Chapter
16

Chapter 16

Geology, soils and groundwater

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16 Geology, soils and groundwater

This chapter provides an assessment of the construction and operational impacts associated with acid sulfate soils, salinity, erosion and sedimentation, groundwater inflow and drawdown. Contamination and ground movement are assessed, and relevant mitigation measures are identified. The impacts associated with the discharge of treated groundwater are detailed in Chapter 17 (Hydrodynamics and water quality).

Assessments of contamination and groundwater have been carried out for the project and are included in Appendix M (Technical working paper: Contamination) and Appendix N (Technical working paper: Groundwater). These assessments have also been informed by geotechnical investigations carried out for the project.

The Secretary's environmental assessment requirements as they relate to the geology, soils and groundwater, and where in the environmental impact statement these have been addressed, are detailed in Table 16-1.

The proposed environmental management measures relevant to geology, soils and groundwater are included in Section 16.7.

Table 16-1 Secretary's environmental assessment requirements – Geology, soils and groundwater

Secretary's requirement	Where addressed in the EIS
Soils	
1. The Proponent must verify the risk of acid sulfate soils (Class 1, 2, 3 or 4 on the Acid Sulfate Soil Risk Map) within, and in the area likely to be impacted by, the project.	Details with respect to the risk of acid sulfate soils are presented within **Section 16.3.3**, **Appendix M** (Technical working paper: Contamination), **Appendix N** (Technical working paper: Groundwater) and **Appendix O** (Technical working paper: Surface water).
2. The Proponent must assess the impact of the project on acid sulfate soils (including impacts of acidic runoff offsite) in accordance with the current guidelines and detail the mitigation measures proposed to minimise potential impacts.	An assessment of the impact of the project on acid sulfate soils is provided in **Section 16.4.1**. Mitigation measures to minimise these impacts are outlined in **Section 16.7**. More specific details with respect to contamination are provided in **Appendix M** (Technical working paper: Contamination), groundwater in **Appendix N** (Technical working paper: Groundwater), and surface water within **Appendix O** (Technical working paper: Surface water).
3. The Proponent must assess whether the land and harbour sediment is likely to be contaminated and identify if remediation of the land is required, having regard to the ecological and human health risks posed by the contamination in the context of past, existing and future land uses. Where assessment and/or remediation is required, the Proponent must document how the assessment and/or remediation would be carried out in accordance with current guidelines.	Qualitative assessment of the potential contamination risks, and the need for land remediation, is provided in **Section 16.4**. Requirements for future remediation activities are identified **Section 16.7.** Human health and ecological risks posed by contamination are assessed in **Chapter 13** (Human health) and **Chapter 19** (Biodiversity).

Secretary's requirement	Where addressed in the EIS
4. Where contaminated spoil and/or sediments are to be handled at Glebe Island and/or White Bay, the Proponent must provide details of contamination characteristics and measures to manage this spoil to avoid adverse impacts to land and water quality;	**Chapter 6** (Construction works) details the proposed construction method which has considered measures from **Appendix Q** (Technical working paper: Marine water quality) to avoid adverse impacts to land and water quality during contaminated spoil handling. **Appendix P** (Technical working paper: Hydrodynamics and dredge plume modelling) outlines the proposed dredge methodology. **Section 16.3.5** and **Section 16.4.3** provide the contamination characteristics of the spoil likely to be handled at Glebe Island and/or White Bay. **Section 16.7** provides the environmental management measures proposed to manage the spoil to avoid adverse impacts to land and water quality.
5. The Proponent must assess whether salinity is likely to be an issue and if so, determine the presence, extent and severity of soil salinity within the project area.	An assessment of the potential for salinity to be present and its severity is provided in **Section 16.3**.
6. The Proponent must assess the impacts of the project on soil salinity and how it may affect groundwater resources and hydrology.	An assessment of the project's impact on soil salinity is provided in **Section 16.3.3** and **Section 16.4.1**.
7. The Proponent must assess the impacts on soil and land resources (including erosion risk or hazard). Particular attention must be given to soil erosion and sediment transport consistent with the practices and principles in the current guidelines.	An assessment of the project's impact on soil and land resources, with particular emphasis on soil erosion and sediment transport, is provided in **Section 16.3.3** and **Section 16.4.1**.
8. The Proponent must assess the impact of any disturbance of contaminated groundwater and the tunnels should be designed so as to not exacerbate mobilisation of contaminated groundwater and/or prevent contaminated groundwater flow.	An assessment of contaminated groundwater impacts and a description of how the tunnel has been designed so as to not exacerbate mobilisation of contaminated groundwater and/or prevent contaminated groundwater flow is provided in **Chapter 5** (Project description) and **Section 16.4**.
Water – Hydrology	
1. The Proponent must describe (and map) the existing hydrological regime for any surface and groundwater resource (including reliance by users and for ecological purposes) and groundwater dependent ecosystems likely to be impacted by the project, including rivers, streams, wetlands and estuaries as described in Appendix 2 of the	**Section 16.3.4** presents the hydrological regime for groundwater. **Chapter 17** (Hydrodynamics and water quality), details of surface water resources likely to be impacted by the project is presented in **Section 17.3**. **Chapter 19** (Biodiversity) provides consideration of

Secretary's requirement	Where addressed in the EIS
Framework for Biodiversity Assessment – NSW Biodiversity Offsets Policy for Major Projects (Office of Environment and Heritage, 2014a).	relevant biodiversity matters.
2. The Proponent must prepare a detailed water balance for ground and surface water including the proposed intake and discharge locations (including mapping of these locations), volume, frequency and duration for both the construction and operational phases of the project.	Refer to **Section 16.4.5** and **Section 16.5.2** for groundwater inflow predictions during construction and operation. **Chapter 17** (Hydrodynamics and water quality) provides a surface water balance for construction and operation.
3. The Proponent must assess (and model if appropriate) the impact of the construction and operation of the project and any ancillary facilities (both built elements and discharges) on surface and groundwater hydrology in accordance with the current guidelines, including: a. natural processes within rivers, wetlands, estuaries, marine waters and floodplains that affect the health of the fluvial, riparian, estuarine or marine system and landscape health (such as modified discharge volumes, durations and velocities), aquatic connectivity, water dependent fauna and flora and access to habitat for spawning and refuge;	**Chapter 17** (Hydrodynamics and water quality) includes detail on surface water hydrological impacts and impacts on natural processes. **Chapter 16** (Geology, soils and groundwater), groundwater impacts during construction **(Section 16.4)** and operation **(Section 16.5)** are included. Hydrological impacts and impacts on natural processes are included in **Chapter 18** (Flooding). **Chapter 19** (Biodiversity) assesses surface water and groundwater hydrological impacts on the health of the fluvial, riparian, estuarine or marine system, aquatic connectivity, fauna and flora, and access to habitat for spawning and refuge.
b. impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, barriers to flows, implications for groundwater dependent surface flows, ecosystems and species, groundwater users and the potential for settlement;	**Chapter 16** (Geology, soils and groundwater), groundwater hydrological impacts are included in **Section 16.4** and **Section 16.5**. Impacts from any permanent and temporary interruption of ground water flow for ecosystems and species and for groundwater users is discussed in **Chapter 19** (Biodiversity).
c. changes to environmental water availability and flows, both regulated/licensed and unregulated/rules based sources including the stormwater harvesting scheme implemented by North Sydney Council at the storage dam at Cammeray Golf Course;	Changes to environmental water availability and flows is provided in **Chapter 17** (Hydrodynamics and water quality).
d. direct or indirect increases in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses;	**Chapter 17** (Hydrodynamics and water quality) assesses the potential impacts on surface water with regard to erosion, siltation, and bank stability. Impacts from scour and erosion on geomorphology and the effects of proposed stormwater and wastewater management on surface water quality

Secretary's requirement	Where addressed in the EIS
	are also assessed in this chapter.
e. minimising the effects of proposed stormwater and wastewater management during construction and operation on natural hydrological attributes (such as volumes, flow rates, management methods and re use options) and on the conveyance capacity of existing stormwater systems where discharges are proposed through such systems;	Minimising the effects of proposed stormwater and wastewater management on natural hydrological attributes and on the existing capacity of stormwater systems is described in **Chapter 17** (Hydrodynamics and water quality).
f. measures to mitigate the impacts of the proposal and manage the disposal of produced and incidental water.	**Chapter 17** (Hydrodynamics and water quality), details environmental management measures relating to surface water. Water drainage and management infrastructure is detailed in **Chapter 5** (Project description) and **Chapter 6** (Construction work).
4. The assessment must provide details of the final landform of the sites to be excavated or modified (e.g. portals), including final void management and rehabilitation measures.	The details of the final landform, including management and rehabilitation measures is provided in **Chapter 22** (Urban design and visual amenity). Landscape treatments for the project are detailed in **Chapter 5** (Project description). The management of voids (shafts and access declines) is detailed in **Chapter 6** (Construction work), **Section 6.4.1**.
5. The Proponent must identify any requirements for baseline monitoring of hydrological attributes.	The requirements for baseline monitoring is provided in **Section 16.6**. **Chapter 17** (Hydrodynamics and water quality) provides a description of surface water monitoring carried out to inform this environmental impact statement, and requirements for operational monitoring.
6. The assessment must include details of proposed surface and groundwater monitoring.	Details relating to the proposed surface and groundwater monitoring are provided in **Chapter 17** (Hydrodynamics and water quality) and **Section 16.6** and **Section 16.7**.
7. The Proponent must identify design approaches to minimise or prevent drainage of alluvium in the paleochannels.	Palaeochannels near the project are described in **Section 16.3.4**. Details of tunnel design are provided in **Chapter 5** (Project description) and **Chapter 6** (Construction work).

16.1 Legislative and policy framework

The impact assessment of the project on soils has been prepared in accordance with the following key guidelines and policies:

- *Managing Urban Stormwater: Soils and Construction Volume 1 (Landcom 2004) and Volume 2* (A. Installation of Services; B. Waste Landfills; C. Unsealed Roads; D. Main Roads; E. Mines and Quarries) (DECC, 2008)
- *Soil and Landscape Issues in Environmental Impact Assessment* (DLWC, 2000)
- *Site Investigations for Urban Salinity* (DLWC, 2002)
- *Landslide risk management guidelines* (Australian Geomechanics Society, 2007)
- *Framework for Biodiversity Assessment* – Appendix 2 (Office of Environment and Heritage, 2014a).

The impact assessment of the project on contamination has been prepared in accordance with the following contamination legislation, policies and guidelines:

- *Contaminated Land Management Act 1997*
- *Acid Sulfate Soils Assessment Guidelines* (Acid Sulfate Soils Management Advisory Committee, 1998a)
- *Acid Sulfate Soils Manual* (Acid Sulfate Soils Management Advisory Committee, 1998b)
- Managing Land Contamination: Planning Guidelines SEPP 55 – Remediation of Land (Department of Urban Affairs and Planning and EPA, 1998)
- *Guidelines for Consultants Reporting on Contaminated Sites* (Office of Environment and Heritage, reprinted 2011b)
- *Guidelines for the NSW Site Auditor Scheme* (NSW EPA, 2017b)
- *Guidelines on the Duty to Report Contamination under the Contaminated Land Management Act 1997* (NSW EPA, 2015)
- *NSW Aquifer Interference Policy* (DPI, 2012)
- *NSW Sustainable Design Guidelines Version 4.0* (Transport for NSW, 2017)
- *Risk Assessment Guidelines for Groundwater Dependent Ecosystems* (Office of Water, 2012a)
- *The Guidelines for Controlled Activities on Waterfront Land* (Office of Water, 2012b)
- Other guidelines made or approved under section 105 of the *Contaminated Land Management Act 1997*.

The impact assessment of the project on groundwater has been prepared in accordance with the following groundwater legislation and policy documents:

- *Water Act 1912* and *Water Management Act 2000*
- Minimal harm criteria presented in the *NSW Aquifer Interference Policy* (Office of Water, 2012c)
- *Rules of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources* (NSW DPI, 2011).

16.2 Assessment methodology

The methodology included:

- A review of the geological context, soil landscapes, salinity and acid sulfate soils
- A review of similar assessments and previous tunnelling projects in the Sydney region, including Sydney Metro City & Southwest (Chatswood to Sydenham) (Jacobs, 2016), North West Rail Link (Transport for NSW, 2012b), M4-M5 Link (AECOM, 2017a), M4 East (GHD, 2015) and the New M5 (AECOM, 2015)
- Field investigations including drilling, permeability testing, monitoring bore installation, and water level and quality monitoring
- Preparation of a Stage 1 Contamination Investigation including a review of background and historical information, site inspections, and sampling
- Development of a conceptual model of the hydrogeological environment and groundwater numerical modelling to predict groundwater inflows and drawdown propagation
- Technical review by a suitably qualified independent expert to confirm the groundwater modelling methodology and outputs
- Identification and assessment of potential construction and operational impacts associated with soils, contamination and groundwater
- Identification of environmental management and monitoring measures required to mitigate impacts and manage tunnel inflows.

16.3 Existing environment

16.3.1 Topography

The terrain along the project corridor is at an elevation of around 10 metres Australian Height Datum (AHD) at its southern extent at Rozelle and gently undulates towards Birchgrove. The maximum depth of the harbour in the vicinity of the crossing is about 40 metres below sea level on the eastern side adjacent to Balls Head.

Once the project crosses Sydney Harbour the topography has a moderate incline towards North Sydney, reaching an elevation of around 90 metres Australian Height Datum at the Pacific Highway, North Sydney.

The Sydney Harbour estuary is a drowned river valley (palaeovalley), characterised by steep sided banks carved into Hawkesbury sandstone between 25 and 29 million years ago. Around 17,000 years ago, the sea level rose, flooding the river valley and forming a flood tide delta (Sydney Institute of Marine Science, 2014). The Sydney Harbour crossing is underlain by estuarine, marine and alluvial sediments overlying Hawkesbury Sandstone at depths of over 40 metres below sea level. Underlying rock within Sydney Harbour along the proposed alignment occurs as two depressions formed by an ancient river system and has sediment cover of up to 30 metres thick.

16.3.2 Geology

The Sydney 1:100,000 Geological Series Sheet 9130 (NSW Department of Mineral Resources, 1983) indicates that the majority of the project area is underlain by geological units associated with the Wianamatta Group. Hawkesbury Sandstone (Rh) underlies the majority of the project area, with isolated occurrences of Ashfield Shale (Rwa) in the north eastern portion of the project area, around North Sydney and Neutral Bay. In addition, areas of disturbed ground (man-made fill (mf)) are mapped within the Rozelle Rail Yards, Birchgrove Park and Waverton Park. An intermediate formation between the Hawkesbury Sandstone and the Ashfield Shale, the Mittagong Formation, is sometimes identified but is not mapped along the project alignment.

A description of the geological formations is presented in Table 16-2 and shown in Figure 16-1.

Table 16-2 Geological units underlying the project area

Unit	Description
Wianamatta Hawkesbury Sandstone (Rh)	Medium to coarse grained quartz sandstone with very minor shale and laminate lenses.
Wianamatta Ashfield Shale (Rwa)	Black to dark grey shale and laminate.
Manmade fill (mf)	Dredged estuarine sand and mud, demolition rubble, industrial and household waste.

Geological structural features

The solid geology within the study area is cross cut by a number of geological structural features that may impact groundwater flow. These include:

- Dykes are known to cross the alignment at Balls Head, while another dyke also runs parallel with the alignment at Yurulbin Park. Other known dykes are projected to intercept the alignment at Waverton and Rozelle
- Geological faults (a fracture within rock where displacement may have occurred), which are typically found within the Hawkesbury Sandstone. The presence of geological faults is associated with increased groundwater inflows. The nearest major fault zone to the project is the Luna Park Fault zone, which is inferred to run parallel to the project in Cammeray.

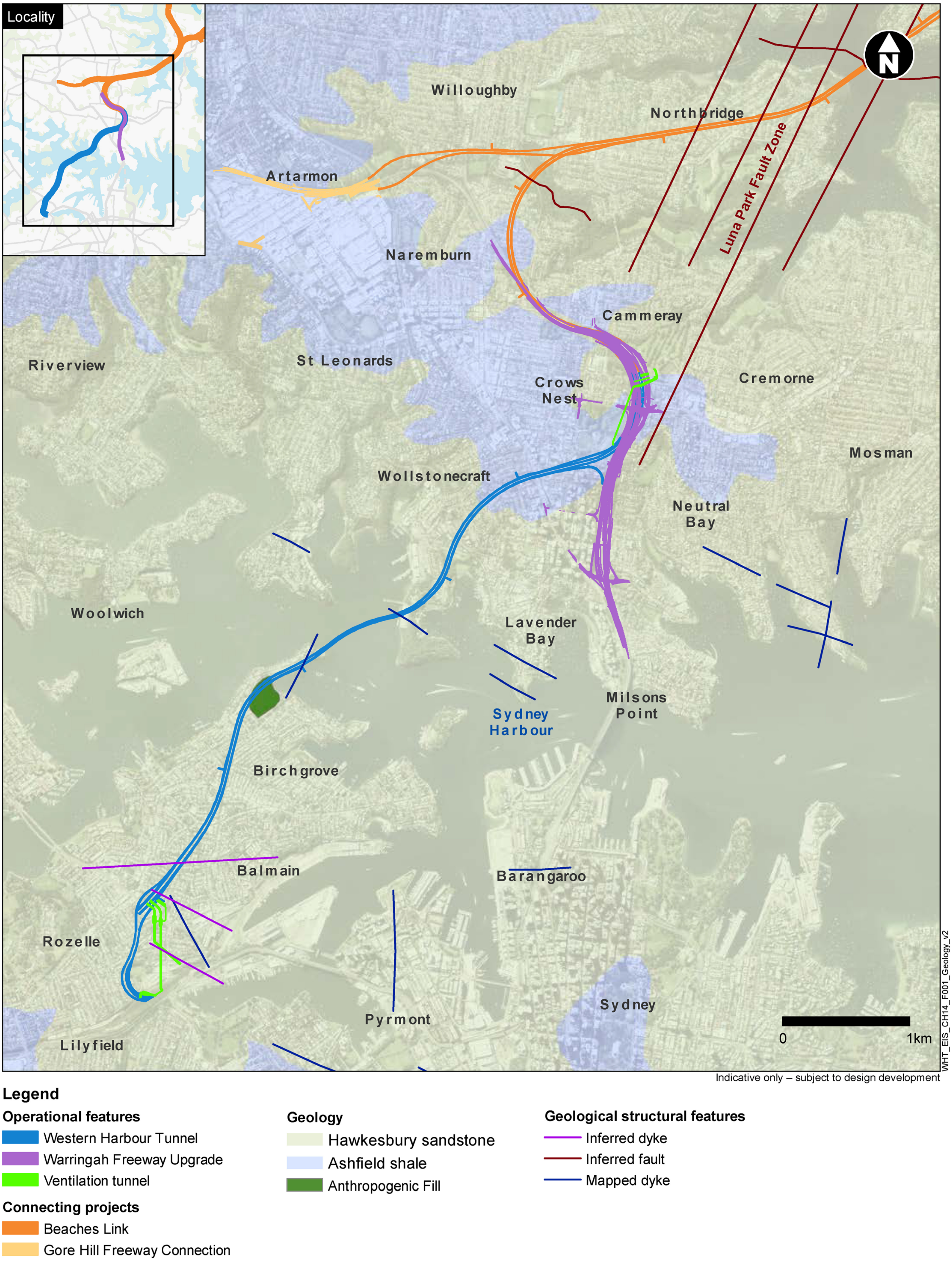


Figure 16-1 Regional geological context

16.3.3 Soils

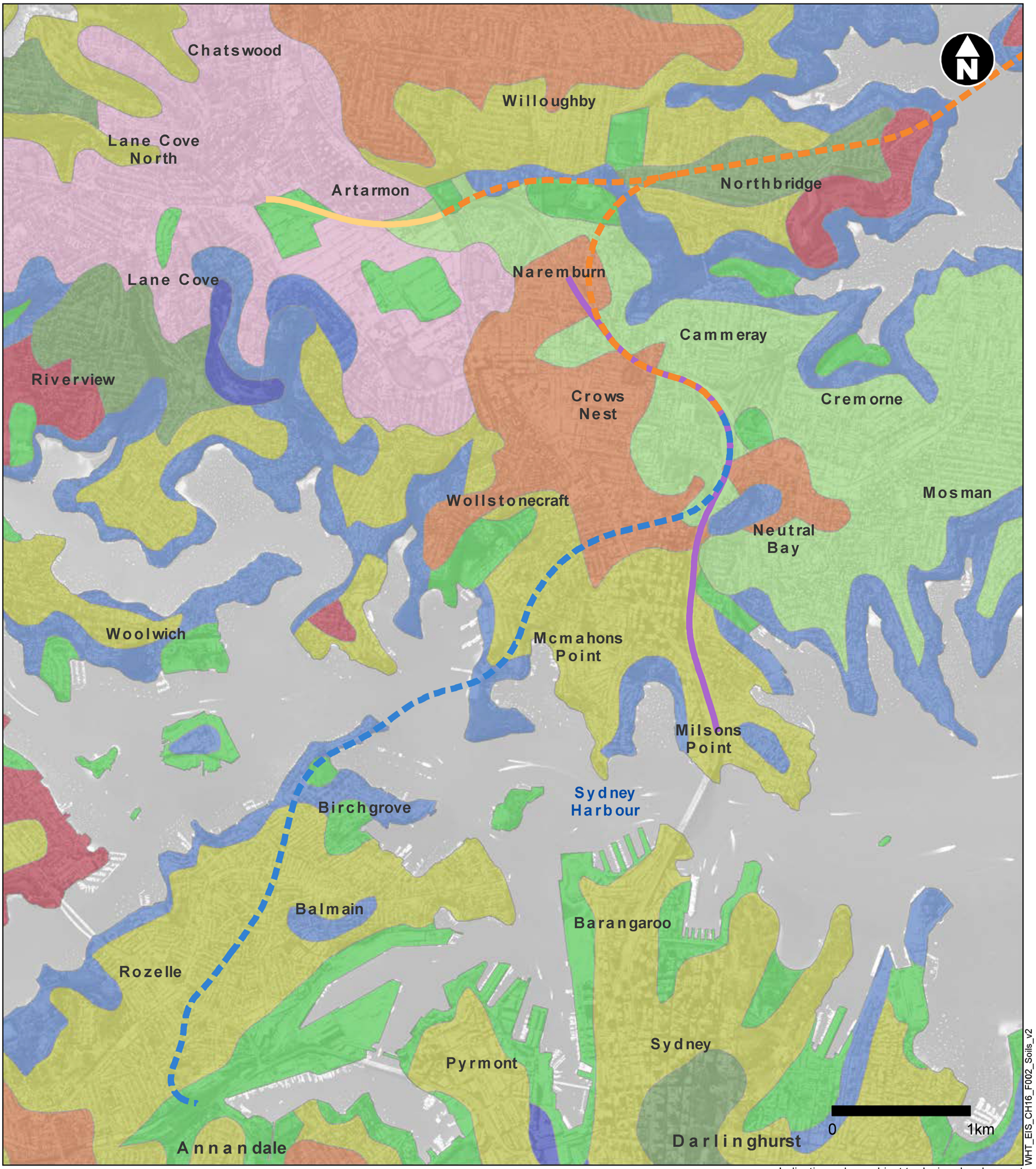
Soil groups

The Sydney 1:100,000 Soil Landscape Series Sheet 9130 (NSW Department of Mineral Resources, 1983) indicates that the residual soils within the project area include Blacktown (bt), Disturbed (xx), Hawkesbury (ha), and Gymea (gy) landscape groups. The majority of the project area is underlain by the Gymea landscape group with Hawkesbury landscape group surrounding the shorelines and isolated occurrences of the Blacktown landscape group around North Sydney. A description of the soil landscape groups is presented in Table 16-3 and shown in Figure 16-2.

Table 16-3 Soil landscape groups across the project area

Soil landscape	Description
Blacktown (bt)	**Landscape** – found on gently undulating rises on Wianamatta Group shales with local reliefs of up to 30 metres and slopes of less than five per cent. **Soils** – soils are shallow to moderately deep, with hardsetting mottled texture contrast soils. Red and brown podzolic soils found on crests grading to yellow podzolic soils on lower slopes and in drainage lines. **Limitations** – Blacktown soils are moderately reactive, with a highly plastic subsoil, low fertility and poor drainage.
Disturbed (xx)	**Landscape** – the topography varies from level plans to undulating terrain and has been disturbed by human activity to a depth of at least 100 centimetres. **Soils** – the original soil has been removed, greatly disturbed or buried. Most of these areas have been levelled to slopes of less than five per cent. Landfill includes soil, rock, building and waste material. The original vegetation has been completely cleared. **Limitations** – the soils are dependent on the nature of fill material, with subsidence resulting in a mass movement hazard. Soil impermeability may lead to poor drainage and low fertility. Care must be taken when these sites are developed.
Hawkesbury (ha)	**Landscape** – found on rugged, rolling to very steep hills on Hawkesbury Sandstone with local reliefs of 40 to 200 metres, slopes of more than 25 per cent and rock outcrops of more than 50 per cent. **Soils** – soils are typically shallow (less than 50 centimetres), with discontinuous lithosols/siliceous sands associated with rock outcrops, earthy sands, yellow earths and some yellow podzolic soils on the inside of benches and along joints and fractures. **Limitations** – Hawkesbury soils pose an extreme soil erosion hazard, with mass movement (rockfall) on steep slopes. The soils are shallow, stony, highly permeable and have low fertility.
Gymea (gy)	**Landscape** – found on undulating to rolling low hills on Hawkesbury Sandstone with local reliefs of 20 to 80 metres, slopes of 10 to 25 per cent and rock outcrops of less than 25 per cent. **Soils** – shallow to moderately deep yellow earths and earthy sands on crests and on the inside of benches. **Limitations** – Gymea soils have a high soil erosion potential. Soils are shallow, highly permeable with very low fertility.

Soil landscape	Description
Lambert (la)	**Landscape** – characterised by undulating to rolling rises and low hills on Hawkesbury Sandstone. Local relief 20 to 120 metres, with slopes around 20 per cent. Other landscape features include rock outcrops with grades of greater than 50 per cent, broad ridges with gently to moderately inclined slopes, wide rock benches with low broken scarps, small hanging valleys and areas of poor drainage. Vegetation includes open and closed heathland, scrub and occasional low eucalypt open woodland. **Soils** – soils are generally shallow (less than 50 centimetres) discontinuous earthy sands and yellow earths on crests and the insides of benches; shallow (less than 20 centimetres) siliceous sands/lithosols on leading edges; shallow to moderately deep (less than 150 centimetres) leached sands; grey earths and gleyed podzolic soils in poorly drained areas; and localised yellow podzolic soils associated with shale lenses. **Limitations** – soils have a very high soil erosion potential, with seasonally perched water tables. The soil is generally shallow, highly permeable and has very low soil fertility.



Indicative only – subject to design development

Legend

Operational features

- Western Harbour Tunnel alignment
- Warringah Freeway alignment

Connecting projects

- Beaches Link alignment
- Gore Hill Freeway connection

Soil landscape

- Blacktown
- Deep Creek
- Disturbed terrain
- Glenorie
- Gymea
- Gymea/Lambert
- Hawkesbury
- Lambert
- Lucas Heights
- West Pennant Hills

Figure 16-2 Soil landscapes

Marine sediments

Sediments infilling the Sydney Harbour estuary (palaeovalley) comprise Pleistocene and Holocene age alluvial, colluvial, estuarine and marine deposits to about 30 metres thick, thickening towards the centre of Sydney Harbour. Palaeovalley sediments are comprised of silty and peaty sands, silts and clays with shell layers.

The surface sediments which form the present seafloor and cover the underlying sediments across the alignment typically consist of interbedded soft silty clay and loose sand. A cross section of the marine sediment profile in Sydney Harbour along the proposed harbour crossing is shown in Figure 16-3.

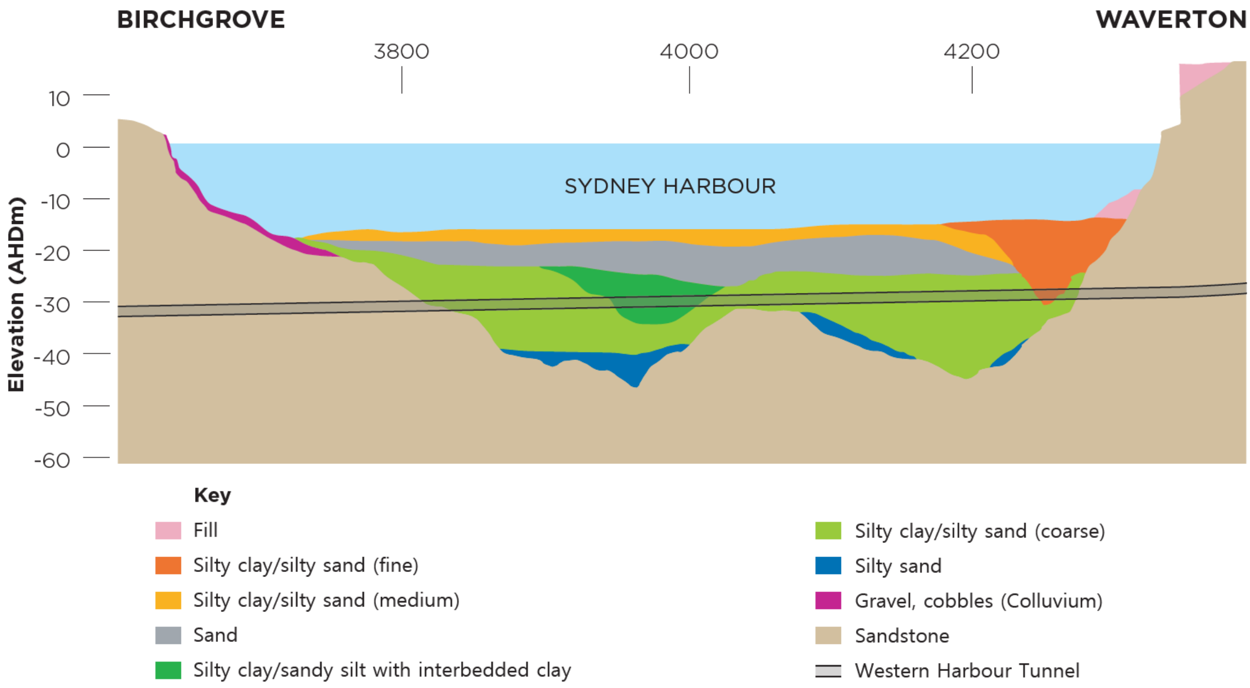


Figure 16-3 Sydney Harbour marine sediment profile

Acid sulfate soils

Acid sulfate soils are the common name given to naturally occurring soils, commonly associated with low lying areas of fine grained sediments and typically occur in lacustrine, estuarine, or swamp type environments, that contain iron sulfides (principally iron sulphide or iron disulphide or their precursors) which, on exposure to air, oxidise and create sulfuric acid.

Acid sulfate soil risk maps from the Australian Soil Resource Information System (ASRIS) database were reviewed to determine the probability of acid sulfate soil being present across the project area. The generalised acid sulfate soil probability across the project area has been assessed as follows:

- Sydney Harbour and Rozelle Bay – (A) high probability/confidence unknown
- Lilyfield to Snails Bay – (B3) low probability/low confidence
- Balls Head to Crows Nest – (C4) extremely low probability/very low confidence
- Artarmon – (B4) low probability/very low confidence.

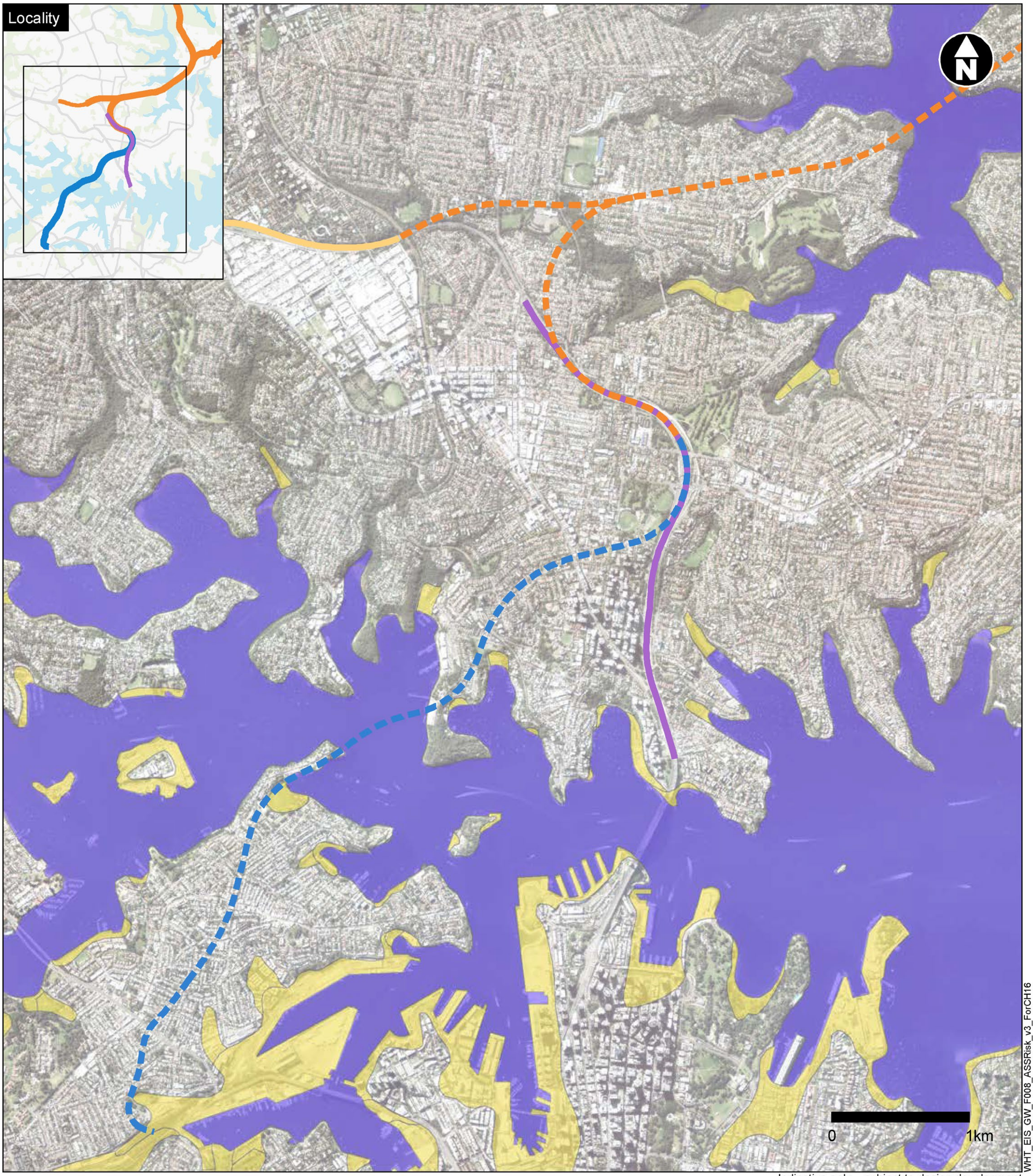
Key areas of acid sulfate soil risk are associated with the sediments beneath Rozelle Rail Yards, Birchgrove Park, Sydney Harbour (tunnel crossing, White Bay and Berrys Bay) and Whites Creek.

A review of the acid sulfate soil risk maps from the Leichhardt Local Environmental Plan (LEP) 2013 (Inner West Council, 2013) indicate that the project is located within areas of predominantly Class 5 acid sulfate soil risk with isolated areas of Class 1 (Rozelle Rail Yards and Whites Creek) and Class 2 (Birchgrove Park) acid sulfate soil risk. North Sydney LEP 2013 (North Sydney Council, 2013) does not contain acid sulfate soil risk maps. The respective LEPs do not cover acid sulfate soil risk within Sydney Harbour and associated bays.

The LEP states that development consent is required for the carrying out of work which may disturb, expose or drain acid sulfate soils and cause environmental damage, within the respective risk classes as follows:

- Class 1 – Any work
- Class 2 – work below the natural ground surface and/or work which is likely to lower the water table
- Class 5 – work within 500 metres of nearby Class 1, 2, 3, or 4 land that is below five metres Australian Height Datum and by which the water table is likely to be lowered below one metre Australian Height Datum on nearby Class 1, 2, 3, or 4 land.

Areas with a high probability of acid sulfate soil occurrence along the project alignment are shown in Figure 16-4.



Indicative only – subject to design development

Legend

Operational features

- Western Harbour Tunnel alignment
- Warringah Freeway alignment

Connecting projects

- Beaches Link alignment
- Gore Hill Freeway Connection

Acid sulfate soil risk

Acid sulfate soils probability

- High probability of occurrence
- Disturbed terrain

Figure 16-4 Acid sulfate soil risk classification

Soil salinity

With reference to the Salinity Potential in Western Sydney map sheet (Department of Infrastructure, Planning and Natural Resources (DIPNR)) (2002), higher salinity risk in western Sydney is generally associated with residual soils overlying Wianamatta Group Bringelly Shales. Residual soils from this geological unit near drainage lines pose a higher salinity risk potential. Notably, however, none of the soil landscapes within the project area document salinity as a limitation to the landscape type. Further to this, based on available geological maps, Bringelly Shales are not present within the project area, and none of the local council environmental plans within the project area contain salinity risk maps.

As such, naturally occurring soil salinity is not expected to be encountered within the project footprint.

Although not mapped, Ashfield Shale may contain marine salts which would result in saline groundwater (discussed in more detail in Section 16.3.4 below).

16.3.4 Groundwater

Groundwater flow

Across the study area the groundwater levels are typically deeper beneath hills and shallowest beneath creeks and gullies. Groundwater within the project footprint is recharged by rainfall runoff and infiltration. Groundwater is present within the following hydrogeological units (Figure 16-1):

- Quaternary alluvium
- Ashfield Shale
- Hawkesbury Sandstone
- Human made fill.

Quaternary alluvium

Quaternary alluvium occurs locally around watercourses and generally exhibits good water quality and high flows. Quaternary sediments associated with the palaeochannels (old river or stream channels which have been filled or buried by younger sediment) of Sydney Harbour have highly variable hydraulic conductivities (water flow), exhibiting very high flows in water bearing zones dominated by sand and gravel, and very low conductivities in water bearing zones with high clay content. Groundwater within the palaeochannels is typically saline, due to recharge from the Ashfield Shale and leakage from tidally flushed rivers and tributaries.

Other than within the palaeochannels of Sydney Harbour there are only limited occurrences of mapped Quaternary sediments along the alignment. The main occurrence is at the southern end of the proposed Western Harbour Tunnel, at the City West Link Road, where there is the potential to encounter sediments beneath manmade fill. The sediments are mapped as comprising silty to peaty quartz sand, silt and clay in places and common shell layers.

Overall, hydraulic conductivity (ie the level of permeability within soils and other materials) in the study area is likely to be low due to the predominance of silty clays and would generally behave as an aquitard (a zone within the earth that restricts groundwater flow from one aquifer to another).

Ashfield shale aquifer

The clay rich Ashfield Shale behaves as an aquitard as it has a very low vertical hydraulic conductivity (low water flow) which reduces groundwater transfer within and between the strata above and below.

Groundwater quality within the shale is highly variable but is typically brackish or saline due to the marine salts contained within it. The shale aquifer is characterised by low yields, limited storage and poor groundwater quality. Due to elevated salinity, low pH and the presence of sulphides, the groundwater can be corrosive to tunnel and infrastructure building materials.

Hawkesbury sandstone aquifer

Hawkesbury Sandstone has a highly variable hydraulic conductivity. It ranges from unconfined to semi confined and locally confined, with the degree of confinement resulting from stratification (bedding layers), which generally increases with depth. The highly stratified nature of the sandstone and the presence of interbedded shales also results in multiple aquifer zones within the sandstone.

The primary porosity of Hawkesbury Sandstone strata is generally low, leading to very low hydraulic conductivities (low water flow) within the sandstone where there is minimal fracturing. However, the flow of groundwater is usually dominated by secondary porosity and, as such, is highly variable and dependant on the distribution of structural defects including fractures, joints and bedding planes. Recharge is via rainfall infiltration on fractured outcrops and through the soil profile and alluvium. Discharge is via seepage to cliffs, such as the exposed quarried sandstone cutting at the Rozelle Rail Yards, and via creeks and evapotranspiration.

Groundwater quality within the Hawkesbury Sandstone is generally slightly acidic but of low salinity. The salinity of the upper part of the aquifer, however, can be elevated due to leakage from the Ashfield Shale. Elevated concentrations of dissolved iron and manganese naturally occur within the Hawkesbury Sandstone. In tunnels, groundwater ingress becomes oxidised, causing the dissolved iron and manganese to form sludge in drainage lines.

Human made fill

Human made fill can act as a water bearing unit supporting perched aquifers (aquifer occurring above the regional water table) but with very high variability and unpredictability. The hydraulic properties of the fill are determined by the materials used for the fill as well as how it was laid. The fill material may behave as an unconfined aquifer or aquitard. The low lying fill at Birchgrove Park may also be susceptible to seawater intrusion if significant drawdown occurs. The largest area of fill along the alignment is at Birchgrove Park where fill is noted as potentially containing harbour dredging debris comprising estuarine sand and mud, demolition rubble, and industrial and domestic waste.

Groundwater levels and movement

The regional water table across the study area typically mimics topography and flows from areas of high topographic relief to areas of low topographic relief. The depth of the water table is highly variable and can range from close to ground surface in low lying areas to 100 metres below ground level beneath elevated ridgelines. Localised water tables may also occur due to the highly stratified nature of the Hawkesbury Sandstone.

A composite water table contour map for the study area is presented in Figure 16-5. These contours were created using baseline groundwater data from the groundwater monitoring network installed for the project, as well as water levels from the DPI Water Pinneena database, and water levels obtained from other nearby projects, including Sydney Metro City & Southwest (Chatswood to Sydenham) (Jacobs, 2016) and M4-M5 Link (AECOM, 2017a). The contours provide a general overview of key groundwater flow directions and trends along the alignment.

The water level contours shown in Figure 16-5 confirm the general trend of the water table following topography, with groundwater flow from elevated areas (recharge) toward the harbours and major drainage lines (discharge).

Deeper groundwater flow would be less controlled by topography and more influenced by the regional structure and stratigraphy (layering) of the Sydney Basin. Regional groundwater flow is predicted to be in an east to south-easterly direction towards Port Jackson and the Tasman Sea.

Hydraulic conductivity is one of the key parameters that controls drawdown in response to tunnel inflows. Hydraulic conductivity was conducted during the field investigation program to provide parameters to support the groundwater modelling.

Packer testing (a technique in which inflatable bladders, or packers, are used to isolate different regions of a borehole for hydraulic testing) was also used to determine hydraulic conductivity cross the study area. The majority of boreholes drilled were either in Hawkesbury Sandstone, or overlying sediments (including fill). Permeability results from the marine based testing are typically 1 to 1.5 orders of magnitude greater that the land based permeability values. This reflects the increased occurrence and concentration of structures associated with the harbour areas. The average hydraulic conductivity for the land based Hawkesbury Sandstone was generally in agreement with the range of values from previous investigations. For a detailed analysis of the testing and results refer to Appendix N (Technical working paper: Groundwater).

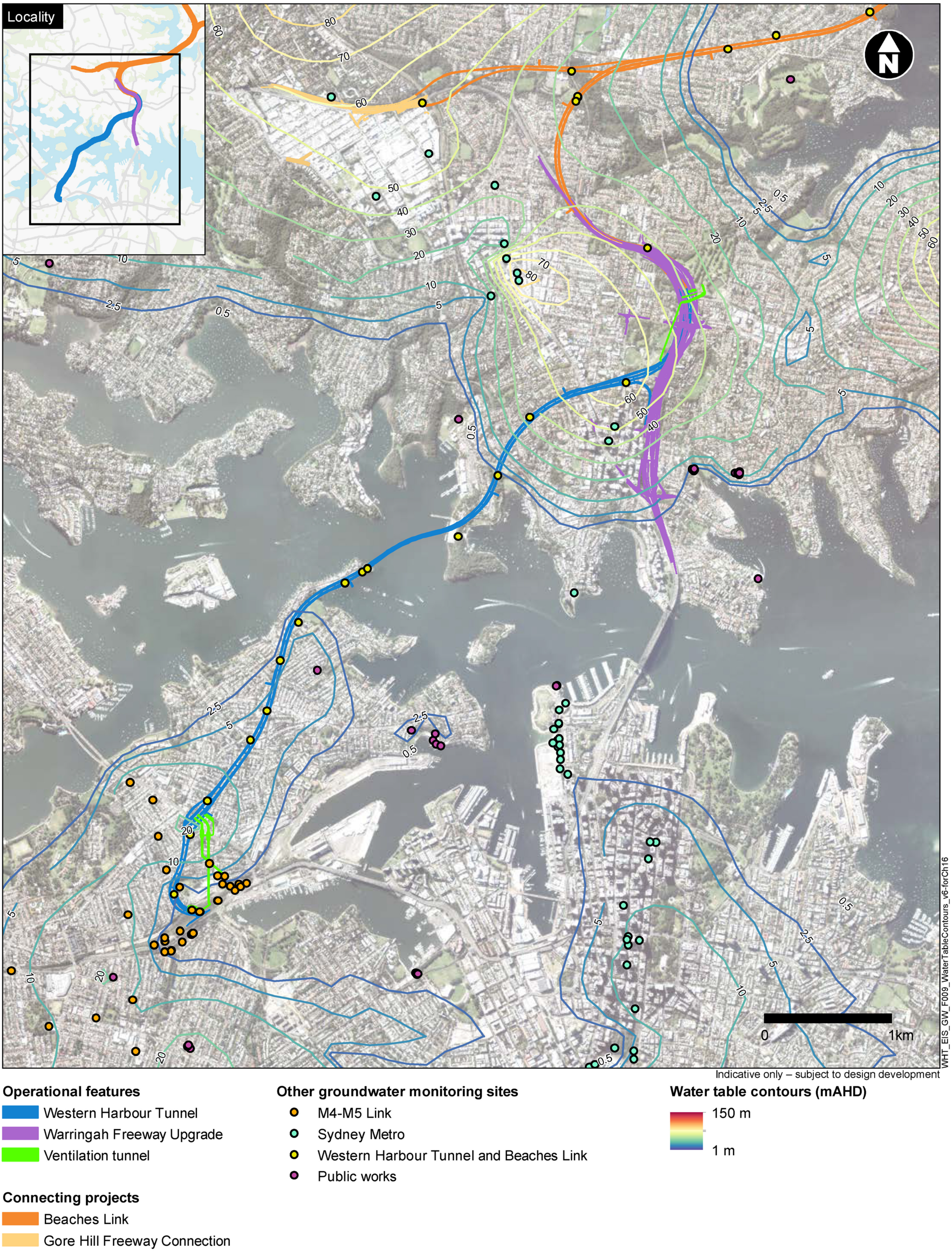


Figure 16-5 Water table contour map and groundwater monitoring network

Groundwater inflow in existing Sydney Tunnels

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 of the proposed Western Harbour Tunnel. These inflow rates are considered long term flow rates throughout the operational life of the infrastructure and are summarised in Table 16-4.

Table 16-4 Measured and predicted drainage rates in other Sydney Tunnels

Existing Tunnel	Opened	Type	Width (metres)	Length (kilometres)	Drainage inflow (L/sec/km)
Existing tunnels					
Eastern Distributor	1999	Three lane road	12 (double deck)	1.7	1
M5 East Motorway	2001	Twin two lane road	8	3.8	0.9
Epping to Chatswood	2009	Twin rail	7.2	13	0.9
Lane Cove Tunnel	2007	Twin three lane road	9	3.6	0.6/1.7[1]
Cross City Tunnel	2005	Twin two lane road	8	2.1	<3
Proposed tunnels					
M4 East	2020[2]	Twin three lane road		5.5	1.5
New M5	2020[2]	Twin three lane road	14 to 21	9	0.67

Note 1: Measured inflow in Lane Cove Tunnel varied from 1.7 L/s/km (2001 – mid 2004) to 0.6 L/s/km (2011).
Note 2: Assumed completion of tunnelling.

Groundwater quality

The groundwater assessment for the Sydney Metro Chatswood to Sydenham project (Jacobs, 2016) reported on general water quality information from previous tunnelling projects in the Sydney area using information provided by Transport for NSW. Groundwater that flows into existing underground structures in Sydney is generally high in iron, may contain manganese and other contaminants, relatively high salinity (as total dissolved salts) and a slightly acidic pH. Typical characteristics from existing tunnel projects in Sydney include:

- Energy Australia cable tunnel – iron 110 milligrams per litre, total dissolved solids 10,000 milligrams per litre, pH 5.9
- Sydney Harbour Tunnel – iron 40 milligrams per litre
- Epping to Chatswood Railway – iron 90 milligrams per litre, total dissolved solids 1300 milligrams per litre average to 6000 milligrams per litre, pH 5.9
- Cross City Tunnel – iron 50 milligrams per litre.

Groundwater is expected to be brackish within Ashfield Shale with neutral pH. Groundwater within the Mittagong Formation and Hawkesbury Sandstone is expected to be fresh to brackish with neutral to slightly acidic pH and slightly elevated levels of iron and manganese. The concentration of dissolved metals and nutrients in the Ashfield Shale, Mittagong Formation and Hawkesbury Sandstone, including residual soils, is expected to be naturally very low. Organic compounds are not naturally associated with Ashfield Shale, Mittagong Formation or Hawkesbury Sandstone.

Contaminants identified during groundwater monitoring are discussed in Section 16.3.5.

Groundwater dependent ecosystems

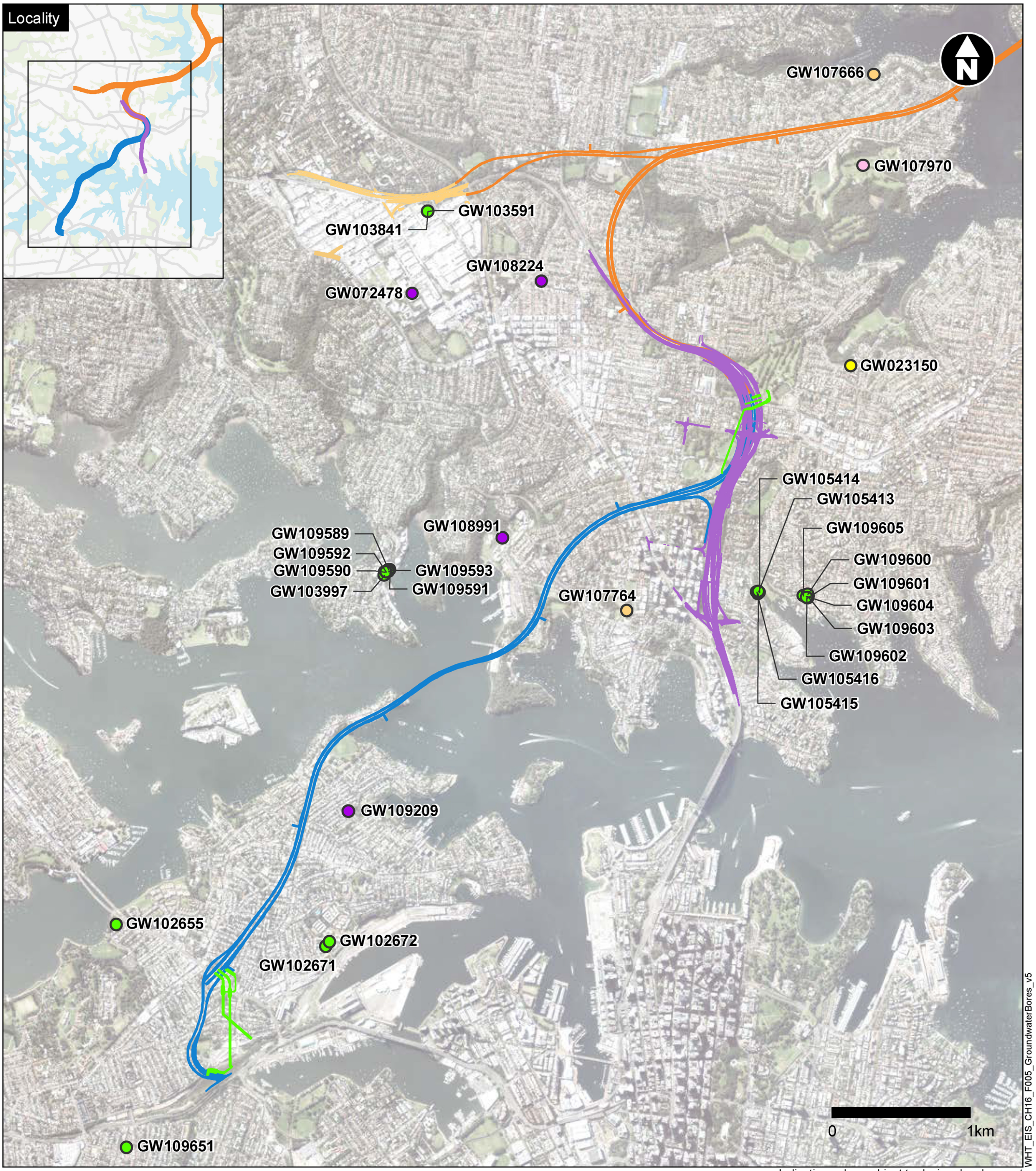
A search of the National Atlas of Groundwater Dependent Ecosystems (Bureau of Meteorology, 2017) did not identify any groundwater dependent ecosystems in the study area (refer to Chapter 19 (Biodiversity)). The nearest groundwater dependent ecosystem (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sand Forest) is located in the upper reaches of Flat Rock Creek at Munro Park, around a kilometre north east of the Warringah Freeway Upgrade and beyond the range of potential impact.

Groundwater users and extraction

Hawkesbury sandstone has been historically used as a water supply in the Sydney area with useful yields when fractures or joints are intersected. Details of groundwater bores sourced from the DPI Water Pinneena database and the Bureau of Meteorology Groundwater Explorer are provided below and shown in Figure 16-6. There were no Water Access Licence (WAL) users within 2.5 kilometres of the project.

There are 24 registered groundwater bores within a one kilometre radius of the project, including:

- Twenty one bores, of which 20 are installed for monitoring purposes and the other’s purpose is unknown
- Three bores are recorded as being installed for abstractive use; one for irrigation purposes and two for water supply purposes.



Indicative only – subject to design development

Legend

Operational features
- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Ventilation tunnel

Connecting projects
- Beaches Link
- Gore Hill Freeway Connection

Groundwater bore
- Water supply
- Irrigation
- Monitoring
- Other
- Unknown

Figure 16-6 Existing groundwater bores within one kilometre of the alignment

16.3.5 Contamination

Land contamination

Several sources were referenced and investigations were carried out to determine the potential for land contamination within and adjacent to the project. The sources and investigations included:

- Historic and current aerial photographs
- NSW EPA Contaminated Sites Register and Record of Notices
- Yellow Pages business directory search
- Contaminated site investigations.

Historical and current aerial photographs

Historical aerial photographs from several years between 1930 to 2005 were reviewed with a focus on the key surface disturbance areas and construction support sites. Additional details are provided in the Stage 1 Contamination Investigation in Appendix M (Technical working paper: Contamination). Based on this review, a summary of the potential contamination issues for surface disturbance areas is provided in Table 16-5.

Table 16-5 Summary of potential contamination issues at surface disturbance areas

Surface disturbance area	Potential contamination issue
Construction support sites	
Rozelle Rail Yards (WHT1)	• Residual contaminants from historical industrial land use • Demolition – Inappropriate handling and disposal of building materials during demolition of on-site structures.
Victoria Road (WHT2)	• Fuel storage – Leaks and spills from underground storage tanks and associated infrastructure present within the adjoining service station.
White Bay (WHT3)	South • Residual contaminants from historical industrial use • Land reclamation and unknown quality of fill materials • Demolition – Inappropriate handling and disposal of building materials during demolition of on-site structures. North • Residual contaminants from historical industrial use • Historical bulk fuel storage adjacent to the site • Land reclamation unknown quality of fill materials • Demolition – Inappropriate handling and disposal of building materials during demolition of on-site structures.
Yurulbin Point, Birchgrove (WHT4)	• Residual contaminants from historical industrial use • Demolition – Inappropriate handling and disposal of building materials during demolition of on-site structures.

Surface disturbance area	Potential contamination issue
Sydney Harbour south cofferdam (WHT 5)	• Contamination of Sydney Harbour sediments (discussed below in the Sydney Harbour contamination section).
Sydney Harbour north cofferdam (WHT6)	
Berrys Bay, Waverton (WHT7)	• Residual contaminants from historical industrial use • Historical bulk fuel storage on and adjacent to the site.
Berry Street north (WHT8)	• Demolition – Inappropriate handling and disposal of building materials during demolition of on-site structures • Particulate matter deposition from vehicles using the Warringah Freeway.
Ridge Street north (WHT9)	• Filling with material of unknown quality during early earthworks associated with the construction of the Warringah Freeway • Particulate matter deposition from vehicles using the Warringah Freeway.
Cammeray Golf Course (WHT10 and WFU8)	• Demolition – Inappropriate handling and disposal of building materials during demolition of buildings for construction of Warringah Freeway • Particulate matter deposition from vehicles using the Warringah Freeway • Chemical use and storage at the golf course.
Waltham Street (WHT11)	• Commercial/industrial use of site and surrounding areas.
Blue Street (WFU1)	• Demolition – Inappropriate handling and disposal of building materials during demolition of buildings for construction of the railway line.
High Street south (WFU2)	• Demolition – Inappropriate handling and disposal of building materials during demolition of buildings for construction of Warringah Freeway • Particulate matter deposition from vehicles using the Warringah Freeway.
High Street north (WFU3)	• Demolition – Inappropriate handling and disposal of building materials during demolition of buildings for construction of Warringah Freeway • Particulate matter deposition from vehicles using the Warringah Freeway.
Arthur Street east (WFU4)	• Demolition – Inappropriate handling and disposal of building materials during demolition of buildings for construction of Warringah Freeway • Particulate matter deposition from vehicles using the Warringah Freeway.

Surface disturbance area	Potential contamination issue
Berry Street east (WFU5)	• Demolition – Inappropriate handling and disposal of building materials during demolition of buildings for construction of Warringah Freeway • Particulate matter deposition from vehicles using the Warringah Freeway.
Ridge Street (WFU6)	• Demolition – Inappropriate handling and disposal of building materials during demolition of buildings for construction of Warringah Freeway • Particulate matter deposition from vehicles using the Warringah Freeway.
Merlin Street (WFU7)	• Demolition – Inappropriate handling and disposal of building materials during demolition of buildings for construction of Warringah Freeway • Particulate matter deposition from vehicles using the Warringah Freeway.
Rosalind Street east (WFU9)	• Demolition – Inappropriate handling and disposal of building materials during demolition of buildings for construction of Warringah Freeway • Particulate matter deposition from vehicles using the Warringah Freeway.
Other surface construction sites	
Modifications and additions to the Rozelle Interchange	• Residual contaminants from historical industrial land use • Land reclamation • Demolition – Inappropriate handling and disposal of building materials during demolition of on-site structures.
Warringah Freeway Upgrade and associated local road upgrade surface works	• Demolition – Inappropriate handling and disposal of building materials during demolition of buildings for construction of Warringah Freeway • Particulate matter deposition from vehicles using the Warringah Freeway and local roads.
Communications cable trenching – Warringah Freeway and Gore Hill Freeway	• Demolition – Inappropriate handling and disposal of building materials during demolition of buildings for construction of Warringah Freeway and Gore Hill Freeway.

Review of recent aerial imagery of the study area identified 23 sites, with activities or operations that could potentially represent contamination sources. These sites were located in Rozelle (six), Balmain (one), Sydney Harbour (one), Waverton (five), North Sydney (eight), Neutral Bay (one), Cammeray (one) and Crows Nest (one). Sites that may be contaminated included those with known infill areas, commercial and industrial land uses and areas subjected to the deposition of vehicle particulates.

NSW EPA Contaminated Sites Register and Records of Notices

An online search of the NSW EPA Contaminated Sites Record of Notices (NSW EPA, 2019) and the list of contaminated sites notified to the NSW EPA indicated that there are eight sites registered with the NSW EPA within 500 metres of the project that are either regulated (current notices) or have been notified. These sites were associated with industrial and service station activities and are listed in Table 16-6.

Table 16-6 Regulated/notified sites within 500 metres of the project

Suburb	Regulated/notified	Site and address	Distance from project
Rozelle	Notified	Rozelle Power Station – Robert Street	About 500 metres south east of the project
Rozelle	Notified	7/11 (former Mobil) service station – 178-180 Victoria Road	Less than 100 metres west of the project
Rozelle	Notified	Caltex service station – 121 Victoria Road	Less than 100 metres north of the project
Rozelle	Notified	Kennards Storage – 15-39 Wellington Street	About 100 metres north of the project
Rozelle	Notified	BP service station – Corner of Darling and Thornton Streets	About 300 metres north west of the project
Neutral Bay	Notified	Caltex service station – 16-38 Military Road	About 100 metres south of the project
Neutral Bay	Notified	Shell service station – 200-204 Ben Boyd Road	About 300 metres south east of the project
Waverton	Regulated	AGL Oyster Cove – 2 King Street	About 500 metres west of the project

Two sites, which were located within 200 metres of the project, were listed on the NSW Environment Protection Authority notified sites database as not being regulated under the *Contaminated Land Management Act 1997*. These sites were Berrys Bay Woodley's Marina (1 Balls Head Drive, Waverton) and SRA Land (95 Bay Road, Waverton). Both sites were assessed as having a low risk of contaminated ground water.

Four service station sites are located in the vicinity of tunnel alignment of the project including:

- 178–180 Victoria Road in Rozelle
- 121 Victoria Road in Rozelle
- Corner Darling Street and Thornton Street in Rozelle
- 16–38 Military Road in Neutral Bay.

Contamination exposure risk from regulated/notified sites located in the vicinity of surface works and construction support sites is likely to be low, due to the relatively large distances from the project and the likely extent of contamination (contamination, if present is likely to be below the depth of construction activities at around four to 10 metres below ground level). The Rozelle Power Station site is assessed as having a moderate risk of contamination due to the historical land use practices of the site and the large footprint.

Yellow Pages business directory search

The Yellow Pages business directory search identified 23 sites within or adjacent to the study area whose activities may cause contamination. These sites were located in Rozelle (14), Balmain (three) and North Sydney (six), and comprised service stations, paint manufacturers, explosives industries, vehicle mechanics and dry cleaners.

Contamination investigations

Soil samples were analysed for common contaminant compounds including heavy metals, polycyclic aromatic hydrocarbons (PAH), total recoverable hydrocarbons (TRH), toluene, ethylbenzene and xylene (BTEX), organochlorine pesticides (OCP), and organophosphorus pesticides (OPP), with selected samples additionally analysed for phenols, volatile and semi volatile organic compounds, cyanide, polychlorinated biphenyls (PCB) and asbestos. The results of the sampling and analysis were compared against guidelines for the protection of ecological and human (investigation and screening levels) receptors under open space and commercial/industrial land usage.

The contamination investigations indicated that soil contamination was present in a number of samples. Exceedances of the human health guidelines were reported for PAH in near surface soils in North Sydney, Cammeray, and Rozelle.

Groundwater contamination

Groundwater samples were analysed for common contaminant compounds including heavy metals, nutrients and hydrocarbons. The contamination investigations indicated a number of groundwater samples from boreholes located in Birchgrove, Balmain and Rozelle exceeded the Australian and New Zealand Environment and Conservation Council (ANZECC) water quality guidelines for freshwater and marine ecosystems (95 per cent level of protection). Concentrations above guideline levels may represent contamination, especially some of those contaminants and associated concentrations reported which may be associated with historical landfill.

Sydney Harbour contamination

A review of the technical report *Sydney Harbour: A systematic review of the science* (Sydney Institute of Marine Science, 2014) indicated that sediments in Sydney Harbour contain high concentrations of a suite of metals (most notably copper, zinc and lead). More recent studies have confirmed that sediments in large areas of Sydney Harbour are not only highly polluted by metals, but also by a wide range of non-metallic contaminants, eg organochlorine pesticides (OCs), polycyclic aromatic hydrocarbons (PAHs) and polychlorinated dibenzo-para-dioxins (dioxins) and dibenzofurans (furans).

Most of the harbour’s contamination results from a combination of historical inputs that remain in the sediments and some current sources such as stormwater. The very highest contamination concentrations are generally restricted to the bedded sediments and macroalgae of the upper reaches of embayments and decrease seaward in the harbour (Sydney Institute of Marine Science, 2014).

Sediment samples were collected as part of the geotechnical investigations carried out for the project in Sydney Harbour, Berrys Bay and White Bay. Sediment samples were collected from a range of depths and analysed for a range of contaminant compounds including heavy metals, hydrocarbon compounds (TRH, BTEX and PAH), OCP, PCB, tributyltin (TBT) poly-fluoroalkyl substances (PFAS) and dioxins. The results of the laboratory analysis were compared against the following guideline criteria:

- High and Low Interim Sediment Quality Guidelines (ANZECC/ARMCANZ, 2000)
- Ecological Investigation Levels (NEPC, 2013)
- *National Assessment Guidelines for Dredging* (Department of Environment, Water, Heritage and the Arts, 2009).

The results of the sediment sampling in Sydney Harbour, White Bay and Berrys Bay indicated a range of guideline exceedances including mercury, zinc, silver, lead, arsenic, copper, heavy metals, PAH, TRH, TBT and OCP. Contaminants were generally detected above guideline criteria in samples collected within the first metre of sediments. Contaminants detected above the respective guidelines in selected sediment samples are discussed in Appendix M (Technical working paper: Contamination).

16.4 Assessment of potential construction impacts

16.4.1 Soils

Erosion and sedimentation

The proposed construction activities associated with the tunnel works, construction support site establishment works and road upgrade works would involve surface excavation and earthmoving (as described in Chapter 6 – (Construction works)). The temporary exposure of soil to water runoff and wind could increase soil erosion potential, particularly where construction is carried out in soil landscapes characterised by a high or extreme erosion hazard (refer to Section 16.3.3). There is the potential for exposed soils – and other unconsolidated materials, such as spoil, sand and other aggregates – to be transported from the construction support sites into surrounding waterways via stormwater runoff.

The highest potential for soil erosion would be associated with the disturbance of soils on existing slopes during construction, particularly at the Berrys Bay (WHT7), Arthur Street east (WFU4), Berry Street east (WFU5) and Ridge Street east (WFU6) construction support sites. The majority of construction support sites are not characterised by significant undulating topography and the soil erosion hazard is unlikely to be significant.

Uncompacted or unconsolidated materials (such as excavated and stockpiled soils) have the potential to leave construction areas during rain through surface water run-off, with the potential to cause downstream sedimentation. Sedimentation in natural waterways can result in reduced water quality as well as smothering of vegetation and clogging of channels, impacting the natural flow paths of the waterway. Further details regarding erosion and sedimentation are provided in Chapter 17 (Hydrodynamics and water quality).

In general, management and control of erosion and sedimentation for major construction projects is well known, tried and proven. Standard management and mitigation measures are expected to be adequate in controlling any potential impacts.

Acid sulfate soils

Class 1 and Class 2 acid sulfate soil risks have been mapped in the vicinity of the Rozelle Rail Yards and Birchgrove Park. Based on the classification scheme presented in the Acid Sulfate Soils Assessment Guidelines (Acid Sulfate Soils Management Advisory Committee, 1998a), any works (Class 1) below natural ground surface and/or works by which the water table is likely to be lowered (Class 2) could present an environmental risk.

There is also the possibility of acid sulfate soils being present within marine sediments within Sydney Harbour, White Bay and Berrys Bay. The handling and treatment of contaminated marine sediments is described in Section 16.4.4.

Acid sulfate soils may be encountered during excavation. Potential impacts may include:

- Damage to aquatic environments due to the release of sulfuric acid generated from oxidised acid sulfate soils during construction

- Mobilisation of aluminium, iron and manganese from soils as a result of increased acidity from disturbance of acid sulfate soils.

Further geotechnical testing of underlying sub soil and rock stratum would be carried out to determine the composition of rock and soil types likely to be present within excavation areas.

If acid sulfate soils are encountered, they would be effectively managed in accordance with the Acid Sulfate Soil Manual (Acid Sulfate Soil Management Advisory Committee, 1998b). The manual includes procedures for the investigation, handling, treatment and management of such soils.

Soil salinity

Construction of the project has the potential to contribute to urban salinity through:

- Removal of deep-rooted vegetation or other activities which could raise the groundwater table above normal seasonal levels
- Soil compaction at areas of surface disturbance, such as at the construction support sites, which can restrict groundwater flow and result in a concentrate of salt in one area.

As outlined in Section 16.3, naturally occurring soil salinity is not considered a major concern within the project footprint. Salinity is considered unlikely to represent a risk to surface water and/or groundwater during the construction of the project.

16.4.2 Ground movement

Ground movement may occur as a result of:

- Tunnel induced movement caused by the relief of stress from tunnelling through intact rock
- Settlement induced from groundwater drawdown.

The risk to individual structures would be dependent on the geotechnical conditions, the depth of the tunnel, the number of storeys of the building, and the position, condition, and masonry of the structure itself.

Table 16-7 provides typical impacts which would be expected in relation to potential ground movement values and typical associated impacts for settlement.

Table 16-7 Building and structure settlement damage classification

Damage category	Maximum settlement of building (mm)	Degree of severity	Typical impact
0		Negligible	Hairline cracks less than 0.1 millimetres.
1	Less than 10	Very slight	Damage generally restricted to internal wall finishes. Cracks (0.1 to one millimetres) may be visible on external brickwork or masonry.
2	10 to 50	Slight	Cracks easily filled. Redecoration probably required. Recurrent cracks can be masked by suitable linings. Cracks may be visible externally and some repointing may be required to ensure weather tightness. Doors and windows may stick slightly. Typical crack widths between one to five millimetres.

Damage category	Maximum settlement of building (mm)	Degree of severity	Typical impact
3	50 to 75	Moderate	Cracks may require some opening and may be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows may stick. Service pipes may fracture. Weather tightness often impaired. Typical crack widths between five to 15 millimetres.
4	Greater than 75	Severe	Extensive repair work involving break out and replacing sections of walls, especially over doors and windows. Windows and door frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably; some loss of bearing in beams. Utilities disrupted. Typical crack widths between 15 to 25 millimetres.
5	Greater than 75	Very severe	Impacts require a major repair job involving partial or complete rebuilding. Beams lose bearing; walls lean badly and require shoring. Windows broken with distortion. Danger of instability. Typical crack widths greater than 25 millimetres.

Note: Degree of severity and typical impact adopted from Burland et al. (1977), and Boscardin and Cording (1989).

A summary of the maximum total predicted settlement along the tunnel alignment is shown in Table 16-8, Figure 16-7 and Figure 16-8. Due to the Rozelle portal (and adjacent tunnelling being constructed under the remit of the M4-M5 project it has not been considered within the summary below.

Table 16-8 Maximum predicted surface settlement

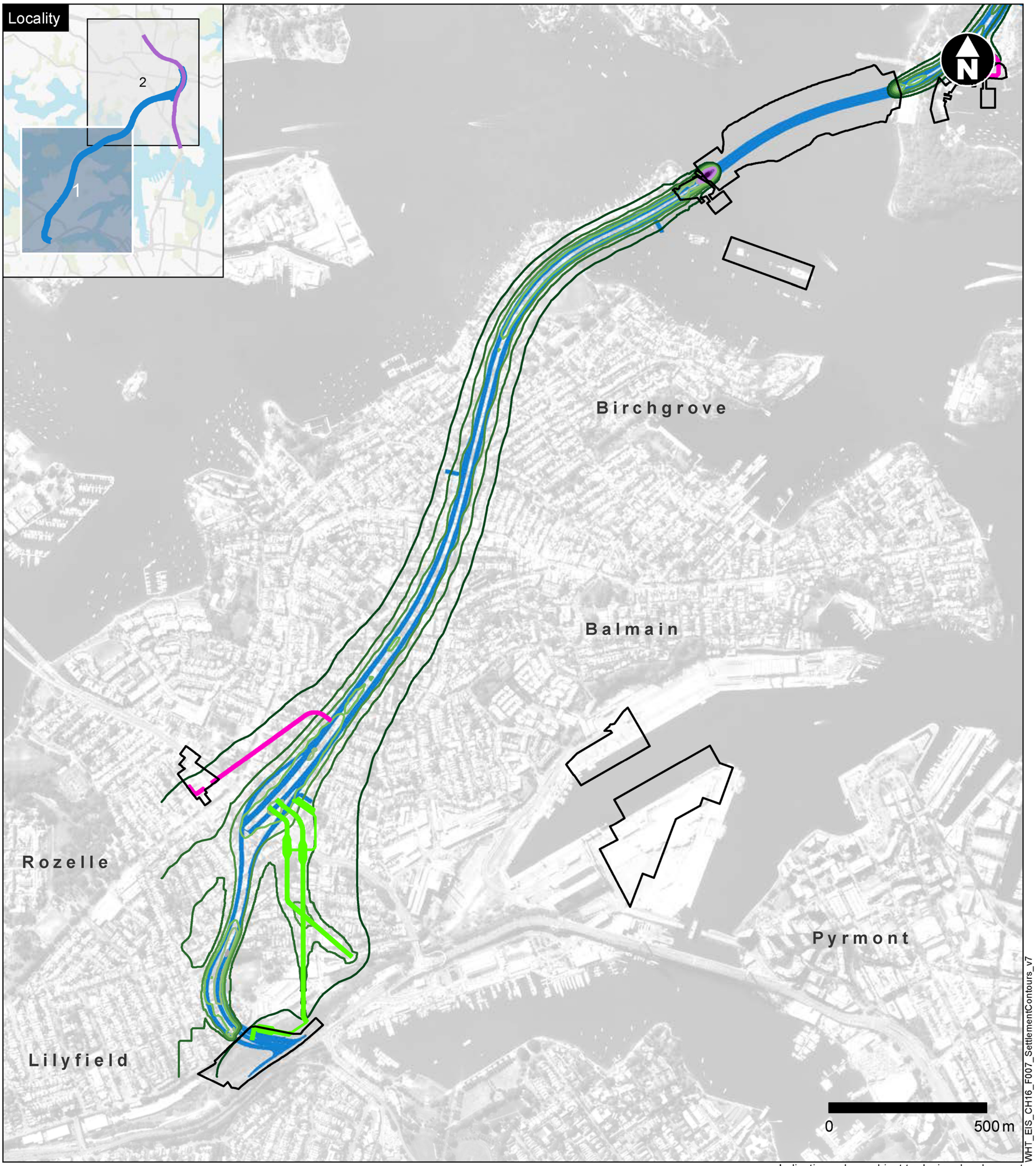
Location	Maximum stress redistribution induced settlement (mm)	Maximum groundwater drawdown induced settlement (mm)	Maximum total settlement (mm)
Waverton coal loader	25-30	Less than five	25-30
Rozelle ventilation tunnels	5-10	Less than five	10-15
Victoria Road access decline	10-15	10-15	25-30
Berrys Bay access decline	5-10	Less than five	10-15
Mainline tunnels between Rozelle and Western Harbour crossing	10-15	5-10	20-25
Mainline tunnels between Rozelle and Western Harbour Tunnel crossing (tanked section)	50-55	5-10	55-60

Location	Maximum stress redistribution induced settlement (mm)	Maximum groundwater drawdown induced settlement (mm)	Maximum total settlement (mm)
Mainline tunnels between Western Harbour crossing and Warringah Freeway	30-35	Less than five	35-40
Warringah Freeway portal	50-55	Less than five	50-55
Cammeray ventilation tunnel	5-25	Less than five	5-25

All project components are expected to experience ground surface settlement impacts of over 10 millimetres. The tanked section (ie the areas that require control of higher levels of groundwater ingress) of the mainline tunnel alignment from Rozelle to the Western Harbour Tunnel crossing and the Warringah Freeway portal are expected to experience long-term surface settlement of between 55-60 and 50-55 millimetres respectively, however such long-term surface settlement would be considered to have a severity degree of ‘moderate’. All other project components are anticipated to be subject to total long-term settlement measurements of 40 millimetres or less, considered to be of ‘slight’ degree of severity under relevant guidelines.

No buildings were found to be in the ‘slight’ to ‘very severe’ damage categories, while approximately 106 buildings along the project alignment were categorised within the ‘very slight’ damage category. ‘Very slight’ damage (fine cracks) are easily treated during normal decoration. Damage is generally restricted to internal wall finishes, with small cracks visible on external brickwork or masonry.

Building/structure condition surveys would be carried out as applicable prior to commencement of construction. Any impacts from settlement caused by the project would be rectified to the condition prior to construction works.



Indicative only – subject to design development

Legend

Operational features
- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Ventilation tunnel

Construction features
- Construction footprint
- Access decline

Connecting projects
- Beaches Link
- Gore Hill Freeway Connection

Settlement contours
- 55 mm
- 5 mm

Figure 16-7 Settlement contours (Rozelle to Sydney Harbour, map 1)

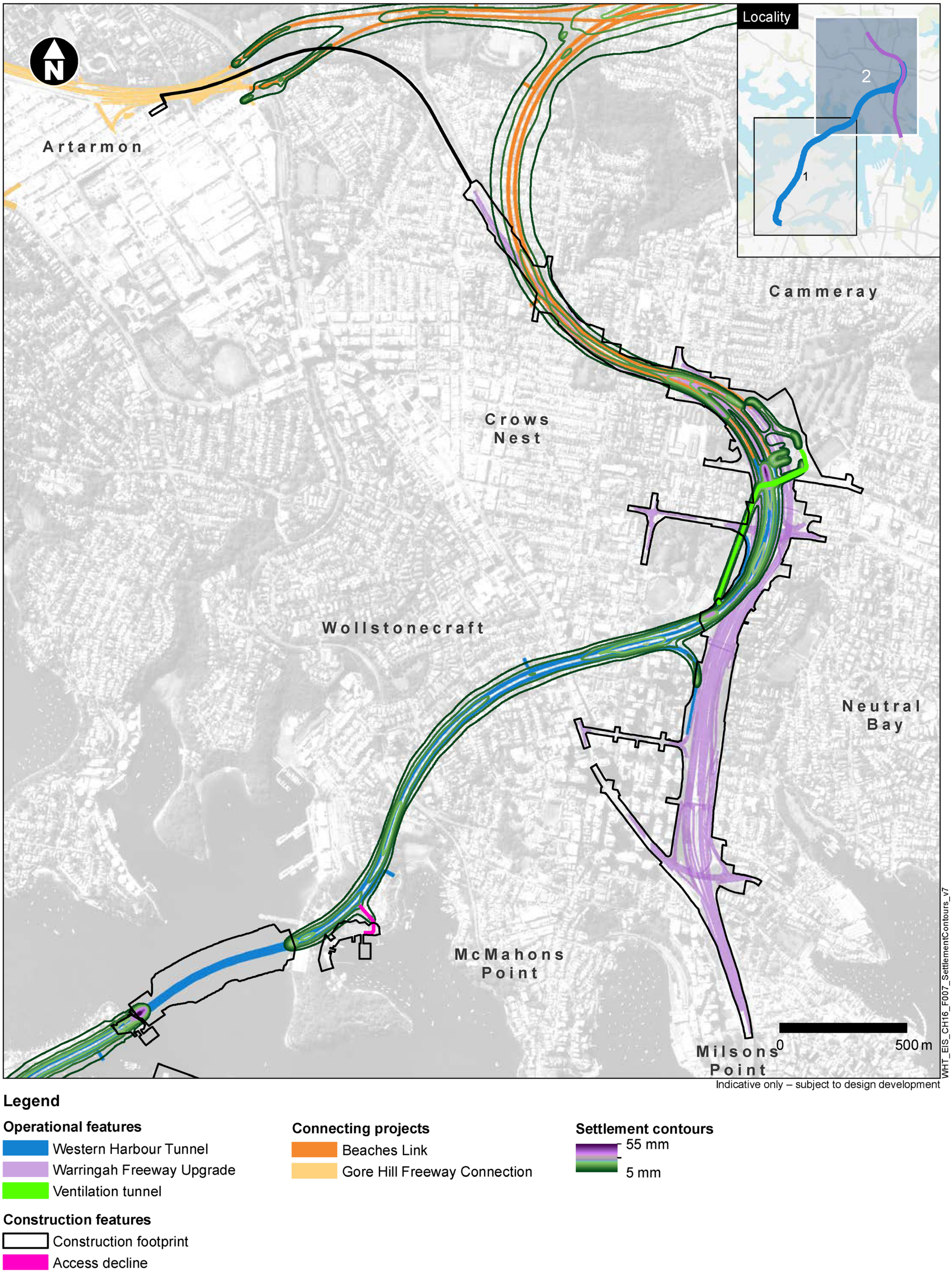


Figure 16-8 Settlement contours (Sydney Harbour to Warringah Freeway, map 2)

16.4.3 Land contamination

Areas of environmental interest

Based on the assessment of known and potentially contaminated sites, most sites within and/or adjacent to the project area are considered to represent a low contamination risk and are not considered further. Nine areas would have a moderate to high risk rating and are considered to be potential areas of environmental interest. A summary of these sites, including their associated contaminants of concern, is provided below. The location of areas of environmental interest identified along the project alignment are shown in Figure 16-9.

Rozelle Rail Yards, Rozelle (AEI1) [W1]

The historical rail yard land use (rail activities) and potential creek infilling at the Rozelle Rail Yards is known to have resulted in contaminated soil and groundwater in the area. This area contains soils contaminated with heavy metals, PAH and asbestos. In addition, the historical infilling of the former creek and subsequent degradation of organics within the infill material may generate leachate which could migrate into and contaminate the underlying groundwater. If considerable organic content (eg timber, paper, green waste) is present within infill materials, this could generate landfill gas. This area poses a high potential contamination risk to construction activities associated with the project given the known presence of contaminated material from historical site activities at this location.

Easton Park, Lilyfield (AEI2) [W2]

The potential infilling of the former creek line and low lying areas adjacent to Easton Park may have resulted in soil, groundwater and potentially gas/vapour contamination sources. Soils may be contaminated with a variety of contaminant compounds including heavy metals, hydrocarbons, pesticides, polychlorinated biphenyls, volatile organic compounds, nutrients, and asbestos. The degradation of organics within the infill could generate leachate which could migrate into and contaminate the underlying groundwater. If considerable organic content is present within infill materials, this could generate landfill gas. This area poses a moderate potential contamination risk associated with the possible presence of various sources of soil contamination as well as leachate and landfill gas underneath the site which could be exposed during tunnelling activities.

Birchgrove peninsula (AEI3) [W3 and W4]

Slag and ash materials may be present across areas of the Birchgrove Peninsula (including Yurulbin Park) associated with historic disposal practices of wastes from nearby industry (eg power stations). These slag and ash materials are generally present within surface fill materials and could contain elevated concentrations of heavy metals and hydrocarbons.

Historical industrial land use and demolition of structures at Yurulbin Park may have also contaminated the site with heavy metals, hydrocarbons, pesticides, polychlorinated biphenyls, phenols, organotins and asbestos. Therefore, it is considered that this area poses a moderate contamination risk to construction given the potential for contamination to be present within the soil which is likely to be excavated and exposed during construction of the Yurulbin Point construction support site (WHT4). Material would be transported to White Bay construction support site (WHT3).

Sydney Harbour (AEI4) [W5]

Contamination has been reported in sediments present within Sydney Harbour. Contamination is likely to be associated with inputs from the surrounding urbanised catchments, historical operations and the general maritime use within the surrounding area. The sediments pose a high contamination risk to construction given that contamination is known to be present within sediments which are likely to be excavated and exposed during construction of the Sydney

Harbour cofferdams (WHT5 and WHT6). Material would be transported to White Bay construction support site (WHT3).

Balls Head peninsula (AEI5) [W6 and W7]

The historical use of the wharf at Balls Head Road, Waverton may have caused localised contamination associated with the loading and unloading of materials (particularly coal and other materials) and general maritime activities. Soil and rock located beneath the former bulk fuel storage site located at Waverton may contain residual heavy metal and hydrocarbon contamination associated with the former use of the site. This area poses a moderate contamination risk to construction considering the potential presence of contamination (in soil and/or rock) and that such materials are likely to be excavated and exposed during construction of the Berrys Bay construction support site (WHT7). Material would be transported to White Bay construction support site (WHT3).

Waverton Park (AEI6) [W8]

Contaminated fill materials have been reported within Waverton Park, however no groundwater samples have been taken to date. It is possible that the contamination reported in respect to fill material could represent a contamination source to groundwater beneath the site. If considerable organic content (eg timber, paper, green waste) is present within infill materials, this could generate landfill gas. This area poses a high contamination risk to construction given that contamination is known within fill material which could impact upon groundwater. Groundwater could be exposed during construction of the tunnel and/or construction could create preferential pathways for groundwater contamination and landfill gas (if present).

Warringah Freeway, North Sydney to Cammeray (AEI7) [W9 to W18]

The unsealed areas adjacent to the Warringah Freeway (including St Leonards Park) represent a potential source of contamination (namely lead, hydrocarbons, pesticides, PCBs and asbestos) associated with the current and historical deposition of particulates from large volume traffic flows using the Warringah Freeway. Asbestos and PAH compounds have been detected in soil samples collected from some locations at concentrations exceeding open space and commercial/industrial guidelines protective of human health. These areas pose a moderate to high contamination risk to construction given that contamination is known and potentially present within soil which is likely to be excavated and exposed during construction of surface works, the pedestrian bridge and the following construction support sites: Berry Street north (WHT8), Ridge Street north (WHT9), Cammeray Golf Course (WHT10 and WFU8), High Street south (WFU2), High Street north (WFU3), Arthur Street east (WFU4), Berry Street east (WFU5), Ridge Street east (WFU6), Merlin Street (WFU7), and Rosalind Street east (WFU9).

Waltham Street, Artarmon (AEI9) [W20]

The current and historical use of the Motorway Control Centre site and adjoining properties at Waltham Street in Artarmon may have caused localised contamination associated with the commercial/industrial uses of this area. This area poses a moderate contamination risk to construction considering the potential presence of soil contamination and that soils are likely to be excavated and exposed during construction of the Motorway Control Centre at Waltham Street construction support site (WHT11).

Potential contamination risks

As indicated above, eight sites would have a moderate to high risk rating and are considered to be potential areas of environmental interest. Table 16-9 identifies the potential contamination impacts and associated risks with these sites.

Management and mitigation measures to address the potential risks are discussed in Section 16.7

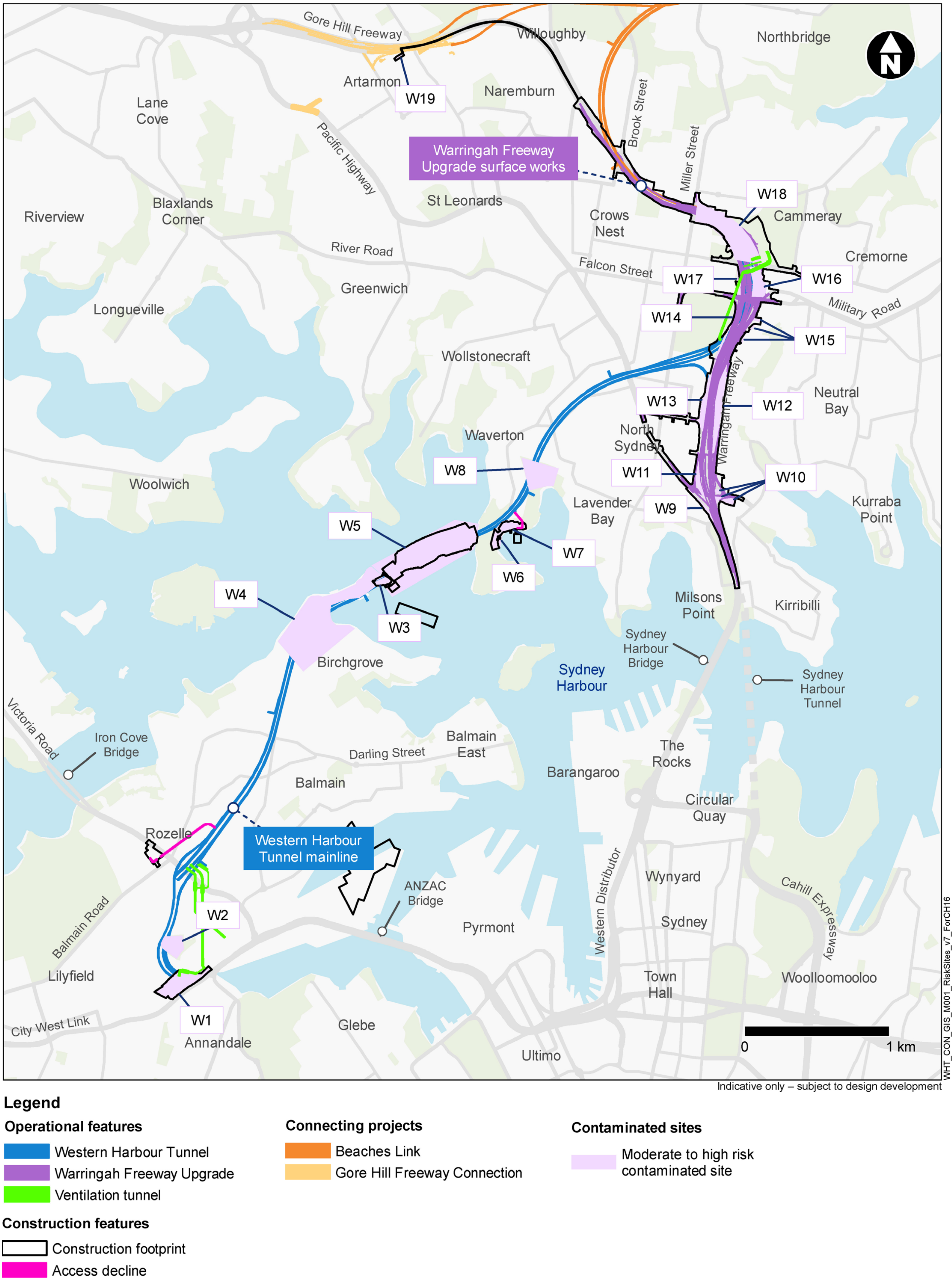


Figure 16-9 Areas of environmental interest and contaminated sites

Table 16-9 Potential contamination risks

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
Rozelle Rail Yards, Rozelle (AEI1) [W1]	Within construction footprint. Above proposed tunnel alignment and within footprint of Rozelle Rail Yards construction support site (WHT1).	• Construction support site establishment works • Tunnel fitout.	Soils may be contaminated with a variety of contaminant compounds including asbestos. Potential soil contamination and degradation of organics within infill could generate leachate which could migrate into and contaminate the underlying groundwater. If significant organic content is present within infill materials, this could generate landfill gas. If contamination is present and not appropriately controlled, there is the potential for: • Inhalation and/or ingestion risk to site workers of hazardous building materials via dust • Cross contamination associated with the incorrect handling or disposal of spoil/unexpected finds • Excavation and tunnelling activities may mobilise and spread buried contaminants • Accidental leaks and spills during the use of the Rozelle Rail Yards construction support site (WHT1).	**High** Known contamination/ excavation activities within potential contamination distribution range (laterally and vertically).	**High** Known groundwater contamination.
Easton Park, Lilyfield	In proximity to ventilation tunnels at	Tunnelling and associated	Soils may be contaminated with a variety of contaminant compounds including asbestos. The degradation of organics	**Moderate** Possible	**Low** No known

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
(AEI2) [W2]	Rozelle.	excavation.	within the infill (of former creek line) could generate leachate which could migrate into and contaminate the underlying groundwater. If significant organic content is present within infill materials, this could generate landfill gas. If contamination is present and not appropriately controlled, there is the potential for tunnelling activities to mobilise and spread buried contaminants.	contamination/ excavation activities within potential contamination distribution range (laterally).	groundwater contamination.
Birchgrove peninsula (AEI3) [W3 & W4]	Within construction footprint. Above proposed tunnel alignment and within footprint of Yurulbin Point construction support site (WHT4).	• Construction support site establishment works • Tunnelling and associated excavation and stockpiling.	Slag and ash materials are present within surface fill materials and could contain elevated concentrations of heavy metals and hydrocarbons. Historical industrial land use and demolition of structures at Yurulbin Park may have also contaminated the site with heavy metals, hydrocarbons, pesticides, PCBs, phenols, organotins (chemical compounds based on tin with hydrocarbon substituents) and asbestos. If contamination is present and not appropriately controlled, there is the potential for: • Inhalation and/or ingestion risk to site workers and nearby residents of hazardous building materials via dust • Cross contamination associated with the incorrect handling or disposal of	**Moderate** Possible contamination/ excavation activities within the site footprint and within potential contamination distribution range (laterally and vertically – surface work only). Potential contamination distribution unlikely to	**Low – Moderate** Known minor groundwater contamination identified at Yurulbin Park.

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
			spoil/unexpected finds • Excavation activities may mobilise and spread buried contaminants • Accidental leaks and spills during the use of Yurulbin Point construction support site (WHT4) • Erosion and offsite transport of sediment and contamination via overland flow and stormwater runoff, affecting the water quality of Sydney Harbour.	impact upon tunnelling (based on depth to tunnel).	
Sydney Harbour (AEI4) [W5]	Within construction footprint. Above proposed tunnel alignment and within footprint of the Sydney Harbour Cofferdam construction support sites (WHT5 and WHT6).	• Construction support site establishment works • Tunnelling and associated excavation and stockpiling.	Contamination has been reported in sediments present within Sydney Harbour. Contamination is likely to be associated with inputs from the surrounding urbanised catchments, historical operations and the general maritime use within the surrounding area, comprising of heavy metals, hydrocarbons (mainly PAH), pesticides, PCB, PFAS, dioxin, and organotins. If contamination is present and not appropriately controlled, there is the potential for tunnelling activities to mobilise and spread buried contaminants.	**High** Known contamination/ dredging activities within potential contamination distribution range (laterally and vertically).	**Low** Low potential for land contamination migration to groundwater due to coastal location.
Balls Head peninsula	Within construction	• Construction support site	Localised contamination at the wharf associated with the loading and unloading	**Moderate** Possible	**Moderate** Possible land

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
(AEI5) [W6 & W7]	footprint. Above proposed tunnel alignment and adjacent to Berrys Bay construction support site (WHT7).	establishment works • Tunnelling and associated excavation and stockpiling.	of materials (potentially coal) and general maritime activities may be present. Soil and rock located beneath the former bulk fuel storage site may also contain residual heavy metal and hydrocarbon contamination. If contamination is present and not appropriately controlled, there is the potential for tunnelling activities to mobilise and spread buried contaminants.	contamination/ excavation activities within site footprint and within potential contamination distribution range (laterally and vertically – surface work only). Potential contamination distribution unlikely to impact upon tunnelling (based on depth to tunnel).	contamination migration to groundwater due to groundwater depths.
Waverton Park (AEI6) [W8]	Within construction footprint. Above proposed tunnel alignment.	• Tunnelling and associated excavation and stockpiling.	Known contamination (TRH) directly above the tunnel. Contamination likely to be a result of historical infilling and reclamation adjacent the shoreline. Potential for contamination migration towards the tunnel. If significant organic content is present within infill materials, this could generate landfill gas. If contamination is present and not appropriately controlled, there is the	**High** Known contamination/ tunnel below site footprint. Potential for contamination migration to tunnel.	**Moderate** Known land contamination with potential for migration to groundwater.

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
			potential for: • Inhalation and/or ingestion risk to site workers of hazardous building materials via dust • Cross contamination associated with the incorrect handling or disposal of spoil/unexpected finds. • Excavation activities may mobilise and spread buried contaminants.		
Warringah Freeway, North Sydney to Cammeray (AEI7) [W9 – W18]	Within construction footprint. Above proposed tunnel alignment and within the following construction support sites: • Ridge Street north (WHT9) • Berry Street north (WHT8) • Cammeray Golf Course (WHT10 and WFU8) • High Street south	• Construction support site establishment works • Tunnelling and associated excavation and stockpiling • Road works • Bridge works.	Unsealed areas adjacent to Warringah Freeway may be contaminated with lead, hydrocarbons and asbestos as a result of the current and historical deposition of particulates from large volume traffic flows. Additionally, possible filling of the site with materials of unknown quality (fill material potentially contaminated with contaminant compounds including but not limited to heavy metals, hydrocarbons, pesticides, PCBs and asbestos) during construction of the Warringah Freeway may have impacted the site. If contamination is present and not appropriately controlled, there is the potential for: • Inhalation and/or ingestion risk to site workers and nearby residents of hazardous building materials via dust	**Moderate to high** Possible contamination/ excavation activities within site footprint and within potential contamination distribution range (laterally and vertically – surface work only). Potential contamination distribution unlikely to impact upon	**Low** No known groundwater contamination.

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
	(WFU2) • High Street north (WFU3) • Arthur street east (WFU4) • Berry Street east (WFU5) • Ridge Street east (WFU6) • Merlin Street (WFU7) • Rosalind Street east (WFU9).		• Cross contamination associated with the incorrect handling or disposal of spoil/unexpected finds • Excavation activities may mobilise and spread buried contaminants • Accidental leaks and spills during the use of land for construction support sites. • Erosion and offsite transport of sediment and contamination via overland flow and stormwater runoff, affecting the water quality of local waterways entering Sydney Harbour.	tunnelling (based on depth to tunnel).	
Waltham Street, Artarmon (AEI9) [W19]	Within construction footprint. Above proposed tunnel alignment.	• Excavation and stockpiling.	The current and historic use of the Motorway Control Centre site and adjoining properties at Waltham Street in Artarmon may have caused localised contamination associated with the commercial/industrial uses of this area. The presence of groundwater contamination is unknown. If contamination is present and not appropriately controlled, there is the potential for tunnelling activities to mobilise and spread buried contaminants.	**Moderate** Possible contamination/ excavation activities within potential contamination distribution range (laterally and vertically).	**Low** No known groundwater contamination.

Potentially contaminated sites identified in Table 16-9 would be subject to further investigation, with the exception of the Rozelle Rail Yards, where contamination is already well known. All identified contamination risk areas would be managed during construction by the comprehensive environmental management measures detailed in Section 16.7 and in accordance with guidelines made or approved under section 105 of the *Contaminated Land Management Act 1997*.

Structures and/or buildings located within the project footprint may also contain hazardous building materials. A hazardous building materials audit would be carried out prior to the demolition of any structure and/or building. Hazardous building materials (where present) would be managed to reduce the potential for contamination and ensure appropriate handling and waste disposal. Management and handling would be carried out in accordance with Australian Standard (AS 2601-2001) – The demolition of structures.

Chapter 23 (Hazard and risk) provides further details regarding management of dangerous goods and hazardous substances.

16.4.4 Marine contamination

The sediments in Sydney Harbour would potentially pose a high contamination risk due to the contamination associated with historical industrial use (over 150 years) of the harbour and the addition of polluted stormwater runoff originating from adjacent catchments. Contaminated sediments are likely to be disturbed during dredging activities required for the installation of the immersed tube tunnel and piling works to establish construction support site wharf structures at White Bay (WHT3), Yurulbin Point (WHT4) and Berrys Bay (WHT7). Potential impacts as a result of disturbance of contaminated sediment may include contaminant exposure risk to project personnel and marine receptors if not appropriately managed.

Sediments requiring excavation and removal during construction, may be disposed of via:

- Offshore disposal – An application for offshore disposal of suitable dredged material has been submitted to the Commonwealth Department of the Environment and Energy. The appropriateness of offshore disposal would be assessed in accordance with the Commonwealth of Australia National Assessment Guidelines for Dredging (Department of Environment, Water, Heritage and the Arts, 2009). Offshore disposal would only be appropriate for material that meets the requirements outlined in the NADG
- Landfill disposal – Sediments unsuitable for offshore disposal and requiring disposal to landfill would be assessed in accordance with the NSW EPA (2014a) Waste Classification Guidelines.

The dredging methodology has been designed to minimise impacts on the marine environment and is detailed in Chapter 6 (Construction works). This includes the use of a closed environmental bucket to avoid the spread of potentially contaminated material and the use of silt curtains. Specific management measures to avoid adverse impacts to water quality as a result of sediment plumes are described in Chapter 17 (Hydrodynamics and water quality).

16.4.5 Groundwater levels

Groundwater within parts of the study area has the potential to be impacted during the construction phase of the project. The potential impacts that have been identified are:

- Tunnel inflows and associated flooding
- Groundwater level decline (drawdown) including potential for:
  - Saltwater intrusion

– Contaminant migration from contaminated sites
– Activation of acid sulfate soils
– Decline in the groundwater baseflow to surface water features (the groundwater that discharges to a creek or river) (discussed in Chapter 17 (Hydrodynamics and water quality)).

Tunnel inflows

During construction of the crossing of Sydney Harbour, tunnel excavation and construction would occur soon after one another. In general, maximum inflows would occur into the project tunnels when excavation is complete, and measures to mitigate inflows (such as tanked sections, the permanent tunnel lining would include a thicker reinforced concrete lining and waterproofing membrane) have not yet been installed. Greatest inflows are predicted to occur around the harbour crossing before the structure being tanked in late 2022/early 2023 with tanking to take place progressively as the tunnel is developed

Groundwater inflow into the tunnel (ie tunnel inflows) was calculated for each year of construction, as shown in Table 16-10. Peak inflows of 0.48 litres per second per kilometre (L/s/km) averaged over the whole tunnel were predicted to occur in 2022. Tunnel inflows would be highest (0.73 L/s/km) at the south side of Sydney Harbour (Rozelle) in 2022. Total inflows over the construction period would be around 1330 mega litres (ML), with annual inflows during construction peaking at around 272 ML/year in 2022.

As shown in Table 16-10, average inflows for each year of construction would be below the accepted limit of one L/s/km. Planned measures to collect and dispose of tunnel inflows during construction are summarised in Section 16.7.

Table 16-10 Summary of modelled average tunnel inflows during construction

Year	Rozelle to Sydney Harbour inflow (L/s/km)	Sydney Harbour to Warringah Freeway inflow (L/s/km)	Entire project inflow (L/s/km)	Entire project total inflow (ML/day)	Total annual inflows (ML/year)
2021	0.44	0.24	0.34	0.51	186
2022	0.73	0.23	0.48	0.75	272
2023	0.63	0.21	0.42	0.65	239
2024	0.58	0.19	0.39	0.60	220
2025	0.57	0.18	0.38	0.58	213
2026	0.55	0.16	0.36	0.56	203

The long term average annual extraction limit for the Sydney Central Basin is 45,915 ML/year and current groundwater access licences equate to 2592 ML/year, leaving around 43,323 ML/year of unassigned water. The predicted peak annual tunnel inflows would be less than one per cent of the water unassigned under the long term average annual extraction limit for the Sydney Central Basin.

Groundwater level decline (Drawdown)

Groundwater modelling has been used to predict groundwater levels at the end of tunnelling construction (beginning of 2026) and is presented in Figure 16-10.

The degree of drawdown would be dependent on a number of factors including the geology intersected, the hydrogeology and the tunnel configuration and depths.

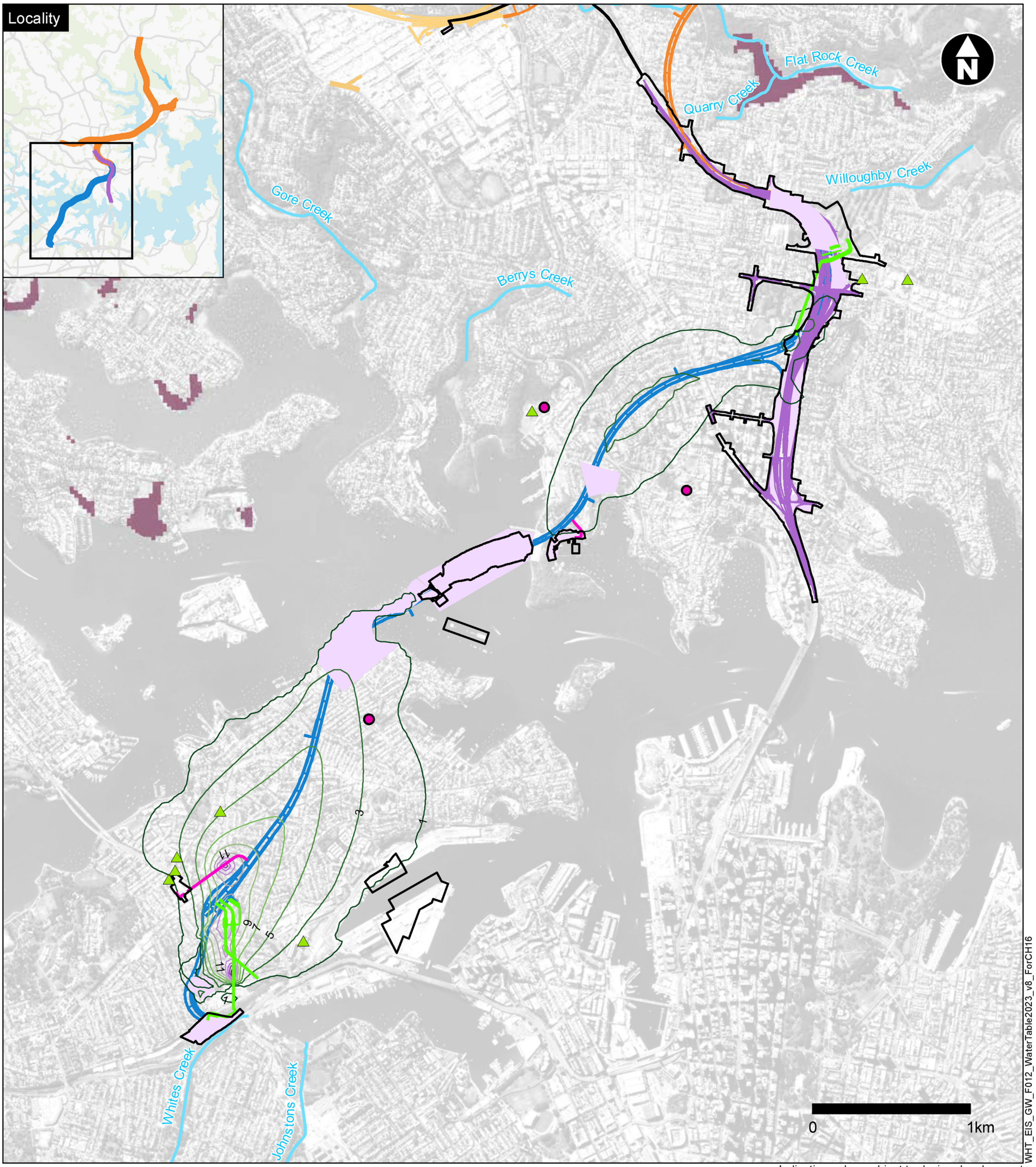
At the end of tunnel construction (beginning of 2026), the maximum drawdown is predicted to be around 20 metres above the Rozelle ventilation tunnels and 15 metres in the vicinity of Victoria Road. Accentuated drawdown of up to 18 metres is also predicted above the Victoria Road access decline. Drawdown propagation is predicted to be limited, with the two metre drawdown contour extending about 650 metres from the tunnel's centreline, largely attenuated by proximity to the harbour. North of the harbour predicted water table drawdown is less, with a maximum drawdown of three metres predicted in Waverton and North Sydney. In the northern area, two metre drawdown contour extends up to about 350 metres from the tunnel centreline. The majority of drawdown would be attributed to ventilation tunnels in Rozelle and access decline from Victoria Road construction support site (WHT2).

A review of current groundwater users has been conducted to identify registered groundwater users within two kilometres of the project footprint (Figure 16-10), which may be potentially impacted by drawdown associated with the construction of the tunnel. There are three existing groundwater bores located in this area that could potentially be impacted.

With respect to the Rozelle/Balmain area, there would be potential impacts to one domestic groundwater (GW109209) bore. This bore is located in Birchgrove, is 4.5 metres deep and situated around 270 metres to the east of the tunnel alignment. Water table drawdown at the bore is predicted to be between two to three metres, which would exceed the minimal impact considerations (as specified in the NSW Aquifer Interference Policy (DIPNR, 2012)). However, based on existing groundwater monitoring bore information, the water table is likely to be 14 metres below the base of this bore. As a result, it is likely that this bore may be accessing a shallow perched groundwater system that may not be connected to the regional water table. The existence and active use of the bore would be confirmed and any loss in yield from the bore would require the implementation of make good provisions as detailed in Section 16.7.

There are two other groundwater bores situated in close proximity to the project alignment that are registered groundwater users (GW108991 and GW107764). Situated in Wollstonecraft and North Sydney respectively, neither of these registered bores are expected to be considerably affected by groundwater drawdown with predicted drawdown rates of less than 1 metre.

There are no groundwater dependant ecosystems or groundwater dependent culturally sensitive sites within the predicted drawdown extents at either the northern or southern tunnel dive structures.



Indicative only – subject to design development

Operational features
- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Ventilation tunnel

Construction
- Construction
- Access decline

Areas of environmental interest
- EPA listed contaminated site
- Moderate to high risk contaminated site

Connecting projects
- Beaches Link
- Gore Hill Freeway

Groundwater features
- Groundwater bore
- Drainage line
- Ecosystems dependent on subsurface groundwater

Water table drawdown
19 m
1 m

Note: Assessment based on the indicative M4-M5 Link (as approved)

Figure 16-10 Groundwater drawdown contours for the project for the end of tunnel construction (2026)

Saltwater intrusion

Aquifers adjacent to the harbour foreshore may experience saltwater intrusion as the hydraulic pressure between the aquifer and the harbour is reduced during drawdown, allowing saltwater to enter the aquifer. The intrusion of saltwater may reduce the beneficial uses of the aquifer for existing users.

Additionally, saltwater intrusion into tunnels has the potential to occur during construction, which would increase saltwater loads requiring management and disposal.

However, groundwater quality impacts due to saltwater intrusion would be unlikely during construction of the project due to the low hydraulic conductivity of the Hawkesbury Sandstone formation and the naturally saline groundwater due to tidal mixing. This includes no anticipated impact to the domestic groundwater bore (GW109209) located in Birchgrove referred to above.

As discussed above, GW109209 is likely to be connected to a shallower perched groundwater system and therefore is unlikely to be affected. If required, make good provisions would be implemented, including provision of alternative water supplies (such as mains water), replacing the bore with a deeper bore, or compensation.

Contaminant migration from contaminated sites

The groundwater model was used to assess the potential groundwater level drawdown at regulated/notified sites and areas of environmental interest, assessed to have a moderate or high risk of existing groundwater contamination within 500 metres of the project alignment. Potential drawdown at contaminated sites is shown in Table 16-11 and is based on the water quality guidelines from the NSW Aquifer Interference Policy (DIPNR, 2012), which states that the beneficial use of a groundwater source 40 metres away from the activity must not be reduced. Drawdown predictions under the ‘project only’ (ie Western Harbour Tunnel and Warringah Freeway Upgrade project in isolation) and ‘cumulative’ (Western Harbour Tunnel and Warringah Freeway Upgrade project and other neighbouring proposed construction projects) scenarios are presented.

Table 16-11 Predicted drawdown at regulated/notified contaminated sites and areas of environmental interest at the end of tunnel construction (2026)

Suburb	Site and address	Predicted drawdown – ‘project only’ (metres)	Predicted drawdown – ‘cumulative’ (metres)
Regulated/notified contaminated sites			
Rozelle	Rozelle – White Bay Power Station – Robert Street	2-3	5-9
Areas of environmental interest			
Rozelle	Rozelle Rail Yards	<1	<1-3
Birchgrove	Yurulbin Park	1-3	1-3
Waverton	Balls Head peninsula	<1	<1
Waverton	Former bulk fuel storage – Balls Head Road	1	1
Waverton	Waverton Park – Woolcott Road	1-2	1-2

The levels of drawdown at regulated/notified contaminated sites and areas of environmental interest during construction would be minor for all sites under consideration for the 'project only' scenario and would not be expected to cause significant migration of contaminants.

Due to the small predicted drawdowns below these sites, contaminant migration into areas of good quality groundwater is unlikely to occur.

Under the 'cumulative' scenario, water table drawdown in areas of environmental interest for contamination around Rozelle would be largely due to the effect of the M4-M5 Link project and indicates that there is a risk of contaminants migrating. The potential for migration would depend on whether or not the contamination reaches the water table, the aquifer permeability at the contaminant location, and the hydraulic gradient at the site. Contaminant migration caused by drawdown from the tunnel may degrade water quality more than 40 metres from the tunnel and does not meet the Level 1 Minimal Impact criteria of the NSW Aquifer Interference Policy. However, there are no groundwater dependant ecosystems, baseflow dependent watercourses or groundwater bores situated between the project alignment and these contaminated sites. The viability of these receptors is not expected to be impacted, which satisfies the Aquifer Interference Policy.

Any migration of contaminants would be towards the tunnel where all water would be collected and treated. Contaminant migration has the potential to impact the integrity of tunnel structures and, where the tunnel would be unlined, the health of people using the underground structures. Given the hydraulic properties of the Hawkesbury Sandstone and the additional dilution that would occur if contaminants are mobilised, the risk of contaminant migration impacting underground structures due to drawdown associated with the project is considered negligible.

Domestic groundwater bore GW109209 is unlikely to be impacted by contaminant migration during construction, as the existing water table is 14 metres below the bottom of the bore, while GW107764 and GW108991 are not situated between the tunnels and any contaminated sites, therefore impacts due to mobilised contamination are not expected.

Management and monitoring measures related to contaminated groundwater where required are detailed in Section 16.7.

Activation of acid sulfate soils

Activation of acid sulfate soil has potential to alter groundwater quality by lowering pH and elevating heavy metal content. Acidic groundwater may impact the integrity of underground structures and the tunnel structure itself. The acidity and associated heavy metal content may also affect the quality of groundwater inflow to the tunnels which would be managed through the wastewater disposal process.

Key areas of acid sulfate soil risk are associated with the sediments beneath Rozelle Rail Yards and Birchgrove Park. Table 16-12 summarises predicted drawdown at these locations. Groundwater drawdown (and associated acid sulfate risk) beneath Sydney Harbour is not applicable due to the constant head of water in the harbour and therefore is not reported below.

Whites Creek is within the drawdown extents but is a lined storm water drain and would not be impacted by groundwater drawdown and the subsequent activation of acid sulfate soils.

Table 16-12 Predicted drawdown in areas of acid sulfate soils at the end of tunnel construction (2026)

Location	Predicted drawdown – project only (metres)	Predicted drawdown – cumulative (metres)
Rozelle Rail Yards	<1	1-15
Birchgrove Park	2-3	2-3

While predicted drawdown at Rozelle Rail Yards and Birchgrove Park indicates a risk of acid sulfate soil activation, mobilisation of heavy metals is not expected to discharge to any surface water features or other groundwater users.

Should soils/sediments in proximity to the Rozelle Rail Yards and Birchgrove Park or within Sydney Harbour (including White Bay and/or Berrys Bay) require excavation to facilitate construction, these sediments would be assessed for the presence of acid sulfate soils prior to excavation. Should acid sulfate soils be identified, an appropriate acid sulfate soils management plan would be developed in accordance in the Acid Sulfate Soil Management Advisory Committee (1998a) guidelines.

There are no groundwater dependent ecosystems, culturally significant sites or groundwater users in the areas of anticipated acid sulfate soils, so these receptors would not be impacted. Poorer quality groundwater may affect the quality of inflows to the tunnels leading a potential human health risk. This risk would be managed through inflow water quality monitoring and the water collection and treatment process.

16.4.6 Groundwater quality

Potential impacts on groundwater quality due to saltwater intrusion, mobilisation of contaminants and potential acidification is discussed in Section 16.5.2.

Activities and materials used during tunnel construction which have the potential to impact groundwater quality in the surrounding aquifer are detailed below:

- Drilling/cutting fluids required for the roadheader
- Particulate material from tunnelling activities leading to an increase in suspended solids
- Cement pollution arising from shotcrete application, grouting or insitu casting of concrete.

These potential contaminant sources are considered low risk. If contamination to groundwater was to occur during tunnel construction, the likelihood of the contaminated groundwater migrating away from the tunnel is considered very low, as the tunnel acts as a drain and groundwater would flow towards it.

The quality of this discharged water during construction is considered in Chapter 17 (Hydrodynamics and water quality). During construction, groundwater inflows would be treated to meet the ANZECC/ARMCANZ (2000) requirements.

16.5 Assessment of potential operational impacts

16.5.1 Spills and leakages

Vehicle or plant and equipment leakages or a vehicle crash may cause spills of oils, lubricants, hydraulic fluids and chemicals during the operation of the project. Spills and leakages within the project footprint have the potential to pollute downstream waterways as a result of being conveyed to waterways via the stormwater network. The severity of the potential impact would depend on the magnitude and/or location of the spill in relation to sensitive receivers, emergency response procedures and/or management measures implemented on site, and the nature of the receiving environment.

Further discussion on accidental spills is included in Chapter 23 (Hazards and risk). Spill control measures, as outlined in Section 16.7, would be implemented to reduce and manage the potential impacts to an acceptable level.

16.5.2 Groundwater levels

Groundwater within parts of the study area has the potential to be impacted during the operation phase of the project. The potential impacts that have been identified are:

- Tunnel inflows
- Groundwater level decline (drawdown) including potential impacts for:
  - Saltwater intrusion
  - Contaminant migration from contaminated sites
  - Activation of acid sulfate soils
  - Decline in groundwater baseflow to surface water features (the groundwater that discharges to a creek or river), discussed in Chapter 17 (Hydrodynamics and water quality).

Tunnel inflows

Inflows during operation were calculated for two time periods – the first year of operation in 2026 and after 100 years of operation (2126) (refer to Table 16-4). Tunnel inflows would diminish over time as the groundwater system reaches equilibrium.

Peak operational inflows of 0.36 L/s/km averaged over the whole tunnel would occur in the first year of operation in 2026. After 100 years of operation, inflows would decline to 0.31 L/s/km. This would be below the limit of one L/s/km threshold, which is consistent with planning approval conditions for similar projects and typical design standards. Annual inflows would be around 203 ML/year in the first year of operation (2026) falling to around 180 ML after 100 years. The predicted peak annual tunnel inflows would be less than one per cent of the water unassigned under the long term average annual extraction limit.

Table 16-13 Summary of modelled average tunnel inflow during operation

Year	Rozelle to Sydney Harbour inflow (L/s/km)	Sydney Harbour to Warringah Freeway inflow (L/s/km)	Entire project inflow (L/s/km)	Entire project total inflow (ML/day)	Total annual inflows (ML/year)
2026	0.55	0.16	0.36	0.56	203
2126	0.49	0.14	0.31	0.49	180

Groundwater Drawdown

Groundwater modelling has been used to predict groundwater levels after around 100 years of operation (2126). Predicted groundwater drawdown at the commencement of operation is the same as that at the end of construction and therefore not reported again here. Please see Table 16-10 for more information.

After 100 years of operation, the magnitude of drawdown would be similar to that at end of construction, with a maximum drawdown of approximately 40 metres in Rozelle. As with the project only scenario, there would be a recovery in water level at the location of the Victoria Road access decline, and a slight propagation of extent of drawdown away from the alignment. North of the harbour there would be a minor increase in the magnitude of drawdown above the alignment, however there would be minor variations in the extent of propagation. As with the end of construction, cumulative drawdown would be dominated by drawdown around the North Sydney Metro Station, and with extended drawdown to the north due to the Beaches Link and Gore Hill Freeway Upgrade project. Predicted drawdown levels and extents are shown in Figure 16-11.

A review of current groundwater users has been conducted to identify registered groundwater users within two kilometres of the project footprint (Figure 16-10), which may be potentially impacted by drawdown associated with the construction of the tunnel.

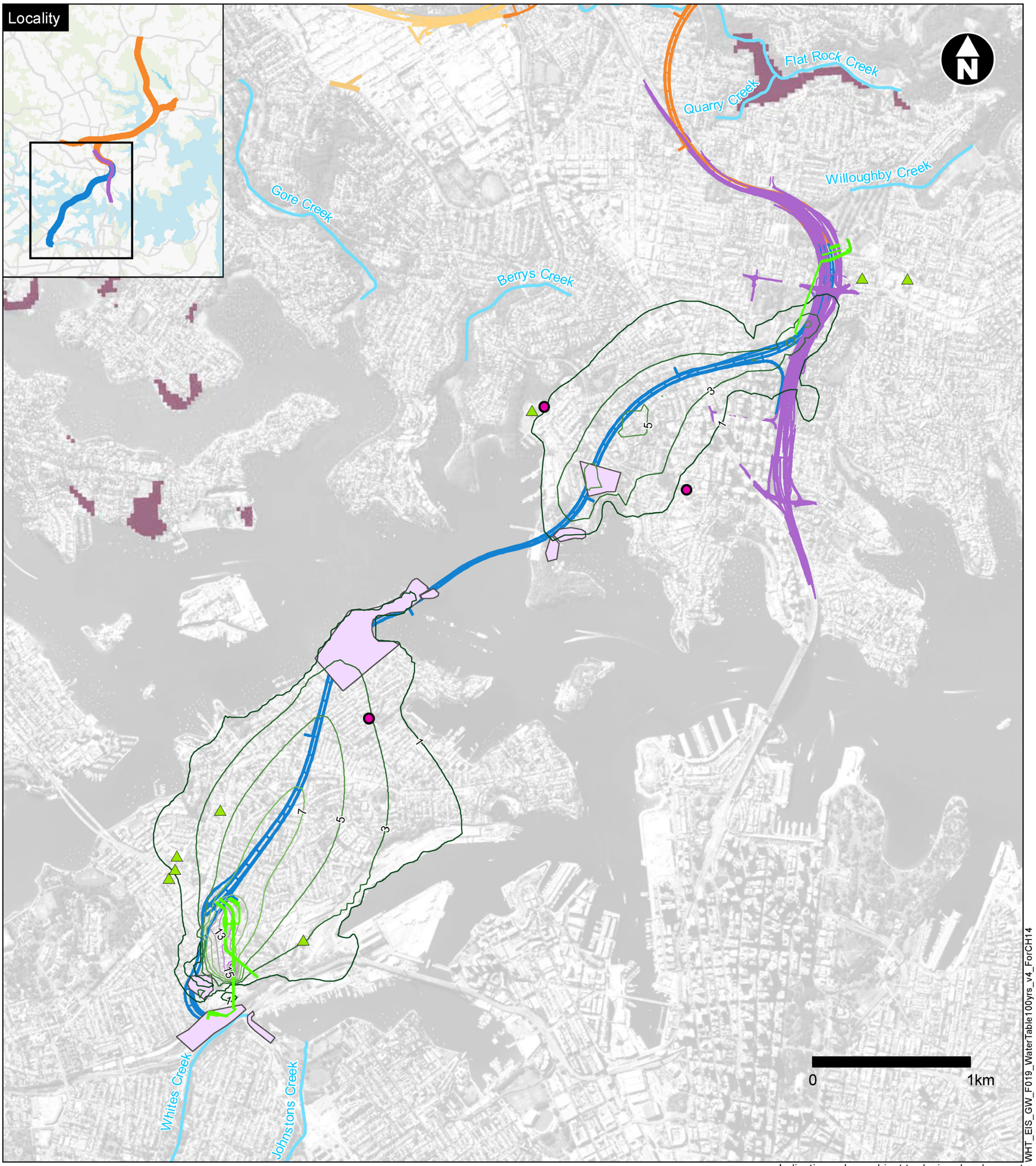
With respect to the Rozelle/Balmain area, there would be potential impacts to one domestic groundwater bore (GW109209) where water table drawdown at the bore is predicted to be up to four metres by 2126, which would exceed the minimal impact considerations (as specified in the NSW Aquifer Interference Policy (DIPNR, 2012)). However, based on existing groundwater monitoring, the water table is likely to be 14 metres below the base of this bore. As a result, it is likely that this bore may be accessing a shallow perched groundwater system that may not be connected to the water table.

In the North Sydney area, there would be potential impacts to the two domestic groundwater bores, GW107764 and GW108991 however such impacts are expected to be less than the minimal impact considerations (as specified in the NSW Aquifer Interference Policy (DIPNR, 2012)) with drawdown of one metre or less.

The existence and active use of the bores would be confirmed and any loss in yield from the bores would require the implementation of make good provisions as detailed in Section 16.7.

There are no registered bores potentially affected by groundwater drawdown at the northern tunnel dive structure.

There are no groundwater dependant ecosystems or groundwater dependent culturally sensitive sites within the predicted drawdown extents at either the northern or southern tunnel dive structure.



Indicative only – subject to design development

Operational features

- Western Harbour Tunnel
- Warringah Freeway Upgrade

Areas of environmental interest

- EPA listed contaminated site
- Moderate to high risk contaminated site

Connecting projects

- Beaches Link
- Gore Hill Freeway Connection
- Ventilation tunnel

Groundwater features

- Groundwater bore
- Drainage line
- Ecosystems dependent on subsurface groundwater

Water table drawdown

13 m

1 m

Note: Assessment based on the indicative M4-M5 Link (as approved)

Figure 16-11 Groundwater drawdown elevations for the project during operation in 2126

Saltwater intrusion

Water table drawdown is predicted to stabilise early in the operational phase of the project due to the harbour acting as a recharge boundary. During the first few years of operation, drawdown would result in groundwater flow inland from the coast and seawater would gradually intrude into the Hawkesbury Sandstone aquifer. At the same time, the fresh water/saltwater interface that is expected to underlie Hawkesbury Sandstone aquifer would rise due to the reduction in pressure caused by the drawdown.

Saltwater intrusions into tunnels may occur during operation, particularly at locations adjacent to Sydney Harbour where the saltwater interface is closer to the surface. Saltwater inflows would slowly increase over time, as drawdown increases and causes greater levels of saltwater intrusion into the aquifer. This would increase saltwater loads requiring management and disposal.

During operation, drawdown at the domestic groundwater bore (GW109209) in Birchgrove is predicted to be up to three metres in 2026 and up to four metres in 2126. Drawdown of up to two metres at bores GW107764 and GW108991 is predicted in 2126, while drawdown of up to one metre is anticipated in 2026. As discussed above the bore in Birchgrove is likely to be connected to a shallower perched groundwater system and therefore is unlikely to be affected by any impact on the regional water table. The bores located in the North Sydney area (GW107764 and GW108991) are predicted to be minor however, make good provisions would be implemented as outlined in Appendix N (Technical working paper: Groundwater).

Contaminant migration from contaminated sites

Predicted drawdown at regulated/notified contaminated sites areas of environmental interest during operation in 2026 (first year of operation) and 2126 (100 years after operation commencement) are shown in Table 16-15.

Table 16-14 Predicted drawdown at contaminated sites during operation in 2026 and 2126

Suburb	Site activity and address	Predicted drawdown – 'project only' in 2026 (metres)	Predicted drawdown – 'project only' in 2126 (metres)	Predicted drawdown – 'cumulative' in 2026 (metres)	Predicted drawdown – 'cumulative' in 2126 (metres)
Regulated/notified contaminated sites					
Rozelle	Rozelle Power Station – Robert Street	2-3	2-3	5-9	7-13
Areas of environmental interest					
Rozelle	Rozelle Rail Yards	<1	<1	1-9	1-9
Birchgrove	Yurulbin Park	1-3	1-3	1-3	1-3
Waverton	Balls Head peninsula	<1	<1	<1	1-3
Waverton	Former bulk fuel storage – Balls	1	1-2	1-2	1-2

Suburb	Site activity and address	Predicted drawdown – 'project only' in 2026 (metres)	Predicted drawdown – 'project only' in 2126 (metres)	Predicted drawdown – 'cumulative' in 2026 (metres)	Predicted drawdown – 'cumulative' in 2126 (metres)
	Head Road				
Waverton	Waverton Park – Woolcott Road	1-2	3-4	1-2	3-5

There is potential for contaminants to migrate and reduce the beneficial uses of groundwater due to drawdowns and increased hydraulic gradients at some areas of environmental interest for contamination, particularly in the cumulative drawdown scenarios. Predicted long term drawdown at areas of environmental interest for contamination around the Rozelle dive structure would be substantial and there would be a risk of contaminants migrating if contaminants have reached the water table. The distance of migration would depend on whether the contamination has reached the water table, the aquifer permeability at the contaminant location, and the hydraulic gradient at the site.

If contamination associated with these sites has reached the water table, then migration caused by drawdown from the tunnel could degrade water quality more than 40 metres from the tunnel, and the Level 1 Minimal Impact criteria of the Aquifer Interference Policy would not be satisfied. However, there are no groundwater dependant ecosystems or baseflow dependent watercourses in the area of drawdown, and the groundwater users (GW107764, GW108991 and GW109209) are not situated between the tunnels and any contaminated sites therefore, impacts due to mobilised contamination are not expected.

Any migration of contaminants would be towards the tunnel where all water would be collected and treated at the Rozelle wastewater treatment plant. Given the hydraulic properties of the Hawkesbury Sandstone and the additional dilution that would occur if contaminants are mobilised, the risk of contaminant migration impacting underground structure due to drawdown associated with the project is considered negligible.

Management and monitoring measures related to contaminated groundwater are detailed in Section 16.7.

Activation of acid sulfate soils

Key areas of acid sulfate soil risk are associated with the sediments beneath Rozelle Railyards and Birchgrove Park. Table 16-15 summarises predicted drawdown at these locations. As already outlined above in respect to construction, groundwater drawdown (and associated acid sulfate risk) beneath Sydney Harbour is not applicable due to the constant head of water in the harbour and therefore is also not reported in Table 16-15 in respect to operation.

Table 16-15 Predicted groundwater drawdown in areas of acid sulfate soils during operation (2026 and 2126)

Location	Predicted drawdown – 'project only' in 2026 (metres)	Predicted drawdown – 'project only' in 2126 (metres)	Predicted drawdown – 'cumulative' in 2026 (metres)	Predicted drawdown – 'cumulative' in 2126 (metres)
Rozelle Rail Yards	<1	<1	1-15	1-15

Location	Predicted drawdown – 'project only' in 2026 (metres)	Predicted drawdown – 'project only' in 2126 (metres)	Predicted drawdown – 'cumulative' in 2026 (metres)	Predicted drawdown – 'cumulative' in 2126 (metres)
Birchgrove Park	2-3	2-3	2-3	2-3

The predicted drawdown at Birchgrove Park and Rozelle Rail Yards (in the cumulative scenario only) indicates there is potential for acid generation and mobilisation of heavy metals. There are no baseflow dependent streams, groundwater users, groundwater dependant ecosystems or culturally significant sites in these areas hence impacts are not expected.

Activation of acid sulfate soils has potential to alter groundwater quality by lowering pH and elevating heavy metal content. There are no groundwater dependant ecosystems, baseflow dependent streams, culturally significant sites or groundwater users in the area of anticipated acid sulfate soils, hence impacts on these matters are not anticipated. However poorer quality groundwater could have implications for the integrity of underground structures and for the tunnel structure itself, due increased acidity. The high acidity and associated heavy metal content would also affect the quality of groundwater inflow to the tunnels which would be managed through the Rozelle wastewater treatment plan treatment and disposal processes.

16.5.3 Groundwater quality

Potential impacts on groundwater quality due to saltwater intrusion, mobilisation of contaminants and potential acidification are discussed in the Section 16.5.2.

The quality of discharged water during operation is considered in Chapter 17 (Hydrodynamics and water quality).

During operation, groundwater collected from drained station excavations and caverns would be transferred to a centralised water treatment plant prior to disposal to stormwater. For operation, the project would be designed to comply with ANZECC (2000) 95 per cent species protection level and a 99 per cent protection level for contaminants that bioaccumulate. Discharge criteria for iron during operation would comply with ANZECC guidelines (ANZECC/ARMCANZ, 2000). The discharge water quality level would be determined in consultation with the NSW Environment Protection Authority; Department of Planning, Industry and Environment (Water) and Sydney Water during further design development, taking into consideration the current water quality of the receiving watercourse.

16.6 Policy compliance

16.6.1 Consistency with minimum harm criteria

The *Water Management Act 2000* includes the concept of ensuring 'no more than minimal harm' for both the granting of water access licences and the granting of approvals. While the project does not require a licence/approval under the *Water Management Act 2000*, the minimal harm criteria in the NSW Aquifer Interference Policy (DIPNR, 2012) have been used for the purposes of assessment (refer to Table 16-16).

Table 16-16 Minimal harm assessment

<table>
<tr><th>Minimal harm criteria</th><th>Assessment</th></tr>
<tr><td colspan="2">Water table</td></tr>
<tr><td>Level 1
Less than or equal to 10 per cent cumulative variation in the water table, allowing for typical climatic “post water sharing plan” variations, 40 metres from any:
• high priority groundwater dependent ecosystem; or
• high priority culturally significant site listed in the schedule of the relevant water sharing plan.
A maximum of a two metre decline cumulatively at any water supply work.</td><td>Schedule 4 of the Water Sharing Plan for the greater Metropolitan Region Groundwater Sources 2011 identifies that within the Hawkesbury Sandstone and Ashfield Shale there are:
• No listed high priority groundwater dependent ecosystems (refer to Section 16.3.4)
• No listed high priority culturally significant sites (refer to Section 16.4.5).
Groundwater modelling has predicted that water table drawdown at bores GW109209 and GW107764 would exceed two metres. Impact minimisation measures are discussed below.</td></tr>
<tr><td>Level 2
If more than 10 per cent cumulative variation in the water table, allowing for typical climatic “post water sharing plan” variations, 40 metres from any:
• High priority groundwater dependent ecosystem; or
• High priority culturally significant site listed in the schedule of the relevant water sharing plan if appropriate studies demonstrate to the Minister’s satisfaction that the variation will not prevent the long term viability of the dependent ecosystem or significant site.
If more than a two metre decline cumulatively at any water supply work then make good provisions should apply.</td><td>Water table drawdown is predicted to be up to four metres at bore GW109209 and up to two metres at bores GW108991 and GW107764.
The approach to ‘make good’ the predicted impacts would be to first confirm whether the bores still exist and are in a usable condition, and if so, to carry out monitoring and/or further modelling. If impacts are realised, then ‘make good’ options would be discussed with the owner. Make good provisions would include provision of alternative water supplies (such as mains water), replacing the bore with a deeper bore, or compensation for additional pumping costs.</td></tr>
<tr><td colspan="2">Water pressure</td></tr>
<tr><td>Level 1
A cumulative pressure head decline of not more than a two metre decline, at any water supply work.</td><td>Investigation and mitigation measures to address impacts at bores GW109209, GW108991 and GW107764 have been proposed.</td></tr>
<tr><td>Level 2
If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister’s satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.</td><td>The current viability of the bores is uncertain but if it is proven, monitoring will be carried out and if impacts are realised, the make good provisions will be applied to either maintain the long term viability of the bores or to provide an alternative access or compensation.</td></tr>
</table>

Minimal harm criteria	Assessment
Water quality	
Level 1 Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	Impacts to groundwater quality associated with the project would be minor, and as the tunnel inflows create a hydraulic gradient towards the tunnel, any contamination mobilised or caused by the works would flow towards the tunnel rather than away from it. Contaminants associated with the project would therefore remain within 40m of the tunnel. Drawdown caused by the project may cause contamination of groundwater more than 40m away from the tunnel due to: • Inland migration of the saline interface • Migration of contaminated groundwater from existing contaminated sites into areas of fresher groundwater • Potential activation of acid sulfate soils. These processes mean that this requirement of the Aquifer Interference Policy would not be satisfied. Impact minimisation measures are discussed below.
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.	Intrusion of saline water from the coast into fresher groundwater, and migration of already contaminated groundwater, will not impact the long term viability of dependent ecosystems or significant sites. If impacted, bores GW109209, GW108991 and GW107764 would be affected by reduced yields before any groundwater quality impacts occur. The make good provisions discussed above would be implemented to provide an alternative water source or compensate the user.
Additional Considerations	
… any advice provided to a gateway panel, the Planning and Assessment Commission or the Minister for Planning and Public Spaces on a State significant development or State significant infrastructure will also consider the potential for: Acidity issues to arise, for example exposure of acid sulfate soils; Water logging or water table rise to occur, which could potentially affect land use, groundwater dependent ecosystems and other aquifer interference activities. Specific limits will be determined on a case by case basis, depending on the sensitivity of the surrounding land and groundwater dependent ecosystems to waterlogging and other aquifer interference activities to water intrusion.	The level of predicted drawdown is sufficient to cause activation of acid sulfate soils if present. No work has been carried out so far to identify and test the acid generating potential of soil and rock in the project area. If acid sulfate soils are identified, measures to mitigate impacts would be needed. There is no risk of water logging or water table rise since the tunnel will be drained during both construction and operation. The only tanked structures will be a short distance either side of the harbour. Waterlogging or damming of groundwater flow would not occur since the hydraulic gradient by that time would cause flow towards the drained sections of the tunnel around Rozelle/Balmain in the south, and Waverton in the north.

16.6.2 Consistency with Water Sharing Plan rules

All groundwater and surface water in the project area is managed through the Greater Metropolitan Region Water Sharing Plan. The Greater Metropolitan Region Water Sharing Plan provides rules to manage and allocate the groundwater resource, including specific rules on taking groundwater near high priority groundwater dependant ecosystems, groundwater dependent culturally significant sites, sensitive environmental areas, and near other licenced bores. The groundwater source relevant to the project is the 'Sydney Basin Central'. While the project does not require a licence and/or approval under the *Water Management Act 2000*, these rules have been used for the purposes of assessment (refer to Table 16-17).

Table 16-17 Compliance with water sharing plan (WSP) rules

WSP rule	Assessment
Part 7 – Rules for granting access licences Part 8 – Rules for managing access licences	Transport for NSW is exempt from the requirement to hold a licence for the take of water during construction and operation of major projects as specified in Schedule 4, Part 1, clause 2 of the Water Management (General) Regulation 2011. *The Water Management Act 2000* requires that road authorities obtain a water supply work approval for groundwater ingress to tunnels. The inflow volume of up to 392 ML/year during construction, and up to 321 ML/year during operation need to be assigned under the long term average annual extraction limit (LTAAEL).
Part 9 – 39: Distance restrictions to minimise interference between supply works	The approval process would determine distance restrictions to minimise interference between water supply works. There are three bores (GW109209, GW108991 and GW107764) that may be impacted by drawdown, and if viable, make good provisions would be applied to maintain access.
Distance restriction from the property boundary is 50 metres	The project is within 50 metres of property boundaries and would result in drawdown at nearby properties. This is considered acceptable as the tunnels are predominantly at depth below properties and there is a reticulated water supply to those properties. The project would therefore not impact water supply to nearby properties. Up to 40 millimetres of surface settlement may occur at properties within 50 metres of the project, which may result in aesthetic damage to buildings.
Distance restriction from an approved water supply work is 100 metres	There are no approved water supply works within 100 metres of the project. Domestic supply bore GW109209, GW108991 and bore GW107764 are within the area of drawdown, but make good provisions would apply, as discussed above.
Distance restriction from a Department observation bore is 200 metres	The Department of Planning, Industry and Environment (Regions, Industry, Agriculture & Resources) does not have any observation bores within 200 metres of the project, or within the area of drawdown surrounding the Project.

WSP rule	Assessment
Distance restriction from an approved work nominated by another access license is 400 metres	There are no approved works nominated by another access licence within 400 metres of the project.
Distance restriction from an approved water supply work nominated by a local water utility or major utility access licence is 1000 metres	There are no water supply works nominated by water utilities within 1000 metres of the project, or within the area of drawdown surrounding the project.
Part 9 – 40 Rules for water supply works located near contaminated sources	In addition to the moderate to high risk areas of environmental interest for contamination identified within the *Technical working paper: Contamination,* the EPA notified contaminated sites have been identified within the area of predicted drawdown around the project which are captured under the description of contaminated sites in Schedule 3 of the WSP. A water supply works approval must not be granted within: • 250 metres of contaminant plumes associated with these sites • 250-500 metres of these sites as long as no drawdown will occur within 250 metres of the contaminant plume • At a specified distance more than 500 metres of a contaminant plume if needed to protect the water source and users. The presence of contaminant plumes at these sites has not been assessed. However, the risk of groundwater contamination has been assessed and is considered to be low. Approval can be granted for water supply works within the specified distance of contaminated sites as long as the water source, dependent ecosystems, and public health and safety are not threatened. There is no risk to groundwater dependant ecosystems or groundwater users as they are not present in the area of drawdown, with the possible exception of bores GW109209, GW108991 and GW107764, as discussed above.
Part 9 – 41 Rules for water supply works located near sensitive environmental areas	The project is outside the required distance for the following sensitive environmental areas: 1. 200 metres of a high priority groundwater dependent ecosystem 2. 500 metres of a karst groundwater dependent ecosystem 3. 40 metres from a lagoon or escarpment. The project is within 40 metres of a first/second order stream (Whites Creek), but as it is more than 30 metres deep and within the underlying parent material it satisfies the requirements of the WSP.
Part 9 – 42 Rules for water supply works located near groundwater dependent culturally significant sites	There are no groundwater dependent culturally significant sites in the area of drawdown surrounding the project.
Part 9 – 44 Rules for water supply works located within	As the potential supply bores GW109209, GW108991 and GW107764 and the contaminated sites are within restricted distances, the proponent must not take more water than specified

WSP rule	Assessment
distance restrictions	in the water access licence. Although Transport for NSW is exempt from having to hold a water access licence, Ministerial approval may still specify an allowable extraction volume (or inflow rates) for the project to protect the bore user and avoid contaminant migration.
Part 10 – Access dealing rules	Refer to Part 7 response.

16.7 Environmental management measures

Environmental management measures relating to geology, soils and groundwater impacts are outlined in Table 16-18.

Table 16-18 Environmental management measures for geology, soils and groundwater impacts

Ref	Phase	Impact	Environmental management measure	Location
SG1	Design	Ground movement impacts	Detailed predictive settlement models will be developed for areas of concern to guide tunnel design and construction methodology, including the selection of options to minimise settlement where required.	WHT/WFU
SG2	Pre-construction	Impact to registered groundwater bores	The viability of domestic bores GW109209, GW107764 and GW108991 will be confirmed prior to construction. If drawdown at the bores exceeds two metres (in accordance with the Aquifer Interference Policy), measures will be taken to 'make good' the impact by restoring the water supply to pre development levels. The measures taken will be dependent upon the location of the impacted bores and will be determined in consultation with the affected licence holder but could include, deepening the bore, providing a new bore or providing an alternative water supply.	WHT
SG3	Pre-construction	Ground movement impacts	An Independent Property Impact Assessment Panel, comprising geotechnical and engineering experts, will be established prior to the commencement of works to independently verify building condition survey reports, resolve any property damage disputes and establish ongoing settlement monitoring	WHT/WFU

Ref	Phase	Impact	Environmental management measure	Location
			requirements.	
SG4	Pre-construction	Ground movement impacts	Building/structure condition surveys will be prepared for properties (and heritage assets) within the zone of influence of tunnel settlement (for example within the 5 millimetre predicted surface settlement contour and within 50 metres of surface works) prior to the commencement of construction.	WHT/WFU
SG5	Construction	Erosion and sedimentation	Erosion and sediment measures will be implemented at all work sites in accordance with the principles and requirements in *Managing Urban Stormwater – Soils and Construction, Volume 1* (Landcom, 2004) and *Volume 2D* (NSW Department of Environment and Climate Change, 2008), commonly referred to as the 'Blue Book'.	WHT/WFU
SG6	Construction	Impacts on site workers and/or local community through disturbance and mobilisation of contaminated material	Potentially contaminated areas directly affected by the project will be investigated and managed in accordance with the requirements of guidance endorsed under section 105 of the *Contaminated Land Management Act 2008*. This includes, but is not limited to, further investigations in potential areas of environment interest in the project footprint, including: • Easton Park • Birchgrove peninsula (including Yurulbin Park) • Balls Head peninsula • Waverton Park • Warringah Freeway (from North Sydney to Cammeray). Subject to the outcomes of the investigations, a Remediation Action Plan will be implemented in the event that site remediation is warranted prior to construction. The Remediation Action Plan will be prepared and implemented in accordance with Managing Land Contamination: Planning Guidelines SEPP 55 – Remediation of Land	WHT/WFU

Ref	Phase	Impact	Environmental management measure	Location
			(Department of Urban Affairs and Planning and EPA, 1998). An independent NSW EPA Accredited site Auditor will be engaged to review all contamination reports and evaluate the suitability of sites for a specified use as part of the project.	
SG7	Construction	Impacts on site workers and/or local community through disturbance and mobilisation of contaminated material	Any soil/fill materials surplus to construction will be classified in accordance with the NSW EPA (2014a) *Waste Classification Guidelines*.	WHT/WFU
SG8	Construction	Impacts on site workers and/or local community through disturbance and mobilisation of contaminated material	Asbestos handling and management will be carried out in accordance with relevant legislation, codes of practice and Australian standards.	WHT/WFU
SG9	Construction	Impacts on site workers and/or local community through disturbance and mobilisation of contaminated material	A hazardous materials assessment will be carried out prior to and during the demolition of buildings. Demolition works will be carried out in accordance with the relevant Australian Standards and relevant NSW WorkCover Codes of Practice, including the NSW Work Health and Safety Regulation 2011.	WHT/WFU
SG10	Construction	Impacts on site workers and/or local community through disturbance and mobilisation of contaminated material	The Construction Waste Management Plan for the project will include procedures for handling and storing potentially contaminated substances.	WHT/WFU
SG11	Construction	Impacts on site workers and/or local community through disturbance and mobilisation of contaminated material	The discovery of previously unidentified contaminated material will be managed in accordance with an unexpected contaminated lands discovery procedure, as outlined in the *Guideline for the Management of Contamination* (Roads and Maritime, 2013a).	WHT/WFU

Ref	Phase	Impact	Environmental management measure	Location
SG12	Construction	Impacts from disturbance of acid sulfate soils	Prior to ground disturbance in high risk acid sulfate areas at Birchgrove Park, Rozelle Rail Yards, Sydney Harbour (tunnel crossing, White Bay and Berrys Bay) and Whites Creek, testing will be carried out to determine the presence of acid sulfate soils. If acid sulfate soils are encountered, they will be managed in accordance with the *Acid Sulfate Soil Manual* (Acid Sulfate Soil Management Advisory Committee, 1998b).	WHT
SG13	Construction	Ground gas impacts	Ground gas investigations will be carried out in Easton Park, Rozelle Rail Yards and Waverton Park to assess for the potential presence landfill generated gas which could impact on the construction and/or operation of the project. Ground gas investigations will be carried out in accordance (where applicable) with the *Guideline for the Assessment and Management of Sites Impacted by Hazardous Ground Gases* (NSW EPA, 2012b).	WHT
SG14	Construction	Groundwater drawdown during construction	Where groundwater inflows exceed 1L/sec/km during construction, feasible and reasonable measures to manage inflow will be applied.	WHT
SG15	Construction	Marine contamination impacts	The appropriateness of offshore disposal will be assessed in accordance with the Department of the Environment, Water, Heritage and the Arts' *National Assessment Guidelines for Dredging* (Department of Environment, Water, Heritage and the Arts, 2009). Offshore disposal will only be appropriate for material that meets the NADG criteria.	WHT
SG16	Construction	Marine contamination impacts	Marine sediments requiring disposal to landfill will be assessed in accordance with the NSW EPA (2014a) *Waste Classification Guidelines*.	WHT

Ref	Phase	Impact	Environmental management measure	Location
SG17	All phases	Groundwater drawdown	Outcomes of updated groundwater modelling will identify any requirements for further groundwater monitoring, and management of groundwater drawdown and associated impacts.	WHT/WFU
SG18	Pre-construction and pre-operation	Groundwater drawdown	As more information becomes available through ongoing groundwater monitoring, groundwater modelling will be updated. Construction and operational inflow predictions will be updated prior to construction, and operational inflow and impact predictions will be updated at the end of the construction period.	WHT/WFU
SG19	Construction and operation	Groundwater drawdown	The existing groundwater monitoring program will be continued through construction and onto the operational phase.	WHT/WFU
SG20	Construction and operation	Groundwater drawdown	A groundwater quality monitoring program will be developed and implemented, taking into consideration the location of areas subject to medium and high risk of groundwater contamination during construction and operation. Where relevant, modelling/mass balance analysis will be carried out to assess potential impacts on beneficial aquifer use and the likely quality of groundwater inflows.	WHT/WFU
SG21	Construction and operation	Groundwater drawdown	If the groundwater quality monitoring and associated analysis identifies potential impacts to beneficial aquifer use from the migration of contaminated groundwater, or the quality of groundwater tunnel inflows, feasible and reasonable management measures will be identified and implemented.	WHT/WFU
SG22	Construction and operation	Groundwater modelling update	As more information becomes available through ongoing groundwater monitoring, groundwater modelling will be updated to refine the predictions documented in this technical working paper. Inflow predictions will be updated during	WHT/WFU

Ref	Phase	Impact	Environmental management measure	Location
			further design development and operational inflow and impacts predictions will be updated at the end of the construction period. If refined predictions indicate that groundwater inflows and water table drawdown will be greater than the impacts documented in this this technical working paper, feasible and reasonable measures will be implemented.	
SG23	Construction and operation	Contamination due to leakage or spills and accidental spills during operation	Emergency Spill measures will be developed to avoid and manage accidental spillages of fuels, chemicals, and fluids to minimise the risk of human health impacts and contamination of groundwater.	WHT/WFU

WHT = Western Harbour Tunnel, WFU = Warringah Freeway Upgrade.

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