practice because inflows are influenced by the presence of fractures, and because the period of time during which fractured rock yields water depends on whether the fractures are connected to permanent sources of water. Neither the presence of fractures nor their connectivity can be predicted in advance of tunnelling. The focus of modelling is therefore on tunnel inflows controlled by bulk averages of hydrogeological properties for HSUs, rather than inflows controlled by individual fractures or other structures than have not yet been identified.

The greatest challenge in predicting inflows is the expectation among stakeholders that a numerical groundwater flow model, using the best available software, is capable of answering questions at a range of spatial scales from tens of metres to tens of kilometres, over a range of time scales from days to months to years. There is sometimes an expectation that tunnels can be represented with fine discretisation, within a regional scale hydrostratigraphic model, about which there is considerable uncertainty. CDM Smith has chosen to represent the main alignment tunnels and the stub tunnels using cells that are 10 m square in plan, i.e. with smaller cells than are often used. Even at this level of discretisation, it is impractical to attempt to predict the dynamic effects that would occur during construction of a tunnel kilometre by kilometre beneath the land surface. Dynamic effects are discussed qualitatively in this report, but the focus of this report is on predicting steady state flows long after the tunnel is constructed and commissioned.

1.6 Approach

The approach taken by CDM Smith is consistent with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012) (the “Guidelines”).

The Guidelines promote a staged approach, with three main stages in a modelling project:

- Collation and analysis of data, followed by development of a conceptual model and a modelling plan;
- Development of a model, followed by calibration and sensitivity analysis; and
- Prediction, followed by additional sensitivity analysis and/or uncertainty analysis, if appropriate and possible.

These three stages have been followed during this brief study.

1.7 Acceptance Criteria

The Guidelines explain that acceptance criteria for a groundwater flow model should be discussed prior to the start of a modelling exercise. There is no single measure of goodness of fit. It is useful to compute a Scaled Root Mean Squared (SRMS) error, as reported below, but achieving a small SRMS is not sufficient. It is important that several other acceptance criteria also be met. It is important to ensure that a model converges, that it has good water balance, and that it passes the “sanity test”, i.e. that it demonstrate behaviours consistent with expectations. All of these tests, both quantitative and qualitative, are utilised in this assessment.

1.8 Confidence Level Classification

The Guidelines introduce the concept of a “confidence level classification” for groundwater models. The intention of the authors was to de-emphasise the importance of model calibration (the need to demonstrate that a model is consistent with and capable of simulating past behaviour) and to focus instead on the predictive capabilities of models (the need to have confidence in simulations of future behaviour).

The confidence level depends on available data and model calibration, but also on the extent to which data have been collected during a time when the stress on a groundwater system is similar to future stresses. If a system has not been stressed historically to anywhere near the same extent as in the future, then almost by definition there will be uncertainty, and a model cannot have the highest confidence level classification.

Since the M5 East Motorway was constructed nearby about 15 years ago, some stakeholders may expect that a model could be constructed to predict the potential impacts of the New M5 tunnel with the highest possible confidence level classification, i.e. Level 3. Observations of water table elevation are available at a number of locations near the M5 East Motorway, but few are directly over the tunnel centrelines (where drawdown would be expected to be greatest) and most measurements are recent, i.e. in 2015, such that the transient response of the water table since the tunnel was constructed is not known. For these reasons, i.e. the relative lack of data and the resulting difficulty in calibrating a model that represents the transient impacts of the M5 East Motorway, the model described here is considered to have a Level 2 confidence level classification. This does not imply a weakness in methodology. Rather it points to the fact that more accurate predictions could have been made if more data had been collected following construction of the M5 East Motorway.

1.9 Structure of this Report

The structure of this report is as follows:

- Section 2 provides a brief description of the project, in the context of existing and future tunnels;
- Section 3 describes available data, and what can be learned from the data;
- Section 4 presents a conceptual model for groundwater flow in the region, before and after construction of the project; it then describes the design of a groundwater flow model suitable for predicting tunnel inflows (or the sensitivity of inflows to hydrogeological properties and estimates of recharge) and potential environmental impacts (on the water table and environmental receivers);
- Section 5 describes the development of a regional scale groundwater flow model, the extent to which the model has been calibrated, and the sensitivity of the model to hydrogeological properties and boundary conditions;
- Section 6 describes model predictions, focused on a project design (the New M5 main alignment tunnels and stub tunnels); and
- Section 7 provides a summary of findings and a number of key conclusions.

Section 2 WestConnex New M5 Project

2.1 Regional Setting

The project would be located within the Canterbury, Hurstville, Rockdale, Marrickville, Sydney and Botany Bay local government areas. The project is located from about five to twenty kilometres to the south and southwest of the central business district of Sydney. The project would traverse the suburbs of Narwee, Beverly Hills, Kingsgrove, Bexley North, Earlwood, Bardwell Park, Bardwell Valley, Arncliffe, Turrella, Wolli Creek, Tempe, Sydenham, St Peters, Alexandria and Mascot. The regional context is shown in Figure 2-1.

The project is located within the Cooks River catchment. The Cooks River catchment extends from Botany Bay in the southeast to Randwick in the northeast, Strathfield in the northwest and Hurstville in the southwest forming part of the greater 116,500 hectare Botany Bay catchment (SMCMA, 2011). The Cooks River catchment is fed by nine tributaries, of which three are located in the vicinity of the project (Wolli Creek, Alexandra Canal and the Eastern Channel).

Wolli Creek is the largest tributary of the Cooks River. The creek begins in the suburb of Beverly Hills and runs through the Wolli Creek Valley in a northeasterly direction from Kingsgrove in the west, flowing towards the east until joining the Cooks River near Tempe. The upper section of Wolli Creek, from Beverly Hills to Bexley Road, is generally anthropogenically modified with hard engineered lining with the majority consisting of a concrete-lined trapezoidal channel. At Bexley Road the creek passes through a box culvert before flowing into a modified (shaped), but more natural, channel. The watercourse travels through the Wolli Creek Regional Park and is joined by Bardwell Creek on the northern side of the passenger rail line at Bardwell Park.

Alexandra Canal is a constructed canal, originally a natural watercourse named Sheas Creek. It flows into the Cooks River near the north-western corner of Sydney Airport.

The Eastern Channel runs along the Sydenham to Tempe railway line, discharging into the Cooks River. The channel conveys stormwater as a trapezoidal-shaped concrete-lined open channel.

Two former quarries were operated on the north side of the Alexandra Canal. A former quarry has been landfilled, closed and redeveloped at Tempe (referred to as Tempe Tip). The Alexandria Landfill was also a brickpit and subject to landfilling. The Alexandria Landfill would closed as part of the project.

There are no wetlands subject to State Environmental Planning Policy No.14 (Coastal Wetlands) in proximity to the project. A number of modified and artificial wetlands are located in the vicinity of the project, including Landing Lights wetland, Eve Street wetland, Marsh Street wetland, and Tempe wetlands.

Groundwater Dependent Ecosystems (GDEs) are ecosystems whose current species composition, structure and function are reliant on a supply of groundwater as opposed to surface water supplies from overland flow paths. The frequency of groundwater influence may range from daily to inter-annually, however it becomes clearly apparent when either the supply of groundwater or its quality (or both) is altered for a sufficient length of time to cause changes in plant function. Groundwater use by an ecological community or individual species does not necessarily imply groundwater dependence.

The most likely GDE types in the Sydney region are terrestrial vegetation communities with deep roots that use groundwater, wetlands, and river base flow systems (Technical Working Paper: Biodiversity (Eco Logical Australia, 2015).

2.2 Existing Tunnels

Existing tunnels in the region are shown in Figure 2-2.

A pair of twin road tunnels, known collectively as the M5 East Motorway, carries traffic between Bexley Road in Bexley North and the western side of Sydney Airport, first via a twin tunnel (about four kilometres in length) beneath the suburb of Arncliffe, and then via a relatively short twin tunnel (about one kilometre in length) beneath Cooks River. The M5 East tunnels are sufficiently close to each other that they show at the scale of the map as a single line. The M5 East Tunnel is not fully lined.

The Airport and East Hills Railway Line connects the Sydney Central Business District with Glenfield and Campbelltown via Sydney Airport and East Hills. The Airport Link includes four kilometres of tunnel in rock and another six kilometres of tunnel in soft ground. Part of the tunnel is shown in Figure 2-2, passing from Green Square Station in the north, beneath the domestic and international terminals at Sydney Airport, beneath Cooks River and eventually joining the above ground rail system near Wolli Creek Station. This tunnel is fully lined.

2.3 New M5 Tunnels

The main alignment tunnels would be about nine kilometres long, with the western tunnel portals located at Kingsgrove and the eastern portals located at the St Peters interchange (see Figure 2-3). The eastern end of the main alignment tunnels would be continued to the north to a point underground around Campbell Street, to form stub tunnels for potential connection to the future M4-M5 Link (WestConnex Stage 3).

The depth of the main alignment tunnels would vary depending on geological constraints. The maximum depth of the tunnels would be about 100 metres below the ground surface, with shallower sections on the approach to the western and eastern tunnel portals. The main alignment tunnels would pass under the eastern portals of the M5 East Motorway tunnels and beneath the Airport Link.

Tunnel decline shafts would be formed during construction and would located at the Bexley Road and Arncliffe surface works. These would be re-purposed following construction to form ventilation shafts to the Bexley Road North motorway operations complex and Arncliffe motorway operations complex.

Again, the main alignment tunnels are sufficiently close that they appear as a single line.

DISCLAIMER
CDM Smith has endeavoured to ensure accuracy and completeness of the data. CDM Smith assumes no legal liability or responsibility for any decisions or actions resulting from the information contained within this map.

Job: PWS150016.01
Date: 26/08/2015

Figure 2-1 Regional setting

DISCLAIMER
CDM Smith has endeavoured to ensure accuracy and completeness of the data. CDM Smith assumes no legal liability or responsibility for any decisions or actions resulting from the information contained within this map.

Figure 2-2 Existing tunnels

Figure 2-3 Stage 2 New M5 main tunnel alignment

Section 3 Assimilation and Analysis of Data

3.1 Topography

Detailed topographic data have been obtained by LiDAR. The land surface shows a dendritic pattern characteristic of erosion in rock (see Figure 3-1). The Cooks River and Wolli Creek drainage lines are clearly visible. Low-lying areas along Cooks River and beneath the northern end of Sydney Airport are characteristic of alluvial deposits.

Western areas of the project corridor are relatively flat, low lying, with gentle undulating hills ranging between 30 and 40 metres above Australian height datum (AHD).

The topography of the project corridor near the confluence of Wolli Creek and the Cooks River is relatively flat and low-lying (five metres to 10 metres above Australian height datum), with elevations gradually declining towards Botany Bay. Land within and adjoining the central and northeastern areas of the project corridor have been substantially modified over time due to land reclamation and industrial activities.

Figure 3-2 shows a three-dimensional representation of the land surface, prepared using Leapfrog Hydro Version 2.4 (ARANZ Geo Limited, 2015). Two existing tunnels and the project tunnels are shown projected onto the land surface, in the same colours as in Figure 3-1.

3.2 Botany Bay, Rivers, Drains and Wetlands

Surface water features are shown in Figure 2-1.

The project is located within the Cooks River catchment. The Cooks River catchment extends from Botany Bay in the southeast to Randwick in the northeast, Strathfield in the northwest and Hurstville in the southwest forming part of the greater 116,500 hectare Botany Bay catchment (SMCMA, 2011).

The Cooks River catchment covers an area of around 10,000 hectares in southwestern Sydney, discharging to Botany Bay at Mascot. The catchment was stripped of its natural vegetation during early European settlement and has been subject to long term anthropogenic degradation. The Cooks River catchment is highly urbanised and has a history of intensive land use ranging from residential to heavy industry. The catchment has very little remaining bushland, and a small amount of parkland (SMCMA, 2011).

The Cooks River flows for roughly 23 kilometres from Graf Park in Bankstown into Botany Bay at Kyeemagh (CRA, 2013). The Cooks River is so highly modified that it functions more like a stormwater drainage system than a river system.

Wolli Creek and its southern tributary, Bardwell Creek, have incised gullies through the Hawkesbury Sandstone and shale plateau, which is higher in elevation than in other parts of the Sydney Basin. Wolli Creek flows to the east to join the Cooks River. The Wolli Creek and Cooks River valleys widen as they approach Botany Bay and the incised valley floors have been filled with alluvial sediment to create flat alluvial plains. The Wolli Creek and Cooks River channels have been modified over much of their length to improve drainage and control flooding.

Many of the surface water features shown as permanent water bodies are tidal, since they are connected to the Pacific Ocean. These include Botany Bay, Cooks River, Alexandra Canal and the tidal part of Wolli Creek. Tidal water bodies are saline, with salinity as high as that of seawater, although the salinity grades through brackish to fresh in an upstream direction, especially after rainfall and runoff from contributing catchments.

The tidal range in Botany Bay is about two metres (www.bom.gov.au/australia/tides/#!/nsw-botany-bay). Tide predictions for 2015 show levels in Botany Bay varying between 0.09 metres and 1.99 metres relative to Lowest Astronomical Tide. The average of all high and low tidal levels in 2015 is 0.998 metres. For all intents and purposes, water levels in Botany Bay and at the mouth of Cooks River vary about a mean of zero metres above Australian Height Datum (AHD).

A number of wetland areas are located in the region. Those relevant to this assessment are the Tempe Wetlands (in a remediated quarry and landfill site), Landing Lights Wetland, Eve Street Wetland and Marsh Street Wetland. These are shown in Figure 2-1.

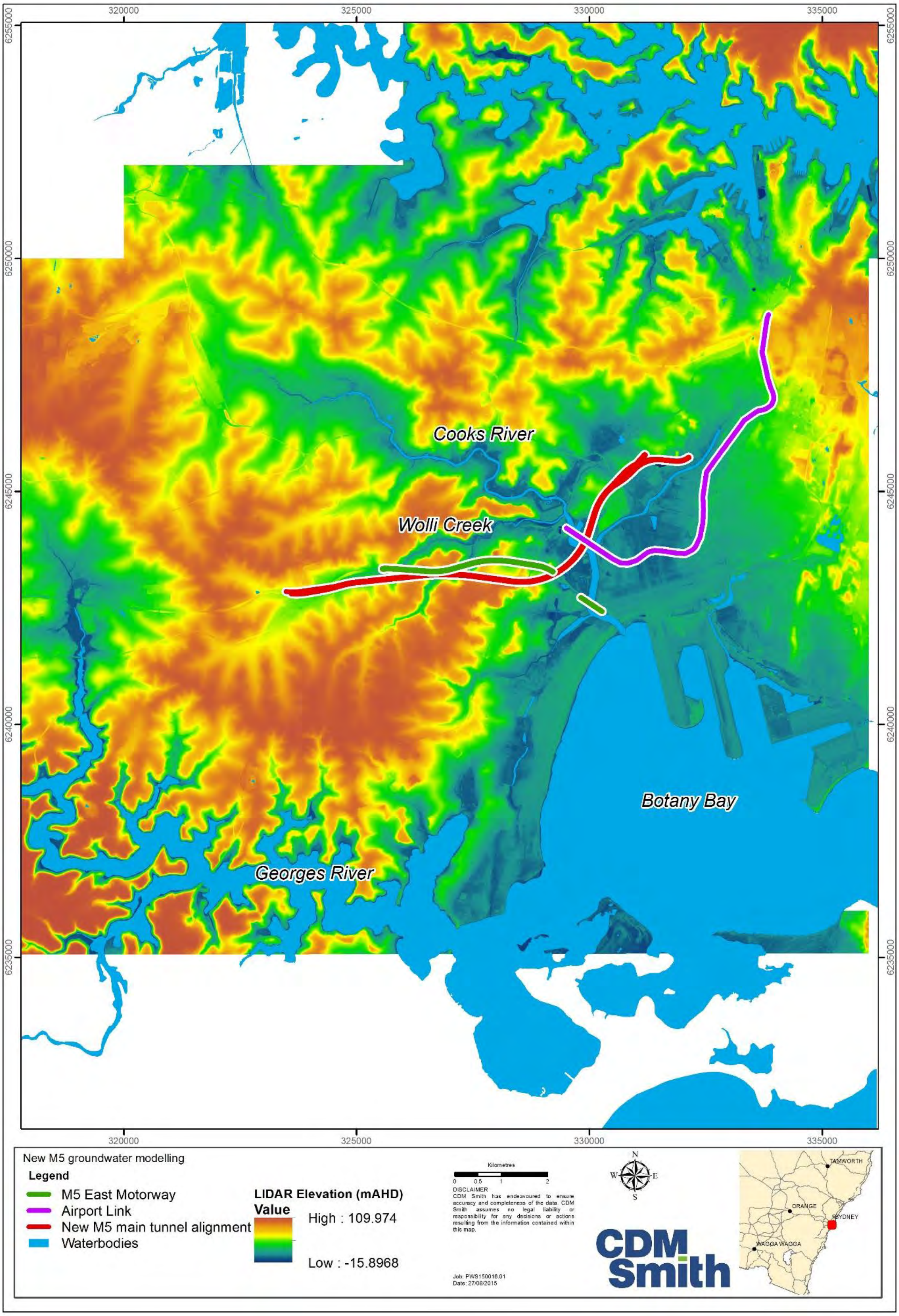


Figure 3-1 Surface topography

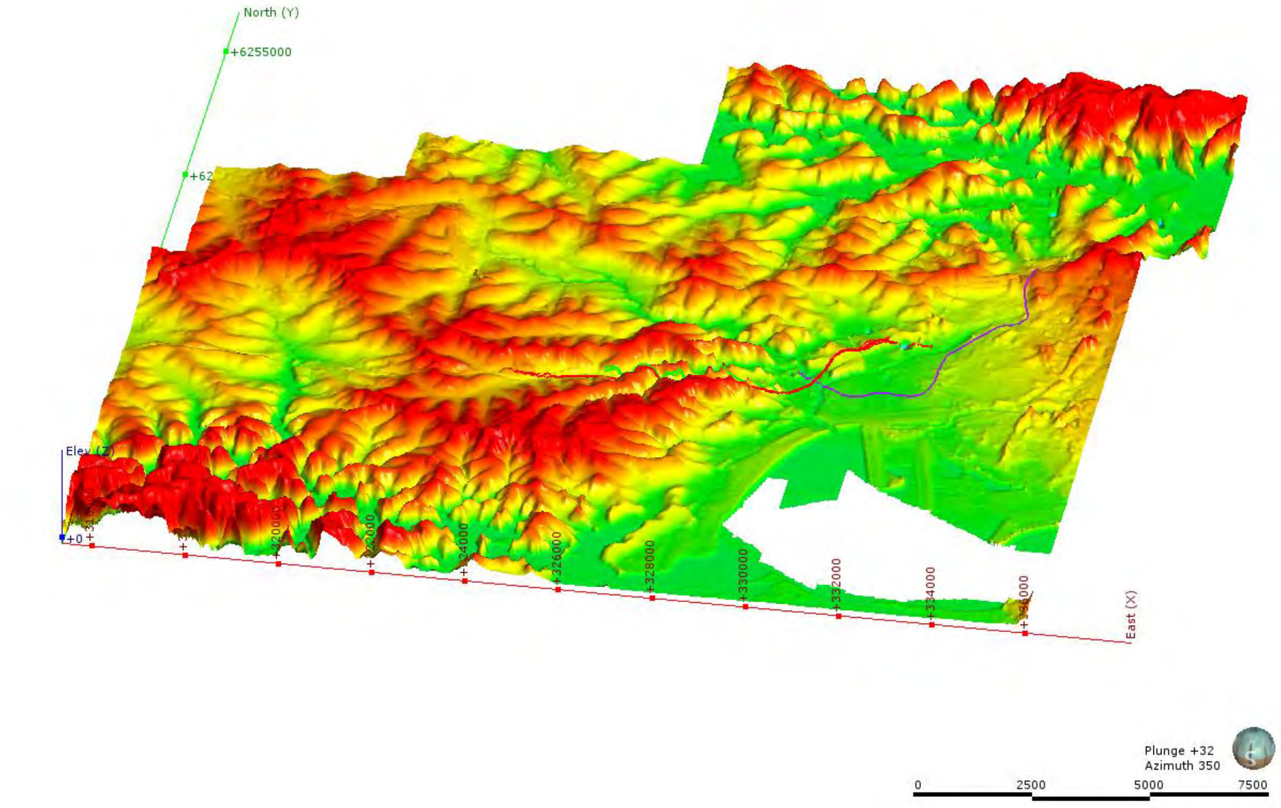


Figure 3-2 Three-dimensional representation of surface topography

3.3 Climate

Climatic data have been collected at Sydney Airport since 1929 (Bureau of Meteorology station number 066037).

Mean annual rainfall is 1085 millimetres, or just over 90 millimetres per month. Monthly average rainfall exceeds 90 millimetres from January to June and is less than 90 millimetres from July to December. June is the wettest month of the year, with an average rainfall of 122 millimetres.

3.4 Geology

3.4.1 Regional geology

The main tunnel alignment for the project lies within the Permo-Triassic Sydney Basin, a large north-northwest trending foreland basin comprising clastic sedimentary successions interstratified with volcanic rocks and coal seams (Och et al., 2009). The basin covers an area of approximately 44,000 square kilometres onshore and another 5,000 square kilometres offshore (Bradd et al., 2012). The eastern portion of the main tunnel alignment lies within the Botany Basin, a sediment-filled depression centred at the Botany Bay which formed from preferential erosion of the Triassic bedrock formations (Hatley, 2004).

3.4.2 Stratigraphy

The stratigraphy of the region is summarised in Table 3-1. Two stratigraphic sections are shown in Figure 3-3 and Figure 3-4. The original source of the second section is unknown – it has been published by the Australian Plants Society (2011), without reference to the source.

The Botany Sands are Quaternary-aged unconsolidated alluvial sediments deposited within the Botany Basin, comprising lenticular beds of clay, peat and ferruginous cemented sands and gravels at varying depths below sea level (Griffin, 1963). The sediments were deposited during the Pleistocene and Holocene into three deeply incised valleys in the Hawkesbury Sandstone. The basal and interbedded clays within the Botany Sands have derived from the weathering of the shales of the Wianamatta Group. The sands and gravels are thought to be derived primarily from the weathering of the Hawkesbury Sandstone (Griffin, 1963).

The Wianamatta Group was deposited during a single regressive episode in the Middle Triassic, giving rise to three recognised formations that include the Ashfield Shale (typically 45 to 60 metres thick comprising dark grey to black siltstone/shale of lacustrine to marine origin), the Minchinbury Sandstone (typically less than four metres thick, quartz-lithic sandstone of a beach and barrier bar complex) and the Bringelly Shale (greater than 250 metres of predominantly shale, claystone and siltstone of lagoonal-marsh facies grading into alluvial or estuarine coastal plain facies) (Herbert, 1979).

The Hawkesbury Sandstone was deposited in the Late Triassic period. The thickness of Hawkesbury Sandstone varies from less than 100 metres in some areas, to approximately 260 metres in the immediate vicinity of the study area. Lithologically the Hawkesbury Sandstone is a medium to coarse grained quartzose sandstone, with interbedded shale beds deposited in a fluvial environment. The shale lenses can be extensive, restricting vertical flow and leading to different values of hydraulic head throughout the sandstone layer cake sequence. Groundwater of generally good quality is present within the primary matrix and also within secondary structural features such as fractures, joints, shears and bedding planes. The Hawkesbury Sandstone is a dual porosity aquifer with the majority of groundwater flow occurring along secondary structural features such as faults, joints and shears.

The Bald Hill Claystone is present between the Hawkesbury Sandstone and the Bulgo Sandstone of the Narrabeen Group. It comprises massive kaolinitic claystone and siltstone with some discontinuous minor sandstone beds.

A number of igneous intrusions in the region are sufficiently remote from the project that their influence is believed to be negligible.

Table 3-1 Lithology

Period	Group	Sub-Group / Formation	Lithology and distribution
Quaternary		Unconsolidated sediments	Sand, gravel, silt and clay along existing channels and creeks. The Botany Sands are included (Griffin, 1963).
Triassic	Wianamatta Group	Liverpool Sub-Group (Bringelly Shale, Minchinbury Sandstone and Ashfield Shales)	Shale, siltstone and claystone with minor sandstone. The Bringelly Shale is absent in the area of the proposed project alignment. Thickness increases to the west, towards the Fairfield Basin (depocentre). The extent is confined to the western and southern edges of the Botany Basin (Griffin, 1963).
		Hawkesbury Sandstone	Quartz sandstone with discontinuous shale beds (about five per cent) up to 300 metres in thickness (Bradd et al., 2012; Pells, 2002). Crops out over an area of approximately 20,000 square kilometres, extending from the Southern Highlands to the Putty area in the north, and to the lower Blue Mountains (Lee, 2009).
	Narrabeen Group		Lithic to quartz lithic sandstone, shale and claystone with thickness 300 to 500 metres (Bradd et al., 2012). Capped by Bald Hill Claystone, a continuous low permeability unit that restricts the migration of water and gas into adjoining units (Haworth, 2003).

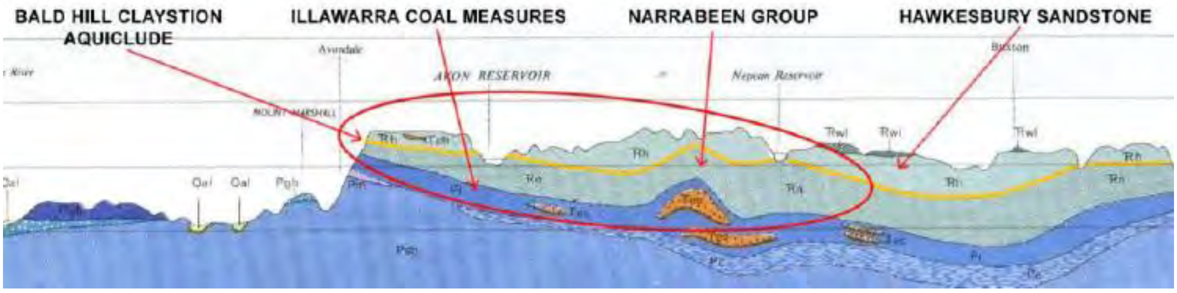


Figure 3-3 South to north stratigraphic cross section of Sydney Basin (after Bradd et al., 2012)

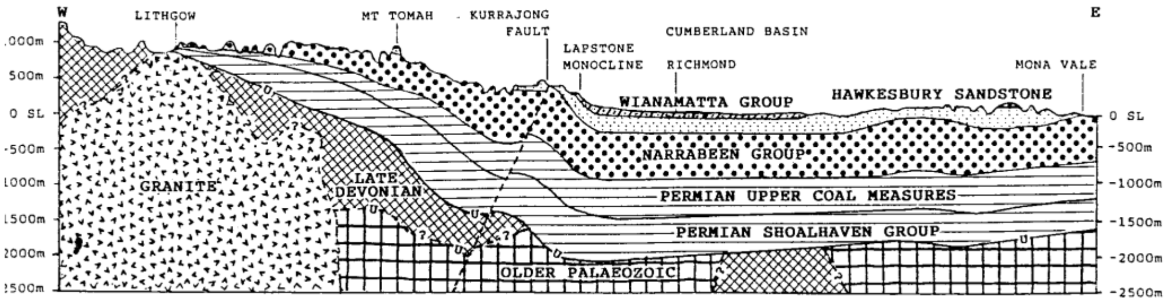


Figure 3-4 West to east stratigraphic cross-section of Sydney Basin (original source unknown)

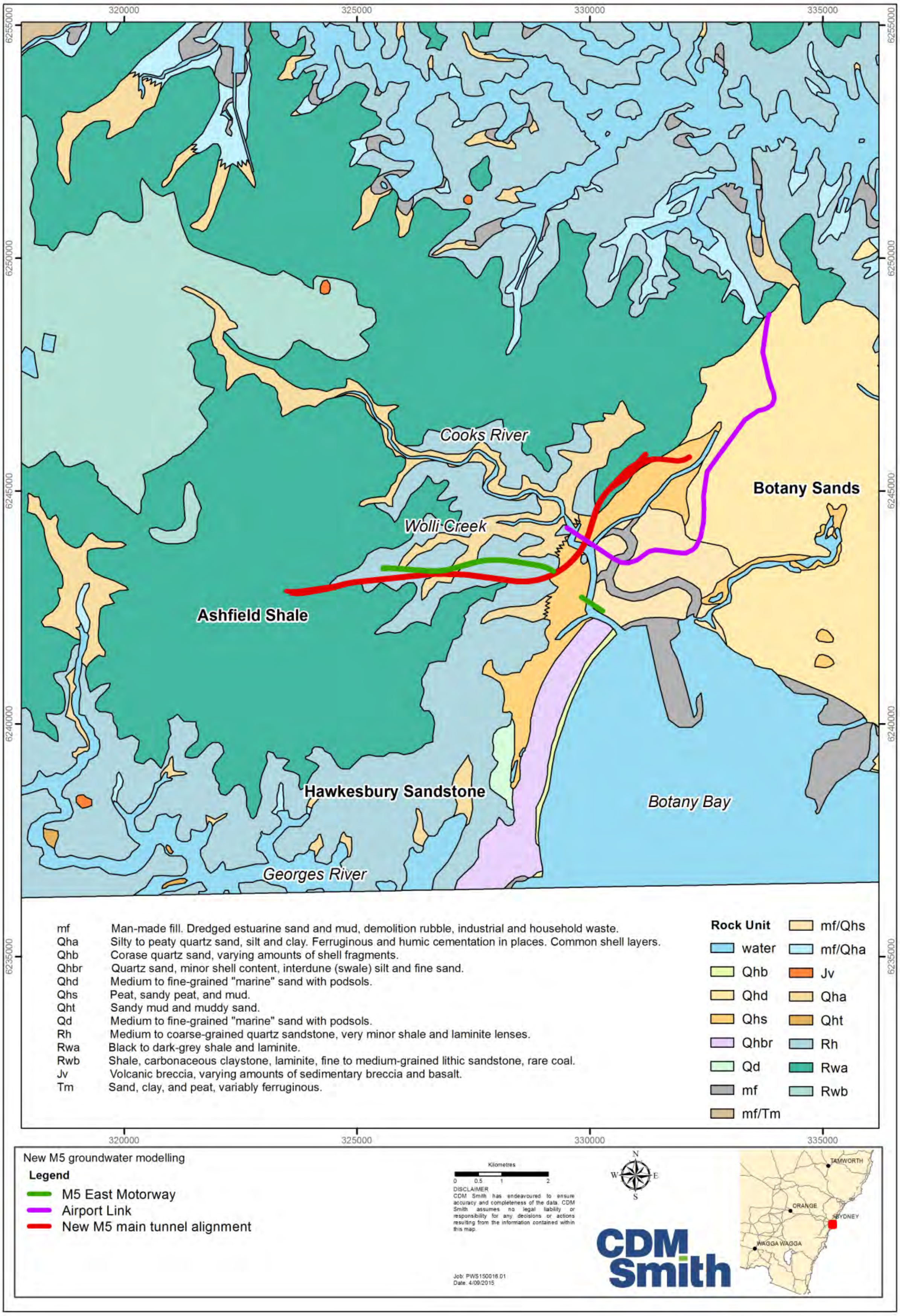
3.4.3 Surface geology

Surface geology is shown in Figure 3-5. A simplified version of the surface geology is shown in Figure 3-6, based on grouping several types of sediments into one group, and two types of shale into another. The reason for simplifying the geology is that there are insufficient bore logs available to develop a three-dimensional (3D) model that includes all of these rock types.

Figure 3-6 has been developed using Leapfrog Hydro (see Section 4.1 below). Several sources of data have been used in Leapfrog Hydro to generate a 3D geological model, including the original surface geology shown in Figure 3-5, geological bore logs, recent mapping of the base of alluvial sediments (top of rock) by Parsons Brinckerhoff (2010) and the depth of occurrence of sandstone in several other boreholes.

3.4.4 Structures

According to Och et al. (2009), several major north-northeast striking fault zones and dykes are present within the Sydney metropolitan area (see Figure 3-7). In particular, the inferred extension of the Luna Park Fault Zone may traverse the western end of the project alignment, where the Hawkesbury Sandstone outcrops, and may have been crossed by the M5 East Motorway. The major fault zones of the Sydney Basin have up to three metres wide brecciated or highly jointed material (Och et al., 2009).



mf	Man-made fill. Dredged estuarine sand and mud, demolition rubble, industrial and household waste.
Qha	Silty to peaty quartz sand, silt and clay. Ferruginous and humic cementation in places. Common shell layers.
Qhb	Corase quartz sand, varying amounts of shell fragments.
Qhbr	Quartz sand, minor shell content, interdune (swale) silt and fine sand.
Qhd	Medium to fine-grained "marine" sand with podsols.
Qhs	Peat, sandy peat, and mud.
Qht	Sandy mud and muddy sand.
Qd	Medium to fine-grained "marine" sand with podsols.
Rh	Medium to coarse-grained quartz sandstone, very minor shale and laminite lenses.
Rwa	Black to dark-grey shale and laminite.
Rwb	Shale, carbonaceous claystone, laminite, fine to medium-grained lithic sandstone, rare coal.
Jv	Volcanic breccia, varying amounts of sedimentary breccia and basalt.
Tm	Sand, clay, and peat, variably ferruginous.

DISCLAIMER
CDM Smith has endeavoured to ensure accuracy and completeness of the data. CDM Smith assumes no legal liability or responsibility for any decisions or actions resulting from the information contained within this map.

Job: PWS150016.01
Date: 4/09/2015

Figure 3-5 Surface geology

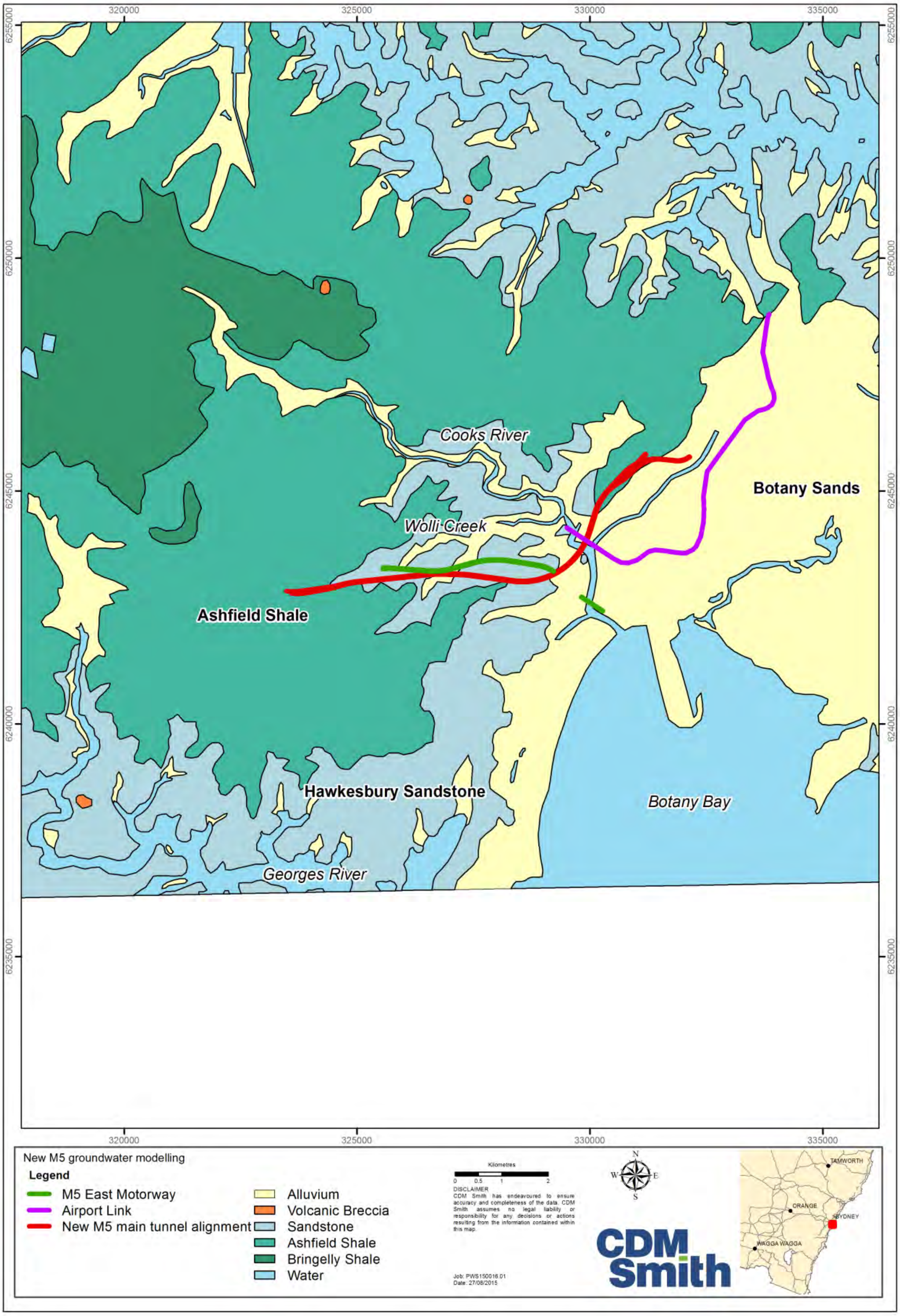
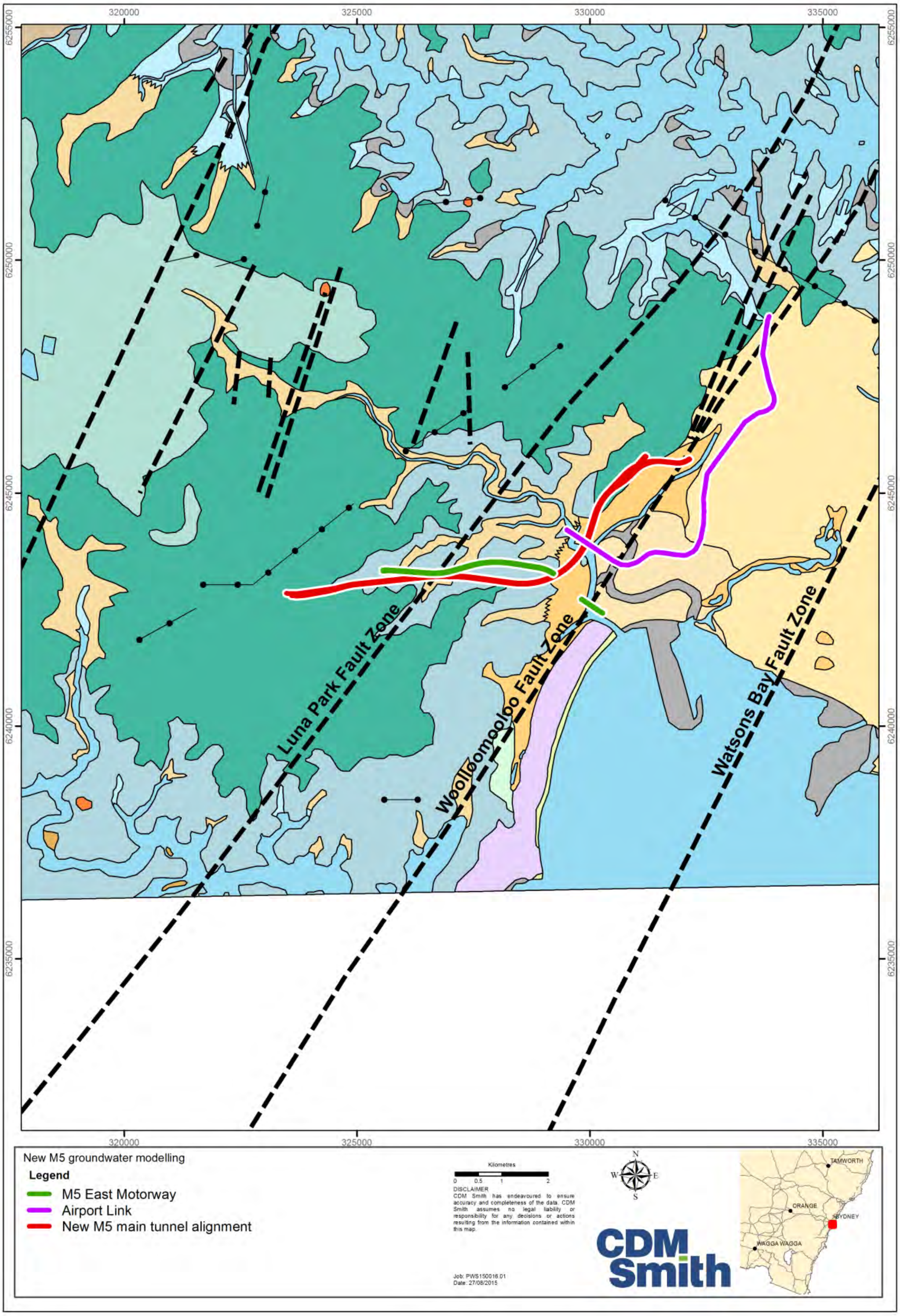


Figure 3-6 Simplified surface geology



DISCLAIMER
CDM Smith has endeavoured to ensure accuracy and completeness of the data. CDM Smith assumes no legal liability or responsibility for any decisions or actions resulting from the information contained within this map.

Job: PWS150016.01
Date: 27/08/2015

Figure 3-7 Regional geological structures (after Och et al., 2009)

3.5 Hydrogeology

3.5.1 Hydrostratigraphy

The hydrostratigraphy of the region is known to depend on the major geological units described above.

The Botany Sands aquifer to the north and east of Sydney Airport is a significant regional aquifer, and transmits far more water than sandstone below. Alluvium along rivers is similarly permeable and capable of transmitting groundwater.

Hawkesbury Sandstone is believed to transmit more groundwater than Ashfield Shale, but the amount of groundwater flowing through the sandstone is limited by recharge (the rate at which water reaches the sandstone, either directly or through overlying shale) and relatively flat gradients towards discharge areas (along rivers and coastlines).

Bald Hill Claystone is believed to be sufficiently impermeable that groundwater flows in higher formations are for the purposes of this study isolated from flows in lower formations.

The hydrological significance of all HSUs is discussed further in Section 4, during development of a conceptual model.

3.5.2 Hydrogeological properties

The focus of this Section is on summarising information available in the literature, to support development of a conceptual model (Section 4) and model calibration (Section 5).

Literature

Unconsolidated sediments

The hydraulic conductivity of alluvial sediments along Wolli Creek in the Turrella area was estimated to range from 0.2 to 0.8 metres per day based on the analysis of slug tests and pumping tests (Hatley, 2004).

Wianamatta Group Shale

Hewitt (2005) indicates that hydraulic conductivity of the Wianamatta Group Shale ranges from 0.0001 to 0.01 metres per day. In the weathered part, the bulk hydraulic conductivity could be up to 0.1 metres per day. Russell et al. (2009) indicate that there is paucity of hydrogeological property data for the Wianamatta Group Shale that may reflect poor groundwater resource potential of the unit, with hydraulic conductivity reported to range from 1×10^{-7} metres per day to two metres per day depending on the degree of weathering.

Hawkesbury Sandstone

According to Hewitt (2005) the hydraulic conductivity of the Hawkesbury Sandstone is about 0.1 metres per day near surface, decreasing to around 0.001 metres per day at a depth of 50 metres. This decrease in hydraulic conductivity is primarily due to a decrease in sub-horizontal defect aperture caused by overburden pressure (Tammetta and Hewitt, 2004). Packer test data for the Hawkesbury Sandstone in the Sydney Basin (Tammetta and Hawkes, 2009) is shown in Figure 3-8, showing a clear reduction in geometric mean hydraulic conductivity with depth (note that this Figure also includes data from the sandstones of the underlying Narrabeen Group). Hewitt (2004) indicates that the log standard deviation in hydraulic conductivity over a five-metre depth interval is comparable to the log standard deviation in sub-horizontal defect spacing.

Russell et al. (2009) indicate that massive sandstone units typically exhibit hydraulic conductivities two orders of magnitude less than the fractured strata. For example, hydraulic conductivity estimated from pumping tests of the fractured strata near Wolli Creek palaeochannel was 0.65 metres per day (Hatley, 2004), which is approximately two orders of magnitude greater than 0.0019 metres per day hydraulic conductivity of the massive units estimated from laboratory analysis of core samples taken in the Lane Cove area (Hewitt, 2005).

Bore yields range from 0.3 to 40 litres per second, although bore yields within the Sydney area are generally less than one litre per second (Russell et al., 2009).

Packer testing along the project corridor

Additional packer testing has been carried out in 57 boreholes drilled into the Hawkesbury Sandstone along and within the vicinity of the project. Packer testing has been undertaken in up to eight discrete vertical intervals per borehole, with each test interval spanning approximately 11 metres.

The packer test results provide estimates of hydraulic conductivity for the intervals measured, including the effects of horizontal and vertical features and the rock matrix itself. Horizontal and sub-horizontal hydraulic conductivities are expected to be higher than vertical hydraulic conductivity because horizontal defects tend to be more extensive, numerous and wider than vertical defects in the Hawkesbury Sandstone and Ashfield Shale. The number of defects tends to decrease with depth.

The estimates of horizontal hydraulic conductivity derived from packer testing are summarised in Figure 3-9. The geometric mean hydraulic conductivity is approximately 0.01 metres per day within the top 40 metres, decreasing to approximately 0.003 to 0.005 metres per day from 40 to 80 metres below ground level (mbgl). Packer tests give no direct indication of vertical hydraulic conductivity.

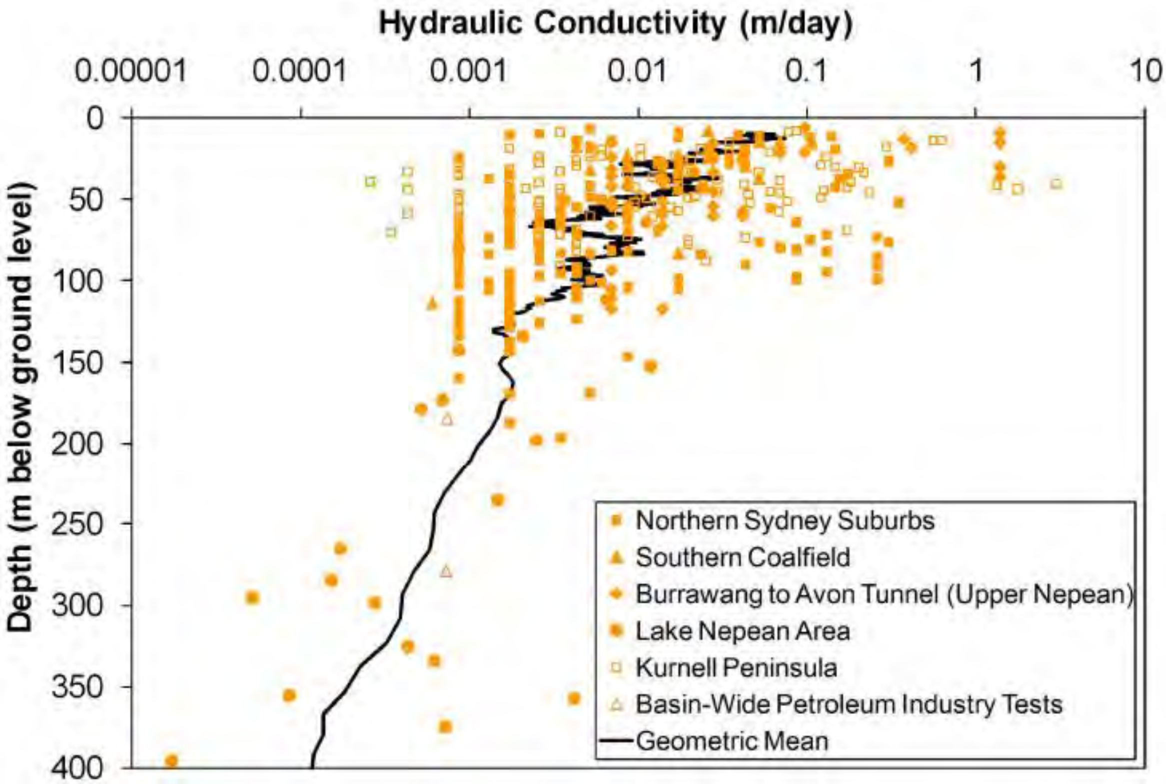


Figure 3-8 Hydraulic conductivity from packer testing of Mesozoic sandstones in Sydney Basin

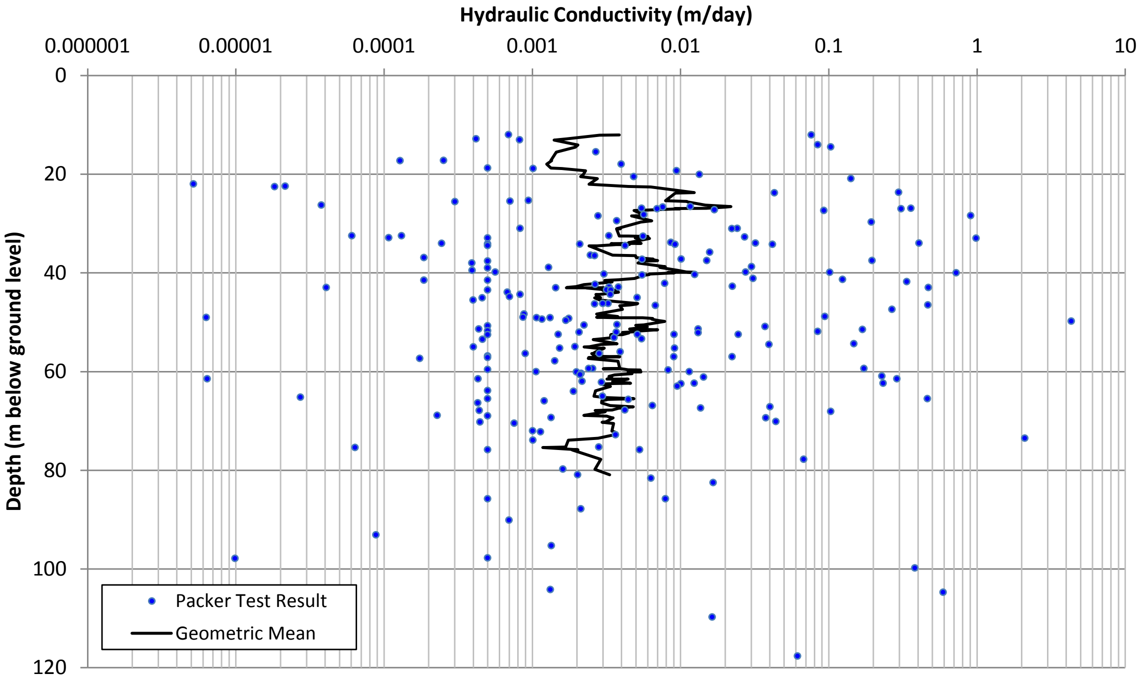


Figure 3-9 Hydraulic conductivity from packer testing along M5 alignment

3.5.3 Groundwater flow regime

Pells (2002) indicates that "the regional water table forms a subdued reflection of topography", with groundwater levels being approximately equal to the sea level along the harbour. This expression is somewhat clichéd, being a text book explanation of the fact that the shape of the water table is related to topography, being at or somewhat lower than the level of drainage lines and even lower below the crests of hills. This description is broadly consistent with inferred groundwater flow directions in the Quaternary unconsolidated sediments (the Botany Sands) presented by Hatley (2004) (see Figure 3-10). The Botany Sands aquifer to the north and east of Sydney Airport drains south towards Botany Bay and west towards the Alexandra Canal.

Groundwater within the Hawkesbury Sandstone typically moves horizontally along bedding planes and vertically via joints. Under natural conditions, horizontal flow is typically much greater than vertical flow, as in aquifers generally (Bradd et al., 2012).

No references have been found that show typical flow directions in the Hawkesbury Sandstone in the study area, or the effects of overlying Ashfield Shale, which generally has a lower hydraulic conductivity.

The Bald Hill Claystone is considered to be a significant regional aquitard that restricts the movement of groundwater between the overlying Hawkesbury Sandstone and the underlying Narrabeen Group (Bradd et al., 2012). For the purpose of this study, the base of the Hawkesbury Sandstone has been assumed to represent the effective hydraulic base of the groundwater flow system of interest.

As the hydraulic conductivity of shallow unconsolidated sediments is higher than the hydraulic conductivity of the Hawkesbury Sandstone at depth, groundwater tends to flow through unconsolidated sediments and regolith faster than through consolidated rock, supplying a larger proportion of baseflow to creeks and rivers (Bradd et al., 2012).

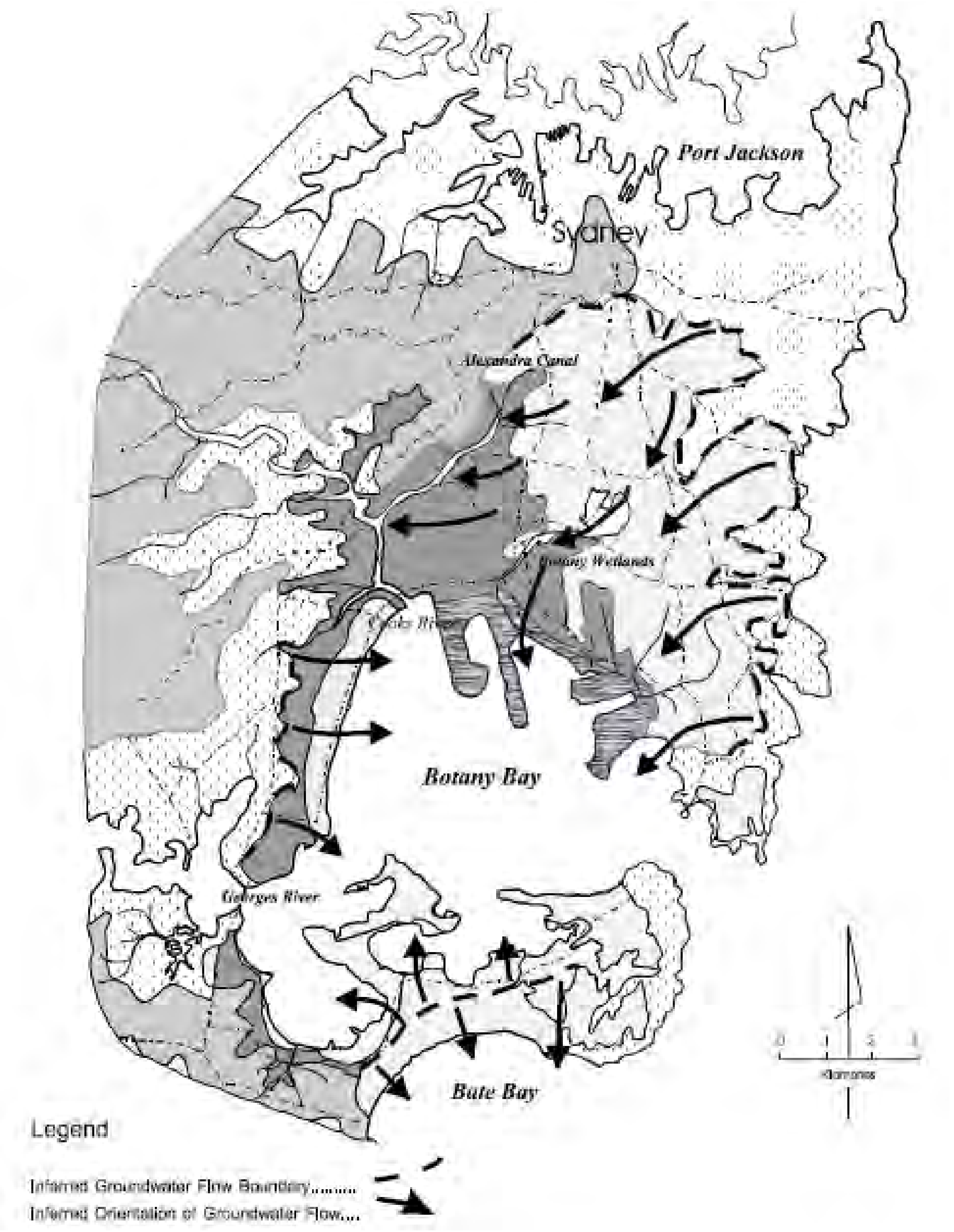


Figure 3-10 Inferred groundwater flow directions in shallow sand aquifers (after Hatley, 2004)

3.5.4 Hydrogeological controls and tunnel inflows

Jointing in the Hawkesbury Sandstone in the Sydney area is characterised by tight sub-vertical joints with limited vertical continuity, typically resulting in minor seepage of groundwater into tunnels – less than one litre per second per kilometre (Best and Parker, 2005; Tammetta and Hewitt, 2004). However, high groundwater inflow rates have been observed in tunnels driven into the Hawkesbury Sandstone where structural features such as faults, joints and dykes connect the tunnels to water sources, i.e. surface water courses and aquifers.

Palaeochannels and valley bulging

According to Russell et al. (2009), local scale fracturing and shearing of the Hawkesbury Sandstone occur beneath valleys or palaeochannels due to the stress relief effect of valley bulging, i.e. removal of the confining rock mass by incision of valleys, resulting in reduction in effective stress, and shearing of horizontally layered strata by upward vertical movement. This effect may or may not apply to the relatively shallow palaeochannels beneath the study area.

Gee et al. (2002) indicate that rocks beneath palaeochannels along the Northside Storage Tunnel contained low angle thrust faults and bedding plane shear features with high hydraulic conductivity. Extensive grouting was carried out beneath a palaeochannel in Middle Harbour at Clontarf to reduce groundwater inflow rates from a predicted 200 litres per second to 10 litres per second (Gee et al., 2002).

Investigations undertaken in the eastern end of the M5 East Motorway tunnels indicated preferential fracturing in the Hawkesbury Sandstone in the vicinity of Wolli Creek (Hatley, 2004), where hydraulic conductivity of around 0.65 metres per day was estimated from pumping tests.

Adams et al. (2001) suggest that higher groundwater inflows into tunnels are common 10 to 20 metres beneath the floor of valleys/palaeochannels, but this may be due to availability of water immediately above the tunnel, rather than to enhanced hydraulic conductivity due to valley bulging in the distant past.

Inflows into the M5 East Motorway tunnels

The M5 East Motorway consists of about four kilometres of twin tunnels driven into the Hawkesbury Sandstone, between Bexley Road and Marsh Street, parallel in parts to the main tunnel alignment of the project, albeit at shallower depth (the maximum depth of 50 metres below ground level). Historical inflows into the twin tunnels are of particular relevance to this project due to their proximity to the project alignment.

The twin tunnels of the M5 East Motorway traverse the palaeochannels and the inferred extension of the Luna Park Fault Zone (Figure 3-7), however no grouting was reported during construction to control groundwater inflows. Localised inflows of two to three litres per second were reported, reducing to 1.5 litres per second within two to three weeks of construction (Best and Parker, 2005). The average inflow of groundwater since the opening of the tunnel in December 2001 has been 0.75 to 0.9 litres per second per kilometre of single tube tunnel (Tammetta and Hewitt, 2004).

Prior to construction, detailed investigations were carried near the eastern end of the tunnels in the Turrella area where shafts and tunnels cross the contact between the alluvial sediments adjacent to Wolli Creek and the underlying Hawkesbury Sandstone (Hatley, 2004). The investigations identified a possible need to seal sections of the shafts and tunnels to minimise inflows and drawdown of the water table.

3.5.5 Licensed users of groundwater

A review of bores registered with the NSW Office of Water groundwater data base within one kilometre of the alignment has identified 61 registered bores. The majority of these bores are shallow water supply bores (less than 10 metres deep) extracting water from the Botany Sands. Only 11 are drilled into bedrock with eight extracting water from the Hawkesbury Sandstone and three intersecting the Ashfield Shale.

Table 3-2 and Figure 3-11 show all licensed bores within a one kilometre radius of the main tunnel alignment.

Table 3-2 Groundwater users within 1 km of the main tunnel alignments

Bore ID	Purpose	Depth	Water Table Elevation (mAHD)
GW013331	Industrial	14.9	7.9-14.8 (saturated material)
GW015954	Industrial	20.1	6.7-19.2 (saturated material)
GW023191	Water Supply - Domestic	3.7	1.20'
GW023194	Water Supply - Domestic	4.9	3.3
GW024109	Water Supply - Domestic	2.1	2.1
GW024673	Water Supply - Domestic	4.3	Not Available
GW027248	Industrial	4.9	2.4
GW027664	Industrial	6.1	0.7
GW040219	Water Supply - Domestic	0	Not Available
GW072161	Water Supply - Domestic	90.5	14
GW072643	Water Supply - Domestic	12	Not Available
GW100053	Water Supply - Domestic	7	1
GW100209	Industrial	108	Not Available
GW101533	Irrigation	20	4.4
GW103504	Commercial and Industrial	6.1	Not Available
GW103505	Other	6	Not Available
GW103506	Unknown	6	Not Available
GW103507	Other	6	Not Available
GW103508	Water Supply - Domestic	6	Not Available
GW104448	Domestic	0	Not Available
GW104449	Monitoring	0	Not Available
GW104450	Monitoring	0	Not Available
GW106830	Monitoring	7	Not Available
GW107993	Monitoring	13.6	1.95
GW108104	Monitoring	N/A	Not Available
GW108295	Monitoring	8	Not Available
GW108406	Monitoring	8	Not Available
GW108439	Monitoring	8	Not Available
GW108497	Water Supply - Domestic	8	Not Available
GW108588	Other-Test Bore	8	Not Available
GW109191	Industrial	186	93
GW109821	Water Supply - Domestic	35	14.5
GW109822	Water Supply - Domestic	10.45	3
GW109823	Water Supply - Domestic	29	12.5
GW109824	Recreation	20.7	4.51
GW109825	Water Supply - Domestic	22	14.9
GW109963	Other	8	Not Available
GW109964	Monitoring	8	Not Available
GW109965	Monitoring	8	Not Available
GW109966	Monitoring	3	Not Available
GW110456	Monitoring	3.6	2.3
GW110457	Monitoring	3.6	1.7
GW110458	Water Supply - Domestic	2.8	2.3
GW110735	Water Supply - Domestic	0	Not Available
GW111316	Water Supply - Domestic	162	4.000'
GW111320	Water Supply - Domestic	5.2	2.52
GW111321	Monitoring	5	2.64

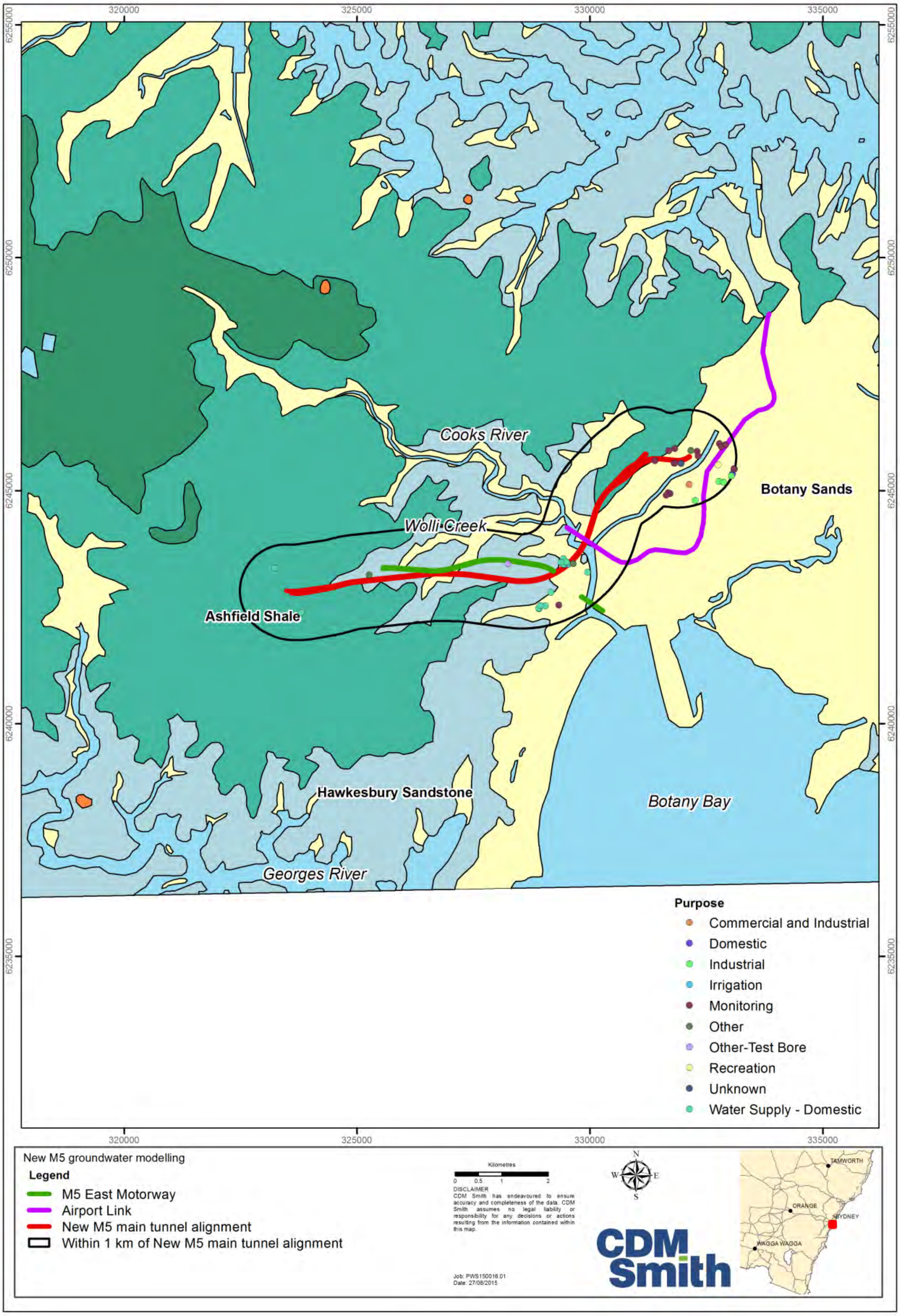


Figure 3-11 Licensed bores within one kilometre of main tunnel alignment

3.5.6 Previous modelling

Many groundwater flow models have been developed of the Botany Sands aquifer to the north and east of Sydney Airport, but a full review is not provided here, mainly because the impact of the Botany Sands on the project, or of the project on the Botany Sands, would be very localised. The reason for impacts being localised is that the hydraulic conductivity of the Botany Sands is much higher than in the Hawkesbury Sandstone and Ashfield Shale, so any gradients in the sands will remain flat, and the sands have so much storage that levels will not be affected by inflows to tunnels.

Groundwater modelling was undertaken during approvals processes for the M5 East tunnel (G. Hawkes, pers.comm.), but AECOM was unable to gain access to reports on this modelling prior to completion of this study.

Section 4 Conceptual Model

4.1 Hydrostratigraphy

A hydrostratigraphic model has been developed based on bore logs and other published information and interpretations.

Bore logs are available at bores that are generally aligned with the M5 East Motorway tunnels and the project (see Figure 4-1, which shows the bores relative to the locations of tunnels). Additional bore logs were sourced from Lovering (1954), defining the contact between the Wianamatta Group and Hawkesbury Sandstone. All borehole data were analysed and summarised, with materials grouped according to the three generalised classifications used in the simplified geological model. A distinction is made between sandstone, shale (siltstone) and alluvium.

The surface geological model (see Figure 3-5) provides another source of data, because the line separating sandstone and shale, or sandstone and alluvium, defines a set of points at the elevation of the topography separating these different units.

The top-of-rock elevation contours of the site ground model presented by Parsons Brinckerhoff (2010) were used to define the contact between the sandstone and alluvium, as well as the base of the palaeovalley.

Figure 4-2 shows the simplified hydrostratigraphic model in 3D, in Leapfrog Hydro. The tunnels are also shown in 3D, so that tunnels visible in Figure 4-2(a), for example, have centrelines located above the top of the sandstone, in shale or alluvium. The Leapfrog Hydro 3D model can be viewed and rotated in 3D, using a free viewer.

Figure 3-6 shows the simplified surface geology and hydrostratigraphy, based on the Leapfrog Hydro model.

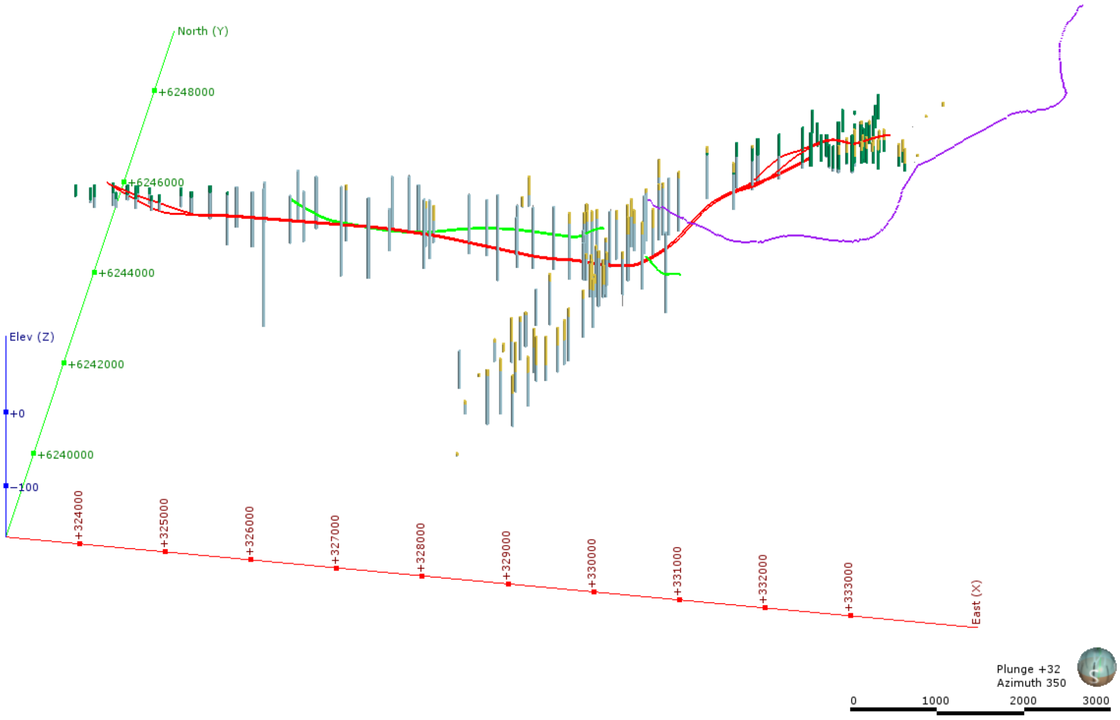


Figure 4-1 Bore logs on which Leapfrog Hydro model is based

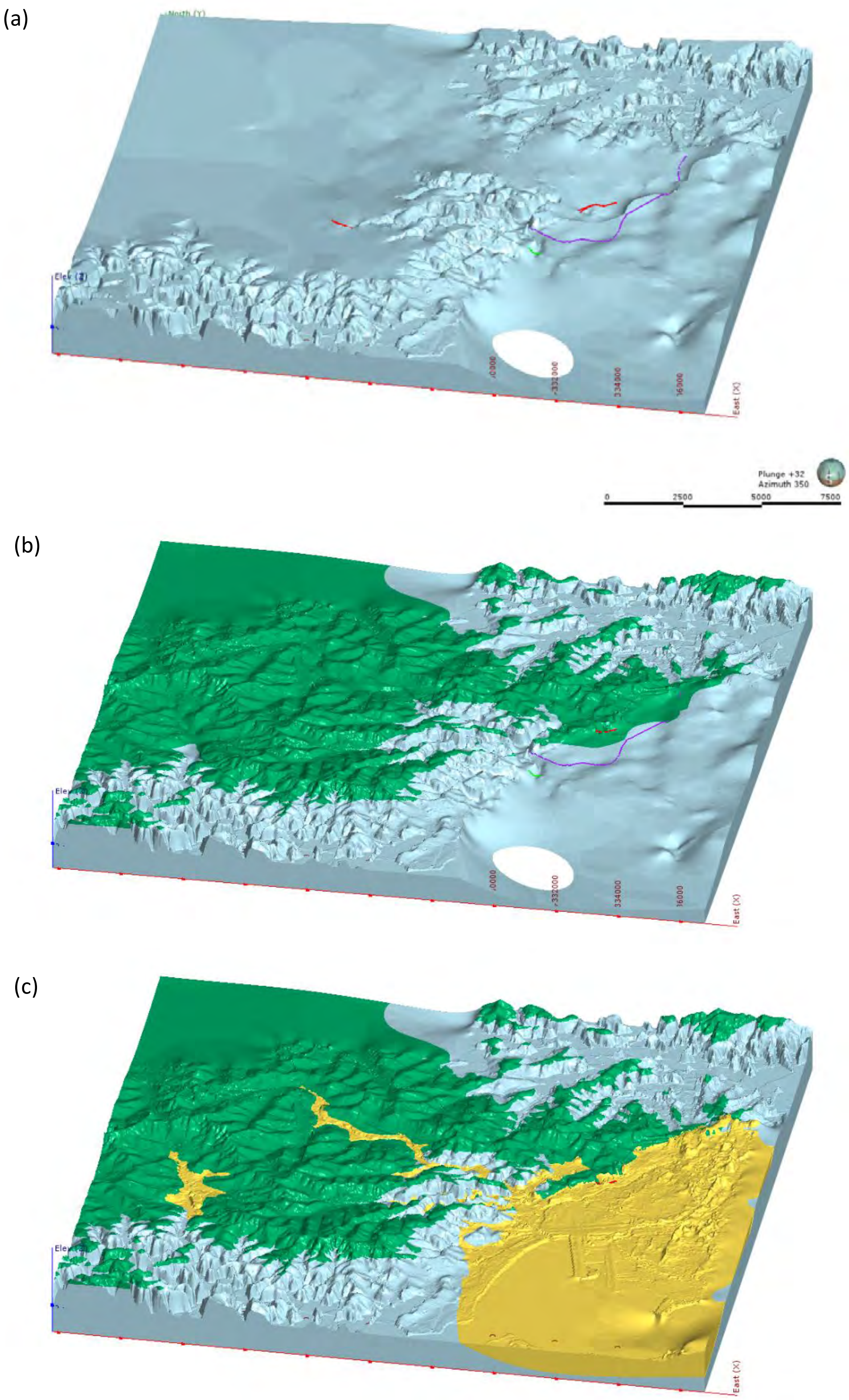


Figure 4-2 Hydrostratigraphic model (a) top of sandstone, (b) with overlying shale, (c) with alluvium

4.2 Surface Water and Surface Hydrology

Botany Bay, Cooks River, Alexandra Canal and the tidal reach of Wolli Creek act as discharge boundaries for the regional groundwater system. Since water levels in these water bodies vary tidally, with an amplitude of one metre (Section 3.2), the water table elevation adjacent to these boundaries also varies tidally, with amplitude decreasing and lag increasing with distance from the boundary. However, most of the regional groundwater system responds to the effect of average sea level, and does not respond to tides. Groundwater flow occurs towards effectively constant head boundaries at zero metres AHD along all tidal boundaries.

Rainfall causes runoff in drainage lines such as the upper reaches of Wolli Creek and Bardwell Creek. These drainage lines are believed to carry surface drainage, rather than acting as discharge boundaries for groundwater. The non-tidal upper reaches of Wolli Creek, and the whole of Bardwell Creek, are therefore represented in the same way as the rest of the land surface, with recharge and depth-dependent evapotranspiration. The latter may hold the water table slightly below the drainage lines in some locations, but groundwater does not flow to these drainage lines.

If surface water were to pond in depressions along the upper reaches of Wolli Creek or along Bardwell Creek, this ponding could cause slightly more localised recharge to the water table below. However this level of conceptualisation has not been considered, because no data are available to support or reject this hypothesis.

Since the M5 East Motorway and the main alignment tunnels of the project are mostly below sea level, water would flow from permanent tidal water bodies towards the tunnels. Some tunnel inflows would ultimately be saline, at a salinity approaching that of seawater.

4.3 Conceptualisation of Tunnel Inflows

Each of the tunnels in the study area is different and interacts differently with the regional groundwater system.

The Airport Link is fully lined and is not known to leak. In essence, the Airport Link is a curvilinear structure that has the potential to act as a barrier to shallow groundwater flows in the Botany Sands. This tunnel is unlikely to have any impact on groundwater movement near the project alignment, and for this reason it is not included in modelling.

The M5 East Motorway tunnel is lined beneath Cooks River. Any leakage into this part of the tunnel would come from Cooks River directly above, and the water table nearby will not be affected.

The longer part of the M5 East Motorway lies entirely in sandstone. This part of the tunnel is not lined and is known to leak.

Construction of the M5 East Motorway tunnel started in August 1998 and the tunnel was opened in December 2001. Since construction started, leakage into the tunnel would have started a transient process that is either continuing or has already led to quasi-equilibrium, i.e. with almost steady flows from a water table above that fluctuates seasonally in response to recharge and evapotranspiration.

Construction of the project would start a new transient, superimposed on the impacts of the M5 East Motorway. The tunnel would pass through shale near both portals, and otherwise through sandstone. While it would in principle be possible to predict the evolution of leakage during construction, this is extremely difficult, mainly because the short term tunnel inflows are influenced by local fracturing and storage of water in nearby fracture networks. Initial inflows to tunnels can be large, because of the large hydraulic gradients that develop near the walls, however these gradients dissipate in time, as inflows approach a steady state.

Ventilation tunnels in sandstone and shafts from the surface to those tunnels would also have the potential to induce leakage. For the purposes of this study, it is assumed that the ventilation tunnels would have a minor effect compared to the main road tunnels. This is because they are relatively short and adjacent to the main tunnel alignments, so that the effects of the project would already be taken into account.

4.3.1 Transient flows during and after construction

Tunnel inflows during construction would be managed by the contractors. The potential for inflow depends on the chosen construction methods.

As explained in Section 1.5, a tunnel in rock has seepage faces on all exterior surfaces, with the potential for inflows into the tunnel. Tunnelling causes the piezometric head on all exterior surfaces to be equal to elevation above datum.

Immediately after tunnelling, groundwater will tend to flow into a tunnel. Hydraulic gradients near the exterior surface of the tunnel are initially steep, so rates of flow are greater than at later times. Water is initially released from the zone adjacent to a tunnel because the water in the rock expands slightly, due to the depressurisation caused by the tunnel. The effect propagates outwards, away from the tunnel, initially radially, and later upwards towards the water table far above. After a period of time, the effect of depressurisation reaches the water table, and at this time, there is the first tendency for the water table to be lowered, towards the tunnel. As time passes, an almost steady flow develops. In a homogeneous material, with uniform hydraulic conductivities in space, the rate of flow would tend to approach the vertical hydraulic conductivity, at least directly above the tunnel.

The point of this discussion is that immediately after tunnelling, the rate of inflow to a tunnel is as large as it ever becomes, but the effect on the water table is zero. With time, the rate of inflow to the tunnel decreases, while the effect at the water table gradually increases. At some time after the water table starts to decline, the rate of inflow into the tunnel would be almost balanced by the rate of change of storage at the water table. If recharge is insufficient to keep the water table high, the water table continues to decline. Ultimately an equilibrium is reached, with inflows to the tunnel balanced by recharge within an elongated capture zone, in many ways equivalent to the radius of influence of a pumping well or a borefield.

From an environmental impact point of view, it is the long term steady situation that is of most interest. Initial transients during construction are local to the tunnel, need to be managed by contractors but have no immediate impacts at the elevation of the water table.

4.3.2 Time scales for equilibration

A time scale for equilibration between the water table and a tunnel can be calculated using estimates of the vertical separation between the water table and the tunnel (e.g. B = 50 metres), vertical hydraulic conductivity (e.g. Kv = 0.001 metres per day) and specific storativity (e.g. So = 0.00001 per day). A time scale can be calculated as $B^2So/Kv = 25$ days. This suggests that in some multiple of 25 days, the vertical hydraulic gradient between the water table and the tunnel would have reached a steady value. If Kv were an order of magnitude smaller (a factor of 10 smaller), the time scale would be ten times larger.

In a homogenous material, the vertical hydraulic gradient would be -1, i.e. piezometric head would drop one metre per metre in the vertical direction. This implies downward flow at a rate equal to Kv, e.g. 0.001 metres per day, one millimetre per day or 365 millimetres per year, which is a significant fraction of annual rainfall. Over a width of 10 metres of tunnel, or perhaps 100 metres of a contributing strip, downward flow would be 1.15 litres per second.

The rate of flow might be partly balanced by recharge. But if recharge were as small as 40 millimetres per year (about four per cent of annual rainfall), the downward flow would be far greater than recharge. This would lead for a tendency for the water table to fall. If specific yield is say 0.05 (perhaps too high in sandstone), a downward flux of 0.365 metres per year would lead to the water table falling 20 times faster, i.e. at about seven metres per year. If the depth to the tunnel is about 50 metres, this means that within about seven years, the water table may have dropped above the alignment of the tunnel, leading to a steeply sloping water table on either side of the tunnel alignment.

This discussion is intended to illustrate the fact that within years and certainly tens of years, it is possible that a steady state may evolve. Simulating the transient response to tunnelling over a period of years is extremely difficult, so this will not be attempted in this report. The focus of this report is on predicting an indicative steady state, which would have greater potential environmental impacts than at any time before the steady state is reached.

A drop in the water table does not necessarily have a direct impact on vegetation such as trees. Some trees are capable of developing very deep roots, following available moisture to tens of metres below the land surface. Regular rainfall contributes water to the unsaturated zone, and since vertical drainage in the unsaturated zone is controlled by hydraulic conductivities that are less than values at saturation, there may still be water available for trees.

Section 5 Calibration and Sensitivity Analysis

5.1 Groundwater Model Construction

5.1.1 Model plan

Based on the belief that tidally influenced surface water near the project (Cooks River, Alexandra Canal and Wolli Creek) would control water levels and prevent large-scale lowering of the water table, as well as the belief that drainage to tunnels is dominated by leakage from above, it was decided to simulate a region that extends several kilometres on all sides of the existing M5 East Motorway and the project. A larger region is not necessary, because of the presence of surface water (connected to the ocean) and the dominant effect of vertical flows.

It was decided to use prescribed head and no flow boundary conditions to represent model boundaries, as well as rainfall-induced recharge on the upper surface.

It was decided to choose a model discretisation that was refined near tunnels, with a cell size similar to tunnel diameter. Enough layers would be used so that tunnels would in general be several cells below the land surface and the water table.

It was decided that modelling would focus on steady state analysis rather than transient analysis. The reason for this decision was that (i) a time scale analysis suggests that a steady state would be achieved relatively quickly (in years or tens of years), (ii) the steady state configuration of the water table would have the greatest potential environmental impact (initial inflows to tunnels have no effect on the water table), and (iii) computation of a steady state was already difficult (attempting to represent tunnels with fine discretisation within a regional scale model).

5.1.2 Software selection

AECOM requested that a model be developed using MODFLOW. To achieve this outcome, models were developed using four combinations of versions of MODFLOW and graphical user interfaces (GUIs).

The model presented here was developed using MODFLOW-USG (USG, as described by Panday et al., 2012) using the Groundwater Modeling System (GMS) graphical user interface (Version 10.0.10, as described by Aquaveo, 2014).

The primary reason for selecting USG under GMS was that GMS supports the development of a hierarchical quad-tree grid, allowing mesh refinement near curvilinear tunnels in plan, while allowing a relatively coarse grid near remote boundaries of the model.

First attempts to run USG under GMS showed that convergence of a steady state solution is harder to achieve using USG than using MODFLOW-SURFACT (SURFACT Version 4, as described by HydroGeoLogic, 2008) or earlier versions of MODFLOW. For this reason, SURFACT was used to compute a steady state solution that was used as an initial guess for USG.

5.1.3 Model domain and location of boundaries

Botany Bay to the southeast and Georges River to the south provide natural boundaries.

In the west, the model boundary follows Salt Pan Creek (a tributary of Georges River, see Figure 2-1) and a drainage line northwards towards Cooks River. In the north east, the boundary follows an approximate flow line in the Botany Sands towards Botany Bay, approximately half way between Alexandra Canal and Mill Stream (Figure 2-1); this boundary lies just east of the Airport Line tunnel. These approximate flow lines act as no flow boundaries from the point of shallow groundwater flow.

Surface topographical highs (ridge lines) are followed in the north. An assumption is made that these highs are high enough that a no flow groundwater divide exists beneath the ridge. It is also assumed that the impact of tunnels is not sufficient to move this boundary.

The model domain in plan is shown in Figure 5-1.

The base of the model has been assumed to be horizontal at an elevation of -100 metres AHD, deep enough below the tunnels that estimates of groundwater flows are unlikely to be significantly affected by this assumption. The upper surface is the land surface, to which recharge is applied at a constant average rate. This is an assumption and an approximation, because recharge may increase if the water table drops, due to a phenomenon known as “induced recharge”.

5.1.4 Grid design

The model grid was generated using GMS’ grid modules with a maximum cell size of 160 metres square and quad tree refinement of cells along the following features:

- Sydney Airport Line, M5 East Motorway, preliminary concept design tunnels and project design tunnels, including ventilation tunnels. Cells were refined to a minimum size of 10 metres square in plan using arcs representing the centre lines of these features. For this purpose the M5 East Motorway, preliminary concept design tunnels and project design tunnels were each represented using two arcs in three-dimensional space long the centre lines of circular single tube tunnels i.e. lines above the roads in the space through which vehicles drive.
- Cooks River, Alexandra Canal and the tidal part of Wolli Creek as well as the coastline, where cells were refined to a minimum size of 40 metres square in plan.
- Interfaces between sandstone, shale (siltstone) and alluvium in the surface geological map, to ensure that the changes in hydrogeological properties between different HSUs are represented in a manner consistent with the hydrostratigraphic model described in Section 4.1.

Figure 5-2 shows the model grid. The inset in Figure 5-2 shows cells that are 160 metres square in the top centre, and four successive reductions in cell size to 80 metres square, 40 metres square, 20 metres square and ultimately 10 metres square in plan.

The model has 13 layers. The relationship between HSUs and USG model layers is summarised in Table 5-1.

An initial model grid was exported from Leapfrog Hydro, with three layers for each of the three simplified HSUs: alluvium, shale and sandstone. The grid was subsequently modified to provide sufficient resolution for representing vertical flow processes. The shale layer was divided into two model layers (from 0.2 to 38 m thick, depending on the local thickness of shale) and the sandstone layer was divided into 10 model layers (each approximately 10 m thick). Each model layer is continuous across the model domain.

The cells representing shale and sandstone are mostly in layers 2-3 and layers 4-13, respectively. However properties need to be reassigned where HSUs pinch out (are not present). Layer 1 is reduced to a minimum thickness where the alluvium pinches out, and the properties are those of the underlying HSU. Similarly, layers 1 to 3 are reduced to a minimum thickness where the alluvium and shale pinch out, and the properties are those of sandstone.

Table 5-1 Model layers

HSU	Model Layers	USG Layer Type
Alluvium	1	LAYCON 4 – Variably confined/unconfined upstream water table
Shale	2-3 (and sometimes 1)	LAYCON 4 – Variably confined/unconfined upstream water table
Sandstone	4-13 (and sometimes (1-3)	LAYCON 4 – Variably confined/unconfined upstream water table

The model has 31,514 cells in each of the 13 layers, and 409,682 cells in total.

5.1.5 Boundary conditions

The location of model boundaries is discussed above. Representation of boundary conditions using the capabilities of USG requires further discussion.

Water table elevation has been set to zero metres AHD in layer 1 in all cells underlying Cooks River, Alexandra Canal, the tidal part of Wolli Creek and along the shoreline of Botany Bay and Georges River. The potential for localised seawater wedges along coastal and tidal river boundaries is recognised, and could cause slightly higher water table elevations upgradient from these boundaries, but this effect has been assumed to be negligible in a model of this scale.

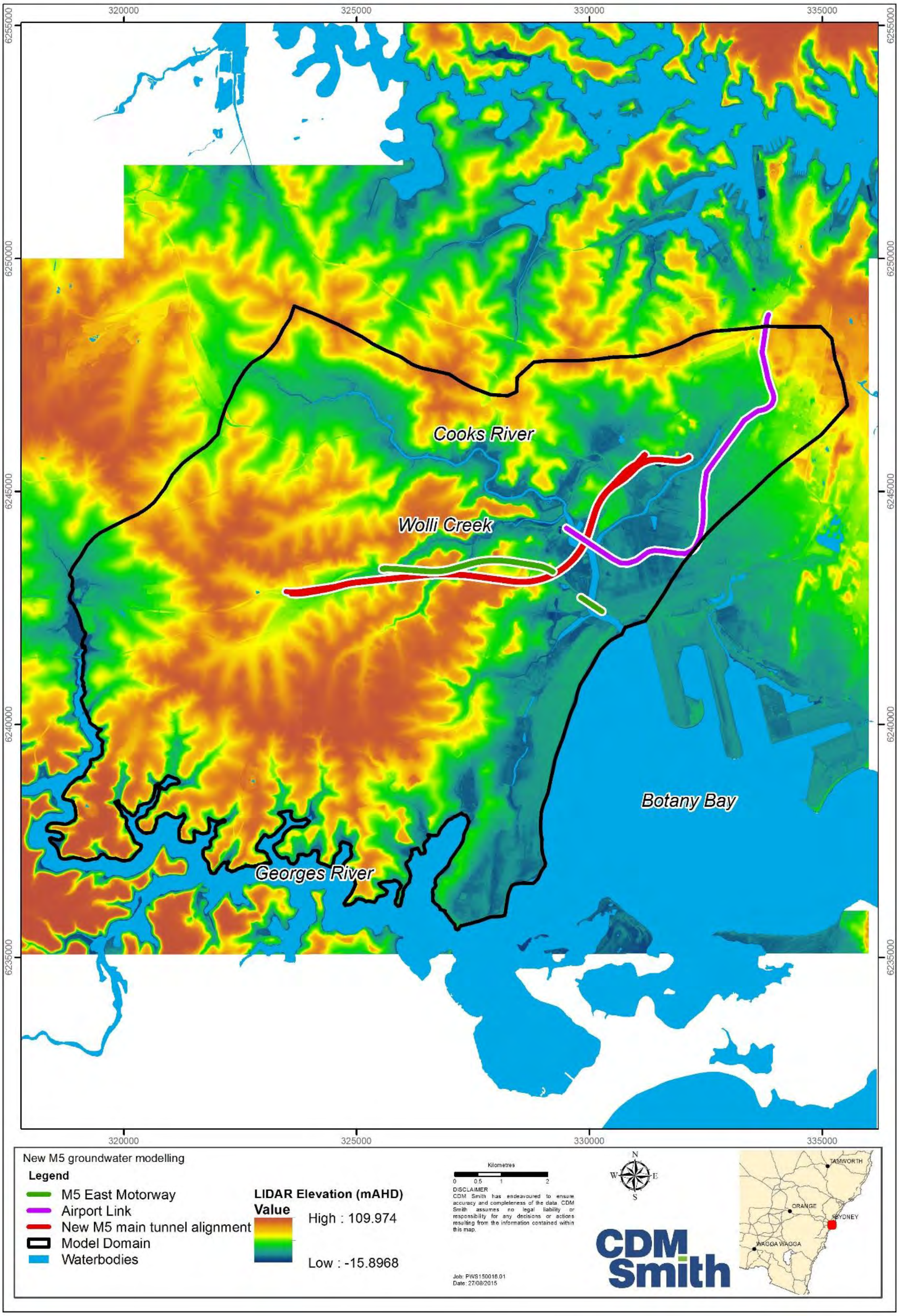
Steady recharge has been assigned to the uppermost active cells. If the water table at any location is in a lower layer, recharge is transmitted to the cell containing the water table.

Maximum evapotranspiration has been set at 870 millimetres per year, with an extinction depth set to one metre below the land surface elevation. Setting evapotranspiration in this way keeps the water table just below stream invert level in the upper reaches of Wolli Creek and Bardwell Creek, but over most of the model domain, where the water table is deep below the land surface, evapotranspiration is zero.

Tunnels have been represented as strings of contiguous cells, determined by finding those cells through which the centreline of each tunnel passes. The M5 East Motorway and project tunnels are each represented by two lines.

Each cell along each tunnel was represented as a drain cell, with a target head equal to the elevation of the tunnel centreline (see earlier discussion in Section 1.5). A high conductance was assigned, so that the computed head in drain cells is always very close to the target, and so that leakage of groundwater into the tunnel is controlled by vertical and horizontal hydraulic conductivities outside the tunnel.

It is difficult to visualise the tunnels in the modelling software because about 1,000 cells, ten metres square in plan, are needed to represent each of the twin tunnels in the main tunnel alignments. Figure 5-3 shows an oblique cutaway through the 3D hydrostratigraphic model in Leapfrog Hydro, showing tunnels in 3D. This illustrates the level of detail with which the tunnels have been represented in the regional scale groundwater flow model.



DISCLAIMER
CDM Smith has endeavoured to ensure accuracy and completeness of the data. CDM Smith assumes no legal liability or responsibility for any decisions or actions resulting from the information contained within this map.

Figure 5-1 Model domain

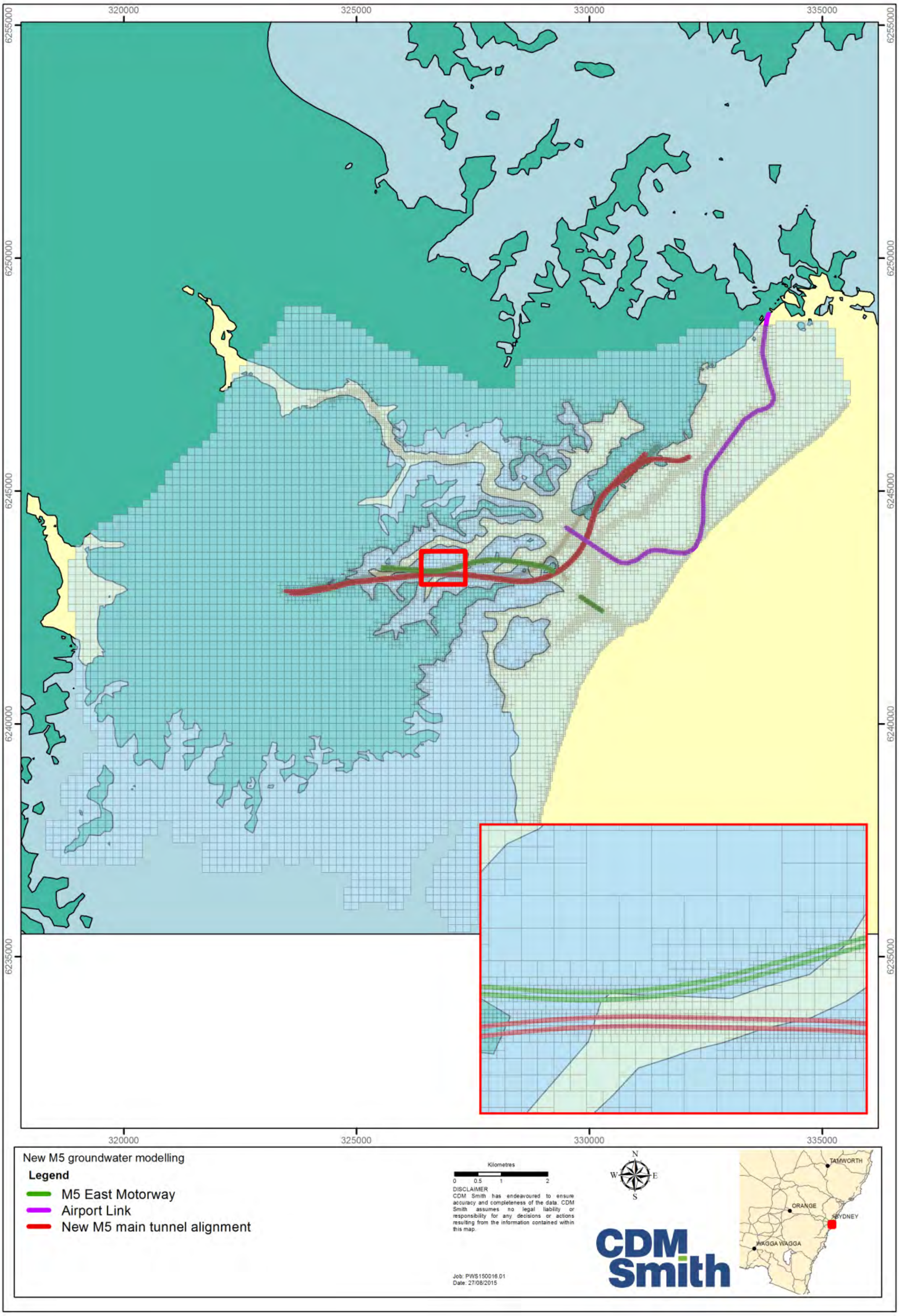


Figure 5-2 Model grid

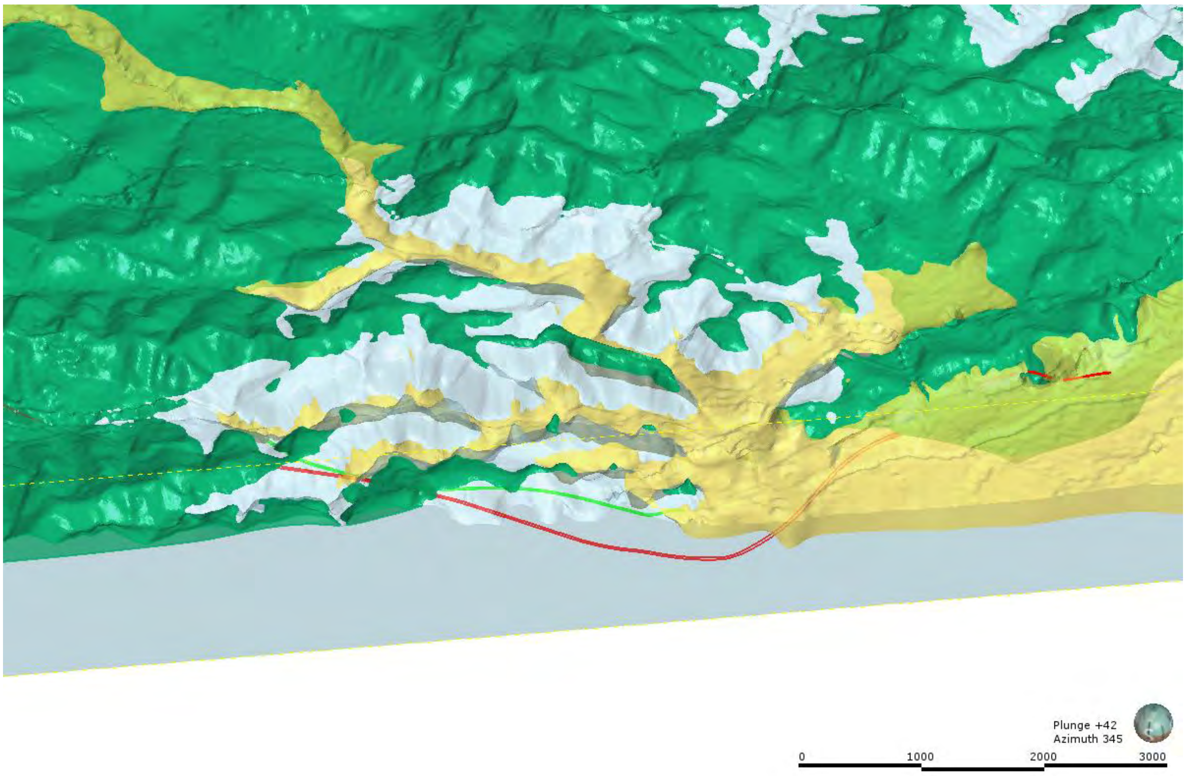


Figure 5-3 Oblique view in Leapfrog Hydro showing tunnels in relation to hydrostratigraphy

5.2 Calibration Data

AECOM collected measurements of water table elevation at a number of locations early in 2015 (see Figure 5-4). Measurements were obtained at several times, and some logger data are also available. The values posted in Figure 5-4 are in most cases the most recent values in April 2015.

Table 5-2 shows observed water table elevation at 11 observations bores within 500 m of the M5 East Motorway, ordered west to east.

- Of particular interest are those locations where the water table is below sea level, such as -4.93 metres AHD near the western portal to the M5 East Motorway (well below the land surface), -0.84 metres AHD near where the M5 East Motorway tunnel passes beneath Bardwell Creek, -5.55 metres AHD to the west of the eastern portal (approximately half way between the land surface and the tunnel), and -0.66 metres AHD near the eastern portal to the M5 East Motorway tunnel.
- While two of these measurements are 65 and 85 metres from the nearest tunnel centreline, the measurement at -5.55 metres AHD is 159 metres away from the nearest tunnel centreline.
- The water table is at 3.71 metres AHD a little to the west of Bardwell Creek (approximately half way between the land surface and the tunnel), possibly significantly lower than before construction of the tunnel.
- The last observation in Table 5-2 is closest to a part of the tunnel that passes beneath Cooks River and is furthest from the tunnel. It is probably the least interesting of the 12 bores listed.

Transient observations have only been made in 2015, 17 years after construction of the M5 East Motorway commenced. The transient data show fluctuations, as might be expected in response to seasonal climatic variations and rainfall, but there is no evidence that the water table elevation has or has not reached equilibrium following construction of the tunnels.

It is significant that none of the observations are located directly over the centreline of any tunnel, even though the greatest impacts of a tunnel would be expected to be directly over the centreline.

Apart from locations near the M5 East Motorway, it is significant that the water table is observed to be at -12.43 metres AHD near the Alexandria Landfill. This is the result of activities at this site over many years, and even though the water table is well below sea level, no evidence has been provided to CDM Smith to suggest that seawater may have been drawn from the Alexandra Canal towards the landfill.

Table 5-2 Measured water table elevation at observation bores within 500 m of M5 East Motorway

Borehole	Easting (m)	Northing (m)	Surface Elevation (mAHD)	Water Table Elevation (mAHD)	Elevation of Nearest Tunnel Centreline (mAHD)	Horizontal Distance to Nearest Tunnel Centreline (m)
BH072	325561	6243243	7.47	4.42	-3.80	81
BH084	325613	6243435	30.14	-4.93	-8.00	85
BH088	326182	6243434	16.79	0.75	-27.24	117
BH018	326717	6243422	34.82	3.71	-30.02	133
BH143	327181	6242912	40.01	19.23	-31.71	432
BH024	327222	6243306	8.30	-0.84	-32.22	65
BH093	327657	6243183	36.40	24.20	-30.24	295
BH094	327867	6243174	31.04	24.11	-28.96	331
BH025	328637	6243271	23.86	-5.55	-24.66	159
BH074	329228	6243670	2.63	-0.66	-7.35	348
BH070	329042	6242920	17.54	6.96	0.25	384
BH029	329350	6242709	4.25	1.74	2.51	462

5.3 Calibration

A large number of model runs was performed by trial and error to attempt to compute water table elevations consistent with the conceptual model and with measurements obtained by AECOM. The results presented here use hydrogeological parameters provided in Table 5-3 and recharge of 40 millimetres per year (about four per cent of average rainfall).

Figure 5-5 shows simulated water table elevations for the whole model domain. Figure 5-6 shows the drawdown in more detail. Dark blue indicates that the water table elevation is near sea level, but it is important to note that colours are shifted slightly because of the use of transparency to allow the land surface to be seen underneath. As colours shift towards purple, pink and ultimately white, the simulated water table is more and more below sea level.

An elongated cone of depression in the water table can be seen roughly aligned with the tunnels, however the water table remains above the crown of the tunnels along their centrelines. The fact that the cone of depression is no narrow, with steep sides in the directions orthogonal to the tunnel alignments, partly explains the difficulty in calibrating the model using data that are not directly over the tunnel (see Figure 5-4).

Along the western part of the M5 East Motorway, there appears to be some variability in the extent of drawdown. This is caused by the fact that each of the tunnels, about four kilometres in length, has been represented using about 400 cells that are ten metres square in plan. As the model attempts to converge on a steady state solution that satisfies regional water balance, the water table is sometimes in one model layer, and sometimes in an adjacent layer, such that the water table moves between layers along the length of the tunnels. This image of the water table may reflect what happens in the real world, caused by variations in structure and properties that cannot be fully characterised. They key finding is that the water table is believed to be below sea level directly over the tunnels. The water table appears to be higher beneath Bardwell Creek, probably caused by the presence of relatively deep alluvium along the creek.

There is little apparent drawdown where the eastern part of the M5 East Motorway passes beneath Cooks River. The tunnel is lined in this area, but the tunnel has been represented using drain cells, as if it were unlined. The fact that little drawdown is seen shows that (in the model) Wolli Creek supplies whatever water is needed to supply leakage to the tunnel below.

The water table is low near the Alexandria Landfill. This has been the case for a long time, because the quarry was originally excavated to elevations well below sea level, and there has been active water management on site for many years.

Figure 5-7 shows a scatter plot of simulated versus observed water table elevations. The colours of dots depend on the magnitude of the difference, with blues being smallest and brown being the largest. There is good agreement in some parts of the model domain. Overall, the model tends to predict water table elevations that are higher than those observed.

The SRMS error is larger than would normally be desired, but there are reasons for some of the outliers.

- The observed water table elevation near the Alexandria Landfill is an outlier, because drain cells located near the landfill are in shale, and perhaps not sufficiently well connected to other units to draw the water table down sufficiently.
- Observed heads near the portals of the M5 East Motorway are affected by the elevation of the floor of the tunnel, so the decision to represent tunnels in the model using tunnel centreline elevations leads immediately to an offset of about five metres.
- The water table is observed to be above 24 metres AHD at two locations near but south of the M5 East Motorway. It is possible that the water table at these locations is perched and is not continuous with the regional water table, but no evidence of perching has been provided.

When heads are prescribed using drain nodes, the model computes fluxes. Analysis of the water balance shows a total flux into drain cells of about 532 cubic metres per day, which is equivalent to 0.8 litres per second per kilometre on average along each of the M5 East Motorway tunnels. This compares favourably with average inflow rates of 0.75 to 0.9 litres per second per kilometre per single tube tunnel reported by Tammetta and Hewitt (2004).

The model mass balance error is approximately 0.0003 per cent which is well below the acceptable thresholds, e.g. 0.5 per cent for Class 3 models and one per cent for Class 2 models (Barnett et al, 2012).

The model is capable of simulating many aspects of the behaviour of the system. Better calibration would be possible if more observations of water table elevation were available directly over the centrelines of the M5 East Motorway tunnels.

Table 5-3 Model parameters

HSU	Kh (m/d)	Kv (m/d)
Alluvium	0.5	0.05
Ashfield Shale	0.001	0.0001
Hawkesbury Sandstone	0.01	0.0005

5.4 Sensitivity Analysis

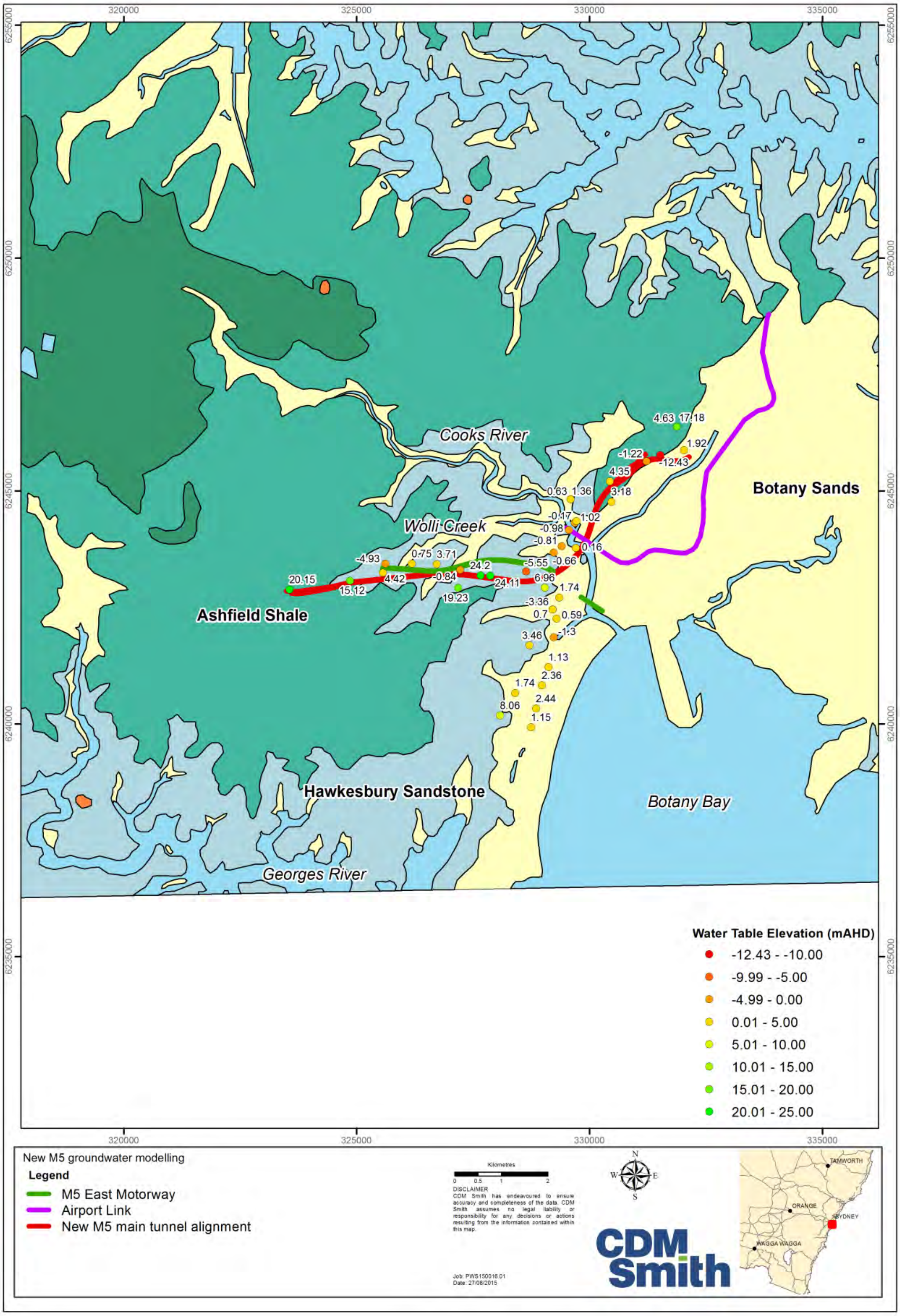
CDM Smith has carried out many more model runs, and has reached a number of conclusions.

A fundamental question relates to whether the M5 East Motorway has already caused drawdown to the level of the tunnels, whether it has caused drawdown to a level much higher than the crown of the tunnels, or whether the water table is still in a transient with the water table elevation still slowly declining. The water table is already as low as -0.84 metres AHD (i.e. below sea level) mid-way between the portals.

If a steady state has already been reached, the steady state would be controlled by a balance between hydraulic conductivities and recharge. In the nearfield of tunnels, i.e. inside the steeply sided cones of depression along tunnel alignments, the shape of the water table is most sensitive to the balance between the vertical hydraulic conductivity of Hawkesbury Sandstone and recharge to the water table. The same shape could be simulated with higher hydraulic conductivities and recharge, or lower hydraulic conductivities and recharge, i.e. it is the ratio of recharge to hydraulic conductivities that controls the steady state.

Attempts have been made to explore the effects of different ratios, but the USG model has difficulty converging, possibly because to the use of so many small cells in a regional scale model. It would be interesting to understand how much the ratio of recharge to hydraulic conductivities would need to change for the steady state cones of depression to have minimum elevations close to sea level, rather than tens of metres below.

If a steady state has not yet been reached, it is possible that drawdown may continue towards the tunnels. This possibility could only be confirmed by analysis of a longer time series of observations of water table elevation at key locations along the alignment of the M5 East tunnel. Such a time series is not available.



DISCLAIMER
CDM Smith has endeavoured to ensure accuracy and completeness of the data. CDM Smith assumes no legal liability or responsibility for any decisions or actions resulting from the information contained within this map.

Job: PWS150016.01
Date: 27/08/2015

Figure 5-4 Measurements of water table elevation in early 2015

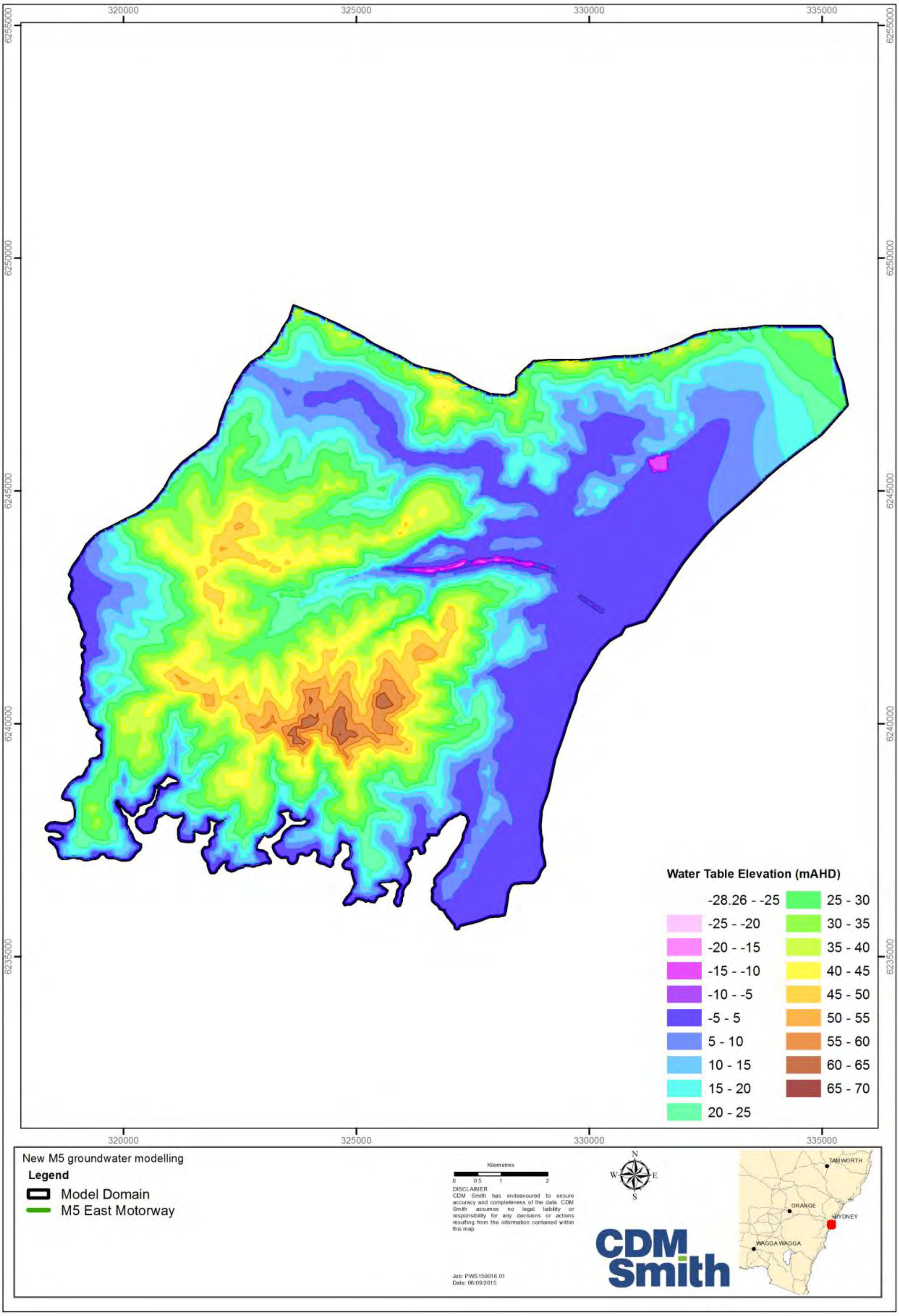


Figure 5-5 Simulated regional water table elevation with M5 East Motorway

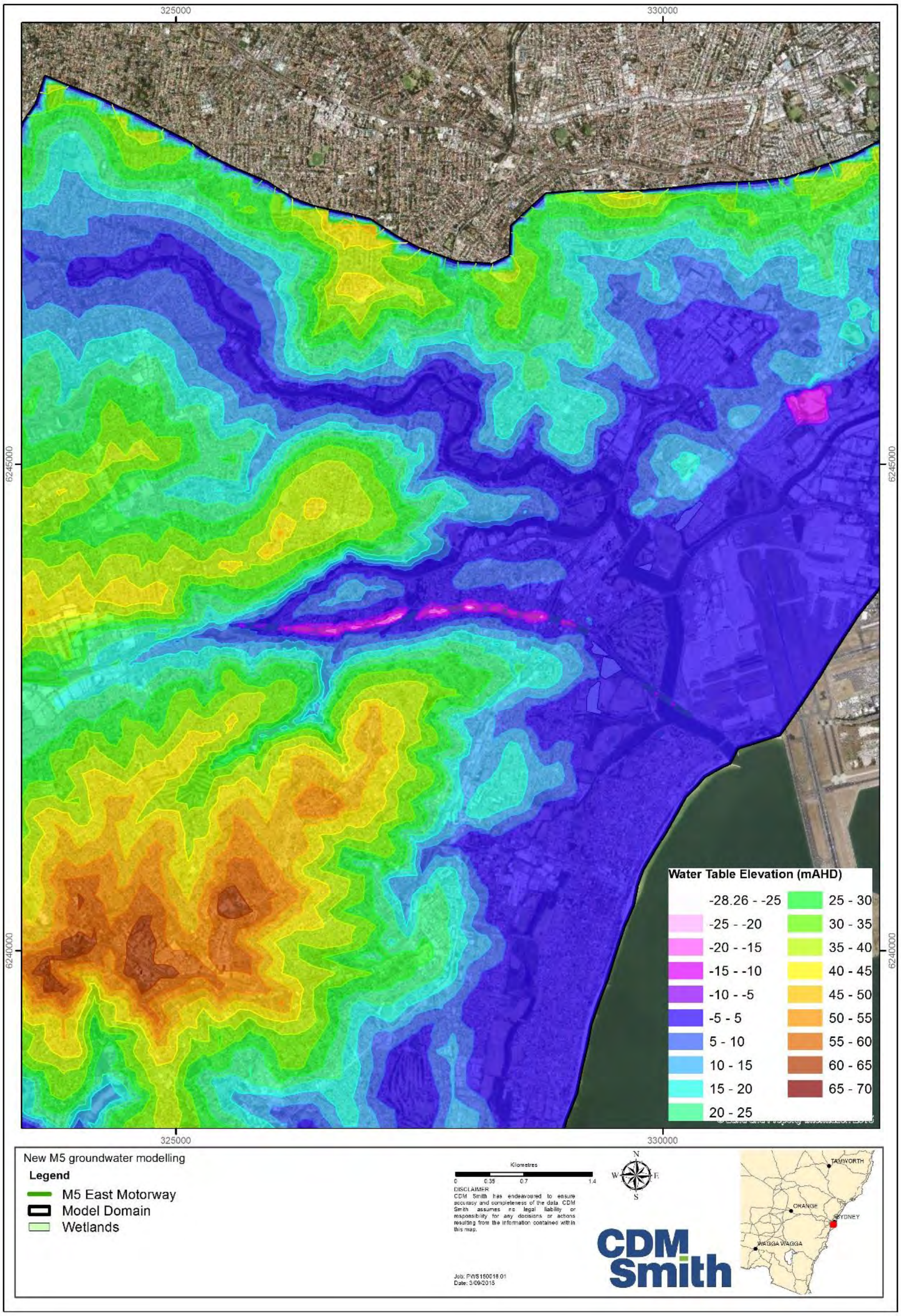


Figure 5-6 Simulated water table elevation near the M5 East Motorway

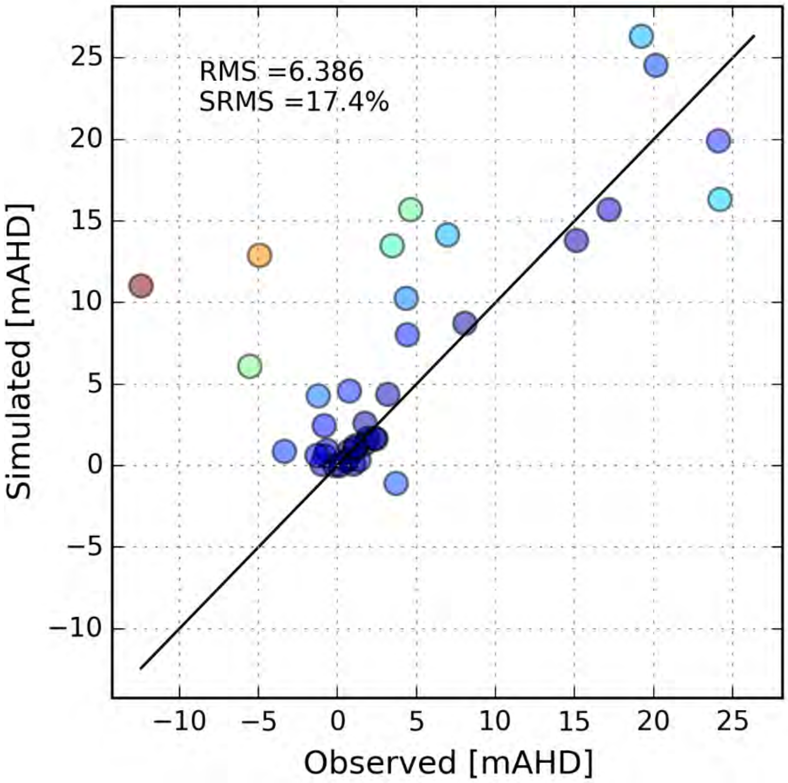


Figure 5-7 Simulated versus observed water table elevations

Section 6 Predictions

6.1 Simulation of Potential Impacts of Project

A centreline was extracted for each of the proposed twin tunnels, including stubs for future tunnels extending at depth past the St Peters interchange towards the city. The total length of tunnels is 19.91 kilometres (10.01 kilometres for the eastbound tunnel and 9.9 kilometres for the westbound tunnel).

As with the earlier simulation of the M5 East Motorway, lines of contiguous cells was identified, with centres closest to the tunnel centrelines. The tunnels were represented using drain cells with drain elevations set equal to the elevation of the tunnel centrelines. The rate of groundwater inflow into the tunnels (outflow from the drain cells) and drawdown in the water table have been predicted to assess potential impacts of the project on groundwater.

The potential impacts of ventilation tunnels and shafts were not simulated as these features may be lined with concrete, and in any case, any drawdown caused by this infrastructure would be expected to be small compared to (and therefore dominated by) the effects of the tunnels.

The model mass balance error is approximately 0.0003 per cent which is well below the acceptable thresholds, e.g. 0.5 per cent for Class 3 models and one per cent for Class 2 models (Barnett et al., 2012).

6.2 Discussion of Potential Impacts of Project

This Section provides discussion on the Secretary's environmental assessment requirements (SEARs) relevant to this report, as defined in Section 1.3 of this report.

Groundwater modelling, which is the subject of this report, is the only methodology that allows the potential impacts of a tunnelling project on regional groundwater to be predicted. At the same time, as discussed in Section 1.5 of this report, a regional scale groundwater model cannot predict all processes, at all scales in space and time.

Some of the comments provided below are supported directly by modelling results. Others are provided on the basis that systematic conceptualisation of groundwater flow systems and the potential impacts of a tunnel allow modellers to extrapolate their findings and to have confidence in general statements made about details that have not been explicitly modelled. All such extrapolations could in principle be examined in more detail, with additional modelling focused on more specific questions.

6.2.1 Predicted drawdown of the water table

Figure 6-1 shows predicted steady state water table elevations, after completion of the project, and Figure 6-2 shows the drawdown caused by the project, i.e. the additional lowering of the water table relative to that of the M5 East Motorway (see Figure 5-5). Figure 6-2 shows drawdown overlain on surface hydrostratigraphy.

As in Figure 5-5, Figure 6-1 suggests that the water table will ultimately be below sea level when it is represented in purple, pink or white.

Figure 6-1 and Figure 6-2 show that some localised drawdown will occur along the western end of the main tunnel alignments, to the west of the western portal of the M5 East Motorway.

The water table remains relatively high near Bardwell Creek, probably because of the presence of deep alluvium along this drainage line.

Yellows and browns in Figure 6-2 between Bardwell Creek and Cooks River show very large drawdown along the main tunnel alignments. The predictions are in a sense “worst case”. The predictions depend on values of hydraulic conductivities used, and on the ratio of hydraulic conductivities to recharge. If recharge is in fact larger than assumed, or if it becomes larger as the water table starts to decline, then the tendency for very large drawdown along the mail tunnel alignments would be less.

Drawdown of the water table is predicted to be less where the tunnels pass beneath Cooks River and its connected alluvium, due to induced leakage from the river. Being connected to the ocean, the river can supply water to the tunnels below, without affecting levels in the river. A gradient would develop, however, from the river in both westerly and easterly directions. It has previously been observed that higher inflows to tunnels beneath palaeovalleys may be an effect of valley bulging, and enhanced hydraulic conductivities due to fracturing (see Section 3.5.4). The model suggests that higher inflows can also be explained by availability of water and rapid transfer of water to alluvium over underlying rock.

To the east of Cooks River, heading eastwards from the edge of the alluvium, the predicted drawdown increases significantly. The sudden change in drawdown as the alignments approach St Peters appears to be due to the tunnel transitioning from sandstone into shale.

Drawdown does not extend far into the main Botany Sands aquifer, because this unit is able to transmit water (due to its higher hydraulic conductivity) with relatively flat hydraulic gradients.

The project would not have additional impacts in the area of the Alexandria Landfill, and in any case this area may be changed in ways that have not been represented in the regional scale model.

The potential impacts of the main tunnel alignments vary along the alignments because of the interplay between the alignments (horizontally and vertically), topography, hydrostratigraphy and the locations of tidal river boundaries. Parts of the alignments are sub-parallel to Wolli Creek and Alexandra Canal, while part of the tunnel is orthogonal to Cooks River and its connected alluvium. Three-dimensional groundwater flow towards the tunnels would be fundamentally different in these different areas.

6.2.2 Predicted impacts on groundwater quality

The model was not designed to predict changes in groundwater quality. However the pattern of drawdown makes it clear that along some parts of the length of the proposed tunnels, groundwater inflows will in the long term have salinities approaching that of seawater.

Cooks River is in contact with alluvium, and has the capacity to supply as much water as would be needed to sustain levels within the alluvium. The alluvium overlies sandstone, and would ultimately supply water from the Cooks River to any tunnel directly below. Because the alluvium has so much capacity to supply, the length of each tunnel that would ultimately receive water from the Cooks River would be longer than the length that lies directly beneath alluvium.

Groundwater beneath the Cooks River is likely already to have elevated salinity. In this sense the project is unlikely to have an adverse impact on groundwater quality beneath the river.

Table 5-2 shows that the water table in one observation bore near the middle of the M5 East Motorway is already below sea level. It is not known whether water table elevations above the centrelines of the M5 East Motorway tunnels are already at steady state, or whether they are already lower than this observed level of -0.84 metres AHD. However the model predicts that levels may be below sea level along the central parts of the M5 East Motorway tunnels and the New M5 tunnels, when steady state is reached. This suggests a tendency for migration of seawater from river boundaries towards the regions underlying tunnels. This would be a form of seawater intrusion, caused by the tunnels acting as sinks for groundwater. It is not possible to prove or disprove this possibility without the existence of data to demonstrate that the steady state water table elevation above tunnel centrelines will not drop below sea level over long distances.

6.2.3 Predicted inflows to tunnels

The model predicts inflow of 1,115 cubic metres per day into the project design tunnels. Over a length of 20.03 kilometres, this equates to an inflow rate of 0.63 litres per second along every kilometre of the eastbound (shallower) tunnel and 0.67 litres per second along every kilometre of the westbound (deeper) tunnel.

These rates are average rates along the length of the twin tunnels. In principle, it would be possible to compute inflows into every cell along each tunnel, and to plot a spatial distribution of inflow rates, perhaps showing lengths of tunnel with slightly higher rates of inflow. However, this type of analysis is difficult. Each tunnel is represented by about 1,000 cells, and the spacing between cells varies. Tunnels are not straight (see Figure 5-2) and the tunnel centreline also passes from through several model layers, from high layers near the portals to deeper layers at the deepest part of each tunnel. As the water table drops to layers well below layer 1, higher layers are considered to be pseudo-unsaturated. The combination of all of these effects means that the distribution of heads and fluxes in the model along a set of 1,000 cells is not perfectly smooth. Nevertheless, the fact that the model preserves mass (maintains a water balance) leads to confidence in the overall pattern of drawdown and the computed average rates of inflow.

It is reasonable to ask where the inflows come from. In steady state, there is a balance between inflows through some boundaries and outflows to other boundaries. In this steady state prediction, inflows to tunnels come from the surface, either from tidal rivers (Cooks River, Alexandra Canal or the tidal part of Wolli Creek), or from recharge to the water table. In principle it would be possible to define capture zones for different lengths of tunnels, showing where the inflows come from for those zones. In steady state, the inflows do not come from a specific HSU, but rather they pass through one or more HSUs. For example, water can flow from Cooks River to Botany Sands (alluvium) and then to Hawkesbury Sandstone below before reaching the tunnel below, but the alluvium and sandstone remain saturated along the flow path.

Inflows to tunnels during construction evolve in time. Inflows depend on the precise nature of the ground at every location along each tunnel. But even if each HSU was homogeneous, with uniform hydraulic conductivities in space, inflows would tend to be greatest at each advancing face, and declining in time as the face advances further. Inflows during construction come initially from confined storage, due to water expanding slightly as pressure drops. This phenomenon is controlled or at least described by specific storativity, which is difficult to measure. At some time after construction of each tunnel, from months to years, the effects of depressurisation in the tunnel lead to downward flows from the water table above, and depending on the rate of recharge locally, the water table tends to migrate downwards. During the period until steady state is reached, water drains from pores above the water table, controlled or described by specific yield. In principle it would be possible to integrate (add up) the volume of water caused by lowering of the water table where it exists in shale, sandstone and alluvium, in order to explain where water is removed from storage during this transition. Very little water is taken from storage in alluvium, because the alluvium is directly connected to tidal rivers and is rapidly replenished.

6.2.4 Predicted impacts on surface flows

Flows in tidal rivers are controlled by the tides, and will not be affected in any way by the project.

Surface flows in the upper reaches of Wolli Creek and Bardwell Creek are likely to be dominated by surface runoff. These drainage lines have not been represented as boundaries in the regional scale groundwater flow model. The water table is held lower than the elevation of the drainage lines by depth-dependent evapotranspiration.

The model presented in this report was not designed to predict surface flows or changes in surface flows.

6.2.5 Predicted impacts on groundwater dependent ecosystems

The model does not explicitly represent Tempe Wetlands, Landing Lights Wetland, Eve Street Wetland or the Marsh Street Wetland, either geometrically or using boundary conditions. No attempt has been made to conceptualise these surface water features, or to consider or compute their water balance.

The Tempe Wetlands are very close to Alexandra Canal, in a part of the model domain where water table drawdown is predicted to be negligible. This is because Cooks River and Alexandra Canal are tidal, with water levels controlled by the Pacific Ocean.

Landing Lights Wetland, Eve Street Wetland and Marsh Street Wetland are located in alluvium, on the fringe of an area where there may be water table decline when steady state has been reached. There are good reasons, however, to suggest that this will not be the case.

The model has been constructed and approximately calibrated using a very simple representation of rainfall-induced recharge. Recharge has been set to a constant value of 40 millimetres per year. It may be that recharge is higher over the alluvium than in areas where the surface geology is sandstone or shale. Furthermore, any tendency for the water table to drop sometimes leads to vegetation taking slightly less water (evapotranspiration is reduced), such that the difference between infiltration and evapotranspiration (net recharge to the water table) increases. This phenomenon is known as induced recharge, and may lead to actual drawdown that is less than predicted, not only near these GDEs, but in other parts of the model domain as well.

6.2.6 Predicted impacts on existing groundwater users

Groundwater drawdown is expected to be minimal in bores intersecting the Botany Sands as these bores receive recharge and groundwater is readily easily redistributed within this HSU. Bores drilled through shale and sandstone may experience significant drawdown depending on how close the bores are to the main tunnel alignment.

Table 6-1 shows bores within 1 km of the main tunnel alignments (as in Table 3-2), with an additional column showing predicted drawdown at the locations of these bores. In the same way that induced recharge may help to maintain the water table near GDEs, induced recharge may also help to maintain the water table near some of these bores.

Table 6-1 Predicted drawdown at bores within 1 km of the main tunnel alignments

Bore ID	Purpose	Depth	Water Table Elevation (mAHD)	Predicted Drawdown (m)
GW013331	Industrial	14.9	7.9-14.8 (saturated material)	0.0
GW015954	Industrial	20.1	6.7-19.2 (saturated material)	0.0
GW023191	Water Supply - Domestic	3.7	1.20'	0.4
GW023194	Water Supply - Domestic	4.9	3.3	6.7
GW024109	Water Supply - Domestic	2.1	2.1	2.2
GW024673	Water Supply - Domestic	4.3	Not Available	0.3
GW027248	Industrial	4.9	2.4	0.0
GW027664	Industrial	6.1	0.7	2.4
GW040219	Water Supply - Domestic	0	Not Available	0.0
GW072161	Water Supply - Domestic	90.5	14	1.9
GW072643	Water Supply - Domestic	12	Not Available	0.1
GW100053	Water Supply - Domestic	7	1	0.1
GW100209	Industrial	108	Not Available	0.3
GW101533	Irrigation	20	4.4	0.0
GW103504	Commercial and Industrial	6.1	Not Available	0.0
GW103505	Other	6	Not Available	0.0
GW103506	Unknown	6	Not Available	0.0
GW103507	Other	6	Not Available	0.0
GW103508	Water Supply - Domestic	6	Not Available	0.0
GW104448	Domestic	0	Not Available	0.0
GW104449	Monitoring	0	Not Available	0.0
GW104450	Monitoring	0	Not Available	0.0
GW106830	Monitoring	7	Not Available	0.4
GW107993	Monitoring	13.6	1.95	11.5
GW108104	Monitoring	N/A	Not Available	0.0
GW108295	Monitoring	8	Not Available	0.2
GW108406	Monitoring	8	Not Available	2.4
GW108439	Monitoring	8	Not Available	0.3
GW108497	Water Supply - Domestic	8	Not Available	0.0
GW108588	Other-Test Bore	8	Not Available	2.7
GW109191	Industrial	186	93	5.7
GW109821	Water Supply - Domestic	35	14.5	0.0
GW109822	Water Supply - Domestic	10.45	3	0.2
GW109823	Water Supply - Domestic	29	12.5	0.2
GW109824	Recreation	20.7	4.51	0.0
GW109825	Water Supply - Domestic	22	14.9	0.1
GW109963	Other	8	Not Available	2.7
GW109964	Monitoring	8	Not Available	2.8
GW109965	Monitoring	8	Not Available	2.4
GW109966	Monitoring	3	Not Available	4.5
GW110456	Monitoring	3.6	2.3	0.0
GW110457	Monitoring	3.6	1.7	0.0
GW110458	Water Supply - Domestic	2.8	2.3	0.0
GW110735	Water Supply - Domestic	0	Not Available	0.4
GW111316	Water Supply - Domestic	162	4.000'	0.4
GW111320	Water Supply - Domestic	5.2	2.52	0.0
GW111321	Monitoring	5	2.64	0.0

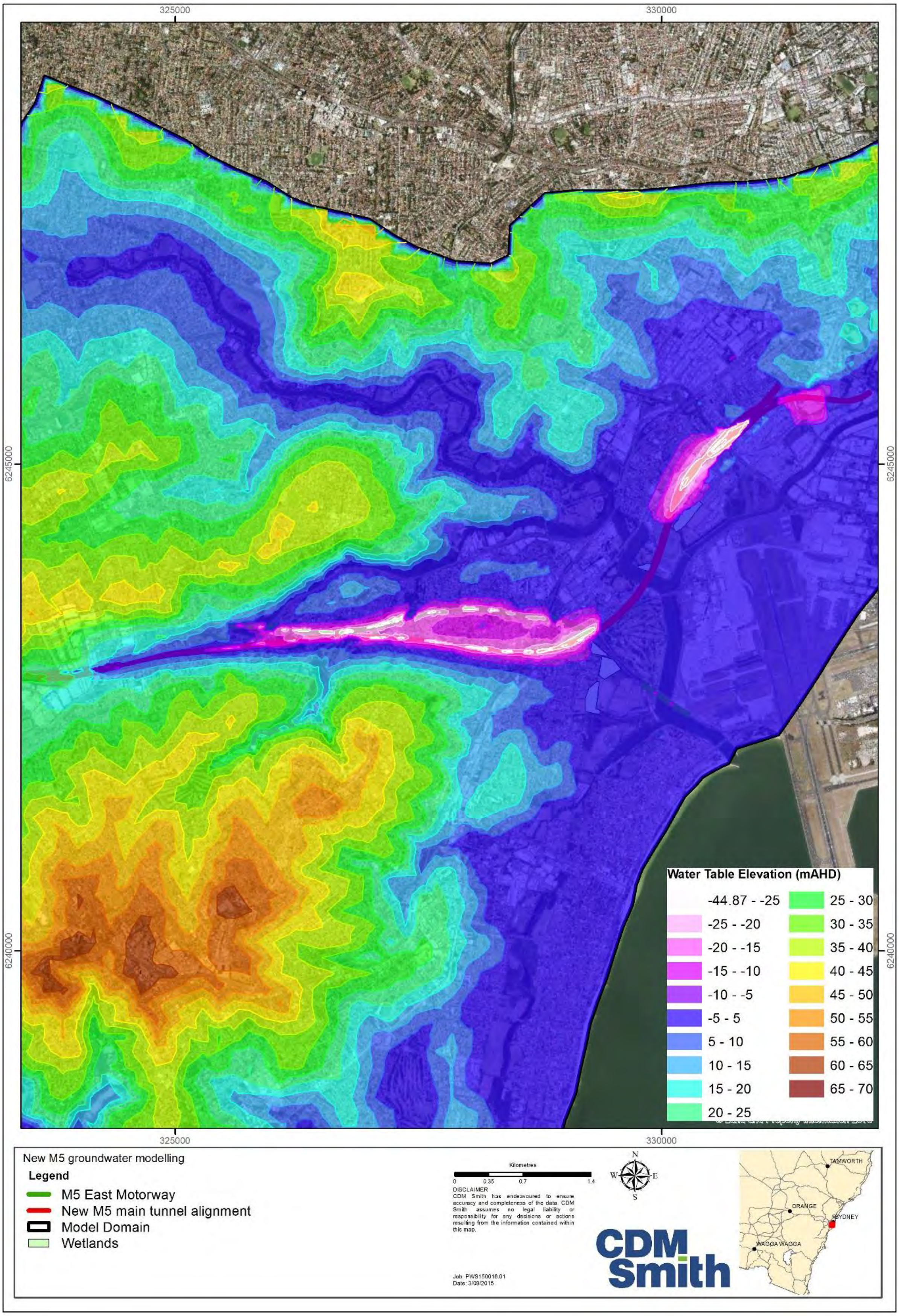


Figure 6-1 Predicted water table elevations after completion of the project

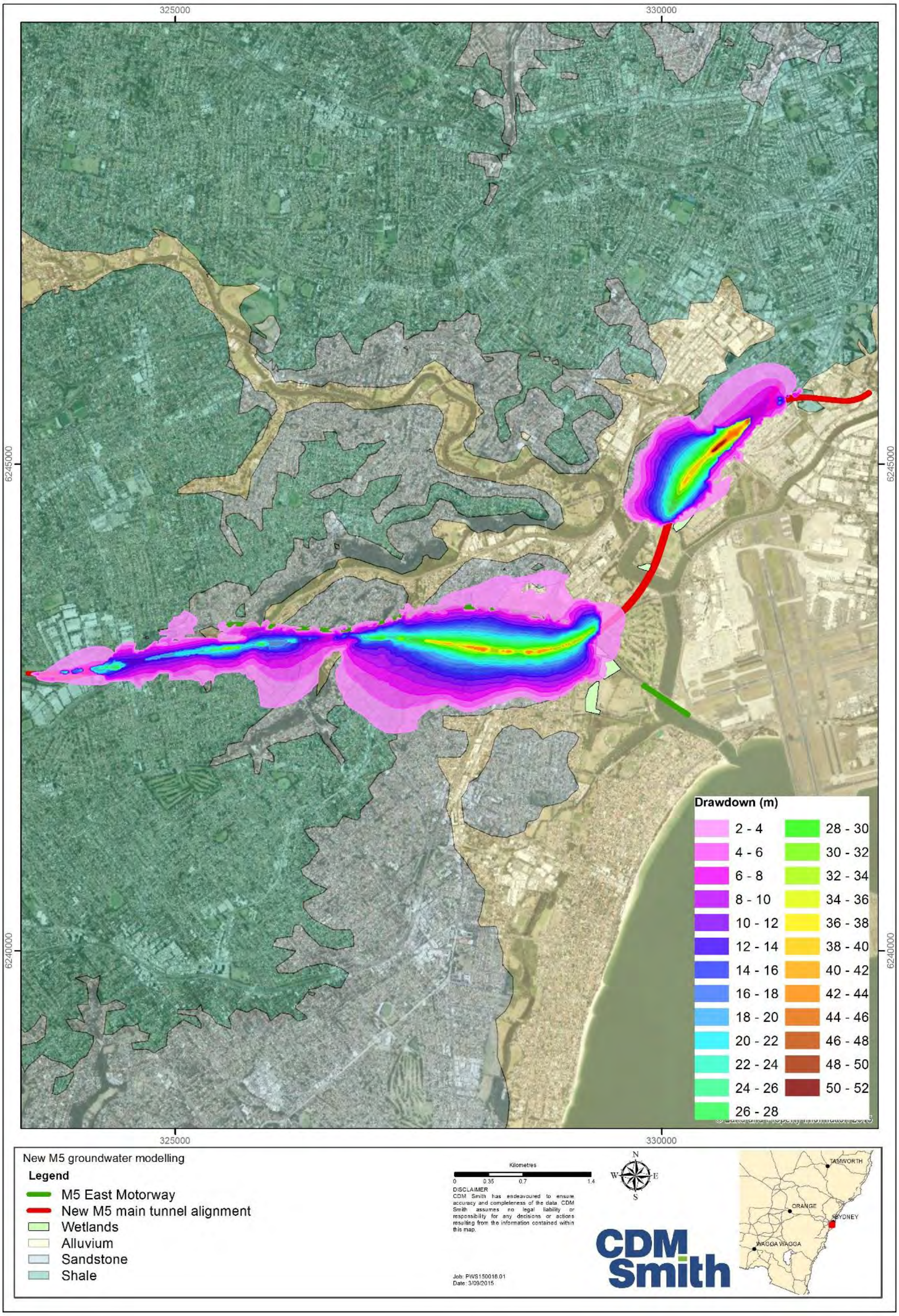


Figure 6-2 Predicted drawdown caused by the project relative to the M5 East Motorway alone

Section 7 Conclusions and Recommendations

A regional scale groundwater flow model has been developed to support the Technical Working Paper: Groundwater (AECOM, 2015) in order to satisfy the Secretary's Environmental Assessment Requirements (SEARs).

The model has been developed using methods consistent with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012). This report describes assimilation and analysis of data, the development of a conceptual model of regional scale groundwater flow, calibration of a model including the M5 East Motorway, and prediction of the combined potential impacts of the M5 East Motorway and the New M5 tunnels.

Predictions have been made of the extent of drawdown of the water table and of inflows to the main alignment tunnels of the project. Comments have been made about potential impacts on groundwater quality, surface water flows, groundwater dependent ecosystems and licensed bores within one kilometre of the main alignment tunnels.

Very little drawdown is expected within the alluvium connected to Cooks River, because the river is tidal and any water lost to tunnels below will be rapidly replenished. The tunnels beneath Cooks River and its connected alluvium will receive inflows that have a salinity approaching that of seawater.

The elongated cone of depression that will develop along the main tunnel alignments, especially to the west of Cooks River, may extend to below sea level, and this may ultimately cause migration of seawater from tidal river boundaries towards the main tunnel alignments. However there is considerable uncertainty about the extent of drawdown, because there are no measurements of drawdown directly over the centrelines of the M5 East Motorway tunnels, and because it is not known whether or not a steady state has been reached.

There are reasons to believe that the model may over-predict drawdown, partly because there is no feedback mechanism built into the model, such as the process of induced recharge. It is possible that recharge increases as the water table declines, and this may counter the tendency towards further drawdown.

The modelling presented here could be improved by additional sensitivity analysis, e.g. exploring the balance between vertical hydraulic conductivity of Hawkesbury Sandstone and recharge, to find combinations that might cause drawdown to be less, with the water table elevation maintained mostly above sea level.

It is recommended that future monitoring include the installation of several chains of vibrating wire piezometers (VWPs) as close as possible to directly above the centrelines of the main alignment tunnels. VWPs should be installed (grouted in) perhaps five to ten metres above the top of the tunnel, perhaps five metres below the pre-project water table, and half way in between. Pressures (piezometric heads) should be recorded using data loggers, in order to track depressurisation from the bottom up, and drawdown once it starts to occur. Such data will support predictions of the potential impacts caused by future tunnelling.

Section 8 References

Adams, D. N., Lechner, M. K. and Lamb, I. (2001). M5 East Tunnels: A Flat Roofed, Bolt and Shotcrete Lined Highway. Rapid Excavation and Tunneling Conference (RETC) Proceedings.

AECOM (2015). WestConnex New M5, Technical Working Paper: Groundwater.

Aquaveo LLC. (2014), GMS User Manual, Volumes 1-4.

Australian Plants Society (2011), North Shore Group, Ku-ring-gai Wildflower Garden, Topic 10 – Geology of the Sydney Region.

Barnett, B., Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A. (2012). Australian groundwater modelling guidelines. Waterlines Report Series No. 82, National Water Commission, Canberra, 191 pp. June.

Best, R.J., and Parker, C.J. (2005). Groundwater in Sydney – tunnel inflows and settlement – theory and experience. 12th Australian Tunnelling Conference, Brisbane, 5-3.

Bradd, J., Cohen, T., Marx, S., Buckman, S., Burkhardt, E., Clarke, A., Cook, N., Cullen, S., Daley, J., Gavin, A., Hu, R., Kiekebosch-Fitt, E., Lemcke, M., Lowe, A., McMahon, T., McNeilage, L., O'Mara, K., Nagle, G., Robson, S., Silveri, C. and Stammers, J. (2012). Bioregional assessment project: Sydney Metropolitan, Southern Rivers and Hawkesbury-Nepean Catchments: data collation phase to study the impact of mining activity and coal seam gas on environmental assets. Wollongong, Australia: University of Wollongong.

Gee, R.A., Parker, C.J., and Cutler, R.J. (2002). Northside Storage Tunnel, Sydney: investigation, design and construction, 11th Australian Tunnelling Conference, March.

Griffin, R.J. (1963). The Botany Basin. Geological Survey of New South Wales. Bulletin No. 18. New South Wales Department of Mines.

Hatley, R.K. (2004). Hydrogeology of the Botany Basin. Australian Geomechanics. Vol 39, No. 3.

Haworth, R. (2003). The shaping of Sydney by its urban geology. Quaternary International vol. 103, pp. 41-55.

Herbert, C. (1979). The Geology and Resource Potential of the Wianamatta Group. Geological Survey of New South Wales. Bulletin No. 25. New South Wales Department of Mines.

Hewitt, P. (2005). Groundwater control for Sydney rock tunnels. AGS ANCTA Mini-Symposium: Geotechnical Aspects of Tunnelling For Infrastructure Projects.

HydroGeoLogic Inc. (2008), MODHMS/MODFLOW-SURFACT, A Comprehensive MODFLOW-Based Hydrologic Modeling System.

Lee, R.J. (2009). Regional Hydrostratigraphic Analysis of the Hawkesbury Sandstone. IAH NSW, Groundwater in the Sydney Basin Symposium, Sydney, NSW, Australia, 4-5 Aug. 2009, W.A. Milne-Home (Ed.).

Lovering, J.F. (1954). The stratigraphy of the Wianamatta Group Triassic System, Sydney Basin. Records of the Australian Museum 23(4):169 – 210, plate xii.

Och, D. J., Offler, R., Zwingmann, H., Braybrooke, J., and Graham, T. (2009). Timing of brittle faulting and thermal events, Sydney region: association with the early stages of extension of East Gondwana. Australian Journal of Earth Sciences, 56:7, 873 – 887.

Panday, S., Langevin, C.D., Niswonger, R.G., Ibaraki, M., and Hughes, J.D. (2012). MODFLOW-USG Version 1: An Unstructured Grid Version of MODFLOW for Simulating Groundwater and Tightly Coupled Processes Using a Control Volume Finite-Difference Formulation. Chapter 45 of Section A, Groundwater Book 6, Modeling Techniques.

Parsons Brinckerhoff (2010). M5 East Expansion Geotechnical Management Draft Desktop Study Report. Prepared for Roads and Traffic Authority.

Pells, P.J.N. (2002). Developments in the design of tunnels and caverns in the Triassic rocks of the Sydney region. International Journal of Rock Mechanics and Mining Sciences, 39, p. 569-587.

Russell, G., McKibbin, D., Williams, J., and Gates, G. (2009). A Groundwater Resource Assessment of the Triassic Rocks of the Sydney Basin. IAH NSW, Groundwater in the Sydney Basin Symposium, Sydney, NSW, Australia, 4-5 Aug. 2009, W.A. Milne-Home (Ed).

Sydney Metropolitan Catchment Management Authority (SMCMA), (2011). Botany Bay & Catchment Water Quality Improvement Plan. Sydney: Botany Bay Water Quality Improvement Program.

Tammetta, P., and Hawkes, G. (2009). Analysis of aquifer tests in Mesozoic sandstones in western Sydney, Australia. IAH NSW, Groundwater in the Sydney Basin Symposium, Sydney, NSW, Australia, 4-5 Aug. 2009, W.A. Milne-Home (Ed).

Tammetta, P., and Hewitt, P. (2004). Hydrogeological properties of Hawkesbury Sandstone in the Sydney region. Australian Geomechanics. Vol 39, No. 3.

Appendix A - Disclaimer and Limitations

This report has been prepared by CDM Smith Australia Pty Ltd (CDM Smith) for the sole benefit of AECOM for the sole purpose of contributing to environmental impact assessment of the proposed WestConnex Stage New M5 tunnel.

This report should not be used or relied upon for any other purpose without CDM Smith's prior written consent. Neither CDM Smith, nor any officer or employee of CDM Smith, accepts responsibility or liability in any way whatsoever for the use of or reliance on this report for any purpose other than that for which it has been prepared.

Except with CDM Smith's prior written consent, this report may not be:

(a) released to any other party, whether in whole or in part (other than to the officers, employees and advisers of AECOM);

(b) used or relied upon by any other party; or

(c) filed with any Governmental agency or other person or quoted or referred to in any public document.

Neither CDM Smith, nor any officer or employee of CDM Smith, accepts responsibility or liability in any way whatsoever for or in respect of any use of or reliance upon this report by any third party.

The information on which this report is based has been provided by AECOM and third parties. CDM Smith (including its officer and employee):

(a) has relied upon and presumed the accuracy of this information;

(b) has not verified the accuracy or reliability of this information (other than as expressly stated in this report);

(c) has not made any independent investigations or enquiries in respect of those matters of which it has no actual knowledge at the time of giving this report to AECOM; and

(d) makes no warranty or guarantee, expressed or implied, as to the accuracy or reliability of this information.

In recognition of the limited use to be made by AECOM of this report, AECOM agrees that, to the maximum extent permitted by law, CDM Smith (including its officers and employees) shall not be liable for any losses, claims, costs, expenses, damages (whether in statute, in contract or tort for negligence or otherwise) suffered or incurred by AECOM or any third party as a result of or in connection with the information, findings, opinions, estimates, recommendations and conclusions provided in the course of this report.

If further information becomes available, or additional assumptions need to be made, CDM Smith reserves its right to amend this report.

Appendix B

Tables

Appendix B Tables

Table B1 Manually Measured Standing Water Levels

Monitoring Well	Lithology Screened	screen interval	Elevation m AHD top of well	SWL^ mbtoc*	Elevation m AHD	SWL^ mbtoc*	Elevation m AHD	SWL^ mbtoc*	Elevation m AHD	SWL^ mbtoc*	Elevation m AHD	SWL^ mbtoc*	Elevation m AHD	SWL^ mbtoc*	Elevation m AHD
				21/01/2015		24/02/2015		5/03/2015		8 to 25 March 201		1/04/2015		19/10/2015	
BH006	Hawkesbury Sandstone	22-25	24.71	4.50	20.21							4.56	20.15	4.56	20.15
BH18	Hawkesbury Sandstone	51-54	34.84	27.36	7.48					30.14	4.70	31.13	3.71	37.65	-2.81
BH024	Hawkesbury Sandstone	26-29	8.17	8.70	-0.53					9.05	-0.88	9.01	-0.84	9.21	-1.04
BH025	Hawkesbury Sandstone	55-58	23.85	29.4	-5.55							na		na	na
BH029	Hawkesbury Sandstone	33-36	4.28	5.40	-1.12					5.54	-1.26	2.54	1.74	2.33	1.95
BH036	Hawkesbury Sandstone	60-63	1.58	2.40	-0.82					2.38	-0.80	2.39	-0.81	2.80	-1.22
BH039	Hawkesbury Sandstone	49-52	3.32					4.28	-0.96	4.19	-0.87	4.30	-0.98	4.36	-1.04
BH040	Basalt	65-68	1.69			1.9	-0.21					1.86	-0.17	2.52	-0.83
BH042	Hawkesbury Sandstone	45.5-48.5	1.85	0.3	1.55					0.89	0.96	0.83	1.02	0.96	0.89
BH070	Hawkesbury Sandstone	35-38	17.54	10.66	6.88							10.58	6.96	10.75	6.79
BH072	Hawkesbury Sandstone	28-31	7.47	2.76	4.71					4.16	3.32	3.05	4.42	2.58	4.89
BH074	Hawkesbury Sandstone	39-42	2.58					3.29	-0.71			3.24	-0.66	3.45	-0.87
BH084	Hawkesbury Sandstone	47.5-50.5	30.02	34.45	-4.43					34.50	-4.48	34.95	-4.93	34.54	-4.52
BH088	Hawkesbury Sandstone	41-44	16.78	15.45	1.33							16.03	0.75	16.13	0.65
BH093	Hawkesbury Sandstone	47-50	36.39	13.30	23.09							12.19	24.20	12.90	23.49
BH094	Hawkesbury Sandstone	54-57	31.17	5.23	25.94							7.06	24.11	3.02	28.15
BH103	Hawkesbury Sandstone	48-51	11.10	6.75	4.35							6.75	4.35	6.64	4.46
BH109	Rouse Hill Siltstone	33-36	6.91	7.74	-0.83					7.84	-0.93	8.13	-1.22	7.57	-0.66
BH115	Ashfield Shale	29.5-32.5	20.33	15.50	4.83			15.23	5.10	15.37	4.96	15.70	4.63	15.00	5.33
BH120	Ashfield Shale	18-21	20.33	3.15	17.18							v		v	v
BH122	Ashfield Shale	15-18	5.72	3.90	1.82			3.80	1.92	3.89	1.83	3.80	1.92	3.70	2.02
BH137	Hawkesbury Sandstone	54-57	15.15									0.03	15.12	0.03	15.12
BH143	Hawkesbury Sandstone	82-85	40.185							20.84	19.35	20.96	19.23	20.76	19.43
BH152s	alluvium	18-21	2.93									2.30	0.63	na	na
BH152d	Hawkesbury Sandstone	48-51	2.87									1.51	1.36	na	na
BH153	Hawkesbury Sandstone	46-49	11.24							8.057	3.18	8.06	3.18	8.00	3.24
BH157	Regentville Siltstone	32-35	16.82	25.95	-9.13							29.25	-12.43	29.74	-12.92
BH168	Hawkesbury Sandstone	48-51	1.36	1.3	0.06	1.3	0.06			1.395	-0.03	1.20	0.16	1.73	-0.37

Notes: ^SWL - Standing Water Level *mbtoc - metres below top of casing

v - well vandalised emporarily not accessible

Table B2 Summary of WCX Phase 2 monitoring well network

Monitoring Well	Location	Date well installed	Co-ordinates		Elevation	Depth to		Lithology
			Easting	Northing	m AHD	Sandstone	screen interval	Screened
BH006	Canterbury Golf Course, Beverly Grove, Kingsgrove	24-Sep-14	323555.37	6242879.56	24.71	9.3	22-25	Hawkesbury Sandstone
BH18	Moore St, on Grass, Bardwell park	17-Nov-14	326717.03	6243421.81	34.84	1.0	51-54	Hawkesbury Sandstone
BH024	off The Glen Rd, in Bardwell Valley Golf Course, Bardwell Val	25-Nov-14	327221.88	6243305.92	8.17	20.1	26-29	Hawkesbury Sandstone
BH025	Queen St, Arncliff	03-Dec-14	328636.69	6243271.02	23.85	1.0	55-58	Hawkesbury Sandstone
BH029	Barton Park Driving Range, near Eve St, Arncliff	17-Oct-14	329349.64	6242708.81	4.28	9.1	33-36	Hawkesbury Sandstone
BH036	Cahill Park, Princes Highway, Wolli Creek	23-Oct-14	329402.60	6243808.71	1.58	19.9	60-63	Hawkesbury Sandstone
BH039	Discovery Park, Brodie Sparke Dr, Wolli Creek (Australand)	14-Jan-15	329553.24	6244157.93	3.32	4.2	49-52	Hawkesbury Sandstone
BH040	View St, Tempe	19-Dec-14	329679.77	6244313.44	1.61	7.5	65-68	Basalt
BH042	Kendrick Park, View St, Tempe	17-Dec-14	329718.7	6244348.17	1.94	9.1	45.5-48.5	Hawkesbury Sandstone
BH070	Off Bellevue St, Arncliffe	07-Nov-14	329041.77	6242920.40	17.54	0.7	35-38	Hawkesbury Sandstone
BH072	Bexley Rd, Gilchrist Park, Kingsgrove	28-Nov-14	325560.61	6243242.77	7.47	6.7	28-31	Hawkesbury Sandstone
BH074	Argyle St, Arncliff	18-Nov-14	329227.87	6243670.15	2.58	14.0	39-42	Hawkesbury Sandstone
BH084	Johnston St, Earlwood	03-Oct-14	325612.90	6243435.43	30.02	1.7	47.5-50.5	Hawkesbury Sandstone
BH088	176 Slade Rd, Bardwell Park	07-Nov-14	326181.73	6243434.42	16.78	6.0	41-44	Hawkesbury Sandstone
BH093	Lorraine Ave,, Bardwell Park	03-Dec-14	327657.04	6243183.19	36.39	1.0	47-50	Hawkesbury Sandstone
BH094	7 Athelstane Ave, Arncliffe	10-Dec-14	327867.31	6243174.27	31.17	1.0	54-57	Hawkesbury Sandstone
BH103	Samuel St, Sydnham, near Henry st	01-Dec-14	330430.65	6245201.04	11.10	shale	48-51	Hawkesbury Sandstone
BH109	Southern Cross Hotel car park, St Peters	13-Nov-14	331220.46	6245632.16	6.91	shale	33-36	Rouse Hill Siltstone
BH115	northern end of Sydney Park,off Barwon Park Road St Peters	20-Nov-14	331875.09	6246376.30	20.33	shale	29.5-32.5	Ashfield Shale
BH120	Edith St, St Peters	25-Nov-14	331875.09	6246376.30	20.33	shale	18-21	Ashfield Shale
BH122	South Perimeter, Sydney Park, Campbell St, St Peters	17-Nov-14	332029.55	6245872.93	5.72	shale	15-18	Ashfield Shale
BH137	2 Bonalbo Street Kingsgrove	03-Feb-15	324858.17	6243065.49	15.15	2.6	54-57	Hawkesbury Sandstone
BH143	Silver Jubilee Park, Bardwell Valley	03-Feb-15	327180.78	6242912.16	40.185	1.0	82-85	Hawkesbury Sandstone
BH152s	Tempe train station (Rail corridor)	05-Mar-15	329588.61	6244818.27	2.93	23.0	18-21	alluvium
BH152d	Tempe train station (Rail corridor)	19-Feb-15	329588.86	6244819.26	2.87	23.0	48-51	Hawkesbury Sandstone
BH153	IKEA car park, Tempe	09-Feb-15	330468.3	6244765.88	11.24	13.0	46-49	Hawkesbury Sandstone
BH157	KFC car park 108 Princes Hwy, St Peters	23-Jan-15	331518.01	6245765.53	16.82	4.2	32-35	Regentville Siltstone
BH168	next to Rockwell Ave, Cahill Park, Wolli Creek	03-Feb-15	329702.24	6243775.17	1.36	25.0	48-51	Hawkesbury Sandstone

Table B3 Packer Test Results

Well ID	Test_Depth From	Test_Depth To	Median Depth	Formation	Lithology	P1 Lugeon	P2 Lugeon	P3 Lugeon	P4 Lugeon	P5 Lugeon	K (test average) (m/day)	Lugeon (average)	Classification
WCX_BH009	9.00	15.00	12.00	Hawkesbury Sandstone	SANDSTONE	0.04	0.07	0.07	0.07	0.06	6.94E-04	0.062	LOW
WCX_bH009	14.50	20.00	17.25	Hawkesbury Sandstone	SANDSTONE	0.01	0.01	0.01	0.01	0.01	1.28E-04	0.01	LOW
WCX_BH016	11.15	14.51	12.83	Mittagong Formation	SILTSTONE / SANDSTONE	0.03	0.06	0.07	0.07	0	4.18E-04	0.046	LOW
WCX_BH016	14	20.42	17.21	Mittagong Formation	SILTSTONE / SANDSTONE	0.02	0.05	0.05	0	0	2.53E-04	0.024	LOW
WCX_BH016	19	25	22.00	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0	5.19E-06	0	LOW
WCX_BH018	29.8	36.1	32.95	Hawkesbury Sandstone	SILTSTONE / SANDSTONE	0	0	0	0	0	0.00E+00	0	LOW
WCX_BH018	35.8	45.1	40.45	Hawkesbury Sandstone	SANDSTONE	0.53	0.6	0.41	0.39	0.41	5.51E-03	0.468	LOW
WCX_BH018	44.7	54.07	49.39	Hawkesbury Sandstone	SANDSTONE	0.27	0.12	0.01	0.09	0	1.16E-03	0.098	LOW
WCX_BH018	53.9	60.1	57.00	Hawkesbury Sandstone	SANDSTONE	3.46	0.43	3.19	2.05	1.09	2.23E-02	2.044	MODERATE
WCX_BH018	62.8	69.1	65.95	Hawkesbury Sandstone	SANDSTONE	0.4	0.03	0.05	0.01	0.07	1.21E-03	0.112	LOW
WCX_BH019	35	41.02	38.01	Hawkesbury Sandstone	SANDSTONE	0.01	0.01	0	0.01	0.15	3.92E-04	0.036	LOW
WCX_BH019	40.8	47.03	43.92	Hawkesbury Sandstone	SANDSTONE / SILTSTONE					0.06	6.80E-04	0.06	LOW
WCX_BH019	46.8	56	51.40	Hawkesbury Sandstone	SANDSTONE	0.15	0	0	0	0.03	4.36E-04	0.036	LOW
WCX_BH019	55.8	65.03	60.42	Hawkesbury Sandstone	SANDSTONE					0.18	2.14E-03	0.18	LOW
WCX_BH019	64.8	70.99	67.90	Hawkesbury Sandstone	SANDSTONE	0.04				0.04	4.40E-04	0.04	LOW
WCX_BH019	69.5	75	72.25	Hawkesbury Sandstone	SANDSTONE	0.22	0.02	0.01	0	0.29	1.14E-03	0.108	LOW
WCX_BH020	29.5	38.6	34.05	Hawkesbury Sandstone	SANDSTONE	0.0023	0.0106	0.0033	0.003	0.0028	2.45E-04	0.0044	LOW
WCX_BH020	38.4	44.6	41.50	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0	0.00E+00	0	LOW
WCX_BH020	44.4	53.8	49.10	Hawkesbury Sandstone	SANDSTONE	0.03	0.17	0.31	0.06	0	1.32E-03	0.114	LOW
WCX_BH020	55.8	63	59.40	Hawkesbury Sandstone	SANDSTONE	0.07	0.17	0.6	0.13	0.18	2.56E-03	0.23	LOW
WCX_BH023	11	18	14.50	Mittagong Formation	SANDSTONE	6.28	15.49	14.7	4.49	5.21	1.03E-01	9.234	HIGH
WCX_BH023	23.8	30	26.90	Hawkesbury Sandstone	SANDSTONE	29.25	30.01	34.32	37.81		3.59E-01	32.84	VERY HIGH
WCX_BH023	17.8	24	20.90	Hawkesbury Sandstone	SANDSTONE	12.49	13.41	17.53	11.76	9.58	1.41E-01	12.954	HIGH
WCX_BH023	29.8	36	32.90	Hawkesbury Sandstone	SANDSTONE	0.03	0.01	0	0	0	1.08E-04	0.008	LOW
WCX_BH023	35.8	42	38.90	Hawkesbury Sandstone	SANDSTONE	0.17	0.29	0.12	0	0	1.29E-03	0.116	LOW
WCX_BH024	24	30	27.00	Hawkesbury Sandstone	SANDSTONE	31.94	33.67	31.21	24.59	20.95	3.09E-01	28.472	VERY HIGH
WCX_BH024	29.5	35.94	32.72	Hawkesbury Sandstone	SANDSTONE	2.74	2.37	2.56	2.53	2.16	2.72E-02	2.472	MODERATE
WCX_BH024	35.5	42	38.75	Hawkesbury Sandstone	SANDSTONE	3.66	2.99	3.51	1.96	1.54	3.01E-02	2.732	MODERATE
WCX_BH027	37.7	47	42.35	Hawkesbury Sandstone	SANDSTONE	0.12	0.24	0.27	0.25	0.24	2.66E-03	0.224	LOW
WCX_BH027	46.8	55.98	51.39	Hawkesbury Sandstone	SANDSTONE	1.12					1.32E-02	1.12	MODERATE
WCX_BH027	48.3	55.98	52.14	Hawkesbury Sandstone	SANDSTONE	0.92	1.2	1.35	1.12	1.19	1.32E-02	1.156	MODERATE
WCX_BH027	55.8	63	59.40	Hawkesbury Sandstone	SANDSTONE	0.21	0.31	0.19	0.18	0.19	2.41E-03	0.216	LOW
WCX_BH027	64	72.22	68.11	Hawkesbury Sandstone	SANDSTONE	11.92	8.38	7.48	8.01	8.93	1.03E-01	8.944	HIGH
WCX_BH027	71.5	80.27	75.89	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0	0.00E+00	0	LOW
WCX_BH035	20.85	29.85	25.35	Hawkesbury Sandstone	SANDSTONE	0.14	0.07	0.01	0.07	0.11	9.43E-04	0.08	LOW
WCX_BH035	28.85	38.85	33.85	Hawkesbury Sandstone	SANDSTONE	0.92	0.81	0.86	0.51	0.51	8.64E-03	0.722	LOW

Table B3 Packer Test Results

Well ID	Test_Depth From	Test_Depth To	Median Depth	Formation	Lithology	P1 Lugeon	P2 Lugeon	P3 Lugeon	P4 Lugeon	P5 Lugeon	K (test average) (m/day)	Lugeon (average)	Classification
WCX_BH035	37.85	44.85	41.35	Hawkesbury Sandstone	SANDSTONE	14.82	12.69	10.414	8.6	8.82	1.24E-01	11.0688	HIGH
WCX_BH035	43.85	53.85	48.85	Hawkesbury Sandstone	SANDSTONE	8.01	7.75				9.45E-02	7.88	HIGH
WCX_BH035	44.35	53.85	49.10	Hawkesbury Sandstone	SANDSTONE	0.07	0.06	0.05	0.19	0.09	1.07E-03	0.092	LOW
WCX_BH035	52.85	59.85	56.35	Hawkesbury Sandstone	SANDSTONE	0.54	0.14	0.13	0.2	0.27	2.84E-03	0.256	LOW
WCX_BH035	58.85	65.88	62.37	Hawkesbury Sandstone	SANDSTONE	23.32	21.89	16.16	20.15	22.79	2.34E-01	20.862	HIGH
WCX_BH036	28	34.1	31.05	Hawkesbury Sandstone	SANDSTONE	1.43	1.95	2.06	1.77	3.02	2.23E-02	2.046	MODERATE
WCX_BH036	33.8	40	36.90	Hawkesbury Sandstone	SANDSTONE	0.04	0	0.01			1.86E-04	0.0167	LOW
WCX_BH036	39.75	49	44.38	Hawkesbury Sandstone	SANDSTONE / SILTSTONE	0	0.12	0.12	0.11	0.01	8.28E-04	0.072	LOW
WCX_BH036	48.75	58.05	53.40	Hawkesbury Sandstone	SANDSTONE	0.26	0.52	0.55	0.52		5.48E-03	0.4625	LOW
WCX_BH036	57.8	64.1	60.95	Hawkesbury Sandstone	SANDSTONE	38.7	27.48	11.71	11.53	15.11	2.29E-01	20.906	HIGH
WCX_BH036	63.8	70	66.90	Hawkesbury Sandstone	SANDSTONE	0.49	0.72	0.61	0.74	0.41	6.47E-03	0.594	LOW
WCX_BH038	23.3	29.8	26.55	Mittagong Formation	SANDSTONE	1.47	1.15	1.14	1.1	0.43	1.17E-02	1.058	MODERATE
WCX_BH038	29.6	38.8	34.20	Hawkesbury Sandstone	SANDSTONE	0.15	0.24	0.2	0.2	0.1	2.09E-03	0.178	LOW
WCX_BH038	38.3	47.8	43.05	Hawkesbury Sandstone	SANDSTONE	0.25	0.05	0.06	0.06	0.18	1.44E-03	0.12	LOW
WCX_BH038	47.3	56.8	52.05	Hawkesbury Sandstone	SANDSTONE	0.42	0.24	0.24	0.24	0.41	3.69E-03	0.31	LOW
WCX_BH038	56.5	65.8	61.15	Hawkesbury Sandstone	SANDSTONE	1.56	1.2	1.08	0.93	1.28	1.43E-02	1.21	MODERATE
WCX_BH038	65.5	68.8	67.15	Hawkesbury Sandstone	SANDSTONE	2.66	1.61	4.3	7.59	4.98	4.01E-02	4.228	MODERATE
WCX_BH038	72.8	77.8	75.30	Hawkesbury Sandstone	SANDSTONE	0.46	0.15	0.15	0.13	0.47	2.81E-03	0.272	LOW
WCX_BH038	68.5	71.8	70.15	Hawkesbury Sandstone	SANDSTONE	6.09	4.56	6.32	4.21	2.03	4.41E-02	4.642	MODERATE
WCX_BH040	31	37	34.00	Hawkesbury Sandstone	SANDSTONE	37.49					4.07E-01	37.49	VERY HIGH
WCX_BH040	36.75	43	39.88	Hawkesbury Sandstone	SANDSTONE	4.03	1.35	2.17			2.75E-02	2.517	MODERATE
WCX_BH040	42	49	45.50	Hawkesbury Sandstone	SANDSTONE	0	0	0.1	0.04		4.00E-04	0.035	LOW
WCX_BH040	48.75	55	51.88	Hawkesbury Sandstone	SANDSTONE	0	0.2	0.49	0.508	32.7	8.42E-02	6.7796	HIGH
WCX_BH040	54.75	61	57.88	Hawkesbury Sandstone	SANDSTONE	0	0	0.39			1.42E-03	0.13	LOW
WCX_BH040	60.75	67	63.88	Basalt	SANDSTONE / BASALT	0	0	0	0	0	0.00E+00	0	LOW
WCX_BH040	65.75	73	69.38	Basalt	BASALT / SANDSTONE	0	8.42	8.28	0	0	1.69E+00	3.34	MODERATE
WCX_BH043	24.35	30.35	27.35	Hawkesbury Sandstone	SANDSTONE	0.02	1.11	1.63	40.05	0	4.33E+00	8.562	HIGH
WCX_BH043	29.9	39.1	34.50	Hawkesbury Sandstone	SANDSTONE	1.12	0.27	0.17	0.14	0.08	1.80E-01	0.356	LOW
WCX_BH043	38.9	48	43.45	Hawkesbury Sandstone	SANDSTONE	0.01	0.03	0.05	0.23	1.06	1.40E-01	0.276	LOW
WCX_BH043	48	57	52.50	Hawkesbury Sandstone	SANDSTONE	0.6	0.01	0.02	0	0	6.37E-02	0.126	LOW
WCX_BH043	57	66	61.50	Hawkesbury Sandstone	SANDSTONE	33.49	25.02	19.85	20.57	23.87	1.24E+01	24.56	VERY HIGH
WCX_BH043	63.5	67.5	65.50	Hawkesbury Sandstone	SANDSTONE	56.74	44.56	38.52	47.04	46.82	2.36E+01	46.736	VERY HIGH
WCX_BH043	72	75	73.50	Hawkesbury Sandstone	SANDSTONE	327.72	227.91	191.61	201.12	183.65	1.14E+02	226.402	EXTREMELY HIGH
WCX_BH072	10	18.1	14.05	Mittagong Formation	SANDSTONE / SILTSTONE	7.76	7.07	5.93	7.49	8.38	3.71E+00	7.326	HIGH
WCX_BH072	18	27.1	22.55	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0.01	1.01E-03	0.002	LOW
WCX_BH072	31.5	34.5	33.00	Hawkesbury Sandstone	SANDSTONE	117.6	105.09	99.03	93.58	120.7	5.41E+01	107.2	EXTREMELY HIGH

Table B3 Packer Test Results

Well ID	Test_Depth From	Test_Depth To	Median Depth	Formation	Lithology	P1 Lugeon	P2 Lugeon	P3 Lugeon	P4 Lugeon	P5 Lugeon	K (test average) (m/day)	Lugeon (average)	Classification
WCX_BH072	34.6	40.6	37.60	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0	0.00E+00	0	LOW
WCX_BH072	40.55	49.55	45.05	Hawkesbury Sandstone	SANDSTONE	0	0	0.07	0.01	0	8.23E-03	0.016	LOW
WCX_BH072	49.55	55.55	52.55	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0	0.00E+00	0	LOW
WCX_BH072	55.55	64.55	60.05	Hawkesbury Sandstone	SANDSTONE	1.43	1.14	0.99	0.89	0.4	4.91E-01	0.97	LOW
WCX_BH073	28	40	34.00	Hawkesbury Sandstone	SANDSTONE		2.19	4.21	0.93	3.01	3.21E-02	2.585	MODERATE
WCX_BH073	40	46	43.00	Hawkesbury Sandstone	SANDSTONE	49.81	44.18	41.02	39.06	43.37	2.20E+01	43.488	VERY HIGH
WCX_BH073	46	52	49.00	Hawkesbury Sandstone	SANDSTONE	0.16	0.05	0.16	0.02	0.01	4.04E-02	0.08	LOW
WCX_BH073	34	46	40.00	Hawkesbury Sandstone	SANDSTONE	58.5					7.25E-01	58.5	EXTREMELY HIGH
WCX_BH073	52	58	55.00	Hawkesbury Sandstone	SHALE BRECCIA / SANDSTONE	0.05	0.02	0.04	0.01	0.06	1.82E-02	0.036	LOW
WCX_BH080	17	23.1	20.05	Hawkesbury Sandstone	SANDSTONE	0.03	0.96	1.3	1.85	2.04	6.25E-01	1.236	MODERATE
WCX_BH080	22.5	28.5	25.50	Hawkesbury Sandstone	SANDSTONE / SILTSTONE	0.01	0.31	0	0.01	0	3.34E-02	0.066	LOW
WCX_BH080	28	34	31.00	Hawkesbury Sandstone	SANDSTONE	0.03	0.05	0.24	0.05	0	3.74E-02	0.074	LOW
WCX_BH080	33.5	39.5	36.50	Hawkesbury Sandstone	SANDSTONE / SILTSTONE	0.11	0.21	0.31	0.36	0.23	1.23E-01	0.244	LOW
WCX_BH080	39.5	46	42.75	Hawkesbury Sandstone	SANDSTONE	0.98	0.67	0.59	1.29	6.6	1.02E+00	2.026	MODERATE
WCX_BH080	46	55	50.50	Hawkesbury Sandstone	SANDSTONE	0.32	0.22	0.25	0.27	0.53	1.61E-01	0.318	LOW
WCX_BH086	24.7	34.2	29.45	Hawkesbury Sandstone	SANDSTONE	0.47	0.23	0.3	0.25	0.34	1.61E-01	0.318	LOW
WCX_BH086	56.5	62.85	59.68	Hawkesbury Sandstone	SANDSTONE	0.6	0.6	0.87	0.89	0.81	3.81E-01	0.754	LOW
WCX_BH086	62.5	68.8	65.65	Hawkesbury Sandstone	SANDSTONE	0.62	0.45	0.37	0.36	0.24	2.06E-01	0.408	LOW
WCX_BH105	14.8	23.8	19.30	Mittagong Formation	SILTSTONE / SANDSTONE	0.6	0.92	0.47	0.76	1.26	4.06E-01	0.802	LOW
WCX_BH105	23.6	32.8	28.20	Hawkesbury Sandstone	SANDSTONE	0.54	0.37	0.51	0.52	0.45	2.42E-01	0.478	LOW
WCX_BH105	32.6	41.8	37.20	Hawkesbury Sandstone	SANDSTONE	1.01	0.41	1.24	1.15	0.47	4.33E-01	0.856	LOW
WCX_BH105	41.6	50.8	46.20	Hawkesbury Sandstone	SANDSTONE	0.59	0.59	0.07	0.08	0.05	1.40E-01	0.276	LOW
WCX_BH105	50.6	59.9	55.25	Hawkesbury Sandstone	SANDSTONE	0.17	0.09	0.15	0.15	0.08	6.48E-02	0.128	LOW
WCX_BH114	9	15.1	12.05	Ashfield Shale	SILTSTONE / SANDSTONE	2.91	7.02	8.71	8.45	8.03	2.38E+00	7.024	HIGH
WCX_BH114	14.8	21.1	17.95	Ashfield Shale	SILTSTONE	0.4	0.6	0.69	0.16	0.12	1.99E-01	0.394	LOW
WCX_BH114	20.8	24.1	22.45	Mittagong Formation	SILTSTONE	0	0	0.01	0	0	1.01E-03	0.002	LOW
WCX_BH114	23.8	30.05	26.93	Hawkesbury Sandstone	SILTSTONE	0.03	0.6	0.96	0.72	0.2	2.54E-01	0.502	LOW
WCX_BH119	10	16.1	13.05	Ashfield Shale	SILTSTONE	0.09	0.23	0.06	0	0	3.84E-02	0.076	LOW
WCX_BH119	15.6	22.1	18.85	Mittagong Formation	SILTSTONE	0.07	0.1	0.2	0.08	0.01	4.65E-02	0.092	LOW
WCX_BH119	21.6	29.6	25.60	Hawkesbury Sandstone	SILTSTONE / SANDSTONE	0.02	0.03	0.04	0.01	0.03	1.32E-02	0.026	LOW
WCX_BH137	35	44	39.50	Hawkesbury Sandstone	SANDSTONE	0.05	0.04	0.03	0.02	0.02	1.62E-02	0.032	LOW
WCX_BH137	43.7	53	48.35	Hawkesbury Sandstone	SANDSTONE	0.06	0.08	0.09	0.08	0.07	3.84E-02	0.076	LOW
WCX_BH137	52.7	62	57.35	Hawkesbury Sandstone	SANDSTONE	0.01	0.02	0.01	0.01	0.02	7.09E-03	0.014	LOW

Table B3 Packer Test Results

Well ID	Test_Depth From	Test_Depth To	Median Depth	Formation	Lithology	P1 Lugeon	P2 Lugeon	P3 Lugeon	P4 Lugeon	P5 Lugeon	K (test average) (m/day)	Lugeon (average)	Classification
WCX_BH137	61.7	71	66.35	Hawkesbury Sandstone	SANDSTONE	0.06	0.02	0.04	0.03	0.02	1.72E-02	0.034	LOW
WCX_BH138	54.79	65.41	60.10	Hawkesbury Sandstone	SANDSTONE	0.29	0.14	0.07	0.17	0.17	8.50E-02	0.168	LOW
WCX_BH138	62.87	75.81	69.34	Hawkesbury Sandstone	SANDSTONE	0.19	0.07	0.03	0.04	0.2	5.37E-02	0.106	LOW
WCX_BH138	75.58	86.26	80.92	Hawkesbury Sandstone	SANDSTONE	0.37	0.08	0.08	0.07	0.23	8.40E-02	0.166	LOW
WCX_BH138	93.81	96.81	95.31	Hawkesbury Sandstone	SANDSTONE	0.08	0.21	0.16	0.18	0.08	7.17E-02	0.142	LOW
WCX_BH140	99.6	108.8	104.20	Hawkesbury Sandstone	SANDSTONE	0.12	0.13	0.1	0.11	0.1	5.67E-02	0.112	LOW
WCX_BH140	114.6	120.8	117.70	Hawkesbury Sandstone	SANDSTONE	7.08	6.28	8.93	3.42	2.56	2.86E+00	5.654	MODERATE
WCX_BH141	58	70	64.00	Hawkesbury Sandstone	SANDSTONE	0.22	0.16	0.11	0.12	0.15	7.69E-02	0.152	LOW
WCX_BH141	69.7	82	75.85	Hawkesbury Sandstone	SANDSTONE	0.53	0.44	0.39	0.39	0.39	2.17E-01	0.428	LOW
WCX_BH141	81.7	94	87.85	Hawkesbury Sandstone	SANDSTONE	0.16	0.18	0.28	0.16	0.09	8.81E-02	0.174	LOW
WCX_BH141	93.7	106	99.85	Hawkesbury Sandstone	SANDSTONE	24.23	28.26	42.17	30.19	28.23	1.55E+01	30.616	VERY HIGH
WCX_BH141	103.5	106	104.75	Hawkesbury Sandstone	SANDSTONE	67.46	69.64	67.21	66.15	63.37	3.37E+01	66.766	EXTREMELY HIGH
WCX_BH142	34.64	45.15	39.90	Hawkesbury Sandstone	SANDSTONE	10.05	8.05	7.45	7.81	8.61	4.25E+00	8.394	HIGH
WCX_BH143	45.15	54.15	49.65	Hawkesbury Sandstone	SANDSTONE	0.36	0.16	0.11	0.04	0.05	7.28E-02	0.144	LOW
WCX_BH143	53.95	66.15	60.05	Hawkesbury Sandstone	SANDSTONE	0.13	0.08	0.07	0.08	0.07	4.35E-02	0.086	LOW
WCX_BH143	65.95	78.15	72.05	Hawkesbury Sandstone	SANDSTONE	0.14	0.08	0.05	0.05	0.09	4.15E-02	0.082	LOW
WCX_BH143	77.95	87.15	82.55	Hawkesbury Sandstone	SANDSTONE	1.79	1.56	1.27	1.24	1.18	7.12E-01	1.408	MODERATE
WCX_BH143	87.15	93.15	90.15	Hawkesbury Sandstone	SANDSTONE	0.12	0.07	0.04	0.03	0.07	3.33E-02	0.066	LOW
WCX_BH144	56	68	62.00	Hawkesbury Sandstone	SANDSTONE	0	0.3	0.3	0.28	0	8.91E-02	0.176	LOW
WCX_BH144	67.8	80	73.90	Hawkesbury Sandstone	SANDSTONE	0	0.14	0.18	0.06	0	3.85E-02	0.076	LOW
WCX_BH144	79.7	91.9	85.80	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0	0.00E+00	0	LOW
WCX_BH144	91.7	103.9	97.80	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0	0.00E+00	0	LOW
WCX_BH144	103.7	115.9	109.80	Hawkesbury Sandstone	SANDSTONE	1	3.39	0.65	0.51	1.03	6.66E-01	1.316	MODERATE
WCX_BH152	31	37.5	34.25	Hawkesbury Sandstone	SANDSTONE	5.77	3.39	2.72	3.22	3.82	1.91E+00	3.784	MODERATE
WCX_BH152	48	51.6	49.80	Hawkesbury Sandstone	SANDSTONE	251.36	135.42	99.16	40.63		6.80E+01	131.6425	EXTREMELY HIGH
WCX_BH153	40.7	51.7	46.20	Hawkesbury Sandstone	SANDSTONE	0.19	0.26	0.31	0.27	0.19	1.23E-01	0.244	LOW
WCX_BH154	34.64	45.03	39.84	Hawkesbury Sandstone	SANDSTONE	0.16	0.06	0.01	0	0	2.33E-02	0.046	LOW
WCX_BH154	45.03	53.12	49.08	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0	3.16E-06	0	LOW
WCX_BH154	53.12	61.2	57.16	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0	0.00E+00	0	LOW
WCX_BH154	61.2	69.28	65.24	Hawkesbury Sandstone	SANDSTONE	0	0	0.01	0	0	1.01E-03	0.002	LOW
WCX_BH157	23.95	32.95	28.45	Ashfield Shale	SILTSTONE	0.18	0.18	0.01	0.16	0.65	1.19E-01	0.236	LOW
WCX_BH157	32.55	41.95	37.25	Ashfield Shale	SILTSTONE / SANDSTONE	0.5	0.87	0.34	0.31	0.31	2.36E-01	0.466	LOW
WCX_BH157	41.6	51	46.30	Ashfield Shale	SILTSTONE		0.05		0.13	0.48	2.64E-03	0.22	LOW
WCX_BH158	40	48.73	44.37	Hawkesbury Sandstone	SANDSTONE / SILTSTONE	0.39	0.25	0.34	0.34	0.12	1.46E-01	0.288	LOW
WCX_BH158	48.5	57.81	53.16	Hawkesbury Sandstone	SHALE BRECCIA / SANDSTONE	0.23	0.28	0.49	0.34	0.16	4.13E-02	0.3	LOW
WCX_BH158	57.5	66.88	62.19	Hawkesbury Sandstone	SANDSTONE	0.38	0.23	0.51	0.1	0.02	1.25E-01	0.248	LOW

Table B3 Packer Test Results

Well ID	Test_Depth From	Test_Depth To	Median Depth	Formation	Lithology	P1 Lugeon	P2 Lugeon	P3 Lugeon	P4 Lugeon	P5 Lugeon	K (test average) (m/day)	Lugeon (average)	Classification
WCX_BH158	66.6	79.1	72.85	Hawkesbury Sandstone	SANDSTONE	0.45	0.07			0.36	1.06E-01	0.293	LOW
WCX_BH165	52.89	59.81	56.35	Hawkesbury Sandstone	SANDSTONE	0	0	0.02	0.03	0.035	8.95E-03	0.017	LOW
WCX_BH165	59.81	70.21	65.01	Hawkesbury Sandstone	SANDSTONE	0.54	0.23	0.21	0.23	0.03	1.25E-01	0.248	LOW
WCX_BH165	70.21	80.6	75.41	Hawkesbury Sandstone	SANDSTONE	0	0	0.01	0.01	0	2.03E-03	0.004	LOW
WCX_BH165	80.6	90.99	85.80	Hawkesbury Sandstone	SANDSTONE	0.76	0.75	0.68	0.69	0.4	3.32E-01	0.656	LOW
WCX_BH165	90.64	95.61	93.13	Hawkesbury Sandstone	SANDSTONE	0.04	0	0	0	0	4.04E-03	0.008	LOW
WCX_BH165	95.38	100.46	97.92	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0	4.95E-06	0	LOW
WCX_BH167	27	38	32.50	Hawkesbury Sandstone	SANDSTONE	0	0	0.05	0	0	5.07E-03	0.01	LOW
WCX_BH167	37.3	47	42.15	Hawkesbury Sandstone	SANDSTONE	0.81	0.9	0.79	0.63	0.15	3.32E-01	0.656	LOW
WCX_BH167	46.8	55	50.90	Hawkesbury Sandstone	SANDSTONE	3.7	3.29	2.77	2.89	3.47	1.63E+00	3.224	MODERATE
WCX_BH168	47	56	51.50	Hawkesbury Sandstone	SANDSTONE	17.93	14.51	11.6	13.08	14.81	7.28E+00	14.386	HIGH
WCX_BH168	53.75	65	59.38	Hawkesbury Sandstone	SANDSTONE	7.74	16.72	13.42	15.47	17.27	7.15E+00	14.124	HIGH
WCX_BH200	28.1	37.1	32.60	Hawkesbury Sandstone	SANDSTONE	0.55	0.47	0.33	0.47	0.57	2.42E-01	0.478	LOW
WCX_BH200	36.8	46.2	41.50	Hawkesbury Sandstone	SANDSTONE	0	0.01	0.05	0.02	0	8.09E-03	0.016	LOW
WCX_BH200	46	55.2	50.60	Hawkesbury Sandstone	SANDSTONE	0.39	0.56	0.3	0.37	0.66	2.29E-01	0.456	LOW
WCX_BH200	55	64.2	59.60	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0	0.00E+00	0	LOW
WCX_BH200	64	74	69.00	Hawkesbury Sandstone	SANDSTONE	0	0	0	0	0	0.00E+00	0	LOW

Table B4 Groundwater Gauging 2015 - Alexandria Landfill

Well ID	Date	Easting	Northing	Total Depth (m BTOC)	Screened interval (m bgs)	TOC (m AHD)	Depth to Groundwater (m BTOC)	Corrected Groundwater Elevation (m AHD)
MW1	20/05/2015	331825.13	6245907.47	34.340	29 to 35	9.59	11.738	-2.15
MW2s	25/02/2015	331800.64	6245593.96	8.930	5 to 8	3.33	4.418	-1.09
MW2d	27/02/2015	331801.32	6245593.95	31.415	23 to 29	3.47	12.595	-9.13
MW4c	20/05/2015	331667.80	6245865.39	30.280	29 to 35**	11.92	15.483	-3.56
MW304	26/02/2015	331447.71	6245723.42	14.200	10.5 to13.5	-4.5	5.530	-10.03
MW305	27/02/2015	331645.14	6245685.87	37.430	34 to 37	5.38	15.263	-9.88
MW306	26/02/2015	331718.97	6245728.16	40.550	32 to 41	8.4	18.317	-9.92
MW307	20/05/2015	331641.67	6245805.27	21.890	18 to 21	9.05	19.150	-10.10
MW308	27/02/2015	331794.8	6245862.6	32.760	30.5 to 33.5	9.47	19.454	-9.98
MW309	25/02/2015	331910.72	6245705.83	10.010	6.32 to 9.32	5.51	4.182	1.33
MW310	25/02/2015	331910.14	6245705.03	5.940	4.749 to 5.149	5.47	3.906	1.56
MW311	23/02/2015	331823.77	6245779.56	12.915	9.95 to 12.95	8.1	12.846	-4.75
MW312	27/02/2015	331769.86	6245583.4	15.075	10.7 to15.075	7.77	7.529	0.24
MW313	25/02/2015	331437.62	6245568.02	10.170	6.45 to 9.45	-5.89	4.371	-10.26
MW314	26/03/2015	331508.64	6245605.23	23.250	19.63 to 22.63	-11.95	0.896	-12.85

Notes :

m BTOC: metres Below Top of Casing
m AHD: metres Australian Height Datum
** original 1997 screen interval, well was since re-installed
bgs - below ground surface

🟧 Shale Wells
🟨 Botany Sands Wells
🟩 Landfill Wells

Data Entry: KM
Data Review:
AECOM

Table B5 Botany sands Wells at Canal Road -24 February 2015

Monitoring Well	Easting	Northing	Total Depth of Well (m BTOC)	Flush / Stick-up	Screened interval (m BTOC)	TOC (m AHD)	Depth to Groundwater (m BTOC)	Groundwater Elevation (m AHD)
MW300	331682.34	6245544.23	5.780	FLUSH	1.9-6.0	4.52	3.608	0.912
MW301	331614.57	6245495.86	4.252	STICK-UP	2.68-4.18	4.53	3.525	1.005
MW302	331562.00	6245434.02	7.445	FLUSH	5.45-7.45	2.25	1.725	0.525
MW303	331562.92	6245434.90	2.390	FLUSH	1.5-3.0	2.25	1.250	1.000
MW316	331446.07	6245524.17	11.705	STICK-UP	10.455-11.455	10.46	10.830	-0.370
MW317	334474.01	6245490.00	11.945	STICK-UP	10.535-12.035	10.69	10.410	0.280

Table B6 Inorganic Chemistry

		Calcium (Filtered)	Magnesium (Filtered)	Sodium (Filtered)	Potassium (Filtered)	Alkalinity (Carbonate as CaCO3)	Alkalinity (Bicarbonate as CaCO3)	Chloride	Sulphur (Total Oxidised as SO4) (Filtered)	Fluoride	Iron	Magnesium (Filtered)	TDS	Electrical conductivity *(lab)	pH (Lab)	Nitrate (as N)	Nitrite (as N)	Nitrogen (Total Oxidised)	Reactive Phosphorus as P
	Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	uS/cm	pH_Units	mg/L	mg/L	mg/L	mg/L
	LOR	1	1	1	1	1	1	1	1	0.1	0.05	1	1	1	0.01	0.01	0.01	0.01	0.01
Monitoring Well	Aquifer	**Cations**				**Anions**					**Metals**					**Nutrients**			
MW018	Hawkesbury Sandstone	421	<1	112	36	31	<1	73	59	0.1	<0.05		3320	5110	12.3	0.34	0.09	0.43	<0.01
MW024	Hawkesbury Sandstone	25	18	83	5	<1	131	146	21	0.2	25.5	0.568	518	797	6.57	0.01	<0.01	0.01	<0.1
MW029	Hawkesbury Sandstone	951	129	3120	97	<1	215	7030	753	<0.1	0.29		13,800	21,300	7.37	0.01	<0.01	0.01	<0.01
MW036	Hawkesbury Sandstone	140	<1	241	21	44	<1	593	16	0.2	0.46		1310	2020	10.7	<0.01	<0.01	<0.01	<0.01
MW039	Hawkesbury Sandstone	141	1	148	10	66	20	119	356	0.3	0.33		845	1300	10.1	<0.01	0.01	<0.01	<0.01
MW042	Hawkesbury Sandstone	83	40	300	8	<1	307	480	19	0.4	3.31		1340	2060	7.7	0.01	<0.01	0.01	<0.01
MW072	Hawkesbury Sandstone	392	<1	834	33	146	<1	891	614	0.4	0.12	0.004	4170	6410	11.7	<0.01	0.02	0.01	<0.01
MW084	Hawkesbury Sandstone	207	<1	190	21	43	<1	222	484	0.4	0.54		1460	2250	11.4	<0.01	<0.01	<0.01	
MW143	Hawkesbury Sandstone	61	16	153	40	6	168	185	124	0.3	6.85		760	1170	8.37	<0.01	<0.01	<0.01	<0.01
MW153	Hawkesbury Sandstone	681	<1	181	140	56	<1	49	<1	0.2	0.1		5400	8310	12.5	0.13	0.02	0.15	<0.01
MW168	Hawkesbury Sandstone	146	116	361	27	<1	209	933	<1	0.4	12.8		2140	3300	7.38	<0.01	<0.01	<0.01	0.07
MW109	Ashfield Shale	321	<1	1880	73	55	<1	3010	40	<0.1	1.45	0.046	6960	10,700	11.4	0.01	0.01	0.02	<0.01
MW122	Ashfield Shale	31	53	534	13	<1	319	677	122	0.7	25.9	0.408	2090	3210	6.21	0.31	<0.01	0.31	<0.1
MW115	Ashfield Shale	258	<1	371	237	84	<1	255	63	0.1	2.08	0.142	3700	5700	12.2	<0.01	0.06	0.05	<0.01

Table B7 Summary of Bores Registered with NoW

Bore ID	Depth of Bore (m)	SWL*	Purpose	From (mBGL)	To (mBGL)	Geology Screened	Lattitude	Longitude	Location relative to M5 Alignment
GW013331	14.9	7.9-14.8	Industrial	0	1.52	Sand (yellow)	-33.9204	151.1909	King Georges Rd to Alexandria - Within alignment boundary, North of Gardener's Road
GW013515	8.2	Not Available	Domestic	0	8.22	Sand	-33.9246	151.1941	King Georges Rd to Alexandria - South East of alignment boundary, West of Botany Road
GW015954	20.1	6.7-19.2	Industrial	0	0.3	Sand	-33.9206	151.192	King Georges Rd to Alexandria - North and East of alignment boundary, North of Gardener's Road
GW023168	4.5	Not Available	Water Supply	0	4.57	Sand	-33.918	151.1989	King Georges Rd to Alexandria - North and East of alignment boundary, West of Botany Road
GW023191	3.70	1.20'	Water Supply - Domestic	0	3.65	Sand	-33.9439	151.1501	South of Alignment - South East of Princes Highway, North of Spring St
GW023194	4.90	3.30	Water Supply - Domestic	0	0.91	Sand	-33.9413	151.1514	South of Alignment - South East of Princes Highway, North of Spring St
GW024109	2.10	2.10	Water Supply - Domestic	0	2.13	Sand	-33.9348	151.1545	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway
GW024374	5.1	4.5	Irrigation	0	5.18	Sand	-33.9206	151.1945	King Georges Rd to Alexandria - North and East of alignment boundary, West of Botany Road
GW024673	4.30	Not Available	Water Supply - Domestic	0	4.26	Loam	-33.9356	151.0875	King Georges Rd to Alexandria - North of alignment, West of Princes Highway
GW027248	4.9	2.4	Industrial	0	1.21	sand	-33.924	151.1853	King Georges Rd to Alexandria - South of alignment, near Coward Street
GW027664	6.10	0.70	Irrigation	0	0.3	Sand	-33.9359	151.1556	King Georges Rd to Alexandria - within alignment boundary, East of Princes Highway
GW027749	16.4	1.80'	Other	0	2.43	Sand	-33.9262	151.1912	King Georges Rd to Alexandria - South East of alignment, West of Botany Road
GW027750	17.3	11.28-17.37 (saturated	Other	0	10.97	Sand	-33.9251	151.1909	King Georges Rd to Alexandria - South East of alignment, West of Botany Road
GW040219	0.00	Not Available	Commercial and Industrial	-	-	Not Available	-33.9209	151.184	King Georges Rd to Alexandria - South of Gardeners Road
GW047123	18.9	1.52-18.29 (saturated	Other	0	1.52	Sand (with peat)	-33.9262	151.1948	King Georges Rd to Alexandria - South East of alignment, West of Botany Road
GW047525	17.1	1.52-17.07 (saturated	Other	0	0.61	Sand (grey)	-33.9235	151.1971	King Georges Rd to Alexandria - South East of alignment, East of Botany Road
GW072161	90.50	14.00	Other	0	16	Sandstone (grey, shale bands)	-33.9358	151.1567	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway
GW072643	12.00	Not Available	Unknown	0	2	Shale (grey, clay bands)	-33.9168	151.1822	King Georges Rd to Alexandria - Within alignment boundary, South East of Princes Highway, North
GW072901	7	4.00'	Water Supply	0	7	Sand (with peat)	-33.9269	151.1924	King Georges Rd to Alexandria - South East of alignment, West of Botany Road
GW073521	3	Not Available	Water Supply	-	-	Not Available	-33.9277	151.1932	King Georges Rd to Alexandria - South East of alignment, West of Botany Road
GW075024	19.5	0.760'	Monitoring	0	4	Sand (with peat)	-33.9251	151.1914	King Georges Rd to Alexandria - South East of alignment, West of Botany Road
GW100053	7.00	1.00	Other	0	0.95	Sand (white)	-33.9143	151.1845	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway, North of
GW100209	108.00	42.00-43.00'	Water Supply - Domestic	0	31	Sandstone (white)	-33.9375	151.16	King Georges Rd to Alexandria - South east of alignment, East of Princes Highway
GW100484	4	Not Available	Monitoring	0	2.2	Sand	-33.9219	151.1927	King Georges Rd to Alexandria - South of alignment, South of Gardeners Road
GW101533	20	4.4	Domestic	0	2	Sand	-33.919	151.1941	King Georges Rd to Alexandria - North of alignment, North of Gardeners Road
GW103504	6.1	Not Available	Monitoring	0	0.5	Sand	-33.918	151.1945	King Georges Rd to Alexandria - North of alignment, North of Gardeners Road
GW103505	6	Not Available	Monitoring	0	0.16	Sand	-33.9181	151.1945	King Georges Rd to Alexandria - North of alignment, North of Gardeners Road
GW103506	6	Not Available	Monitoring	0	0.17	Sand	-33.9181	151.1945	King Georges Rd to Alexandria - North of alignment, North of Gardeners Road
GW103507	6	Not Available	Monitoring	0	0.16	Sand	-33.9181	151.1945	King Georges Rd to Alexandria - North of alignment, North of Gardeners Road
GW103508	6	Not Available	Monitoring	0	0.16	Sand	-33.9181	151.1945	King Georges Rd to Alexandria - North of alignment, North of Gardeners Road
GW103588	7	Not Available	Domestic	0	7	Sand	-33.9237	151.1923	King Georges Rd to Alexandria - South of alignment, South of Gardeners Road
GW104297	0	4.000'	Water Supply	-	-	Not Available	-33.9268	151.1901	King Georges Rd to Alexandria - South East of alignment, West of Botany Road
GW104448	0.00	Not Available	Monitoring	-	-	Not Available	-33.9226	151.1795	King Georges Rd to Alexandria - South East of Princes Highway
GW104449	0.00	Not Available	Monitoring	-	-	Not Available	-33.9224	151.1791	King Georges Rd to Alexandria - East of Alexandra Canal, South of Ricketty Street
GW104450	0.00	Not Available	Monitoring	-	-	Not Available	-33.9229	151.1786	King Georges Rd to Alexandria - South East of Princes Highway
GW104988	7	Not Available	Domestic	0	7	Sand	-33.9241	151.1942	King Georges Rd to Alexandria - South East of alignment, West of Botany Road
GW106830	7.00	Not Available	Water Supply - Domestic	0	7	Sand	-33.9443	151.0933	King Georges Rd to Alexandria - South of alignment, West of Princes Highway
GW107976	3.5	Not Available	Dewatering	0	0.7	Sand	-33.9235	151.1956	King Georges Rd to Alexandria - South East of alignment, West of Botany Road
GW107993	13.60	1.95	Other-Test Bore	0	0.3	Sandstone (brown)	-33.9356	151.1416	King Georges Rd to Alexandria - North of alignment, West of Princes Highway
GW108104	Not	Not Available	Industrial	-	-	Not Available	-33.9194	151.1938	King Georges Rd to Alexandria - North of alignment, North of Gardeners Road
GW108295	8.00	Not Available	Water Supply - Domestic	0	8	Sand	-33.9444	151.1486	Southern Alignment - South East of Princes Highway, near Coward St
GW108406	8.00	Not Available	Water Supply - Domestic	0	8	Sand	-33.9356	151.1553	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway
GW108439	8.00	Not Available	Water Supply - Domestic	0	8	Sand	-33.9443	151.1485	Southern Alignment - South East of Princes Highway, near Coward St
GW108497	8	Not Available	Recreation	-	-	Not Available	-33.9172	151.1908	King Georges Rd to Alexandria - East of Alexandra Canal, North of Orchard Road
GW108588	8.00	Not Available	Water Supply - Domestic	0	8	Sand	-33.9358	151.1546	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway
GW109191	186.00	93.00	Other	0	1	Sandstone (brown)	-33.9373	151.1093	King Georges Rd to Alexandria - North of alignment, West of Princes Highway
GW109821	35.00	14.50	Monitoring	0	2.2	Shale	-33.9139	151.1808	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway, North of
GW109822	10.45	3.00	Monitoring	0	2.6	Sand	-33.9167	151.1806	King Georges Rd to Alexandria - Within alignment boundary, South East of Princes Highway, North
GW109823	29.00	12.50	Monitoring	0	3	Sand	-33.9167	151.1807	King Georges Rd to Alexandria - Within alignment boundary, South East of Princes Highway, North

SWL = Standing Water Level

Bore ID	Depth of Bore (m)	SWL*	Purpose	From (mBGL)	To (mBGL)	Geology Screened	Lattitude	Longitude	Location relative to M5 Alignment
GW109824	20.70	4.51	Monitoring	0	4.5	Sandstone (brown)	-33.9162	151.1761	King Georges Rd to Alexandria - Within alignment boundary, South East of Princes Highway, North
GW109825	22.00	14.90	Monitoring	0	4.5	Shale	-33.9143	151.1794	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway, North of
GW109963	8.00	Not Available	Water Supply - Domestic	0	8	Sand	-33.936	151.1546	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway
GW109964	8.00	Not Available	Water Supply - Domestic	0	8	Sand	-33.9359	151.1544	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway
GW109965	8.00	Not Available	Water Supply - Domestic	0	8	Sand	-33.9355	151.1551	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway
GW109966	3.00	Not Available	Water Supply - Domestic	0	3	Clay	-33.9355	151.1539	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway
GW110456	3.6	2.3	Monitoring	0	0.3	Sand	-33.9131	151.1912	King Georges Rd to Alexandria - North of alignment, West of Princes Highway/North of Gardeners
GW110457	3.6	1.7	Monitoring	0	0.25	Sand	-33.9137	151.1916	King Georges Rd to Alexandria - North of alignment, West of Princes Highway/North of Gardeners
GW110458	2.8	2.3	Monitoring	0	0.7	Sandstone	-33.9133	151.1926	King Georges Rd to Alexandria - North of alignment, West of Princes Highway/North of Gardeners
GW110735	0.00	Not Available	Water Supply - Domestic	-	-	Not Available	-33.9438	151.1489	South East of Princes Highway, near Coward St
GW111316	162	4.000'	Monitoring	0	37	Sandstone (brown)	-33.9438	151.1532	South East of Princes Highway, near Coward St
GW111320	5.20	2.52	Monitoring	0	0.18	Sand	-33.9145	151.186	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway, North of
GW111321	5.00	2.64	Monitoring	0	0.18	Sand	-33.9154	151.1862	King Georges Rd to Alexandria - Within alignment boundary, East of Princes Highway, North of

SWL = Standing Water Level