Annexure H – Groundwater modelling report – HydroSimulations

HYDROSIMULATIONS

WESTCONNEX M4-M5 LINK

Groundwater Modelling Report

FOR

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TABLE OF CONTENTS

LIST OF TABLES

FIGURES

ANNEXURES

1 INTRODUCTION

NSW Roads and Maritime Services (Roads and Maritime) is seeking approval to construct and operate the WestConnex M4-M5 Link (the project), which would comprise a new multi-lane road link between the M4 East Motorway at Haberfield and the New M5 Motorway at St Peters. The project would also include an interchange at Lilyfield and Rozelle (the Rozelle interchange) and a tunnel connection between Anzac Bridge and Victoria Road, east of Iron Cove Bridge (Iron Cove Link). In addition, construction of tunnels, ramps and associated infrastructure to provide connections to the proposed future Western Harbour Tunnel and Beaches Link project would be carried out at the Rozelle interchange. An overview of the project is shown in (**Figure 1-1**).

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

Approval is being sought under Part 5.1 of the Environmental Planning and Assessment Act 1979 (NSW) (EP&A Act) for the project. A request has been made for the NSW Minister for Planning to specifically declare the project to be State significant infrastructure and also critical State significant infrastructure. An environmental impact statement (EIS) is therefore required.

The construction and operation of the project will potentially impact on groundwater levels and groundwater quality due to tunnelling activities and associated works. A groundwater assessment is being undertaken by AECOM to outline the predicted impacts of the project, as well as the cumulative impacts with other stages of WCX works. HydroSimulations (HS) has been requested to develop a three-dimensional numerical groundwater model to quantify groundwater impacts due to construction and throughout the operations phase. This groundwater assessment will form a component of the EIS.

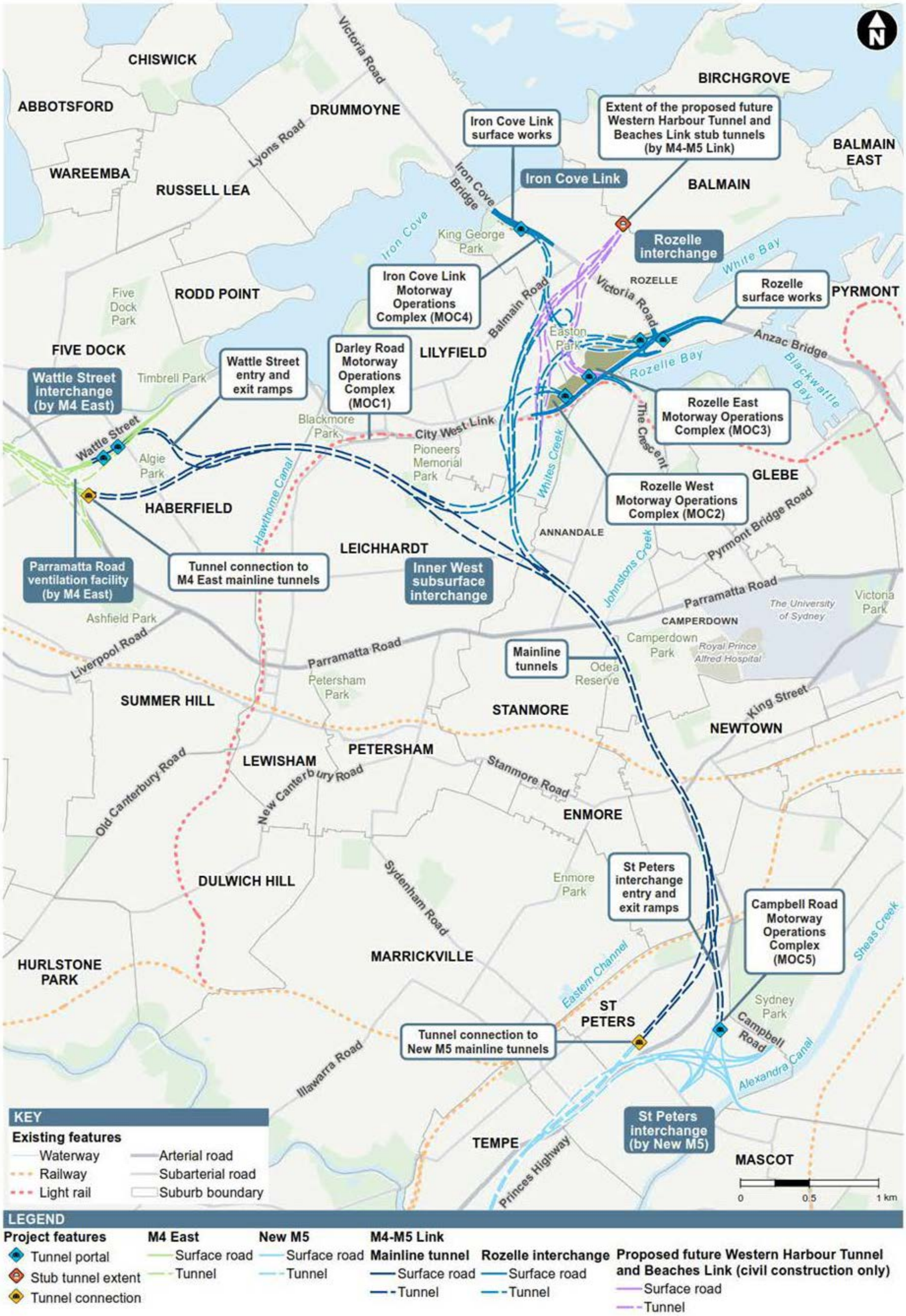


Figure 1-1 Project location

1.1 SCOPE OF WORK

The key tasks for this groundwater modelling assessment are:

1. Review of literature and data, as well as of tunnel design.
2. Analysis of data, namely geology, groundwater levels, groundwater recharge, permeability and porosity parameters, and any groundwater inflow data from existing tunnel projects in combination with AECOM.
3. Construction of a groundwater model (e.g. geology/layers, recharge, permeability, tunnels, boundary conditions).
4. Calibration of this model under steady state and transient conditions to historical groundwater levels and potentially considering any available groundwater inflow data from nearby tunnels.
5. Run a 'null' run to determine baseline conditions (as per Barnett *et al*., 2012) and predictive scenarios (2) to predict groundwater inflow into the tunnel during construction and long-term operations for both the project and the cumulative WCX program of works.
6. Predict the groundwater drawdown around the tunnel due to groundwater inflow to the tunnel during construction and long-term operations.
7. Predict the impacts (groundwater drawdown and water quality) to nearby registered groundwater users and groundwater dependant ecosystems, in accordance with the Aquifer Interference Policy and other requirements.
8. Predict impacts to groundwater quality due to salt water intrusion.
9. Preparation of a groundwater modelling report outlining the model development, assumptions, calibration and predictions in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012).

Groundwater modelling has been conducted in accordance with the *Australian Groundwater Modelling Guidelines* (Barnett *et al.*, 2012) as well as the *MDBC Groundwater Flow Modelling Guideline* (MDBC 2001). Analysis and assessment has been carried out with consideration of the following groundwater-related technical and policy guidelines:

- NSW Aquifer Interference Policy (Department of Primary Industries Office of Water), September 2012;
- NSW Guidelines for Controlled Activities on Waterfront Land (NOW, 2012);
- National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (Agriculture and Resource Management Council of Australia and Australian and New Zealand Environment and Conservation Council [ARMCANZ & ANZECC, 2000]);
- NSW State Groundwater Policy Framework Document (NSW Department of Land and Water Conservation [DLWC, 1998]);
- NSW Wetlands Policy (DECCW, 2010);
- NSW State Groundwater Quality Protection Policy (DLWC, 1998);
- NSW State Groundwater Quantity Management Policy (DLWC, undated) Draft;
- NSW Groundwater Dependent Ecosystem Policy (DLWC, 2002);
- Groundwater Modelling Guidelines, namely:
  - Murray-Darling Basin Groundwater Quality. Sampling Guidelines. Technical Report No 3 (Murray-Darling Basin Commission [MDBC, 1997]);
  - Australian National Groundwater Modelling Guidelines, published by the National Water Commission (Barnett *et al*, 2012); and
- Draft Guidelines for the Assessment & Management of Groundwater Contamination (NSW Department of Environment and Climate Change [DECC, 2007]).

1.2 GROUNDWATER MANAGEMENT AREA

The WCX project is located within the Water Sharing Plan (WSP) for the *Greater Metropolitan Region Groundwater Sources*. The relevant Groundwater Management Areas (GMAs), as defined by the DPI Water, are:

1. The Sydney Basin - Central GMA area covers the majority of the project. This is a porous hard rock aquifer.
2. Zone 2 of The Botany Sands Groundwater Source Management Zone – an alluvial and coastal sand bed aquifer occurring in a small portion of the project area near St Peters.

The locations of these GMAs are shown in **Figure 1-2** relative to the WCX program of works.

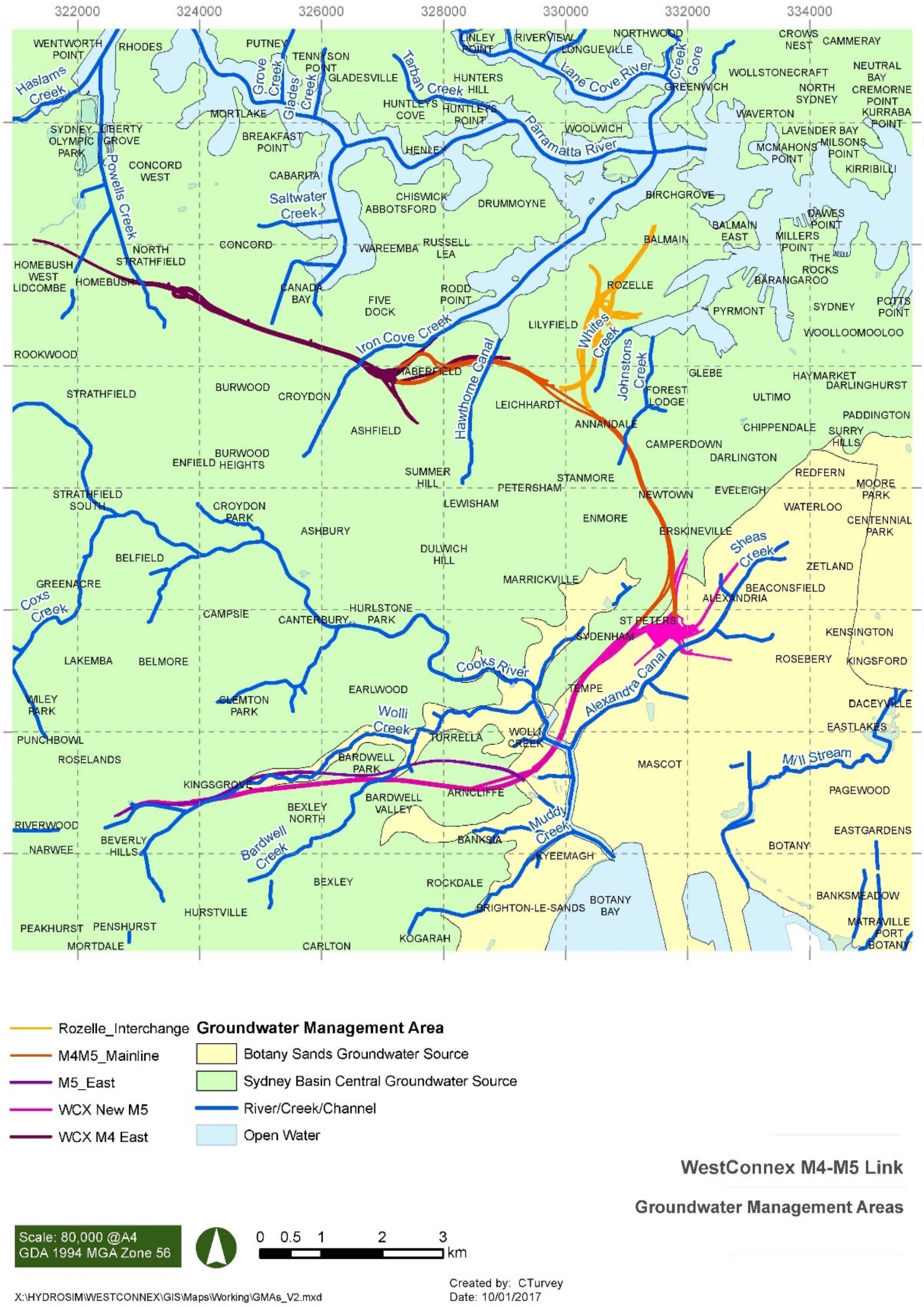


Figure 1-2 Groundwater management areas

1.2.1 GROUNDWATER PRODUCTIVITY

The *NSW Aquifer Interference Policy* (the AI Policy) (NSW Government, 2012) establishes minimal impact considerations for 'Highly Productive' and 'Less Productive' groundwater.

The Botany Sands aquifer and the land overlying it has been subject to contamination from historical unregulated industrial activity, and therefore parts of the aquifer are under embargo for certain uses. Within Zone 2 domestic bore use is banned to protect the health of users and minimise the risk of contamination spread through pumping. Industrial bores are permitted providing annual testing and reporting requirements are followed. However, there are no industrial bores registered within the project area in the Botany Sands Aquifer. Despite the contamination, DPI Water still classify this aquifer as "highly productive".

The porous hard rock units of the Sydney Basin are considered "less productive". In this area, this is because groundwater in the Ashfield Shale is generally saline and corrosive, and while groundwater in the underlying Hawkesbury Sandstone is typically of better quality and often potable, typical bore yields from the Hawkesbury Sandstone are not high enough to be considered "highly productive".

1.3 REQUIREMENTS FOR THE EIS

Requirements for the EIS are outlined in AECOM (2017) Groundwater Technical Assessment Report, to which this report is an Annexure.

2 BACKGROUND TO WESTCONNEX AND M4-M5 LINK PROJECT

The following subsections describe the background to the WestConnex program of works with specific regard for the M4-M5 Link portion.

Three terms are used frequently in the following sections and are defined as:

- **The Project** – Specific to the M4-M5 Link portion of WCX inclusive of the M4-M5 Link mainline tunnel, Rozelle Interchange and the Iron Cove Link (Figure 1-1).
- **Study area** – a 11 x 11 km area, as shown on **Figure 2-1**, and defined as such to encompass the geological and hydrological features that might be important to the M4-M5 Link project and to the numerical model built for the purpose of impact assessment for this portion of the overall WCX program of works.

2.1 WESTCONNEX PROGRAM OF WORKS

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

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

The WestConnex program of works, as well as related projects, are shown in **Figure 2-1** and described in **Table 2-1**.

Table 2-1 WestConnex and related projects

PROJECT	DESCRIPTION	STATUS
WESTCONNEX PROGRAM OF WORKS		
M4 WIDENING	Widening of the existing M4 Motorway from Parramatta to Homebush.	Planning approval under the EP&A Act granted on 21 December 2014. Open to traffic.
M4 EAST	Extension of the M4 Motorway in tunnels between Homebush and Haberfield via Concord. Includes provision for a future connection to the M4-M5 Link at the Wattle Street interchange.	Planning approval under the EP&A Act granted on 11 February 2016. Under construction.
KING GEORGES ROAD INTERCHANGE UPGRADE	Upgrade of the King Georges Road interchange between the M5 West and the M5 East at Beverly Hills, in preparation for the New M5 project.	Planning approval under the EP&A Act granted on 3 March 2015. Open to traffic.
NEW M5	Duplication of the M5 East from King Georges Road in Beverly Hills with tunnels from Kingsgrove to a new interchange at St Peters. The St Peters interchange allows for	Planning approval under the EP&A Act granted on 20 April 2016. Commonwealth approval under the *Environment Protection and*

PROJECT	DESCRIPTION	STATUS
	connections to the proposed future Sydney Gateway project and an underground connection to the M4-M5 Link. The New M5 tunnels also include provision for a future connection to the proposed future F6 Extension.	*Biodiversity Conservation Act 1999* (Commonwealth) granted on 11 July 2016. Under construction.
M4-M5 LINK (THE PROJECT)	Tunnels connecting to the M4 East at Haberfield (via the Wattle Street interchange) and the New M5 at St Peters (via the St Peters interchange), a new interchange at Rozelle and a link to Victoria Road (the Iron Cove Link). The Rozelle interchange also includes ramps and tunnels for connections to the proposed future Western Harbour Tunnel and Beaches Link project.	The subject of this EIS.
RELATED PROJECTS		
SYDNEY GATEWAY	A high-capacity connection between the St Peters interchange (under construction as part of the New M5 project) and the Sydney Airport and Port Botany precinct.	Planning underway by Roads and Maritime and subject to separate environmental assessment and approval.
WESTERN HARBOUR TUNNEL AND BEACHES LINK	The Western Harbour Tunnel component would connect to the M4-M5 Link at the Rozelle interchange, cross underneath Sydney Harbour between the Birchgrove and Waverton areas, and connect with the Warringah Freeway at North Sydney. The Beaches Link component would comprise a tunnel that would connect to the Warringah Freeway, cross underneath Middle Harbour and connect with the Burnt Bridge Creek Deviation at Balgowlah and Wakehurst Parkway at Seaforth. It would also involve the duplication of the Wakehurst Parkway between Seaforth and Frenchs Forest.	Planning underway by Roads and Maritime and subject to separate environmental assessment and approval.
F6 EXTENSION	A proposed motorway link between the New M5 at Arncliffe and the existing M1 Princes Highway at Loftus, generally along the alignment known as the F6 corridor.	Planning underway by Roads and Maritime and subject to separate environmental assessment and approval.

Figure 2-1 Overview of WestConnex and related projects and study area

2.2 M4-M5 LINK AND IRON COVE LINK

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

Key components of the project include:

- Twin motorway tunnels between the M4 East at Haberfield and the New M5 at St Peters. Each tunnel would be around 7.5 km in length and would be built to accommodate a maximum of four lanes of traffic in each direction. Each tunnel would integrate with tunnel stubs constructed underground as part of the proposed M4 East at the Wattle Street interchange and proposed New M5 at St Peters Interchange.
- A new road interchange at Rozelle at the disused Rozelle Rail Yard, to provide connections to and from the M4-M5 Link with City West Link, Victoria Road and the Anzac Bridge intersection.
- Tunnel stubs to allow for a potential future connection to the Western Harbour Tunnel and Beaches Link (an additional Sydney Harbour Tunnel road crossing) in the vicinity of the Rozelle interchange.
- Connections to the St Peters interchange (constructed as part of the proposed New M5), including the construction of the M4-M5 Link southern portal and integration works within the 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.
- New service utilities and modifications to existing service utilities.

- Modifications to the surface road network to integrate the new interchanges, including but not limited to the City West Link and Victoria Road.
- Temporary construction ancillary facilities and temporary works to facilitate the construction of the project.

The indicative construction program for the mainline tunnels and the Rozelle interchange that the groundwater model was based on is shown in **Table 2.1**. Since the modelling has been completed, there have been minor changes to program. The current indicative program shows construction of the mainline tunnels starting in Q3 2018 and finishing in Q4 2022 and the Rozelle interchange starting in Q4 2018 and finishing in Q3 2023. This change has no potential impact on the findings of the groundwater modelling report.

Table 2-2 Construction program overview

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

2.2.1 DESIGN EVOLUTION OF THE M4-M5 LINK PROJECT

The above project scenario as summarised in **Figure 1-1** and detailed in AECOM (2017) was assessed in the groundwater modelling. However, project design is an iterative process taking into consideration the results of various studies and late design alterations have been proposed including the following minor (potential) changes:

- Possible increase of around 200m of construction access tunnelling from the Parramatta Road West civil and tunnel site as part of EIS construction “Option B”, **Figure 2-2** shows the difference in location, with the blue dots (Option A) representing the situation simulated in the model and purple dots (Option B) showing the alternative configuration;
- Minor changes in the mainline tunnel design (bifurcation) to improve merging and weaving traffic movements at various locations in the tunnel including:
  - Wattle Street interchange at Haberfield
  - The Inner-West interchange at Leichhardt
  - North of the St Peters interchange.

These changes in the mainline tunnel design are shown in **Figure 2-3**, **Figure 2-4** and **Figure 2-5**.

Refer to AECOM (2017) for full detail of proposed construction sites and options. The proposed changes in design are minor and have no material impact on the findings of this groundwater modelling report.

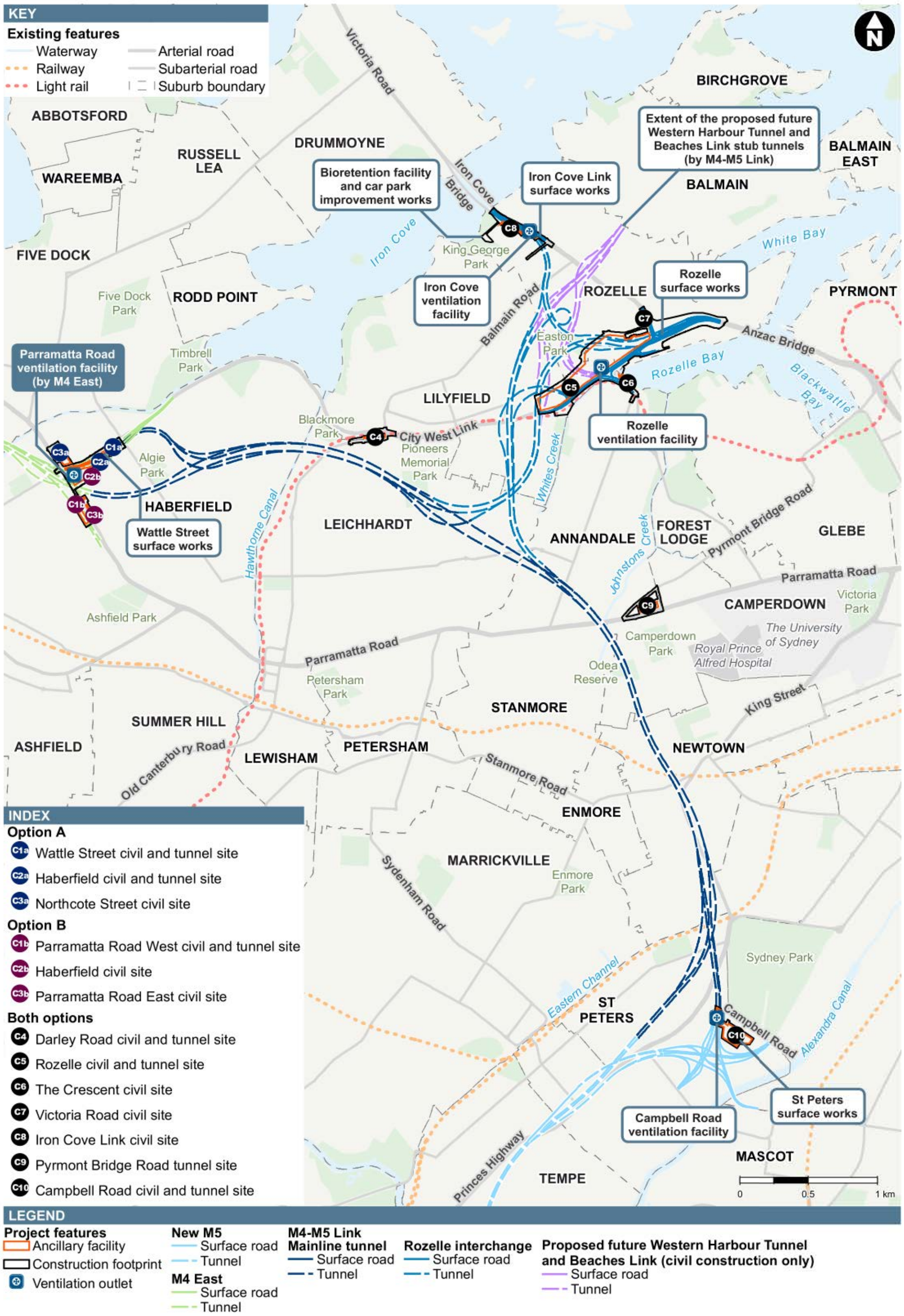


Figure 2-2 Construction ancillary facility locations

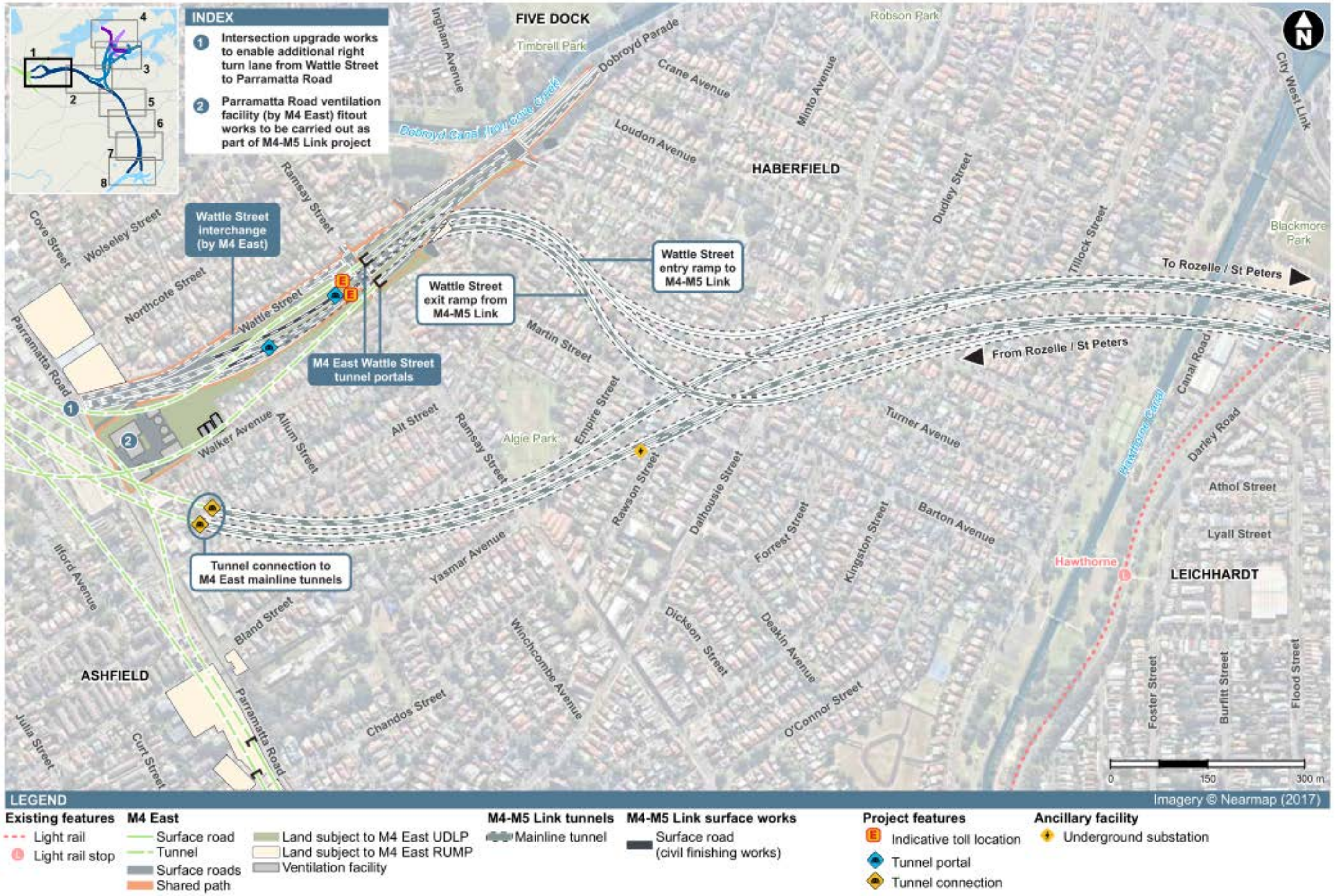


Figure 2-3 Proposed bifurcation at Haberfield

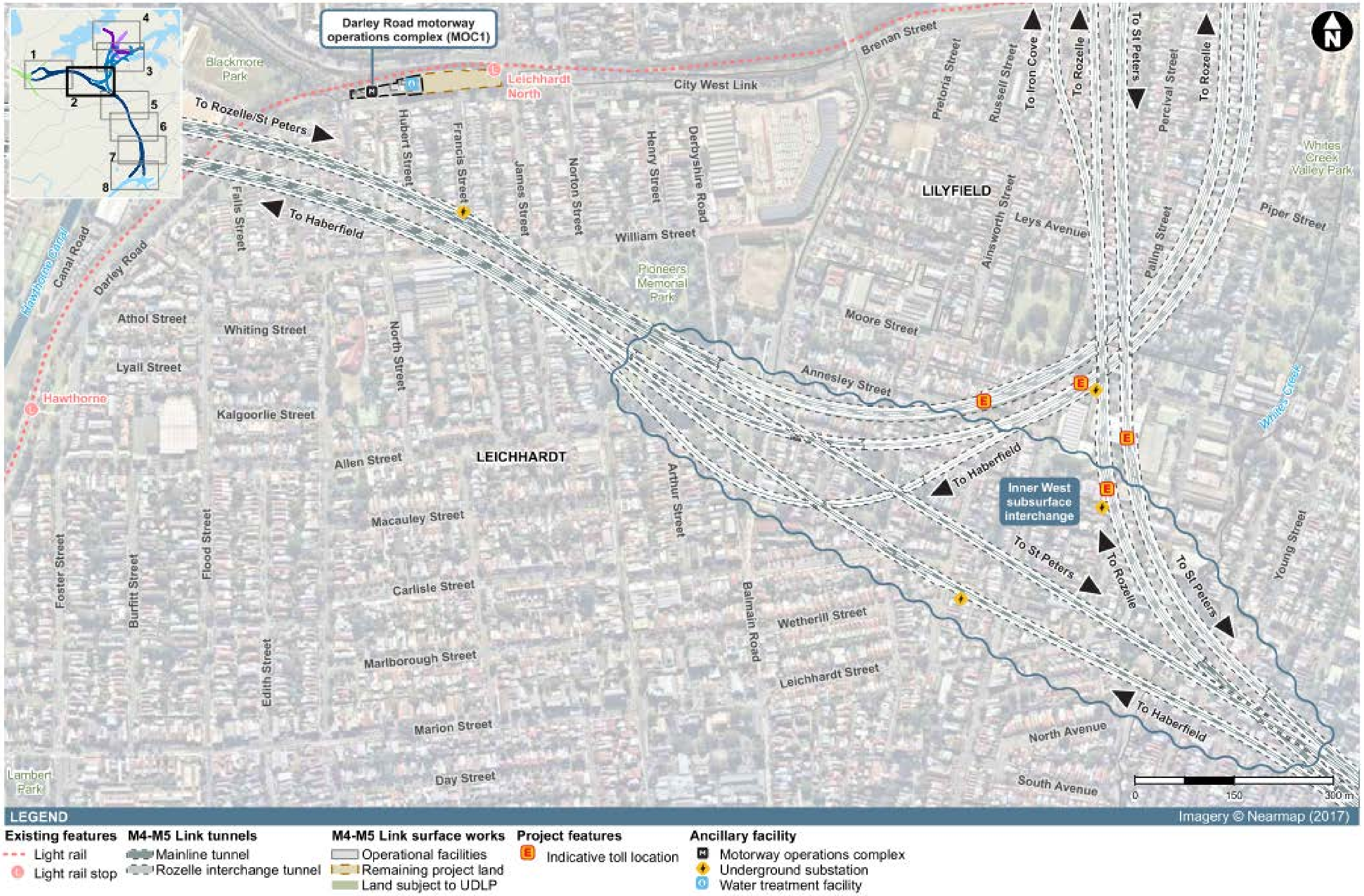


Figure 2-4 Proposed bifurcation at Leichhardt

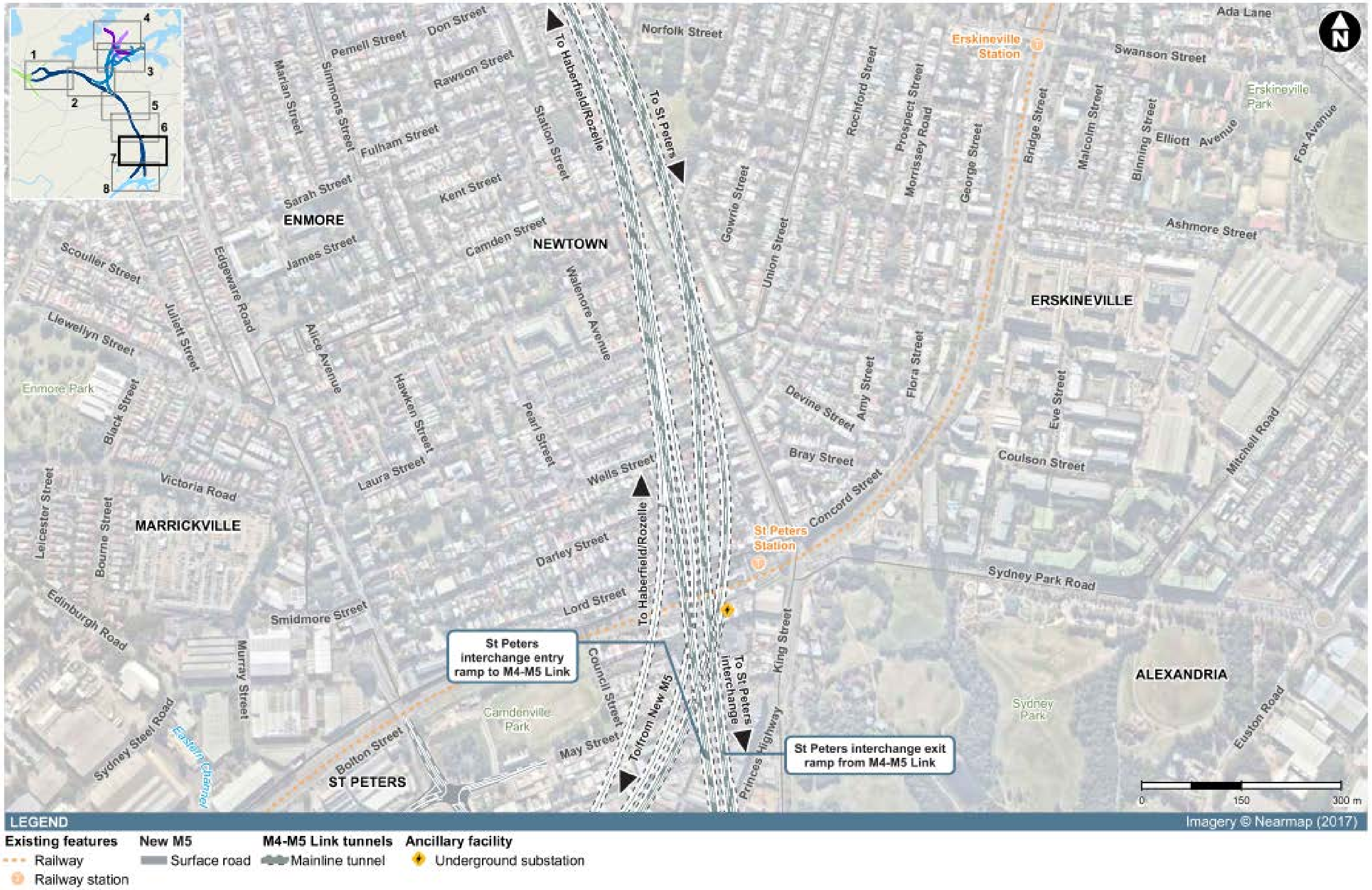


Figure 2-5 Proposed bifurcation at St Peters

2.3 M4 EAST AND NEW M5 PROJECTS

As part of this assessment it is a requirement to determine the cumulative impacts of existing infrastructure and the greater WCX project as well as determining the individual potential impacts due to this project.

The relevant components of the early stages of WCX are the tunnelling associated with the M4 East and New M5. The New M5 is located just south of the existing M5 East motorway tunnel and consists of 9 km of unlined twin tube tunnels, with the exception of a lined component where the tunnel passes beneath Cooks River. The tunnels are of variable width being constructed to accommodate up to three lanes between the western portals and Arncliffe and up to five lanes between Arncliffe and St Peters in both directions. The New M5 is planned for completion in 2019, as per **Table 2-3**. The M4 East project includes 5.5 km of unlined tunnel of up to 3 lanes width in both directions. The M4 East is planned for completion in 2019. Scheduling for M4 East is shown in **Table 2-4**.

Table 2-3 New M5 Construction program overview

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

from RMS, 2015

Table 2-4 M4 East Construction program overview

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

from WDA, 2015

Other proposed motorway and public transport projects that are yet to obtain approval include:

- Western Harbour Tunnel: linking Rozelle Interchange with tunnels beneath Sydney Harbour.
- Sydney Metro: railway connecting the north-west region to the Sydney CBD and further south to Bankstown, including 15.5 km of twin tunnels from Chatswood to Sydenham.
- Sydney Gateway: linking the New M5 at St Peters Interchange with the airport precinct and Port Botany.
- SouthLink: linking the New M5 from Arncliffe to Sutherland along the F6 motorway corridor, including twin drained tunnels.

The northern part of Sydney Metro was approved in early January 2017 but was not approved when preparing the groundwater model for this report. The twin tunnels are to be fully tanked undrained tunnels and consequently the impacts to the local hydrogeological regime after construction will be negligible as groundwater will not flow into the tunnel and consequently there will be no associated impacts due to groundwater extraction such as groundwater drawdown, settlement or saline water intrusion. The tunnels are not expected to create a groundwater barrier as the infrastructure will be constructed within the Hawkesbury Sandstone (a thick geological unit, see Section 3.2.6) allowing groundwater to flow around the tunnels. Since there are to be no significant groundwater impacts caused by the Sydney Metro it was not considered necessary to include the alignment in the model.

As the designs for Sydney Gateway, SouthLink and Western Harbour Tunnel are not yet available they are not simulated by the groundwater model. It is expected that as each of these projects proceeds through the approvals process the cumulative impacts with WCX will be included within their respective EISs.

The methodology for assessing these cumulative impacts is discussed in the Groundwater Modelling (Section 4).

3 HYDROGEOLOGICAL CONCEPTUAL MODEL

3.1 TOPOGRAPHY

Topography within the study area has been defined based on 1 m contour interval LIDAR information. The M4-M5 Link project area can be divided into five main catchment areas (**Figure 3-1**). These are the Iron Cove catchment to the west, Alexandra Canal catchment to the east, Eastern Channel catchment to the south, Rozelle catchment at the centre and White Bay catchment at the north. The New M5 project lies within the Cooks River Catchment to the south-west, and the M4 East project within the Parramatta River Catchment to the north-west. Topographical highs of up to 50 mAHD (Australian Height Datum) form a topographic dived across the centre of the study area (running from approximately Ashbury to Darlington), as well as at the south-west corner of the study area (Earlwood), and topographical lows of around 0 mAHD within the Botany Bay precinct and along major waterways (**Figure 3-2**).

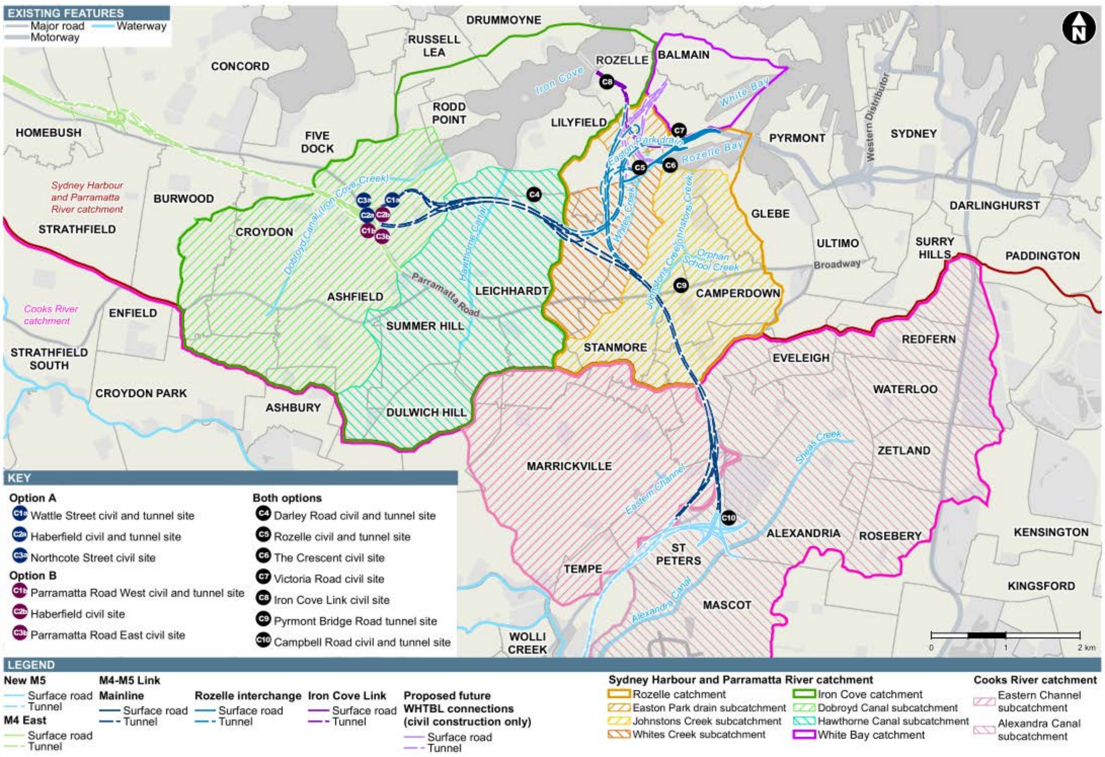


Figure 3-1 Surface water catchment areas

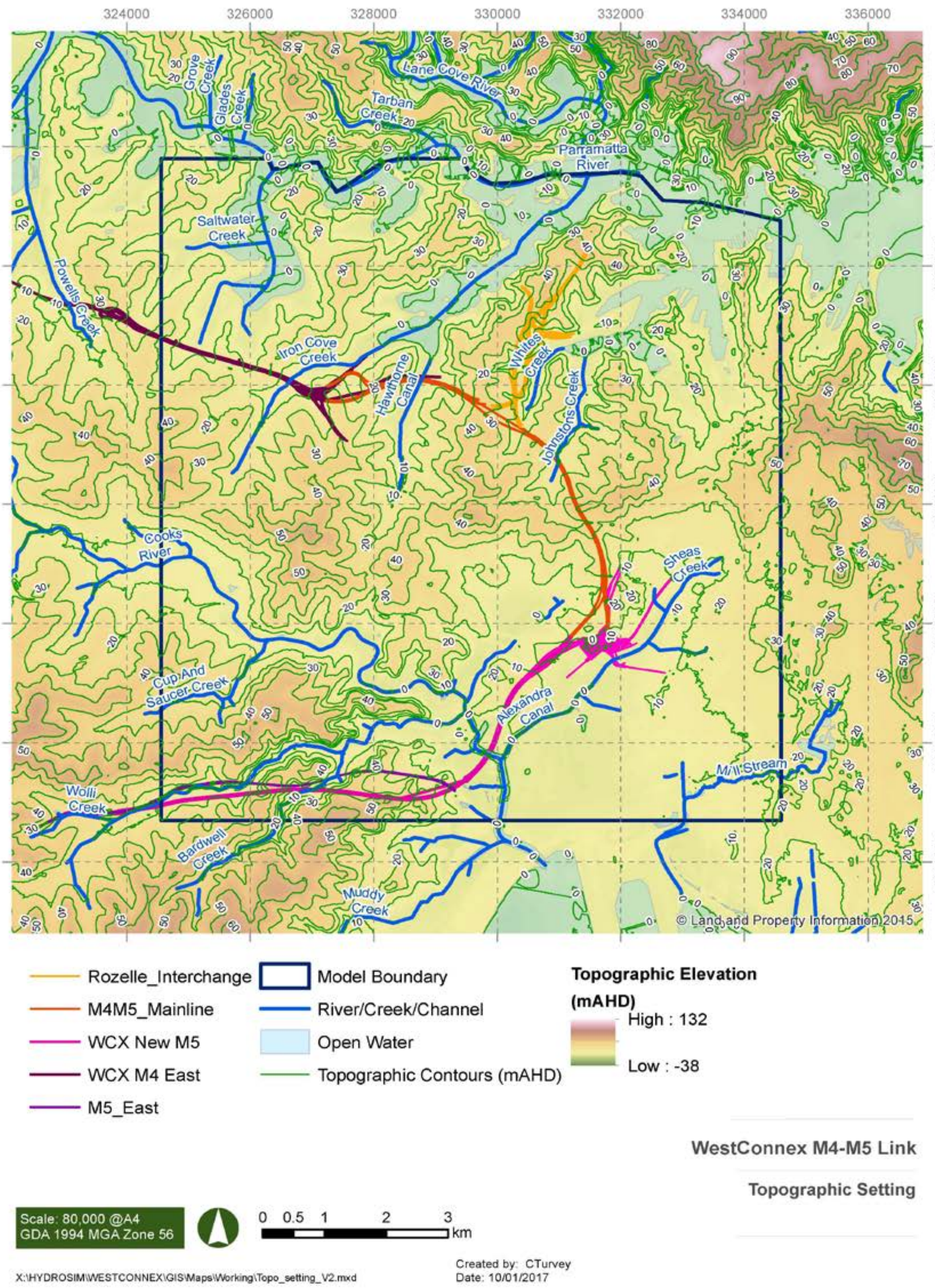


Figure 3-2 Topographic setting

3.2 GEOLOGY

The Project is situated within the Permo-Triassic Sydney Basin. The Sydney Basin is a regional foreland basin comprising sub-horizontal layered clastic sedimentary successions of mostly sandstone and shale, with some interbedded coal seams and localised igneous volcanic rocks and dykes (Och *et al*., 2009). To the east of the main tunnel alignment is the Botany Basin, which comprises sediment eroded from the Triassic basement and is centred at Botany Bay (Hatley, 2004).

The stratigraphy of the project area is summarised in **Table 3-1**. The outcrop geology is shown in **Figure 3-3**.

Table 3-1 Stratigraphy

Age	Stratigraphic Unit	Description
Quaternary	Fill	Waste material and engineered fill
	Botany Sands	Aeolian sand and clay
	Estuarine and alluvial sediments	Interbedded sands and clay
	Marine Sediments	Clayey sediments with sand lenses
Jurassic	Volcanics	Dykes
Triassic	Wianamatta Group – Bringely Shale, Ashfield Shale	Shale sometimes weathered to clay
	Mittagong Formation	Interlaminated siltstone and sandstone
	Hawkesbury Sandstone	Fine to coarse quartz sandstone with minor shale lenses

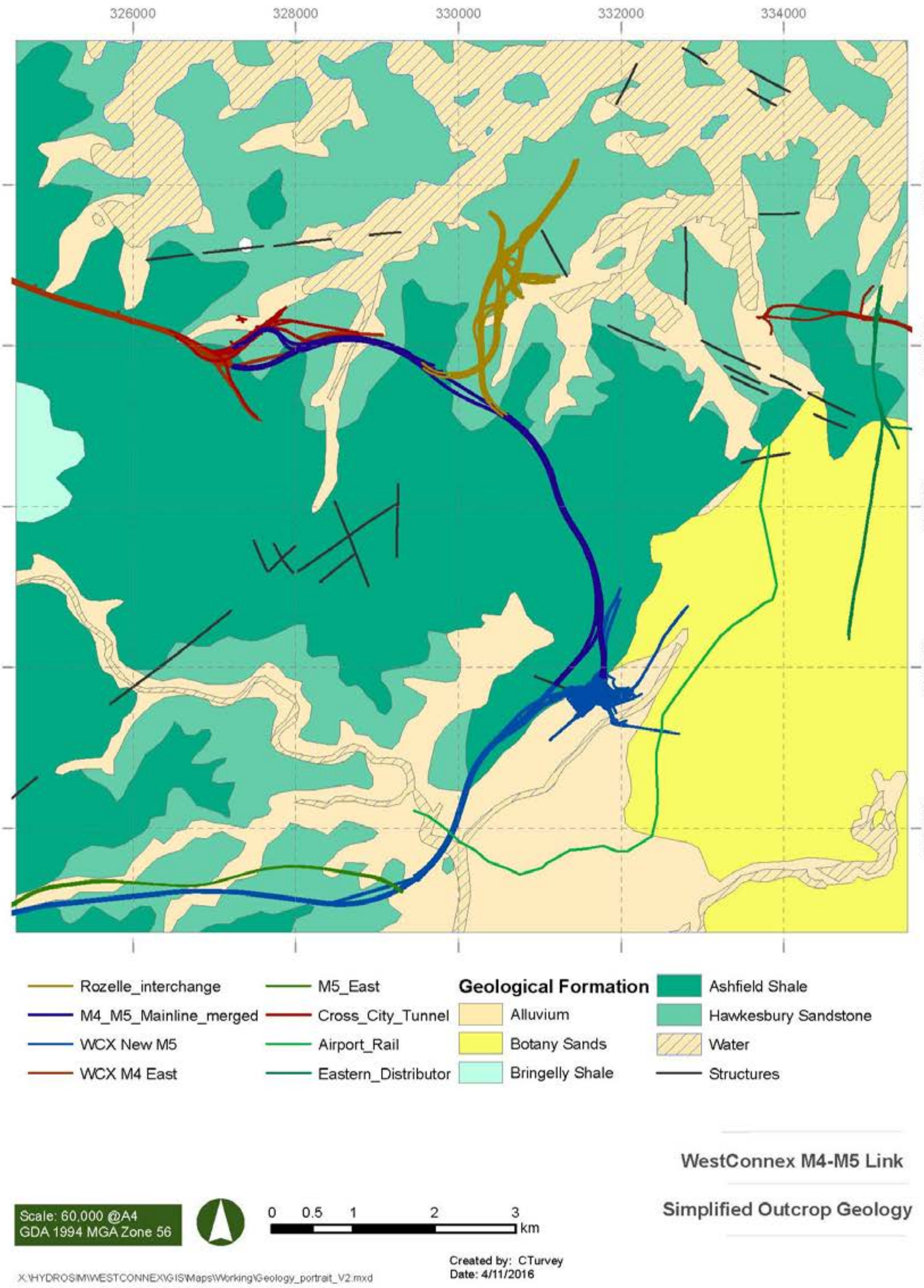


Figure 3-3 Simplified outcrop geology

3.2.1 FILL MATERIALS

Fill material is extensive across the project area due to the urban environment in which it is situated. The fill is highly variable ranging from well compacted engineered fill to unconsolidated waste. Substantial filling has occurred along low lying areas such as reclamation works associated with the perimeter of Rozelle Bay and Iron Cove, Rozelle Rail Yards, Hawthorne Canal and Alexandra Canal, Tempe, and St Peters Brick Pit Fill materials typically consist of local dredged material and imported rubble and waste. The most substantial fill deposits occur at the Alexandria Landfill which has been infilled with uncompacted fill to depths of 35 to 40 m.

3.2.2 ALLUVIUM

Alluvial sediments consisting of sand, silt, clay and gravel are found along the major creeks and gullies within the study area. Paleochannels up to 28 m thick, associated with the alluvium are found beneath Hawthorne Canal, Whites Creek and Johnstons Creek underlying the Rozelle Rail Yards to the south of the proposed Rozelle interchange (AECOM, 2017).

3.2.3 BOTANY SANDS

The Botany Sands overlie the Ashfield Shale and Hawkesbury Sandstone at the south east of the study area and underlie part of the St Peters Interchange. The Botany Sands consist of unconsolidated clayey sand, silty sand, muds with occasional gravel (Hatley, 2004).

3.2.4 WIANAMATTA GROUP

The Wianamatta Group of sedimentary rocks consists of the Bringelly Shale, Minchinbury Sandstone and Ashfield Shale, of which the Ashfield Shale is the only member intercepted by the project at the southern part of the alignment at St Peters and Alexandria. The Ashfield Shale is a laminated fine grained sequence of clay, silt and sand that was deposited in a marine environment and has undergone minor deformation. Where the Ashfield Shale outcrops at the surface it has a typical weathering profile of 3 m to 10 m consisting of stiff to hard clay of medium to high plasticity (AECOM, 2017).

3.2.5 MITTAGONG FORMATION

The Mittagong Formation is a transitional unit between the Ashfield Shale and Hawkesbury Sandstone, containing an interbedded sequence of silty sandstone and shales. The Mittagong Shale rarely outcrops within the study area and for the purposes of this project has been included within the Ashfield Shale.

3.2.6 HAWKESBURY SANDSTONE

The Hawkesbury Sandstone extends across the entire Sydney Basin and is therefore present across the whole study area. The Hawkesbury Sandstone is a fluvial sequence up to 290 m thick and contains massive fine to medium grained sandstones, cross-bedded sandstone and sandstone interlaminated with siltstone. Jointing and fracturing are common in the Hawkesbury Sandstone, predominantly where it is at or close to the surface.

3.3 CLIMATE

3.3.1 RAINFALL

The nearest long-term Bureau of Meteorology (BoM) climate stations to the Project are Sydney Airport AMO (station 066037), with records going back to 1929, and Sydney Observatory (station 066062) with records going back to 1858.

Rainfall records show a long-term average annual rainfall of 1087 mm at Sydney Airport AMO and 1226 mm at Sydney Observatory (**Table 3-2**). Average monthly rain records (**Table 3-2**) show that the highest rainfall occurs in June and the lowest in September, with the first six months of the year (January to June) typically having higher rainfall than the latter six months (July to December).

Table 3-2 Average monthly rainfall [mm]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Sydney Airport AMO	95.9	111.1	115.8	108.9	97.6	124.3	70.2	77.4	60.3	70.3	81.5	74.0	1087.3
Sydney Observatory	111.2	122.4	133.0	119.9	108.4	143.0	77.7	86.8	66.1	79.9	94.4	82.7	1225.6

Data period 1929-2016

Information on long-term rainfall trends is provided by the Residual Mass Curve (RMC). This curve is generated by aggregating the residuals between actual monthly rainfall and long-term average rainfall for each month. The procedure is essentially a low-pass filter operation which suppresses the natural spikes in rainfall and enhances the long-term trends.

Given the usually slow response of groundwater levels to rainfall inputs, the RMC can be expected to correlate well with groundwater hydrographs over the long term. The groundwater levels recorded during periods of rising RMC are expected to rise while those recorded during periods of declining RMC are expected to decline.

The RMC plot using rainfall data from the Sydney Airport AMO and Sydney Observatory stations since 1929 (**Figure 3-4**) shows that the long-term trend in rainfall comprises a long period of lower than average rainfall between during 1936-1950. This was followed by a sustained period of mostly above average rainfall until the early 1990s, with short-lived droughts interspersed, including 1980-83. The 'Millennium Drought' (1997-2011), which affected much of South-eastern Australia, shows a strong signature in the record. Rainfall levels approach average to slightly above average conditions from 2012.

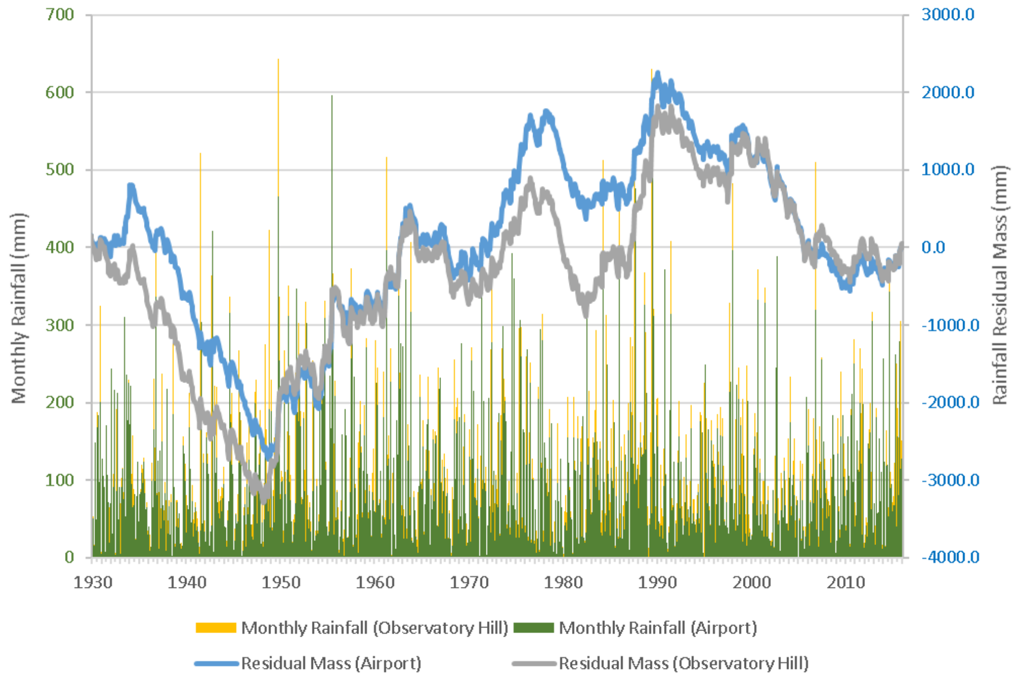


Figure 3-4 Rainfall residual mass

3.3.2 EVAPORATION

Potential evaporation (PE) for the region is approximately 1220 mm/a, while actual evapotranspiration (AE) for the region is up to approximately 620 mm/a (BoM, 2009)[1] (**Table 3-3**).

Table 3-3 Summary of evaporation data [mm]

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANNUAL
Potential ET	181	134	122	78	51	38	40	55	80	127	153	162	1221
Actual ET	109	78	66	32	20	22	21	17	23	62	85	88	623

The derived average pattern of PE is compared against rainfall in **Figure 3-5**. This shows that there is a rainfall deficit (i.e. PE is higher than rainfall) from September to March, and a rainfall surplus April to August. Actual evapotranspiration only exceeds rainfall November through January.

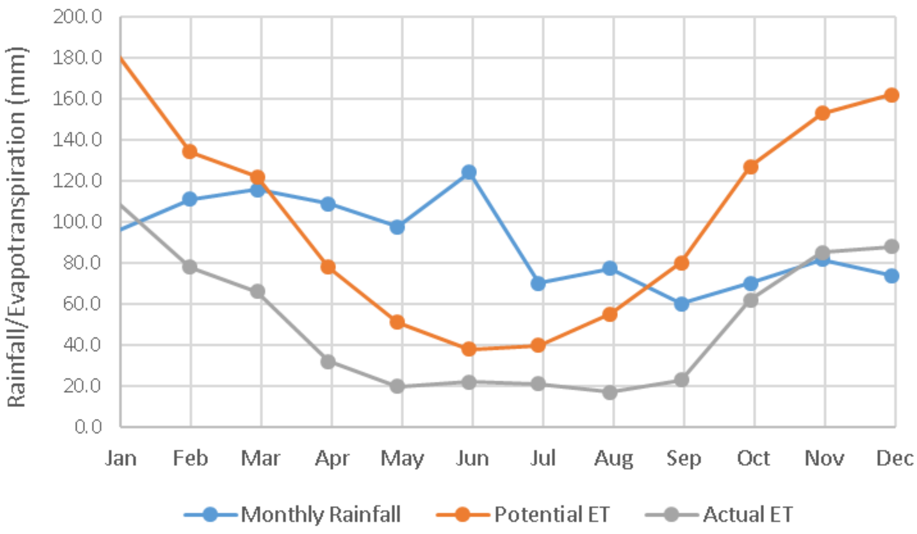


Figure 3-5 Monthly rainfall vs potential and actual evapotranspiration

3.4 SURFACE WATER

The major watercourses in the project area are the creeks and infilled creeks that drain into Sydney Harbour and the various coves and bays in Sydney Harbour.

To the north, major tributaries Johnstons Creek and Whites Creek drain to Rozelle Bay. Iron Cove Creek and Hawthorne Canal discharge into Iron Cove. To the south Alexandra Canal drains into Cooks River. (**Figure 3-2**). The majority of these watercourses have been modified to improve drainage during urbanisation, and most rivers are now in fact concrete lined channels along much of their length.

[1] These regional PE and Actual Evapotranspiration (AE) values have been obtained from the BoM map viewer. AE is the evapotranspiration that takes place under current water supply or rainfall conditions, calculated or averaged over a large area so as to remove local variation. See http://www.bom.gov.au/jsp/ncc/climate_averages/evaporation/index.jsp.

3.5 LAND USE

The project area is situated to the south-west of Sydney CBD and consists largely of highly urbanised developments such as low to medium density housing, commercial and industrial precincts, and scattered parklands and recreational areas. AECOM (2017) provides a detailed description of the major uses of the land adjacent to the project.

3.6 GROUNDWATER DEPENDENT ECOSYSTEMS

The NSW State Groundwater Dependent Ecosystems Policy (DLWC, 2002) describes the five broad types of groundwater systems in NSW, each with associated dependent ecosystems as follows:

- **Deep Alluvial Groundwater Systems** – occurring under floodplains of major rivers west of the Great Dividing Range (e.g. Namoi, Macquarie, Lachlan, Murrumbidgee and Murray alluvium).
- **Shallow Alluvial Groundwater Systems** – coastal rivers and higher reaches west of the Great Dividing Range (e.g. Hunter, Peel and Cudgegong alluvium, and beds and lateral bars of the lower Macleay, Bellinger and Nambucca Rivers).
- **Fractured Rock Groundwater Systems** – outcropping and sub-cropping rocks containing a mixture of fractures, joints, bedding planes and faults that contain and submit small and occasionally large amounts of groundwater (e.g. Alstonville Basalt, Molong Limestone and the Young Granite).
- **Sedimentary Rock Groundwater Systems** – sedimentary rock aquifers including sandstone, shale and coal (e.g. Great Artesian Basin, Sydney Basin and Clarence Moreton Basin).
- **Coastal Sand Bed Groundwater Systems** – significant sand beds along the coast of NSW (e.g. Botany and Tomago sand beds).

There are no high priority GDEs listed within the Greater Metropolitan WSP within the project area. The closest high priority GDE is Lachlan Swamp which is located within the Botany Sands approximately 5 km east from the easternmost point of the WCX work and falls outside of the project study area. It is most unlikely that this location would be affected by construction of the WCX tunnels.

A review of the BoM GDE Atlas[2] and relevant legislation and other literature has been conducted. Inspection of the BoM GDE Atlas indicated that there are 24 potential GDEs which access groundwater in the subsurface (i.e. 'terrestrial GDEs'). Of these, 6 are identified as having high potential for groundwater interaction, 7 have moderate potential and 11 have low potential (**Table 3-4**). All are in the southern area of the study area near Wolli Creek, Bardwell Creek and Mill Stream (**Figure 3-6** and **Figure 3-7**). The closest GDEs to the M4-M5 project are approximately 1.5 km from the connect at St Peters Interchange (at Wolli Creek in Turrella). Impact assessments for some of these potential GDEs were included in the New M5 EIS.

[2] http://www.bom.gov.au/water/groundwater/gde/map.shtml

Table 3-4 Potential GDEs listed in BoM GDE Atlas

BoM Identifier	Easting	Northing	Potential for GW Interaction	Location
1975350	333654	6243381	High potential for GW interaction	Mill Stream Wetlands at Lakes Golf Club
1975328	334127	6243434	High potential for GW interaction	Mill Stream Wetlands at Lakes Golf Club
1975556	334310	6243249	Low potential for GW interaction	Mill Stream Wetlands at Lakes Golf Club
1975531	334310	6243249	Low potential for GW interaction	Mill Stream Wetlands at Lakes Golf Club
1975590	334310	6243249	Low potential for GW interaction	Mill Stream Wetlands at Lakes Golf Club
1974035	328775	6244399	Moderate potential for GW interaction	Wolli Creek Turrella
1974071	328750	6244408	Moderate potential for GW interaction	Wolli Creek Turrella
1974062	328733	6244428	Low potential for GW interaction	Wolli Creek Turrella
1974150	328408	6244329	High potential for GW interaction	Wolli Creek Turrella
1974138	328161	6244308	Low potential for GW interaction	Wolli Creek Turrella
1974223	328060	6244267	High potential for GW interaction	Wolli Creek Turrella
1974416	327802	6243997	High potential for GW interaction	Wolli Creek Turrella
1974540	327676	6243933	High potential for GW interaction	Wolli Creek Turrella
1974116	328030	6244369	Low potential for GW interaction	Wolli Creek Turrella
1974462	327575	6244046	Low potential for GW interaction	Wolli Creek Turrella
1974496	327536	6244028	Low potential for GW interaction	Wolli Creek Turrella
1975211	327216	6243370	Moderate potential for GW interaction	Bardwell Valley Golf Club
1975149	327071	6243393	Low potential for GW interaction	Bardwell Valley Golf Club
1975262	326892	6243328	Moderate potential for GW interaction	Bardwell Valley Golf Club
1975237	326680	6243362	Moderate potential for GW interaction	Bardwell Valley Golf Club
1975206	326646	6243374	Low potential for GW interaction	Bardwell Valley Golf Club
1975273	326612	6243342	Low potential for GW interaction	Bardwell Valley Golf Club
1975433	326286	6243194	Moderate potential for GW interaction	Bardwell Valley Stotts Reserve
1975481	326111	6243151	Moderate potential for GW interaction	Bardwell Valley Stotts Reserve

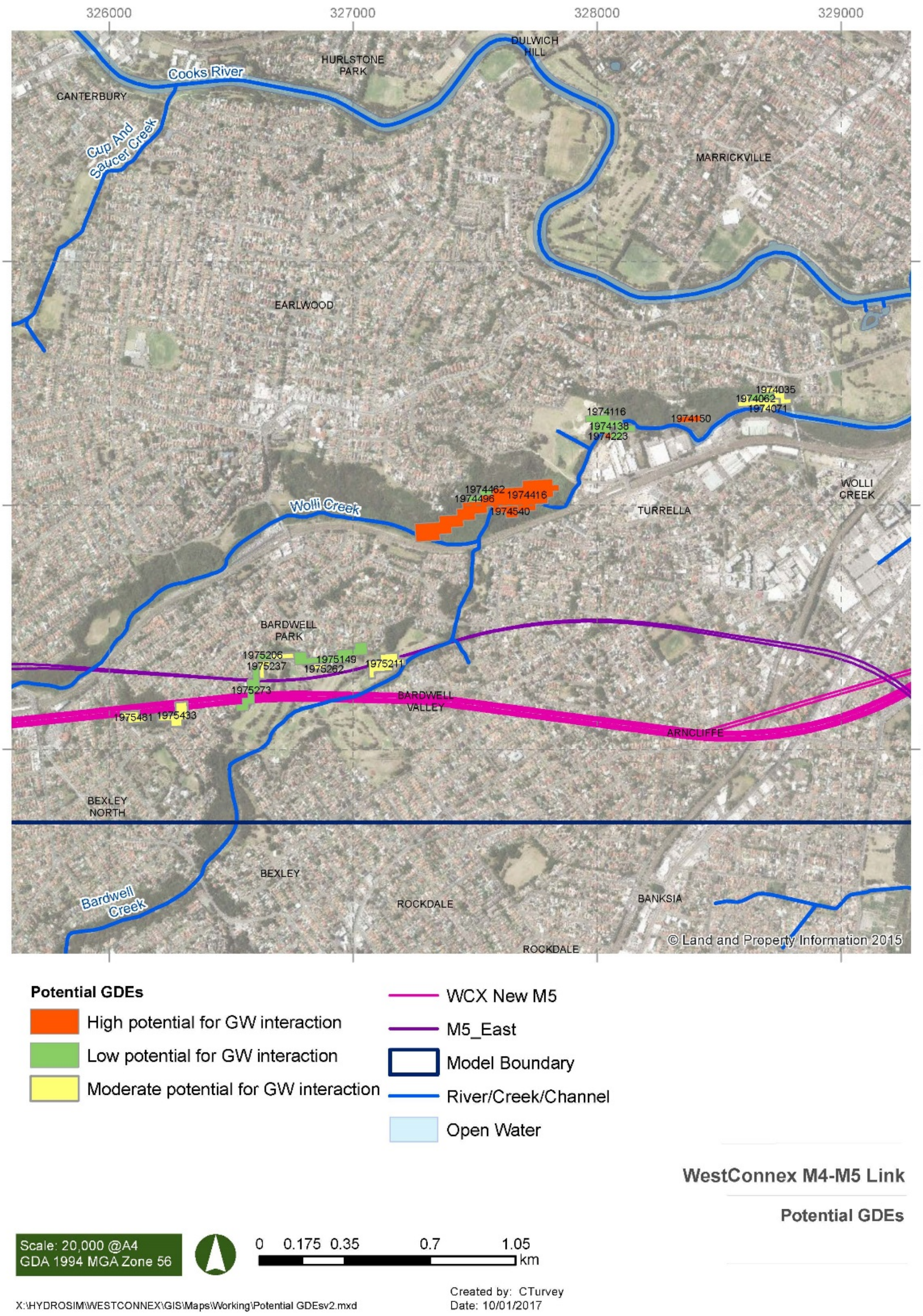


Figure 3-6 Potential GDEs at Bardwell Valley

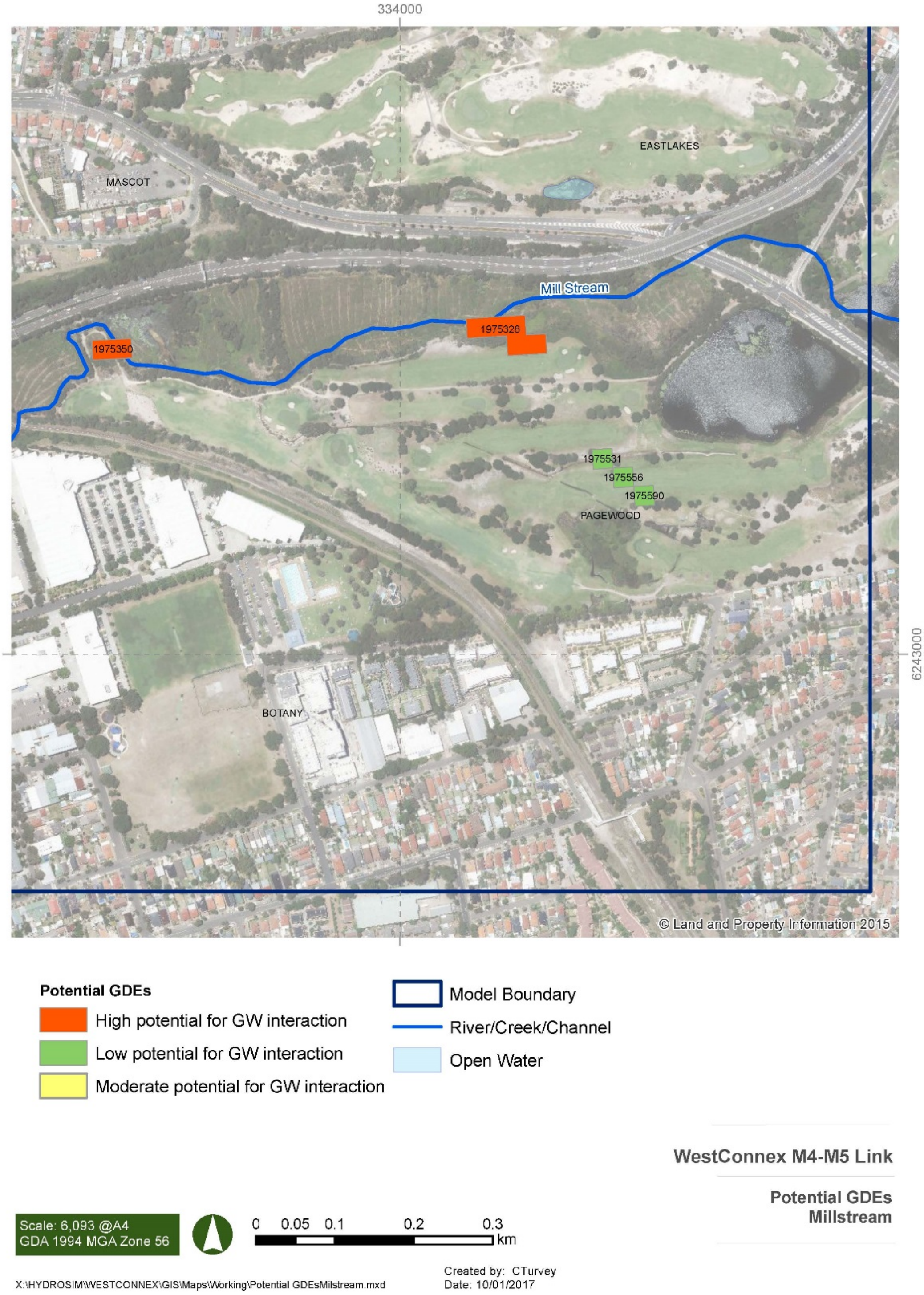


Figure 3-7 Potential GDEs at Mill Stream

3.7 HYDROGEOLOGY

3.7.1 ANTHROPOGENIC GROUNDWATER USE

Based on data received from BoM's National Groundwater Information System (NGIS) and the DPI(Water) Pinneena groundwater database in September 2016, there are 398 registered groundwater works within the study area (11x11 km), mostly shallow bores located within Botany Sands or from alluvial aquifers. The numbers of bores and their registered uses are summarised in **Table 3-5**. The majority of bores are shallow monitoring bores assumed to be constructed for the purposes of investigation/monitoring of contamination, particularly within the Botany Sands. As noted in Section 1.2.1, abstraction of groundwater from much of the Botany Sands for domestic use is no longer allowed due to the risk of spreading contamination, therefore many of these bores will no longer be operational.

Table 3-5 Registered groundwater bores in Pinneena and the NGIS

Purpose	Number	Min Depth (m)	Max Depth (m)
Domestic	81	0	210
Water Supply	27	2.1	13.2
Industrial	31	0	148
Recreation	18	0	186
Unknown	12	0	90
Monitoring	226	0	40
Exploration	1	18.2	18.2
Drinking	2	3.5	15

3.7.2 GROUNDWATER LEVELS

A review of groundwater levels from both WCX monitoring bores and other data sources, including bores registered on the NGIS database has been conducted. The majority of historical data from the NGIS registered bores is limited to notes on levels and salinity records taken at the time of drilling or installation.

Groundwater monitoring along the M4-M5 Link project alignment commenced in June 2016, with boreholes being added to the monitoring network as drilling investigation continues. The monitoring network constructed by AECOM consists of 58 monitoring bores constructed to depths between 6 and 73 m as shown in **Figure 3-8.** The majority of monitoring bores were constructed in the Hawkesbury Sandstone but are also screened in the Ashfield Shale and alluvium. At some locations dual monitoring bores were installed to screen the alluvium and underlying Hawkesbury Sandstone. Monitoring bores are equipped with automatic data loggers, and are manually dipped on a monthly basis.

Groundwater level monitoring for the first two stages of WCX (M4 East and New M5) began in early 2015 and available data has been included in the model dataset. Some sporadic water level data is available from these and other tunnel infrastructure projects. NGIS boreholes with ongoing monitoring records are restricted to the Botany Sands.

The water level records available across the study area show that water table elevation tends to mimic topography, with the water-table closely reflecting topography within the surficial unconsolidated layers and showing more of a subdued reflection of topography within the consolidated Triassic units (**Figure 3-9**). A detailed discussion of the spatial water levels near to the project can be found in AECOM (2017).

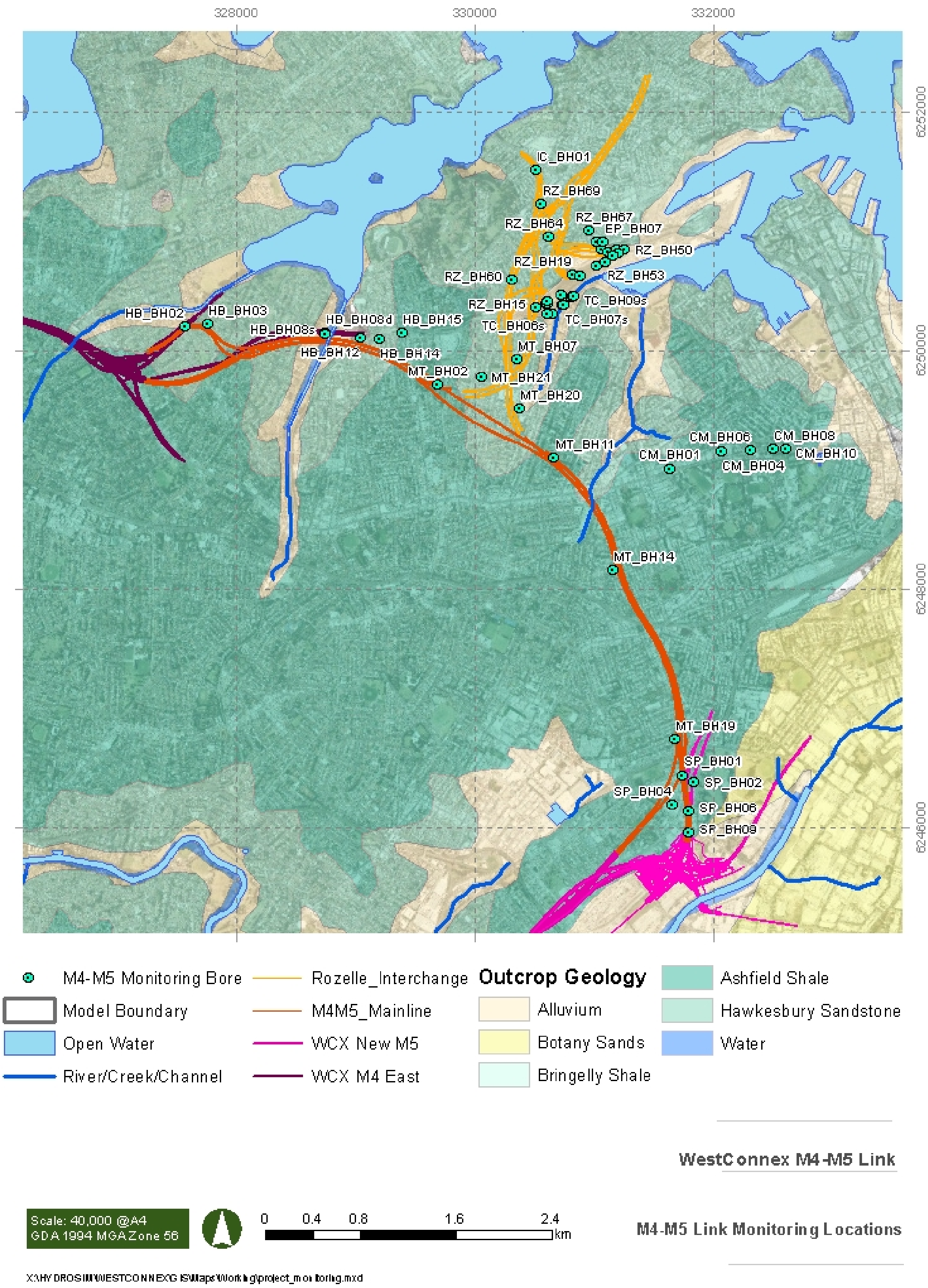


Figure 3-8 Project monitoring bore locations

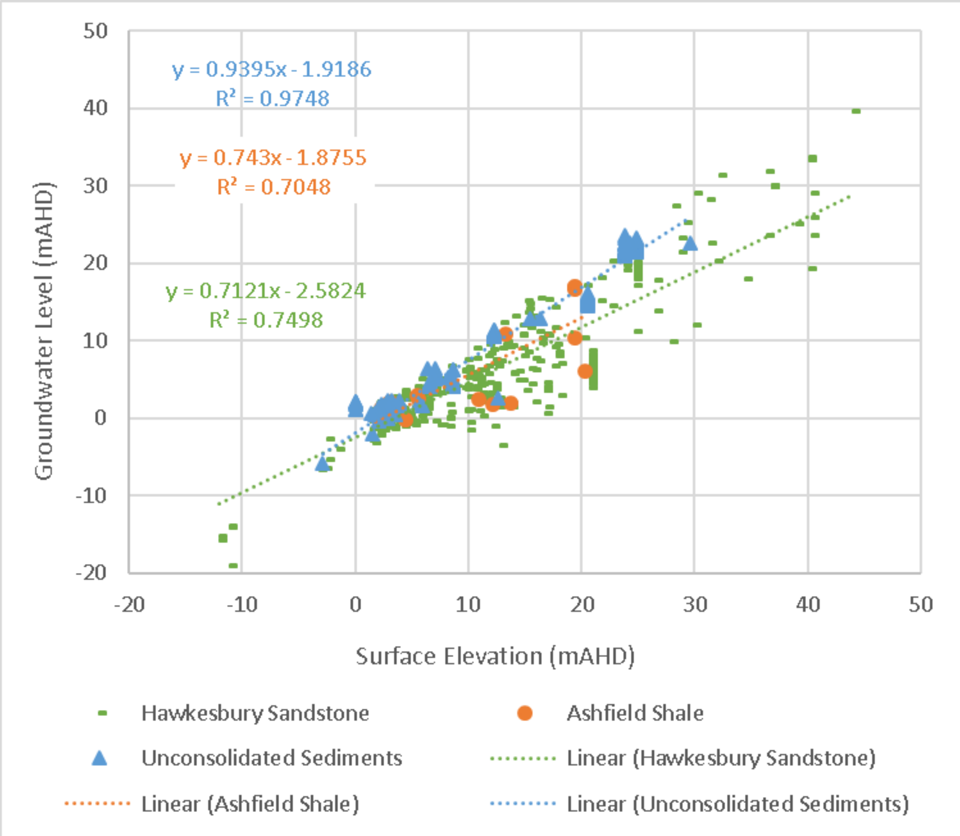


Figure 3-9 Water table relationship to topography

3.7.3 GROUNDWATER HYDROGRAPHS

The AECOM (2017) interpretive report provides a detailed description of all water levels monitored as part of the Project. A selection of key hydrographs for each formation is discussed here. **Figure 3-10** shows the locations of the selected bore hydrographs. The following example hydrographs are from boreholes located at Rozelle and St Peters where the longest records are available. Additional hydrographs for the other monitoring bore locations are shown in AECOM (2017).

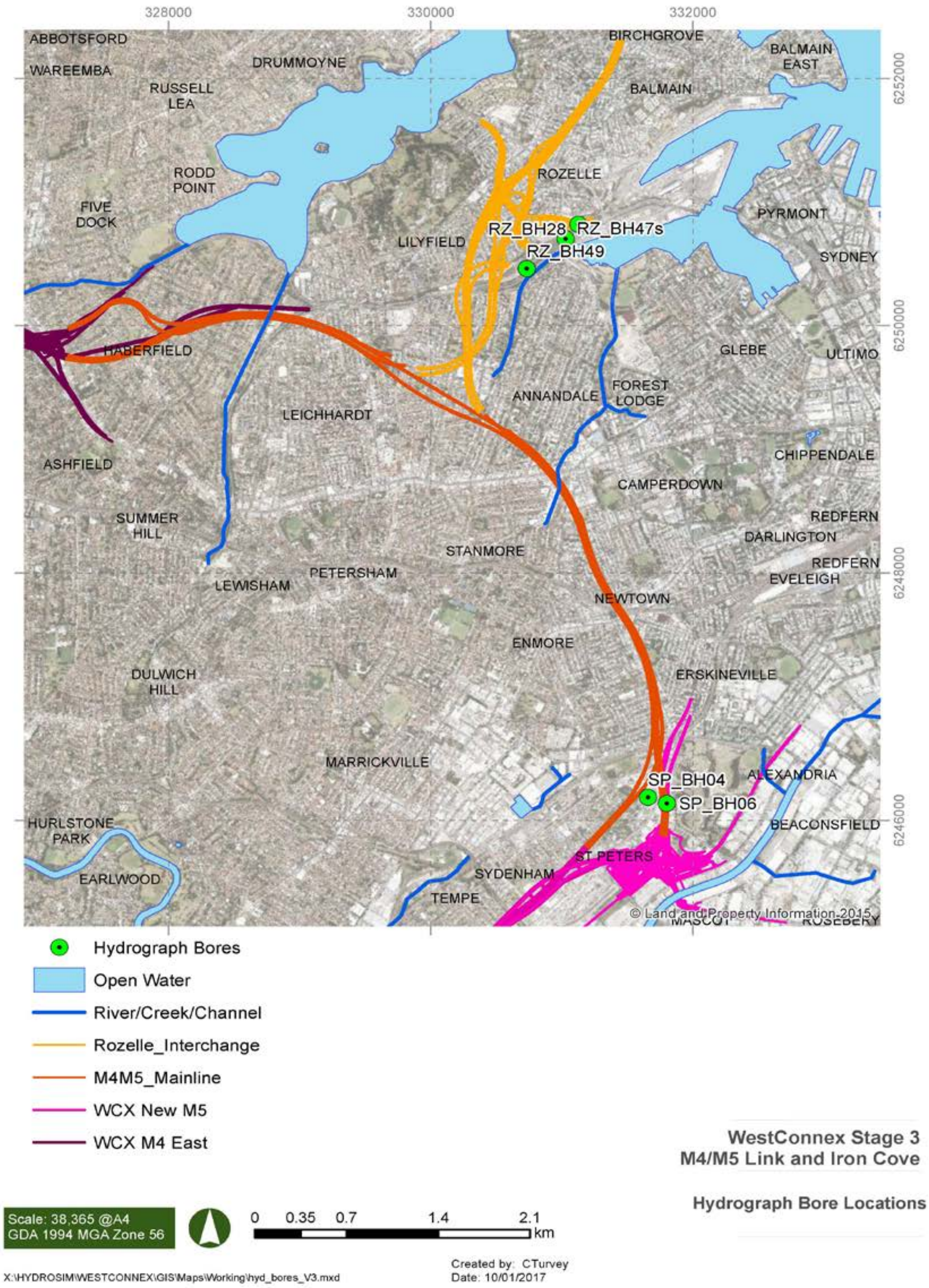


Figure 3-10 Selected hydrograph bore locations

Alluvium

Figure 3-11 and **Figure 3-12** show alluvial hydrographs located at Rozelle for boreholes RZ_BH49 and RZ_BH47s respectively. The daily rainfall and Rainfall Residual Mass Curve (RMC) are also plotted. Both boreholes show a gradual decline in water level with a fall of approximately 0.5 m of groundwater head over the period between August 2016 and early February 2017, which is consistent with the RMC trend. A sharp increase in water level of 0.3 m occurs after the 85 mm rainfall even on 8th February 2017, and data available to the February 15th appears to be following the RMC trend which indicates above average rainfall for the February-March 2017 period. Small oscillations in water level are likely to be associated with the tidal influence of Rozelle Bay. These oscillations tend to mask any notable change in water level due to small rainfall events, particularly in RZ_BH47s, however overall the groundwater level trend tends to follow that of the RMC.

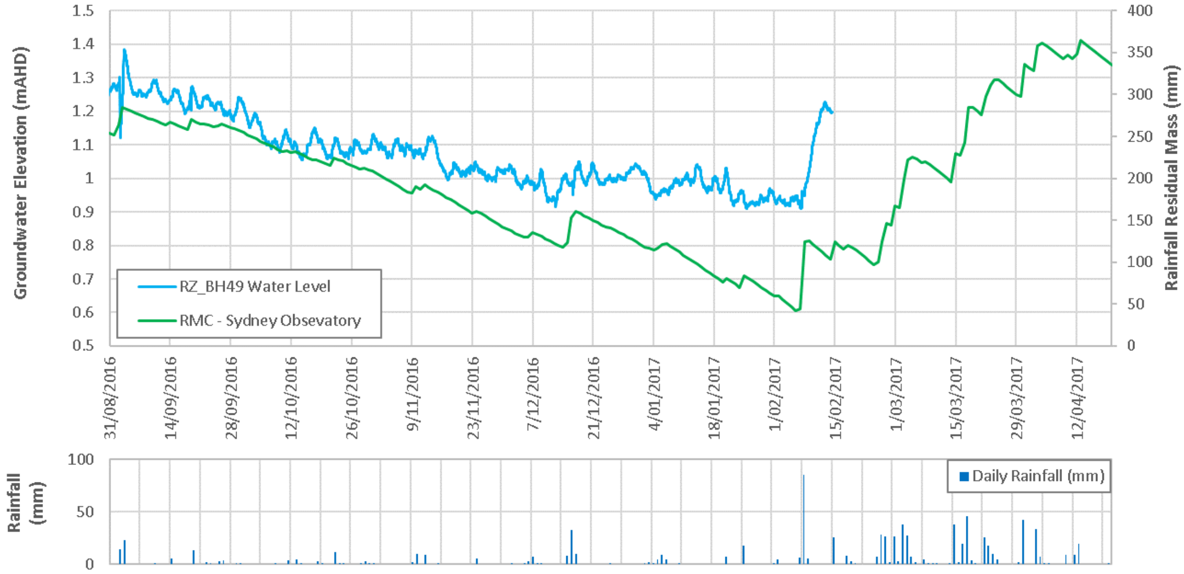


Figure 3-11 Hydrograph RZ_BH49 screened in alluvium

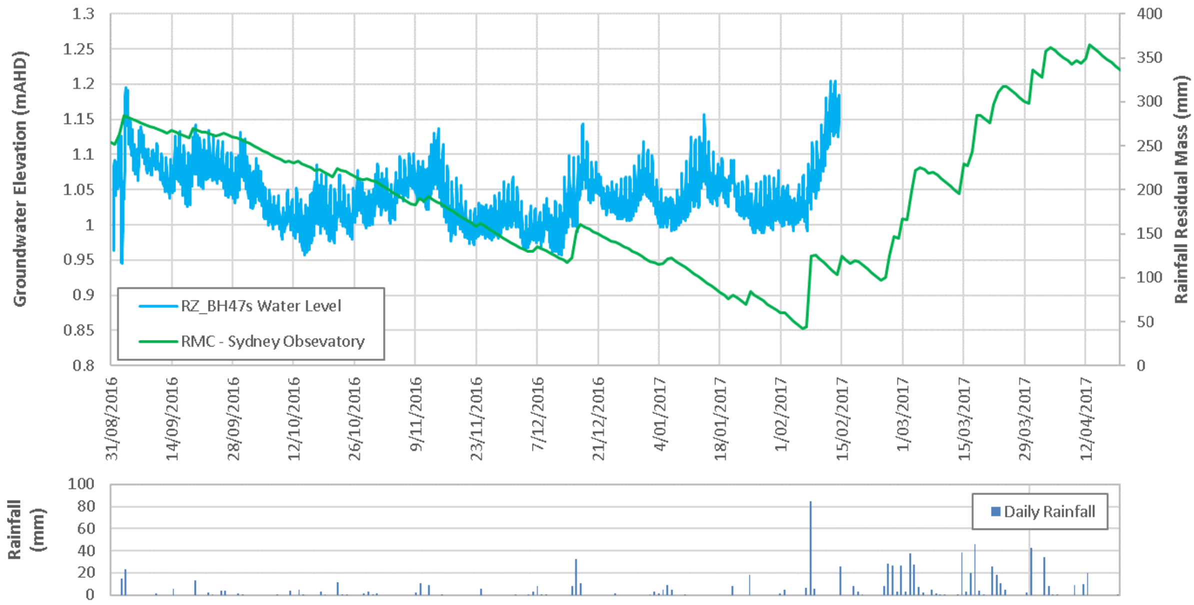


Figure 3-12 Hydrograph RZ_BH47s screened in alluvium

Ashfield Shale

Water levels in borehole SP_BH06 within Ashfield Shale at St Peters Interchange are shown in **Figure 3-13**. The Ashfield Shale water levels follow the RMC trend very closely indicating that rainfall recharge is still a significant mechanism in maintaining the hydraulic head in the shale. Similar to the alluvium, heads decline by about 0.5 m over the monitoring duration to December 2016. At the time of writing this report no data for the first quarter of 2017 was available.

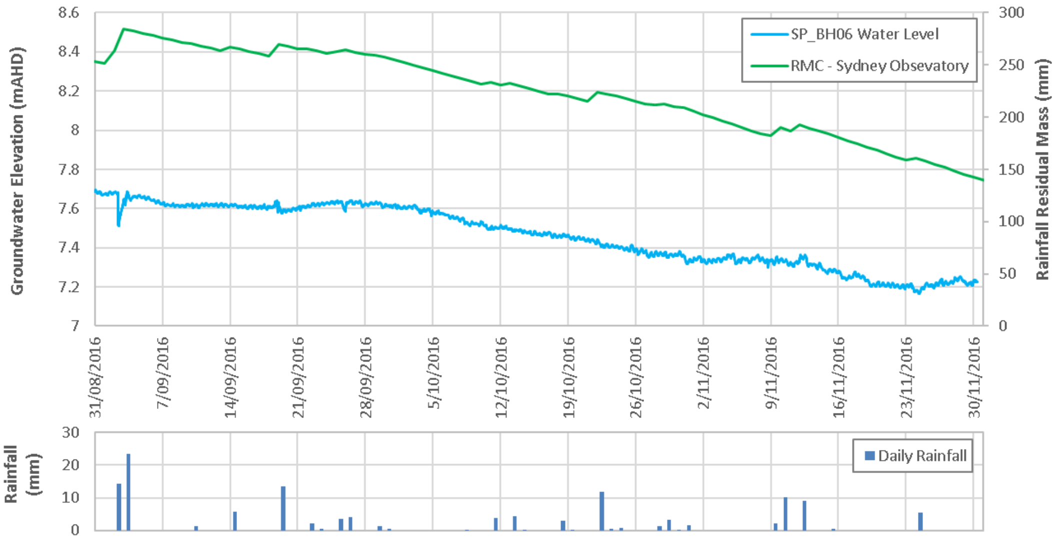


Figure 3-13 Hydrograph SP_BH06 screened in Ashfield Shale

Hawkesbury Sandstone

Boreholes RZ_BH28 and SP_BH04 are screened within the Hawkesbury Sandstone (**Figure 3-14** and **Figure 3-15**). RZ_BH28 shows the same declining trend and similar magnitude as the overlying units, with sub-daily oscillations of 0.1 m again assumed to be a tidal influence from Rozelle Bay.

Borehole SP_BH04 located at the St Peters Interchange shows a less-definitive correlation with the RMC, with water levels showing a slight recovery from mid-November 2016 due to a relaxation of stress that is not corresponding with climate trends. Water levels are drawn down again from mid-January 2017. It is not clear what is causing these changes in water level, however the levels do appear to respond to the high rainfall in February 2017 with a groundwater level trend that again appears to follow the RMC for the last period of available data. The monitoring data is also less smooth than expected, with daily variations and bi-weekly oscillations that are yet to be understood. These variations could be due to a combination of the commencement of the New M5 tunnel construction at St Peters and/or leachate pumping from the Alexandria Landfill.

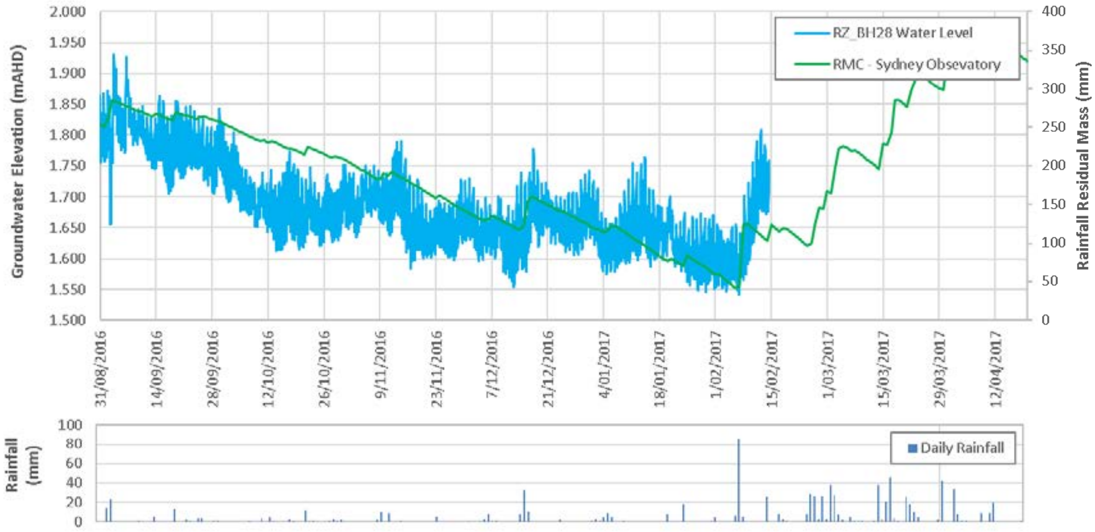


Figure 3-14 Hydrograph RZ_BH28 screened in Hawkesbury Sandstone

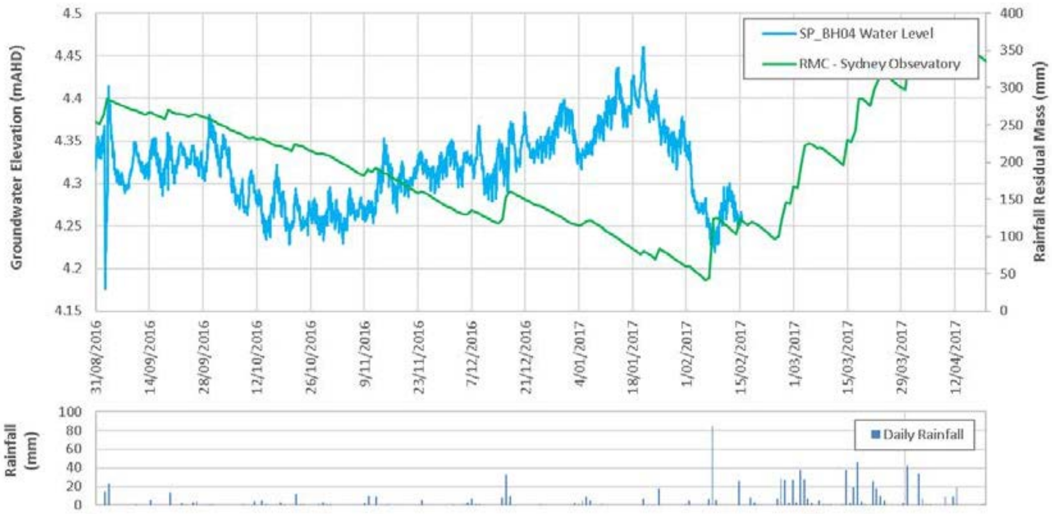


Figure 3-15 Hydrograph SP_BH04 screened in Hawkesbury Sandstone

3.7.4 HYDRAULIC PROPERTIES

Four major hydrogeologic units exist within the study area, the unconsolidated sediments of the alluvium, the Botany Sands aquifer, and the layered sedimentary sequences of the Ashfield Shale and Hawkesbury Sandstone. For the purposes of this project the Mittagong Formation is considered to be comparable in properties to the Ashfield Shale and therefore these units are grouped together. **Table 3-6** presents a summary of the hydraulic properties reported for the study area.

Table 3-6 Summary of hydraulic properties from nearby studies

	AGE	TYPE	Kh [m/d]	Kv [m/d]	Sy	Ss [m^{-1}]	SOURCE
ALLUVIUM	Quaternary	Aquifer	4.32E-1	8.64E-3			1
			5.00E-1	5.00E-2			2
			1.00E+0				3
			1.00E+0				4
			1.00E-2 to 1.00E+0	Ratio Kv:Kh 1:10 to 100	2.00E-1		6
BOTANY SANDS	Quaternary	Aquifer	8.64E-1	1.73E-2			1
			1.00E-2 to 1.00E+1	Ratio Kv:Kh 1:10 to 100	2.00E-1		6
ASHFIELD SHALE	Triassic	Leaky aquitard	8.00E-4	8.00E-4			1
			1.00E-3	1.00E-4			2
			1.08E-2				3
			1.91E-4 to 6.62E-3				4
			1.00E-4 to 1.00E-2				5
			1.00E-4 to 1.00E-2		1.00E-2	1.00E-5	6
MITTAGONG FORMATION	Triassic	Leaky aquitard	5.00E-3	Ratio Kv:Kh 1:10 to 1000			4
HAWKESBURY SANDSTONE	Triassic	Aquifer	1.00E-2	1.00E-2			1
			1.00E-2	5.00E-4			2
			1.00E-3 to 5.16E-3				3
			1.00E-3 to 5.00E-2				4
			1.00E-3 to 1.00E-1				5
			1.00E-3 to 1.00E-0	Ratio Kv:Kh 1:10 to 100	2.50E-2	5.00E-6 to 5.00E-5	6

sources: 1. Golder, 2016 M4 East model calibration (SS). 2. CDM Smith, 2016 New M5 Model calibration (SS). 3. GHD, 2015 M4 East Model Calibration (steady-state). 4. GHD, 2015 M4 East Model Calibration (transient). 5. Hewitt (2005). 6. Golder, 2016 Regional Literature Review

3.7.5 QUATERNARY ALLUVIUM

Alluvium is found along the edges of the watercourses within the study area and forms localised unconfined aquifers. As the water level is typically connected to adjacent water courses the water levels are typically shallow and strongly controlled by topography. Lower in the catchments groundwater within the alluvial aquifers is typically influenced by tidal fluctuations. Reported hydraulic conductivity values within the study area range from 0.1 m/day to 1 m/day, with vertical hydraulic conductivity being an order of magnitude or more less than horizontal due to the layered depositional sequence.

3.7.6 ASHFIELD SHALE

The Ashfield Shale is considered a regional leaky aquitard due to its low ability to transmit water through its fine-grained sequence and tight bedding planes. Groundwater flow is mostly restricted to flow through fractures and joints (secondary porosity), although the bulk hydraulic conductivity is typically low, in the order of 0.01 to 0.00001m/day.

Packer testing conducted by AECOM (2017) indicates that the horizontal hydraulic conductivity of the shale in the areas of Camperdown and St Peters typically averages close to 0.01 m/day, although a zone of higher hydraulic conductivity (up to 0.8 m/day) seems to occur at depths between 10 and 20 m below ground surface (**Figure 3-16**). This is likely due to the surficial shales being weathered to plastic clays, while the fresher material beneath the weathered zone is likely to contain a higher fracture/joint density thereby increasing the hydraulic conductivity. Testing of shale below 40 m depth has not been undertaken but it is expected that the hydraulic conductivity will continue to decrease with depth as a function of decreasing density of fracturing and tighter bedding partitions.

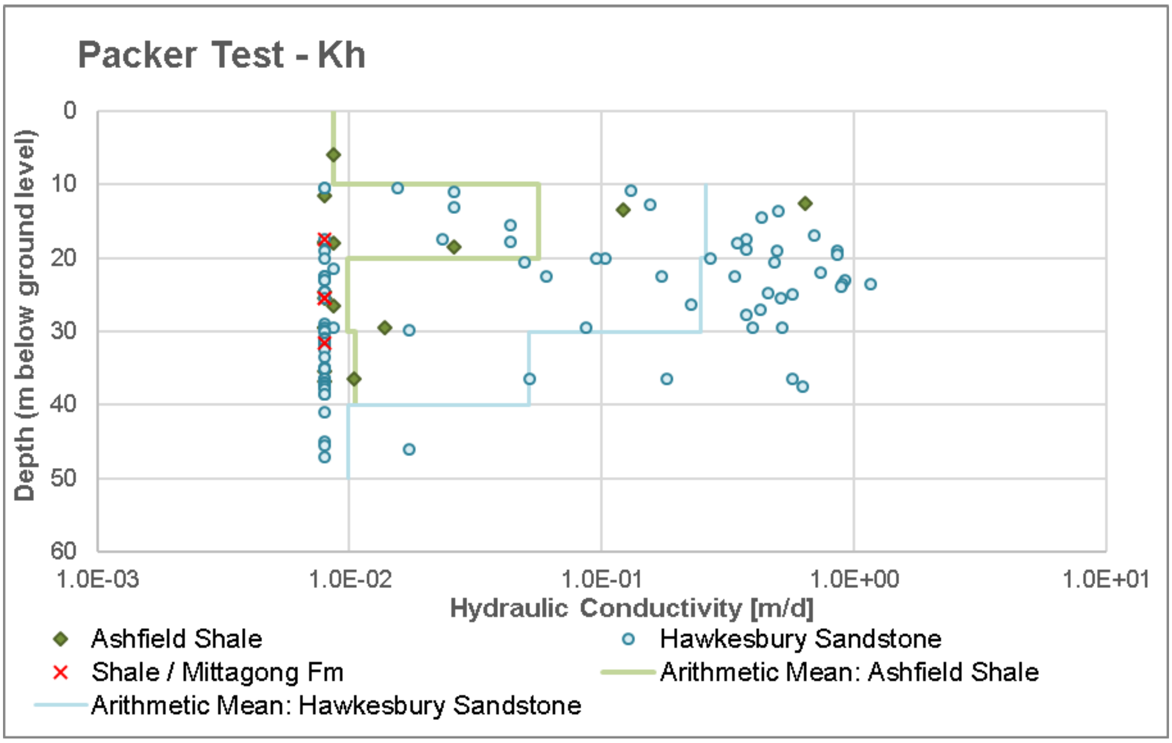


Figure 3-16 Hydraulic conductivity from packer testing along M4-M5 alignment

3.7.7 HAWKESBURY SANDSTONE

The Hawkesbury Sandstone is a dual porosity aquifer with groundwater dominantly transmitted via interconnected fracturing. The bulk hydraulic conductivity of the Hawkesbury Sandstone is typically in the order of 0.001 to 0.1 m/day (**Table 3-6**). Vertical anisotropy (K_V:K_H) is in the range of 1:10 to as low as 1:100. Extensive packer testing has been undertaken in the Hawkesbury Sandstone across the Sydney Basin. Tammetta and Hawkes (2009) have compiled the results of many of these tests (**Figure 3-17**), with the horizontal conductivities reported ranging from over 1m/day in the upper 50m to as low at 0.00003 m/day at 400 m depth. There is a clear trend of decreasing hydraulic conductivity with depth from ground surface, which is again most likely to be due to less frequent fracture spacing with depth.

Packer testing has been undertaken for the Hawkesbury Sandstone as part of the current Project (**Figure 3-16**). However, hydraulic conductivities in the Hawkesbury Sandstone are likely to be lower in several instances than has been indicated by packer testing due to the lower bounds of readings being restricted to 1 Lugeon, which is equivalent to approximately 0.009 m/day. 43% of Hawkesbury Sandstone readings returned the minimum value of "<1 Lugeon", therefore calculation of averages using this data are likely to be higher than the actual average of hydraulic conductivities. Results suggest hydraulic conductivities range between 1 m/day and 0.009 m/day (lower limit of recording). Packer testing that was undertaken for the New M5 alignment (**Figure 3-18**) appears to have been able to record lower values than that completed during the M4-M5 Link investigations, with minimum recorded values of 0.000004 m/day. The majority of test results indicate that the conductivity in the Hawkesbury Sandstone is highly variable, with most measurements within 0.00001 to 0.0001 m/day. Again a general trend of decreasing hydraulic conductivity with depth can be seen in packer test results associated with the WCX projects.

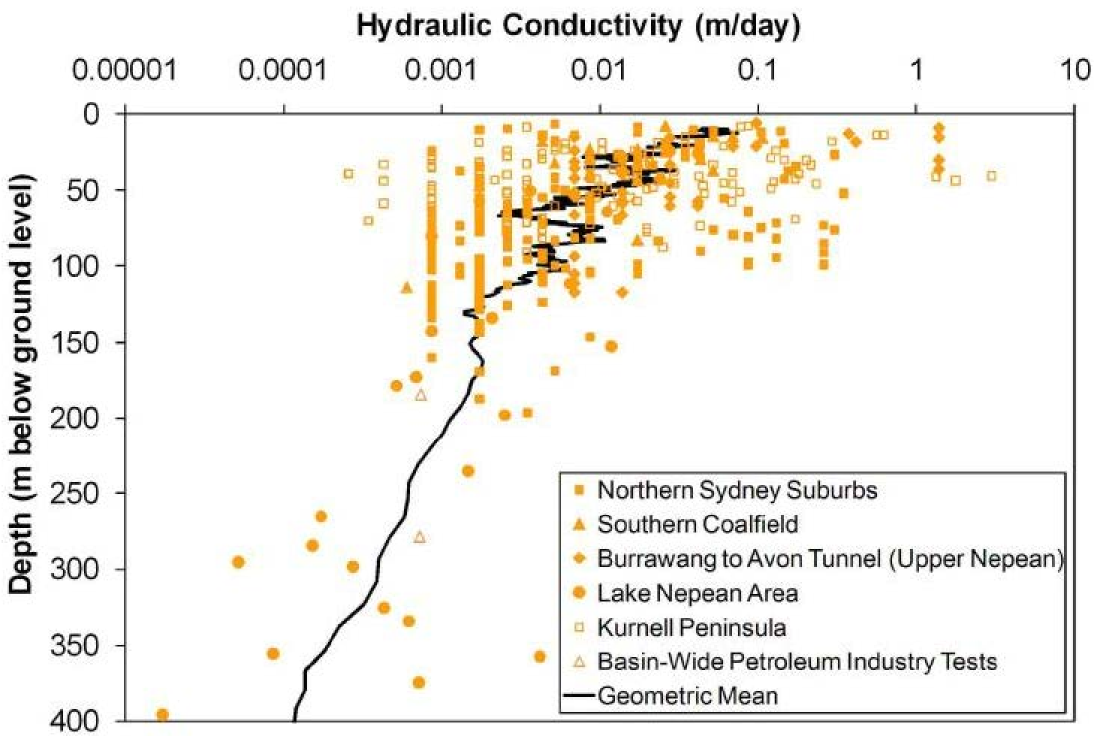


Figure 3-17 Hydraulic conductivity from packer testing of Mesozoic sandstones in Sydney Basin (Tammetta & Hawkes, 2009)

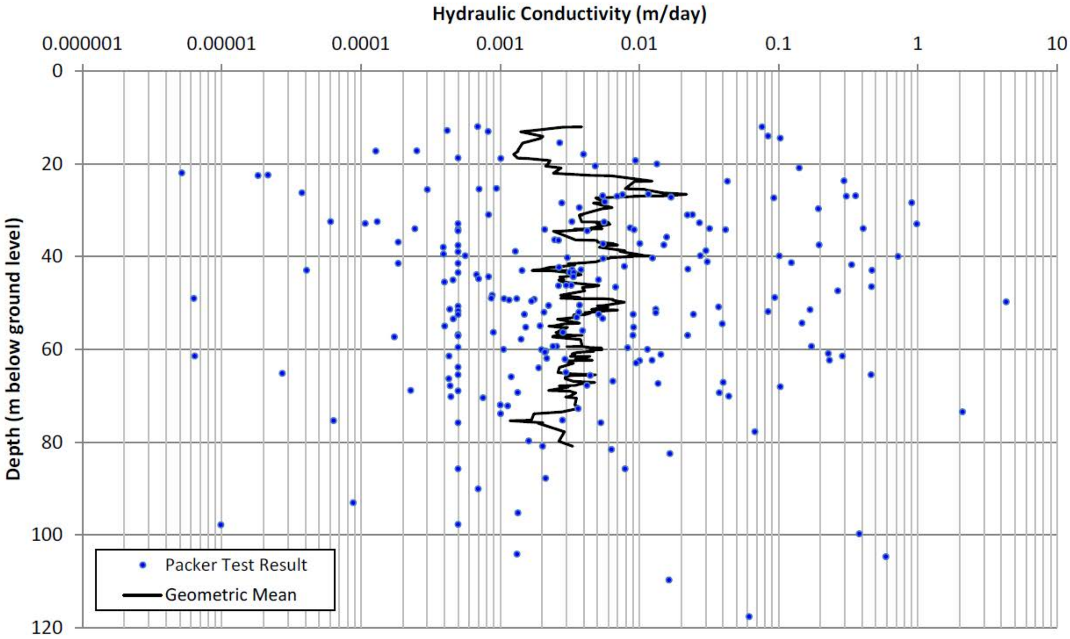


Figure 3-18 Hydraulic conductivity from packer testing along the New M5 alignment (RMS, 2015)

Studies conducted in the Sydney metropolitan area and elsewhere indicate a specific yield of between 0.01 and 0.02 (i.e. 1-2%) is reasonable for typical Hawkesbury Sandstone (Tammetta and Hewitt, 2004).

Core porosity (total) and permeability testing was undertaken for a few boreholes within the M4-M5 alignment, with results shown in **Table 3-7**. Total porosity ranges from 11 to 19% in the Hawkesbury Sandstone. Measured vertical hydraulic conductivity ranges between 0.01 m/day in the Ashfield Shale to 0.0001 m/day in the Hawkesbury Sandstone, typically decreasing with depth.

Table 3-7 M4-M5 Link core porosity and permeability testing

Monitoring	Sample Interval (m)	Lithology	Vertical Hydraulic Conductivity	Total Porosity
Well			m/day	%
EP_BH04	25.3 - 25.46	Hawkesbury Sandstone	2.76E-03	13.6
HB_BH24	18.27 - 18.45	Hawkesbury Sandstone	4.58E-03	14.1
MT_BH01	59.43 - 59.61	Hawkesbury Sandstone	5.53E-03	13.1
MT_BH07	42.38 - 42.58	Hawkesbury Sandstone	4.15E-03	11.3
MT_BH11	53.38 - 53.56	Hawkesbury Sandstone	3.80E-04	13.6
MT_BH12	46.11 - 46.25	Hawkesbury Sandstone	3.54E-03	18.7
MT_BH16	79.45 - 79.58	Hawkesbury Sandstone	1.99E-04	14.6
RZ_BH60	49.15 - 49.30	Hawkesbury Sandstone	1.21E-04	14.3
MT_BH16	39.25 - 39.43	Mudstone (Ashfield Shale)	1.30E-02	5.6

3.7.8 GROUNDWATER INFLOW TO TUNNELS

The tunnels associated with the WCX program of works are primarily designed to be free draining, under the restriction of a maximum inflow rate of 1L/sec/km during tunnel operation. Local grouting will be undertaken as necessary where high inflow features (such as conductive faults and large fractures) are intercepted during tunnel excavation. The tunnelling that passes under the Cooks River in the New M5 alignment is planned to be tanked, as are some of the tunnels that approach roads to the Rozelle Interchange in poor ground conditions near to the Whites Creek Palaeochannel in the M4-M5 Link alignment. Water cut-off walls are adopted locally in cut and cover structures across the Rozelle Rail Yard. These tanked and lined structures are assumed to be impermeable and therefore groundwater inflow will be zero **Figure 3-19**).

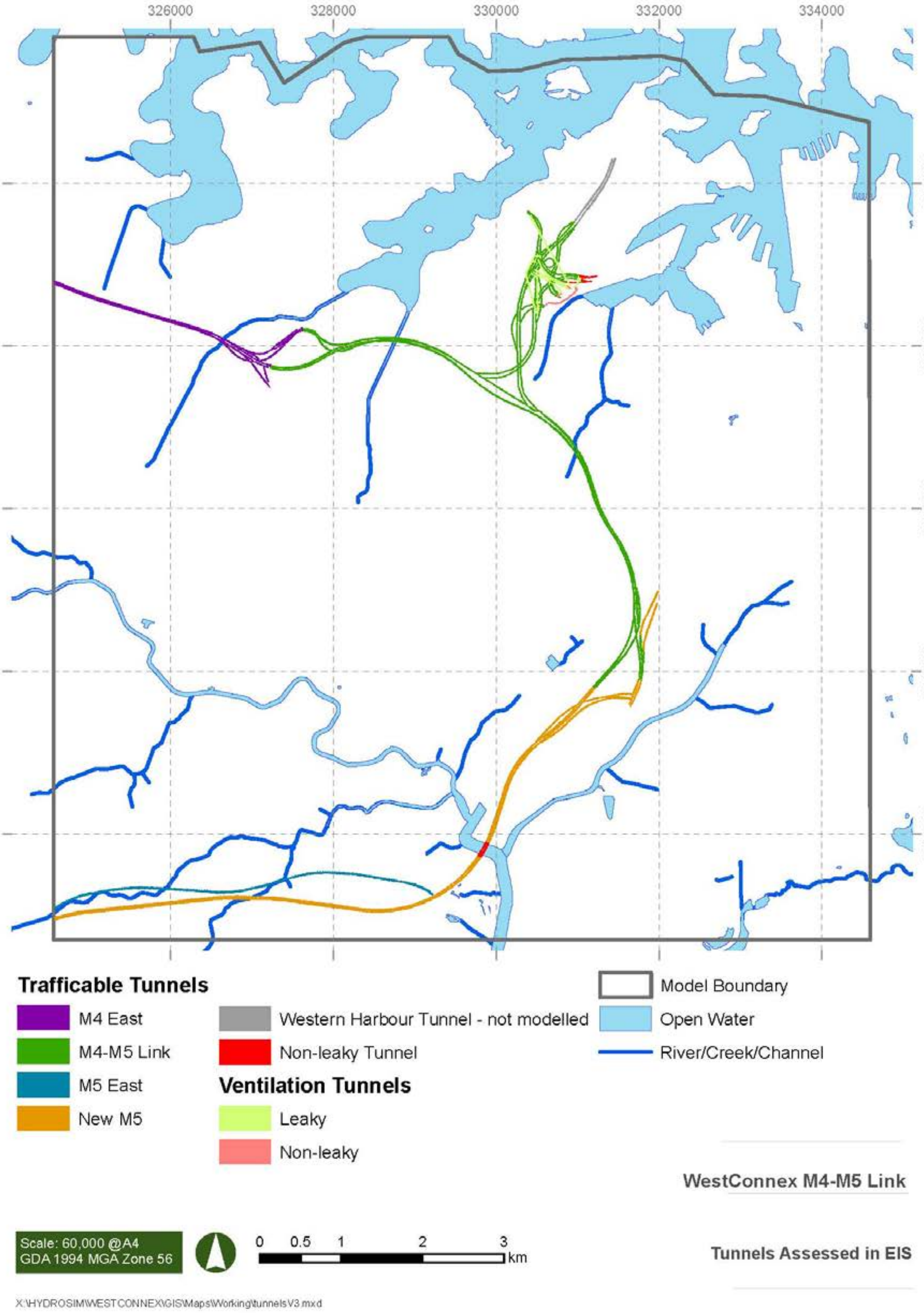


Figure 3-19 WestConnex tunnels assessed as part of the groundwater model

Hewitt (2005) has compiled a list of the long term inflow to existing tunnels in Sydney metropolitan area (**Table 3-8**). Drainage inflow rates range from 0.1L/sec/km to <3L/sec/km. The M5 East motorway is the only existing drained tunnel within the project area, having a long term inflow rate of 0.8 to 0.9 L/sec/km.

Tunnel	Type	Length (km)	Span/diameter (m)	Maximum rock cover (m)	Long-term measured inflow (L/s/km)
Northside Storage	Water	20	6	90	0.9 (10 without extensive grouting)
Epping to Chatswood	Rail	13	7.2 (twin)	60	0.9
M5 East	Road	3.9	8 (twin)	60	0.8–0.9
Eastern Distributor	Road	1.7	12 (double deck)	40	1
Hazelbrook	Water	9.5	2	50	0.1
Cross City	Road	2.1	8 (twin)	53	<3
Lane Cove	Road	3.6	9 (twin)	60	<3

Table 3-8 Long term inflow to existing tunnels (Hewitt, 2005)

Modelling for M4 East and the New M5 of WCX has been undertaken prior to this project. Modelling results from those projects predict inflow values of between 0.16 L/sec/km to 3.76 L/sec/km (recharge dependant) for the M4 East (GHD, 2015) and 0.67 L/sec/km for the New M5 (CDM Smith, 2015). The groundwater inflow design criteria for M4 East, the New M5 and NorthConnex was also set at 1L/sec/km.

3.7.9 RAINFALL RECHARGE

The Coastal porous rock aquifer recharge study by EMM (2015) completed a literature review of the reported recharge values for areas east of the NSW Great Dividing Range, with 5% mean annual rainfall being the average for the Hawkesbury Sandstone. There is limited data for the Wianamatta Formation, but it is suggested that recharge to the shales will be equal to or less than the sandstone.

Crosbie (2015) conducted a study to estimate recharge based on the chloride mass balance method in the Sydney Basin, and provided recharge estimates as follows (**Figure 3-20**):

- Botany Sands – 40 to 100% rainfall;
- Hawkesbury Sandstone – 2 to 10% rainfall;
- Wianamatta Shale – 1 to 2 % rainfall.

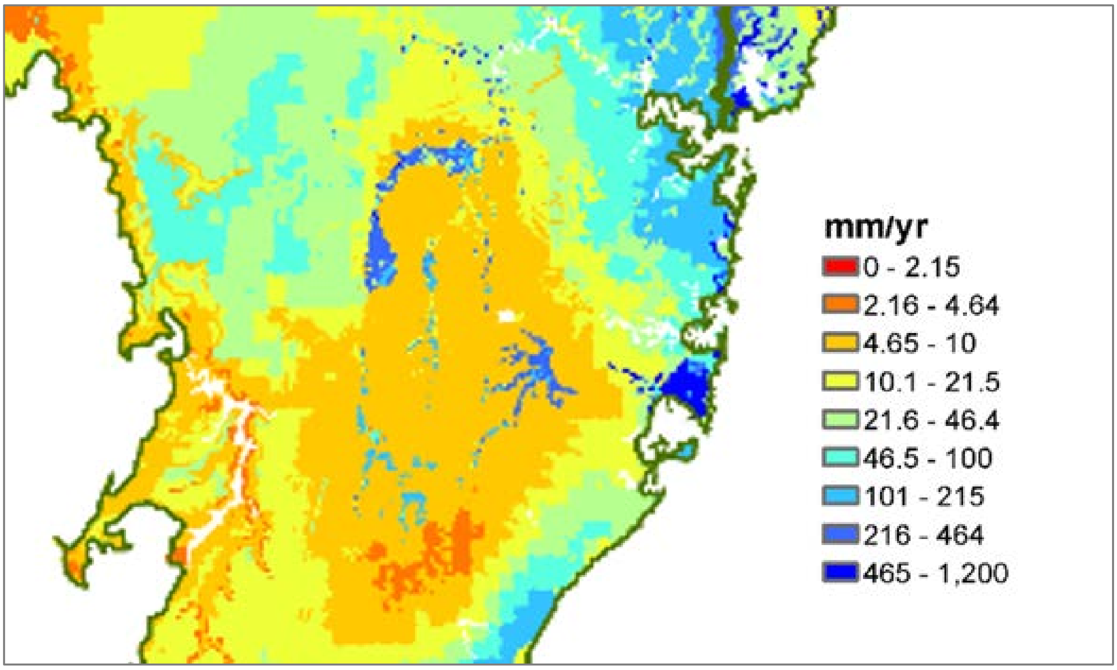


Figure 3-20 Estimated recharge from Crosbie (2015)

Hatley (2004) conducted a literature review of rainfall recharge to the Botany Basin, with values between 6% to 37% of rainfall reported, based primarily on transient model calibration by Merrick (1994).

Due to the study area being within an urban setting, the recharge received in natural environments with unmodified surface cover is likely to be significantly reduced with increased surface runoff to stormwater drains and surface channels. However localised recharge from leaky pipes and stormwater drains may partially counteract this reduction, as well as the reduced evapotranspiration associated with lower density vegetation and an impervious ground cover.

4 GROUNDWATER MODELLING

4.1 MODEL SOFTWARE AND COMPLEXITY

Numerical modelling has been undertaken using Geographic Information Systems (GIS) in conjunction with MODFLOW-USG, which is distributed by the United States Geological Survey (USGS). MODFLOW-USG is a relatively new version of the popular MODFLOW code (McDonald and Harbaugh, 1988) developed by the United States Geological Survey (USGS). MODFLOW is the most widely used code for groundwater modelling and has long been considered an industry standard.

MODFLOW-USG represents a major revision of the MODFLOW code, in that it uses a different underlying numerical scheme: control volume finite difference (CVFD), rather than traditional MODFLOW's finite difference (FD) scheme. 'USG' is an acronym for Un-Structured Grid, meaning that MODFLOW-USG supports a variety of structured and unstructured model grids, including those based on cell shapes including prismatic triangles, rectangles, hexagons, and other cell shapes (Panday *et al*., 2013). The CVFD method also means that a model cell can be connected to an arbitrary number of adjacent cells, which is not the case with a standard FD scheme.

In contrast with structured rectangular finite-difference grids, flexible meshes have a number of advantages. Firstly, they allow finer grid resolution to be focused solely in areas of a model that require it (e.g. along the tunnel alignments), as opposed to refinement over the entire grid, significantly decreasing cell count and consequently model runtimes. Secondly, spatial areas not required in the model may be omitted rather than deactivating cells or retaining "dummy" layers (e.g. for layer pinch-outs). Thirdly, flexible meshes allow cell boundaries to follow important geographical or geological features, such as watercourses or outcrop traces, more accurately modelling the physical system. Finally, the orientation of the flow interfaces between cells may vary, allowing preferential flow directions to be modelled with higher accuracy.

Additionally, MODFLOW-USG is able to simulate variably saturated flow and can handle desaturation and re-saturation of multiple hydrogeological layers without the "dry cell" problems of traditional MODFLOW. This is pertinent to models which simulate layers, such as surficial regolith, which frequently alternate between unsaturated and saturated, as well as the depressurisation and desaturation that occurs due to tunnel excavation. Traditional versions of MODFLOW can handle depressurisation and desaturation to some extent, but model cells that are dewatered (reduced below atmospheric pressure) are replaced by "dry" cells, which can interfere with the simulation of various processes and also cause model instability.

4.2 MODEL GEOMETRY

4.2.1 MODEL EXTENT

The maximum extent of the groundwater model for the project is shown in **Figure 4-1**, and is the same as the study area shown on many figures in this report. This area is roughly 11 x 11 km, with the northern boundary being represented by the central channel of Sydney Harbour/Parramatta River. This extent is based on the need for inclusion of adjoining WCX works and other major tunnel infrastructure (M5 East) as part of the cumulative impact assessment, and practical considerations for modelling (most notably model run time, file size and processing of results).

The active domain is centred on the Project, and partially includes neighbouring M4 East and New M5 WCX works. Consideration was given to including the Eastern Distributor and Cross City Tunnel within the model boundary (both approximately 3 km from the nearest WCX tunnelling at their closest points), however due to lack of water level data and tunnel inflow data it was considered that modelling the Eastern Distributor/Cross City Tunnel would result in increased model uncertainty; thus they were not included. In any case, any drawdown associated with these tunnels is not expected to interact with the planned WCX tunnels nor contribute to the cumulative impacts of the project. Fully lined tunnels such as the Airport Rail Link and Harbour Tunnel were also excluded from the model on the basis that they would not impact the regional flow regime, as there is no drawdown associated with their operation and local groundwater is able to flow around the tunnels.

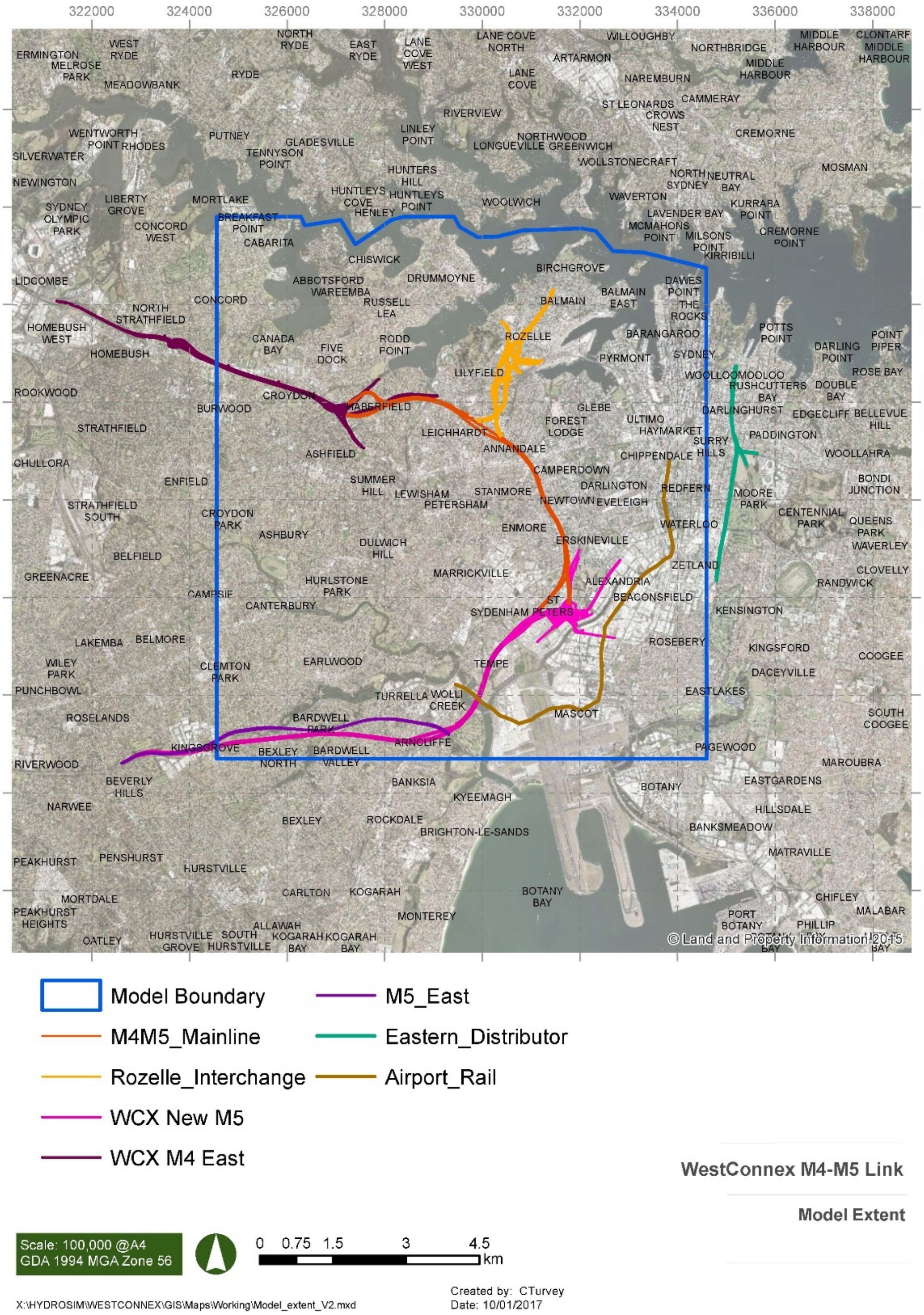


Figure 4-1 Model extent

4.2.2 MODEL LAYERING

The topography of the model relies on LiDAR data provided by AECOM. The model domain is discretised into eight (8) layers, as shown in **Table 4-1.** All layers are fully extensive, however where a particular hydrogeological unit is not present (e.g, because of erosion), the model layer representing that unit has been assigned a layer thickness of 0.5 m and the layer has been given the same hydraulic properties as the layer below. This approach ensures that each layer represents a discrete hydrogeological unit.

Table 4-1 Model layering and hydrostratigrahpy

Layer	Unit	Average Thickness# (m)	Min Thickness (m)	Max Thickness (m)
1	Fill, Regolith, Alluvium, Botany Sands	7.8	0.5	64.6
2	Upper Ashfield Shale	4.2	0.5	5
3	Lower Ashfield Shale/ Mittagong Formation	7.8	0.5	41.5
4	Hawkesbury Sandstone	16.2	0.5	70.5
5	Hawkesbury Sandstone	19.4	0.5	20
6	Hawkesbury Sandstone	19.9	3.2	20
7	Hawkesbury Sandstone	20	20	20
8	Hawkesbury Sandstone	20	20	20

Average thickness does not include 0.5m thickness assigned where the geological unit is not present

The lateral boundaries of the geological model are based on the Sydney 1:100,000 Geological Map. Vertical boundaries were developed using:

- The intersection of LIDAR data with the Sydney 1:100,000 geology outcrop extents.
- Geological logs from drilling investigations specific to the M4-M5 project.
- Compiled GINT database information provided by AECOM for nearby road infrastructure projects.

The two main rock units, the Ashfield Shale and the Hawkesbury Sandstone have been subdivided into multiple model layers. This is particularly important in the Hawkesbury Sandstone, and has been done for the following reasons:

- The Hawkesbury Sandstone cannot be considered to be a single aquifer. HydroSimulations experience in the wider Sydney Basin but also observed here, is that multiple aquifers often exist through the Hawkesbury Sandstone sequence. There are usually a perched water table or two, plus the 'regional' water table or confined aquifer.
- When simulating a tunnel with a discrete height, it is best that the model layers approximate this height. If the Hawkesbury Sandstone were represented as a single layer with a thickness of 100 m (or more), the effective transmissivity of the stratum that controls inflow to the void would be based on that thickness, not the actual tunnel height. Additionally, the drawdown imposed by tunnel dewatering would occur across the model layer thickness, so using thicker layers would cause overestimation of the upward transmission of drawdown.
- On this last point, it is acknowledged that the tunnel height is not 20 m (it is typically 8 m to 10 m). However, the model layers do not follow the tunnel invert elevation (rather the proposed tunnel cross-cuts the model layers), therefore it is not possible

to directly replicate the upper and lower tunnel surfaces by using thinner layers. Given this constraint, a 20 m layer thickness is considered an appropriate compromise between model precision and model run times to represent the changing vertical head gradient due to tunnel excavation while maintaining a workable model size.

4.2.3 MODEL ZONES

As discussed in Hydraulic Properties data analysis (**Section 3.7.4**) the hydraulic conductivity of the geological units typically decreases with depth. Accordingly, zonation within the Ashfield Shale and Hawkesbury sandstone was applied as per **Table 4-2**, using the top of Layer 1 minus the layer mid-point elevation to determine the relevant zone within each layer. Thus each layer contained several depth-dependant hydraulic zones for calibration.

Table 4-2 Model hydraulic zonation

Depth (mbgl)	Ashfield Shale Model Zone Number	Hawkesbury Sandstone Model Zone Number
0 to 10	21	41
10 to 20	22	42
20 to 40	23	43
40 to 60	24	44
60 to 80	25	45
80 to 100	NA	46
>100	NA	47

As the Alluvium, Botany Sands and Fill/regolith occur only in Layer 1, a single zone was applied to each and no variation in hydraulic conductivity with depth was modelled. Although within the alluvium in the Whites Creek Palaeochannel two sub aquifers were identified it was considered that separating these two aquifers in the model would not provide additional model accuracy since the differential head of approximately 0.5m would be within the range of model uncertainty.

4.2.4 MODEL GRID

The use of MODFLOW-USG (**Section 4.1**) allows the use of an unstructured or irregular mesh. For this project, a Voronoi-based mesh has been adopted (Amenta and Bern, 1998), which has the advantage of being not only irregular but maintaining the property that a line connecting adjacent cell-centres is perpendicular to the shared cell boundary. Use of the unstructured mesh allows refinement by using small cell sizes along road tunnels and watercourses while letting the cell size increase in areas that are not near features of interest.

The model domain is discretised into 69,701 cells for each layer, with a total cell count of 557,608 cells. The use of MODFLOW-USG could have been better optimised by allowing layers to pinch out where the layer thickness was less than 0.5m; however due to the use of the relatively new program mod-PATH3DU (which has had some issues with models incorporating pinch-outs) it was considered more efficient to leave all layers fully extensive given the time constraints on the project. This does not compromise model results; rather it simply increases the model run-time slightly due to a greater cell count. Where a model layer extends across an area where the geological unit represented by that layer is not present (e.g. where the Ashfield Shale has been eroded away in Layer 2 and 3), the layer is given a thickness of 0.5m and assigned the hydraulic properties of the next present geological unit below it (in this example the Hawkesbury Sandstone in Layer 4), creating a continuous vertical profile.

The Voronoi mesh was generated using the proprietary HydroAlgorithmics software 'AlgoMesh' (Merrick and Merrick, 2015), which provides significant control over the mesh generation process, and can export MODFLOW-USG files, in addition to other formats.

The following general approach was taken when using AlgoMesh:

- Polylines mapped along the proposed tunnel alignments were used to create a mesh of Voronoi cells to define the tunnel with a maximum single tube width of 20m.
- Polylines along mapped rivers and creeks were used to ensure the mesh conformed to mapped drainage networks, and to enforce variable spatial detail along streams (e.g. greater detail along streams closest to the Project).
- Calibration target boreholes were included in the mesh generation process to ensure sufficient spatial detail in areas with observations (bores) located close to one another.
- Maximum grid cell resolution in key areas of interest is as follows:
  - 12.5 m in 2-lane road tunnels;
  - 14.5 m in 3-lane road tunnels;
  - 18 m in 4-lane road tunnels;
  - 20 m in 5-lane road tunnels;
  - 25 m along waterways;
  - 50 m in alluvium areas.

Maximum cell width is approximately 500 m, with cells gradually grading to this size in areas away from tunnels and watercourses.

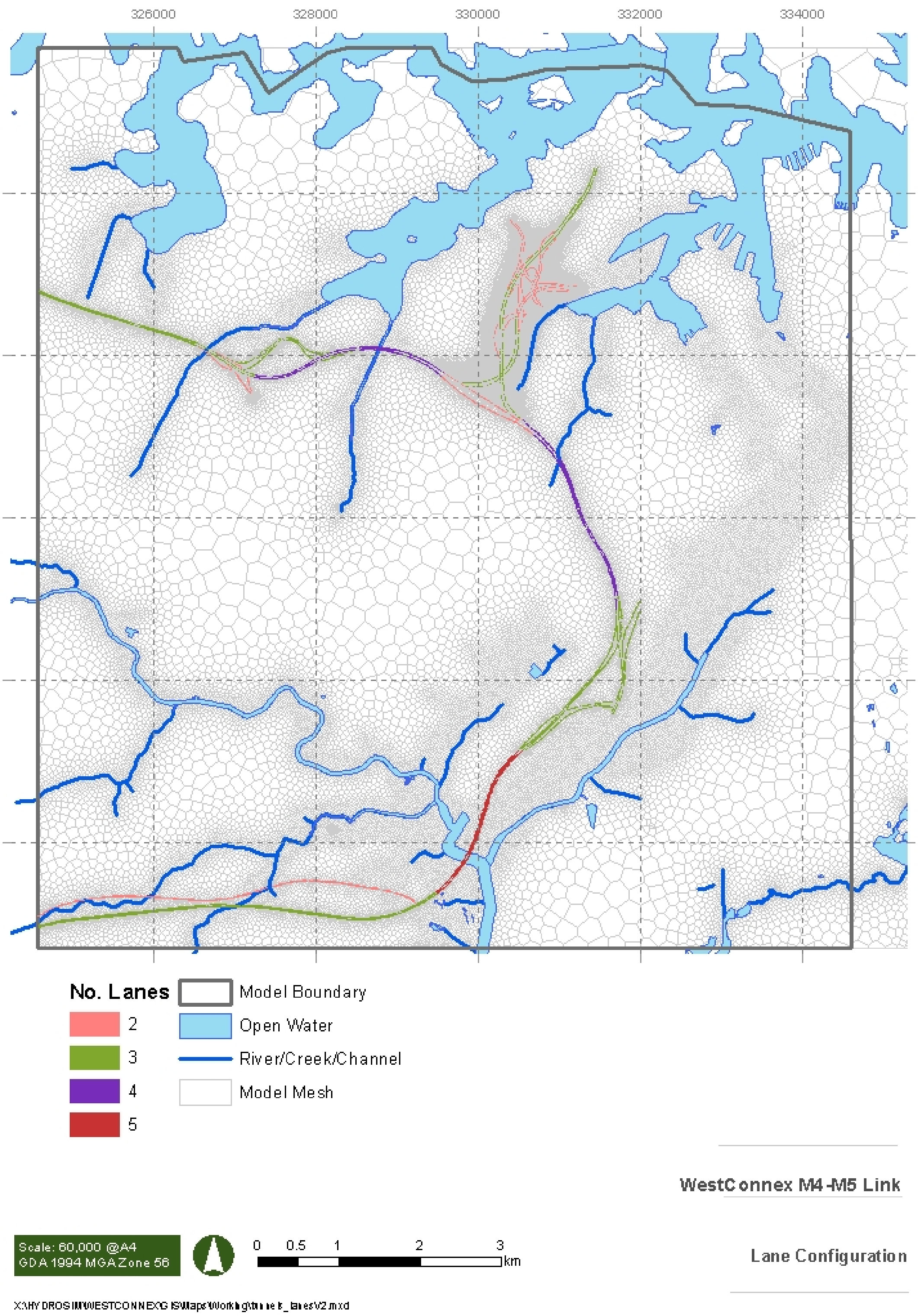


Figure 4-2 Lane configuration

4.3 MODEL VARIANTS

Both steady-state and transient models have been developed:

- Steady-state model of inferred existing conditions, including any drawdown associated with existing tunnels including the M5 East Motorway. The purpose of the steady-state model is to generate plausible initial conditions for the start of the transient simulation.
- Transient model of the transition from recent and existing conditions to the end of WCX construction (inclusive of the current project and the M4 East project and New M5 Project) and extending to year 2100 (total simulation time of 85 years). The purpose of the transient model is to simulate the changing groundwater regime over time with tunnel construction and long-term operation.

An additional transient model was run without the M4-M5 Link in order to determine the project's individual contribution to the modified groundwater regime by comparing the model predictions with the run that includes the M4-M5 Link.

The steady-state and transient periods are incorporated into a single run (i.e. the steady-state period automatically provides initial conditions for the subsequent transient period). The transient model is broken into phases of calibration, construction and prediction, although the actual construction of the WCX programs of works occurs in all three model phases. For the purpose of the modelling the "calibration" period reflects the period for which monitoring data exists (i.e. 2015 to early 2017), and is inclusive of the initial tunnelling activities for M4 East and New M5. The "construction" phase represents the period from the end of calibration to the end of proposed tunnelling activities (M4-M5 Link ventilation tunnels at Rozelle at the end of 2022) and "long-term" reflects the ongoing operational inflows into the tunnel after tunnel excavation is complete. The timing of the model is described in **Figure 4-3**.

	SP	From	To	No Days	Num months	Total days	Total years
Initial Conditions	1	STEADY STATE					
Transient Calibration	2	1/01/2015	31/01/2015	31	1	31	0.08
	3	1/02/2015	28/02/2015	28	1	59	0.16
	4	1/03/2015	31/03/2015	31	1	90	0.25
	5	1/04/2015	30/04/2015	30	1	120	0.33
	6	1/05/2015	31/05/2015	31	1	151	0.41
	7	1/06/2015	30/06/2015	30	1	181	0.5
	8	1/07/2015	31/07/2015	31	1	212	0.58
	9	1/08/2015	31/08/2015	31	1	243	0.67
	10	1/09/2015	30/09/2015	30	1	273	0.75
	11	1/10/2015	31/10/2015	31	1	304	0.83
	12	1/11/2015	30/11/2015	30	1	334	0.91
	13	1/12/2015	31/12/2015	31	1	365	1
	14	1/01/2016	31/01/2016	31	1	396	1.08
	15	1/02/2016	29/02/2016	29	1	425	1.16
	16	1/03/2016	31/03/2016	31	1	456	1.25
	17	1/04/2016	30/04/2016	30	1	486	1.33
	18	1/05/2016	31/05/2016	31	1	517	1.42
	19	1/06/2016	30/06/2016	30	1	547	1.5
	20	1/07/2016	31/07/2016	31	1	578	1.58
	21	1/08/2016	31/08/2016	31	1	609	1.67
	22	1/09/2016	30/09/2016	30	1	639	1.75
	23	1/10/2016	31/10/2016	31	1	670	1.83
	24	1/11/2016	30/11/2016	30	1	700	1.92
	25	1/12/2016	31/12/2016	31	1	731	2
	26	1/01/2017	31/01/2017	31	1	762	2.09
	27	1/02/2017	28/02/2017	28	1	790	2.16
	28	1/03/2017	31/03/2017	31	1	821	2.25
	29	1/04/2017	30/04/2017	30	1	851	2.33

	SP	From	To	No Days	Num months	Total days	Total years
Prediction - Construction	30	1/05/2017	31/05/2017	31	1	882	2.41
	31	1/06/2017	30/06/2017	30	1	912	2.5
	32	1/07/2017	31/07/2017	31	1	943	2.58
	33	1/08/2017	31/08/2017	31	1	974	2.67
	34	1/09/2017	30/09/2017	30	1	1004	2.75
	35	1/10/2017	31/10/2017	31	1	1035	2.83
	36	1/11/2017	30/11/2017	30	1	1065	2.92
	37	1/12/2017	31/12/2017	31	1	1096	3
	38	1/01/2018	31/03/2018	90	3	1186	3.25
	39	1/04/2018	30/06/2018	91	3	1277	3.5
	40	1/07/2018	30/09/2018	92	3	1369	3.75
	41	1/10/2018	31/12/2018	92	3	1461	4
	42	1/01/2019	31/03/2019	90	3	1551	4.25
	43	1/04/2019	30/06/2019	91	3	1642	4.5
	44	1/07/2019	30/09/2019	92	3	1734	4.75
	45	1/10/2019	31/12/2019	92	3	1826	5
	46	1/01/2020	31/03/2020	91	3	1917	5.25
	47	1/04/2020	30/06/2020	91	3	2008	5.5
	48	1/07/2020	30/09/2020	92	3	2100	5.75
	49	1/10/2020	31/12/2020	92	3	2192	6
	50	1/01/2021	31/03/2021	90	3	2282	6.25
	51	1/04/2021	30/06/2021	91	3	2373	6.5
	52	1/07/2021	30/09/2021	92	3	2465	6.75
	53	1/10/2021	31/12/2021	92	3	2557	7
	54	1/01/2022	31/03/2022	90	3	2647	7.25
	55	1/04/2022	30/06/2022	91	3	2738	7.5
	56	1/07/2022	30/09/2022	92	3	2830	7.75
	57	1/10/2022	31/12/2022	92	3	2922	8

	SP	From	To	No Days	Num months	Total days	Total years
Prediction - Long Term	58	1/01/2023	31/03/2023	90	3	3012	8.25
	59	1/04/2023	30/06/2023	91	3	3103	8.5
	60	1/07/2023	30/09/2023	92	3	3195	8.75
	61	1/10/2023	31/12/2023	92	3	3287	9
	62	1/01/2024	31/03/2024	91	3	3378	9.25
	63	1/04/2024	30/06/2024	91	3	3469	9.5
	64	1/07/2024	30/09/2024	92	3	3561	9.75
	65	1/10/2024	31/12/2024	92	3	3653	10
	66	1/01/2025	31/03/2025	90	3	3743	10.25
	67	1/04/2025	30/06/2025	91	3	3834	10.5
	68	1/07/2025	30/09/2025	92	3	3926	10.75
	69	1/10/2025	31/12/2025	92	3	4018	11
	70	1/01/2026	31/12/2026	365	12	4383	12
	71	1/01/2027	31/12/2027	365	12	4748	13
	72	1/01/2028	31/12/2028	366	12	5114	14
	73	1/01/2029	31/12/2029	365	12	5479	15
	74	1/01/2030	31/12/2030	365	12	5844	16
	75	1/01/2031	31/12/2035	1826	60	7670	21
	76	1/01/2036	31/12/2040	1827	60	9497	26
	77	1/01/2041	31/12/2045	1826	60	11323	31
	78	1/01/2046	31/12/2050	1826	60	13149	36
	79	1/01/2051	31/12/2099	17897	586	31046	85

Figure 4-3 Model stress period timing

4.4 MODEL STRESSES AND BOUNDARY CONDITIONS

The model domain and boundaries shown in **Figure 4-4** have been selected to incorporate the significant hydrological processes identified in the conceptual model (**Section 3**), including features such as watercourses that could be affected by tunnelling. Following is a detailed description of each of the modelled boundary conditions.

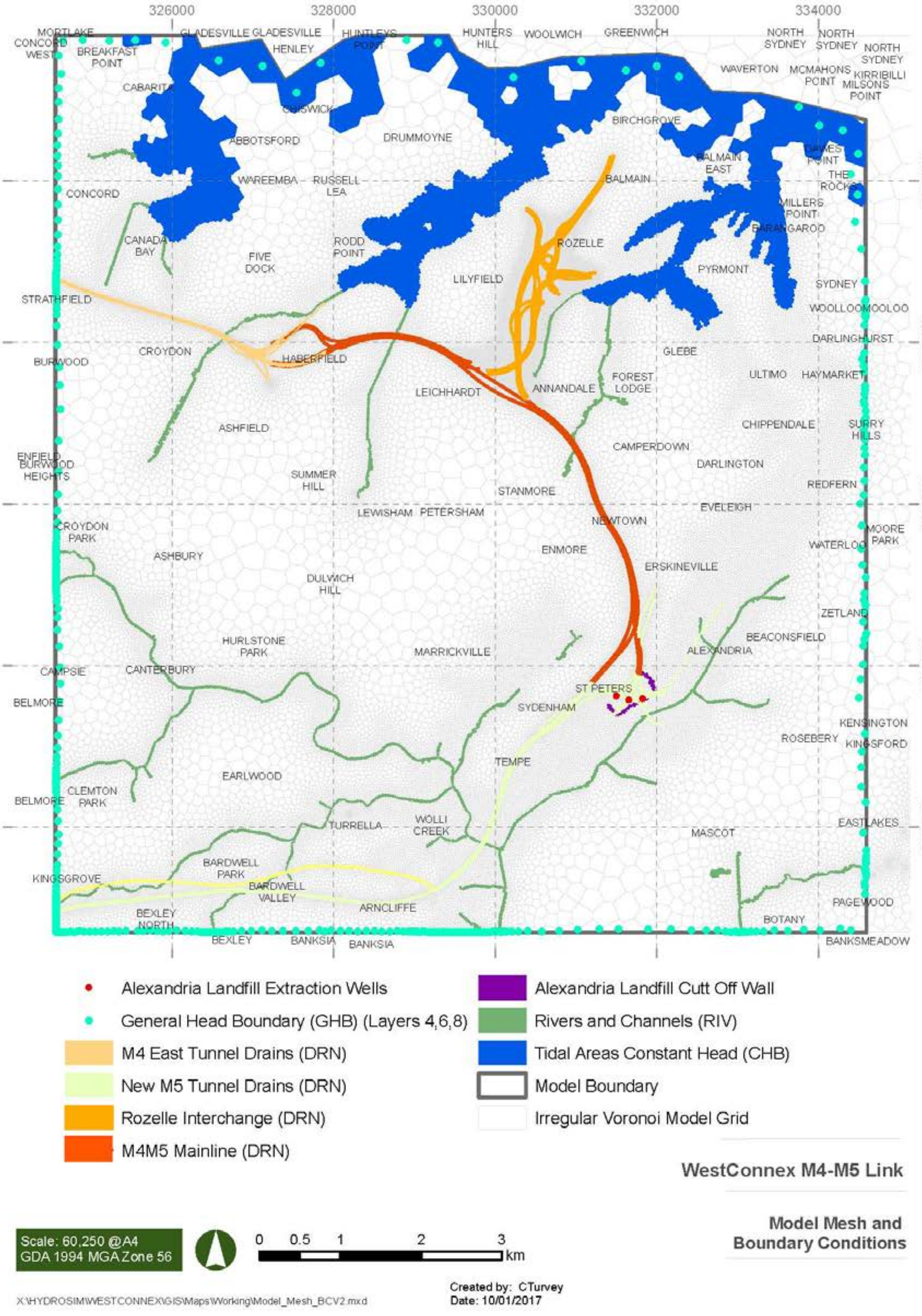


Figure 4-4 Model mesh and boundary conditions

4.4.1 RECHARGE

The MODFLOW Recharge (RCH) package is used to simulate diffuse rainfall recharge. Rainfall recharge has been imposed as a percentage of actual rainfall (for transient calibration) or long term average rainfall (for steady-state calibration and prediction). Refer to the rainfall recharge analysis and discussion in **Section 3.7.9**.

Spatially and temporally variable groundwater recharge rates were applied to the groundwater model. Spatial variations are based on the outcropping hydrogeological units (Botany Sands, Ashfield Shale and Hawkesbury Sandstone). These are then divided into further zones based on paved vs unpaved areas identified from open-source land use data (DP&E, 2016), giving a total of six recharge zones as per **Figure 4-5**. No differentiation of paved areas into density of urbanisation/use has been attempted, and no specific recharge due to stormwater drainage pipes/culverts/channels, as this is difficult to quantify both volumetrically and spatially. Any leakage from the urban infrastructure is assumed to balance out with overall recharge estimation.

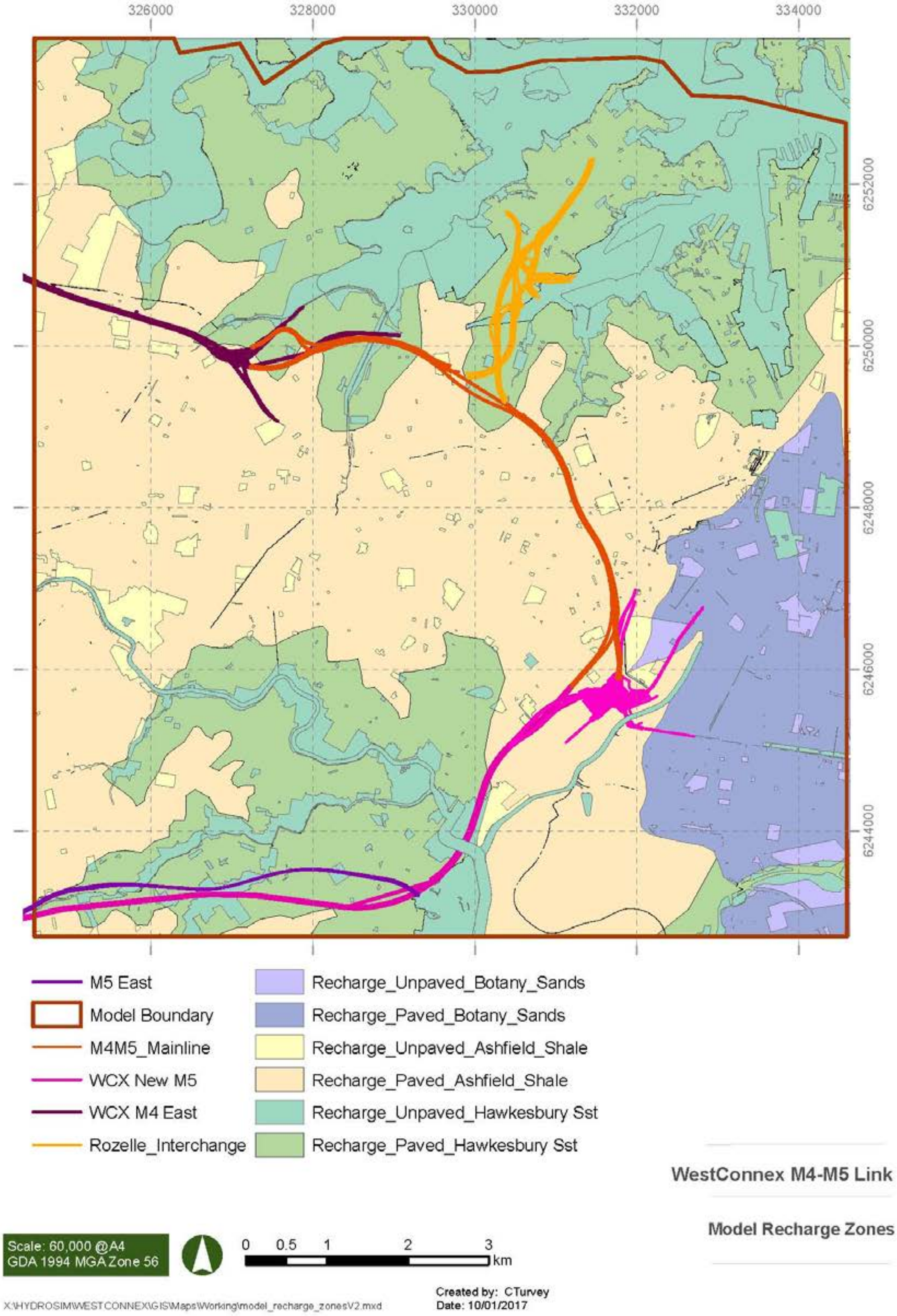


Figure 4-5 Model recharge zones

Temporal variation to recharge for the transient simulation has been calculated using the ratio between actual observed monthly rainfall data and the long term monthly/annual averages, with resulting multipliers applied to the steady-state recharge as per **Figure 4-6**.

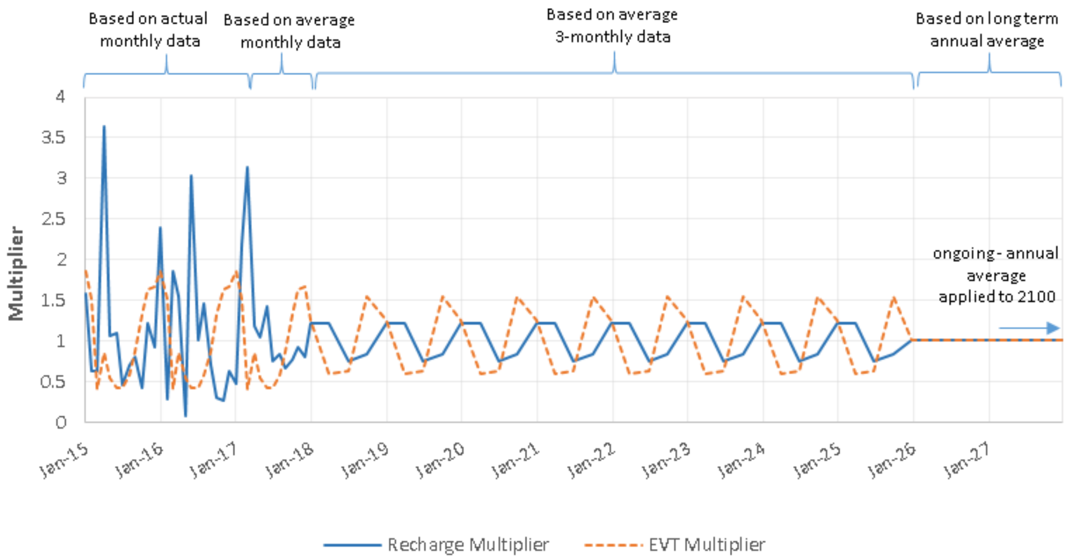


Figure 4-6 Recharge and evapotranspiration transient multipliers

4.4.2 EVAPOTRANSPIRATION FROM GROUNDWATER

The MODFLOW Evapotranspiration (EVT) package was used to simulate evapotranspiration from the groundwater system. Extinction depths were set to 0.5 m below ground across most of the model domain to reflect the reduced evapotranspiration in paved areas, and extinction depths of 1 m for open grassland areas and 5 m for forested areas (based upon average rooting depths reported in Canadell (1996)). Evapotranspiration zones are shown in **Figure 4-7**). Maximum potential rates were set using potential evapotranspiration values and transient multipliers in the same manner as described above for recharge.

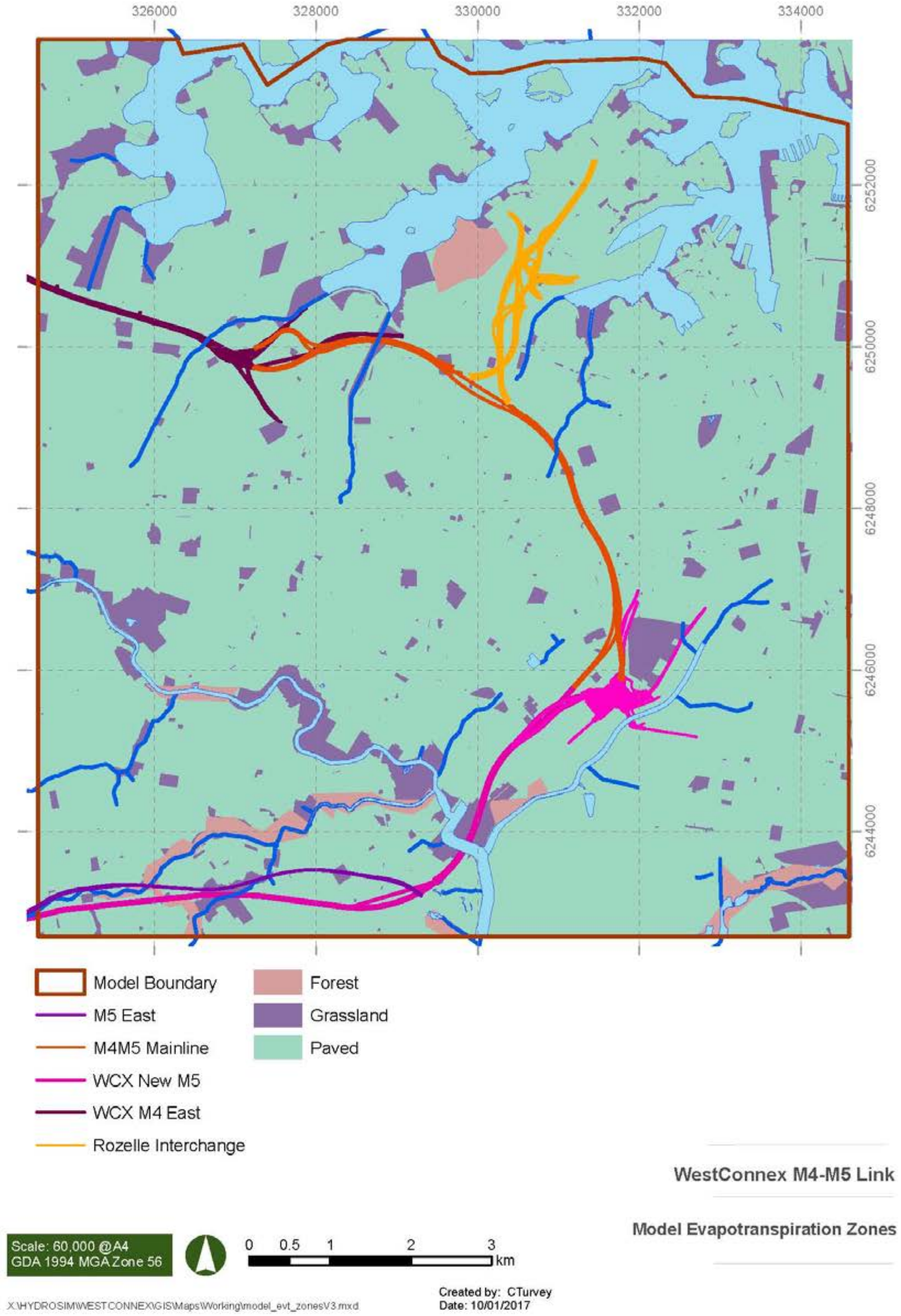


Figure 4-7 Model evapotranspiration zones

4.4.3 WATERCOURSES

The watercourses in the area are mostly lined channels designed to rapidly transmit surface water runoff and shallow groundwater drainage out of the urbanised areas. Major lined channels include Cooks River and Alexandra Canal flowing towards Botany Bay in the south, and Iron Cove Creek, Whites Creek, Johnstons Creek and Hawthorne Canal discharging to Parramatta River and its tributaries in the north. These lined channels are established as "River" cells in model Layer 1 (denoted by green cells in **Figure 4-4**) using the MODFLOW RIV package, with the river stage equal to the river bed elevation (set at the topographic surface). This allows water to flow unrestricted into the channel from the aquifer if/when the groundwater level reaches the ground surface, but not allowing unrestricted leakage out of the channels, effectively acting as "drains".

It is assumed some leakage will occur from these lined channels due to the deterioration of the lining (disintegration, cracking, root damage etc.). A second set of RIV boundary cells has been applied beneath the aforementioned freely draining cells to enable the model to simulate minor recharge from the lined channels. Leakage from the channels has been restricted by using a channel conductance equivalent to a hydraulic conductivity of 0.001m/day, approximately 3 orders of magnitude lower than the hydraulic conductivity of the alluvium. Wolli Creek and Bardwell Creek have bed conductance values of 1 m/day (roughly equal to the hydraulic conductivity of alluvium) as they have unmodified (natural) banks. Due to the lack of surface water gauge levels, river stage elevations have been set as static across the model, with a constant stage of 2 m applied in channels known to be influenced by the tide, 0.5 m in non-tidal major channels, and 0.1 m in minor channels.

Major water bodies including Parramatta River and Sydney Harbour were represented using constant head (CHD) boundary conditions of 1 m AHD to represent mean annual tide (shown in blue in **Figure 4-4**). This is based on an approximate average of tidal ranges reported for Botany Bay and Port Denison by BoM (2016b).

4.4.4 REGIONAL GROUNDWATER FLOW

The model perimeter is set as a 'no-flow' boundary by default, except where regional groundwater flow is likely to enter or leave the active model area in which case a general head boundary (GHB) is specified. The GHB boundary condition is used to represent the regional flow into and out of the model area and has been assigned using GHBs in Hawkesbury Sandstone model layers 4, 6 and 8 using the relationship of observed water level to topography for bores screened in the relevant layer (as per **Figure 4-8**). Groundwater will enter the model where the head set in the GHB is higher than the modelled head in the adjacent cell, and leave the model when the water level is lower in the GHB. Conductance is calculated using the modelled hydraulic conductivity of the Hawkesbury Sandstone divided by the cell area, and is therefore variable in this model due to variable cell-size.

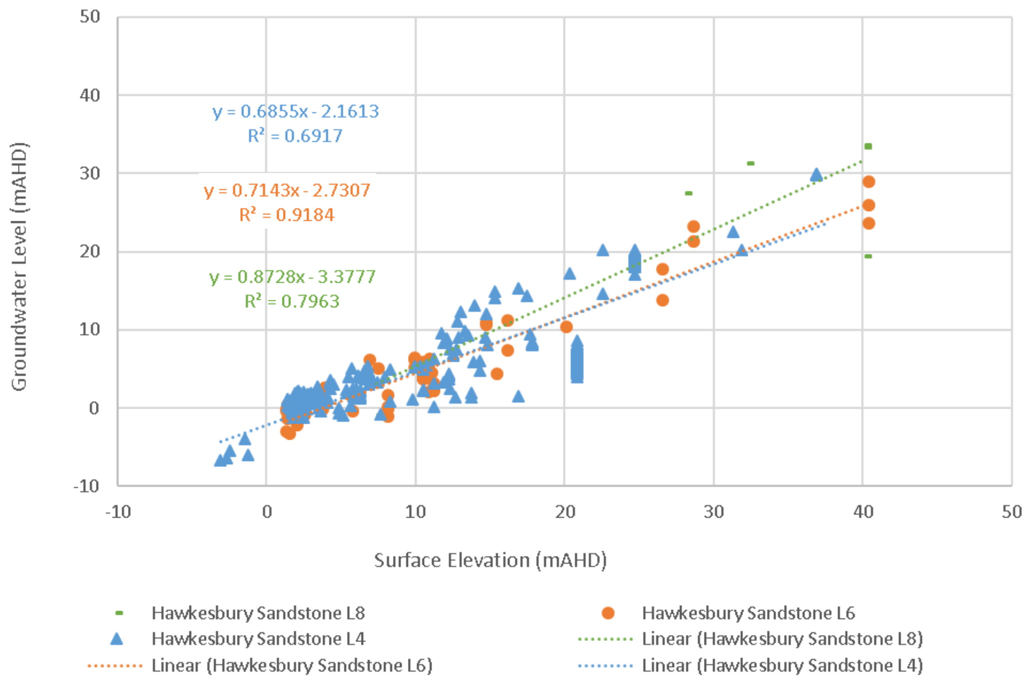


Figure 4-8 Relationship between topography and water level in the Hawkesbury Sandstone

4.4.5 GROUNDWATER USE

With one exception, groundwater pumping bores have not been included in the modelling due to lack of abstraction data. Due to low groundwater abstraction across the model area it is likely that the bores have very localised drawdowns and will not significantly impact model results.

The exception is the groundwater abstraction carried out at Alexandria Landfill. At this site, pumping is known to have occurred since 2001 to present day, at a rate of about 0.18 ML/day. Water level monitoring carried out for this project shows the drawdown effect of this pumping (AECOM, 2017). In order to calibrate the groundwater model to this data, it is therefore necessary to include the two extraction wells situated in the Botany Sands to the east of the landfill, and the pumping from the landfill sump which collects leachate from the waste as well as drainage from the Ashfield Shale and Botany Sands (**Figure 4-9**). The rates applied to each of these extraction points is given in **Table 4-3**.

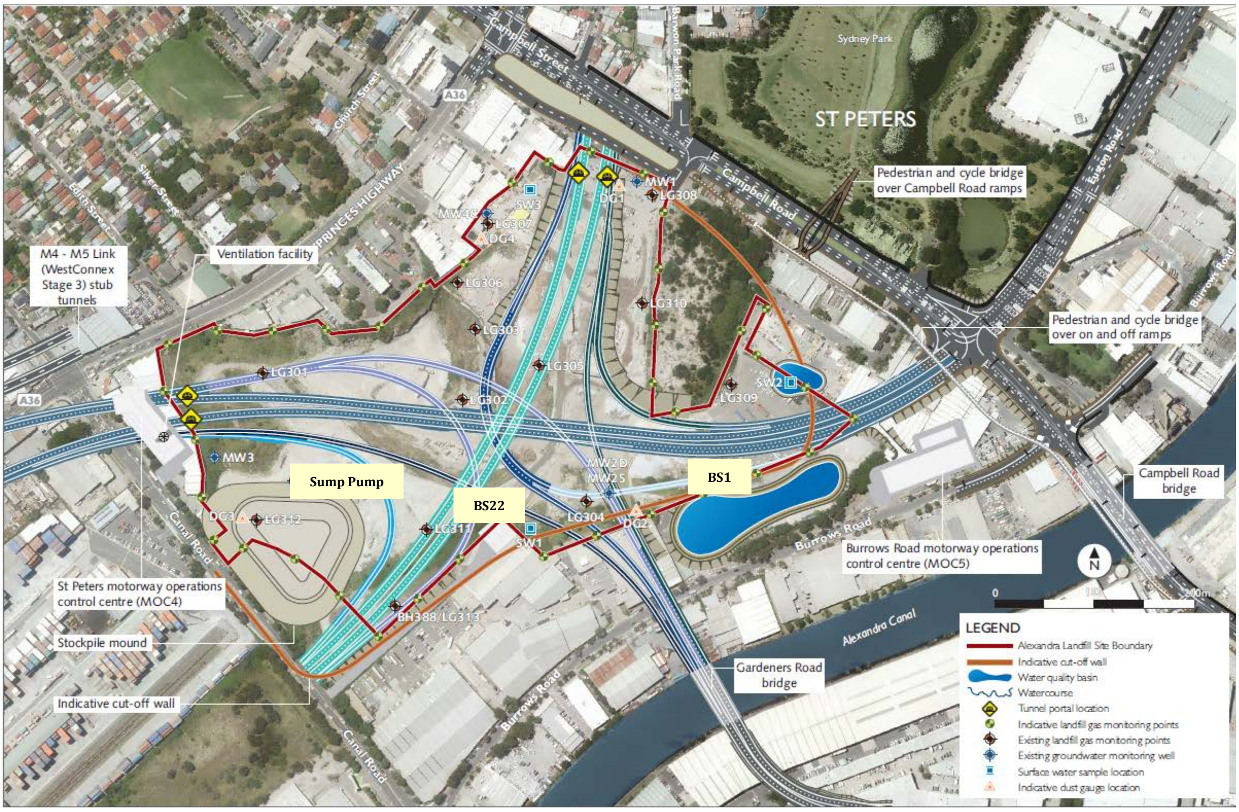


Figure 4-9 Alexandria Landfill layout and proposed cut-off wall alignment

Table 4-3 Modelled extraction rates from Alexandria Landfill

Bore	Current Abstraction Rate (ML/day)	Post July 2017 Abstraction Rate (ML/day)
BS1	0.018	0
BS2	0.025	0
Sump Pump	0.14	0.1
Total	0.183	0.10

Based on AECOM (2015) it is anticipated that a cut-off wall will be installed around the south-eastern extent of the landfill during the development of the St Peters Interchange. The approximate timing of this is expected to be mid to late-2017. Once the cut-off wall is in place, pumping will be discontinued from the Botany Sands bores, and leachate pumping will be reduced to approximately 0.1 ML/day. This assumption has been incorporated into predictive modelling by the use of a reduced hydraulic conductivity zone implemented with the Time-Variant Materials (TVM) package available with USG-Beta software. The Hydraulic Flow Barrier (HFB) package in MODFLOW could not be used to represent the cut-off wall due to the inability to turn this feature on part way through the model simulation. The cut-off wall has a design hydraulic conductivity of 1.0E-08 m/sec (8.6E-04 m/day) which was applied in the model zone used to represent the wall. Pumping from the Botany Sands bores will be turned off simultaneously with the addition of the cut-off wall.

4.4.6 TUNNEL WORKINGS

"Drain" (DRN) cells are used to represent the tunnel alignment. Invert levels were determined from .dxf design files provided by AECOM, with the invert level of the DRN cell calculated to be the minimum elevation of all features on the design files that are positioned within each model cell (**Figure 4-10**). For the M4-M5 Link and Rozelle, the minimum elevation of modelled tunnel is -53 mAHD, with the deepest areas located at the Rozelle Interchange. The deepest point for the greater WCX program of works is where the New M5 passes under Cooks River, with an elevation of -75 mAHD. The timing for activating the drain cells in the model was interpreted as much as possible from the published Environmental Impact Statement (EIS) documents for the M4 East and New M5 projects, and from preliminary scheduling data provided by AECOM for the M4-M5 Link and Iron Cove project. Relative timing of drain activation applied in the model is shown in **Figure 4-11**. Refer to **Figure 4-3** for dates corresponding with model periods.

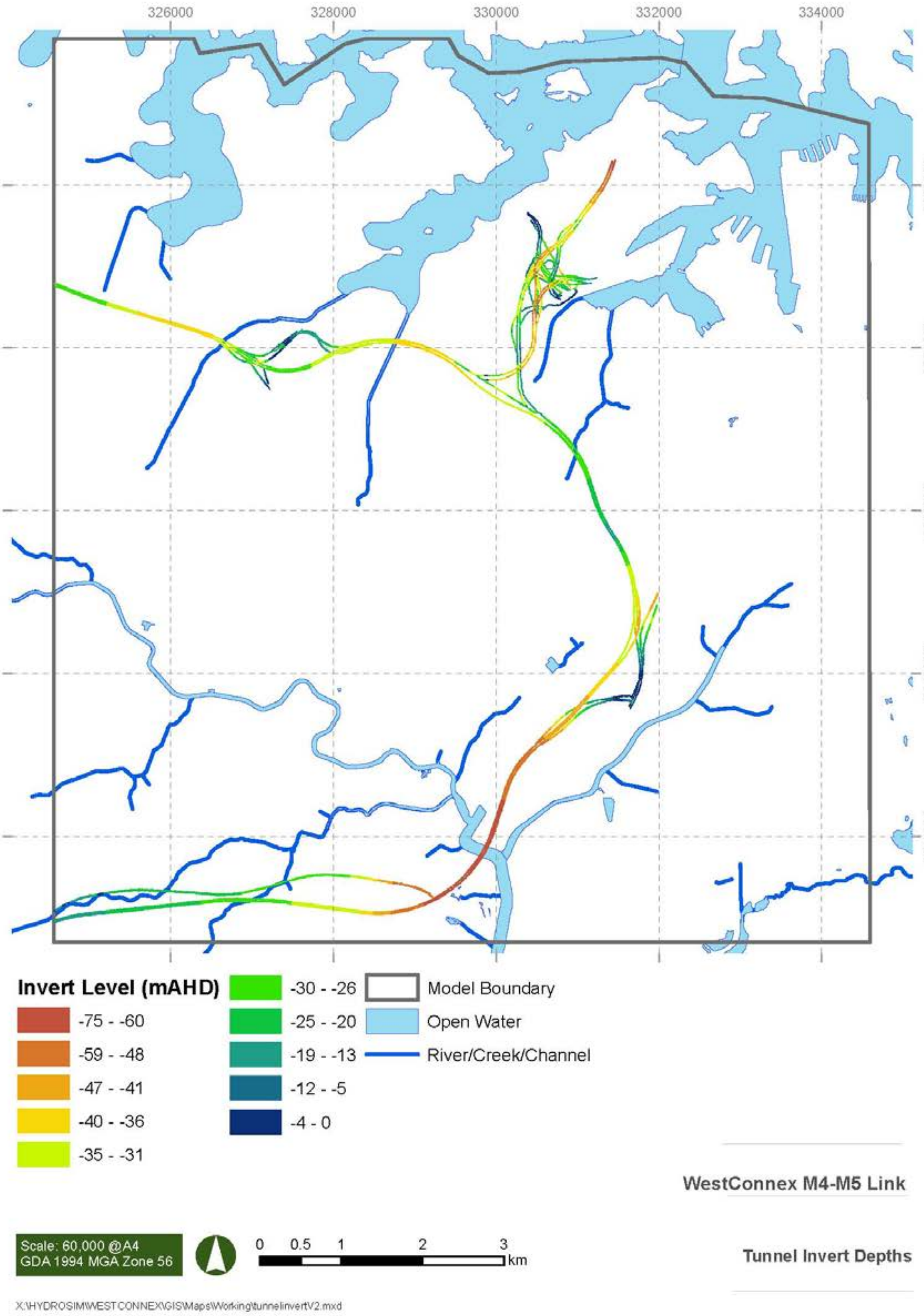


Figure 4-10 Tunnel invert elevations

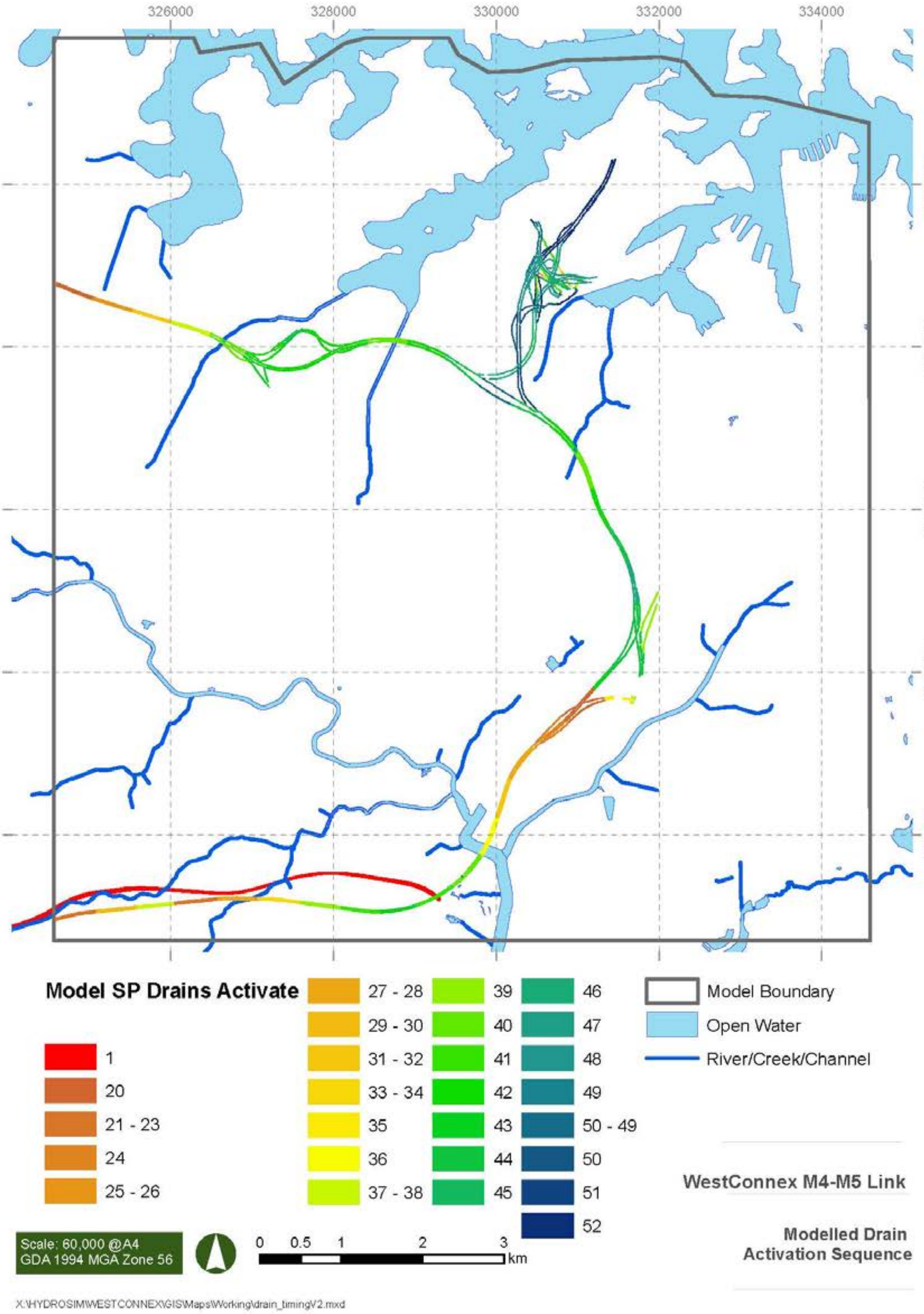


Figure 4-11 Tunnel drain activation sequence

The existing M5 East tunnel opened in 2001, therefore it is considered likely that the drawdown associated with the long-term inflows to the tunnel will have begun to approximate steady-state levels. Thus, the M5 East tunnels drains were included in the steady-state model simulation, and throughout the entire transient simulation.

The conductance of the DRN cells associated with tunnels was initially set to 1000 m^2/day and adjusted as required to constrain inflows to 1 L/sec/km under the assumption that areas of high inflow will be shotcreted during construction (AECOM, 2017), as per the conditions of approval set for the WCS program of works and NorthConnex. A conductance of 0.1 m2/day was required to constrain inflows to less than or equal to 1 L/sec/km.

4.5 MODEL CALIBRATION

4.5.1 STEADY STATE CALIBRATION

Steady-state calibration was undertaken using the automated calibration utility PEST (Doherty, 2010) with 280 groundwater targets. Manual parameter tweaking was then undertaken to ensure the calibrated parameters were consistent with the conceptual understanding of the hydrogeological system, most specifically with the trend of declining hydraulic conductivity with depth. Calibration focused on both horizontal and vertical hydraulic conductivity, with parameter bounds informed as per **Table 4-4**. Vertical hydraulic conductivity was calibrated as a factor of horizontal conductivity (K_V/K_H) with a maximum ratio of 0.5 to represent the reduced vertical hydraulic conductivity typically observed due to sedimentary layering in the Hawkesbury Sandstone and Ashfield Shale.

Table 4-4 Parameter calibration limits used during PEST calibration

Layer	Zone	Units	Depth Below Ground (m)	Initial K_H (m/day)	Min K_H (m/day)	Max K_H (m/day)	Initial K_V (m/day)	Allowed K_V/K_H Ratio
1	10	Alluvium	Any	1.0E+00	1.0E-02	1.0E+01	5.0E-02	*0.1 to 0.001*
1	11	Botany Sands	Any	1.0E+01	1.0E-02	3.0E+01	2.0E-02	*0.1 to 0.001*
1	12	Regolith	Any	1.0E-01	1.0E-03	1.0E+00	1.0E-02	*0.1 to 0.001*
2-3	21	Ashfield Shale	<10	5.0E-02	1.0E-04	1.0E-01	5.0E-03	*0.1 to 0.001*
2-3	22	Ashfield Shale	10 - 20	5.0E-02	1.0E-04	1.0E-01	5.0E-03	*0.1 to 0.001*
2-3	23	Ashfield Shale	20 - 40	1.0E-02	2.0E-04	2.0E-01	1.0E-03	*0.1 to 0.001*
2-3	24	Ashfield Shale	40 - 60	5.0E-03	2.0E-05	2.0E-01	5.0E-04	*0.1 to 0.001*
2-3	25	Ashfield Shale	>60	1.0E-03	5.0E-05	5.0E-01	1.0E-04	*0.1 to 0.001*
4-8	41	Hawkesbury Sandstone	<10	1.0E-01	5.0E-04	5.0E-01	1.0E-02	*0.5 to 0.001*
4-8	42	Hawkesbury Sandstone	10 - 20	8.0E-02	5.0E-04	5.0E-01	8.0E-03	*0.5 to 0.001*
4-8	43	Hawkesbury Sandstone	20 - 40	5.0E-02	5.0E-04	5.0E-01	5.0E-03	*0.5 to 0.001*
4-8	44	Hawkesbury Sandstone	40 - 60	1.0E-02	5.0E-04	5.0E-01	1.0E-03	*0.5 to 0.001*
4-8	45	Hawkesbury Sandstone	60 - 80	9.0E-03	5.0E-04	5.0E-01	9.0E-04	*0.5 to 0.001*
4-8	46	Hawkesbury Sandstone	80 - 100	8.0E-03	5.0E-04	5.0E-01	8.0E-04	*0.5 to 0.001*
4-8	47	Hawkesbury Sandstone	>100	6.0E-03	5.0E-04	5.0E-01	6.0E-04	*0.5 to 0.001*

Storage parameters are not required during steady-state calibration. Recharge was calibrated as per **Table 4-5**.

Table 4-5 Recharge values used in steady-state

Zone	Recharge (m/day)	Equivalent Recharge (mm/year)	% Mean Annual Precipitation
Botany Sands (paved)	4.00E-04	146	12%
Botany Sands (unpaved)	5.00E-04	183	15%
Ashfield Shale (paved)	3.00E-05	11	1%
Ashfield Shale (unpaved)	3.00E-05	11	1%
Hawkesbury Sandstone (paved)	6.00E-05	22	2%
Hawkesbury Sandstone (unpaved)	1.00E-04	37	3%

The conductance of the M5 East Motorway drain cells was varied during calibration in order to obtain a flow of approximately 0.8 to 0.9 L/sec/km (as per Hewitt, 2005 (see **Section 3.7.8**)).

Calibrated parameters are shown in **Table 4-6**. Relative sensitivity of each of the calibrated parameters is shown in **Figure 4-12** (as calculated by PEST using Jacobian sensitivity matrices), indicating that the horizontal hydraulic conductivity of the alluvium and the vertical conductivity of the Hawkesbury Sandstone (at depths of 40-80 m below ground level) tend to dominate the calibration results.

Table 4-6 Steady-state calibrated parameters

Layer	Zone	Units	Depth Below Ground (m)	Calibrated K_H	Calibrated K_V
1	10	Alluvium	Any	1.00E+00	5.03E-01
1	11	Botany Sands	Any	2.00E+01	7.61E-01
1	12	Regolith	Any	1.00E+00	4.30E-01
2-3	21	Ashfield Shale	<10	6.00E-02	2.00E-04
2-3	22	Ashfield Shale	10 - 20	5.00E-02	2.00E-04
2-3	23	Ashfield Shale	20 - 40	2.00E-02	1.85E-04
2-3	24	Ashfield Shale	40 - 60	1.00E-02	1.70E-04
2-3	25	Ashfield Shale	>60	1.00E-03	1.00E-04
4-8	41	Hawkesbury Sandstone	<10	1.30E-01	6.65E-02
4-8	42	Hawkesbury Sandstone	10 - 20	6.25E-02	3.10E-02
4-8	43	Hawkesbury Sandstone	20 - 40	8.00E-03	1.60E-04
4-8	44	Hawkesbury Sandstone	40 - 60	6.00E-03	1.20E-04
4-8	45	Hawkesbury Sandstone	60 - 80	2.00E-03	4.00E-05
4-8	46	Hawkesbury Sandstone	80 - 100	1.50E-03	3.00E-05
4-8	47	Hawkesbury Sandstone	>100	1.50E-03	3.00E-05

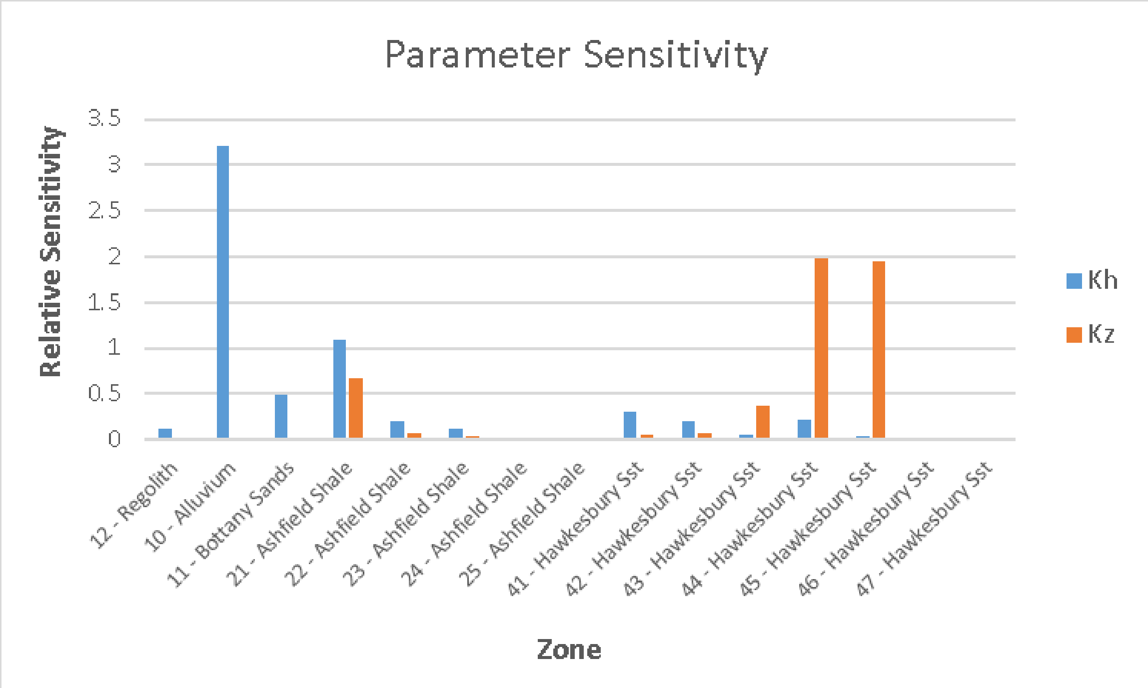


Figure 4-12 Relative parameter sensitivity as determined by PEST

4.5.2 CALIBRATION STATISTICS

Steady-state calibration was assessed against groundwater levels provided by AECOM for the M4-M5 Link project, as well as those collated from other WCX and tunnelling projects. Water levels recorded in the NGIS database / Pinneena were also used. Some quality analysis of calibration targets was undertaken, and dubious targets were removed. Key reasons for selected target removal include:

- Locations where the only water level record was taken on the date of borehole drilling in the Ashfield Shale and Hawkesbury Sandstone (as slow recovery to standing water level is expected in these sediments);
- Where there were two or more levels within the same borehole at similar times with significantly different readings (likely to be due to water quality sampling and/or aquifer testing); and
- Where there is uncertainty regarding which model layer the bore is monitoring.

Resulting calibration statistics for the steady-state simulation are shown in **Table 4-7**. Spatial plots of the target residuals for each lithology are presented in **Figure 4-13** to **Figure 4-15,** and average residuals are shown in **Table 4-8**. A graphical plot of observed vs modelled water levels is shown in **Figure 4-16**. Predictions within ±2 m of target levels are distributed evenly across the model domain (**Figure 4-17**). The scaled RMS error is 5.1% and is satisfactory according to the suggested statistical target below 5% to 10% indicated in groundwater modelling guidelines (MDBC, 2001 and Barnett *et al.*, 2012) to indicate “goodness of fit”. A lower scaled RMS indicates a closer match between modelled and observed water levels. Most of the RMS error comes from the Hawkesbury Sandstone, which is primarily due to the majority of targets being within the Hawkesbury Sandstone. No layers consistently over or under predict groundwater elevation, and it is probable that the monitored heads in the Hawkesbury Sandstone show local variations (due to it being a multi-layered aquifer system) that have not been represented in the regional scale of the model.

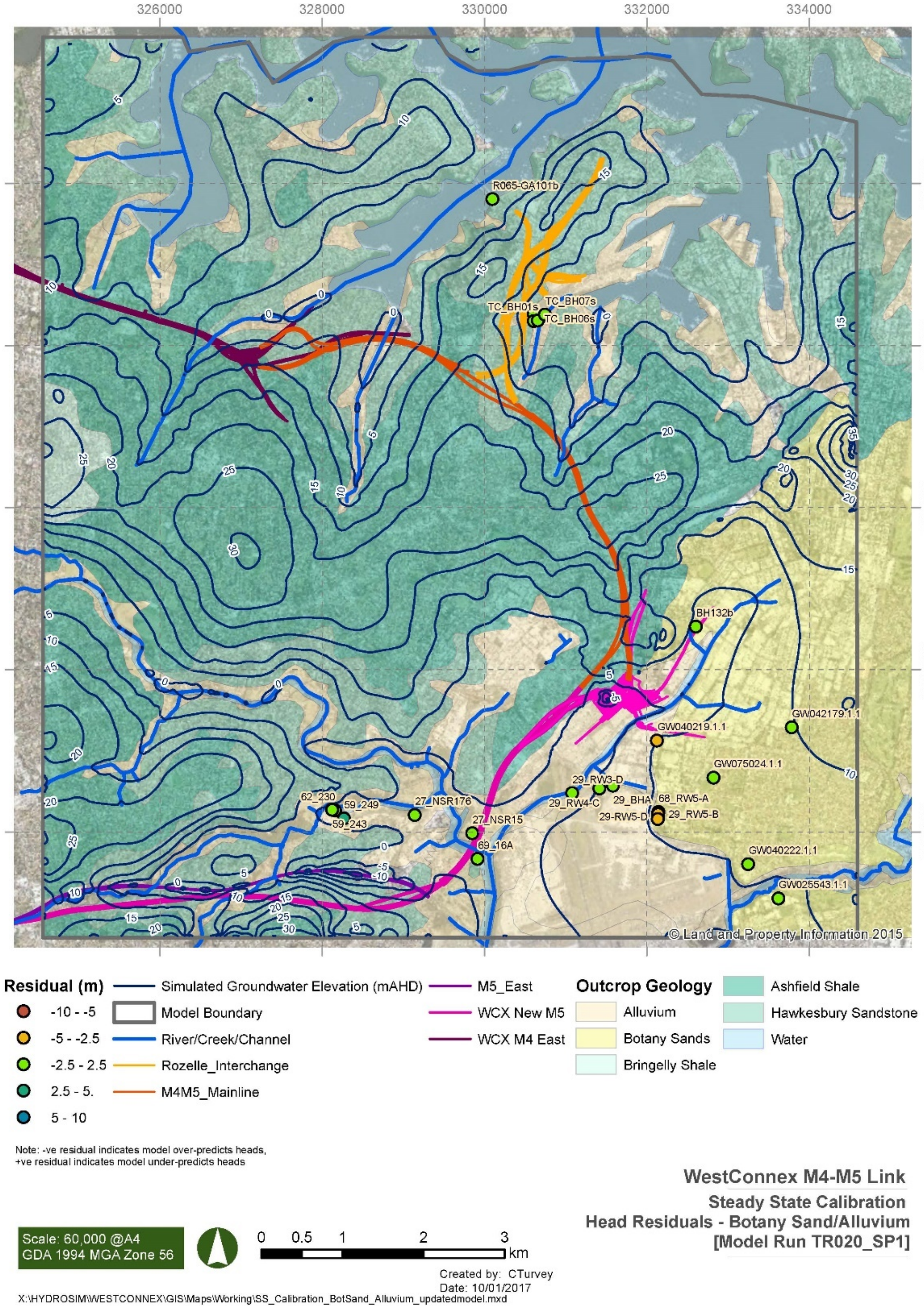


Figure 4-13 Steady-state calibration head residuals and groundwater levels – alluvium, Botany Sands and fill

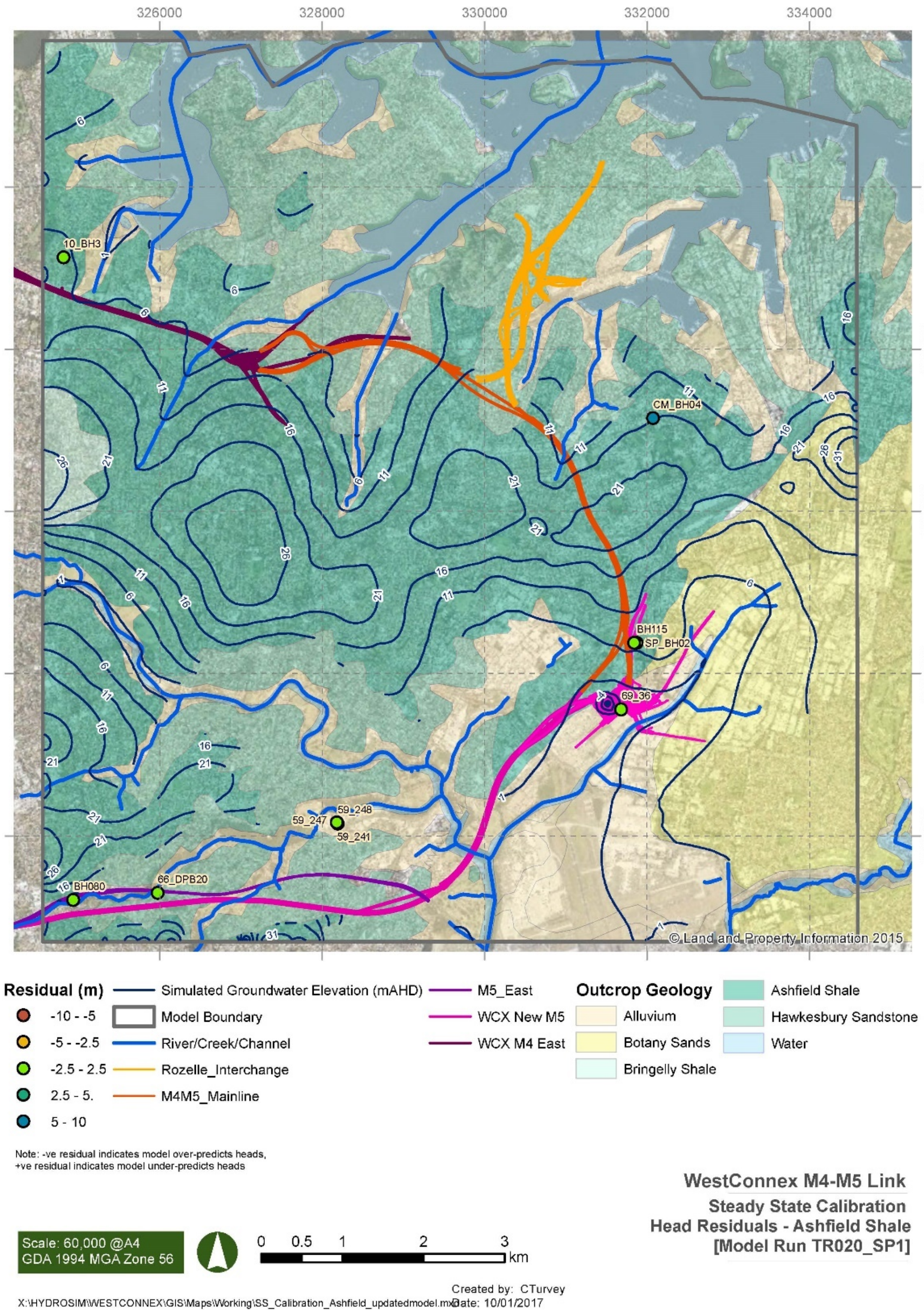


Figure 4-14 Steady-state calibration head residuals and groundwater levels – Ashfield Shale

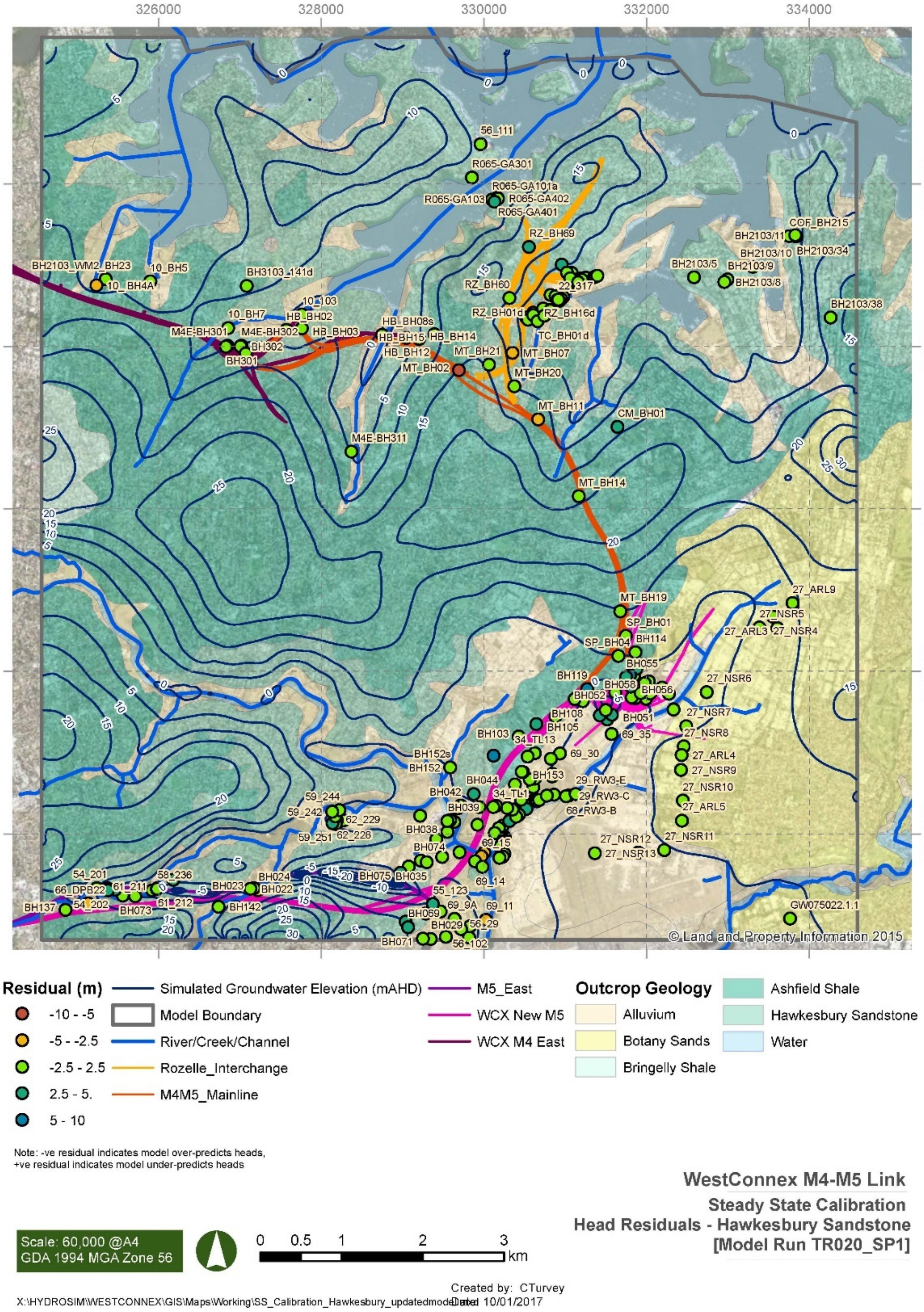


Figure 4-15 Steady-state calibration head residuals and groundwater levels – Hawkesbury Sandstone

Table 4-7 Steady-state calibration statistics (from model run WCX_020TR_SP1)

Statistic	Value
Residual Mean (m)	0.53
RMS Error (m)	1.88
Minimum Residual (m)	-6.80
Maximum Residual (m)	6.61
Scaled RMS Error	5.1%
% Targets within ±2m	79%
% Targets within ±5m	98%

Table 4-8 Average residual by model layer (from model run WCX_020TR_SP1)

Model Layer	Formation	Average Residual (m)	Number of Locations
1	Fill, Regolith, Alluvium, Botany Sands	-0.05	23
2	Ashfield Shale	0.21	7
3	Ashfield Shale	1.77	10
4	Hawkesbury Sandstone	0.72	159
5	Hawkesbury Sandstone	0.03	49
6	Hawkesbury Sandstone	0.40	19
7	Hawkesbury Sandstone	0.28	13

Negative residuals indicate modelled heads too high, positive indicate modelled heads too low.

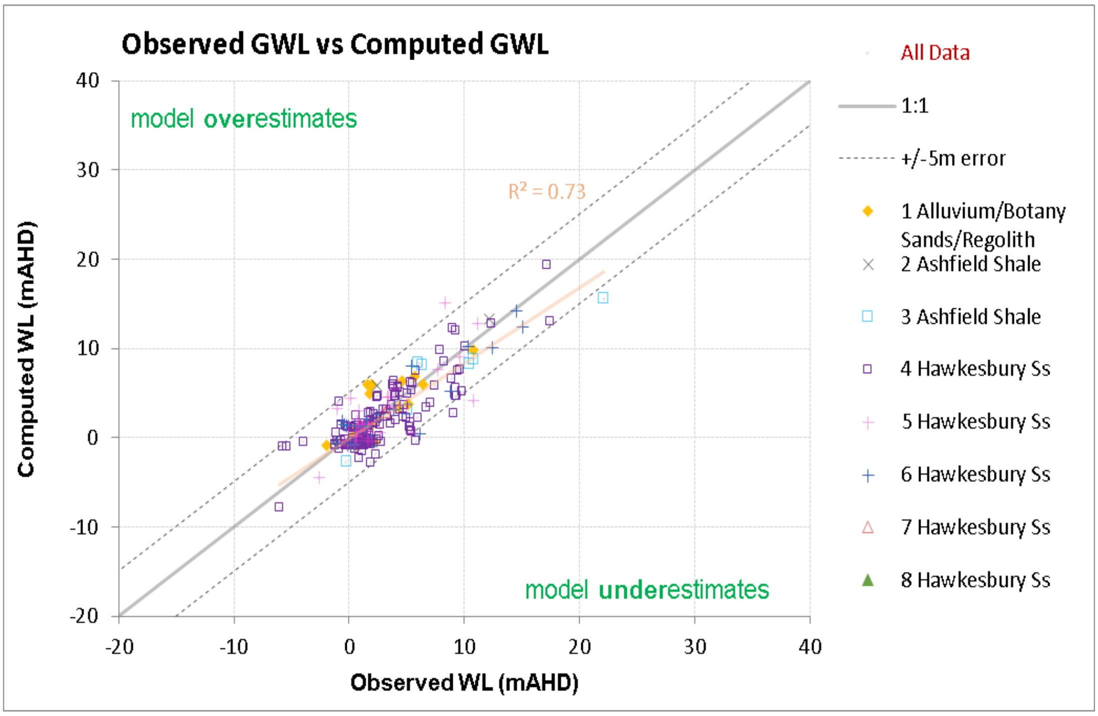


Figure 4-16 Plot of observed vs computed water levels for steady-state model

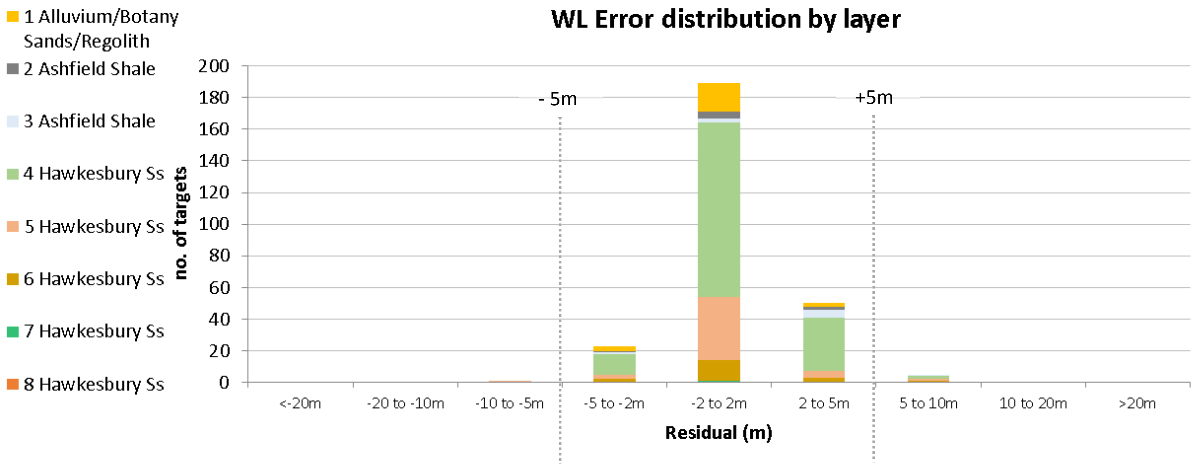


Figure 4-17 Residual error distribution for steady-state model

4.5.3 STEADY-STATE MASS BALANCE

The water balance for the steady-state simulation is presented in **Table 4-9**. It can be observed that over half of the recharge to groundwater comes from regional groundwater inflow at model boundaries, with rainfall recharge also a key input. Most of the losses to the system occur via regional outflow at the model edges and drainage to creeks/channels. Evapotranspiration also represents a significant mechanism of loss from the system.

Outflow to drains (in this case solely representing M5 East) is 0.44 ML/day, which equals 5.9 L/sec. The modelled length of the M5 East is approximately 6 km, thus this volume of flow represents 0.85 L/sec/km of tunnel, which is consistent with the long term inflows of 0.8 to 0.9 L/sec/km reported by Hewitt (2005). Zonebudget (Harbaugh, 1990) software was used to confirm the flow was fairly uniform along the length of the tunnel (i.e. there was not one unique area providing a significant amount of the inflow volume).

The model mass balance indicates that the man-made impacts to the groundwater system (i.e. drainage to the M5 East tunnel and pumping at Alexandria Landfill) are very small compared to the natural recharge and discharge processes, in particular regional groundwater throughflow.

Table 4-9 Steady-state model mass balance

	INFLOW (ML/DAY)	OUTFLOW (ML/DAY)
RECHARGE (RCH)	8.98	0.0
ET (FROM GW) (EVT)	0.0	1.56
GW EXTRACTION ALEXANDRIA LANDFILL (WEL)	0.0	0.08
SW-AQUIFER INTERACTION RIVERS/CHANNELS (RIV)	1.46	12.5
REGIONAL GW FLOW (GHB)	24.9	21.3
TIDAL AREAS CONSTANT HEAD (CHD)	1.4	0.85
TUNNELS (DRN)	0.0	0.44
STORAGE	NA	NA
TOTAL	36.8	36.8
% ERROR	0.0	0.0

GHB = General Head Boundary

4.5.4 TRANSIENT CALIBRATION

Transient calibration was performed for the period January 2015 to April 2017 using monthly stress periods. The use of these periods allows the groundwater model to replicate the transitional behaviour of key groundwater hydrographs with seasonal fluctuations. In all, 397 target heads were established for 82 sites.

Due to limited data for transient calibration, hydraulic conductivity parameters calibrated in the steady-state model were held constant for transient calibration, while calibration was attempted using only changes to specific storage (Ss) and specific yield (Sy) (**Table 4-10**). Recharge was set to vary with time using the multiplication factors calculated from monthly rainfall (**Section 4.3.1**).

Table 4-10 Calibrated storage parameters (WCX_020TR)

Layer	Zone	Units	Depth Below Ground (m)	Calibrated Ss (m^{-1})	Calibrated Sy
1	10	Alluvium	Any	1.0E-05	2.0E-01
1	11	Botany Sands	Any	1.0E-05	2.0E-01
1	12	Regolith	Any	1.0E-05	1.0E-01
2-3	21	Ashfield Shale	<10	1.0E-05	2.5E-02
2-3	22	Ashfield Shale	10 - 20	1.0E-05	2.0E-02
2-3	23	Ashfield Shale	20 - 40	1.0E-05	2.0E-02
2-3	24	Ashfield Shale	40 - 60	1.0E-05	2.0E-02
2-3	25	Ashfield Shale	>60	1.0E-05	2.0E-02
4-8	41	Hawkesbury Sandstone	<10	1.0E-05	5.0E-02
4-8	42	Hawkesbury Sandstone	10 - 20	1.0E-05	5.0E-02
4-8	43	Hawkesbury Sandstone	20 - 40	1.0E-05	3.0E-02
4-8	44	Hawkesbury Sandstone	40 - 60	1.0E-05	3.0E-02
4-8	45	Hawkesbury Sandstone	60 - 80	1.0E-05	2.0E-02
4-8	46	Hawkesbury Sandstone	80 - 100	5.0E-06	2.0E-02
4-8	47	Hawkesbury Sandstone	>100	5.0E-06	2.0E-02

Resulting calibration statistics for the transient simulation are shown in **Table 4-11** and average residuals are shown in **Table 4-12**. The model scaled RMS is 4.7%, again considered a good fit using statistical targets suggested by the MDBC (2001) and Barnett *et al.* (2012). The spatial distribution of residuals is shown in **Figure 4-18**. The calibration scatter plot is shown in **Figure 4-19** and the distribution of error by layer in **Figure 4-20**. Transient calibration hydrographs are presented in **Annexure A.**

The transient calibration hydrographs are plotted for the period January 2015 to April 2017 and display observed groundwater levels, modelled groundwater levels and the rainfall residual mass curve (from Sydney Observatory). Seven hydrographs are simulated within the Botany Sands and alluvium in Layer 1. Within the alluvium the modelled data tends to be flatter than observed data, reflecting hydraulic influences from surface water bodies (that have been represented as constant stages in in the model while the observed data show a head variation of up to almost 1 m). Three hydrographs represent groundwater trends within the Ashfield Shale (Layer 3). Modelled groundwater levels are between one and four metres of the observed groundwater levels. The remainder of the hydrographs (67) simulate groundwater levels within the Hawkesbury Sandstone with 30 representing Layer 4, 10 representing Layer 5, 16 representing Layer 6 and 11 representing Layer 7. Overall the modelled hydraulic heads within the Hawkesbury Sandstone tend to be slightly below observed levels, typically in the order of 0.3 m, except in model Layer 4 where modelled heads are typically slightly higher than observed (0.52 m on average) as outlined in **Table 4-12**. Similar to hydrographs for the alluvium, modelled water levels in the Hawkesbury Sandstone for bores near watercourses tend to show flatter trends than the observed data. This is likely to be due to the application of constant stage levels for the RIV boundary conditions causing local modelled levels to remain relatively consistent, while monitoring data records show fluctuations of up to 1 m typically following the rainfall trend.

Table 4-11 Transient calibration statistics (from model run WCX_020TR)

Statistic	Value
Residual Mean (m)	-0.21
RMS Error (m)	1.25
Minimum Residual (m)	-5.87
Maximum Residual (m)	4.48
Scaled RMS Error	4.7%
% Targets within ±2m	88%
% Targets within ±5m	97%

Table 4-12 Average residual by model layer (from model run WCX_020TR)

Model Layer	Formation	Average Residual (m)	Number of Observations
1	Fill, Regolith, Alluvium, Botany Sands	-0.21	44
2	Ashfield Shale	-1.01	1
3	Ashfield Shale	1.41	4
4	Hawkesbury Sandstone	-0.52	205
5	Hawkesbury Sandstone	0.21	110
6	Hawkesbury Sandstone	0.30	30
7	Hawkesbury Sandstone	0.33	6

Negative residuals indicate modelled heads too high, positive indicate modelled heads to low.

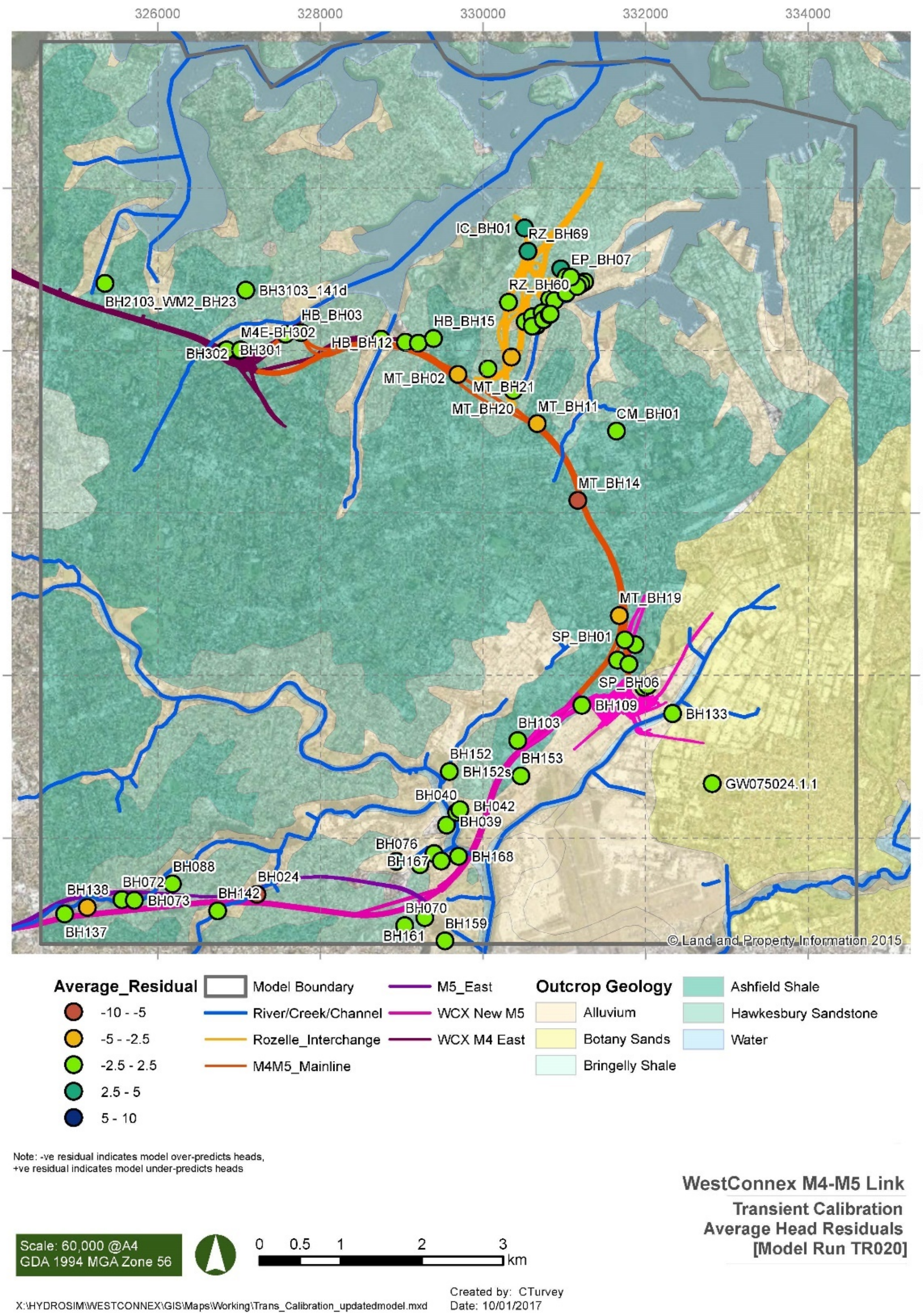


Figure 4-18 Transient calibration average head residuals

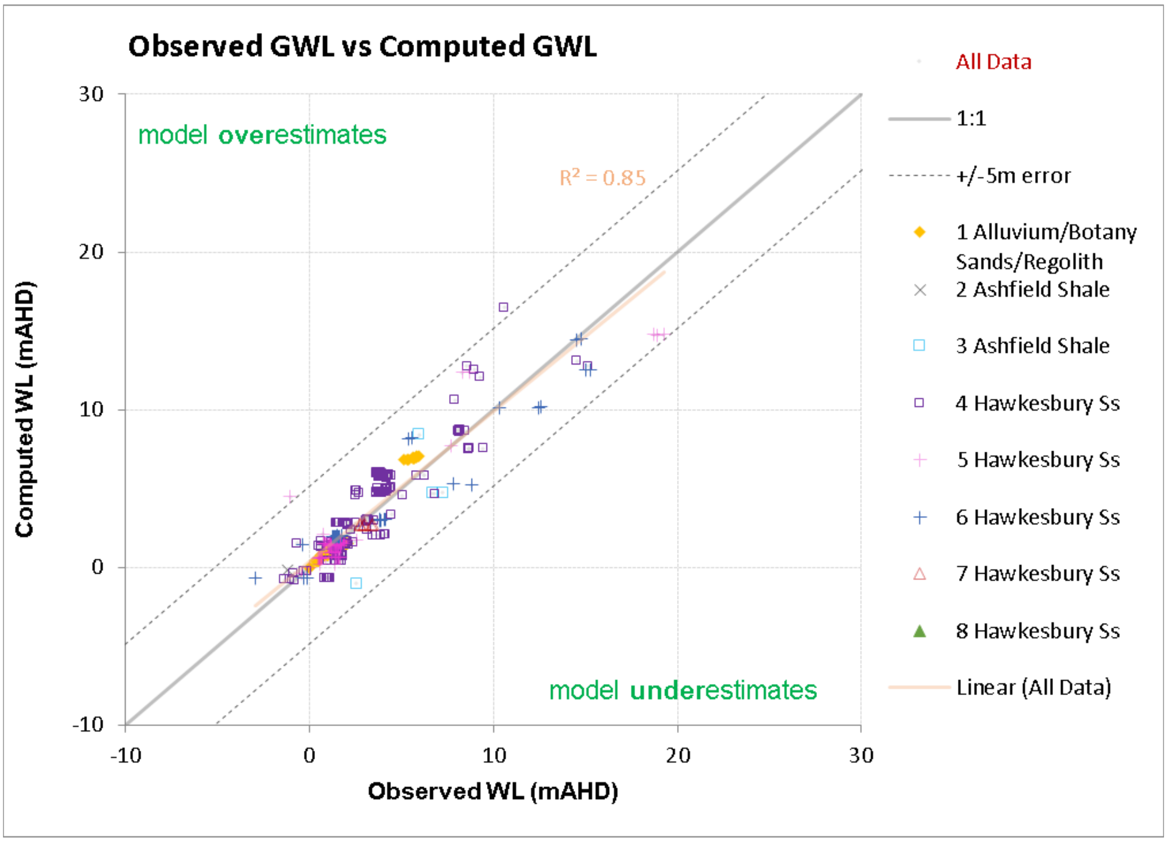


Figure 4-19 Plot of observed vs computed water levels for transient model

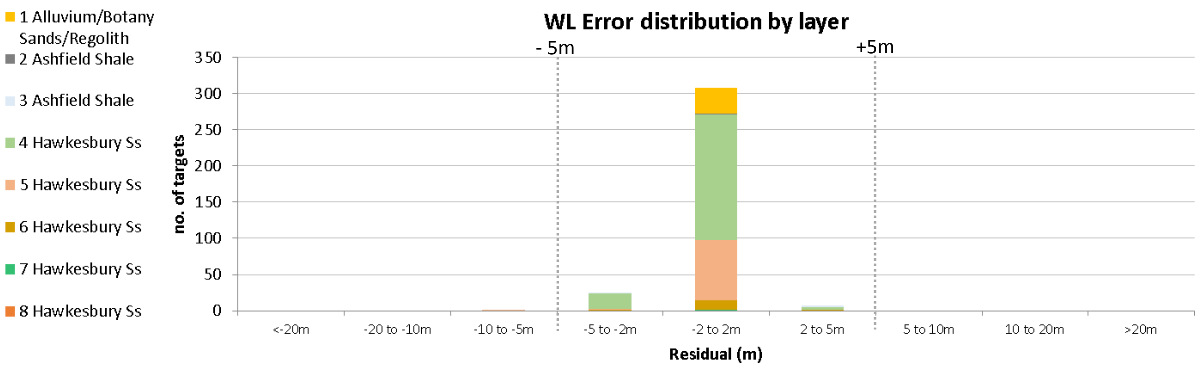


Figure 4-20 Residual error distribution for transient model

4.5.5 TRANSIENT MASS BALANCE

The water balance for the transient simulation is presented in **Table 4-13**. Regional groundwater inflow at model edges is shown to be the most significant sources of groundwater inflow to the model, followed by rainfall recharge and minor leakage from creeks/channels. Regional outflow at model edges and drainage to creeks/channels are the major losses of water from the system, and to a lesser amount evapotranspiration. Over the calibration period, there was a net gain to storage of 0.41 ML/day, which is likely attributable to above average rainfall during the calibration period (as indicated by the upwards trend on the rainfall residual mass curve (see **Section 3.3.1**)).

Tunnel inflow (i.e. model outflow via drains) is 0.67 ML/day, including the M5 East as well as minor contributions from the M4 East tunnel construction (western end) and New M5 construction (western end and near St Peters Interchange). The average inflow attributed to the WCX tunnels excavated during the calibration period is 0.87 L/sec/km.

Table 4-13 Transient model mass balance (averaged over calibration period)

	INFLOW (ML/DAY)	OUTFLOW (ML/DAY)
RECHARGE (RCH)	10.8	0.0
ET (FROM GW) (EVT)	0.0	1.61
GW EXTRACTION ALEXANDRIA LANDFILL (WEL)	0.0	0.08
SW-AQUIFER INTERACTION RIVERS/CHANNELS (RIV)	1.44	12.8
REGIONAL GW FLOW (GHB)	24.6	21.1
TIDAL AREAS CONSTANT HEAD (CHD)	1.2	0.89
TUNNELS (DRN)	0.0	0.67
STORAGE	2.87	3.58
TOTAL	40.8	40.8
% ERROR	0.0	0.0

GHB = General Head Boundary

4.6 ASSESSMENT OF MODEL PERFORMANCE AND LIMITATIONS

4.6.1 MODEL CONFIDENCE LEVEL

Under the earlier MDBC, 2001 modelling guideline, the model is best categorised as an Impact Assessment Model of medium complexity. That earlier guide (MDBC, 2001) describes this model type as follows:

> *"Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies."*

Barnett *et al.*, 2012, developed a system within the modelling guidelines to classify the confidence level for groundwater models. Models are classified as Class 1, Class 2 or Class 3 in order of increasing confidence based on key indicators such as available data, calibration procedures, consistency between calibration and predictive analysis and level of stresses. Under these guidelines, this model would be classified as a Confidence Level 2 (Class 2) groundwater model, with the following key indicators (based on **Table 2-1** of Barnett *et al.*, 2012):

- daily rainfall and evaporation data are available (Level 3 – higher than Level 2);
- groundwater head observations and bore logs are available and with a reasonable coverage around the WCX works, but without spatial coverage throughout the full model domain (Level 2);
- seasonal fluctuations not accurately replicated in all parts of the model domain (Level 2);
- scaled RMS error and other calibration statistics are acceptable (Level 3);
- suggested use is for prediction of impacts of proposed developments in medium value aquifers (Level 2).

4.6.2 MODEL LIMITATIONS

Model calibration data is limited to approximately 9 months of monitoring data for the Project at the time of model construction, and limited data from the other WCX phases and surrounding projects (up to 23 months of intermittent data for the greater WCX program of works). The consequence of this is a poor calibration to seasonal variations in water level.

Similarly, tidal variations of up to 1.5 m (which occur on a bi-daily basis) are not able to be represented in a model that simulates only monthly variations in groundwater stress conditions. Therefore it is assumed that the data used for calibration represents a median water level in areas that are tidally affected.

The use of a MODFLOW-USG unstructured grid allows optimal grid mesh design to represent tunnel workings and other key areas of interest. The groundwater model mesh is based on the design plans issued 21 October and 19 November of 2016. If the final reference design contains significant changes to the tunnel depth and/or alignment, major reworking to the model would be required due to the requirement to recreate a mesh specific to the new design.

All tunnels are assumed to be constructed as unlined except where information is available to indicate areas of lining as part of the design (e.g. beneath Cooks River and specific locations within the Rozelle Interchange, see **Section 3.7.8**). Any changes to this design may affect the predicted impacts from the Project. The existing M5 East tunnels have been simulated with the invert levels set to the design invert level of the New M5 located to the south.

Only major tunnelling works are included in the model to induce drawdown to the water table or reduce potentiometric heads. No other interferences to the water table from pumping, dewatering activities, stormwater drainage channels is included, other than the leachate pumping at Alexandria Landfill. Similarly, recharge from leaking pipeworks and drainage lines, or any artificial recharge (e.g. irrigation) is not included in the model.

The scheduling of tunnel excavation within the model is a best estimate interpretation of the available data within the existing EIS documentation and preliminary draft scheduling for this Project. It is not considered that the model accurately represents the inflows that are likely to be obtained during construction and should not be used for the purposes of planning water management during the construction phase. Rather the model simulates an approximate scenario with enough detail to represent indicative impacts from the construction phase.

The project design and timing may change from what has been modelled once the contractor undertakes detailed design.

The purpose of the groundwater modelling presented in this report is to provide a regional model and represents predicted regional changes due to the M4-M5 Link and interfacing projects. The model inputs are not necessarily sufficiently refined for assessment of groundwater response to the project works in localised areas. Should a particular local area require more detailed assessment of groundwater drawdown and inflow, further analysis should be undertaken as part of the detailed design process.

5 PREDICTIVE MODELLING

5.1 MODELLING APPROACH

Three main predictive model scenarios were run:

1. Scenario 1: A 'No-WCX' or 'Null' run (as per Barnett *et al.*, 2012), without any of the stages of WCX works, but including the existing tunnel M5 East. Hereafter referred to as the 'Null' run or condition.
2. Scenario 2: "Null" run plus the current approved WCX tunnelling (M4 East, New M5), with scheduling as per **Figure 4-11**.
3. Scenario 3: A run the same as Scenario 2, but including the current project (M4-M5 Link) as per **Figure 4-11**.

Comparison of these three runs then allows project-specific and cumulative impact assessment to be carried out. It is not appropriate to run only the current project without the other components of WCX, as the M4-M5 Link will not operate in isolation without M4 East and New M5. Additionally, construction of the M4 East and New M5 has already commenced.

The Aquifer Interference Policy requests impacts assessments to be carried out inclusive of all stresses to the groundwater condition that are known to exist at the time of assessment, therefore in the following sections the cumulative model inclusive of all WCX works is considered representative of the expected changed groundwater regime. Where appropriate the impacts specific to the Project are quantified for its relative contribution.

All models use the calibrated transient historical period, as described in **Section 4.5.4**, as a run-in precursor to the predictive simulation period.

5.2 WATER BALANCE

The simulated water balance for all three scenarios is presented in **Table 5-1**. The water balance indicates that for all scenarios the major inputs into the model are from regional boundary inflows and rainfall recharge. The key outflows from the model are via regional outflow, river baseflow and evapotranspiration, with the volume of water exiting the model by these outlets reducing with each scenario as a response to additional water being removed with extra lengths of tunnels. The relative impacts of each component of WCX on the water balance is discussed in the following sections. By the project opening in June 2023 there is expected to be a small gain in storage (net volume of water available in the aquifer equating to a slight overall rise in water levels) of about 0.13 ML/day for Scenario 1. This is due to the simulated recharge over the period between 2015 and 2017 being higher than the steady-state (long-term average) recharge which was used to create initial conditions for the model (refer to Section 4.4.1). Scenario 2 and Scenario 3 have a predicted loss in storage of 0.76 ML/day and 1.67 ML/day respectively, indicating that the successive lengths of tunnel are increasingly draining water from the system.

Table 5-1 Simulated groundwater balance to project opening (June 2023)

Component (ML/day)	Inflow (Recharge)			Outflow (Discharge)		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Recharge (RCH)	9.52	9.52	9.52	0.00	0.00	0.00
ET (from GW) (EVT	0.00	0.00	0.00	1.59	1.55	1.53
SW-Aquifer Interaction Rivers/Channels (RIV)	1.46	1.58	1.60	12.78	12.54	12.44
Tunnels (DRN)	0.00	0.00	0.00	0.45	1.80	2.87
GW Extraction Alexandria Landfill	0.00	0.00	0.00	0.06	0.05	0.05
Regional GW Flow (GHB)	24.90	24.95	24.95	21.42	21.40	21.40
Tidal Areas Constant Head (CHD)	1.43	1.43	1.43	0.88	0.88	0.88
Storage	1.54	2.37	3.26	1.67	1.61	1.59
TOTAL	38.84	39.84	40.75	38.84	39.84	40.75

Scenario 1= Null run (M5 East tunnel only), Scenario 2 = Scenario 1 + M4 East + New M5, Scenario 3 = Scenario 2 + M4-M5 Link

5.3 PREDICTED WATER LEVELS

Predicted groundwater levels at the end of construction for the project (model Scenario 3) are shown in **Figure 5-1** to **Figure 5-9.** These figures show groundwater levels for the water table, Ashfield Shale and Hawkesbury Sandstone in representative model layers 1, 3 and 6 (respectively).

5.3.1 SCENARIO 1 – NULL RUN WITH ONLY THE EXISTING M5 EAST TUNNEL OPERATIONAL

Figure 5-1 to **Figure 5-3** show predicted groundwater levels in each unit for Scenario 1 (only M5 East tunnel operational).

Water levels in Scenario 1 with no WCX show the water table in **Figure 5-1** is controlled by topography with drainage towards Parramatta River/Sydney Harbour in the north and Cooks river in the south. Depressed water levels exist along the M5 East alignment. Pre-WCX groundwater levels in the Ashfield Shale (**Figure 5-2**) and Hawkesbury Sandstone (**Figure 5-3)** show dominant flow direction towards Botany Bay and Parramatta River.

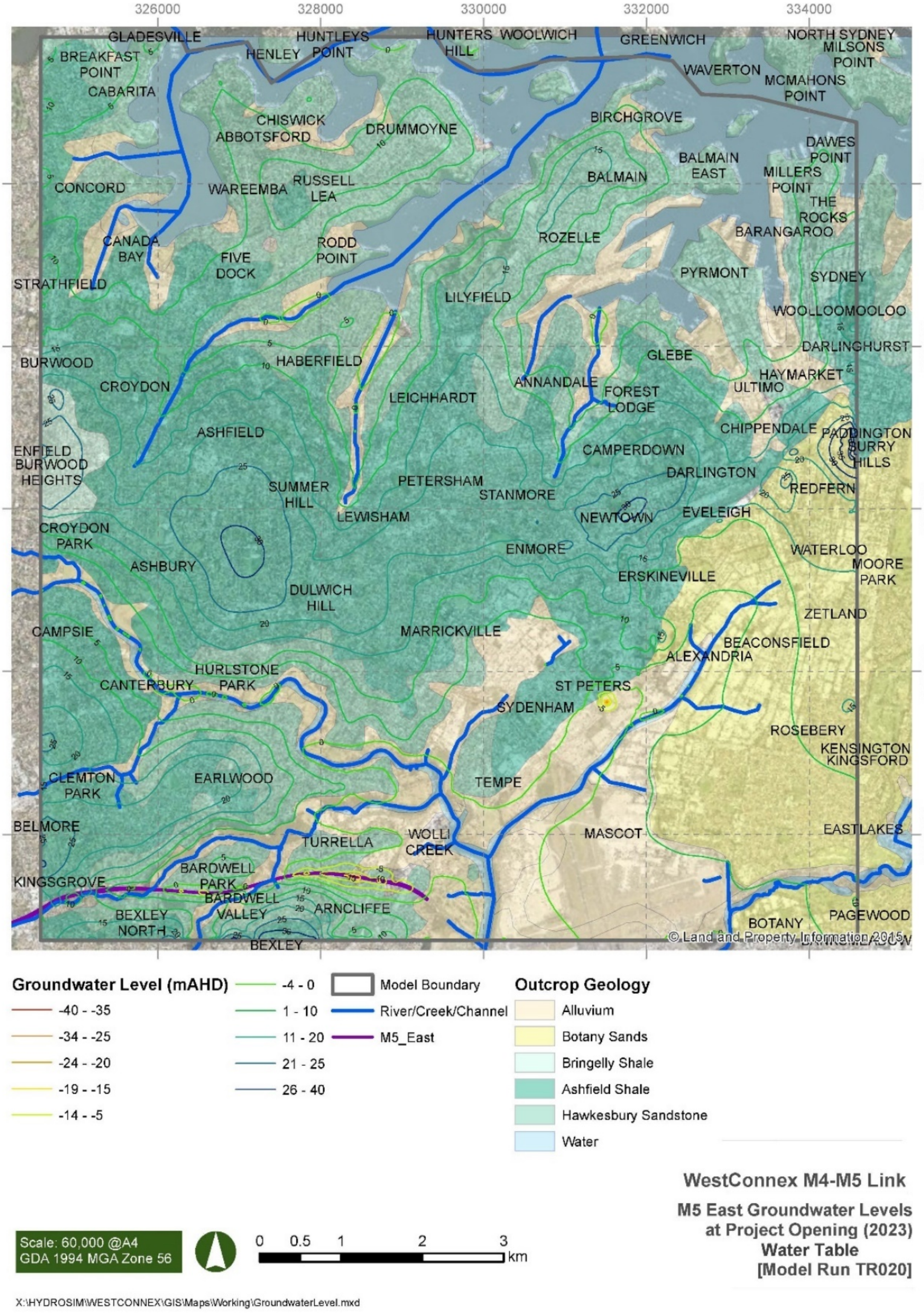


Figure 5-1 Scenario 1 – Water table at June 2023

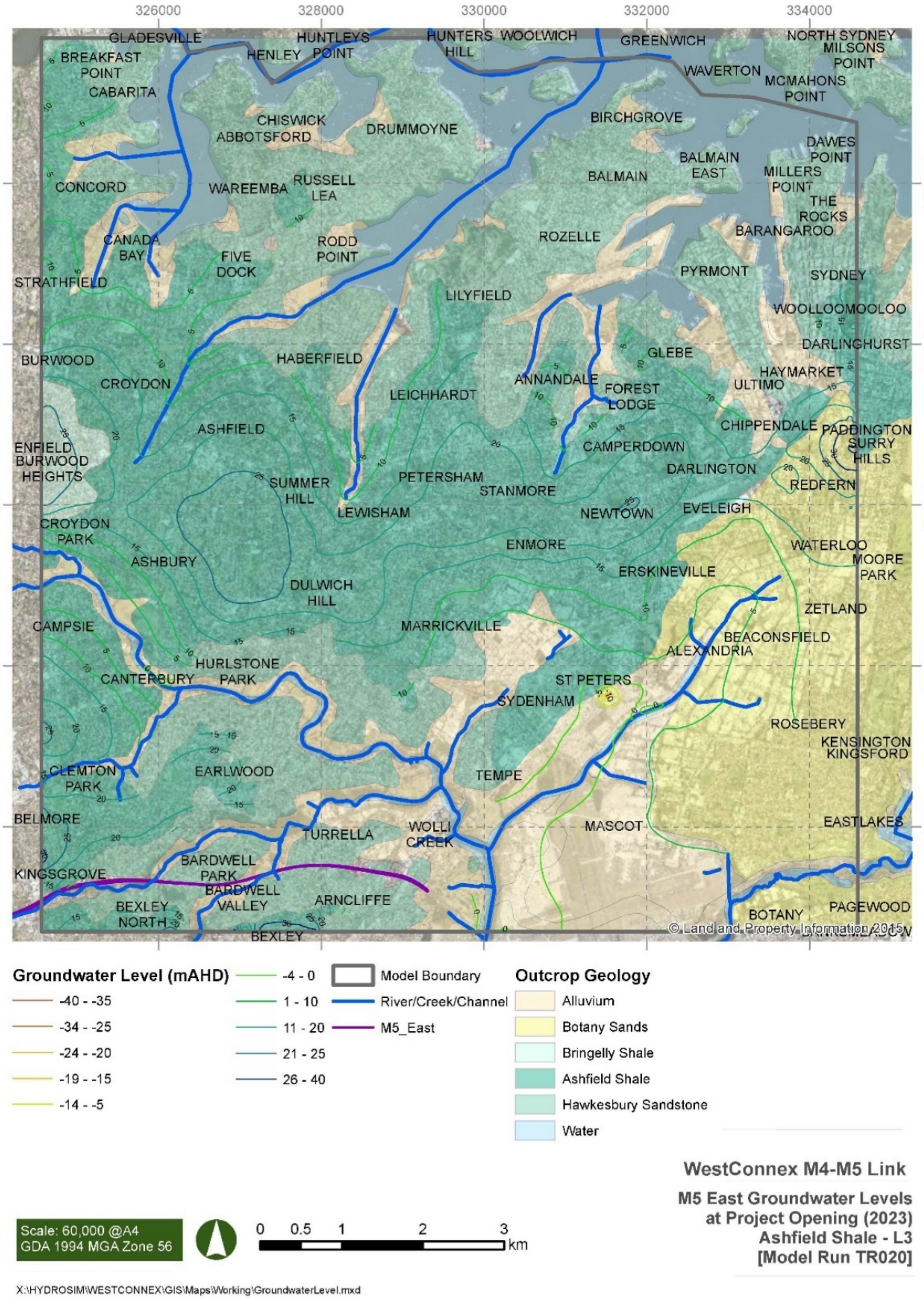


Figure 5-2 Scenario 1 - Groundwater levels in the Ashfield Shale at June 2023

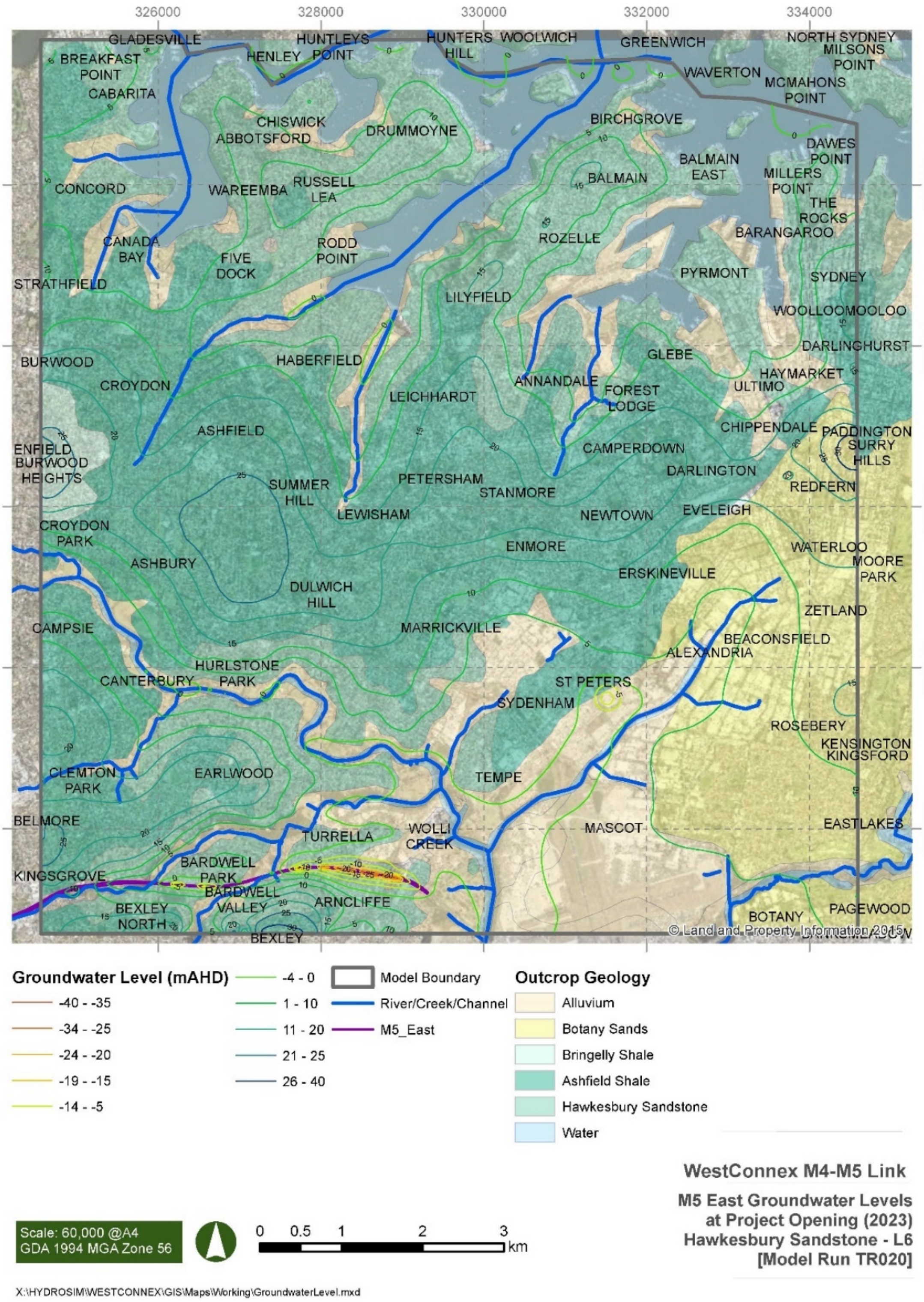


Figure 5-3 Scenario 1 - Groundwater levels in the Hawkesbury Sandstone at June 2023

5.3.2 SCENARIO 2: NULL RUN PLUS THE CURRENT APPROVED WCX TUNNELLING (M4 EAST, NEW M5)

With the addition of the approved WCX works (Scenario 2 with only the M4 East and New M5) shown in **Figure 5-4** to **Figure 5-6** the groundwater levels form steep elongated cones of depression along the tunnel alignments, indicating hydraulic connection between the deeper layers that the tunnel is excavated within (typically Hawkesbury Sandstone) and the surface, with lesser variation in water levels seen in areas of alluvium. The depressed contours are localised, with no variation in contours observable beyond approximately 500 m of the alignments, therefore the regional groundwater flow pattern does not appear to be significantly affected by the construction of the tunnels and only localised flow direction changes towards the tunnels would occur.

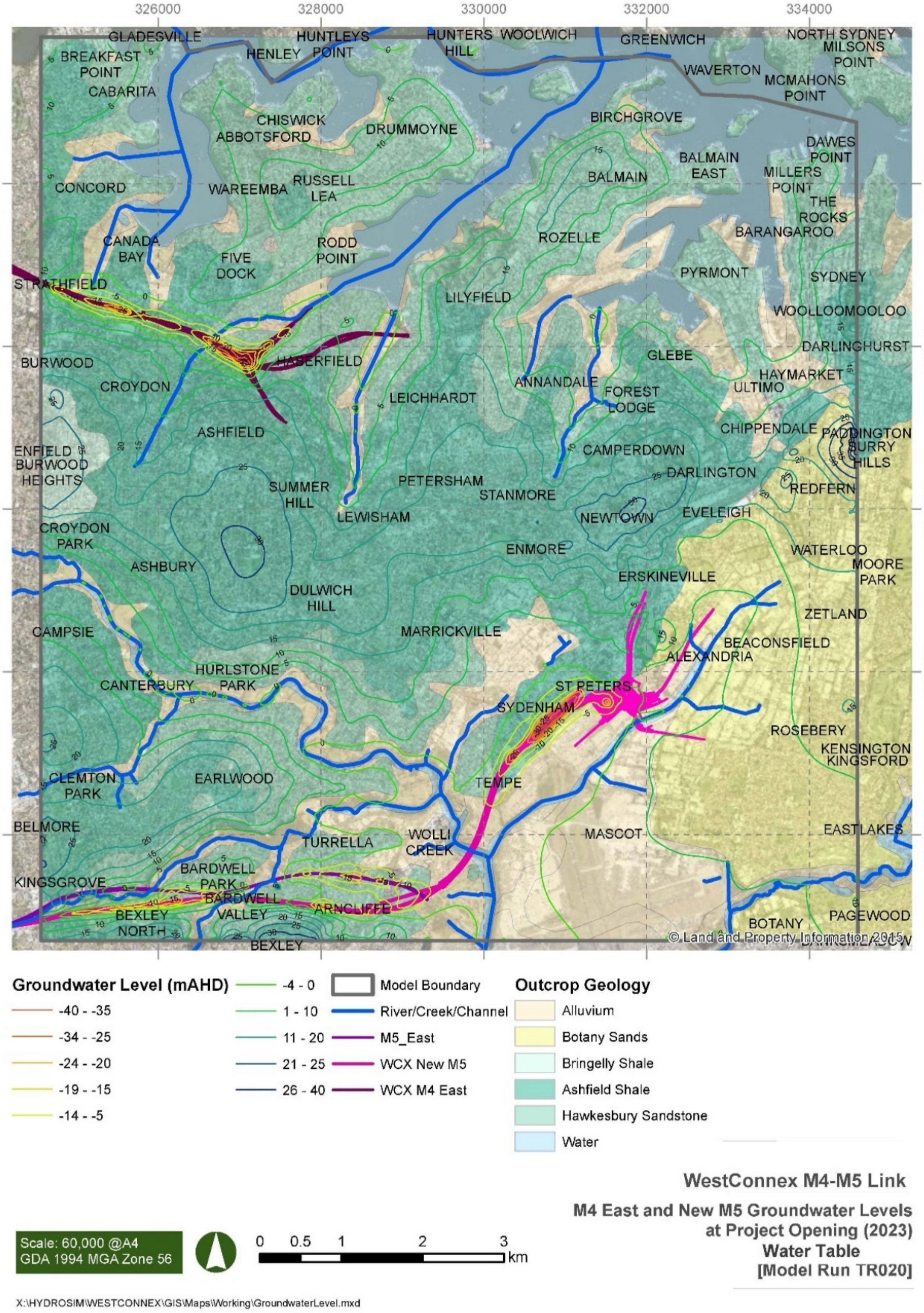
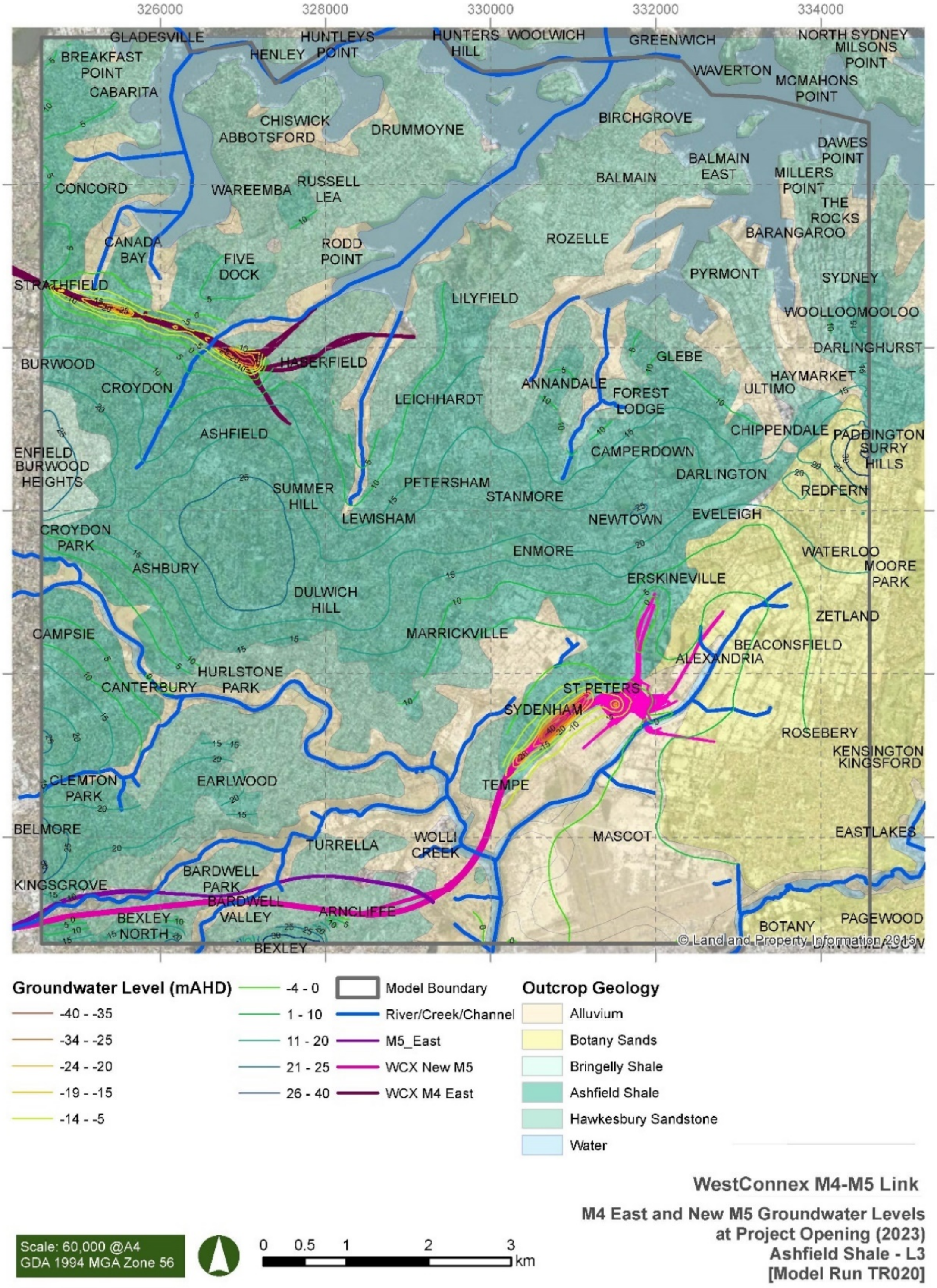


Figure 5-4 Scenario 2 – Water table at June 2023



X:\HYDROSIM\WESTCONNEX\GIS\Maps\Working\GroundwaterLevel.mxd

Figure 5-5 Scenario 2 - Groundwater levels in the Ashfield Shale at June 2023

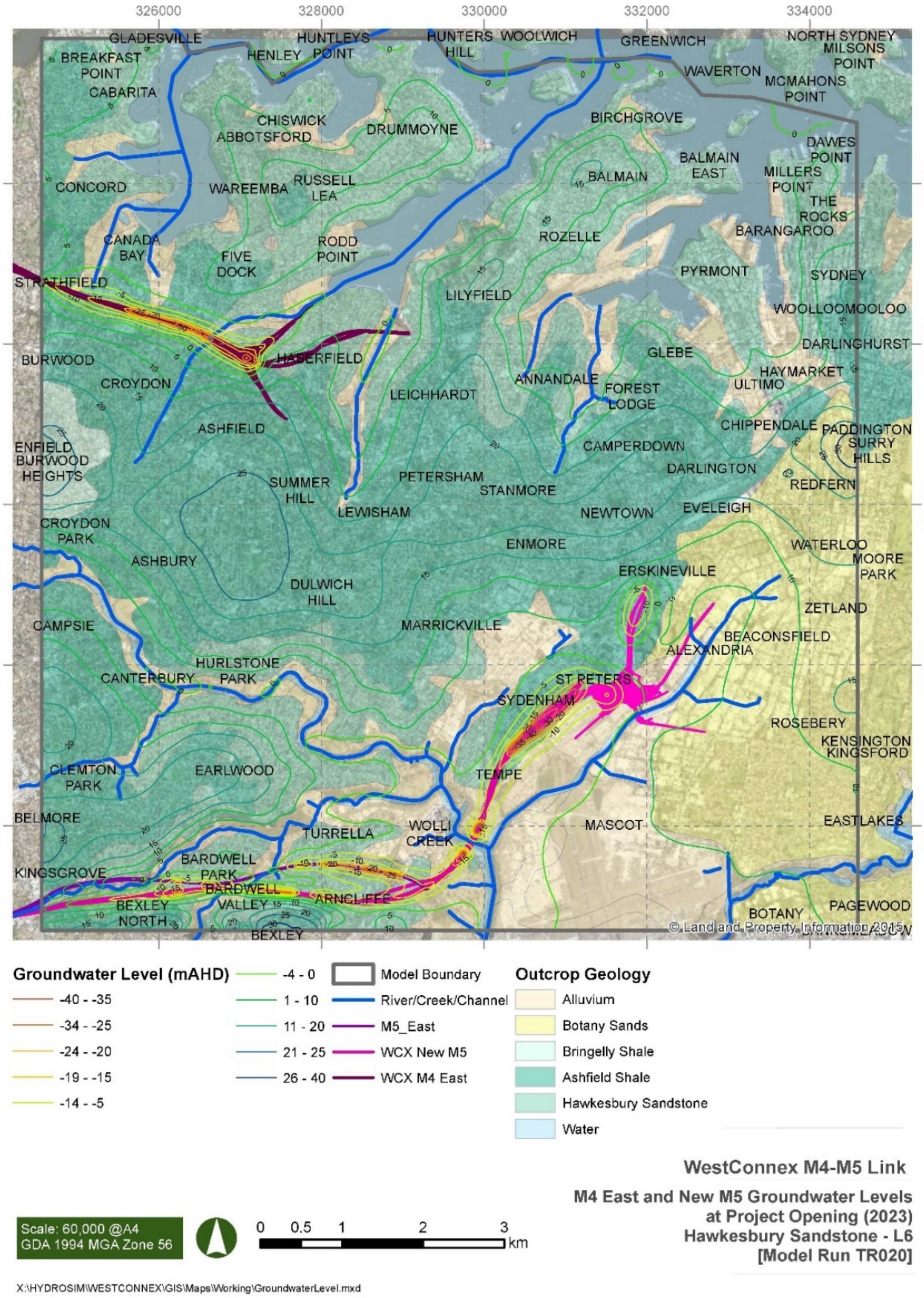


Figure 5-6 Scenario 2 - Groundwater levels in the Hawkesbury Sandstone at June 2023

5.3.3 SCENARIO 3: SCENARIO 2 PLUS THE CURRENT PROJECT (M4-M5 LINK)

Groundwater contours for Scenario 3 with all WCX tunnels operational are shown in **Figure 5-7** to **Figure 5-9.** As with Scenario 2, groundwater flow direction is altered such that flow is towards the WCX tunnels. This remains a relatively localised change, however the tunnel acts as a sink along almost its entire length effectively blocking the transmission of groundwater to its original discharge points. This is particularly evident in the Hawkesbury Sandstone (**Figure 5-9**), in part due to the fact most of the tunnelling occurs with the Hawkesbury Sandstone, and in part due to the fact the other geological units are not fully continuous across the model. It is expected that due to the thickness of the Hawkesbury Sandstone (up to 290 m regionally), groundwater at some depth below the tunnel would cease being drawn upwards towards the tunnels and regional groundwater flow would continue uninterrupted towards natural zones of discharge; however this process would occur beyond the base of the sandstone modelled (the maximum thickness of Hawkesbury Sandstone modelled is 150 m, with 100 m being the average thickness).

The minor project design changes that have been proposed post groundwater modelling (**Section 2.2.1**) are not anticipated to result in a significant change to the groundwater flow regime from that modelled.

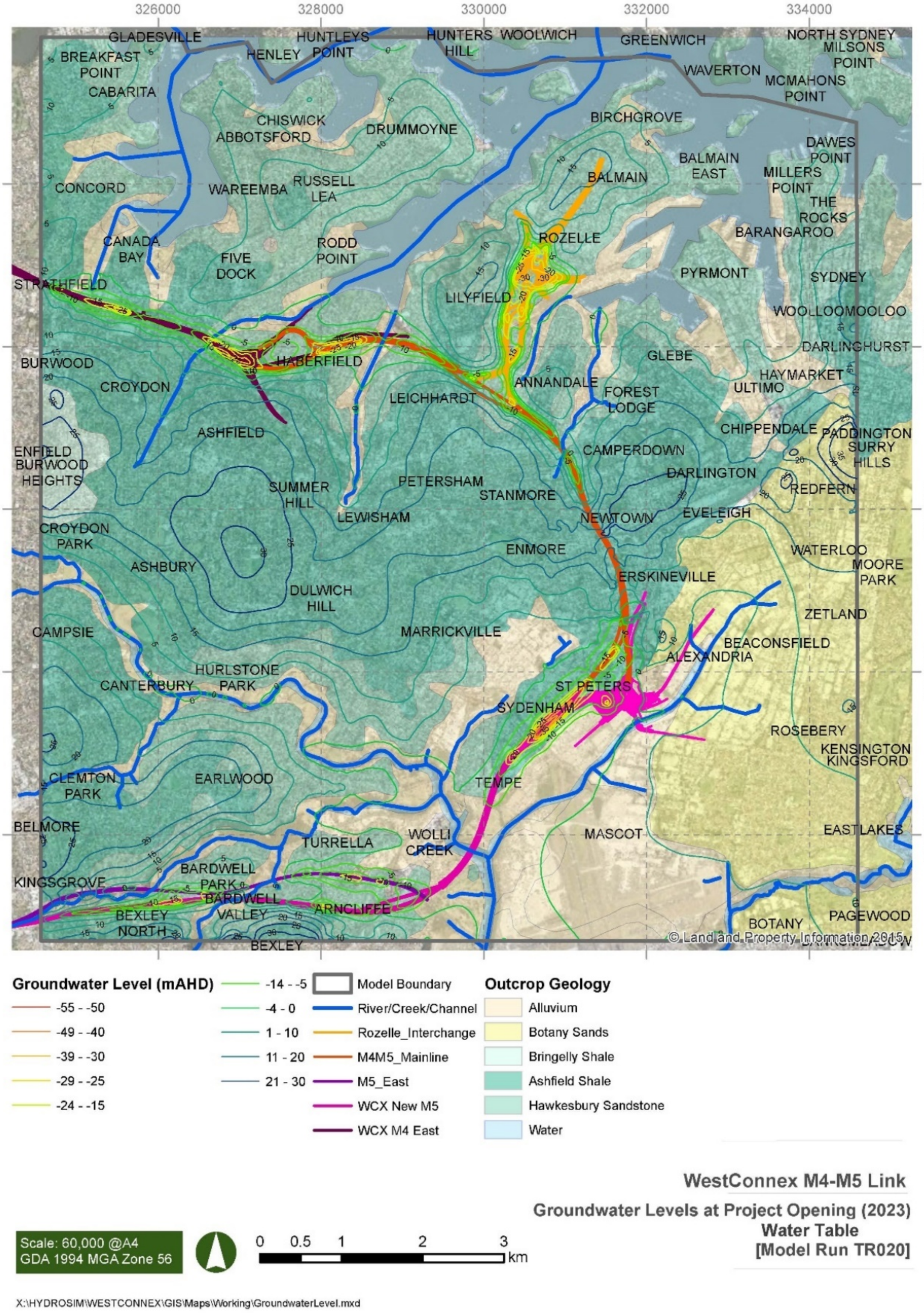


Figure 5-7 Scenario 3 - Water table at June 2023

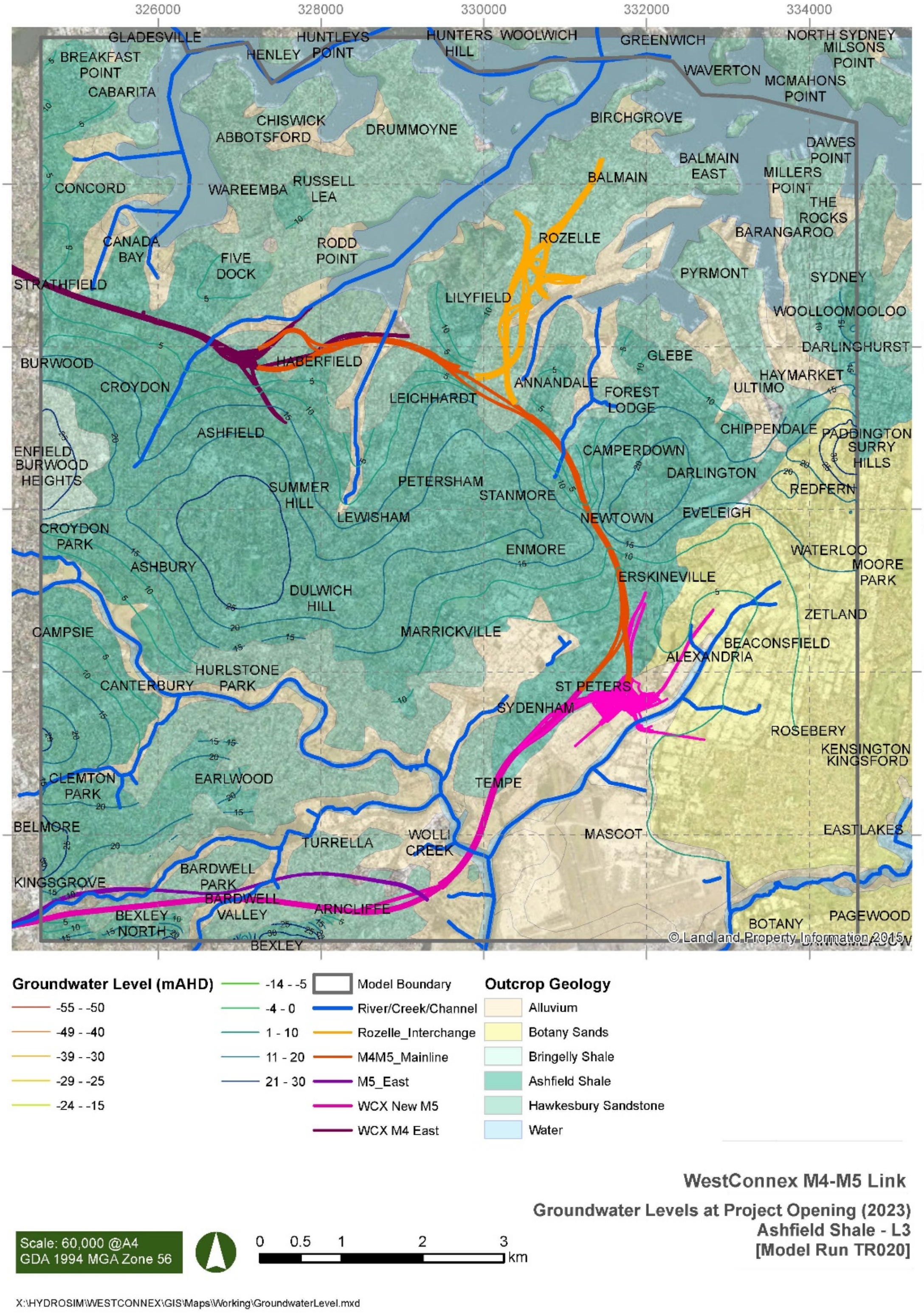


Figure 5-8 Scenario 3 - Groundwater levels in the Ashfield Shale at June 2023

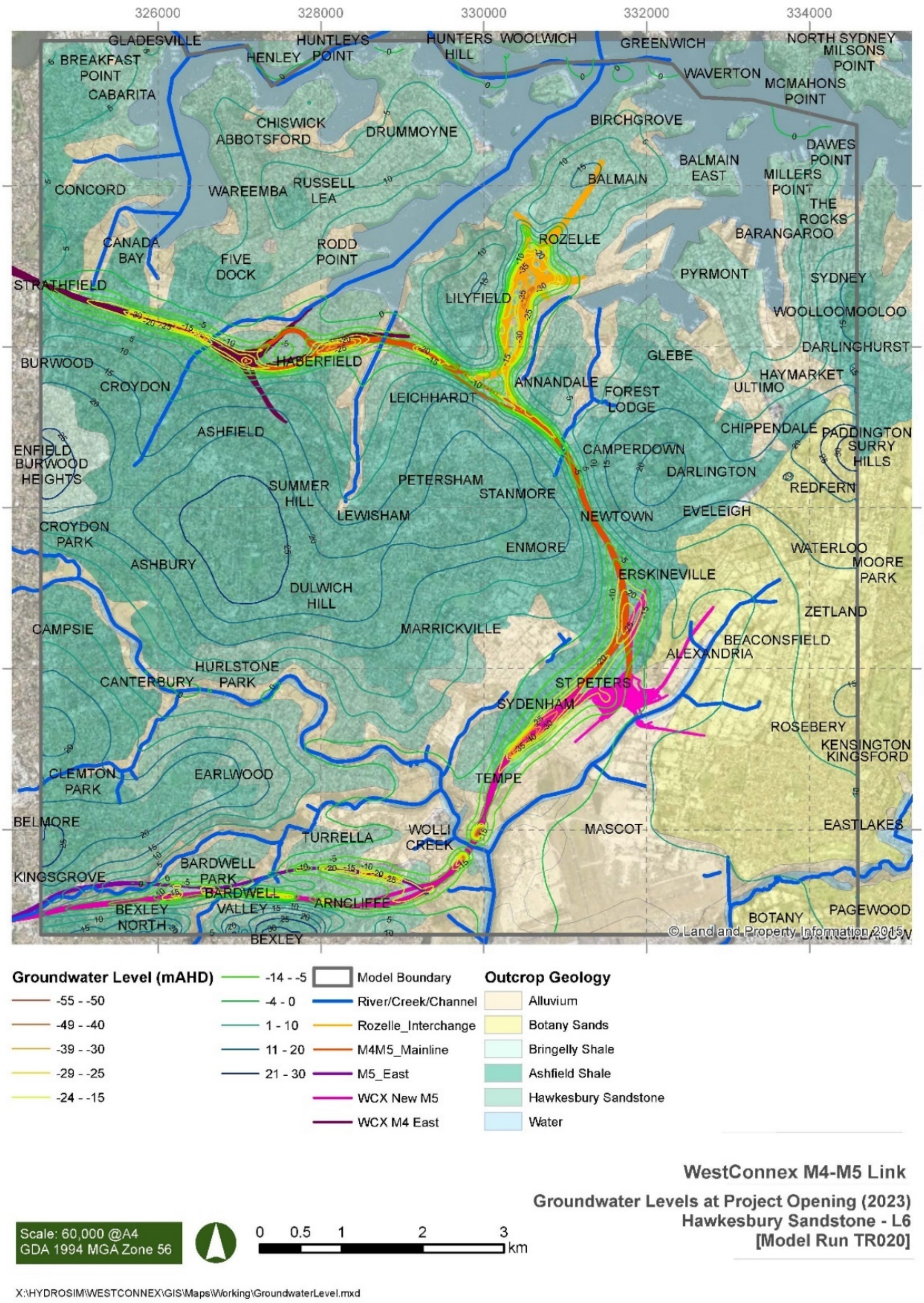


Figure 5-9 Scenario 3 - Groundwater levels in the Hawkesbury Sandstone at June 2023