4.9 Groundwater levels and movement

Baseline groundwater level data has been collected in the groundwater monitoring network installed along the proposed project footprint. The monitoring network consists of 58 monitoring wells intersecting groundwater from the alluvium, Ashfield Shale and Hawkesbury Sandstone as summarised in Table B1, **Annexure B**. The baseline monitoring is based on manual groundwater level data collected monthly from June 2016 and time series data collected from dataloggers and compared to rainfall. The monitoring wells have been surveyed and groundwater levels converted to metre AHD as summarised in Table B2, **Annexure B**. Based on these reduced levels, groundwater contours have been interpolated in key areas for each aquifer.

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

The depth to groundwater, groundwater flow directions, the distribution of piezometric and potentiometric heads for each aquifer is discussed in more detail in **sections 4.9.2** to **4.9.4**.

4.9.1 Regional groundwater flow

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

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

Along the proposed project footprint alluvium flanks the creeks and Sydney Harbour, and is more widespread where deep palaeochannels have been identified, such as beneath Hawthorne Canal and the Rozelle Rail Yards. Within the alluvium, groundwater is typically unconfined and flowing along the axis of the palaeochannel or, in the case of alluvium flanking the harbour, towards the closest surface waterbody. In areas of widespread filling, such as the foreshore of Rozelle Bay, there may be some perched groundwater within the fill, however discharge to Rozelle Bay would be controlled by local discharge and drainage zones that are likely to respond to rapid, short term, rainfall events.

4.9.2 Alluvium

Groundwater levels within the alluvium are monitored in 10 monitoring wells installed for the project. Groundwater levels are primarily controlled by local recharge and discharge conditions. Since the alluvium is typically low lying and connected to surface water within creeks or Sydney Harbour, the elevation of the water table within the unconfined aquifers is typically less than one metre AHD. Monitored tidal oscillations within the alluvium indicate hydraulic connectivity with surface waterbodies including the canals, creeks and Sydney Harbour (see **section 4.9.5**).

Nested wells have been constructed at seven locations where alluvium overlies the Hawkesbury Sandstone to investigate differences in groundwater levels and quality. The hydrogeological technical details based on August 2016 gauging are summarised in **Table 4-2**.

HydroSimulations 2017, have compared hydrographs RZ_BH47s and RZ_BH49 with the rainfall residual mass curve (**Figure 4-3**) to compare groundwater trends with the long term rainfall average for the same period. In each case rainfall residual mass curve approximates the groundwater level trend suggesting that the alluvium responds in general accordance with long term rainfall and is not influenced substantially by any other factor.

Table 4-2 Summary of groundwater levels measured in nested wells

Precinct	Borehole Nest (shallow and deep)	Alluvial aquifer (s)		Hawkesbury Sandstone (d)		SWL[1] mAHD
		Screen interval (m)	SWL[1] m AHD (Aug 2016)	Screen interval (m)	SWL[1] m AHD (Aug 2016)	Difference (m)
Haberfield	HB_BH08	10 – 13	1.04	22 – 25	1.49[2]	0.45[2]
Rozelle	RZ_BH01	7 – 10	2.04	22 – 25	1.56	-0.48
Rozelle	RZ_BH44	12 – 15	1.11	25 – 28	1.87	0.76
Rozelle	RZ_BH47	15 – 18	1.16	27 – 30	1.55	0.39
The Crescent	TC_BH01	3 – 6	1.00	25 – 28	1.65	0.65
The Crescent	TC_BH07	3 – 6	0.47	19 – 22	1.63	1.16
The Crescent	TC_BH09	2 – 5	0.69	21 – 24	1.61	0.92

Notes:

1 SWL Standing water level

2 HB_BH08d is artesian and thus the pressure head is greater than 1.49 metre

With one exception, groundwater levels measured in nested monitoring wells have demonstrated that groundwater levels in the alluvium are typically lower than those in the underlying Hawkesbury Sandstone. The difference in pressure heads between the alluvium and Hawkesbury Sandstone varies from -0.48 to 1.16 metre. Since HB_BH08d is artesian and the well cap prevents water from discharging from the well the pressure head is greater than 0.45 metre. Hence, overall there is upward pressure from the Hawkesbury Sandstone to the alluvium where groundwater from the Hawkesbury Sandstone could be discharging into the alluvium if there is hydraulic connection. This upward pressure gradient may not be indicative of the whole sandstone unit along the proposed project footprint as the Hawkesbury Sandstone is often compartmentalised due to stratigraphic confining layers and structural defects creating different hydraulic conditions throughout the aquifer. The one exception is RZ_BH01 at Rozelle where the pressure head in the alluvium is 0.48 metres higher than the underlying Hawkesbury Sandstone. This pressure head differential is attributed to local conditions, as the alluvium associated with Whites Creek is located 50 metres up-gradient from the bore and is topographically higher which may be providing the higher hydraulic head in the alluvium.

Groundwater contours within the alluvium have been interpolated and are presented in **Figure 4-10** and **Figure 4-11**. Along Hawthorne Canal, alluvial groundwater is shallow and flowing northward, discharging into Parramatta River. Collation of groundwater levels beneath Whites Creek and the Rozelle Rail Yards indicates there are two alluvial sub-aquifers; one shallow sub-aquifer that is 10 metres or less thick and a deeper palaeochannel greater than 10 metres thick. Reference to the borelogs for the Rozelle area (AECOM 2017a) indicates there is a clay layer that is providing a confining layer between the upper and lower alluvial aquifers. Groundwater levels measured within the shallow alluvium (around The Crescent at Annandale) measured from 0.47 metres AHD to 1.08 metres AHD. Similarly the groundwater levels measured within the deep palaeochannel (within the

Rozelle Rail Yards at Rozelle) range from 1.11 metres AHD to 2.04 metres AHD. Comparison of the two sets of groundwater levels indicate the water levels in the palaeochannel are higher by about 0.5 metres than the shallow alluvium indicating there is upward pressure from the palaeochannel into the shallow alluvium, and groundwater from the palaeochannel may be discharging into the shallow alluvium. In each case, groundwater within the alluvium is flowing eastward discharging into Rozelle Bay.

On a regional scale the groundwater flow direction is controlled by topography with drainage towards Parramatta River and Sydney Harbour in the north, and Cooks River in the south.

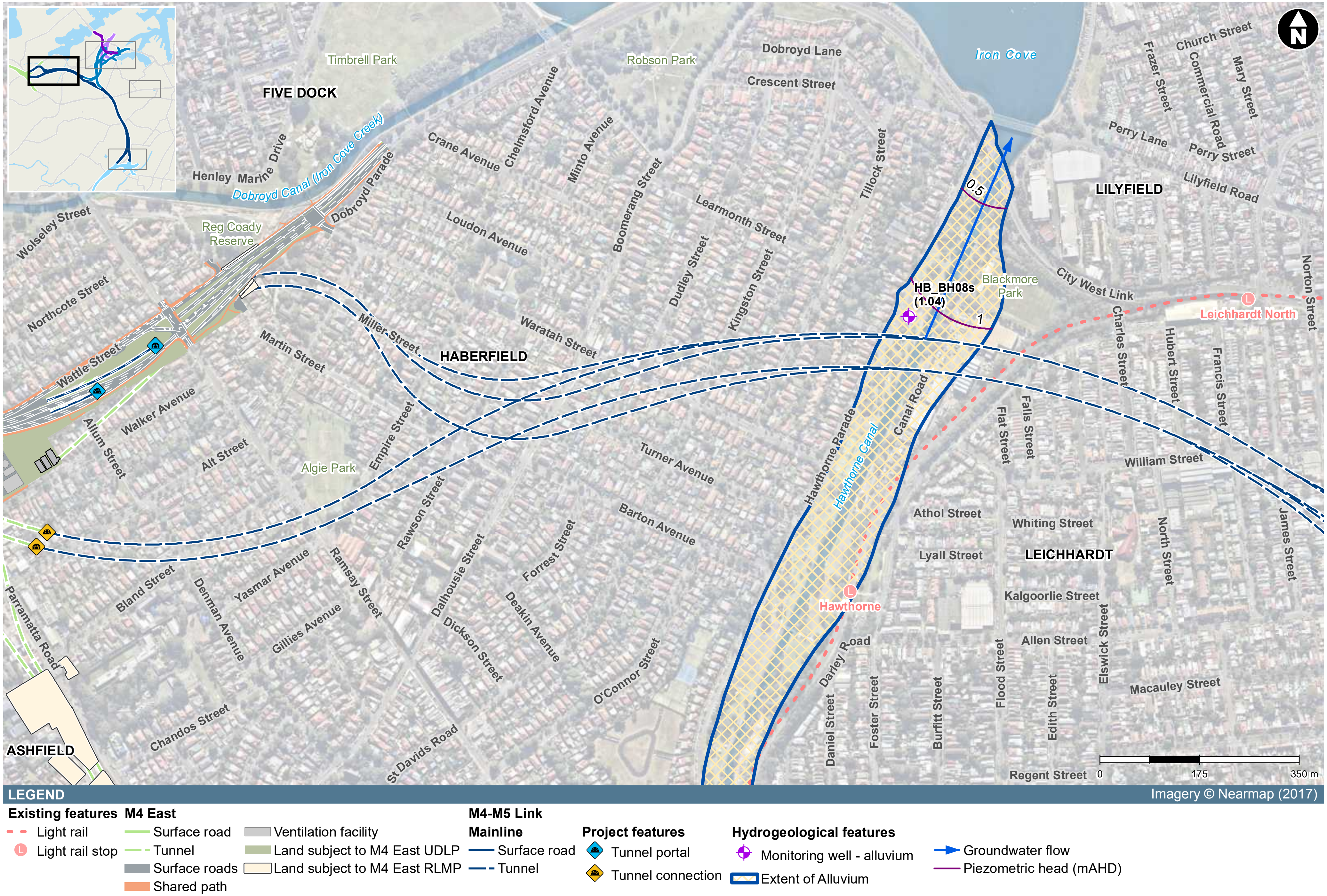


Figure 4-10 Groundwater contours - alluvium (Hawthorne Canal)

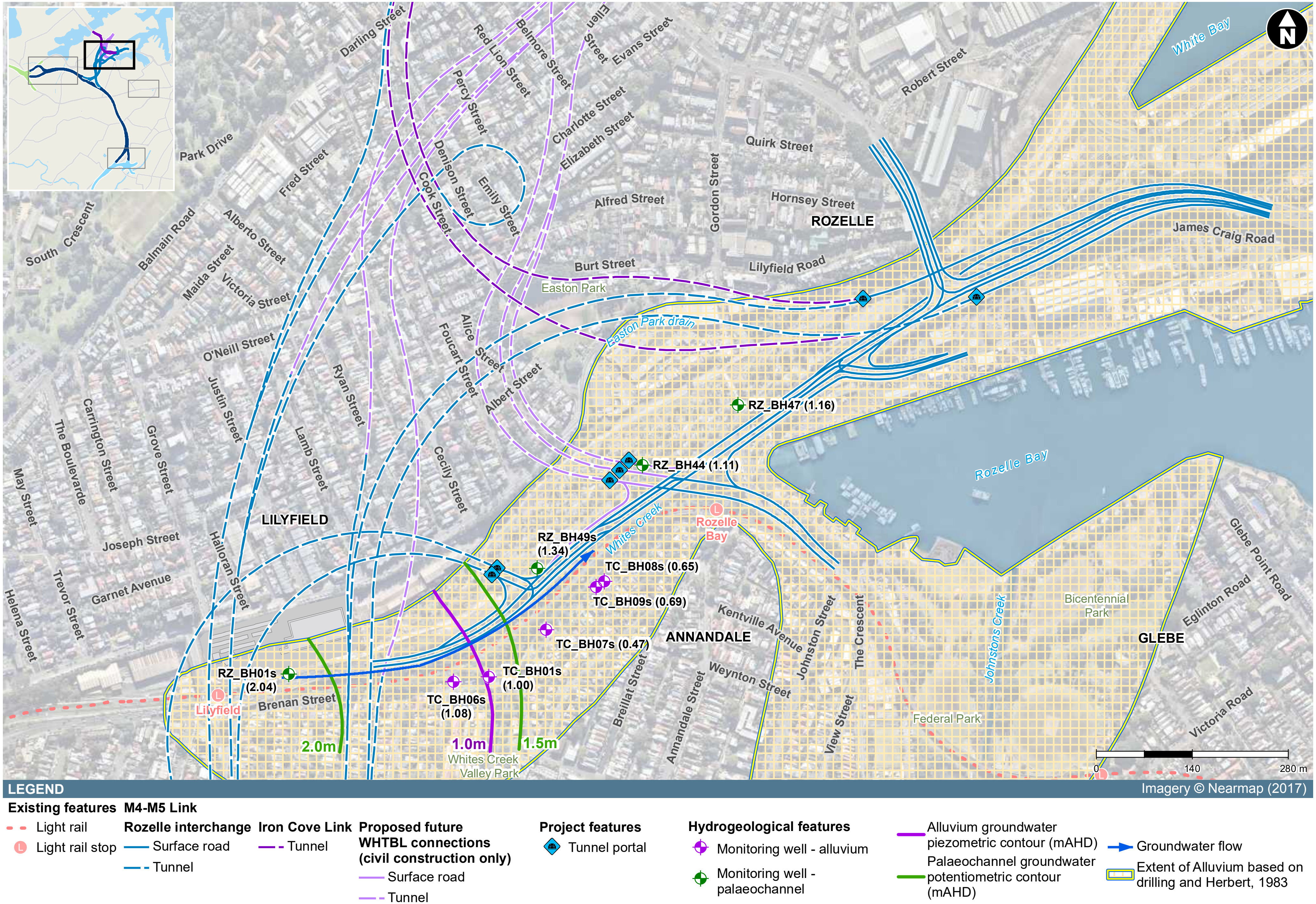


Figure 4-11 Groundwater contours - alluvium (Whites Creek)

4.9.3 Ashfield Shale

Groundwater levels within the Ashfield Shale are monitored within the Camperdown and St Peters precincts of the project in eight monitoring wells. At St Peters, groundwater levels are influenced by ongoing leachate pumping from the former Alexandria Landfill (Hawkes and Evans 2016). Although no longer receiving waste and while undergoing rehabilitation, the former landfill still generates leachate that requires extraction via pumping, followed by on-site treatment, then discharge into Alexandra Canal. Groundwater monitoring undertaken as part of the WestConnex New M5 hydrogeological investigation confirmed that there is radial flow within the Ashfield Shale centred on the landfill caused by leachate pumping.

Potentiometric heads measured within the Ashfield Shale in the St Peters and Camperdown areas are presented in **Figure 4-12** and **Figure 4-13**. The highest groundwater level measured in the Ashfield Shale was measured in monitoring well CM_BH04, located at Camperdown at an elevation of 22.1 metre AHD, where the topography along the project footprint is at a high point. At the southern part of the project footprint next to the St Peters interchange, groundwater flows radially towards the western part of the landfill due to ongoing leachate pumping. This radial flow pattern and reversed hydraulic gradients prevents contamination from dispersing into the Ashfield Shale. Within the Sydney Basin, perched groundwater is typically present within the residual soil profile or where jointing and bedding plane partings are well developed but not infilled with clay of the Ashfield Shale. The monitoring wells have been constructed to extend beyond any perched aquifers to intersect the regional aquifer. Consequently, the data collected during this program is considered suitable for inclusion in the groundwater model calibration.

HydroSimulations 2017 have compared hydrograph SP_BH06 with the rainfall residual mass curve (see **Figure 4-3**) to compare groundwater trends with the long term rainfall average for the same period. Groundwater levels within the Ashfield Shale at this location closely follow the rainfall residual mass curve for the same period indicating that rainfall recharge is the primary mechanism in maintaining the hydraulic head within the shale.

On a regional scale, the natural groundwater level contours within the Ashfield Shale have been simulated as part of the groundwater model development based on groundwater level measurements (see **Figure 4-14**). Review of the groundwater level contours shows the dominant groundwater flow direction is towards Botany Bay and Sydney Harbour.

4.9.4 Hawkesbury Sandstone

Groundwater levels within the Hawkesbury Sandstone are monitored in 40 monitoring wells across the project footprint. The elevation of measured groundwater levels ranges from 0.63 metre AHD (RZ_BH47d) beneath the Rozelle Rail Yards to 20.27 metre AHD (CM_BH01) beneath Camperdown. Artesian groundwater within the Hawkesbury Sandstone has been intersected in two monitoring wells in the low lying areas beneath Hawthorne Parade and Darley Road, Leichhardt. The distribution of potentiometric heads measured within the Hawkesbury Sandstone at Haberfield and Rozelle are shown on **Figure 4-15** and **Figure 4-16** respectively.

HydroSimulations 2017 have compared two hydrographs screened in the Hawkesbury Sandstone that have produced different trends. Monitoring well RZ_BH28 located within the Rozelle Rail Yards displays a declining groundwater trend from August 2016 through to February 2017 and rising after a large February 2017 rainfall event. This trend mimics the rainfall residual mass curve suggesting rainfall recharge is the primary mechanism maintaining hydraulic heads at this location. In contrast, the groundwater level trend in monitoring well SP_BH04, screened within the Hawkesbury Sandstone does not appear to respond to rainfall recharge and does not follow the rainfall residual mass curve. These trends are attributed to external influences which could be a combination of the commencement of the New M5 tunnel construction and leachate pumping at St Peters from the former Alexandria Landfill.

At Haberfield, measured groundwater levels within the Hawkesbury Sandstone are variable and range from 0.5 to 8 metre AHD. The groundwater elevation tends to reflect the position of the monitoring well in the landscape with the hydraulic head increasing with distance from Rozelle Bay. Along Hawthorne Parade, since early June 2016, the potentiometric head (measured in HB_BH08d at a depth interval of 22–25 metres) has been artesian and on 28 October 2016 the head was measured at 0.16 metres above ground level (or 1.65 metre AHD). Similarly, at HB_BH12, located at Darley

Road, Leichhardt, the well was flowing when completed in June 2016 but in October 2016 the standing water level was measured at 0.05 metres below the top of casing. At Haberfield and Rozelle, groundwater contours for the potentiometric head within the Hawkesbury Sandstone have not been constructed due to the flat hydraulic gradients.

On a regional scale, the natural groundwater level contours within the Hawkesbury Sandstone have been simulated as part of the groundwater model development based on groundwater level measurements (see **Figure 4-17**). Review of the groundwater level contours shows the dominant groundwater flow direction is similar to the Ashfield Shale, flowing towards Botany Bay and Sydney Harbour. Depressed groundwater levels exist along the existing M5 East alignment due to groundwater leakage to the M5 East tunnels.

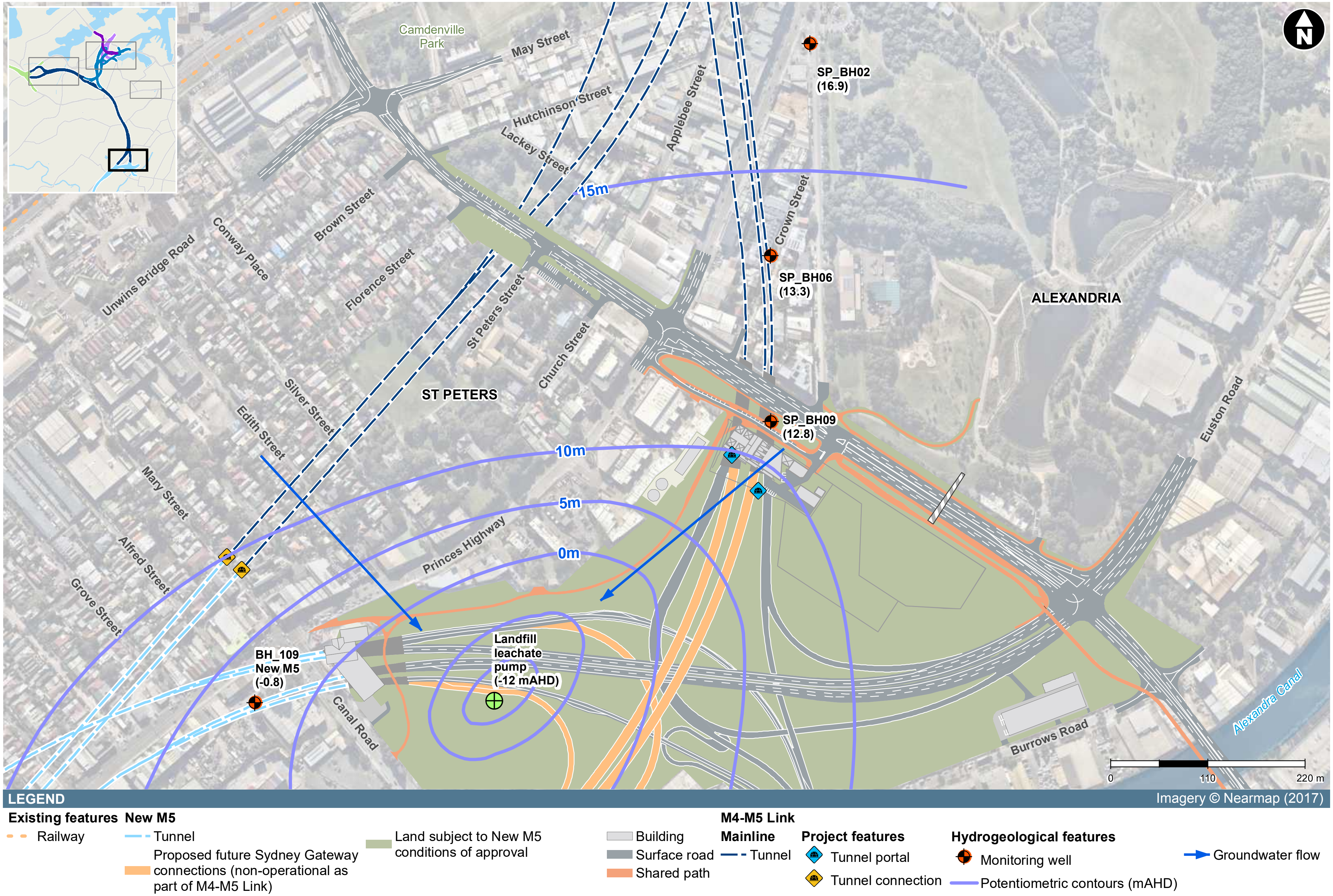


Figure 4-12 Groundwater contours - Ashfield Shale (St Peters)

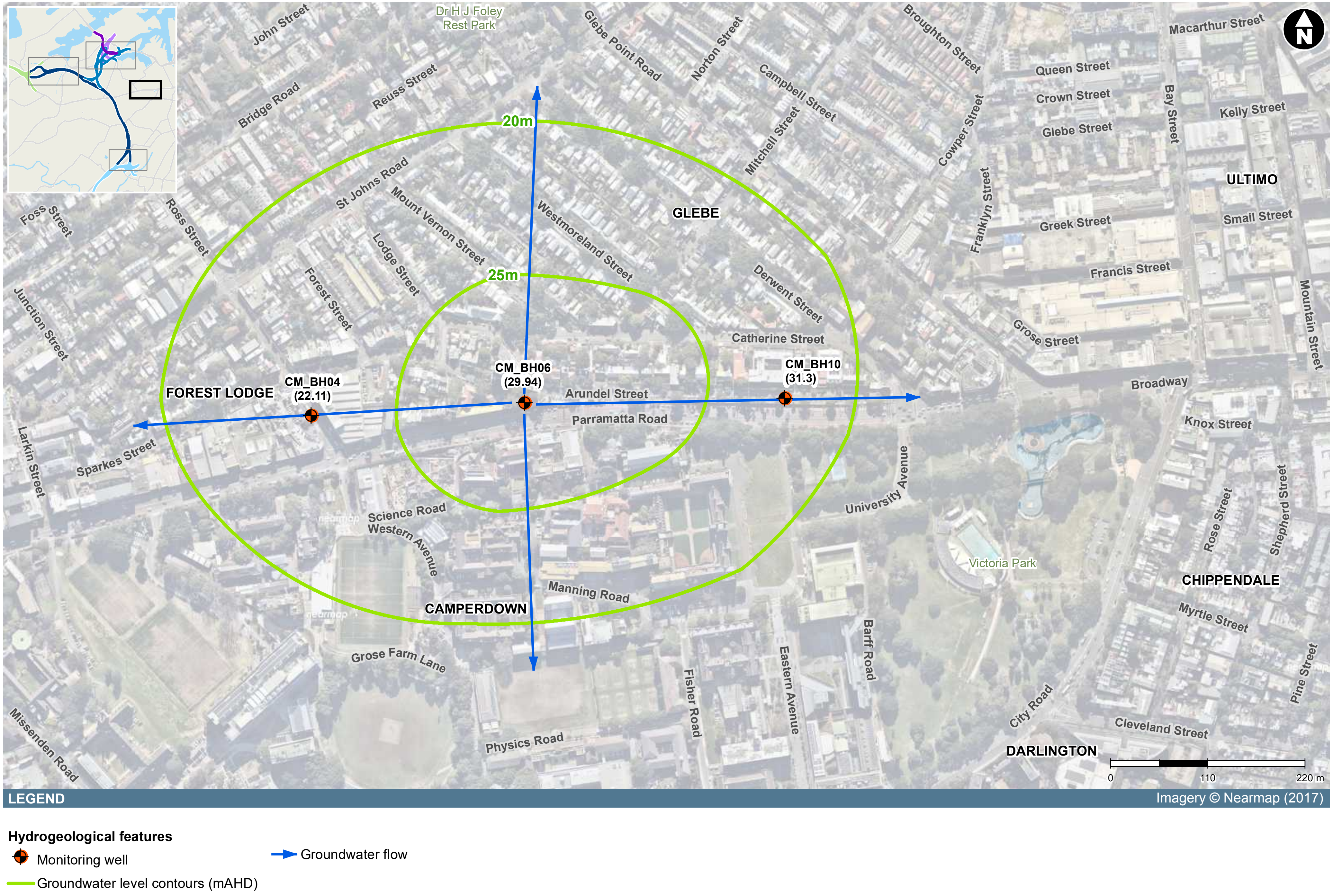


Figure 4-13 Groundwater contours - Ashfield Shale (Camperdown)

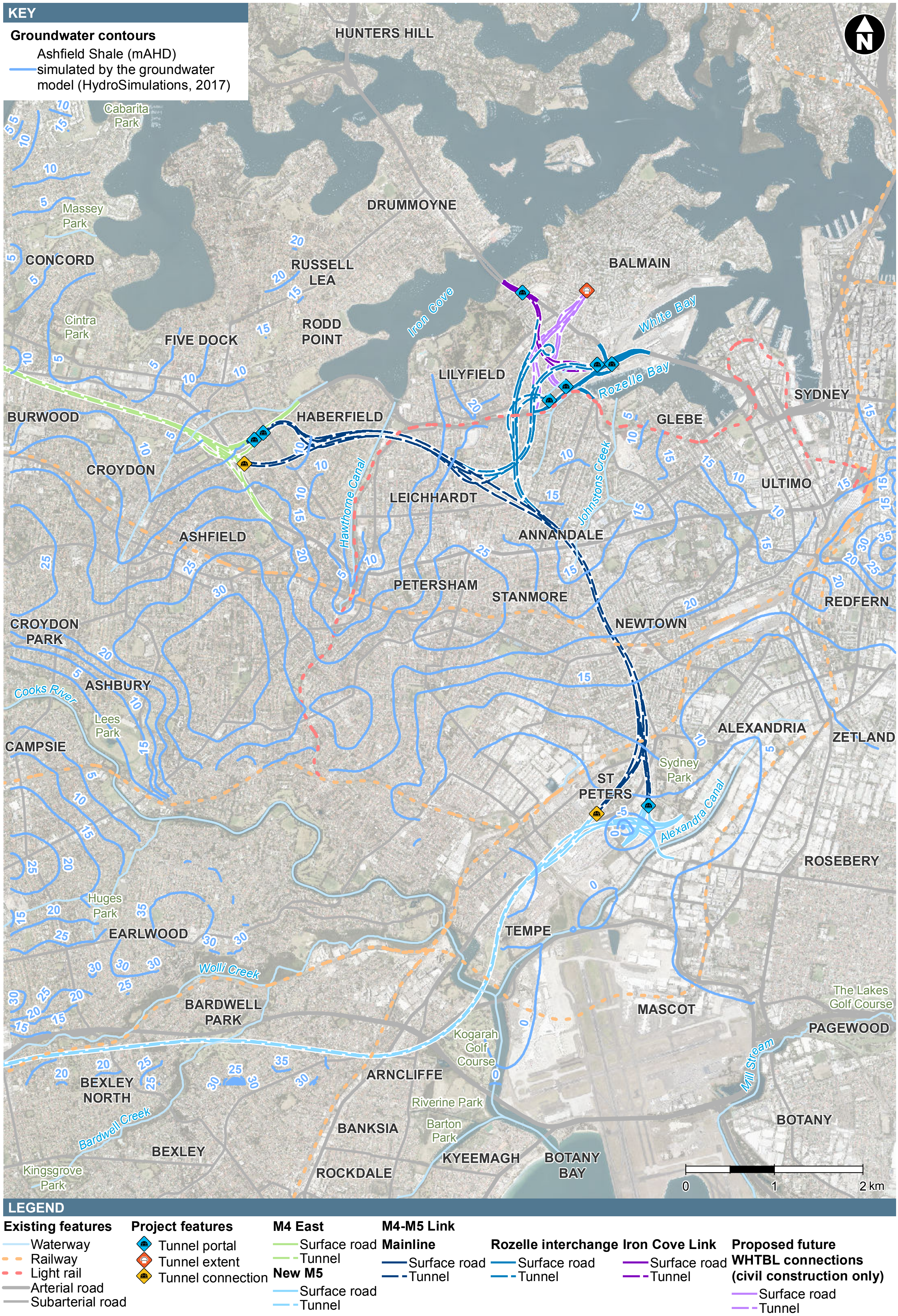


Figure 4-14 Groundwater contours - Ashfield Shale

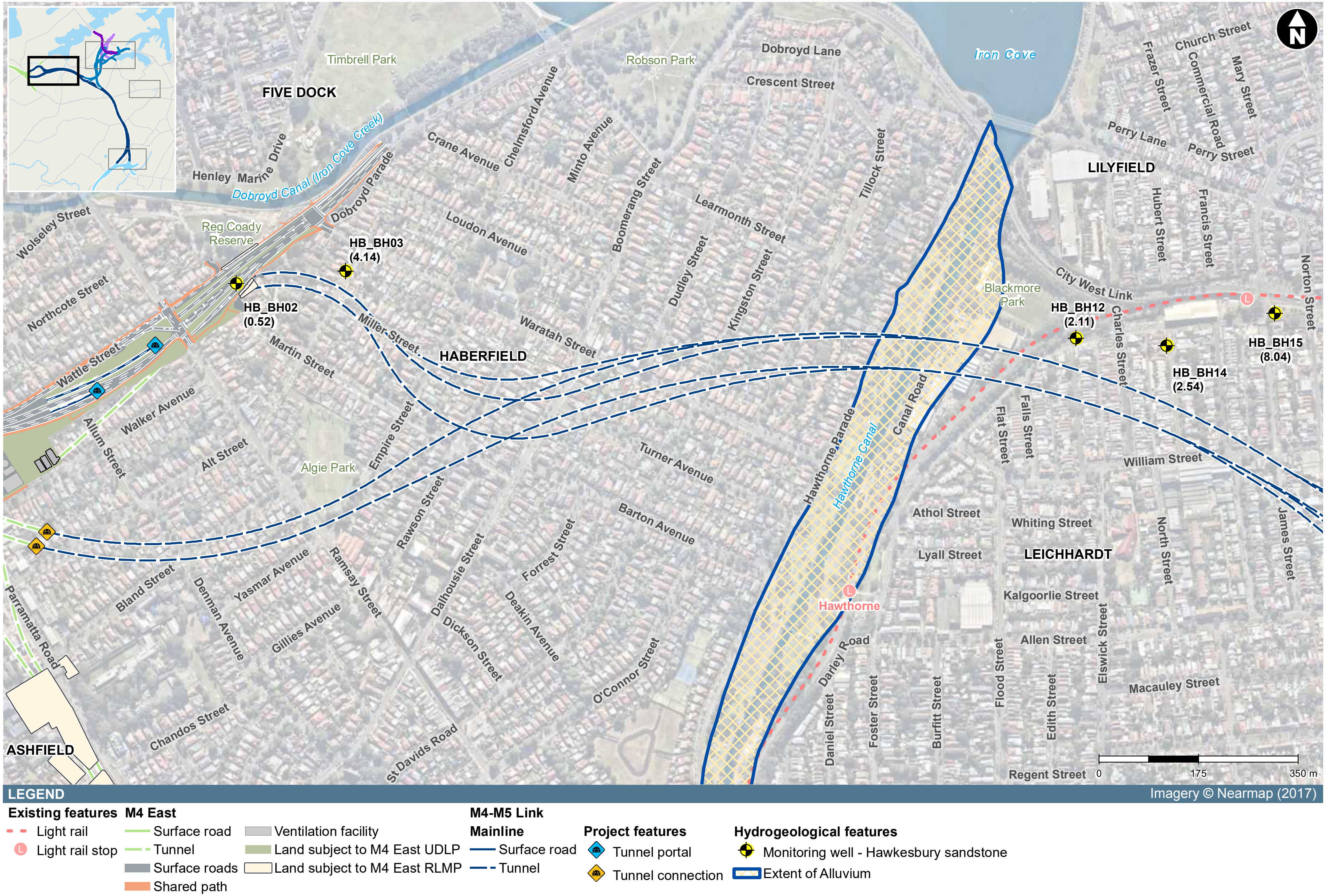


Figure 4-15 Measured potentiometric heads - Hawkesbury Sandstone (Haberfield)

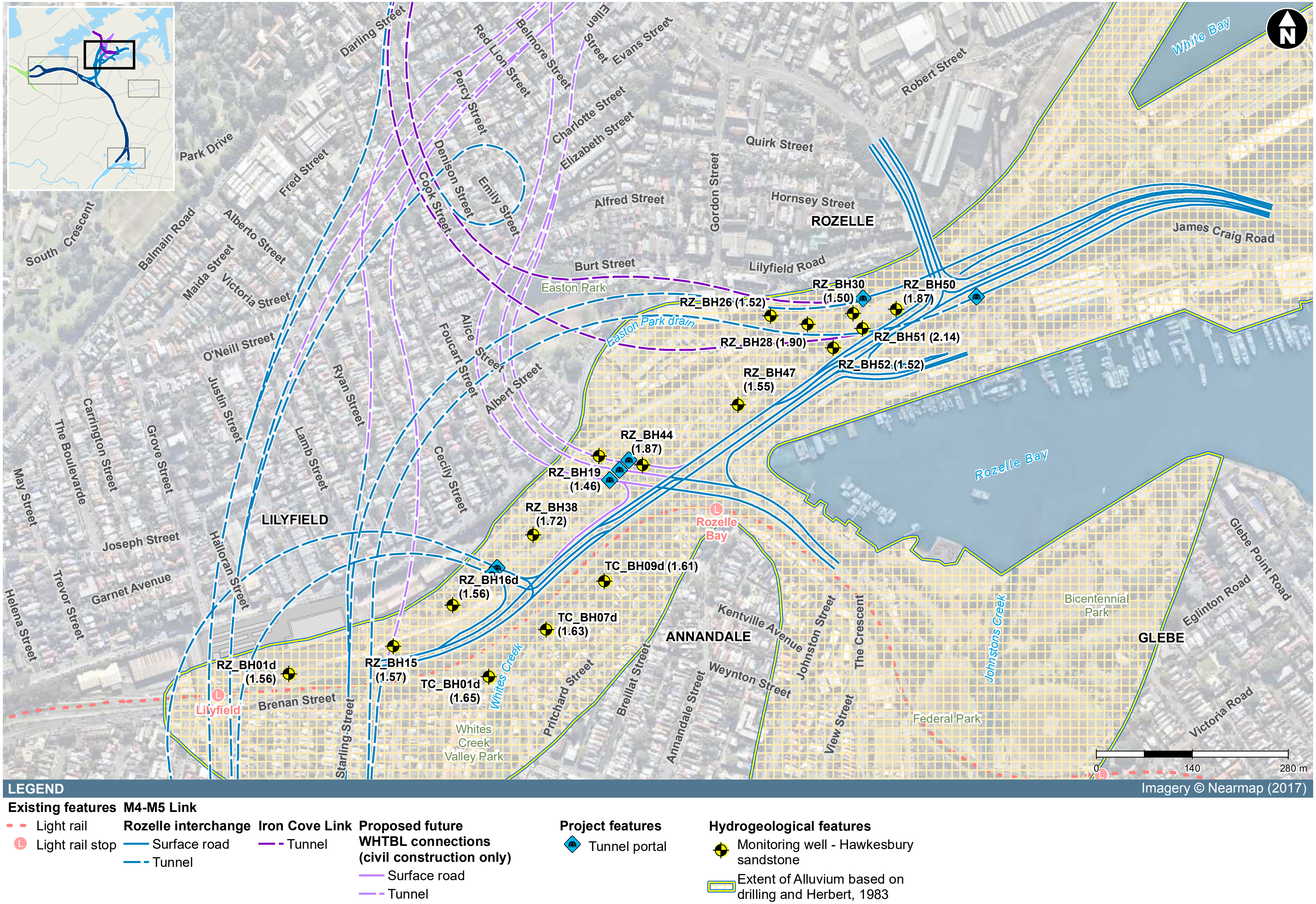


Figure 4-16 Measured potentiometric heads - Hawkesbury Sandstone (Rozelle)

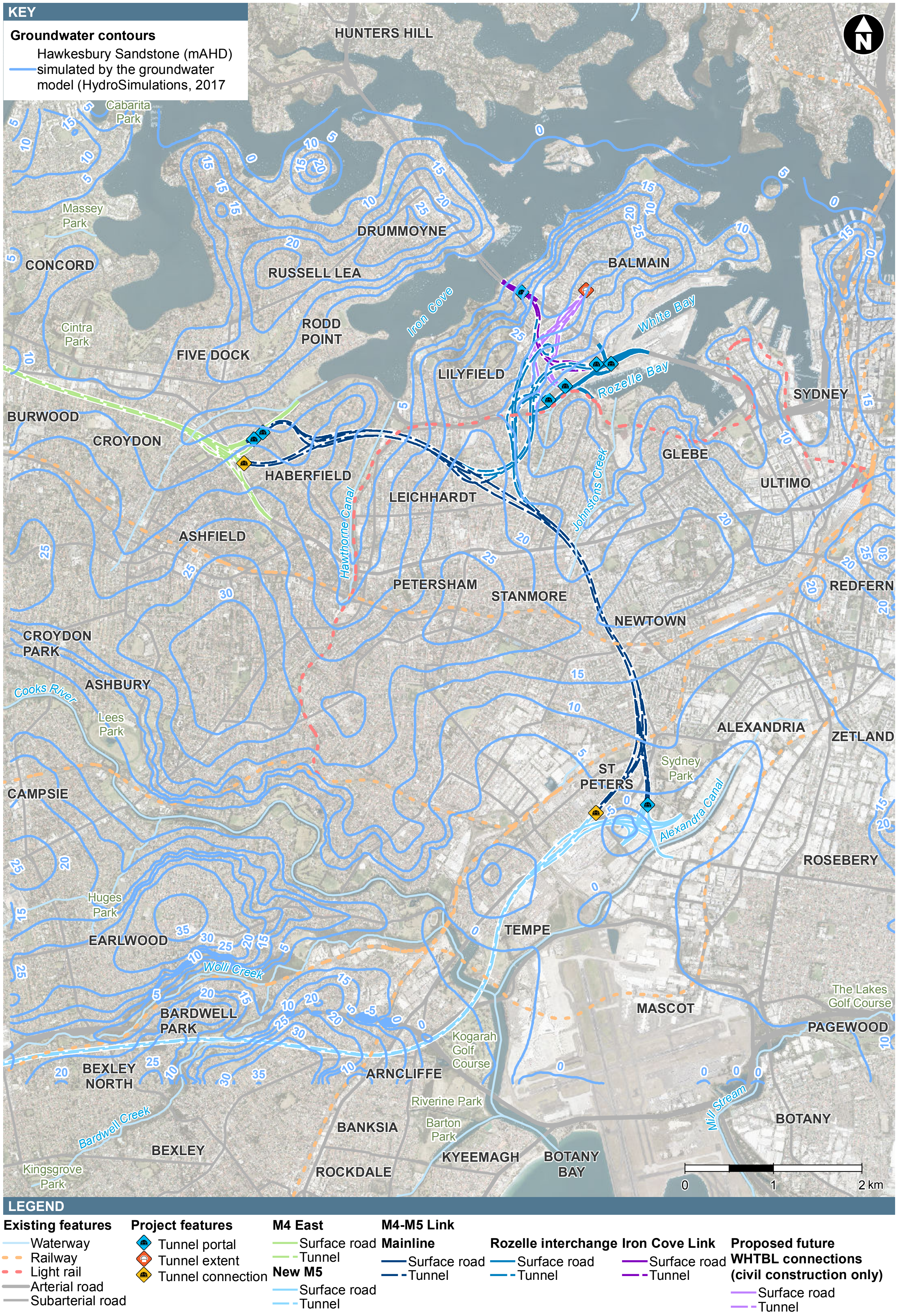


Figure 4-17 Groundwater contours - Hawkesbury Sandstone

4.9.5 Time series groundwater level trends

Groundwater levels have been monitored on an hourly basis by data loggers since June 2016, in monitoring wells constructed within the project footprint within the alluvium, Ashfield Shale and Hawkesbury Sandstone. The data has been corrected for barometric pressure effects. The resultant hydrographs, plotted with daily rainfall for comparison, are presented in **Annexure C**.

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

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

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

Groundwater level fluctuations within the alluvium are monitored in 10 monitoring wells in Haberfield and Rozelle. At Haberfield (HB_BH8s), groundwater fluctuations oscillate over an amplitude of about 0.35 metres which appears related to rainfall recharge and with tidal influences of about 0.10 metres. Similarly at Rozelle, groundwater is shallow ranging from one to 4.5 metres AHD, and increase following rainfall events and rainfall recharge and decline following periods of low rainfall. The largest recharge events follow high rainfall recorded in early and late August 2016. Superimposed over the climatic and seasonal fluctuations are variable tidal fluctuations ranging from 1 to 2 millimetres that increase closer to Rozelle Bay.

Similarly, time series groundwater levels measured in the shale generally increased between early July and September 2016 and then declined for the remainder of 2016 reflecting the impacts of rainfall and recharge conditions. Superimposed over the climatic trends are minor daily fluctuations that could be related to the leachate pumping or hydraulic tidal influences from Alexandra Canal. Natural groundwater fluctuations within the shale are typically over a low amplitude between 10 to 20 millimetres which are attributed to the low bulk hydraulic conductivity within the weathered shale profiles.

Time series groundwater level fluctuations measured in the Hawkesbury Sandstone at Haberfield and Rozelle ranged over a short amplitude of less than one metre, responding to rainfall recharge and periods of low rainfall. Superimposed over the climatic trends are tidal fluctuations that vary from 30 to 50 millimetres that diminish with increasing distance from the Parramatta River and Rozelle Bay. With the exception of the influences of variable tidal oscillations and rainfall recharge on groundwater levels, there does not seem to be any other external influences on the aquifer such as pumping or localised dewatering. Measured groundwater level fluctuations indicate that the oscillations are less than one metre, suggesting that the Hawkesbury Sandstone groundwater system is in equilibrium. This means that the components of the hydrogeological regime including recharge (primarily rainfall infiltration) and discharge (primarily discharge to creeks, Sydney Harbour and evapotranspiration) are balanced. There are clear correlations with rainfall, with the groundwater level rising generally in excess of 10 millimetres following a rainfall event.

4.10 Groundwater extraction

A review of bores registered with DPI-Water accessed through the Bureau of Meteorology (9 May 2016) and the PINNEENA groundwater database identified 197 boreholes within a two kilometre radius of the project footprint. There may also be other private bores present within the two kilometre radius that have not been registered with DPI-Water. The distribution of registered boreholes extracted from the database is shown in **Annexure D**. In analysing the data, there are two distinct types of bores: bores with recorded hydrogeological data (66), and bores with only the borehole number and coordinates recorded (131). The results of this search are summarised in Table D1 and D2 in **Annexure D**.

Typically, boreholes with only coordinates recorded are monitoring wells constructed as part of contamination investigation programs. Contamination investigation areas identified include Green Square, a former brewery at Camperdown, Ramsay Street at Haberfield, Barangaroo and Blackwattle

Bay northern foreshore as outlined in Table B7b in **Annexure D**. In most cases these monitoring wells would no longer be monitored as the site investigation or remediation programs are completed and the sites redeveloped.

In addition, HydroSimulations 2017, extracted data from the Bureau of Meteorology (September 2016) and the PINNEENA groundwater database across the 121 square kilometres model domain, identifying 398 registered groundwater works. The majority of these bores are shallow monitoring wells constructed within the Botany Sands. The groundwater modelling has been applied to quantify potential impacts on these registered bores due to the project (see **Chapters 5** and **6**).

Analysis of the remaining data indicates that the majority of registered wells are constructed for monitoring purposes with the minority developed for recreation, irrigation and domestic water supply purposes (see **Table 4-3**).

Table 4-3 Summary of DPI-Water registered bores within two kilometres of the project footprint

Purpose	Number of bores	Predominant lithology	SWL min	SWL max	Bore depth min	Bore depth max
Recreation	1	Sandstone	11.6	11.6	180	180
Domestic	4	Sand	4	31	2.5	210
Monitoring	61	shale/sandstone	0.4	7.7	1.3	48

Note: SWL = Standing Water Level (metres below ground level)

Review of the lithological data indicates that the majority of boreholes are shallow (less than 10 metres) and monitor groundwater in the sand, clay, shallow sandstone or shale. The majority of monitoring wells are clustered at various investigation sites along the project footprint. A 180 metre deep recreation bore is located at Redfern Park within the Hawkesbury Sandstone, and is used to irrigate Redfern Oval. Four domestic bores are located along the project footprint ranging in distance between 210 and 1480 metres from the project footprint. It is not known if these bores are still used for domestic use or have been abandoned. A 210 metre deep bore (GW110247) at Sydney University extracts groundwater from the Hawkesbury Sandstone is registered for domestic use.

Even though groundwater quality is generally good within the Hawkesbury Sandstone, groundwater use across most of the project footprint is low as bore yields are typically low and the area has access to reticulated water.

At Rozelle Rail Yards, there are few registered monitoring wells suggesting that there has been limited historical groundwater investigations undertaken at this former industrial site (prior to the investigations undertaken for this assessment), or monitoring wells have not been registered.

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

4.10.1 Groundwater extraction entitlements

At a macro scale, the project footprint is located within Sydney Basin Central as part of the Greater Metropolitan Region Groundwater Resources Water Sharing Plan (NoW 2011). The Botany Sands aquifer flanks the project footprint to the east and has been included in the discussion as the aquifer may be impacted by the project. Within the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources, groundwater is to be extracted from the Sydney Basin Central and the Botany Sands aquifer as outlined in **Table 5-1** and **Table 6-2**. The AIP (NoW 2012) is addressed in **sections 9.1** and **9.2**.

The Sydney Basin Central Water Source covers an area of 3,758 square kilometres, receives an annual rainfall of 3,820,386 megalitres per year and, with an estimated infiltration rate of 6 per cent, the estimated average annual rainfall recharge is 229,223 megalitres per year (Table 7, NoW 2011). Based on water that is potentially available for extraction, NoW (2011) assessed that the sustainability of groundwater extraction from the Sydney Basin Central is of moderate environmental risk.

By contrast, the Botany Sands Water Source covers an area of 91 square kilometres, receives an annual rainfall of 101,413 megalitres per year and, with an estimated infiltration rate of 3 per cent, the estimated average annual rainfall recharge is 30,424 megalitres per year (Table 7, NoW 2011). The sustainability of groundwater that is potentially available for extraction within the Botany Sands groundwater resource has been assessed as to be of moderate environmental risk.

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

Table 4-4 Groundwater extraction entitlement and limit

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

Note: * Based on the commencement of the WSP (July 2011)

4.11 Regional hydraulic parameters

The hydraulic properties across the project footprint within the Sydney Basin have been collated from previous investigations and published data. Realistic hydraulic parameters are required for input into the numerical groundwater modelling and then these are refined as the model is calibrated. The hydraulic properties of the various hydrogeological units are discussed below and the model ranges are presented in HydroSimulations 2017.

4.11.1 Alluvium and fill

Alluvium along the rivers and creeks are composed of silts and clays weathered from the Hawkesbury Sandstone and Ashfield Shale. No site specific data has been collected during these investigations for hydraulic conductivity. Typical hydraulic conductivity values for similar lithologies across the Sydney Basin would be expected to range from 0.001 metres per day for clayey alluvium up to 1 metre per day for sandy alluvium. The hydraulic conductivity of alluvium in a similar depositional environment associated with Wolli Creek is noted to be between 0.2 and 0.8 metres per day based on slug tests (CDM Smith 2016).

4.11.2 Wianamatta Group Shale

The bulk hydraulic conductivity range of the Wianamatta Group Shale varies from 0.0001 to 0.01 metres per day for fresh rock, increasing to 0.0001 to 0.1 metres per day for weathered shale (Hewitt 2005). Russell *et al* 2009 indicates there is a general lack of hydrogeological permeability data for the Ashfield Shale possibly due to the unit having poor resource potential.

4.11.3 Hawkesbury Sandstone

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

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

Regionally there is a hydraulic conductivity anisotropy where the horizontal (K_h) is typically greater than the vertical (K_v) by up to two orders of magnitude or more. In the groundwater model developed for the adjacent New M5 project (CDM Smith 2015) the hydraulic conductivity parameters for K_h and K_v were 0.01 and 0.0005 metres per day respectively. Literature values for specific storage range from $1x10^{-5}$ to $1x10^{-4}$ (Hawkes, Ross and Gleeson 2009) and $3.7x10^{-3}$ to $1x10^{-1}$ (Tammetta and Hewitt 2004).

4.11.4 Hydraulic conductivity and porosity

Hydraulic conductivity and porosity testing was conducted during the field investigation program to provide parameters to support the groundwater modelling. Hydraulic conductivity was measured *in situ* by water pressure (packer) testing and by the laboratory testing of drill core. Porosity was also measured in the laboratory from core samples.

The packer test results provide estimates of hydraulic conductivity for the intervals measured, for the effects of horizontal (Kh) features whereas the laboratory results provide estimates for vertical (Kv) features in the rock matrix. Horizontal and sub-horizontal hydraulic conductivities are expected to be higher than vertical hydraulic conductivity because horizontal defects tend to be more extensive, numerous and wider than vertical defects in the Hawkesbury Sandstone and Ashfield Shale.

Domenico and Schwartz (1990) state that hydraulic conductivity data is typically represented as a log normal distribution where the calculated average is more suited to the harmonic mean rather than the arithmetic mean. That is by calculating the harmonic mean the impacts of outliers are removed. In contrast to hydraulic conductivity, porosity values have a normal rather than a log normal distribution and the average population is better represented as the arithmetic mean. Consequently, hydraulic conductivity and porosity averages in this report are described by the harmonic mean and arithmetic mean respectively.

A comparison of the average packer test results for the Hawkesbury Sandstone (K_h = 0.093 metres per day) and laboratory hydraulic conductivity (K_v = 0.0031 m/day) confirms K_h is greater than K_v by about two orders of magnitude. Hydraulic conductivity statistics are summarised on Table B4a in **Annexure B**.

No site specific data was collected during the groundwater investigations for the hydraulic conductivity of the alluvium. Typical hydraulic conductivity values for similar lithologies across the Sydney Basin would be expected to range from 0.001 metres per day for clayey alluvium up to 1 metre per day for sandy alluvium.

Laboratory testing

Throughout the drilling program core samples were selected from the Hawkesbury Sandstone and Ashfield Shale for laboratory testing for hydraulic conductivity and porosity. Thirteen core samples were tested for hydraulic conductivity and porosity, 11 from the Hawkesbury Sandstone and two from the Ashfield Shale. The results are summarised in Table B11 in **Annexure B** and the laboratory output is presented in **Annexure G**.

Porosity results within the Hawkesbury Sandstone range from 11.3 to 19.2 per cent and 5.6 per cent for the Ashfield Shale. Laboratory hydraulic conductivity results for the Hawkesbury Sandstone represent vertical hydraulic conductivity (K_v) through the aquifer. The K_v results vary over a narrow range between 0.00008 to 0.0055 metres per day.

Water pressure testing

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

Packer testing was performed in selected cored sections using a single stage pneumatic HQ packer and calibrated flow meters provided by the drilling contractor. Water pressure testing was carried out in 94 boreholes (uncased as distinct from monitoring wells) with multiple tests performed in each borehole. Each test was typically carried out in five different pressure stages (three increasing and two decreasing stages), at the nominated test interval (typically about three, six, nine or 12 metres). Where angle holes were tested (MT_BH08, MT_BH16 and MT_BH22) the test section was corrected to represent the vertical depth interval.

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

The hydraulic conductivity has been measured by conducting 220 packer tests in 94 boreholes. The location of boreholes where packer tests were conducted is shown on **Figure 4-18**. The packer test results are presented in Table B4, **Annexure B**. Results of the packer tests are expressed as lugeon units where a lugeon (L) is equivalent to a hydraulic conductivity of $1x10^{-7}$ metres per second ($8.8x10^{-3}$ metres per day). The location of packer test results for all lithologies are presented in **Table 4-5** and show the majority of the rock mass results are of low permeability, suggesting that inflows along the majority of the proposed tunnel would be low.

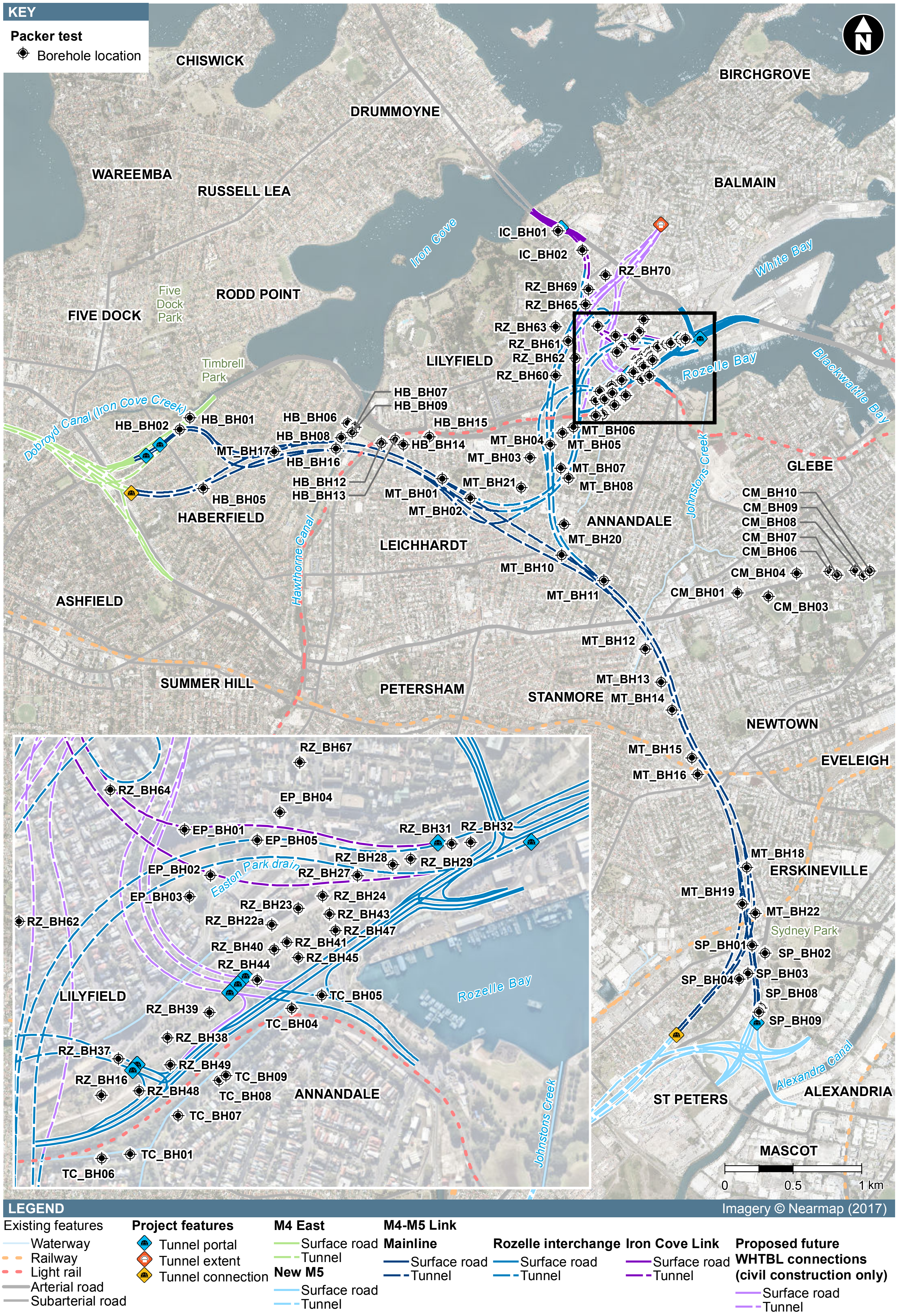


Figure 4-18 Locations of packer tests

Table 4-5 Distribution of rock mass permeability

Relative permeability	Permeability range		Measurements	
	Lugeons	m/day	Ashfield Shale	Hawkesbury Sandstone
N/A[1]			1	8
Low	<1 Lugeon	<0.0086	13	102
Moderate	1 to 5 Lugeons	0.0086 – 0.043	7	51
High	5 to 20 Lugeons	0.043 – 0.17	2	6
Very high	20 to 50 Lugeons	0.17 – 0.43	0	14
Extremely high	>50 Lugeons	>0.43	1	9
Total			**24**	**196**

Notes:

1 N/A Packer Test conducted but no results due to difficult field conditions

To provide an understanding of the measured bulk hydraulic conductivity within each lithology, statistics including mean, maximum, minimum, median and standard deviation are presented in **Table 4-6**. The majority (89 per cent) of packer tests were conducted within the Hawkesbury Sandstone which is reflective of the majority of the project footprint being located within this stratigraphic unit. For comparison, hydraulic conductivity values within the Hawkesbury Sandstone across the whole Sydney Basin were compiled by McKibbin and Smith (2000) from the DPI-Water groundwater database with results ranging between 0.01 and 0.15 metres per day. This range is higher than the packer test results which is attributed to the results being derived from test pumping results data, obtained from successful production bores that intersect highly permeable faults and fractures.

Table 4-6 Rock mass permeability statistics

Lithology/Statistics	Ashfield Shale	Hawkesbury Sandstone
Units	**m/day**	**m/day**
Arithmetic mean	0.017	0.10
Harmonic mean	0.010	0.012
Minimum	0.0086	0.0086
Maximum	0.12	1.17
Standard deviation	0.024	0.21
Total number of packer tests	24	181

The distribution of hydraulic conductivity results and the 10 point geometric mean plotted against depth are presented in **Figure 4-19**. The plot shows a wide variation in hydraulic conductivity values, with the overall trend of decreasing hydraulic conductivity with depth. The log-average hydraulic conductivity varies from about 0.1 metres per day at 10 metres to about 0.01 metres per day below 50 metres. The large scatter is caused by the variation in defect spacing which tends to decline with depth due to an increased influence of overburden pressure.

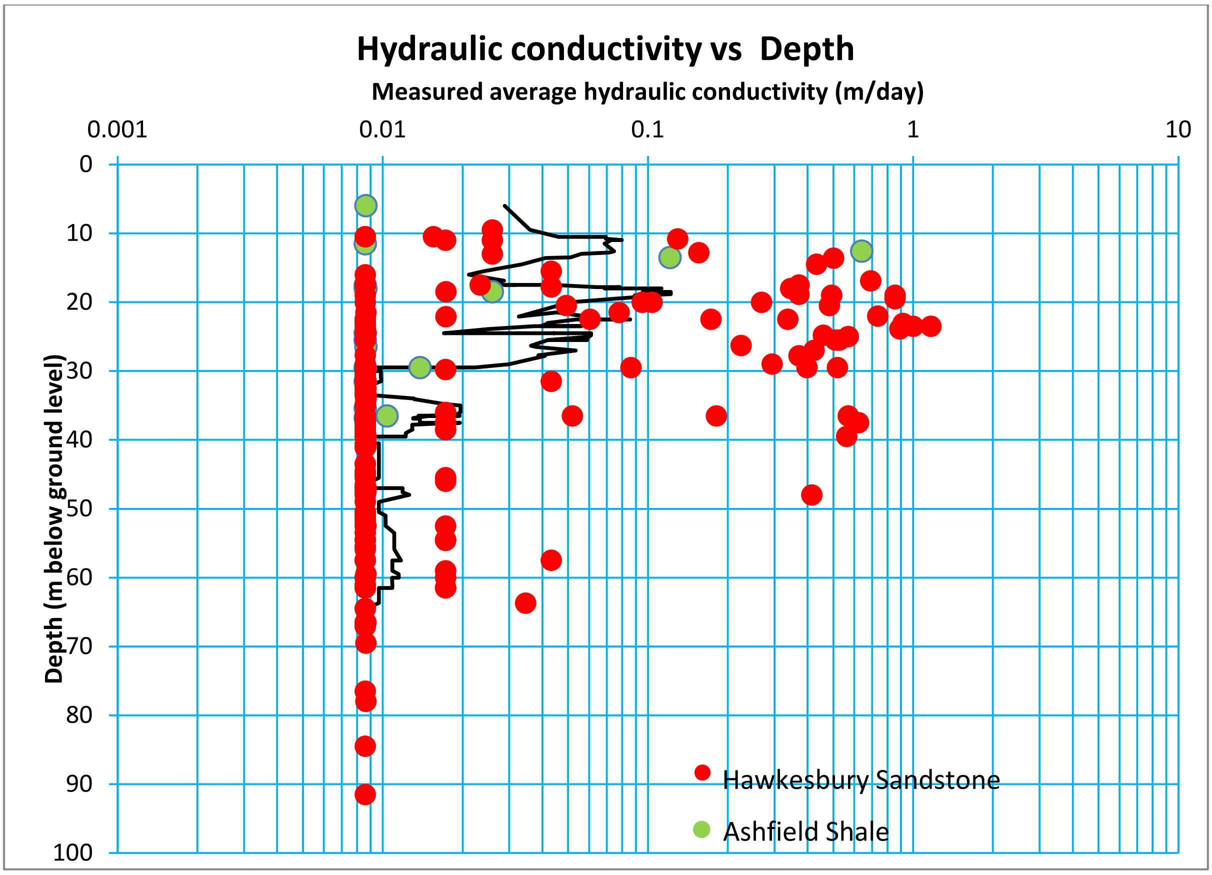


Figure 4-19 Hydraulic conductivity value vs depth from packer tests

4.12 Groundwater inflow in other tunnels

Within the Hawkesbury Sandstone, Mittagong Formation and Ashfield Shale, water inflow is dependent upon the number and aperture of saturated secondary structural features intersected. Rates of water inflows have been monitored in recent years from several unlined tunnels in the Sydney area with similar geology, hydrogeology and construction to that proposed by the M4-M5 Link project. These inflow rates are considered long term flow rates throughout the operational life of the infrastructure, and are summarised in **Table 4-7** (after Hewitt 2005).

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

Table 4-7 Measured drainage rates from other Sydney tunnels

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

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

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

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

4.13 Hydrogeochemistry

Routine project monthly groundwater quality monitoring, commenced in June 2016 and continued throughout the EIS assessment period. Monitoring will continue during construction and into the operations phase for at least one year or as directed by project approvals. The laboratory analytical results of routine monthly groundwater monitoring program are presented for the June 2016 to May 2017 monitoring events in AECOM 2016c,e and AECOM 2017c,e and discussed herein.

The purpose of the groundwater quality monitoring program is to:

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

Monthly groundwater samples collected for laboratory analysis initially increased each month as more monitoring wells were added to the groundwater monitoring network as outlined in **Table 4-8**.

Table 4-8 Groundwater quality sampling program

Month	Groundwater samples collected			
2016/2017	**Alluvium**	**Ashfield Shale**	**Hawkesbury Sandstone**	**Total**
June	1	2	3	**6**
July	10	3	19	**32**
August	9	4	23	**36**
September	10	3	19	**32**
October	10	2	23	**35**
November	8	4	21	**33**
December	9	4	20	**33**
January	10	2	28	**40**
February	10	3	29	**42**
March	9	3	30	**42**
April	10	1	30	**41**
May	10	3	30	**43**
Total	**106**	**34**	**275**	**415**

The groundwater quality sampling program included the following analytes:

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

The hydrogeochemistry has been characterised for each of the major aquifers (alluvium, Ashfield Shale and Hawkesbury Sandstone) along the project footprint based on the results from the above suite.

4.13.1 Groundwater assessment criteria

The groundwater quality criteria have been developed in accordance with guidelines from the Australian and New Zealand Environment Conservation Council (ANZECC 2000). For highly disturbed receiving environments such as those that could be impacted by the project, ANZECC (2000) recommends that suitable guidelines for groundwater quality trigger values can be derived from a local reference data set for nutrients, dissolved oxygen and pH. For toxicants (such as heavy metals or organic chemical compounds), the water quality requirements should be consistent with the 95 per cent protection level for freshwater ecosystems (Table 3.4.1, ANZECC 2000). For analytes not covered by the ANZECC (2000) guidelines the amended National Health and Medical Research Council (NHMRC) *Australian Drinking Water Guidelines* (2015) have been adopted. The adopted guideline values are presented in Table ST7, ST8 and ST9 in **Annexure B**.

To assess the potential impacts of groundwater to building materials, dissolved sulfate, chloride and pH values are assessed against the aggressivity criteria outlined in the exposure classification criteria for concrete and steel piles presented in Australian Standard 2159-2009 Piling, Design and Installation (2010).

4.13.2 Field parameters

Measured groundwater temperatures varied over a narrow range between 14 and 26.5°C. Seasonally, groundwater temperatures tended to vary by one or two degrees, although there was no variation between lithologies. The average temperature of monthly water samples tended to increase between July and December. Dissolved oxygen values varied along the project footprint although there were no spatial or temporal trends identified within the major lithologies. Redox conditions were also variable along the project footprint but for each lithology had a relatively short range with negative values indicating a robust data set.

Measurement of the electrical conductivity and calculation of average values confirmed that the groundwater from the Ashfield Shale (2860 microsiemens per centimetre) is more saline than from the Hawkesbury Sandstone (1700 microsiemens per centimetre). Elevated electrical conductivity values within the Ashfield Shale is attributed to connate salts within the sediments of marine origin (Old 1942). The electrical conductivity measured within the alluvium is variable, ranging from 328 to 34,900 microsiemens per centimetre. The alluvial groundwater variability is due to groundwater in the upper reaches being predominately derived from rainfall recharge and increasing in salinity downstream as tidal mixing increases.

Some elevated pH levels have been recorded in monitoring wells, which has been attributed to cement grout entering the well screen through the bentonite seal that had not formed a sufficient hydraulic seal. In most cases, additional well development was successful in reducing pH levels. Natural pH levels within the Hawkesbury Sandstone and Ashfield Shale are acidic, ranging from pH 5 to 6.5. The pH of groundwater in the Ashfield Shale is sometimes low due to sulphides naturally occurring within the shale. pH levels within the alluvium was also weakly acidic to neutral.

4.13.3 Major ions

Major cations (calcium, magnesium, sodium and potassium) and major anions (chloride, sulfate, carbonate and bicarbonate) have been routinely sampled and are tabulated in Table B6, **Annexure B**. The data has also been plotted on Piper diagrams for each month and each lithology to assess the hydrogeochemical distribution of major ions to assess if there are any temporal or spatial variations. Piper diagrams from the three major aquifers are presented in **Annexure E**.

Groundwater within the alluvium is dominated by sodium, magnesium, chloride and bicarbonate. The dominance of sodium and chloride is attributed to tidal influences and interaction with sea water in Rozelle Bay. Although the majority of alluvial samples cluster in the sodium and chloride sector of the Piper diagram there are some outliers with elevated calcium and carbonate. These outliers (with elevated electrical conductivity values) are likely to be due to groundwater derived from marine sediments that contain shells. Overall there is upward hydraulic pressure measured from the potentiometric heads from the Hawkesbury Sandstone to the alluvium. Therefore, groundwater from the Hawkesbury Sandstone may be discharging into the alluvium influencing the groundwater inorganic chemistry.

The hydrogeochemical signature of groundwater from the Ashfield Shale is highly variable which may be due to the intermittent development of secondary mineralisation such as calcite (calcium carbonate) and siderite (iron carbonate) and the variable flushing of connate salts of marine origin. The hydrogeochemical signature of the Ashfield Shale is not similar to seawater further suggesting that the flushing of marine salts has occurred since the sediments were deposited in the Triassic period. Comparison of monthly groundwater data from the Ashfield Shale over six months presented on Figure E5.2, **Annexure E**, confirms the variable nature of the shale, although there does not appear to be any seasonal trends.

Groundwater derived from the Hawkesbury Sandstone is dominated by sodium and chloride and may be in part due to evaporation and/or the influence of saline harbour water. As for the shale, the hydrogeochemical signature of Hawkesbury Sandstone groundwater is different to that of seawater indicating there are other influences on the groundwater chemical evolution. In topographically high areas where the Ashfield Shale overlies the Hawkesbury Sandstone, leakage from the shale influences the hydrogeochemical signature of shallow groundwater within the Hawkesbury Sandstone.

4.13.4 Heavy metals

Groundwater has been monitored monthly for 10 dissolved metals including arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc since June 2016. The analytical results have been presented in Table B7 in **Annexure B** along with the adopted groundwater guidelines. Since groundwater discharges into Sydney Harbour and the lower lying areas are tidal, the ANZECC 2000 guidelines for freshwater (95 per cent level of protection) are considered the most appropriate. Schoeller diagrams have been prepared for selected monitoring wells for each lithology and sampling event and are presented in **Annexure E**.

Within the alluvial groundwater the maximum recorded value has exceeded the guideline concentration value for metals As, Cr, Cu, Fe, Pb, Mn, Hg and Zn. In most cases the guidelines have been marginally exceeded, indicating that background levels are elevated, which is consistent with the low standard deviation recorded for these metals. However the alluvial groundwater consistently has elevated iron, lead and zinc.

Within the groundwater derived from the Ashfield Shale, the maximum recorded value has exceeded the guideline concentration value for metals Cr, Cu, Fe, Mn, Ni and Zn. Iron and manganese are commonly elevated within the Ashfield Shale, often causing red-brown or black staining when the groundwater becomes oxidised and the metals precipitate as oxides. Pyrite is a common secondary mineral in shale and is likely to be a partial source of iron (McLean and Ross 2009). Although average chromium and copper concentrations exceed the guidelines the low standard deviation of 0.038 and 0.001 respectively suggests the metal concentrations are at background levels.

Within the groundwater derived from the Hawkesbury Sandstone, the maximum recorded value has exceeded the guideline concentration value for metals Cr, Cu, Fe, Pb, Mn, Ni and Zn. In most cases the guidelines have been marginally exceeded however the groundwater consistently has elevated iron and manganese. Iron and manganese are known to be elevated within the Hawkesbury Sandstone, McKibbin and Smith 2000. Sources of iron include siderite (iron carbonate) and iron oxyhydroxides and oxides (McLean and Ross 2009). Although average chromium, copper and zinc concentrations exceed the guidelines, the low standard deviation of 0.026, 0.0056 and 0.67 respectively suggests the metal concentrations are at background levels.

4.13.5 Nutrients

Nutrients including nitrite as N, nitrate as N and reactive phosphorus have been measured monthly since June 2016 for each major lithology and have been tabulated in Table B6 in **Annexure B**. Analytes ammonia, total nitrogen and total Kjeldahl nitrogen have been monitored periodically throughout the EIS investigation period.

Within the alluvium, nitrite and nitrate concentrations ranged from below detection limits to 0.31 and 2.38 milligrams per litre respectively. In comparing these results to the amended *Australian Drinking Water Guidelines* (NHMRC 2015) nitrite and nitrate concentrations are below the health criteria of three and 50 milligrams per litre indicating background nutrient levels are low. Reactive phosphorous as P ranged from below detection limits to 0.04 milligrams per litre indicating phosphorous levels are also low. Ammonia values range from 3.81 to 5.76 exceeding the guideline value of 0.91 milligrams per litre. Although the alluvium flanks some parklands, the impact of nutrient runoff from fertilisers (with the exception of ammonia) appears to be minimal.

Dissolved nitrite and nitrate concentrations in groundwater derived from the Ashfield Shale ranged from below detection limits to 0.1 and 1.17 milligrams per litre respectively. In comparing these results to the *Australian Drinking Water Guidelines* (NHMRC 2015) nitrite and nitrate concentrations are below the health criteria of 3 and 50 milligrams per litre indicating background nutrient levels are low. Reactive phosphorous as P ranged from below detection limits to 0.67 milligrams per litre indicating reactive phosphorous levels are low. Ammonia values range from 0.2 to 3.19 milligrams per litre averaging 1.2 milligrams per litre exceeding the guideline value of 0.91 milligrams per litre. Dissolved background nitrite and nitrate concentrations within the shale were higher than those measured in the alluvium but still remain relatively low. Ammonia concentrations may be elevated due to the natural degradation of organic material within the alluvium or the application of nitrogen fertilisers.

Dissolved nitrite and nitrate concentrations in groundwater derived from the Hawkesbury Sandstone ranged from below detection limits to 1.18 and 1.31 milligrams per litre respectively. In comparing these results to the *Australian Drinking Water Guidelines* (NHMRC 2015) nitrite and nitrate are below the health criteria of 3 and 50 milligrams per litre indicating nutrient levels are low. Ammonia values range from 0.2 to 3.41 milligrams per litre averaging 0.93 milligrams per litre marginally exceeding the guideline value of 0.91 milligrams per litre. Reactive phosphorous as P ranged from below detection limits to 0.16 milligrams per litre indicating reactive phosphorous levels are very low.

4.13.6 Groundwater aggressivity

An assessment of groundwater aggressivity has been conducted to better understand the corrosive nature of the natural groundwater intersected to assist in selecting building materials to minimise corrosive impacts on the tunnel and its infrastructure. The corrosion assessment applies to infrastructure to be constructed with concrete and steel below the water table. The assessment has been conducted by collating the major ion chemistry and hydrogeochemical parameters including salinity, pH, sulfate and chloride concentrations by application of the exposure classification in the Australian Standard AS2159-2009 (AS2159-2009) for piling. The average primary parameters of groundwater aggressivity are presented in Table ST10 in **Annexure B** for Ashfield Shale and Table ST11 in **Annexure B** for Hawkesbury Sandstone. To assess groundwater aggressivity average concentrations of relevant analytes has been applied.

By application of the water classification for concrete piles in AS2159-2009 and applying the average values from Table ST10 in **Annexure B** groundwater aggressiveness has been assessed and the results are summarised in **Table 4-9** for the Ashfield Shale, Hawkesbury Sandstone and alluvium. The aggressivity assessment indicates that groundwater within the Ashfield Shale is non aggressive with respect to average chloride, pH and sulfate for concrete piles. Similarly the average values from Table ST11 in **Annexure B** for groundwater within the Hawkesbury Sandstone indicate the groundwater is mildly aggressive to concrete piles with respect to average chloride, pH and sulfate. Average values for groundwater aggressivity in the alluvium presented in Table ST12 in **Annexure B** are similar to the properties of groundwater within the Hawkesbury Sandstone, although the alluvial groundwater is moderately aggressive to chloride in cement grout.

The aggressivity of groundwater to steel piles has also been assessed by application of the water classification for steel piles in AS2159-2009. With reference to the average values from Table ST 10 in **Annexure B** the groundwater within the Ashfield Shale is non aggressive with respect to average chloride and pH, however the groundwater is moderately aggressive with respect to resistivity. Similarly the average values from Table ST11 in **Annexure B** for groundwater within the Hawkesbury Sandstone indicate the groundwater is mildly aggressive to steel piles with respect to average chloride, pH but is severely aggressive with respect to resistivity. Average values from Table ST12 in **Annexure B** for groundwater within the alluvium indicate the groundwater is mildly aggressive to steel piles with respect to average chloride, non-aggressive to pH but is severely aggressive with respect to resistivity.

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

Table 4-9 Groundwater aggressivity assessment

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

4.13.7 Sulfate reducing bacteria

Sulfate reducing bacteria (SRB) is measured as a colony forming unit (CFU) per 100 millilitres. The presence of SRB promotes the increased corrosion of metals as does elevated sulfate concentrations. SRB are anaerobic but can cause severe corrosion of iron material in the groundwater as enzymes are produced which can accelerate the reduction of sulfate compounds to corrosive hydrogen sulphide. Sulfate reduction by bacteria can increase in the presence of elevated dissolved organic carbon.

Twenty groundwater samples have been collected from the Ashfield Shale (2) and Hawkesbury Sandstone (18) and analysed during the October and December 2016 monitoring events. The groundwater within the alluvium was not tested as it typically does not have elevated iron or manganese to the extent of the bedrock aquifers. The results vary from five CFU per millilitre to the maximum laboratory measurement limit of 500,000 CFU per millilitre. Of the 20 groundwater samples analysed, five samples had more than 500,000 CFU per millilitre, seven samples had a count of 115,000 CFU per millilitre and the remaining nine samples had an average count of 8,500 CFU per millilitre. No pattern with lithology was assessed because many samples were above the measurement limit. Seawater is a known prime habitat for SRB, and it is possible that the dissolution of marine salts from the Ashfield Shale into the Hawkesbury Sandstone makes the groundwater prone to SRB growth. Summary statistics have not been calculated for SRB as the maximum measurement limit of 500,000 CFU per millilitre skews the results.

4.13.8 Groundwater treatment

The majority of project tunnels are designed to be drained during operation and would require groundwater seepage, tunnel wash or deluge system water to be collected, treated and discharged. Water treatment may involve:

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

Permanent water treatment plants are to be constructed at Rozelle, adjacent to Rozelle Bay in the Rozelle Rail Yards and Darley Road, Leichhardt, with discharge directed into Rozelle Bay and Iron Cove under the same discharge conditions as collected surface water. The tunnel operation water treatment facilities would be designed such that effluent will be of suitable quality for discharge to the receiving environment (refer to **Appendix Q** (Technical working paper: Surface water and flooding)) of the EIS.

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

4.14 Contamination

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

4.14.1 Rozelle Rail Yards

The Rozelle Rail Yards are located to the north and north-west of Rozelle Bay. Parts of the site are contaminated due to historical filling and use for railway and industrial/commercial activities. Roads and Maritime is planning to carry out a limited suite of site management works on part of the Rozelle Rail Yards site. The works are needed to manage the existing environmental and safety issues at the site and would also improve access to surface conditions, which would allow for further investigation into the location of utilities and the presence of contamination and waste. The works would benefit future uses of the site (including construction of the M4-M5 Link project if it is approved) because the works would remove material and redundant facilities associated with rail and rail related infrastructure from the site.

The site management works were subject to a separate environmental assessment. The works were assessed in a review of environmental factors (REF) which was approved by Roads and Maritime under Part 5 of the EP&A Act on 10 April 2017. It is anticipated that the site management works would be conducted over a period of 12 months and would commence in mid-2017.

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

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

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

The excavation of low lying natural soil during the tunnel excavation program may also uncover PASS. Consequently, the risks associated with PASS and other contaminants of concern would be managed under acid sulfate soil management procedures which would form part of the CSWMP.

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

4.14.2 Leichhardt

The Hawthorne Canal and Leichhardt North area have undergone historic, widespread land reclamation with fill from unknown sources, indicating that subsurface soil contamination could be present in some areas. Other potential soil contamination sources include the storage and use of chemicals, pesticides, fuels and oils and hazardous building materials in the former Public Works Depot and the former Ordnance Depot within Blackmore Park. There are potentially pockets of soil contamination present across these areas that could contaminate groundwater within the underlying palaeochannels. The tunnels are to be constructed either at depth, to extend beneath the palaeochannels, or through the palaeochannels as undrained (tanked) tunnels so the local groundwater does not seep into the tunnels. PASS have been mapped across the majority of this area. PASS have been mapped across the majority of this area. The risks associated with ASS would be managed under the CSWMP.

At The Crescent (TC_BH07s) shallow alluvial groundwater may have become contaminated with hydrocarbons via hydraulic connection with Whites Creek or activities associated with the Inner West Light Rail line and former freight line.

4.14.3 Haberfield and St Peters

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

Wattle Street Interchange

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

St Peters interchange

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

The New M5 tunnels and access portals through the former landfill are to be undrained (tanked), preventing the ingress of contaminated groundwater into the tunnel drainage system. The deeper tunnels constructed in the Hawkesbury Sandstone or Ashfield Shale are to be drained, but are unlikely to intersect contaminated groundwater. The risk of contaminated groundwater entering the M4-M5 Link tunnel from leachate derived from the landfill is low because leachate would continue to be pumped, collected and treated in a newly constructed water treatment plant as part of the New M5 project. Pumping the leachate would locally reverse groundwater flows, creating an internal flow network centred on the sump in the former landfill, drawing groundwater away from the tunnels. Thus groundwater flow would be directed away from the M4-M5 Link and New M5 tunnels due to the ongoing leachate pumping system. Leachate generation is to be reduced due to the cut-off wall that is to be constructed along the eastern perimeter of the landfill to reduce groundwater inflow and capping the former landfill to reduce rainfall infiltration.

Hydrocarbon contamination within the weathered clay and residual shale (SP_BH02) is attributed to fuel leaks and spills from the nearby service station.

4.15 Hydrogeological features along the project footprint

The natural geological and hydrogeological conditions impose a series of considerations that require addressing in the design phase. These considerations and implications are summarised for the various components of the project.

4.15.1 Hawthorne Canal

At Hawthorne Canal groundwater is present within the alluvium and underlying Hawkesbury Sandstone. Beneath Hawthorne Canal a palaeovalley is carved into the Hawkesbury Sandstone at depths of up to 20 metres. The project corridor has been designed to dive beneath the unconsolidated saturated sediments and constructed within the more competent Hawkesbury Sandstone. Groundwater ingress from the Hawkesbury Sandstone would be predominately via saturated secondary structural features such as fractures and joints rather than from the primary matrix. Groundwater ingress from the overlying alluvium would be dependent upon the hydraulic connection between the Hawkesbury Sandstone and the alluvium.

Typically the Hawkesbury Sandstone has a higher percentage of fractures beneath a palaeovalley as the structural weaknesses in the sandstone are the main reason the palaeovalley developed in that location. Hence surface water from Hawthorne Canal could enter the tunnel via fractures within the sandstone connected to the alluvium. Analysis of rock core and packer test data collected during the geotechnical investigation program provides an indication of the degree of fracturing within the

Hawkesbury Sandstone and potential hydraulic connection with the infilled palaeovalley sediments and surface water within the canal.

Other creek crossings along Rozelle Bay are Johnstons Creek and Whites Creek where the top of rock is at -8 metres AHD and 0 metres AHD respectively. The tunnels are to be constructed below these creeks within the Hawkesbury Sandstone to minimise groundwater ingress from the alluvium.

4.15.2 St Peters interchange

The ground conditions at St Peters are dominated by thick residual clay soils over shale, modified by the excavation of several large former brick pits. These brick pits were excavated into a residual shale soil profile about 30 metres below ground surface to the near top of the underlying Hawkesbury Sandstone. Following the completion of quarrying, the pits were then backfilled with uncontrolled fill material (typically waste). The proposed tunnel ramps at St Peters interchange commences in weathered shale exposed in the wall of a former brick pit and descends through shale and sandstone to merge with the main line tunnel project corridor.

At the future St Peters interchange, groundwater is present within the Ashfield Shale and Hawkesbury Sandstone. Immediately east of the St Peters interchange, groundwater is present within the Botany Sands. At Alexandria, the tunnel portal is located at the edge of the Botany Sands aquifer. Surface water flows would be directed towards Alexandra Canal. The Ashfield Shale is the dominant lithology where groundwater flows along secondary structures such as laminations, fissures and joints rather than the primary matrix. Groundwater levels are low and typically three to five metres below ground level at elevations of around three to five metres AHD. Groundwater levels are also influenced locally by leachate pumping from the Alexandria Landfill which is hydraulically connected to the shale. The former landfill is to be rehabilitated to form the St Peters interchange but would still require ongoing leachate pumping. The cut-off wall to be constructed as part of the St Peters interchange design around the eastern side of the landfill would prevent inflow from the Botany Sands discharging into the former landfill to reduce leachate generation. The Hawkesbury Sandstone underlies the Ashfield Shale at an elevation of around -35 metres AHD and is not likely to be intersected by the St Peters interchange tunnel ramps.

4.15.3 Rozelle interchange

The ground conditions at the proposed Rozelle interchange are dominated by a deep palaeovalley eroded into Hawkesbury Sandstone by Whites Creek. This palaeovalley was filled with soft, water saturated estuarine sediments, which were then covered by fill during reclamation works associated with the formation of the Rozelle Rail Yards in the mid-1910s. Excavation of sandstone along the northern site boundary may have been a source of some of this fill. The fill comprises generally granular material including sand, railway ballast, and sandstone cobbles. A layer of sandstone boulders and cobbles appears to be present immediately above the estuarine sediments. The estuarine sediments comprise very soft to soft organic clays interbedded with loose clayey sands. The depth to bedrock ranges from less than one metre to over 20 metres. Several dykes have been mapped crossing the site trending north-west. Groundwater is present within the fill, within the alluvium of the deep palaeovalley associated with Whites Creek, and within the underlying Hawkesbury Sandstone. Thus large scale dewatering of the alluvium during construction would be impractical due to the large volumes required to be pumped. Groundwater elevations within the alluvium and Hawkesbury Sandstone are shallow and about one metre below the current ground level, or one to two metres AHD, indicating groundwater flow is eastward and discharging into Rozelle Bay

4.15.4 M4 East interface

The ground conditions at the M4 East interface are challenging, with a palaeovalley associated with Iron Cove Creek located 100 metres east of the approved driven tunnel portals. The top of rock in the base of the palaeovalley is up to eight metres below ground surface, while the crown of the tunnels are located less than eight metres below ground. The palaeovalley is infilled with a combination of soft estuarine clays and firm, water saturated clayey sands which are alluvial in origin. Some 150 metres to the east of the palaeovalley, an igneous dyke crosses the project footprint.

Groundwater is present within the fill, and within the alluvium of a palaeovalley associated with Iron Cove Creek, carved into the underlying Hawkesbury Sandstone. The water table within the sandstone, outside the palaeochannel is shallow in this area, measured at about three metres below ground level or 0.8 metres AHD (HB_BH03). Groundwater levels within the alluvium are expected to be at similar depths. The approved M4 East tunnel alignment near the Wattle Street interchange intersects a dolerite dyke about 12 metres thick. The dolerite dyke can act as either a barrier to groundwater flow or a conduit for flow depending on the hydraulic properties of the basalt. Given the weathered nature of the dolerite, the dyke is more likely to act as a barrier than a conduit for groundwater flow and if intersected by the tunnel could increase groundwater inflow to the tunnels. Long term the dyke is likely to require rock support in which case the tunnel intersected by the dyke could be waterproofed as part of the support structures by the installation of shotcrete and a membrane to reduce long term groundwater ingress.

The remainder of the M4 East interface tunnels intersects good quality sandstone and would be constructed as a drained tunnel. During construction, increased groundwater inflows to the tunnels can occur when saturated fractures, fissures, faults and joints are intersected. Such flows are reduced by decreasing the bulk hydraulic conductivity by the addition of shotcrete during construction. The electrical conductivity was measured in the Hawkesbury Sandstone at 5574 microsiemens per centimetre indicating the groundwater quality is of low to moderate salinity. Groundwater quality in the overlying alluvium is expected to be similar, suggesting that groundwater quality at this location should not pose constraints on building materials.

4.15.5 Iron Cove

Ground conditions comprise a thin cover of residual soils or fill over Hawkesbury Sandstone. Good quality, relatively unweathered sandstone is generally several meters below the top of rock, although some boreholes contain thin seams of poorer quality rock. The twin Iron Cove Link tunnels are proposed to be constructed within good quality saturated Hawkesbury Sandstone. At the Iron Cove Link portal there is up to five metres of fill overlying Hawkesbury Sandstone. The fill is likely to contain minor perched water at the interface with the sandstone. Waterproofing would be required around the portal during construction and long term to prevent the ingress of perched groundwater. A 1.3 metres thick deeply weathered dolerite dyke was intersected in borehole IC_BH02, located on the western side of Victoria Road at Booth Street. Due to the weathered nature of the dolerite, the dyke is likely to behave as a barrier with the clays restricting groundwater flow.

4.16 Surface water monitoring

Surface water monitoring has been undertaken to characterise the existing water quality of the waterways within the vicinity of the project to inform the EIS and to provide a baseline of environmental conditions against which compliance can be measured during construction and operation. Dry weather sampling has been conducted monthly for surface water since July 2016. A dry weather event is defined as no heavy rainfall (greater than 15 millimetres) for three days prior to sampling. Wet weather sampling is conducted periodically when rainfall exceeds 15 millimetres over a 24 hour period.

The surface water samples were monitored for field parameters including turbidity, temperature, dissolved oxygen, electrical conductivity, redox conditions and pH. Water samples were submitted to the laboratory for total metals, nutrients and TRH, semi volatiles and volatiles (BTEXN).

The surface water monitoring sites are summarised in **Table 4-10** and their location is presented on **Figure 4-20**.

Table 4-10 Surface water monitoring locations

Site reference	Water course	Location	Easting and northing	Monitoring purpose
Tidal locations				
SW01	Rozelle Bay	Whites Creek outlet at City West Link/The Crescent, Rozelle	331068.514 6250619.522	Down-stream of construction
SW02	Whites Creek	Whites Creek Valley Park, Railway Parade Annandale	330675.138 6250214.659	Down-stream of construction
SW03	Johnstons Creek	Smith Park pedestrian bridge, Neilson Lane Annandale	331348.646 6249812.856	Down-stream of construction

Site reference	Water course	Location	Easting and northing	Monitoring purpose
SW05	Hawthorne Canal	Hawthorne Canal Reserve, Canal Road, Leichardt	328710.519 6249937.233	Up-stream of construction
SW06	Hawthorne Canal	Canal Road (between City West Link and Lilyfield Road) Lilyfield	328944.974 6250424.174	Down-stream of construction
SW07	Open stormwater channel	Adjacent to 88-90 Lilyfield Road, Lilyfield	330816.164 6250769.419	Down-stream of construction
SW08	Iron Cove Creek	Pedestrian bridge between Timbrell Park and Reg Coady Reserve, Dobroyd Parade, Haberfield	327694.599 6250353.662	Down-stream of construction
SW09	Iron Cove Creek	West of Ramsey Road bridge at Dobroyd Parade, Haberfield	327295.048 6250337.517	Up-stream of construction
SW11	Rozelle Bay	Iron Cove Bridge	330030.753 6251603.377	Down-stream of construction
SW12	Rozelle Bay	Iron Cove King George Park	330123.434 6251830.863	Down-stream of construction
SW14	Johnstons Creek	Johnstons Creek (South)	330955.253 6248607.264	Down-stream of construction
Non-tidal locations				
SW04	Johnstons Creek	Adjacent to playground, Chester Street,	331137.734 6249151.793	Down-stream of construction
SW10	Sheas Creek	South side of Huntley Street, Alexandria	332868.793 6246433.815	Up-stream of construction

Note:

SW13 was monitored as part of the contamination assessment (refer to **Appendix R** (Technical working paper: Contamination)) and is not relevant to the groundwater assessment

The surface water monitoring program is discussed further in the surface water monitoring report (AECOM 2016f) and surface water impacts are discussed in **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS.. Results of the surface water monitoring program are summarised in **Table 4-11** along with exceedances with reference to the ANZECC (2000) guidelines for estuarine and marine waters.

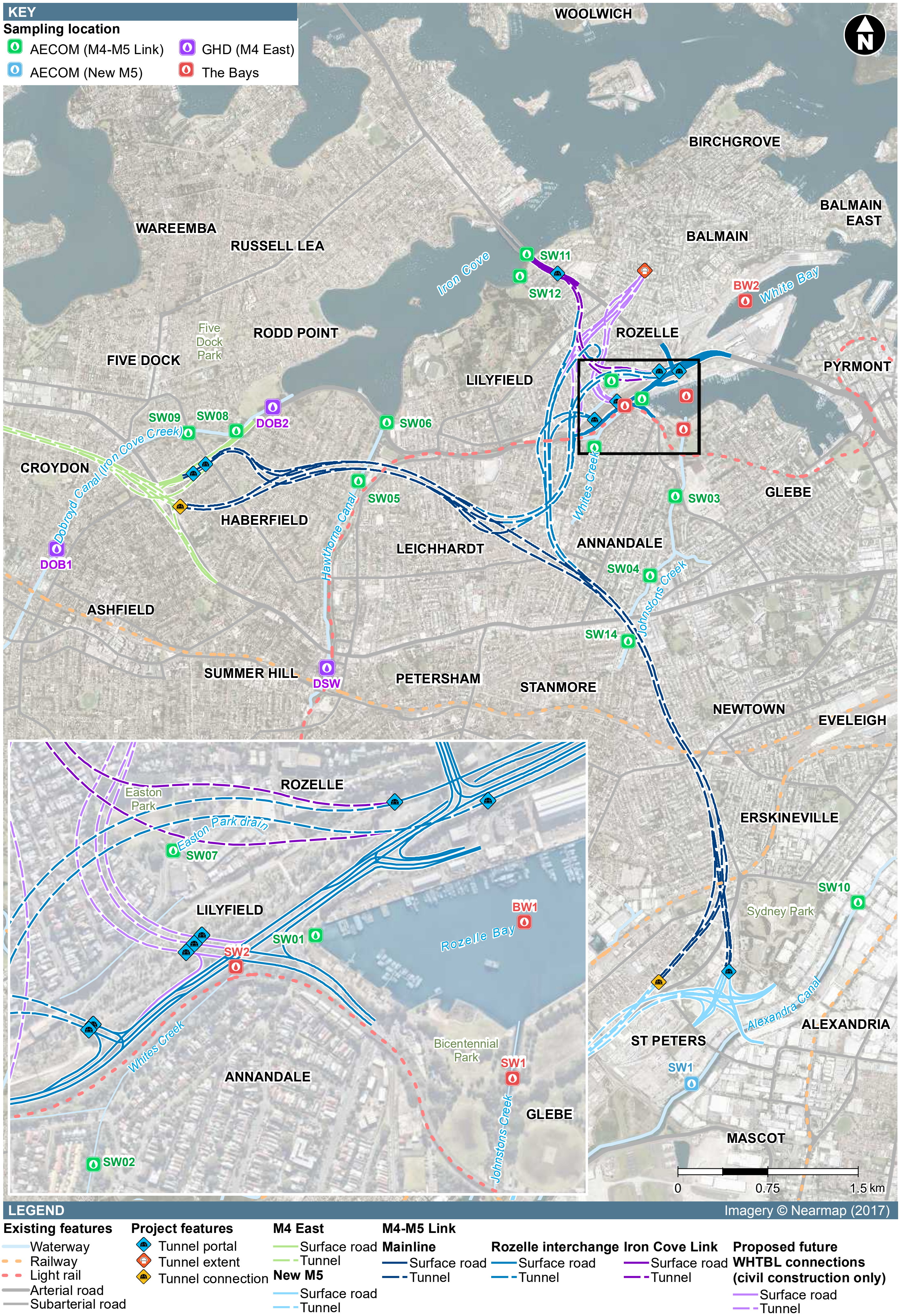


Figure 4-20 Location of surface water monitoring sites

Table 4-11 Summary of the water monitoring program

Waterway	Waterway influences	Exceedances (ANZECC (2000)
Dobroyd Canal	Tidal and non-tidal	• Heavy Metals (Cu, Cr, Pb, Ni, Zn) • Nutrients (nitrate, nitrogen and phosphorus) • pH and turbidity • Total recoverable hydrocarbons detected
Hawthorne Canal	Tidal	• Heavy Metals (Cu, Cr, Pb, Zn) • Nutrients (nitrate, nitrogen and phosphorus) • pH and turbidity
Whites Creek	Tidal	• Heavy Metals (Cu, Pb, Zn) • Nutrients (nitrate, nitrogen, phosphorus, ammonia) • pH and turbidity
Easton Park drain	Tidal	• Heavy Metals (Cu, Pb, Zn) • Nutrients (nitrate, nitrogen, phosphorus) • pH and turbidity
Johnstons Creek	Tidal and non-tidal	• Heavy Metals (Cu, Cr, Pb, Ni, Zn) • Nutrients (nitrate, nitrogen and phosphorus) • pH and turbidity • Total recoverable hydrocarbons detected
Rozelle Bay	Tidal	• Heavy Metals (Cu, Cr, Pb, Zn) • Nutrients (nitrate, nitrogen, phosphorus, ammonia, chlorophyll) • pH and turbidity
Iron Cove	Tidal	• Heavy Metals (Cu, Cr, Pb, Zn. Hg) • Nutrients (nitrogen, phosphorus) • Turbidity
White Bay	Tidal	• Heavy Metals (Cu, Zn) • Nutrients (nitrate, nitrogen and phosphorus) • Turbidity
Alexandra Canal	Tidal	• Heavy Metals (Cu, Pb, Zn, Cr^{3+}, Cr^{6+}, Ni, Mn, Zn) • Nutrients (nitrate, nitrogen and phosphorus) • Turbidity

5 Assessment of construction impacts

A numerical groundwater model as outlined in **section 3.3.3** has been developed to quantify potential impacts. Groundwater levels and/or quality along the project footprint during construction could be impacted due to the project. Mitigation measures and management strategies to eliminate, reduce or manage potential impacts are outlined in **Chapter 8**.

The potential impacts on the hydrogeological regime during construction of the M4-M5 Link project are:

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

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

5.1 Reduced groundwater recharge

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

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

5.2 Tunnel inflow

The short term inflow during construction would be dependent upon a number of factors including tunnelling progress, tunnelling construction methodology (including the success of pre-grouting), fractured zones intersected, localised groundwater gradients and storativity. Initial inflows to tunnels can be large, because of the large hydraulic gradients that initially develop near the tunnel walls, however these gradients will reduce in time as drawdown impacts extend to greater distances from the tunnels and inflows approach steady state conditions. Higher inflow rates are likely from zones of higher permeability, where saturated geological structural features are intersected by the tunnels. During construction these high inflow zones are to be grouted to reduce the inflow rate to below the one litre per second per any kilometre length of tunnel criterion.

Inflows from the Hawkesbury Sandstone and Ashfield Shale are expected to be highest during construction, as hydraulic gradients would be at their highest and then would decline as equilibrium is reached. Groundwater modelling has predicted groundwater inflows after grouting to the tunnels during construction to range between 0.45 megalitres per day (M5 East tunnel scenario only) and 2.87 megalitres per day (M4-M5 Link) as reflected in the groundwater modelling construction water balance.

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

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

The predicted water take during construction (Year 2023) from each of the Greater Metropolitan Regional resource due to tunnel inflows is compared to the LTAAEL and is summarised in Table 5-1. Comparison of predicted tunnel inflows indicates the reduction in the groundwater availability within the Botany Sands during construction will be reduced by 0.004 per cent of the LTAAEL. Similarly the predicted reduction in the groundwater availability during construction will be reduced by 661 ML/year or 1.4 per cent of the LTAAEL for the Sydney Basin Central groundwater resource.

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

Aquifer	LTAAEL	Water take - year 2023	Percentage of LTAAEL
Units	**ML/year**	**ML/year**	**(%)**
Botany Sands	14,684	0.62	0.004
Sydney Basin Central	45,915	661	1.4

Source: NoW, 2011 and HydroSimulations(2017)

5.2.1 Connection to Wattle Street

The modelling has been undertaken for construction Option A at Haberfield, therefore the above results reflect tunnelling from Wattle Street civil and tunnel site (C1a) and Haberfield civil and tunnel site (C2a).

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

5.3 Predicted groundwater level decline

Groundwater modelling has been used to predict groundwater levels at the end of the construction period within the alluvium, Ashfield Shale and Hawkesbury Sandstone. Within the alluvium, the groundwater levels are predicted to form a steep elongated cone of depression along the project footprint indicating a good hydraulic connection with the Hawkesbury Sandstone. The depressed groundwater contours however are localised extending no further than about 500 metres from the tunnels indicating localised changes to groundwater flow patterns with negligible impacts on the regional groundwater flow.

At the end of construction, steep localised cones of depression are predicted to develop beneath Newtown and St Peters within the Ashfield Shale. Local groundwater sinks are created at these locations due to the low hydraulic conductivity of the shale and the influence of the leachate pumping at the former Alexandria Landfill.

As for the alluvium and shale, the groundwater levels within the Hawkesbury Sandstone are predicted to be depressed along the tunnels at the end of the construction period. While the impacts are localised extending no further than about 600 metres from the tunnels, the groundwater sink developed creates a barrier along the length of the project footprint to the base of the tunnel. At some point below the tunnel invert, groundwater flow would cease being drawn upwards and groundwater flow within the sandstone would continue uninterrupted.

The predicted groundwater elevations (metres AHD) at the end of the construction phase (2023) are presented for the project in **Figure 5-1**. The drawdown presented in is the total drawdown for all three aquifers. Predicted drawdown for each individual aquifer including the alluvium, Ashfield Shale and Hawkesbury Sandstone is presented in **Figure 5-2**, **Figure 5-3** and **Figure 5-4** respectively. In **Figure 5-4** the Ashfield Shale drawdown is presented from the top of the shale extending into the underlying Hawkesbury Sandstone.

5.4 Groundwater level drawdown

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

During construction, the regional extent of drawdown impacts due to tunnel construction would be minimal even though groundwater inflows are high. This is due to groundwater storage depletion from the immediate vicinity of the tunnel restricting the lateral extent of drawdown and the relatively short construction timeframe. As construction continues the inflows would decrease but the depressurisation caused by the tunnel inflows would propagate to the surface causing the water table to decline and would extend outwards to progressively greater distances until steady state conditions are reached, which is expected to be well after the completion of construction. The longer term regional impacts on groundwater levels would therefore be greater and would progressively increase until steady state conditions are reached as outlined in **section 6.3**.

Grouting will be undertaken throughout the construction program which will reduce groundwater inflows and hence limit the groundwater level decline. Groundwater levels would be monitored throughout the construction phase in accordance with a CSWMP to be developed as part of the CEMP. Additional groundwater modelling is proposed to be conducted by the contractors during the construction program using measured tunnel inflow rates and monitored groundwater drawdown to better calibrate the model and predict impacts.

The predicted groundwater drawdown (metres AHD) at the end of the construction phase (2023) is presented for the project in **Figure 5-1** and represents the total drawdown within three aquifers. Predicted drawdown for each individual aquifer including the alluvium, Ashfield Shale and Hawkesbury Sandstone after construction are presented in **Figure 5-2** to **Figure 5-4** respectively.

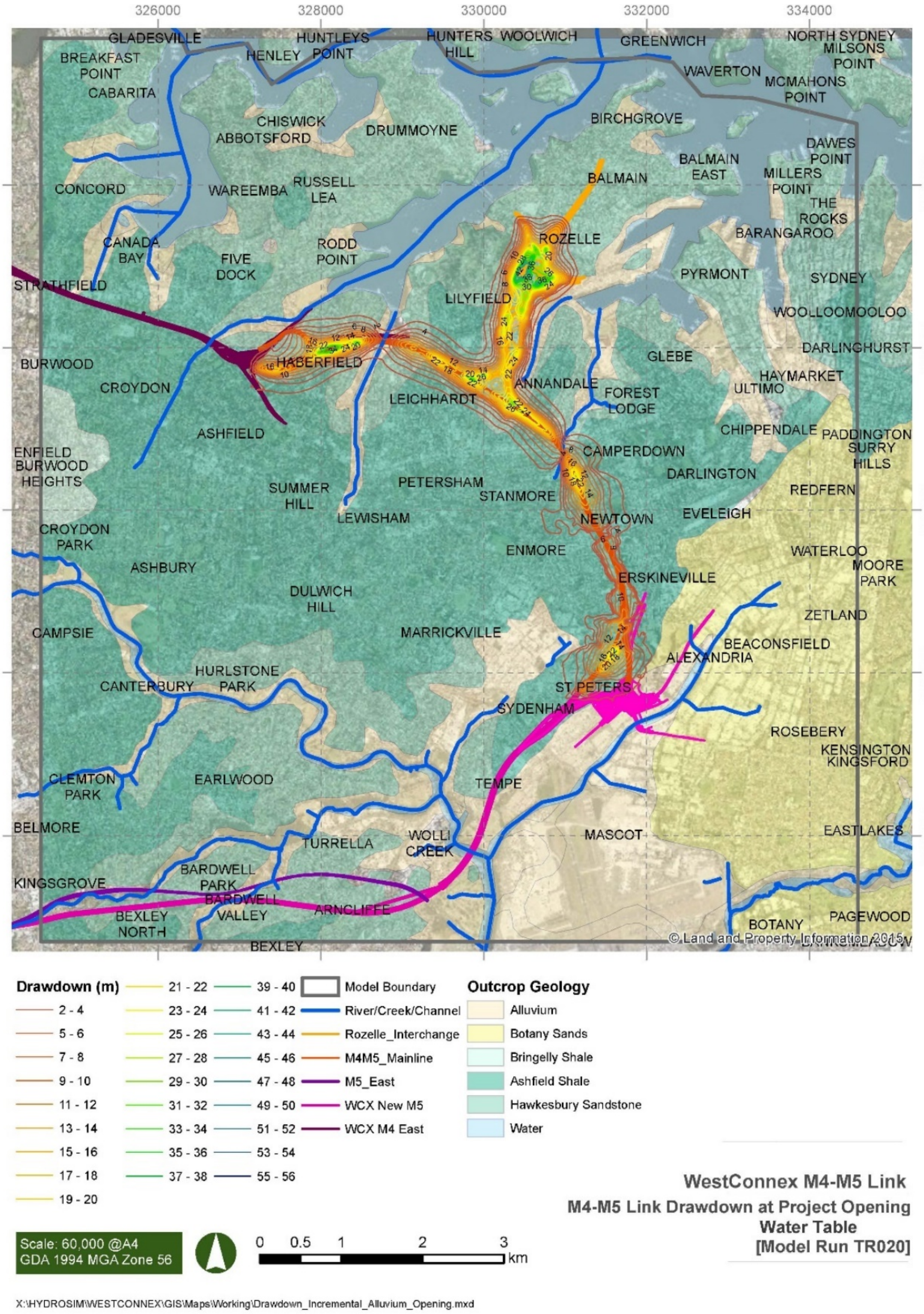


Figure 5-1 Predicted water table drawdown for the project after construction – 2023 (from HydroSimulations 2017)

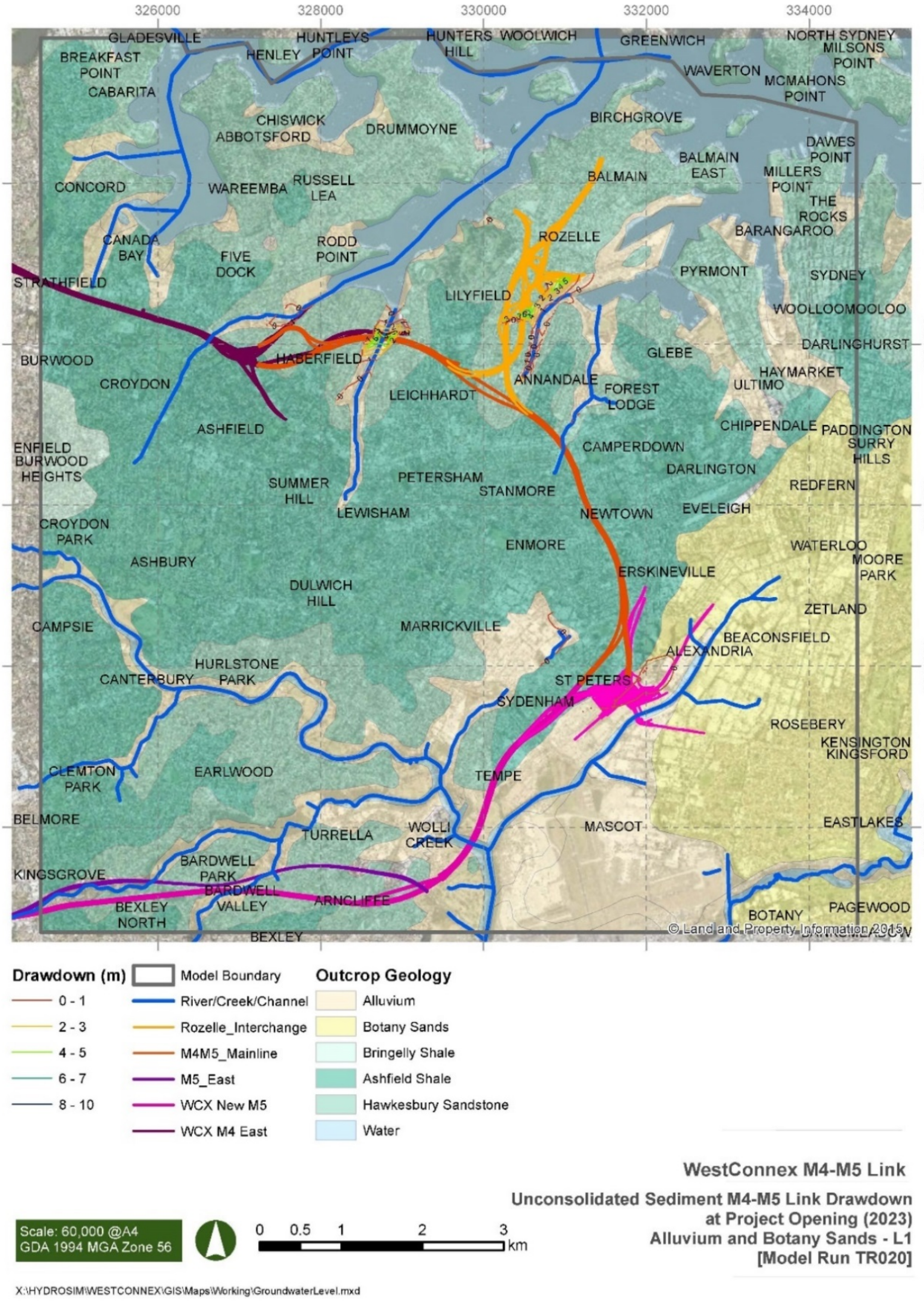


Figure 5**-**2 **Predicted drawdown in the alluvium after construction – 2023 (from HydroSimulations 2017)**

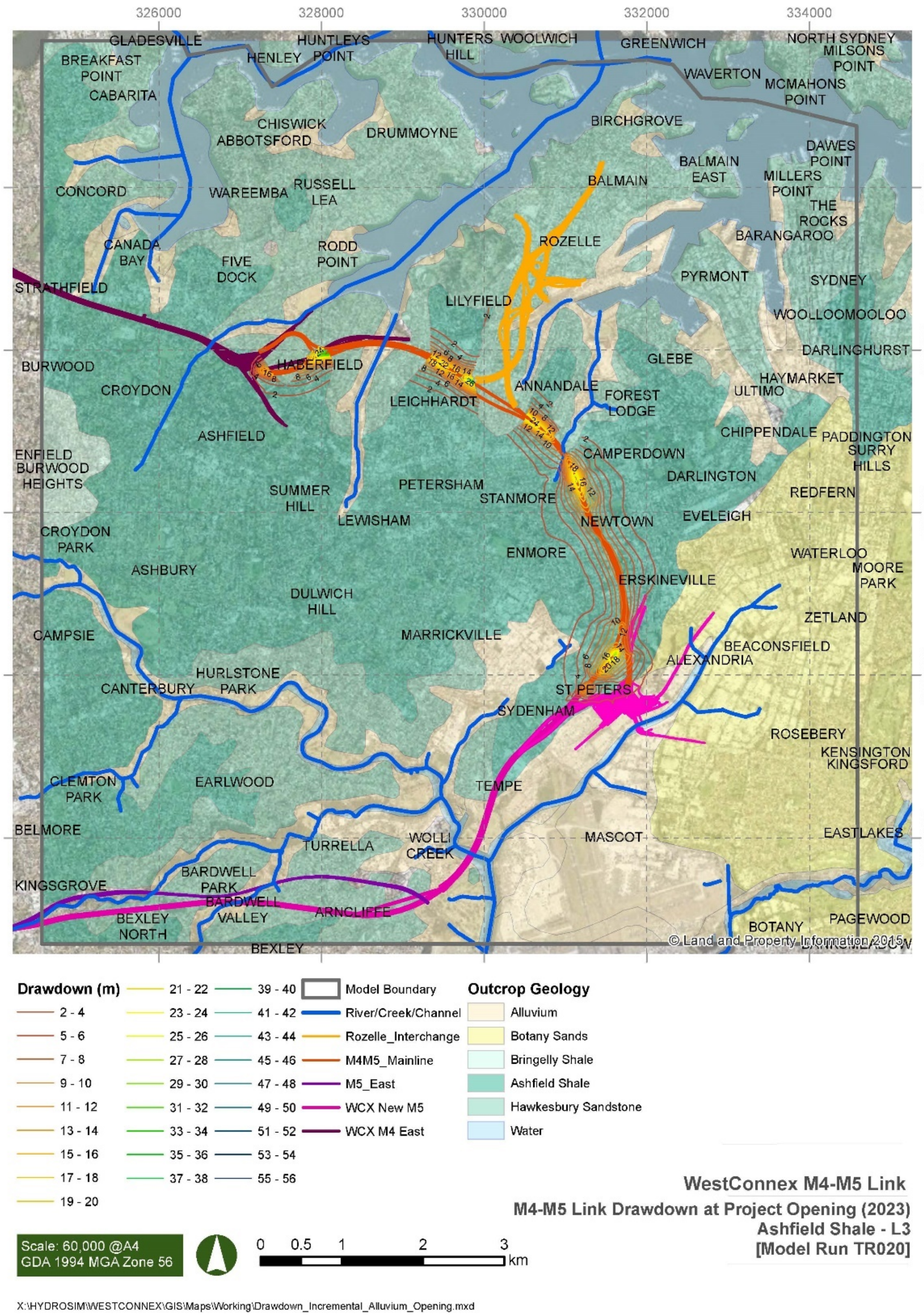


Figure 5-3 Predicted groundwater drawdown in the Ashfield Shale after construction – 2023 (from HydroSimulations 2017)

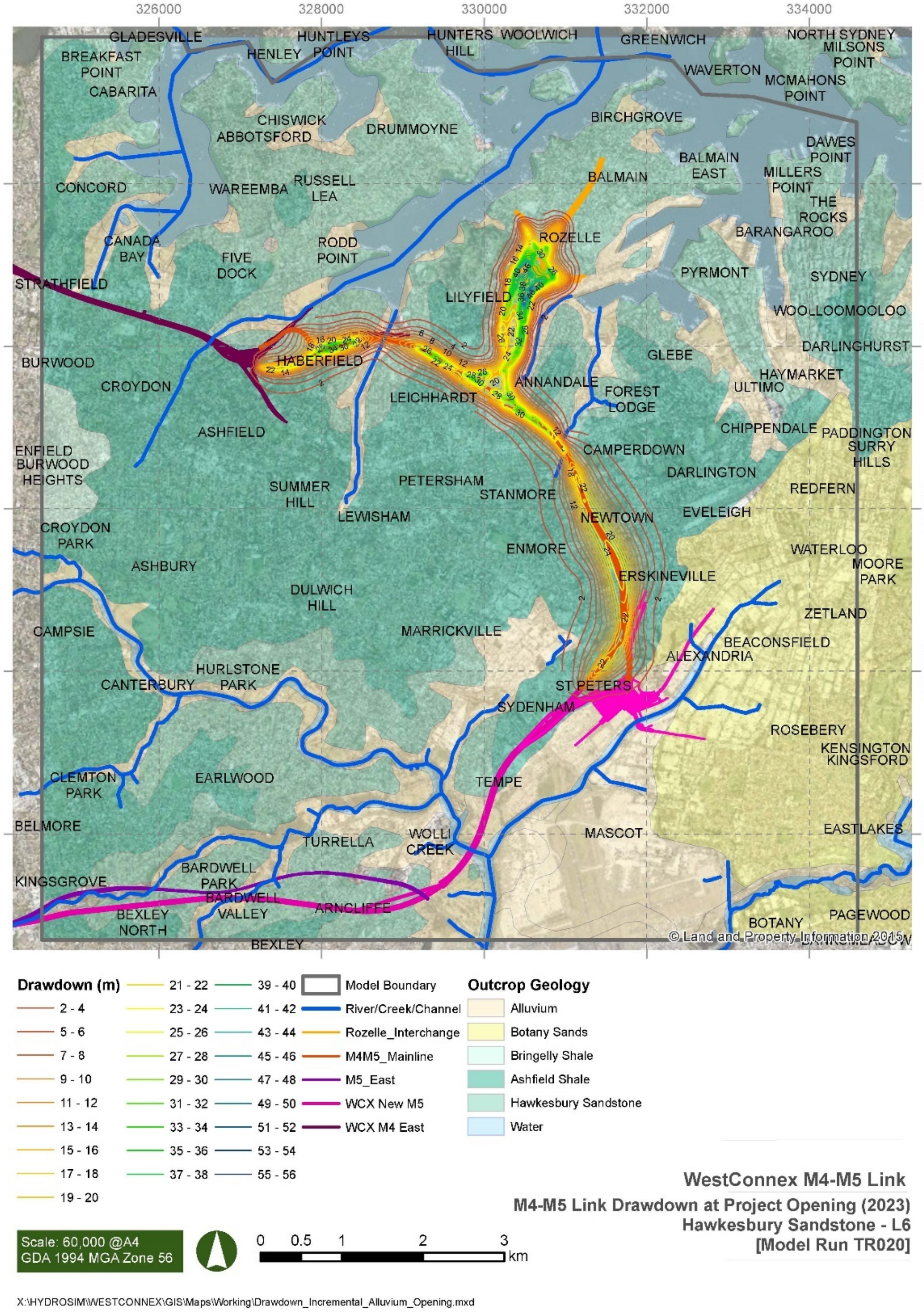


Figure 5-4 Predicted groundwater drawdown in the Hawkesbury Sandstone after construction – 2023 (from HydroSimulations 2017)

5.4.1 Potential impacts on groundwater dependent ecosystems

In accordance with the AIP, groundwater drawdown must be within an allowable range of 10 per cent of baseline levels within 40 metres of a significant GDE. No priority GDEs have been identified within the project footprint. The closest priority GDEs are the Botany Wetlands and Lachlan Swamps within the Botany Sands, located in Centennial Park around five kilometres east of the project footprint. These wetlands are at a sufficient distance from the project footprint to not be impacted by the project. Potential impacts to these wetlands and GDEs due to the New M5 were assessed in the New M5 EIS.

There is a man-made wetland constructed in Annandale at Whites Creek Valley Park in 2002, located immediately before Whites Creek. Groundwater levels within the alluvium associated with Whites Creek are unlikely to be adversely impacted during construction because the tunnels are below the alluvium. Groundwater levels are predicted to be drawn down in the Hawkesbury Sandstone but are unlikely to have any groundwater dependence in this area.

Waterways in or adjacent to the proposed works (Whites Bay, Rozelle Bay and Iron Cove) are not suitable habitat for threatened fish species and there are no SEPP 14 wetlands in the study area (refer to **Appendix S** (Technical working paper: Biodiversity)) of the EIS. It is also unlikely that there is valuable or specific aquatic habitat for threatened aquatic/estuarine species, populations or communities listed under the *Fisheries Management Act 1994* (NSW), *Threatened Species Conservation Act 1995* (NSW) or *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth) present within the project footprint.

Groundwater dependence of ecosystems is unlikely to be adversely impacted by groundwater level decline associated with the construction phase of the project.

An assessment of the impacts to natural processes as a result of the operational discharges which may affect the health of the fluvial, riparian and estuarine systems and landscape health within the study area is provided in **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS. These natural processes are outlined in **section 4.4**. In summary, no wetlands, marine waters or natural floodplain systems are considered to be affected by the project. Impacts to fish habitat are considered in **Appendix S** (Technical working paper: Biodiversity) of the EIS.

5.4.2 Potential impacts on surface water and baseflow

Surface water features within or in proximity to the project footprint are described in **section 4.4**. There is unlikely to be any direct surface water inflow to the tunnels from the alluvium since sections of the tunnels are designed as undrained (tanked) tunnels through the Whites Creek alluvium beneath the Rozelle Rail Yards or are designed to dive beneath the palaeochannels such as beneath Hawthorne Canal. Since the majority of the creeks and canals are concrete lined, the risk for surface water from creeks or canals to seep into the tunnels via leakage to the alluvium is considered low. There may be some seepage from the canals as a result of cracks in the aged concrete.

Surface water quality would be monitored throughout the construction phase in accordance with a surface water management plan (CSWMP) to be developed as part of the CEMP. The Sydney Water proposal to naturalise sections of Whites Creek, Johnstons Creek and Iron Cove Creek (Dobroyd Canal) is likely to increase groundwater recharge and may partially increase the baseflow to these creeks. Surface water monitoring is discussed in more detail in **section 4.16** and in **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS.

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

Where the channels are concrete lined, groundwater would be expected to flow within the alluvium surrounding the channel, discharging downstream directly into Rozelle Bay or Parramatta River. However, if groundwater levels are lowered, due to tunnel inflows, then groundwater flow could be reduced or reversed. Therefore, there is potential for groundwater quality to decline as a result of the groundwater drawdown of the brackish water. The natural groundwater is already known to be brackish in the lower lying reaches of the catchment where there is natural tidal interaction. Higher in the catchments, any groundwater loss from the creeks to groundwater via leakage is unlikely to degrade groundwater quality as the surface water would be of lower salinity.

Predicted impacts of construction on baseflow for major creeks has been modelled (**Annexure H**). For the purposes of modelling, baseflow is considered to be the groundwater that discharges to a creek or river and is simulated in the model only when groundwater reaches the ground surface and enters the drainage system. The majority of river flow would be derived from stormwater runoff rather than baseflow as indicated by the surface water monitoring investigation (AECOM 2017b). Predicted changes in baseflow at the end of construction are summarised in **Table 5-2**.

Table 5-2 Predicted changes in baseflow at the end of construction (2023)

2023	Hawthorne Canal	Dobroyd Canal (Iron Cove Creek)	Whites Creek	Johnstons Creek
Existing baseflow (m^3/day)	298	281	177	289
Reduction in baseflow due to M4-M5 Link project (m^3/day)	96	14	132	59
% reduction	32	5	75	20

During construction, the baseflow to major non-tidal creeks is predicted to be reduced by between 5 and 75 per cent. These predicted baseflow reductions are unlikely to substantially impact the local environment as the majority of baseflow is anticipated to be derived from surface water runoff and since the groundwater baseflow volumes only represent the periods when groundwater levels are higher than creek levels and the assessment therefore represents a worst case scenario. Consequently groundwater is unlikely to sustain ecosystems before discharging into Rozelle Bay or Parramatta River. There may be some leakage through the aged cracked concrete that could sustain groundwater however this leakage would be minor. Although the base flow component of streamflow in Whites Creek is substantially reduced, it is expected that the overall contribution to river flow from groundwater input is relatively small due to Whites Creek being lined, tidally influenced and the catchment being heavily urbanised. There is no predicted impact due to the project during construction on other major creeks along the New M5 corridor including Cooks River, Wolli Creek and Bardwell Creek.

5.4.3 Impacts on existing groundwater users

A review of current groundwater use has been conducted to identify registered groundwater users and the environment (GDEs) within a two kilometre buffer of the project footprint. In accordance with the AIP, existing groundwater bores impacted by the lowering of groundwater levels in excess of two metres due to the project would be protected by to the ‘make good’ provisions. This would require the project to restore supply to pre-development levels. The measures taken to ‘make good’ would be dependent upon the location of the impacted bore but could include deepening the bore, providing a new bore, providing an alternative water supply, or alternatively providing appropriate monetary compensation. A review of existing users within and adjacent to the project footprint is summarised in **section 4.10**.

The groundwater model has been used to assess the potential groundwater level drawdown at sensitive areas, registered groundwater users and where the impacts are expected to be in excess of minimal impact considerations as specified in the AIP, mitigation measures have been recommended. Potential impacts on existing users during construction include drawdown in registered wells due to the extraction of groundwater during tunnelling. Registered users within two kilometres of the project alignment were input into the groundwater model and none were predicted to be drawn down in excess of two metres during the project construction program.

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

5.5 Groundwater quality

Groundwater quality risks from construction activities include the potential to contaminate groundwater from fuel, oil, other chemical spills and from the captured groundwater intersected during tunnelling. There is also potential to intersect acid sulfate soils and contaminated groundwater due to previous industrial land use. Contaminants within soil at the Rozelle Rail Yards could be mobilised due to altered groundwater flow paths. As groundwater drawdown increases due to tunnel inflows there is the potential for tidal waters to be drawn into the tunnels causing saltwater intrusion. Groundwater quality would be monitored throughout the construction phase in accordance with the CSWMP to be developed as part of the CEMP. These potential risks to groundwater quality are discussed further.

5.5.1 Spills and incidents

There is potential to contaminate groundwater through incidents within the construction ancillary facilities during the storage of hazardous materials or refuelling operations. Groundwater could become contaminated via fuel and chemical spills, petrol, diesel, hydraulic fluids and lubricants particularly if a leak or incident occurs over the alluvium, palaeochannel or fractured sandstone. Stockpiling of construction materials may also introduce contaminants to the groundwater of the project footprint by the leaching of contaminants followed by run-off and accession to the water table.

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

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

5.5.2 Intercepting contaminated groundwater

A number of sites with the potential for groundwater contamination due to various current and historical land-uses are located along the project footprint as outlined in **section 4.14** and in **Appendix R** (Technical working paper: Contamination) of the EIS. A potential contamination risk would be associated with the migration of contaminated groundwater plumes towards the tunnels.

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

There is potential to intersect contaminated groundwater during construction while excavating the portals and dive structures that are constructed from the top down, although groundwater would typically be isolated from these structures by cut-off walls such as diaphragm walls or secant piled walls.

Groundwater contamination investigations have been conducted as part of EIS investigations and have identified some areas where contaminated groundwater may occur, such as St Peters Landfill, Rozelle Rail Yards and former industrial sites in areas such as Alexandria and Haberfield. Contaminated groundwater, if intersected, will enter the tunnels and will be treated prior to discharge at one of the water treatment plants. It is not considered feasible to estimate the concentration of contaminants with any certainty due to significant variabilities and associated uncertainties. An approach which is consistent with the two previous WestConnex projects is to provide management measures and treatment to control pollutants.

The primary risk to groundwater quality is the migration of contaminated groundwater through altered groundwater flow paths due to the tunnel construction. At the Rozelle Rail Yards, groundwater beneath the site within the alluvium is shallow and impacted by historical industrial land uses. Potential contaminants of concern include heavy metals (arsenic, cadmium, copper, lead, nickel and zinc) and hydrocarbons. The tunnels through the alluvium are to be constructed as undrained (tanked) tunnels to reduce the ingress of groundwater from the palaeochannels, minimising potential contaminated groundwater migration, and addressing the requirements of DPI-Water. In addition, cut-and-cover sections that intersect the alluvium are to be constructed with secant pile walls or diaphragm walls founded in competent sandstone, for example, to reduce groundwater inflow from the alluvium.

During ground excavation works associated with the construction of the tunnel access decline, shallow groundwater is likely to be encountered within the alluvium and would require management during construction. It is also possible that un-predicted localised perched groundwater may be intersected. At Rozelle, localised temporary dewatering may be required which would be decided during the detailed design phase (**sections 2.3.2**, **5.2**, and **5.7**). The volume of shallow groundwater to be extracted has been accounted for in the groundwater modelling predictions.

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

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

Groundwater and surface water captured as a result of tunnelling are likely to be contaminated with suspended solids and increased pH due to tunnel grouting activities. These flows would be captured and treated prior to discharge via water treatment plants located at construction ancillary facilities. Where possible, the treated water would be reused during construction for purposes such as dust suppression, wheel washing and plant washing, rock bolting, earthworks or irrigation before discharge. Groundwater reuse would be undertaken in accordance with the policies of sustainable water use of DPI-Water (National Water Quality Management Strategy, 2006). The volume of recycled water required for beneficial use will be variable and dependent on site conditions and will be likely be driven by a demand for beneficial use water. The estimated total volume of water required during construction is not available at this stage of the project and will be determined during detailed design. It is expected that there will be a water surplus during construction and recycled water for operational purposes would be used in preference to potable water where possible.

At St Peters interchange there is known groundwater contamination including elevated ammonia associated with the former landfill. Geotechnical drilling as part of the project did not identify localised faulting or fracturing which could provide leachate conduits to the tunnels. Although the tunnel depths are shallow near the portals, the risk of landfill contaminated groundwater being intersected by the tunnels is considered low as continual leachate pumping from the former landfill would locally reverse groundwater gradients and pumped groundwater would be treated by the landfill water treatment plant.

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

Given the tunnel depth, location of the tunnel in relation to the contaminant source and low inflow rates, the risk of intercepting contaminated groundwater from the sandstone and shale is considered to be low. The risk of contaminated groundwater ingress from the alluvium is also considered low because the tunnel is to be tanked in the alluvium, restricting groundwater movement from the alluvium. All groundwater captured during construction would be directed to water treatment plants at the following construction ancillary facilities:

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

5.5.3 Groundwater treatment

The volume of groundwater and treatment requirements will differ depending on the depth of the tunnel to be constructed, and the geological units through which the tunnel passes. Groundwater and surface water captured as a result of tunnelling are likely to be contaminated with suspended solids and increased pH due to tunnel grouting activities. During construction, the wastewater generated in the tunnel would be captured, tested and treated at a construction water treatment plant (if required) prior to reuse or discharge, or disposal offsite if required.

Based on the knowledge gained from the adjoining projects (M4 East and New M5) it is likely that the water treatment plants will be required to include pH correction as well as the ability to remove iron, manganese, suspended solids, hydrocarbons and other settleable compounds. The results collected as part of this project as outlined in **section 4.13** indicate that groundwater in the study area may also be impacted by elevated levels of ammonia, total nitrogen and total phosphorus compared to ANZECC (2000) guideline levels (marine, freshwater and recreational protection levels). Other metals including copper, chromium, lead, nickel and zinc were also recorded at elevated levels on a limited number of occasions. The type, arrangement and performance of construction water treatment facilities will be developed and finalised during detailed design.

The receiving waterways and ambient water quality are all highly disturbed compared to the water discharge quality. Given the nature of the receiving waterways and temporary nature of the construction phase the ANZECC 90 per cent protection level for discharge quality could be adopted in accordance with guidelines. The 99 per cent protection level would apply to analytes that bio-accumulate such as heavy metals.

The assessment of the potential impacts of the quality of water discharged from the water treatment plants during construction is discussed in **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS.

5.5.4 Acid sulfate soils

Potential acid sulfate soils (PASS) have been identified within natural alluvium beneath the former Rozelle Rail Yards and possibly within the alluvium along Hawthorne Canal. When exposed to air, the iron sulphides (commonly pyrite) within acid sulfate soils can oxidise, producing sulphuric acid. The soils become exposed to air by either excavation or dewatering. At Rozelle Rail Yards the excavation of low-lying natural soil may uncover PASS during the excavation for tunnel infrastructure which will require treatment and removal under the CEMP. However the majority of the tunnels would be deep and well below the areas where PASS may be expected. The only expected intersection of PASS would be during the construction of tunnel portals or cut-and-cover sections in areas of known PASS.

Acid sulfate soils could be disturbed by the project and may cause the generation of acidic runoff and/or the increased acidity of groundwater. The risks associated with PASS and acid sulfate soil would be managed under a CSWMP as part of the CEMP prepared in accordance with *NSW Acid Sulfate Soils Manual* (Stone *et al* 1998). The CSWMP would include water quality monitoring and acid sulfate soil management.

5.5.5 Soil salinity

Salts naturally present in soil and rock are mobilised in the subsurface by the movement of groundwater. The concentration of salts within the soil is related to the geological unit from which the soil is derived. Along the project footprint, soils derived from the Ashfield Shale typically have a high salt content due to the presence of connate marine salts. Salt concentrations within soils derived from the Hawkesbury Sandstone and alluvium are variable, and within the alluvium are impacted by tidal influences. Under shallow groundwater conditions, saline groundwater may be drawn to the ground surface by capillary action or altered recharge/discharge conditions, precipitating the salts as the water evaporates.

Urban salinity becomes a problem when the natural hydrogeological balance is disturbed by human interaction through the removal of deep rooted trees (causing groundwater levels to rise and potentially dissolve and mobilise salts from the soil profile) or construction of structures that intersect the water table. Since the majority of deep rooted trees were removed from the study area over 150 years ago a new equilibrium has been established and the removal of any further remaining trees on the new equilibrium would not be substantial. The development of urban salinity may cause corrosion of building materials, degrade surface water quality or prevent the growth of all but highly salt tolerant vegetation.

During construction of the M4-M5 Link project, there is potential for salts within the alluvium to be mobilised by local dewatering or associated with the tunnel construction program. Tunnels constructed within the alluvium are to be undrained (tanked), and consequently could alter local flow paths creating groundwater mounding causing the dissolution of soil salts. Beneath the Rozelle Rail Yards area, where the tanked, undrained (tanked) tunnels are to be constructed in the Whites Creek alluvium, saline groundwater reaching the ground surface would be directed towards the modified drainage system removing the mobilised salts from the system. It is unlikely the salts with Ashfield Shale would become mobilised as the short and long term impacts due to the drained tunnels are expected to draw down the water table preventing the groundwater reaching the ground surface. Hence the impact of the project on the groundwater resources or hydrology based on the mobilisation of saline soils is likely to be negligible.

5.5.6 Saltwater intrusion

During construction there are unlikely to be any impacts associated with saline groundwater entering the tunnels. Saltwater intrusion would commence as soon as the drawdown cone of depression reaches the shoreline of nearby tidal surface waterbodies which would start to impact groundwater close to the shoreline. However during construction, saline groundwater would not inflow to the tunnels from tidal areas because the tidal surface waterbodies are a considerable distance from the tunnels. The calculated groundwater travel times from these waterbodies are too long for saline water to reach the tunnels. Close to the shoreline, groundwater quality would become more saline during the construction period due to saltwater intrusion however the slight salinity increase is unlikely to impact on the environment since the groundwater along the tidal fringe is naturally saline due to tidal mixing. In addition there are no registered water supply wells or priority groundwater dependent ecosystems along this tidal fringe.

In HydroSimulations 2017) travel times for saline water to enter the tunnels within the alluvium have been tabulated for minimum, maximum and average times. The minimum travel times for saltwater to enter the tunnels at Alexandra Canal and Whites Creek are predicted to be 2 days and 8 days respectively, although after these times the volume to saline water entering the tunnels would be negligible. Initially (minimum travel time), the saline water would be a small fraction of total groundwater entering the tunnel but this is expected to increase over time as water is drawn from further afield. Average travel times are computed to be 30 years and 13 years respectively although the saline water entering the tunnels would always be a minor component of total inflow.

5.5.7 Groundwater monitoring

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

- Groundwater levels (manual monitoring and automatic monitoring by data loggers)

- Groundwater quality (within key boreholes and tunnel inflows)
- Groundwater inflows to the tunnels.

Groundwater would be monitored in the alluvium, Hawkesbury Sandstone and Ashfield Shale. The monitoring wells in the monitoring program used to inform this assessment would be used as required for monitoring. It may be necessary to construct additional monitoring wells if some of the existing wells are damaged during construction or other key areas are identified during the detailed design phase where monitoring is required.

It is expected that manual groundwater level monitoring and groundwater quality monitoring would be undertaken monthly. The quality and volume of tunnel inflows are expected to be monitored weekly.

The following analytes are likely to be sampled:

- Field Parameters (pH, electrical conductivity, dissolved oxygen, temperature and redox conditions)
- Metals (arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc)
- Nutrients (nutrients (nitrate, nitrite, Total Kjeldahl Nitrogen (TKN), ammonia and reactive phosphorous)
- Major cations (sodium, potassium, calcium, magnesium) and anions (chloride, sulphate, carbonate, bi-carbonate).

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

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

5.6 Construction of ancillary infrastructure and facilities

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

- Tunnel portals
- Ventilation systems
- Water treatment facilities
- Construction of ancillary facilities
- Drainage channels and wetland areas.

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

The water treatment facilities are to be constructed to enable captured groundwater and surface water to be treated and discharged within the appropriate guideline concentration values. The water treatment plants are not expected to impact groundwater other than groundwater being taken from the local hydrogeological system which is covered elsewhere in this impact assessment. Potential surface water impacts such as discharge from the water treatment plant that could increase flows to local waterways are discussed in **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS.

5.7 Utility adjustments

Utility adjustments would be required during the construction phase. These would include the protection of existing utilities, construction of new utilities and relocation of existing utilities. The majority of the utility adjustments would occur in new utility service corridors at the Iron Cove Link, parallel to Victoria Road and within and surrounding the Rozelle Rail Yards. The utilities to be impacted include:

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

These works would involve excavating trenches to varying depths and may intersect the water table. At the Iron Cove Link impact to groundwater is expected to be minimal as the groundwater level is typically below the expected depth of utility trenches. In contrast at the Rozelle Rail Yards the water table is shallow and within one metre of the ground surface indicating that utility trenches are likely to intersect the groundwater. During trench excavations sheet piling may be required to temporarily provide support in the alluvium and to restrict groundwater inflows to the trench. Once the sheet piling is removed, groundwater levels would return to pre excavation levels. The trenches may be encased in concrete or plastic pipes to water proof the utility service corridors. Deeper trenches or excavations may require temporary dewatering during the construction phase.

Where feasible the new utility corridors are designed to contain multiple utilities to minimise the project footprint. These works will be undertaken in accordance with **Appendix F** (Utilities Management Strategy) and the CSWMP.

5.8 Ground movement (settlement)

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

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

Since ground settlement is more likely to occur within the alluvium where tunnels are constructed, design measures have been instigated to minimise settlement at those locations. Where alluvium is intersected the tunnels would be tanked to minimise groundwater ingress. In addition, beneath Hawthorne Canal and Johnstons Creek the tunnels have been designed to dive beneath the alluvium to reduce groundwater ingress to the tunnels from the alluvium and hence reduce settlement. During tunnel construction the bulk hydraulic conductivity of the sandstone will be decreased by grouting, decreasing groundwater inflow and hence reducing settlement.

Monitoring of settlement throughout the construction program would be included as part of the CEMP. The groundwater drawdown computed in this investigation has been calculated on a regional scale and consequently due to the lithological and hydrogeological assumptions made the model output is unsuitable for calculating settlement at a detailed localised scale. Detailed settlement modelling would be required to be undertaken by the construction contractors as part of the detailed design within the Rozelle Rail Yards area where the water table within alluvium may be drawn down.

Small scale dewatering of the alluvium and Hawkesbury Sandstone may be required during construction that would result in an increase in effective stress potentially leading to ground settlement. It is anticipated that dewatering the Hawkesbury Sandstone would result in negligible settlement. Resultant movement in the clay soils would result in consolidation settlement and creep settlement which may result in settlement continuing over a long period of time.

Although the groundwater model has predicted groundwater drawdown within the alluvium and Botany Sands, it is not considered appropriate to use these regional results to calculate localised ground settlement. The model is a regional groundwater model and is not considered appropriate for use in estimating groundwater induced settlement at a more localised level. A preliminary assessment based on geotechnical conditions has been carried out to assess the potential for ground movement as a result of the project and the results of this assessment are provided in **Chapter 12** (Land use and property) of the EIS. A geotechnical model of representative geological and groundwater conditions would be prepared by the construction contractor prior to excavation and tunnelling for the project. The model would be used to assess predicted settlement impacts and ground movement caused by excavation and tunnelling on adjacent property and infrastructure.

Environmental management measures to control groundwater inflows (which influence groundwater drawdown and therefore ground movement) during construction are outlined in **section 8**.

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

Settlement monitoring would be undertaken during construction and may include the installation of settlement markers or inclinometers. In the event that settlement criteria are exceeded during construction for property and infrastructure, measures would be taken to 'make good' or to manage the impact.

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

5.9 Groundwater balance

The simulated groundwater balance computed for the end of construction (year 2023) is summarised in **Table 5-3** based on the water balance presented in the groundwater modelling report (**Annexure H**).

Table 5-3 Simulated groundwater balance – construction (2023)

Water component	Inputs (Recharge)	Output (Discharge)
	ML/day	
Rainfall infiltration (Rf)	9.52	0.0
Evapotranspiration (Et)	0.0	1.53
River inflow/outflow (Ri/Ro)	1.60	12.44
Tunnels (M4-M5 Link) (T)	0.0	2.87
Pumping wells (Pw)	0.0	0.05
Regional boundary flow (RBi/RBo)	24.95	21.40
Tidal seepage (TSi/TSo)	1.43	0.88
Storage (Si/So)	3.26	1.59
TOTAL	40.75	40.75
% Error	0.0	0.0

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

At the completion of construction in 2023 there would be a net loss in storage of 1.67 megalitres per day (3.26 megalitres per day storage input and 1.59 megalitres per day storage discharge) indicating that water is being drained from the system. The water 'take' or loss to the local hydrogeological regime is the water lost to tunnel drainage that would not be returned including direct tunnel seepage, storage loss and river loss. Review of the total inputs and outputs for each scenario indicates the water components are balanced.

The water balance includes the above groundwater components but would also include some surface water components not included in the groundwater balance such as rainfall runoff in facility enclosures (RO) or water treatment discharges (SWo).

In summary the water balance can be summarised as follows:

Inputs = Outputs; where

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

6 Assessment of operational impacts

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

6.1 Reduced groundwater recharge

The Rozelle Rail Yards are underlain by alluvium where groundwater recharge would be expected to be higher than areas underlain by sandstone and shale. The Rozelle Rail Yards currently behave as a flood storage area where much of the floodwaters would recharge the alluvium, which is attributed to the site being low lying and poorly drained. Post construction of the project, the area is to be drained by flood channels to minimise flooding, which may result in a reduction of natural groundwater recharge. Sections of the Rozelle Rail Yards are also to be capped to further reduce recharge. Parts of the Rozelle railyards not used for road infrastructure would be converted to open space or project landscaping. These areas would continue to receive rainfall recharge albeit less due to improved drainage. A reduction in groundwater recharge at the Rozelle Rail Yards is considered beneficial as it will locally reduce groundwater levels within the alluvium reducing the risk of mobilising legacy groundwater contamination (see **section 6.4.1**).

Elsewhere across the project footprint there are areas where buildings and paved areas are to be temporarily used for construction purposes such as those at Haberfield, Darley Road, Iron Cove and Pyrmont. At construction completion if these areas no longer feature buildings or structures and are no longer paved then groundwater recharge could be enhanced.

The majority of the project is below ground surface and is unlikely to directly impact groundwater recharge. Above ground, the surface area of the road network would slightly increase with additions in some key areas such as City West Link, Victoria Road, Anzac Bridge and The Crescent. Given the limited increase in surface area of the surface road infrastructure, including operational infrastructure such as the motorway operations complexes, ventilation infrastructure, substations and water treatment plants, the reduction in rainfall recharge across the project footprint is considered negligible.

6.2 Tunnel inflow

Inflow to the drained tunnel is influenced by the geology, structural geology and hydrogeological features of the intersected lithologies. This includes the hydraulic conductivity, storativity and hydraulic connectivity.

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

Conservative estimates of tunnel inflows can be made by assuming a uniform groundwater inflow rate of one litre per second per kilometre along the whole drained tunnel length during operation of the project even though there will be sections of the tunnels where inflow rates will be less than the maximum allowed rate of inflow. The total tunnel length including motorway and ventilation tunnels is around 47,940 metres. The total tunnel length of drained tunnel is around 44,950 metres.

Assuming a worst case scenario of a uniform groundwater inflow rate of one litre per second per kilometre along the whole tunnel length, a groundwater inflow of around 44.95 litres per second (3.9 megalitres per day) would be expected. This calculated inflow however is an over estimate as the tunnels are designed to restrict groundwater inflow to below one litre per second per kilometre. At the Rozelle interchange, groundwater inflows in each tunnel would be further restricted due to the number of tunnels in close proximity to each other and the associated interference of available groundwater flowing into these multiple tunnels.

Long term groundwater inflows have been modelled and vary over time as local conditions change. After the commencement of operations in 2023 the estimated long term inflows into the motorway tunnels are predicted to be 0.47 litres per second per kilometre initially, reducing to 0.25 litres per second per kilometre in 2100. Similarly the groundwater inflows into the ventilation tunnels are predicted to be 0.25 litres per second per kilometre in 2023 reducing to 0.18 litres per second per kilometre in 2100.

Groundwater inflow from the Hawkesbury Sandstone is expected to be low due to low bulk hydraulic conductivity values typically 0.008 metres per day (see **Table 4-5**). The Ashfield Shale overlying the Hawkesbury Sandstone typically has a lower hydraulic conductivity in the order of $1x10^{-3}$ to $1x10^{-2}$ metre per day (Hewitt 2005) indicating groundwater inflow is expected to be lower in the shale than sandstone.

The regional impact on the Sydney Basin Central of long term groundwater inflow (or ‘take’) as a result of the project has been estimated by comparing the annual recharge with the modelled long term inflow. Annual rainfall recharge to Sydney Basin Central is 229,223 ML (NoW 2011). The predicted long term tunnel inflow or ‘take’ (from the combined motorway tunnels and ventilation tunnels) is estimated to vary from 1.74 megalitres per day (635.1 megalitres per year) in 2023 reducing to 0.99 megalitres per day (361.4 megalitres per year) in 2100. Consequently the groundwater ‘take’ due to long term groundwater inflow to the tunnels represents 0.27 per cent of the annual recharge across the Central Sydney Basin in 2024 and 0.15 per cent in 2100. Although the groundwater ‘take’ from the local hydrogeological system is considerable in volume terms, when compared with regional recharge across Sydney Basin Central, the groundwater ‘take’ is less than 0.3 per cent of the annual rainfall recharge.

Groundwater modelling (HydroSimulations 2017) has predicted inflows over the six kilometres length of the existing M5 East tunnels. Modelling Scenario 1 presents the base case and predicts the inflow to the M5 East tunnels to range between 0.86 and 0.73 litres per second per kilometre, gradually declining over time. These results are consistent with the long term inflow of 0.8 to 0.9 litres per second per kilometre reported by Hewitt (2005) confirming the model accurately predicts tunnel groundwater inflow. It should be noted that while groundwater inflows are calculated as accurately as possible within the model confines, the inflows are averages along the alignment and actual inflow rates could be highly variable and dependent upon local geological features and the success of grouting during construction. Consequently the long term inflow rates should not be used for the purpose of planning water management during construction.

The predicted long term water take from each of the Greater Metropolitan Regional resource due to tunnel inflows and compared to the LTAAEL is summarised in **Table 6-1**. Comparison of predicted tunnel inflows indicates the long term reduction in the groundwater availability within the Botany Sands over the life of the project will vary from 0.005 per cent to 0.019 per cent. Similarly the predicted long term tunnel inflows represent a small percentage of the LTAAEL for the Sydney Basin Central which range from 0.7per cent to 1.3 per cent. Long term the predicted take from the Botany Sands aquifer increases with time due to the increasing extent of drawdown associated with tunnel operational inflows. Long term inflows to the Sydney Basin Central Regional Groundwater Resource decline as storage declines, almost halving over the project life.

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

Aquifer	LTAAEL	Water take maximum (year 2024)	Water take minimum (year 2100)	Percentage reduction of LTAAEL
Units	**ML/year**	**ML/year**	**ML/year**	**(%)**
Botany Sands	14,684	0.76	2.78	0.005 – 0.019
Sydney Basin Central	45,915	582	323	0.70 - 1.3

Source: NoW, 2011 and HydroSimulations, 2017

6.2.1 Mainline tunnel refinements

Design refinements at the proposed Inner West subsurface interchange located underground at Leichhardt and Annandale bifurcate a three lane tunnel on the approach to the subsurface interchange into a two lane tunnel and a one lane tunnel. These separate tunnels would extend south and southwest for a distance of around one kilometre, joining with the northbound mainline tunnel generally at a point below Norton Street at Leichhardt. This, along with the bifurcation of tunnels north of the St Peters interchange are likely to increase the total volume of inflow over a given time period due to the addition of extra length of drained tunnels. This will be partly offset by a reduction in inflow to the mainline tunnels due to a decreased tunnel width, however it is qualitatively expected that there will be an overall net increase in flow due to an increased extent of tunnelling leading to (minimally) increased groundwater drainage. The entire proposed bifurcation tunnel lanes are to be constructed in Hawkesbury Sandstone and Ashfield Shale therefore no increased connectivity of the project to the alluvium or unconsolidated sediments is expected.

6.2.2 Botany Sands

The tunnels do not pass through the Botany Sands or Zone 2 of the Botany Sands Source Management Zone so there would be no direct inflow of groundwater from the Botany Sands into the drained tunnels. The sandstone and shale surrounding the tunnels, however, are likely to be hydraulically connected to the Botany Sands. Hydraulic connection would however be limited due to a basal residual alluvial clay layer (reducing vertical flow) and the poor water transmitting properties of the Ashfield Shale (reducing horizontal flow). If there are locations where the basal clay has been eroded then there is potential for groundwater from the Botany Sands aquifer to enter the tunnel via fractured rock or downward leakage induced by drawdowns in the underlying Hawkesbury Sandstone. This downward leakage of groundwater from the Botany Sands to the Hawkesbury Sandstone could potentially occur anywhere within the area of drawdown in the Hawkesbury Sandstone where the sandstone is overlain by the Botany Sands.

Groundwater inflow from the Botany Sands is currently a major contributor to leachate generation at the Alexandria Landfill, as the landfill was excavated partly into the Botany Sands on its south-eastern side. Groundwater inflows at the former landfill are currently managed by a pump and treat system, which discharges to sewer. Leachate generation is to be reduced by the installation of a cut-off wall and a landfill capping that will reduce groundwater flow from the Botany Sands into the former Alexandria Landfill, as part of the New M5 project (Roads and Maritime 2015).

6.2.3 Alluvium

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

6.2.4 Palaeochannels

Deep incised palaeochannels infilled with saturated sediments are present beneath Whites Creek, Hawthorne Canal and Iron Cove Creek and extend up to 25 metres below the ground surface. To reduce the risk of large groundwater inflows to the tunnel from the palaeochannels, it is proposed to construct the tunnels beneath the palaeochannels at Hawthorne Canal and Iron Cove Creek. Beneath the Rozelle Rail Yards, the tunnels would be constructed as un-drained (tanked) tunnels through the Whites Creek palaeochannel to prevent seepage of the alluvial groundwater into the tunnels. In addition, cut-and-cover sections that intersect the saturated alluvium at Rozelle Rail Yards and Haberfield are likely to be constructed would with cut-off walls such as diaphragm walls or cut-off walls to minimise long term tunnel leakage. Where a tunnel portal intersects alluvium, the tunnel is to be tanked (undrained) and would continue beyond the portal as a cut-and-cover section with cut-off walls.

6.2.5 Dykes

Dykes such as those identified within the sandstone cutting north of the Rozelle Rail Yards and 150 metres east of the Rozelle Rail Yards cross-cut the Hawkesbury Sandstone and Ashfield Shale. The dykes may affect tunnel drainage in the short term as competent (fresh) dykes or dykes weathered to clay can form natural hydraulic barriers. Alternatively the metamorphosed zone around the volcanic intrusion within the sandstone or shale can be fractured causing a conduit for preferred groundwater flow. Several dykes have been identified along the project footprint.

6.2.6 Management of groundwater inflows during operation

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

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

Another option to reduce the bulk rock mass permeability and long term inflows is the installation of water proofing membranes during construction.

At the dive structures, ventilation shafts and cut-and-cover sections, groundwater flow within unconsolidated saturated sediments, fill, alluvium and weathered shale or sandstone would be restricted by the construction of diaphragm walls and cut-off walls founded in good quality Ashfield Shale or Hawkesbury Sandstone.

At the former Alexandria Landfill and quarry, water entering the former landfill is to be restricted by engineering solutions associated with the landfill rehabilitation. Rainfall infiltration into the former landfill is to be reduced by capping the landfill and directing captured rainfall runoff off-site. Groundwater flow into the landfill from the Botany Sands is to be restricted by the construction of a cut-off wall around the southern perimeter of the landfill as part of the New M5 project. This would locally reverse groundwater gradients away from the landfill and towards Alexandra Canal restoring pre-quarry hydrogeological flow conditions. Ongoing pumping would still be required to collect and treat leachate generated from within the landfill and the shale.

6.3 Groundwater level decline

6.3.1 Long term groundwater inflow

Previous tunnelling in the Hawkesbury Sandstone in the Sydney region has shown that groundwater inflow is typically highest during construction and then steadily reduces as the cone of drawdown expands and an equilibrium or steady state conditions are reached. This equilibrium is achieved when the tunnel inflow is matched by rainfall recharge via infiltration and/or surface water inflows. Long term groundwater inflows to the tunnels are influenced by the geology intersected (see **section 5.2**) and the tunnel construction method to reduce the bulk hydraulic conductivity. Long term groundwater inflow rates are expected to be lower than construction inflow rates. The reduction in long term inflow rates is due to the “cone” of drawdown depression expanding laterally at a rate that is proportional to the log of time. As the cone of depression expands further, the hydraulic gradients towards the tunnels reduce, and as inflow rates are directly proportional to the hydraulic gradient, inflow rates would decline. Water is derived from storage depletion but will be partly offset by recharge, both in the short term and long term.

Based on historical groundwater inflows to other drained Sydney tunnels, the long term inflow rate into the M4-M5 Link tunnels is expected to be below the one litre per second per kilometre for any kilometre tunnel length. Specific zones capable of higher rates of inflow identified during construction would require treatment such as grouting to reduce the bulk permeability of the rock mass to reduce inflow rates to meet the design inflow criterion.

Groundwater modelling has calculated inflows for the construction and operations phases. At project opening (2023) tunnel inflows are estimated to be 441 megalitres per year, declining to 267 megalitres per year at the end of the model simulation in 2100. As observed in other Sydney tunnels, inflow is likely to decrease with time. This is primarily due to the groundwater levels drawing down and inducing flow towards the tunnels from an increasingly broader region, as the cone of depression expands over time. Inflows would also decline over time as groundwater pressures around the tunnel decline as the storages of higher inflow features are drained. Similarly, siltation, chemical induration and organic slimes that accumulate in the tunnel defects may reduce the surrounding rock mass permeability, further reducing inflows.

Groundwater modelling assumes that the overall groundwater inflow for the project would achieve less than one litre per second per kilometre for any kilometre length of tunnel, and would be substantially less in some tunnel sections post grouting. Groundwater inflow is dependent upon the final construction methodology and water proofing solutions determined during detailed design. Tunnel inflows would be monitored in accordance with an Operational Environmental Management Plan (OEMP). The OEMP would outline the monitoring and management measures for groundwater inflows, treatment, discharge and settlement.

The regional impact of the project to the Zone 2 Botany Sands Management Zone for long term groundwater inflow (or 'take') has been estimated by the groundwater model. The Ashfield Shale is present in the areas where the New M5 project tunnelling occurs in the vicinity of the Botany Sands (at St Peters interchange) which, combined with the high hydraulic conductivity and rainfall recharge in the Botany Sands, appears to minimise the propagation of drawdown. This in turn indicates there is a negligible change in natural groundwater flow direction within the Botany Sands as a result of the project, therefore groundwater take from the Botany Sands aquifer due to tunnelling for the M4-M5 Link is minimal. Estimates of the groundwater 'take' from the Botany Sands due to tunnel inflows range from 1.7 kilolitres per day (year 2023) to 7.6 kilolitres per day (year 2100) or up to 2.8 megalitres per year (year 2100). Annual rainfall recharge to the Botany Sands Aquifer is 30,424 megalitres (NoW 2011). Consequently the groundwater 'take' due to long term groundwater inflow to the M4-M5 Link tunnels represents 0.009 per cent of the annual recharge within the Botany Sands aquifer, indicating the take would be negligible.

6.3.2 Predicted groundwater drawdown

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

There are two main mechanisms that influence groundwater drawdown: the actual water table drawdown and the hydraulic pressure drawdown. Actual groundwater drawdown of the water table would be dependent on a number of factors including hydraulic parameters and proximity to the project footprint. Immediately after tunnelling is completed, groundwater inflows would be at their highest. With time, groundwater inflow to the tunnel would decrease while the water table would gradually decline until equilibrium is reached. In zones where the inflow rates are likely to exceed one litre per second per kilometre for any kilometre length of tunnel, the fractured lithology would be pre-treated or have waterproof membranes installed to reduce permeability during construction to reduce on-going groundwater inflow and drawdown in operation.

Since the Hawkesbury Sandstone is interbedded with shale lenses that locally act as aquicludes or aquitards, groundwater movement is restricted.

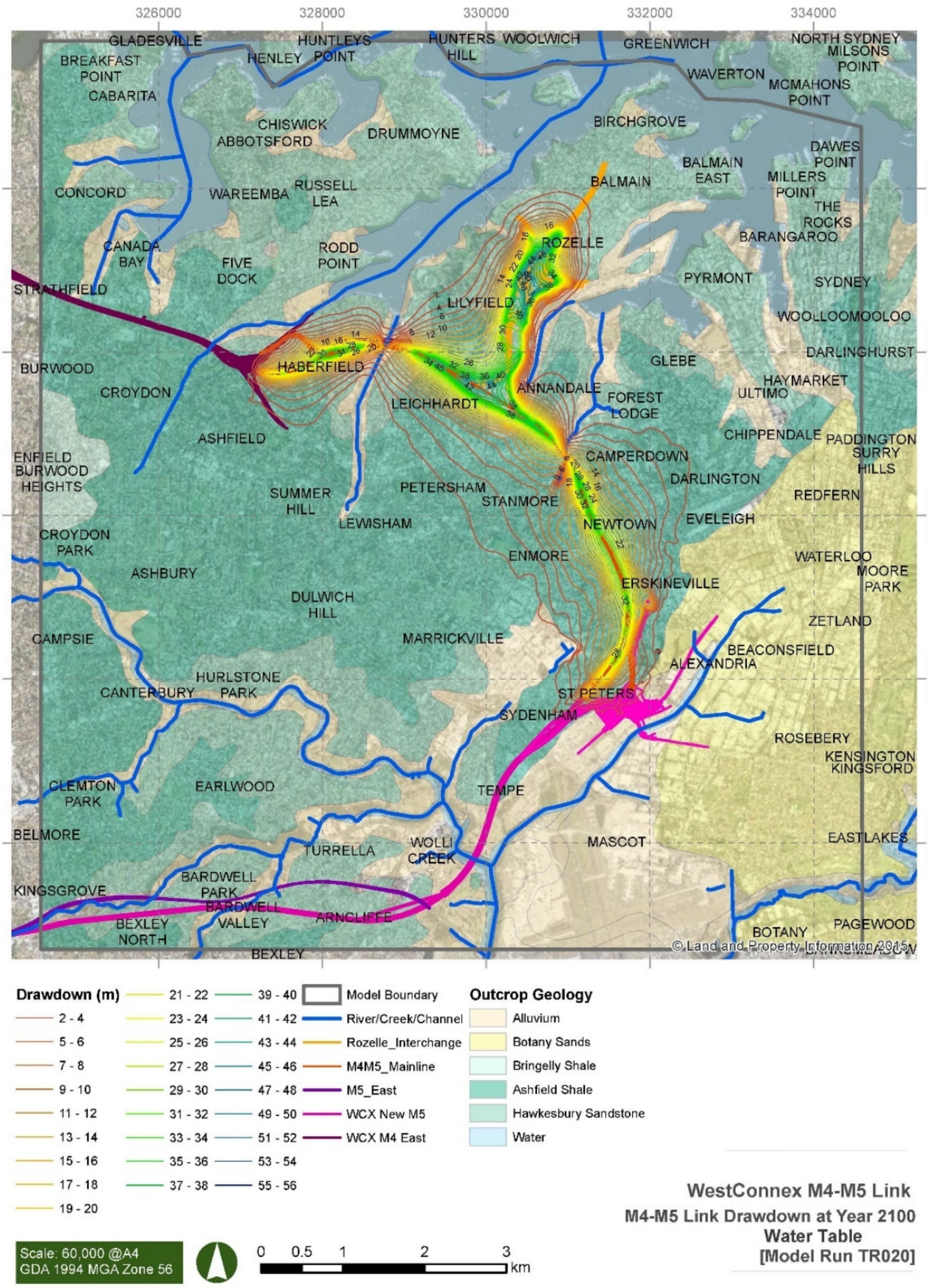
Groundwater drawdown within the palaeochannels and river alluvium within the project footprint would be minimal or not likely to occur as the hydraulic heads within saturated sediments are maintained by direct hydraulic continuity with surface water, supported by a reduction in stream baseflow (refer to **section 6.3.5**).

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

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

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

Groundwater drawdown due to the M4-M5 Link has been calculated by subtracting the results of modelling Scenario 3 (M5 East, M4 East, New M5 and M4-M5 Link) from Scenario 2 (M5 East, M4 East and New M5). Calculated long term (Year 2100) drawdown for the project is presented in **Figure 6-1**. The drawdown in **Figure 6-1** is the total drawdown for all three aquifers. Predicted drawdown for each individual aquifer including the alluvium and Botany Sands, Ashfield Shale and Hawkesbury Sandstone is presented in in **Figure 6-2**, **Figure 6-3** and **Figure 6-4** respectively. Within **Figure 6-3** the Ashfield Shale drawdown is presented from the top of the shale extending into the underlying Hawkesbury Sandstone to show the full extent of the drawdown in the bedrock.



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

Figure 6-1 Predicted drawdown during operations for the project (Year 2100) (from HydroSimulations 2017)

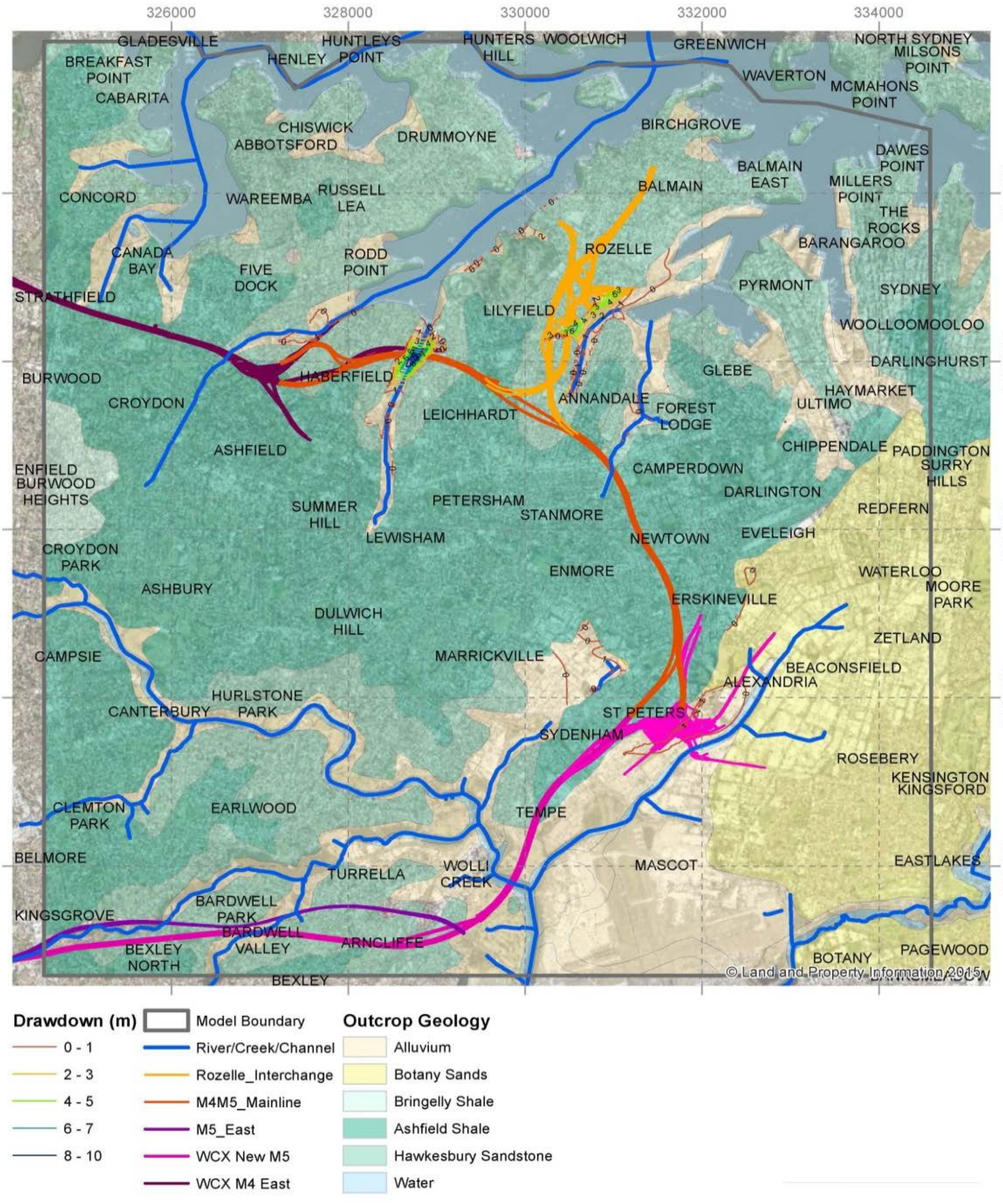


Figure 6-2 Predicted drawdown in the alluvium during operations for the project (Year 2100) (from HydroSimulations 2017)

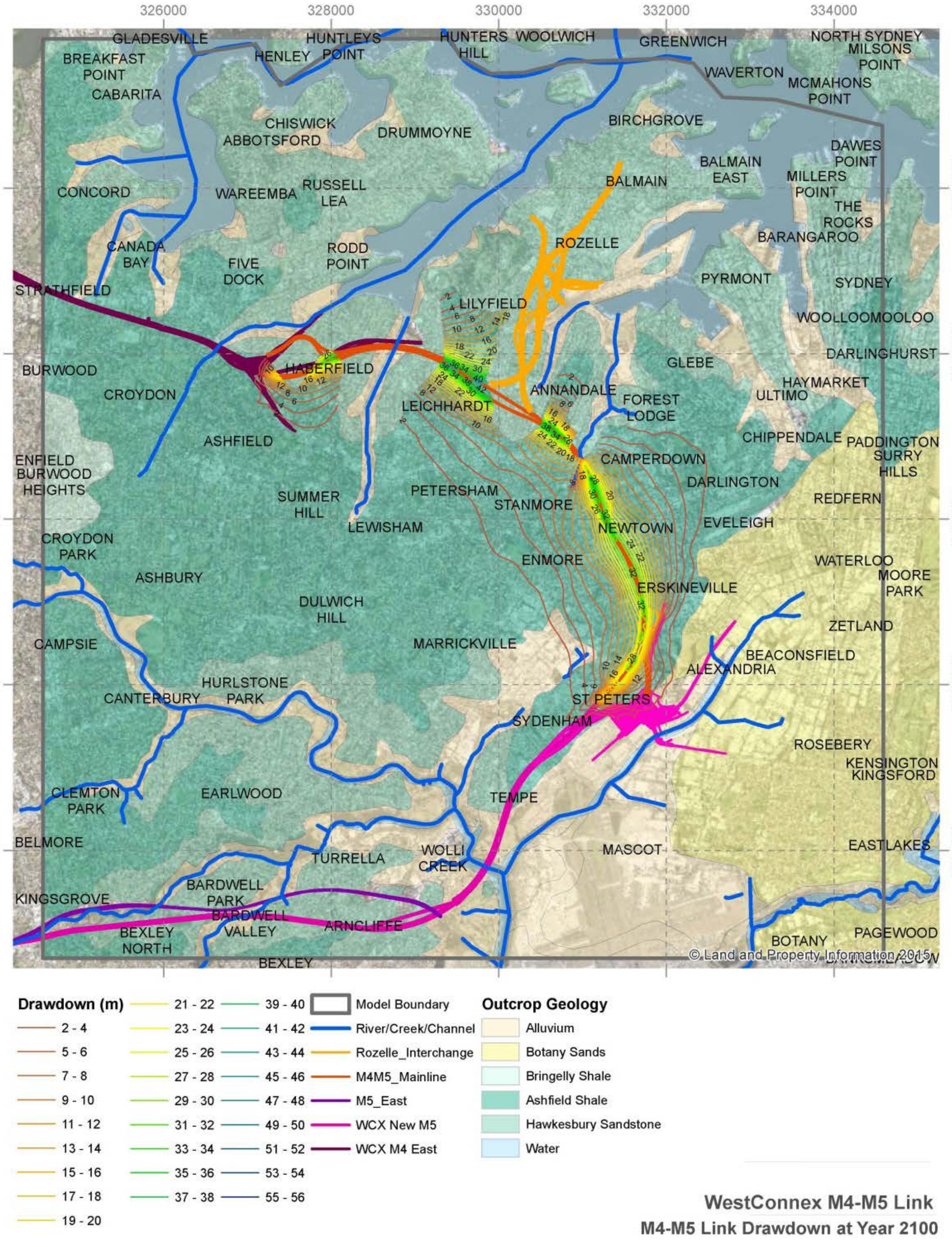


Figure 6-3 **Predicted groundwater drawdown in the Ashfield Shale during operations for the project (Year 2100) (from HydroSimulations 2017)**

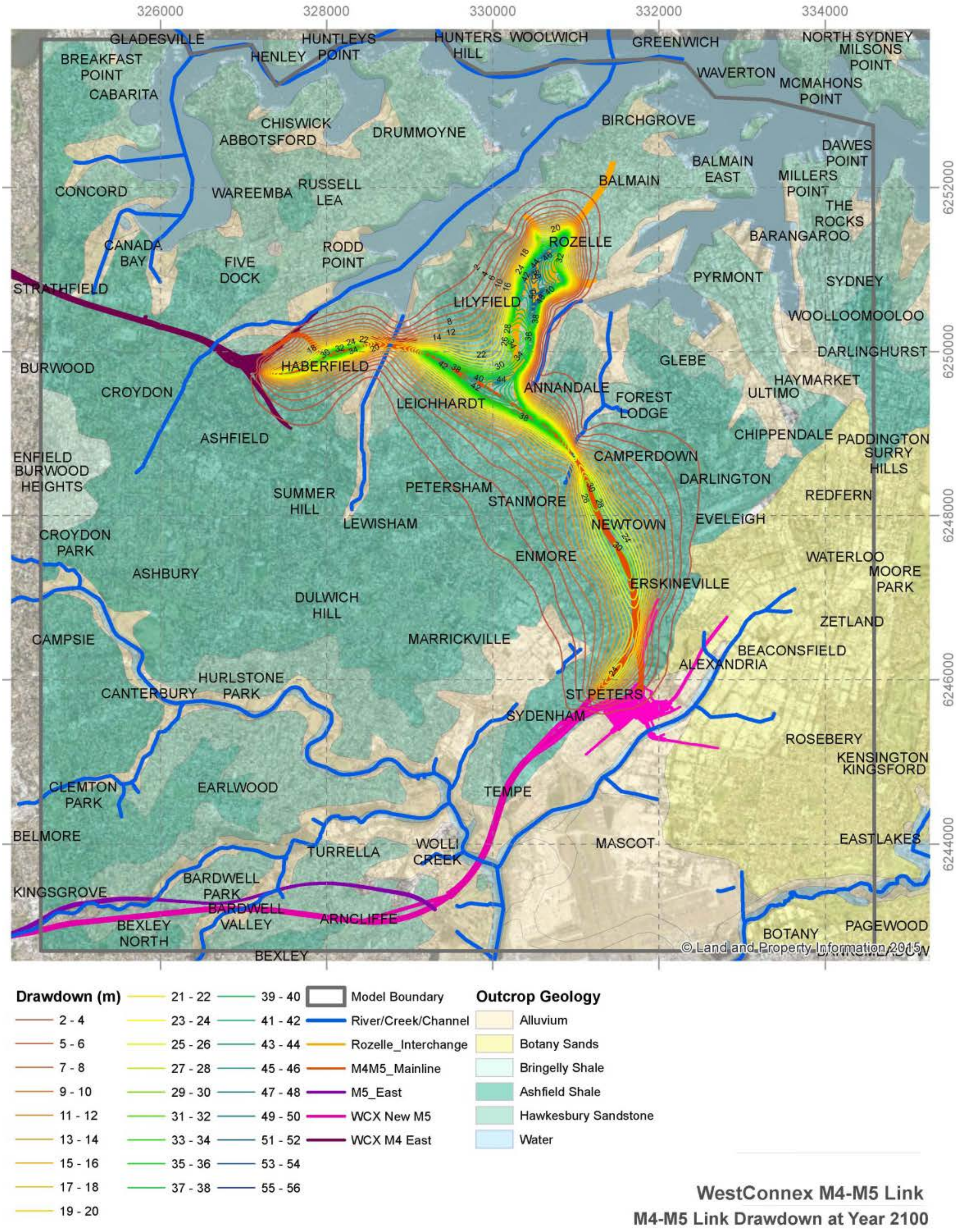


Figure 6-4 Predicted groundwater drawdown in the Hawkesbury Sandstone during operations for the project in (Year 2100) (from HydroSimulations 2017)

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

Long term drawdown (Year 2100) within the Ashfield Shale (see **Figure 6-3**) and Hawkesbury Sandstone (see **Figure 6-4**) extends to the tunnel invert and continues to spread laterally over time. Predicted drawdown in the Hawkesbury Sandstone at Rozelle is a maximum depth of 55 metres, extending laterally 1.4 kilometres either side of the tunnel to the two metre drawdown contour. Similarly near St Peters interchange within the Ashfield Shale groundwater is predicted to be drawdown to the tunnel invert to a depth of 44 metres and extending laterally extending laterally 0.5 kilometres either side of the tunnel to the two metre drawdown contour. The reduction is the lateral extend of drawdown within the Ashfield Shale in comparison to the Hawkesbury Sandstone is consistent with the sandstone being more permeable than the shale.

Groundwater levels would be monitored periodically during the operations phase in accordance with OEMP. Additional groundwater monitoring wells are likely to be required once the tunnels are constructed and some would be located directly over the project footprint to monitor the groundwater levels/pressures. Long term groundwater levels/pressures would also be measured by the installation of vibrating wire piezometers (VWP) which would allow for the measurement of pore pressures at various depths. It is recommended that at one selected location both a standpipe monitoring well and VWP well are constructed to allow for the comparison of groundwater levels and pore pressures.

6.3.3 Potential impacts on groundwater dependent ecosystems

There are no priority GDEs identified within the Greater Metropolitan Water Sharing Plan within five kilometres of the project footprint. The closest priority GDEs are the Botany Wetlands and Lachlan Swamps within the Botany Sands, located at Centennial Park, around five kilometres east of the project footprint. These wetlands are at a sufficient distance from the project footprint not to be impacted by the project. Potential impacts on these wetlands and GDEs due to the New M5 project were assessed in the New M5 EIS.

Consequently, no priority GDEs are likely to be impacted by groundwater level decline associated with the long term impacts of the project. The closest priority GDEs are the Botany Wetlands and Lachlan Swamps within the Botany Sands, located in Centennial Park around five kilometres east of the project footprint. These wetlands are at a sufficient distance from the project footprint to not be impacted by the project.

Long term dewatering caused by tunnel drainage could lower the water table and potentiometric heads within the Hawkesbury Sandstone, reducing the amount of groundwater available for shallow rooted plants. The minimum depth of the water table underlying the majority of the project footprint is on average two metres below ground surface. Areas where the water table is shallow, such as at the Rozelle Rail Yards, are typically subjected to periodic flood inundation which would provide water for shallow rooted plants that may have some groundwater dependence. At other more elevated topographic areas such as Rozelle, Leichhardt and Newtown the water table is much deeper below ground surface and consequently flora is unlikely to be dependent on groundwater.

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

An assessment of the impacts to natural processes as a result of the operational discharges which may affect the health of the fluvial, riparian and estuarine systems and landscape health within the study area is provided in **Appendix Q** (Technical working paper: Surface water and flooding) of the EIS. These natural processes are outlined in **section 4.4**. In summary, no wetlands, marine waters or natural floodplain systems are considered to be affected by the project.

6.3.4 Potential impacts on existing groundwater users

Existing groundwater use and extraction is outlined in **section 4.10.1**. Long term tunnel drainage could impact existing groundwater users registered with DPI-Water. A review of the DPI-Water groundwater database indicates that of the registered bores within two kilometres of the project footprint, the majority are registered as monitoring wells. Only five bores are registered for water supply or irrigation. Of these five wells, four are domestic wells and the fifth is registered for irrigation. Two of the domestic wells are located within the Botany Sands and are no longer permitted to be used for domestic purposes due to embargos imposed by DPI-Water.

Groundwater modelling has been used to predict drawdown at the location of registered bores across the project footprint. Only one bore (GW110247) located in the Sydney University grounds, registered for domestic use, is predicted to have a drawdown in excess of two metres that is directly attributable to the M4-M5 Link project. This bore is predicted to have a drawdown of about 2.4 metres to the piezometric head in the Hawkesbury Sandstone by the end of the long term simulation in the year 2100. Given the standing water level is recorded as 31 metres below ground level and the bore is 210 metres deep, the drawdown is likely to have a negligible impact on the bore capacity however the drawdown in excess of two metres triggers 'make good provisions' in accordance with the AIP. The capture analysis predicts that in 2100 the impact on water quality in GW110247 due to saltwater intrusion would be negligible since the bore is at least two kilometres from the nearest salt waterbody at Rozelle Bay and predicted saline water travel times are in excess of 1,000 years.

6.3.5 Potential impacts on baseflow

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

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

Predicted impacts on baseflow of major non-tidal creeks within the project footprint during the operations phase has been modelled (**Annexure H**). Baseflow, as simulated in the model, only represents the occasions when groundwater reaches the ground surface or the streambed and enters the drainage system. Predicted long term changes in baseflow as a result of the project are summarised in **Table 6-1**.

Although the baseflow component of river flow is reduced in several of the water courses, the volumes are small and it is possible that the overall contribution to river flow from groundwater input is even smaller due to the rivers being mostly lined channels. It has not been possible to quantify the proportion of stream flow that is baseflow due to the lack of gauging data, however it is likely that the majority of stream flow would be derived from stormwater runoff. The reduction in baseflow in Whites Creek and Hawthorne Canal are higher due to the creek morphology. Base flow in the model occurs when groundwater reaches ground surface and enters the channel are higher. Hence the occasions when groundwater reaches the ground surface at Iron Cove Creek and Johnstons Creek are limited.

Table 6-2 Predicted long term changes in baseflow

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

A water quality objective outlined in **Chapter 15** (Soil and water quality) of the EIS is to "maintain groundwater within natural levels and variability that are critical to surface flows and ecosystems of the upper estuary" in the Sydney Harbour and Parramatta River Catchment. The long term drawdown due to tunnel inflows has been modelled and the groundwater drawdown contours are presented in **Figure 6-2**, **Figure 6-3** and **Figure 6-4** for the alluvium, Ashfield Shale and Hawkesbury Sandstone respectively. These figures show that groundwater drawdown will not extend as far to the north as Rozelle Bay so consequently the natural variability of groundwater levels adjacent to Sydney Harbour and the Parramatta estuary would not be impacted by the project. Groundwater modelling has predicted varying decreases in creek base flow, however under current conditions these creeks are concrete lined, restricting groundwater entering the surface water flow during high flow conditions. Thus it is expected that these reductions in base flow will not substantially impact the ecosystems of the upper estuary catchment. If sections of these creeks are naturalised, groundwater recharge will be enhanced increasing the groundwater component available for surface water availability.

Long term, the baseflow to major non-tidal creeks is predicted to be reduced by between seven and 83 per cent. Although the predicted percentage reduction in baseflow in Hawthorne Canal and Whites Creek is substantial, this reduction represents a small reduction in stream flow since baseflow as simulated in the model only represents the occasions when the groundwater reaches ground level and enters the channels. There is no impact predicted on the baseflow of other major creeks along the New M5 corridor including Cooks River, Wolli Creek and Bardwell Creek due to the M4-M5 Link project. It is expected that the majority of stream flow would be derived from rainfall runoff and tidal inflow.

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

No permanent springs that contribute to surface flow or river baseflow have been identified within the project footprint. Intermittent springs have been reported to occur within the Hawkesbury Sandstone in the Rozelle and Lilyfield area following prolonged periods of rainfall. These springs are not known to support any ecosystems but instead tend to cause problematic water flows within the urban area sometimes inundating basements or back yards.

6.3.6 Ground settlement

Residual soil profiles developed on the weathered sandstone and shale bedrock are typically relatively thin, stiff and of low compressibility and as such would be less susceptible to ground settlement from groundwater drawdown. The risks associated with water table drawdown within the alluvium beneath the Rozelle Rail Yards and associated dewatering induced settlement is dependent upon the amount of groundwater drawdown within the alluvium and the geotechnical properties of the soil. Settlement caused directly by tunnelling occurs within days of the tunnel opening and is localised whereas groundwater induced drawdown is typically spread over a large area and can take years to occur. The tunnels have been designed to reduce groundwater drawdown within the unconsolidated sediments by constructing tanked (undrained) tunnel sections through the alluvium which would also minimise settlement in these areas.

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

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

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

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

6.4 Groundwater quality

6.4.1 Intercepting contaminated groundwater

There is a risk that contaminated groundwater along the project footprint (such as a hydrocarbon plume emanating from a former service station or industrial site, for example) could be intercepted during operation of the project, as groundwater is induced to flow towards the tunnel. Altered groundwater flow paths due to the tunnels construction and hydraulic gradient changes may locally cause existing contaminant plumes (if present) to migrate towards the project footprint. During the operational phase these risks would be managed as outlined in **section 8.2**.

Leachate and elevated concentrations of ammonia are generated at the former Alexandria Landfill. The risk of contaminated groundwater entering the M4-M5 Link tunnels from leachate derived from the former landfill is considered low, since groundwater flow would be directed away from the M4-M5 Link tunnel due to the ongoing leachate pumping system to be operated as part of the New M5 project. Pumping the leachate would locally reverse groundwater gradients creating an internal flow network centred on the sump in the former landfill, minimising the risk of leachate migration to the M4-M5 Link tunnel. Leachate generation was further reduced by constructing a capping layer across the former landfill to reduce rainfall infiltration. In the New M5 EIS (Roads and Maritime 2015) a secondary leachate pump at the former landfill was additionally recommended to reduce the risk of leachate migration towards the New M5 and M4-M5 Link tunnels in the event of a mechanical breakdown or during periods of maintenance. Groundwater contamination at the former Alexandria Landfill at St Peters is to be managed as part of the New M5 project.

Contamination generated within the M4-M5 Link tunnels during operations is unlikely to impact the local hydrogeological regime as groundwater gradients are towards the tunnel. The contamination would be captured within the tunnel drainage system and removed during the water treatment process prior to discharge.

At the Rozelle Rail Yards, there is a risk that the groundwater within the alluvium is contaminated from a variety of previous industrial activities. The risk of intersecting shallow contaminated groundwater during operation of the project is considered to be low because the tunnels intersecting the alluvium are to be tanked. However there may be hydraulic connection between the Hawkesbury Sandstone and alluvium, through which potentially contaminated groundwater could enter the unlined section of the tunnel. Also at Rozelle Rail Yards there is potential for contaminated groundwater to recharge surface water. This may occur after high rainfall events cause shallow groundwater levels to reach the ground surface that has been impacted by legacy contamination. To reduce recharge and the risk of mobilising legacy contamination at the Rozelle Rail Yards a number of mitigation measures are to be put in place including removing some of the contamination during site works, improving groundwater quality by managing the legacy groundwater contamination by the installation of additional drainage and capping the surface to reduce rainfall infiltration. Lowering the water table within the alluvium at Rozelle will reduce the risk of groundwater intersecting point source contamination.

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

Captured contaminated groundwater through tunnel inflows will be treated in water treatment plants in water treatment plants proposed at Rozelle and Darley Road at Leichhardt in accordance with the discharge criteria. Groundwater quality of tunnel inflows would be monitored throughout the operation phase in accordance with the OEMP to detect changes in water quality and treat as needed.

6.4.2 Groundwater treatment

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

Groundwater monitoring (see **section 4.13**) indicates the groundwater is brackish with elevated metals and nutrients recorded during groundwater sampling. Metal, nutrient and ammonia loading to Hawthorne Canal and Rozelle Bay is likely to increase as a result of the continuous treated groundwater discharges. In order to prevent adverse impacts on downstream water quality within Rozelle Bay and Hawthorne Canal, treatment facilities would be designed so that the effluent would be of suitable quality for discharge to the receiving environment.

The operation water treatment plant at Rozelle and Darley Road would treat iron and manganese. The proposed constructed wetland at Rozelle would provide ‘polishing’ treatment to the treated groundwater flows removing a proportion of the nutrient and metal load. As no constructed wetland is proposed at Darley Road, opportunities to incorporate other forms of nutrient treatment (for example ion exchange or reverse osmosis) within the plant at Darley Road would be investigated during detailed design with consideration to other factors such as available space, increased power requirements and increased waste production.

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

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

6.4.3 Saltwater intrusion

Saltwater intrusion would commence as soon as the hydraulic pressure within the aquifer declines due to groundwater drawdown via the tunnels causing the displacement of fresher water along the shoreline with more saline tidal water. In some locations, saline intrusion could cause saline water to reach the tunnels.

A capture zone analysis has been undertaken as part of the groundwater modelling to investigate tunnel catchment areas. From this analysis it is not possible to quantify volumes or concentrations of saline water entering the tunnels so consequently the following discussion is qualitative. Backward particle tracking analysis has been used via MODPATH3DU to determine the capture zone of the tunnels during operation and the potential for water to be drawn from the tidal regions into the tunnels. The calculated travel time is sensitive to the porosity applied in the model so total porosity values, obtained during the field program (**Annexure G**), were used to generate values of effective porosity.

The capture zone analysis indicates that groundwater from the tidal zones associated with Sydney Harbour and the Parramatta River would enter the project tunnels at the proposed Rozelle interchange. Similarly groundwater from the alluvium associated with the Cooks River would enter the project tunnels near the St Peters interchange. As groundwater levels are drawn down below sea level, saline waters from tidal water bodies would start flowing towards the tunnels, and would ultimately enter the tunnels via hydraulic connection with the alluvium.

Travel times for tidal water to enter the tunnels have been computed by the groundwater model and the average timeframes range from 13 years (Rozelle interchange from Whites Creek) to in excess of 1,000 years (mainline tunnel from Parramatta River and Botany Sands at St Peters interchange).

Early saline inflows would occur when water in the alluvium directly above and adjacent to the proposed tunnels rapidly drain into the tunnels. Initially, the saline water would be a small fraction of total groundwater entering the tunnel but this is expected to increase over time as water is drawn from further afield, although it will always be a minor component of total inflow.

Even though at Rozelle interchange for example the first saline groundwater is modelled to enter the interchange after year 13, this represents an extremely small inflow which will slowly become a larger proportion of flow over time. Thus groundwater quality in the tunnel catchment zones would slowly become more saline over thousands of years. Since the operational lifetime for major infrastructure is in the order of 100 years the slow salinity increase should have minimal impacts on the tunnels, infrastructure and the environment in the short term. Similarly there is the potential to increase the salinity in registered bores due to saltwater intrusion however the slow progress is expected to have a minimal impact on these bores over a period of 100 years as the registered bores are a considerable distance from Rozelle Bay.

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

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

6.4.4 Groundwater aggressivity

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

The aggressivity assessment (see **section 4.13.6**) indicates that groundwater within the Ashfield Shale is non aggressive with respect to average chloride, pH and sulfate for concrete piles. For steel piles groundwater within the Ashfield Shale is non aggressive with respect to average chloride and pH, however the groundwater is moderately aggressive with respect to resistivity. Similarly groundwater within the Hawkesbury Sandstone indicates the groundwater is mildly aggressive to concrete piles with respect to average chloride, pH and sulfate. For steel piles groundwater within the Hawkesbury Sandstone is mildly aggressive to steel piles with respect to average chloride, pH but is severely aggressive with respect to resistivity.

6.4.5 Groundwater monitoring

The groundwater monitoring program prepared and implemented during construction (see **section 5.5.7**) would be augmented and continued during the operational phase. Groundwater would be monitored during the operations phase for three years or as otherwise required by the project conditions of approval and would include trigger levels for response or remedial action based on monitoring results and relevant performance criteria.

At least three monitoring wells and VWPs should be constructed as close as possible to the tunnel centrelines to allow for the comparison of pore pressures and standing water levels. The wells could be constructed about five to ten metres above the top of the tunnel crown to allow for groundwater drawdown monitoring in the Hawkesbury Sandstone.

The exact nature and frequency of the ongoing groundwater monitoring during operation would be determined by the project operator. The operational groundwater monitoring program would be developed in consultation with the NSW EPA, DPI-Fisheries, DPI-Water and the Inner West and City of Sydney councils and documented in the OEMP or EMS.

6.5 Impacts due to ancillary facilities and infrastructure

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

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

Options for the construction of tunnel portals and cut-and-cover structures include secant piled walls or diaphragm walls socketed into the underlying bedrock to prevent the long term ingress of alluvial or perched groundwater into the tunnels. The construction of these structures would potentially alter local groundwater flow directions and could create groundwater mounding if the structures behave as barriers to groundwater flow. Mitigation measures such as the installation of drainage blankets to direct groundwater around these barriers would be explored during the detailed design phase. These impacts are discussed further in **section 6.6** and potential impacts to the final landform are discussed in **section 6.7**.

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

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

6.6 Barriers to groundwater flow

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

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

Although the proposed M4-M5 Link project tunnels are unlikely to create physical barriers, drained tunnels may create hydraulic barriers impacting local groundwater flow patterns. The hydraulic barrier is formed by the lowering of groundwater levels centred on the project footprint and in some cases as a result of locally reversing the groundwater flow direction. Permanent drawdown around the drained tunnels for the M4-M5 Link project is likely to occur and the impacts are discussed in **sections 5.4** and **6.3**. The creation of this groundwater sink would occur along the project footprint and extend to a depth beneath the tunnel invert. Below this depth, there will be no discernible lowering of groundwater pressures and the groundwater flow pattern would remain unchanged. The groundwater model prepared for the project has simulated the effects of the hydraulic barrier due to tunnel seepage, allowing potential impacts to be predicted.

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

6.7 Impact to the final landform

The primary impact on the final landform is likely to be due to groundwater drawdown in the alluvium, Botany Sands and bedrock aquifers. Drawdown in the unconsolidated alluvial sediments and Botany Sands could result in ground settlement, which is discussed in **Chapter 12** (Land use and property) of the EIS. Groundwater drawdown in the Hawkesbury Sandstone at Rozelle interchange and other areas along the alignment is unlikely to cause substantial settlement due to the competent nature and the geotechnical properties of the sandstone. Ongoing groundwater inflow near tidal surface water features may cause localised saltwater intrusion over time, resulting in an increase in groundwater salinity.

Groundwater settlement within the alluvium is likely to be more substantial than the sandstone because of the unconsolidated complex lithology within the alluvium.

Induced groundwater drawdown may impact the environment or groundwater users. The environment may be impacted by reducing the base flow to creeks or restricting flow to high priority groundwater dependent ecosystems as discussed in **sections 6.3.5** and **6.3.3** respectively. Lowering potentiometric heads may result in a reduced registered bore capacity as described in **section 6.3.4.**

6.8 Groundwater management

Where higher long-term groundwater inflows into the proposed tunnels are identified during construction, these could be reduced by a combination of pre-grouting and the installation of waterproofing. However, because the proposed tunnels are designed as drained tunnels, with groundwater being captured, treated and discharged at the surface, the need for this measure is likely to be minimal. Strip drains or similar would be installed behind wall panels to assist in dissipating groundwater. Tunnel drainage and treatment infrastructure would be designed to accommodate groundwater ingress. Separate sumps would be provided at tunnel low points to collect tunnel drainage from groundwater ingress.

Groundwater would be pumped from the sumps to a water treatment plant at the Darley Road motorway operations complex (MOC1) at Leichhardt, with treated flows ultimately discharged to Hawthorne Canal and at the Rozelle East motorway operations complex (MOC3) with treated flows discharged to a constructed wetland within the Rozelle Rail Yards.

Groundwater seepage would flow into the drainage system and then via gravity to the sumps near the proposed water treatment plants at Darley Road motorway operations complex (MOC1) at Leichhardt, or at Rozelle East motorway operations complex (MOC3). The groundwater is to be pumped to the surface, treated and discharged to a constructed wetland and channel to Rozelle Bay. The beneficial reuse of the treated water would also be considered, the most likely reuse option being the irrigation of parks and playing fields, for example at the Rozelle Rail Yards. Groundwater reuse would be in accordance with DPI-Water policies for sustainable water use.

6.9 Groundwater balance

A groundwater balance for the long term operational phase (Year 2100) of the groundwater model has been conducted by HydroSimulations 2017. The water balance has been developed based on the transient model mass balance, averaged over the calibration period, and is summarised in **Table 6-3** is based on the water balance presented in the groundwater modelling report (**Annexure H**).

Table 6-3 Estimated water balance – operational phase

Water component	Inputs (recharge)	Output (discharge)
Unit	**ML/day**	**ML/day**
Rainfall infiltration	10.8	0.0
Evapotranspiration	0.0	1.61
River inflow/outflow	1.44	12.8
Tunnels (M4-M5 Link)	0.0	0.67
Pumping wells (Alexandria Landfill)	0.0	0.08
Regional Boundary Flow	24.6	21.1
Tidal Seepage	1.2	0.89
Storage	2.87	3.58
TOTAL	**40.9**	**40.7**

The transient water balance confirms that regional boundary flows and rainfall infiltration is the primary recharge parameter and the primary discharge parameters are river leakage and regional outflow. Throughout the transient calibration period, the average leakage into the tunnels (M5 East, M4 East, New M5 and M4-M5 Link) is 0.8 litres per second. The total recharge and discharge components match within an acceptable margin of error, indicating that the water components of the model balance.

6.10 Climate change

The effects of climate change that may impact the groundwater regime are increased rainfall, increased rainfall intensity and sea level rises. The *Floodplain Risk Management Guideline - Practical Consideration of Climate Change* (DECC 2007) suggests values of sea level rises of 0.4 metre (Year 2050) and 0.9 metres (Year 2100). Similarly for the 200 year and 500 year average recurrence interval (ARI) rainfall intensities are predicted to represent 10 per cent or 30 per cent increase in 2016 (present day) rainfall intensities, respectively.

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

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

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

The proposed impacts of climate change are expected to be minimal on the predicted outcomes due to the conservative nature of the modelling and model assumptions. Consequently the climate impact changes are not expected to alter the proposed mitigation and management measures.

7 Assessment of cumulative impacts

7.1 Requirement for an assessment of cumulative impacts

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

Where drawdown occurs, for example, the drawdown cone of depression from a tunnel section may intersect with a drawdown cone from a neighbouring tunnel section or neighbouring activity such as the New M5, M4 East, Sydney Metro City and Southwest and the proposed future Western Harbour Tunnel and Beaches Link and F6 Extension. The cumulative effect of overlapping drawdown cones results in a greater overall total drawdown, which may increase impacts on groundwater dependent receptors in the areas of overlap. Similarly, cumulative effects to groundwater quality may occur where the groundwater has been impacted by previous or current land use practices and/or saltwater intrusion.

A cumulative impact assessment has been conducted as part of the groundwater modelling (**Annexure H**) on the local hydrogeological regime taking into account other relevant infrastructure including the New M5, M4 East tunnels and the existing M5 East tunnels. In addition the cumulative impacts of other projects including the Sydney Metro and southwest (focusing on the Chatswood to Sydenham section), the proposed future Western Harbour Tunnel Beaches Link and the F6 Extension have been qualitatively assessed. The proposed future Sydney Gateway project has not been included in the groundwater cumulative impact assessment because the updated road infrastructure is to be constructed along the ground surface and is unlikely to substantially impact groundwater.

7.2 Quantitative cumulative impact assessment for the WestConnex projects

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

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

Scenario 3 represents the cumulative impact assessment scenario including 'Null' run plus the approved WestConnex projects (M4 East and New M5) and the proposed project (M4-M5 Link)

The groundwater model has been used to predict groundwater inflows to the WestConnex tunnels at the end of construction (Year 2023) and throughout the operations phase (to Year 2100) for the three scenarios. The maximum calculated inflow rates are summarised in **Table 7-1**.

Inflow rates are predicted to decline over time and by Year 2100 would have almost halved since the end of construction (Year 2023). The declining inflow rate over time indicates that the modelled recharge does not supply enough water to the system to maintain the initial flow rates. For the Null Run (Scenario 1) the maximum inflow is calculated as 0.45 megalitres per day in 2016 and is predicted to gradually decline over time with drawdown being spread from the nearby New M5 drained tunnels. Cumulative inflows for scenarios 2 and 3 peak at 2.2 megalitres per day in 2019 and 4.3 megalitres per day in 2021 respectively. The predicted tunnel inflows remain below the overall WestConnex tunnel inflow criterion of one litre per second per kilometre for any kilometre length of tunnel.

Table 7-1 Predicted maximum cumulative WestConnex tunnel inflows

Tunnel scenario	Combined tunnel length	Max inflow		
Units	(km)	Year	ML/day	L/sec/km
1.M5 East (pre project)	6	2016	0.45	0.86
2. M4-M5 Link (project) plus M5 East	32.5	2019	2.2	0.79
3. Project plus M4 East and New M5	74.15	2021	4.3	0.68
(3-2) M4-M5 Link (project)	39.83*	2021	2.55	0.71

Note:

* At this stage the drained ventilation tunnels are incomplete

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

During construction, cumulative impacts on groundwater would be greatest at the extremities of the project near the St Peters interchange in the south for the New M5 overlap and the Wattle Street interchange in the north-west, where the M4-M5 Link project overlaps with the New M5. The consecutive construction period for these projects would extend over several years between 2016 and 2021. Cumulative impacts on groundwater drawdown are predicted to be localised to areas where the adjoining tunnels connect: at St Peters interchange and Wattle Street interchange. Once all WestConnex projects are operational, groundwater drawdown due to the cumulative impact of the three tunnel projects is not expected to be greater than in any one section of the overall project footprint.

At the St Peters interchange there will be influences to the groundwater levels due to on-going leachate extraction from the former Alexandria Landfill, depressing the local groundwater levels. Leachate production is to be reduced by the installation of a groundwater cut-off wall, capping of the former landfill which will be managed under a landfill closure plan.

Cumulative groundwater drawdown for the three WestConnex tunnel projects representing the total drawdown for the three aquifers is presented in **Figure 7-1.** Predicted drawdown for each individual aquifer including the alluvium, Ashfield Shale and Hawkesbury Sandstone in Year 2100 is presented in **Figure 7-2** to **Figure 7-4** respectively. Drawdown within the alluvium (**Figure 7-2**) is limited by the aquifer thickness with a maximum of seven metres predicted at the Rozelle interchange. Water table drawdown does not extend into the Botany Sands where higher hydraulic conductivity and recharge replenish any removal of water due to tunnel drainage.

Drawdown within the Ashfield Shale (see **Figure 7-3**) and Hawkesbury Sandstone (see **Figure 7-4**), at Year 2100 extends to the tunnel invert levels. Within the Ashfield Shale (see **Figure 7-3**) the drawdown is presented from the top of the shale extending into the underlying Hawkesbury Sandstone. Drawdown in the Ashfield Shale is predicted to be greatest at Sydenham where 44 metres of drawdown is predicted. Other deep areas of drawdown within the Ashfield Shale occur at St Peters, Strathfield and Haberfield. The largest lateral extent of groundwater drawdown within the Ashfield Shale extends 1400 metres from the project footprint to the 2 metres drawdown contour at Newtown and Enmore. Drawdown in the Hawkesbury Sandstone shows a more continuous pattern along the project footprint with the greatest drawdown predicted at Rozelle. Other deep areas of drawdown within the Hawkesbury Sandstone occur in the deepest parts of the New M5 at Arncliffe and at St Peters. The largest lateral extent of groundwater drawdown within the Hawkesbury Sandstone extends 1200 metres from the project footprint to the two metres drawdown contour at Camperdown and Petersham. The cumulative impact trends are similar to those predictions for the construction phase where drawdown does not extend much deeper, however the cumulative lateral drawdown extends further over time.

Cumulative groundwater drawdown has the potential to cause settlement. Settlement within the sandstone and shale is not expected to exceed the settlement criteria due to the geotechnical properties of these geological formations. Settlement within the Botany Sands aquifer is not expected since groundwater modelling has predicted the water level would not decline as a result of groundwater ingress to the tunnels. Beneath the Rozelle Rail Yards additional settlement due to cumulative impacts are not expected since none of the neighbouring projects are likely to extract any additional groundwater from the alluvium. Localised groundwater modelling in the Rozelle area would be undertaken to support a detailed settlement analysis. This would be undertaken during the detailed design phase.

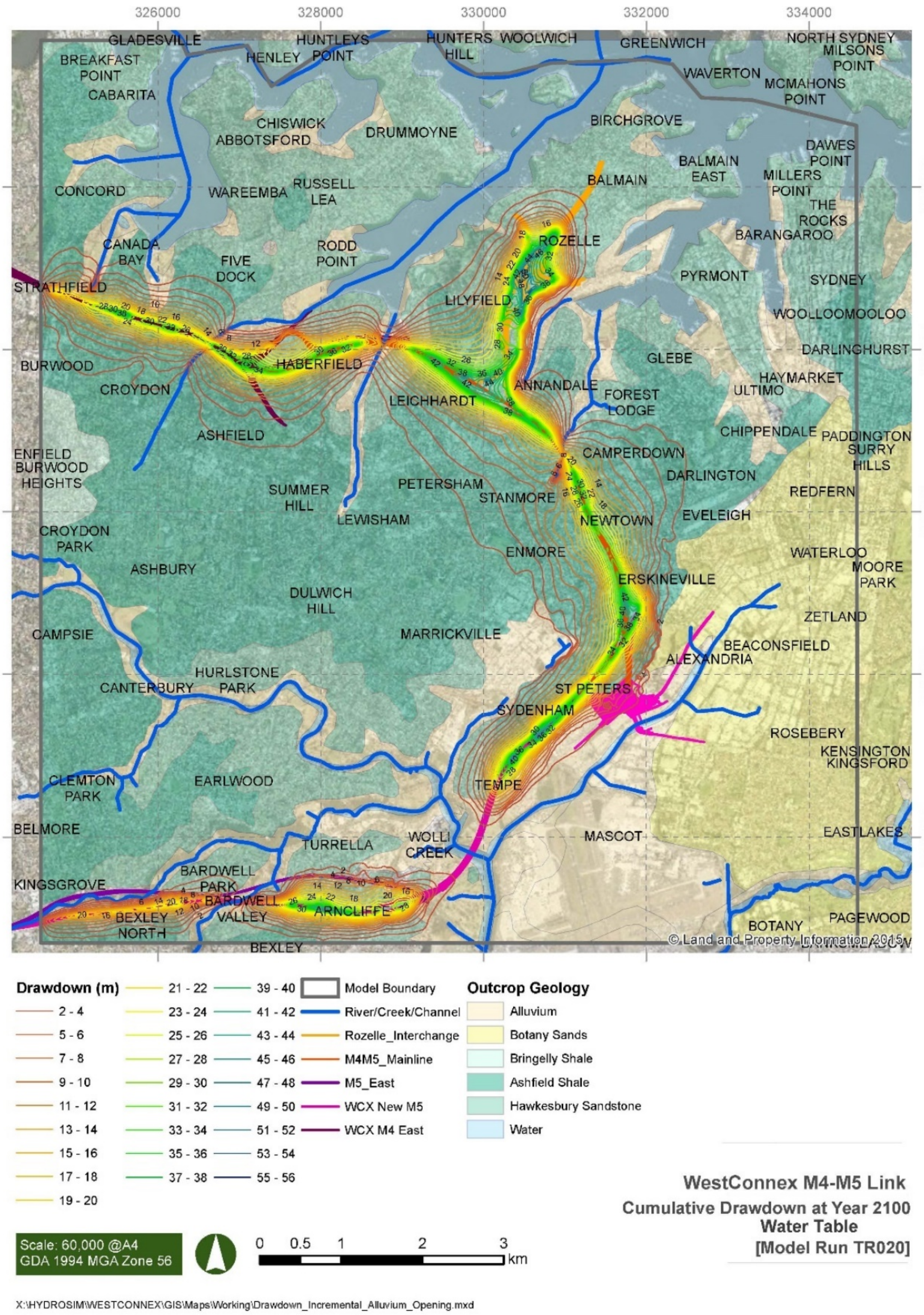


Figure 7-1 Predicted cumulative groundwater drawdown for the project (Year 2100) (from HydroSimulations 2017)

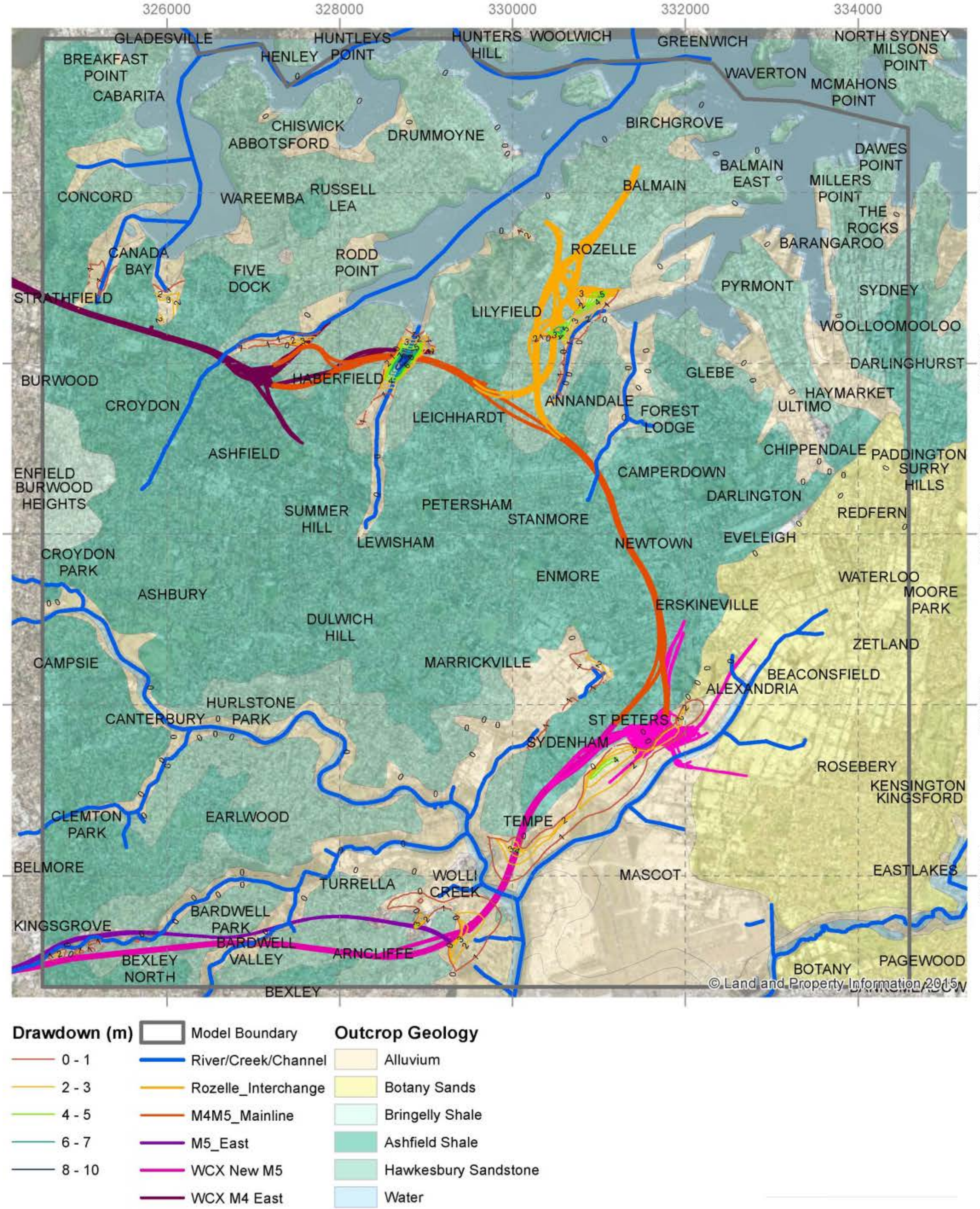


Figure 7-2 Predicted cumulative groundwater drawdown in the alluvium (Year 2100) (from HydroSimulations 2017)

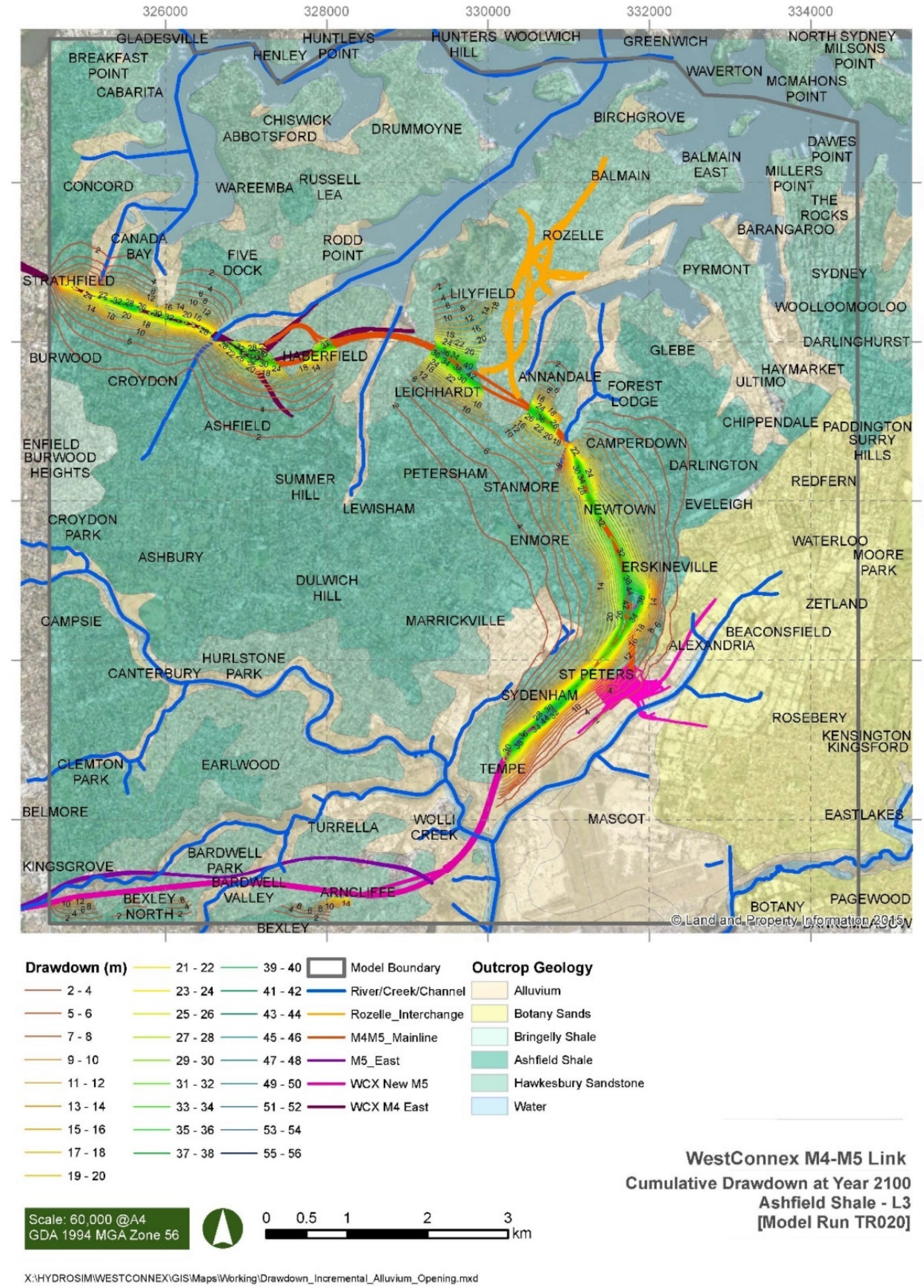


Figure 7-3 Predicted cumulative groundwater drawdown in the Ashfield Shale (Year 2100) (from HydroSimulations 2017)

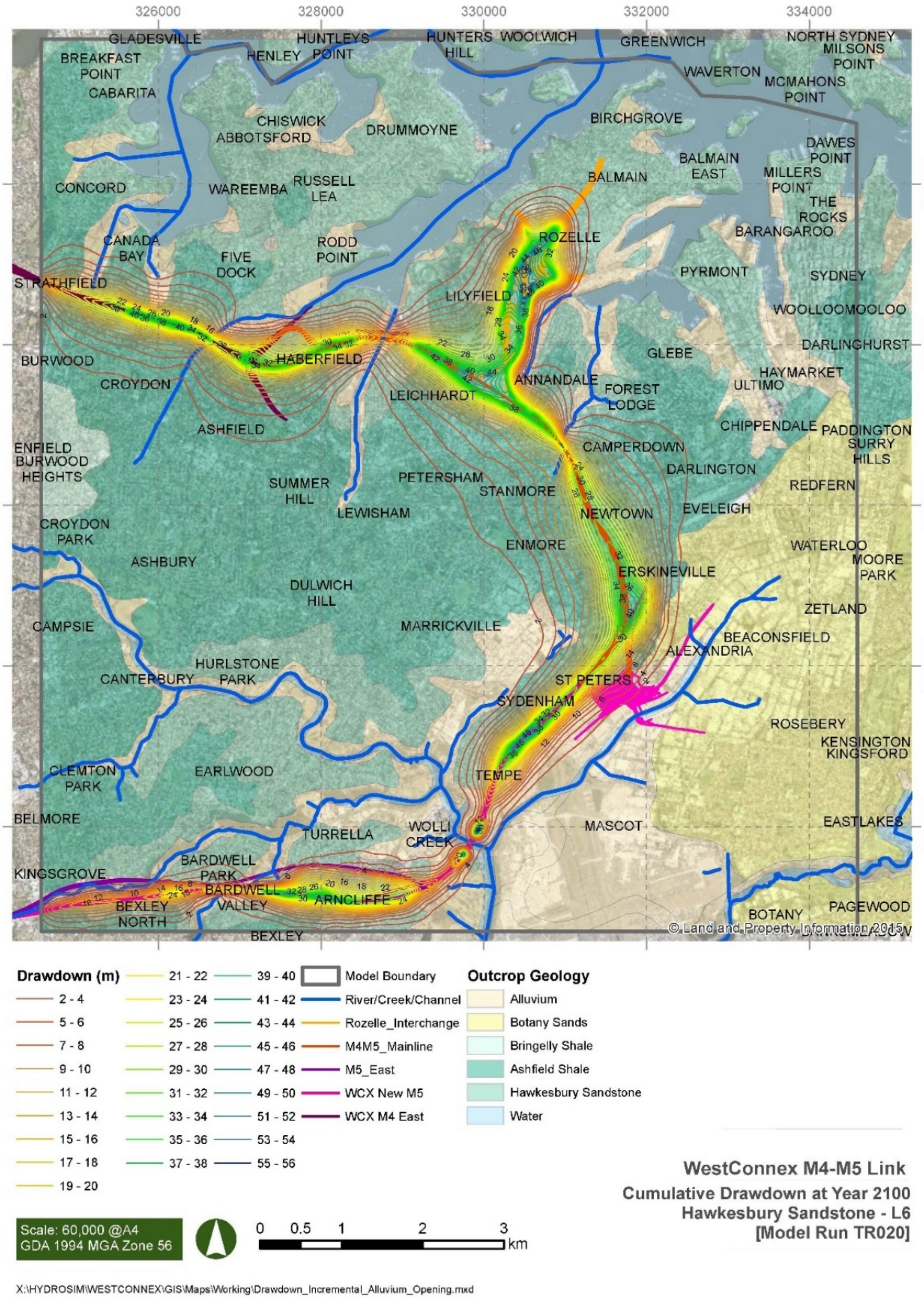


Figure 7-4 Predicted cumulative groundwater drawdown in the Hawkesbury Sandstone (Year 2100) (from HydroSimulations 2017)

Groundwater inflow rates would increase during construction of the M4-M5 Link but would decline after completion of construction as the cone of depression extends to greater distance thus causing the hydraulic gradient towards the tunnel to decrease over time. Reduction of groundwater storage would continue to reduce throughout the tunnel project until equilibrium is reached with recharge, if that ever occurs. Throughout the operation phase, the groundwater inflow rate at the confluence with the New M5 and M5 East tunnels would reach an equilibrium which is dependent upon the hydrogeological conditions that the tunnel has intersected.

The groundwater modelling has predicted that only one registered bore would be drawn down in excess of two metres due to the cumulative impacts of the WestConnex tunnels along the project footprint. This is generally the same as the impact identified in the assessment for the M4-M5 Link project only. Mitigation measures for this bore (GW110247), located at Sydney University are outlined in this assessment (see **section 4.10**). Ten other registered bores are predicted to be impacted by the New M5 project however these impacts along with mitigation measures were discussed in the New M5 EIS. Groundwater modelling has predicted that the drawdown in these bores would not be increased due to cumulative impacts. This is attributed to the tunnels being linear infrastructure and the drawdown impacts being similar along the route within each geological unit.

The cumulative impacts of the three WestConnex tunnels are predicted to impact groundwater quality due to saline intrusion. That is, depressurisation of the Hawkesbury Sandstone aquifer due to groundwater ingress into the tunnels would cause saline tidal waters to flow slowly towards the tunnels impacting groundwater salinity between the tunnels and estuary's. Groundwater modelling of the cumulative scenario has indicated that the degradation of water quality by saltwater intrusion is likely to occur in an average timeframe of between 26 years and in excess of 1,000 years HydroSimulations 2017. This is generally the same as the impact identified in the assessment for the M4-M5 Link project only (which is an average timeframe of 13 years and excess of 1,000 years). Consequently, cumulative groundwater quality impacts are unlikely to be of concern in the short to medium term and any impacts would be managed in accordance with the 'make good' provisions outlined in the AIP. Make good provisions could include providing treated water from the water treatment plants or the installation of a reticulated water supply.

7.3 Quantitative assessment of future and current tunnel infrastructure projects

Three major tunnel infrastructure projects (Sydney Metro City and South-west–Chatswood to Sydenham section, the proposed future Western Harbour Tunnel and Beaches Link and the F6 Extension) have been considered in the cumulative impact assessment for the M4-M5 Link. However, at the time of groundwater modelling there was insufficient publically available data on these three projects and as such the potential cumulative impact of these projects are discussed qualitatively based on the information available.

7.3.1 Sydney Metro City and Southwest

The proposed Sydney Metro City and Southwest project is a proposed rail alignment linking Sydney's north-western suburbs to the Sydney CBD and continuing further south to Bankstown. The northern section of the project, Chatswood to Sydenham, was approved in early January 2017, while the southern section of the project, Sydenham to Bankstown, is currently under assessment. The approved northern alignment consists of 15.5 kilometres of twin railway tunnels extending from Chatswood, beneath Sydney Harbour to Sydenham. Tunnelling is expected to commence in late 2018 and be completed by 2021.

The alignment of the Sydney Metro City and Southwest project would be closest to the M4-M5 Link project at St Peters where it is proposed to cut into the Ashfield Shale immediately north and north-west of Sydney Park. The metro tunnels are to be constructed as concrete lined undrained (tanked) tunnels. Consequently there would be some groundwater extraction and drawdown during construction, however these impacts would be temporary and groundwater levels are not expected to be drawn down long term by the project. The groundwater impact assessment for the northern section of Sydney Metro (Transport for NSW 2016) Chatswood to Sydenham outlined that the project is unlikely to trigger significant impacts to groundwater as the metro tunnels are predominately tanked.

Since the twin metro tunnels would be constructed as tanked tunnels, there would be negligible impacts on groundwater as the undrained tunnels are designed to prevent groundwater ingress. The stations are to be constructed as drained shafts and would extract groundwater from the local hydrogeological regime over time. The closest proposed drained structure is at Marrickville Station, about 2.5 kilometres west of the M4-M5 Link which is considered a sufficient distance not to substantially impact the project. There is potential for the concrete lined tunnels of the Sydney Metro City and Southwest project to create a partial hydraulic barrier to groundwater flow, however the risk is considered low since the tunnels are constructed below the water table and groundwater is expected to be able to flow above and below the tunnels.

7.3.2 Western Harbour Tunnel and Beaches Link

The proposed future Western Harbour Tunnel and Beaches Link would include tunnelling which is likely to impact groundwater during the construction and operation phases. The M4-M5 Link project would construct tunnels and on-ramps that will link the Rozelle interchange with the proposed future Western Harbour and Beaches Link tunnels. These structures have been included in the current groundwater model. At the time of preparing this impact assessment there were insufficient project details regarding the alignment, construction program and construction technique of the proposed future Western Harbour Tunnel and Beaches Link available to assess potential cumulative groundwater impacts with the M4-M5 Link project. The proposed future Western Harbour Tunnel and Beaches Link project will be subject to a separate environmental impact assessment in which it is expected that the EIS would include a cumulative impact assessment that would include potential impacts to groundwater as a result of both projects.

7.3.3 Proposed future F6 Extension

The F6 Extension project (formerly called SouthLink) may include tunnelling that is likely to impact groundwater during the construction and operations phases of the M4-M5 Link project. The F6 Extension would extend from the New M5 Motorway south of the Cooks River, southwards underground through Rockdale, Brighton Le Sands, Sans Souci and beyond. At the time of preparing this impact assessment there were insufficient project details available regarding the F6 Extension, including the potential alignment, construction program and construction technique, to be able to assess potential groundwater cumulative impacts. This project would be subject to a separate environmental impact assessment and it is expected that the EIS will include a cumulative impact assessment that would include potential cumulative impacts to groundwater in addition to the M4-M5 Link project.

7.4 Summary

A cumulative impact assessment has been conducted to assess the cumulative groundwater impacts of the M4-M5 Link project and other WestConnex projects including the M4 East and New M5. The groundwater model predicts the combined groundwater impacts of these projects during the construction (to Year 2023) and long term operations phase (to Year 2100). Other WestConnex projects including the M4 widening and King Georges Road Interchange Upgrade were not included in this assessment because these works do not impact the groundwater during operation. Groundwater modelling has been used to predict potential cumulative groundwater impacts during construction and operations of the WestConnex projects.

The groundwater cumulative impacts for other major tunnel infrastructure projects including the Sydney Metro City and South-west (Chatswood to Sydenham section), the proposed future Western Harbour Tunnel and Beaches Link and proposed future F6 Extension have been considered qualitatively since there was insufficient publically available information available for inclusion in the M4-M5 Link groundwater model. The proposed future Sydney Gateway project has not been included in the groundwater cumulative impact assessment because the updated road infrastructure is to be constructed along the ground surface and is unlikely to substantially impact groundwater.

During construction, cumulative impacts on groundwater would be greatest at the extremities of the project near the St Peters interchange in the south and the Wattle Street interchange in the north-west, where the M4-M5 Link project overlaps with the adjoining sections of WestConnex. At St Peters interchange there will be influences to the groundwater levels due to on-going leachate extraction from the former Alexandria Landfill, depressing the local groundwater levels. Leachate production is to be reduced by the installation of a groundwater cut-off wall, capping of the former landfill which will be managed under a landfill closure plan.

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

Long term cumulative groundwater tunnel inflows due to the WestConnex tunnel projects may cause groundwater salinity to increase due to surface water from tidal reaches being drawn into or towards the tunnels. Initially, the saline water would be a small fraction of total tunnel ingress but this is expected to increase over time as water is drawn from further afield, although it will always be a minor component of total inflow. The groundwater modelling has predicted that only one registered bore would be drawn down in excess of two metres due to the cumulative impacts of the WestConnex tunnels along the project footprint.

Cumulative groundwater impacts of other future and current tunnelling projects have been considered including Sydney Metro City and Southwest, the proposed future Western Harbour Tunnel and Beaches Link and the proposed future F6 Extension. The Metro twin tunnels are to be constructed as tanked tunnels and consequently there will be negligible impacts on groundwater due to the tunnels. The closest drained structure is proposed around 2.5 kilometres west of the M4-M5 Link, which is considered a sufficient distance to the M4-M5 Link so as to not substantially cumulatively impact groundwater. There is insufficient data available to quantitatively assess the cumulative impacts of the proposed future Western Harbour Tunnel and Beaches Link and F6 Extension as the construction technique, alignment, construction program were unknown at the time of modelling, however it is likely that these projects would contribute to the cumulative impact to groundwater during their construction and operation phases. It is expected that these other projects will assess the cumulative effects on groundwater.

8 Management of impacts

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

8.1 Management of construction impacts

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

Table 8-1 Construction mitigation and management measures

Potential impact	Mitigation and management measures
High groundwater inflows which would cause significant groundwater inflows and groundwater drawdown	Groundwater inflows within the tunnels will be minimised by designing the final tunnel alignment to minimise intersections with known palaeochannels and alluvium present in the project footprint. Tunnel sections intersecting the alluvium at the Rozelle Rail Yards are to be tanked to minimise groundwater inflows from the alluvium. Pre-excavation pressure grouting will be used in locations that are suspected of being more permeable to reduce groundwater inflows to an acceptable level. Post grouting may also be required to further reduce groundwater inflows.
	Appropriate waterproofing measures will be identified and included in the detailed design to permanently reduce the inflow into the tunnels to below one litre per second per kilometre for any kilometre length of the tunnel.
	Appropriate measures will be investigated and implemented at dive structures and shafts and for cut-and-cover sections of the tunnel to minimise groundwater inflow. These measures could include but are not limited to retaining walls such as secant pile, sheet pile walls or diaphragm walls founded in good quality Ashfield Shale or Hawkesbury Sandstone.
Corrosion of building materials by sulfate reducing bacteria	Further assessment of the risk posed by the presence of sulfate reducing bacteria and groundwater aggressivity will be undertaken prior to construction. A corrosion assessment will be undertaken by the construction contractor to assess the impact on building materials that may be used in the tunnel infrastructure such as concrete, steel, aluminium, stainless steel, galvanised steel and polyester resin anchors. The outcomes of the corrosion assessment will be considered when selecting building materials likely to encounter groundwater.
Groundwater drawdown impacting a water supply well water level by more than two metres	In accordance with the AIP, measures will be taken to 'make good' the impact to an impacted water supply bore by restoring the water supply to pre-development levels. The measures taken will be dependent upon the location of the impacted bore but could include, for example, deepening the bore, providing a new bore or providing an alternative water supply.
Alteration of groundwater flows and levels due to the installation of subsurface project components	Potential impacts associated with subsurface components of the project intercepting and altering groundwater flows and levels will be considered during detailed design. Measures to reduce potential impacts will be identified and included in the detailed construction methodology and the detailed design as relevant. Re-injection of treated groundwater is a high management activity and that could be considered during the construction phase to reduce

Potential impact	Mitigation and management measures
	groundwater drawdown. It is not considered suitable as a long term operational solution due to on-going maintenance and clogging of the well screens due to the oxidation of iron and manganese. Discussions with DPI-Water will be required to consider the feasibility of injecting relatively high quality water into the aquifer.
Poor water management could lead to adverse impacts on the environment	A CEMP will be developed to manage potential impacts on groundwater and soil. The CEMP will be a 'live' document with the capacity to be updated if conditions are different to those expected. As part of the CEMP a CSWMP will prepared by the contractor to manage soil and water impacts during construction, identifying potential impacts and recommending mitigation measures to eliminate or reduce the identified risks. The CSWMP will outline the groundwater monitoring plan that will include: • Groundwater levels (manual monitoring and automatic monitoring by data loggers) • Groundwater quality (within key boreholes and tunnel inflows) • Groundwater inflows to the tunnels. Trigger levels would be established that if exceeded would instigate mitigation measures. Water quality trigger levels will be based on the ANZECC 2000 marine and non-marine guidelines in accordance with the 90 percent level of protection during construction. The monitoring will be used to inform the operators of the water treatment plant which contaminants require treatment. The CEMP would also manage the following potential groundwater impacts: • Spill prevention and response procedures. • Management measures for the storage and stockpiling of materials, fuel and wastes during construction to contain spills and reduce the risk of contaminating groundwater • A protocol for the management of acid sulfate soils during bulk earthworks that will include the types of treatment required for ASS, leachate, bunding and requirement for treatment pond • A protocol to address unexpected contaminated finds or unforeseen contamination issues during surface works and tunnelling. This will consider approaches to remove the source of contamination by excavation, or an engineering solution to prevent the migration of contaminated groundwater into the tunnels.
Actual groundwater inflows and drawdown in adjacent areas exceed expectations	A detailed groundwater model will be developed by the construction contractor. The model will be used to predict groundwater inflow rates and volumes within the tunnels and groundwater levels (including drawdown) in adjacent areas during construction and operation of the project.
	Groundwater inflow within and groundwater levels in the vicinity of the tunnels will be monitored during construction and compared to model predictions and groundwater performance criteria applied to the project. The groundwater model will be updated based on the results of the monitoring as required and proposed management measures to minimise potential groundwater impacts adjusted accordingly.

Potential impact	Mitigation and management measures
	Groundwater quality monitoring will be conducted.
Potential impacts on existing buildings and infrastructure due to settlement	Groundwater drawdown may induce ground settlement and impact existing and future infrastructure. Detailed settlement modelling will be carried out during detailed design. If excessive settlement is predicted then construction methodologies would be revised to minimise impacts. Settlement monitoring would be undertaken in accordance with the protocols developed in the CEMP and may include the installation of settlement markers or inclinometers. Before the commencement of tunnelling, dilapidation assessments would be undertaken on buildings and structures which may be impacted by settlement. A post construction inspection will also be conducted to identify any building defects that could be attributed to the project so make good provisions could be initiated.

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

8.2 Management of operational impacts

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

Table 8-2 Operational mitigation and management measures

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

Potential impact	Mitigation and management measures
	markers or inclinometers.
Adverse impacts on the local hydrogeological regime due to groundwater discharge	Long term groundwater inflows will be pumped to the surface, treated and discharged to Rozelle Bay via Hawthorne Canal or a constructed wetland and channel at Rozelle. The tunnel operation water treatment facilities would be designed such that effluent will be of suitable quality for discharge to the receiving environment. The level of treatment will consider the characteristics of the discharge and receiving waterbody, any operational constraints or practicalities and associated environmental impacts and be developed in accordance with ANZECC (2000) and with consideration to the relevant NSW Water Quality Objectives. Ultimately the water quality objectives would be set by the catchment manager of the receiving waters in consultation with the EPA.
Corrosive groundwater could adversely impact the tunnel and associated infrastructure	Where the corrosion assessment that will be carried out prior to construction indicates potential issues, corrosion and other associated impacts of highly aggressive groundwater on the tunnel infrastructure will be monitored during operations. The monitoring program will be documented in the OEMP or EMS. Corroded or otherwise impacted infrastructure will be repaired or replaced as required to maintain operational integrity of the road infrastructure.
Groundwater drawdown due to the project may exceed two metres in registered bores or at other receptors	In accordance with the AIP, measures will be taken to ‘make good’ the impact to an impacted water supply bore by restoring the water supply to pre-development levels. The measures taken will be dependent upon the location of the impacted bore but could include, for example, deepening the bore, providing a new bore or providing an alternative water supply.
Treated groundwater may be discharged to stormwater without consideration to a suitable sustainable use.	Sustainable water re-use options will be considered for treated groundwater during operations. Re-use options may include the irrigation of open space at the Rozelle interchange or discharge into artificial wetlands. Groundwater reuse will be undertaken in accordance with the policies of sustainable water use of DPI-Water.

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

8.3 Management of cumulative impacts

As noted in **section 7.4**, once the full extent of the WestConnex projects is operational, groundwater drawdown due to the cumulative impact of the three tunnel projects is not expected to be greater than in any one section of the overall project footprint.

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

9 Policy compliance

9.1 Aquifer Interference Policy

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

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

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

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

9.2 Minimal impact assessment

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

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

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

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

The Botany Sands are not intersected by the tunnel but it is close by to the east and is likely to be impacted by the project. Potential impacts of the M4-M5 Link project to the Botany Sands were assessed in this assessment. The groundwater within the Botany Sands is considered to be in a ‘Highly Productive Groundwater Source’ despite the groundwater being highly contaminated.

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

Table 9-1 Minimal Impact Considerations for a ‘Less Productive Fractured Rock Aquifer’

Minimal impact considerations	Response
<u>Water Table – Level 1</u> Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic ‘post water sharing plan’ variations, 40 m from any: (a) High priority groundwater dependent ecosystem; or (b) High priority culturally significant site listed in the schedule of the relevant water sharing plan, or (c) A maximum of a 2 m decline cumulatively at any water supply work.	There are no high priority groundwater dependent ecosystems listed under Schedule 4 of the *Greater Metropolitan Regional Groundwater Sources Water Sharing Plan* that are within the Hawkesbury Sandstone or Ashfield Shale. No culturally significant sites were identified within the *Greater Metropolitan Regional Groundwater Water Sharing Plan*. Groundwater modelling has indicated there is one registered bore within a 2 km radius of the tunnels registered for water supply purposes (domestic) where the long term drawdown is predicted to exceed two metres. The approach to minimising impacts is outlined below.
<u>Water Table – Level 2</u> If more than 10% cumulative variation in the water table, allowing for typical climatic ‘post water sharing plan’ variations, 40 m from any: (a) High priority groundwater dependent ecosystem; or (b) High priority culturally significant site; (c) listed in the schedule of the relevant water sharing plan, if appropriate studies demonstrate to the Minister’s satisfaction that the variation will not prevent the long term viability of the dependent ecosystem or significant site. If more than a 2 m decline cumulatively at any water supply work then make good provisions should apply.	The predicted long term drawdown in domestic bore GW110247 is 2.4 m. The bore is 210 m deep with water table depth recorded at 31 m below ground level. Given the standing water level is recorded as 31 m below ground level and the bore is 210 m deep, the 2.4 m of drawdown is likely to have a negligible impact on the bore yield capacity. The approach to ‘make good’ the supply to predevelopment levels would be adopted. This approach would commence with discussions with the bore owner about ‘make good’ options. Mitigation options would include lowering the pump or providing an alternative water supply (such as mains water).
<u>Water Pressure – Level 1</u> A cumulative pressure head decline of not more than a two metre decline, at any water supply work.	Mitigation measures have been recommended for one bore (GW110247) located at Sydney University where it has been predicted that the drawdown exceeds a water level decline of more than 2 m.

Minimal impact considerations	Response
Water Pressure – Level 2 If the predicted pressure head decline is greater than condition 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	The predicted groundwater level decline will not prevent the long term viability of the bore and make good provisions are proposed.
Water Quality – Level 1 Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.	Groundwater within the study area has limited beneficial use potential due to the quality of the water and presence of a Sydney Water reticulated water supply across the study area. The Ashfield Shale groundwater is typically of poor quality and of low hydraulic conductivity limiting the beneficial use potential. Groundwater from the Hawkesbury Sandstone is used for domestic and irrigation purposes. Groundwater modelling predicts there is likely to be saline water ingress from Rozelle Bay and Iron Cove to the project footprint over time (**section 5.5.6**), which may increase the salinity of groundwater between the project footprint and Sydney Harbour. Given the low level of groundwater use, elevated metals and ongoing pollution potential within an urban environment, the lowering of the aquifer system beneficial use category is unlikely.
Water Quality – Level 2 If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long term viability of the dependent ecosystem, significant site or affected water supply works.	Level 2 does not apply as Level 1 criteria are not exceeded.

Table 9-2 Minimal Impact Considerations for a 'Highly Productive Coastal Aquifer'

Minimal impact considerations	Response
Water Table – Level 1 Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic 'post water sharing plan' variations, 40 m from any: (a) High priority groundwater dependent ecosystem; or (b) High priority culturally significant site listed in the schedule of the relevant water sharing plan; or (c) A maximum of a 2 m decline cumulatively at any water supply work.	The closest high priority ecosystems listed under Schedule 4 of the *Greater Metropolitan Regional Groundwater Sources Water Sharing Plan* are the Botany Wetlands including the Lachlan Swamps, Mill Pond, Mill Stream and Engine Pond located within the Botany Sands. These ecosystems are located more than 2 km from the project footprint. Groundwater modelling conducted as part of this investigation indicates that the water table at these wetlands is unlikely to undergo a water level decline of more than 2 m (**section 5.4.1**). No culturally significant sites were identified within the *Greater Metropolitan Regional Groundwater Water Sharing Plan*. Groundwater modelling predicted that no registered bores a 2 km radius of the tunnels that intersect alluvium are likely to be drawn down by

Minimal impact considerations	Response
	more than 2 m. Given the primary beneficial use of groundwater in the Botany Sands is for domestic use and within Zone 2 of the Botany Sands Source Management Zone domestic use is banned the drawdown impacts are not considered significant.
<u>Water Table – Level 2</u> If more than 10% cumulative variation in the water table, allowing for typical climatic 'post water sharing plan' variations, 40 m from any: (a) High priority groundwater dependent ecosystem; or (b) High priority culturally significant site; listed in the schedule of the relevant water sharing plan, if appropriate studies demonstrate to the Minister's satisfaction that the variation will not prevent the long term viability of the dependent ecosystem or significant site. If more than a 2 m decline cumulatively at any water supply work then make good provisions should apply.	Level 2 does not apply as Level 1 criteria are not exceeded.
<u>Water Pressure – Level 1</u> A cumulative pressure head decline of not more than a 2 m decline, at any water supply work.	Groundwater modelling predicted that potentiometric pressures within the Botany Sands are unlikely to exceed more than a two metre decline at registered bores (**section 5.4.3**).
<u>Water Pressure – Level 2</u> If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	Level 2 does not apply as Level 1 criteria are not exceeded.
<u>Water Quality – Level 1</u> Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.	Groundwater within the study area has limited beneficial use potential due to the water quality and since the study area has a reticulated water supply provided by Sydney Water. The Botany Sands aquifer contains a significant groundwater resource under natural conditions, however due to contamination, DPI-Water has embargoed domestic groundwater use under the Metropolitan Water Sharing Plan. Groundwater modelling predicts there is likely be saline water ingress from Alexandria Canal to the project footprint which may increase the salinity of groundwater between the project footprint and Sydney Harbour. Since groundwater from the Botany Sands can no longer be used for domestic and ongoing pollution potential within an urban environment the lowering of the aquifer system beneficial use category is unlikely.

Minimal impact considerations	Response
Water Quality – Level 2 If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.	Level 2 does not apply as Level 1 criteria are not exceeded.

9.3 Licensing

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

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

9.4 Compliance with the Water Sharing Plan

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

Table 9-3 Project compliance with the Water Sharing Plan

Rule	Assessment
Part 7 – Rules for granting access licences	Road authorities are exempt (under Schedule 5, Part 1, clause 2 of the Water Management (General) Regulation 2011) from the requirement to hold a water access license to access water during the construction and operation of projects.
Part 8 – Rules for managing access licences	Refer to the assessment for Part 7.
Part 9 – 39 Distance restrictions to minimise interference between supply works	As outlined in section 3.1 under the WM Act road authorities are not exempt for the requirement of obtaining a water supply work approval. An approval would be required for this project for the water ingress to the drained tunnels.
Distance restriction from the property boundary is 50 m	The drained tunnels would in many cases be within 50 m of property boundaries and hence the project would not comply with this rule. However this non-compliance is considered acceptable since the tunnels are at depth in a highly urbanised area with a reticulated water supply and limited water supply works in the immediate vicinity of the project footprint.
Distance restriction from an approved water supply work is 100 m	Ten registered boreholes have been identified within 100 m of the project footprint and hence the project would not comply with this rule. However this non-compliance is considered acceptable since all these boreholes are registered as monitoring wells associated with

Rule	Assessment
	development sites in Lilyfield, Glebe and Haberfield that are unlikely to require on-going monitoring.
Distance restriction from a Department observation bore is 200 metres	There are no DPI-Water observation bores within 200 m of the project footprint.
Distance restriction from an approved work nominated by another access license is 400 m.	There are no water supply works nominated by another access licence within 400 m of the project footprint.
Distance restriction from an approved water supply work nominated by a local water utility or major utility access licence is 1,000 m	There are no local or major water utilities within 1,000 m of the project footprint.
Part 9 – 40 Rules for water supply works located near contaminated sources	Contaminated groundwater has been identified within the alluvium beneath the Rozelle Rail Yards. To minimise the migration of contaminated groundwater, the tunnels, portals and cut-and-cover sections within the alluvium are to be tanked preventing groundwater ingress to the tunnels.
Part 9 – 41 Rules for water supply works located near sensitive environmental areas	The project footprint is located outside the required distance for the following sensitive environmental areas: 1. 200 m of a high priority groundwater dependent ecosystem 2. 500 m of a karst groundwater dependent ecosystem 3. 40 m from a lagoon or escarpment (**section 4.3**). The project footprint is not located outside the required distance of the following sensitive environmental areas: 1. 40 m from third order streams or above. The non-compliance of the third order streams as discussed in **section 4.4.1** is considered acceptable since the creeks are concrete lined and the tunnels are to be excavated within the Hawkesbury Sandstone.
Part 9 – 42 Rules for water supply works located near groundwater dependent culturally significant sites	The project footprint is not located near a groundwater dependent culturally significant site.
Part 9 – 44 Rules for water supply works located within distance restrictions	There are no water supply works that are located within restricted distances along the project footprint.
Part 10 – Access dealing rules	Refer to the assessment for Part 7.

10 Conclusions

This groundwater impact assessment has been prepared to support the EIS for the project and was prepared in accordance with NSW water policy under the WM Act, administering water policy under the AIP and the *Greater Metropolitan Region Groundwater Source Water Sharing Plan.* The objectives of the groundwater impact assessment are outlined in the SEARs issued on 26 August 2015 which, in summary, must address the following:

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

The methodology to conduct the groundwater impact assessment included outlining the existing environmental conditions from available reports, maps and databases. A field investigation was conducted to investigate the geology along the tunnel alignment, assess the hydraulic conductivity by packer tests and laboratory testing of core, laboratory testing of porosity, install monitoring wells along the tunnel alignment, conduct monthly hydrogeochemical sampling and groundwater gauging to establish background conditions. Data loggers have been installed in the majority of the monitoring wells to monitor groundwater levels. A three dimensional numerical groundwater model (using MODFLOW-USG) has been developed to simulate existing groundwater conditions. By simulating the project footprint the groundwater model has also been used to predict future groundwater conditions and impacts related to the project.

The tunnels would be excavated predominately through competent Hawkesbury Sandstone and Ashfield Shale with parts of the tunnels intersecting alluvium. The majority of the tunnels would be constructed as drained (untanked) tunnels that would allow groundwater to leak into the tunnel from the sandstone. Groundwater would be directed into the drainage system, pumped to the water treatment plants at Rozelle and Leichhardt, eventually discharging into Rozelle Bay and to Iron Cove via Hawthorne Canal. Undrained (tanked) tunnel sections would be constructed where the tunnel intersects unconsolidated saturated alluvium at Rozelle. The project is designed achieve a maximum groundwater inflow of one litre per second per kilometre for any kilometre length of tunnel during its operation. To achieve this design criterion, water proofing may be required in parts of the tunnels to reduce the bulk rock permeability.

10.1 Potential impacts

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

- Reduced groundwater recharge, caused by the temporary construction of paved ancillary facilities
- Tunnel inflows and associated groundwater drawdown. Tunnel inflows and drawdown have been predicted by groundwater modelling. Peak tunnel inflows occur for the project in 2021 at 1.8 megalitres per day. Drawdown within the Hawkesbury Sandstone at the end of construction in 2023 is predicted to be a maximum of 55 metres at St Peters. Drawdown exceeding two metres would extend approximately 500 metres from the tunnel
- Degradation of groundwater quality during the tunnel construction program as a result of:
  - The intersection of acid sulfate soils during excavation works that could cause the production

  of acidic groundwater

  - The spilling of hazardous materials such as fuels and oils
  - The intersection of contaminated groundwater during tunnelling that could further spread the contamination
  - The natural groundwater may be aggressive to tunnel building materials and cause corrosion of the tunnel structures.

Operational impacts are likely to include:

- Flood mitigation and reduction of water logging at the Rozelle Rail due to the installation of stormwater drainage to drain the former flood storage area. Runoff from additional road infrastructure would be directed to stormwater drainage
- Tunnel inflows and associated groundwater drawdown. Tunnel inflows are limited by the design criterion of one litre per second per kilometre for any kilometre length of tunnel. Drawdown is likely to eventually extend to the tunnel invert extending to depths of up to 60 metres at Rozelle. The extent of predicted drawdown of two metres or more extends up to a maximum of 1.2 kilometres at Camperdown within the Hawkesbury Sandstone
- Groundwater drawdown that impacts the natural environments
- No impacts on groundwater dependent ecosystems were identified
- Potential impacts on river or stream baseflow
- Only one water supply bore was identified where the drawdown was predicted to be in excess of two metres
- Groundwater quality could be degraded through:
  - Intersection of contaminated groundwater
  - Saltwater intrusion
  - Natural groundwater aggressivity to tunnel building materials that could cause corrosion of the tunnel structures
  - Drainage lines within the tunnel could become blocked due to the natural iron and manganese oxidising within the drains causing sludges
  - Tunnel inflows could include leachate derived from the Alexandria Landfill
- Barriers to groundwater flow. caused by ancillary infrastructure extending into the water table and the groundwater sinks created by tunnel drainage induced drawdown
- Long term cumulative groundwater drawdown or groundwater inflows due to the WestConnex tunnel projects are minimal as the tunnel projects do not overlap spatially but are adjoining and thus the sum of impacts are similar to a continuous tunnel
- The cumulative impacts on groundwater drawdown or groundwater inflows due to the WestConnex tunnel projects are minimal in terms of the timing of the projects overlapping since construction is staged with the maximum cumulative impact occurring at the end of construction in 2023.

10.2 Mitigation and management measures

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

- Preparation and implementation of a CEMP by the contractors that addresses the hazards associated with soil and groundwater contamination and groundwater management. The CEMP will include a CSWMP that addresses:
  - Groundwater management and monitoring
  - Surface water management and monitoring
  - Acid sulfate soils
- Management measures for the storage and stockpiling of materials, fuel and wastes during construction including spill prevention and response procedures
- Waterproofing would be installed during construction in areas identified that could have potential higher inflows. Post- grouting may also be required to further reduce groundwater inflows if monitoring indicates excessive inflows.
- Water from within the tunnels would be collected and treated prior to discharge at temporary water treatment plants prior to discharge to White Bay and Iron Cove
- Building materials that are resistant to aggressive groundwater conditions would be selected
- In accordance with the AIP, measures will be taken to 'make good' the impact to an impacted water supply bore by restoring the water supply to pre-development levels. The measures taken will be dependent upon the location of the impacted bore but could include, for example, deepening the bore, providing a new bore or providing an alternative water supply
- A groundwater monitoring program is to be prepared and implemented to monitor groundwater quality impacts during construction. The program shall be developed in consultation with the NSW EPA, DPI-Fisheries, DPI-Water and the Inner West and City of Sydney councils. Strategies would to be developed and implemented to reduce adverse impacts on groundwater quality due to construction activity if they are identified by the monitoring program. The monitoring program would include groundwater inflows, groundwater quality and groundwater levels.
- A detailed groundwater model will be developed by the construction contractor. The model will be used to predict groundwater inflow rates and volumes within the tunnels and groundwater levels (including drawdown) in adjacent areas during construction and operation of the project.
- Groundwater drawdown may induce ground settlement and impact existing and future infrastructure. Detailed settlement modelling will be carried out during detailed design. Settlement monitoring would be undertaken in accordance with the protocols developed in the CEMP. In addition structural inspections of buildings and infrastructure in areas identified that may be susceptible to settlement would be conducted. This would identify any structural defects that could be attributed to the project so make good provisions could be initiated.

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

- A groundwater monitoring program will be prepared and implemented to monitor groundwater inflows in the tunnels, groundwater levels and groundwater quality in the three main aquifers at the commencement of the operations phase. during construction. The monitoring program will be developed in consultation with the EPA, DPI-Fisheries, DPI-Water and the Inner West and Sydney City Councils.
- An OEMP will be developed by the tunnel operators to manage potential impacts to groundwater. The OEMP will be a 'live' document with the capacity to be updated if conditions are different to those expected. The OEMP would include the management of groundwater monitoring, surface water monitoring, drainage system maintenance and settlement monitoring.
- Long term groundwater inflows will be pumped to the surface, treated and discharged to Rozelle Bay via Hawthorne Canal or a constructed wetland and channel at Rozelle. The tunnel operation water treatment facilities would be designed such that effluent will be of suitable quality for

discharge to the receiving environment. Ultimately the water quality objectives would be set by the catchment manager of the receiving waters in consultation with the EPA.

- To reduce the impacts of water level decline in existing water supply wells mitigation measures would be taken to 'make good' the impact by restoring the water supply to pre-development levels. The measures taken would be dependent upon the location of the impacted bore but could include, deepening the bore, providing a new bore or providing an alternative water supply

11 References

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AECOM (2016b); Groundwater Management Plan. M4-M5 Link Technical and Environmental advisor. Report No M4M5-REP-20-0000-GT-274a. Prepared for Sydney Motorway Corporation Pty Ltd; dated 3 August.

AECOM (2016c); M4-M5 Link. Groundwater Factual Progress Report. June 2016 to August 2016. Report No M4-M5-REP-20-0000-GT-274B, dated September.

AECOM (2016d); Tranche 1 and Tranche 2 Geotechnical data report. WestConnex M4-M5 Link GI. Prepared for Sydney Motorway Corporation Pty Ltd. Document No 60493796_RPGT__0002_A, dated 17 October.

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