NSW GOVERNMENT

Transport for NSW

Beaches Link and Gore Hill Freeway Connection

Chapter 16

Geology, soils and groundwater

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16 Geology, soils and groundwater

This chapter outlines the potential geology, soils and groundwater impacts associated with the project and identifies measures which address these impacts. The impacts associated with the discharge of treated groundwater are detailed in Chapter 17 (Hydrodynamics and water quality).

Assessment of contamination and groundwater impacts 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.

Avoiding or minimising impacts has been a key consideration throughout the design and development process for the Beaches Link and Gore Hill Freeway Connection project. A conservative approach has generally been used in the assessments, with potential impacts presented before implementation of environmental management measures. The environmental management measures proposed to minimise the potential impacts in relation 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 and contamination	
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 **Sections 16.4.1** and **Section 16.5.2**. Management measures to minimise these impacts are outlined in **Section 16.7**. More specific details with respect to acid sulfate soil risk are provided in **Appendix M** (Technical working paper: Contamination) and risk of acid sulfate soil activation due to groundwater drawdown in **Appendix N** (Technical working paper: Groundwater).

Secretary's requirement	Where addressed in the EIS
3. The Proponent must assess whether the land and harbour sediment are 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.	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). Further details of the assessment of contamination risk and the management of contamination are provided in **Appendix M** (Technical working paper: Contamination).
4. Where assessment and/or remediation is required, the Proponent must document how the assessment and/or remediation would be undertaken in accordance with current guidelines.	**Section 16.4.3** provides an outline of the risk of contamination identified in the assessment and an assessment of potential contamination risk. **Section 16.7** documents the assessment and remediation process that would be followed for the management of potential contamination risk. Further details of the assessment of contamination risk and the management of contamination are provided in **Appendix M** (Technical working paper: Contamination).
5. Where contaminated spoil and/or sediments are to be handled, 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**, **Section 16.4.3** and **Chapter 24** (Resource use and waste management) provide details on the likely contamination characteristics of spoil and how contaminated spoil will likely be managed. **Section 16.7** and **Chapter 24** (Resource use and waste management) provides the environmental management measures proposed to manage the spoil to avoid adverse impacts to land and water quality.
6. 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**.
7. 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**.

Secretary's requirement	Where addressed in the EIS
8. 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**.
9. 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 **Sections 16.4** and **Section 16.5.2**.
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 *Framework for Biodiversity Assessment – NSW Biodiversity Offsets Policy for Major Projects* (Office of Environment and Heritage, 2014).	**Section 16.3.4** and **Figure 16-6** present the hydrological regime for groundwater. **Chapter 17** (Hydrodynamics and water quality), details surface water resources likely to be impacted by the project is presented in **Section 17.3**. **Sections 16.3.4**, **16.4.5** and **16.5.2** discuss groundwater dependent ecosystems that are to be potentially impacted by the project. **Chapter 19** (Biodiversity) provides consideration of 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 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),	**Section 16.4** describes potential construction impacts to groundwater and **Section 16.5** describes potential operational impacts to groundwater. Details of the modelling undertaken to assess impacts to groundwater are presented in Annexure F of Appendix N (Technical working paper: Groundwater). **Chapter 17** (Hydrodynamics and water quality) includes detail on surface water hydrological impacts and impacts on natural processes. Potential hydrological impacts and impacts on natural processes are included in **Chapter 18** (Flooding).

Secretary's requirement	Where addressed in the EIS
aquatic connectivity, water dependent fauna and flora and access to habitat for spawning and refuge;	**Chapter 19** (Biodiversity) assesses potential 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;	Potential groundwater hydrological impacts are included in **Section 16.4** and **Section 16.5**. The potential for settlement is discussed in **Section 16.4.2**. Potential 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;	Potential changes to environmental water availability and flows, including to the storage dam at Cammeray Golf Course, 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 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; and	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).

Secretary's requirement	Where addressed in the EIS
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, are 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 groundwater 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 construction and 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**, respectively.
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* (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 and/or consideration of the following contamination legislation, policies and guidelines:

- *Contaminated Land Management Act 1997*
- *Acid Sulfate Soils Assessment Guidelines* (Ahern, Stone and Blunden, 1998)
- *Acid Sulfate Soils Manual* (Acid Sulfate Soils Management Advisory Committee (ASSMAC), 1998)
- *PFAS National Environmental Management Plan Version 2.0* (Heads of EPAs Australia and New Zealand (HEPA), 2020)

- *Managing Land Contamination: Planning Guidelines SEPP 55 – Remediation of Land* (Department of Urban Affairs and Planning and Environmental Protection Authority, 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, 2015a)
- *NSW Aquifer Interference Policy* (NSW DPI, 2012a)
- *NSW Sustainable Design Guidelines Version 4.0* (Transport for NSW, 2017)
- *Risk assessment guidelines for groundwater dependent ecosystems* (Office of Water, 2012b)
- *Guidelines for controlled activities on waterfront land – Riparian corridors* (NSW Department of Industry, 2018)
- Other guidelines made or approved under section 105 of the *Contaminated Land Management Act 1997*
- *High and Low Interim Sediment Quality Guidelines* (ISQG), that form a part of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018)
- *National Assessment Guidelines for Dredging* (NAGD) (Department of Environment, Water, Heritage and the Arts, 2009).

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* (NSW DPI, 2012a)
- *Rules of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources* (NSW DPI, 2011a).

16.2 Assessment methodology

The methodology for the assessment 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 (now M8) (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 alignment rises from an elevation of about 65 metres Australian Height Datum (AHD) at the southern extent of the project at Cammeray and undulates towards Middle Harbour. The depth of the harbour in the vicinity of the crossing is approximately 32 metres below sea level. Once the project crosses Middle Harbour the topography has a steep incline up to the ridge line at North Balgowlah, before resuming a moderate incline towards Frenchs Forest, reaching an elevation of about 150 metres AHD at Warringah Road at the northern extent of the project.

Middle Harbour is a sub catchment of Sydney Harbour. 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 (Hedge et al., 2013). The Middle Harbour crossing would occur in areas underlain by estuarine, marine and alluvial sediments overlying Hawkesbury Sandstone. The deepest sediments along the alignment are anticipated along a buried palaeovalley where they are predicted to be about 32 metres deep between Northbridge and Seaforth.

16.3.2 Geology

The Sydney 1:100,000 Geological Series Sheet 9130 (NSW Department of Mineral Resources, 1983) indicated 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) present in the southern and western portion of the project area, around Cammeray, Naremburn, Artarmon, Willoughby and Northbridge. 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. In addition, areas of disturbed ground (manmade fill (mf)) are mapped within Bicentennial Reserve Baseball Diamond and Flat Rock Reserve.

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

Table 16-2 Geological units underlying the project area

Unit	Description
Hawkesbury Sandstone (Rh)	Medium to coarse grained, quartzose sandstone. A combination of highly cross bedded and massive sandstone units with interbedded siltstone.
Ashfield Shale (Rwa)	Consists of four variable thickness sub units of siltstone and laminate.
Mittagong Formation (Rm)	Consists of fine grained sandstone and inter-bedded sandstone/siltstone.
Manmade fill (mf)	Typically comprising waste, emplaced material and engineered fill.

Geological structural features

The solid geology within the study area is cross cut by a number of volcanic structural features that may impact groundwater flow. This includes 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, along with an associated parallel trending joint swarm mapped at Willoughby Creek, is inferred to intersect the alignment at Middle Harbour.

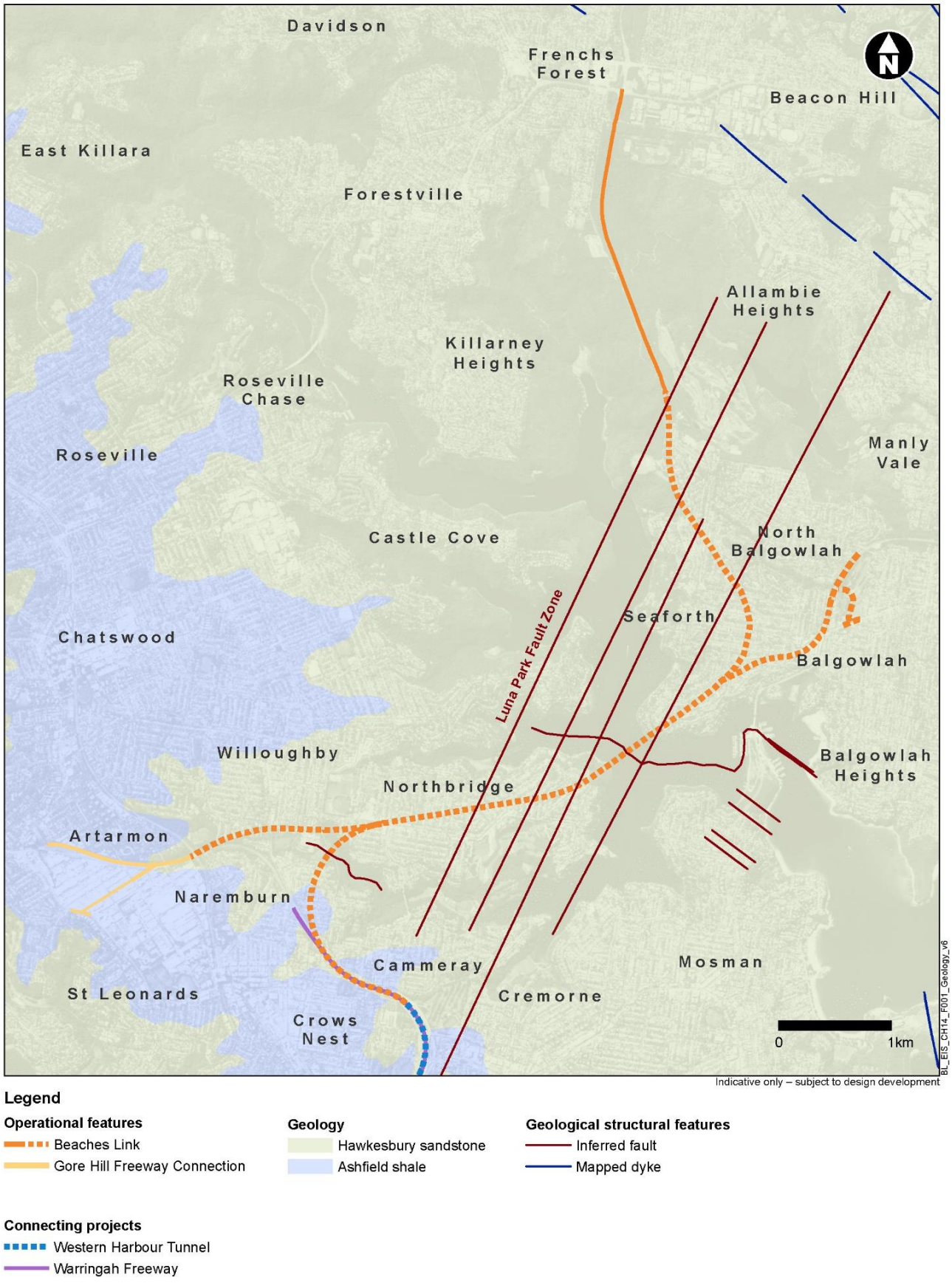


Figure 16-1 Regional geological context

16.3.3 Soils

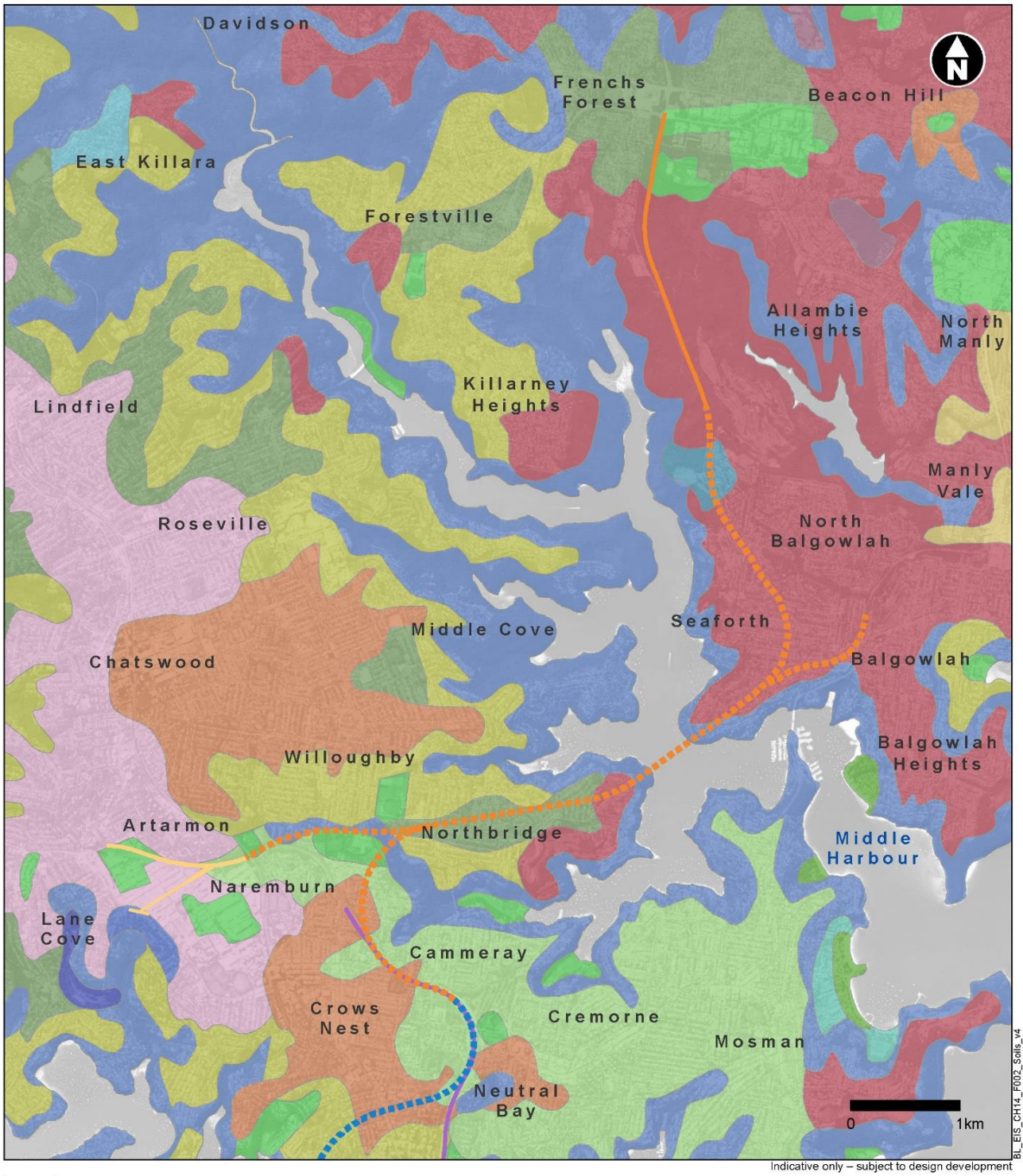
Soil groups and erosion potential

The Sydney 1:100,000 Soil Landscape Series Sheet 9130 (Chapman and Murphy, 1989) indicates that the residual soils within the project area includes the Blacktown (bt), Disturbed (xx), Hawkesbury (ha), Gymea (gy), Lucas Heights (lh), Lambert (la), Somersby (so) and Glenorie (gn) landscape groups. The majority of the project area is underlain by the Gymea landscape group with the Hawkesbury landscape group surrounding the shorelines. 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 hard-setting 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, and 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. Manmade fill 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 and 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.
Glenorie (gn)	**Landscape** – low rolling and steep hills. Local relief 50 to 120 metres, slopes five to 20 per cent. Convex narrow (20 to 300 metres) ridges and hillcrests grade into moderately inclined side slopes with narrow concave drainage lines. Moderately inclined slopes of 10 to 15 per cent are the dominant landform elements. **Soils** – shallow to moderately deep (less than 100 centimetres) red, brown and yellow podzolic soils on crests and slopes. Siliceous sands, leached sands and humic gleys on shale lenses and along drainage lines. **Limitations** – high soil erosion hazard, localised impermeable highly plastic, moderately reactive.

Soil landscape	Description
Gymea (gy)	**Landscape** – found on undulating to rolling low hills on Hawkesbury Sandstone with local reliefs of 20 to 80 metres and 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 low soil fertility.
Lucas Heights (lh)	**Landscape** – characterised by gently undulating crests and ridges on plateau surfaces of the Mittagong formation (alternating bands of shale and fine grained sandstones). Local relief to 30 metres, slopes less than 10 per cent. Rock outcrops are absent. Extensively or completely cleared, with dry sclerophyll low forest and woodland. **Soils** – soils are moderately deep (50 to 150 centimetres), hardsetting yellow podzolic soils and yellow soloths, yellow earths on the outer edges. **Limitations** – stony soil, with low soil fertility and low available water capacity.
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, and 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.
Somersby (so)	**Landscape** – characterised by gently undulating to rolling rises on deeply weathered Hawkesbury Sandstone plateau. Local relief up to 40 metres with slopes below 15 per cent grade. Rock outcrops are absent. Crests are broad and convex, and valleys are narrow and concave. Vegetation includes extensively cleared low open woodland and scrubland. **Soils** – soils are moderately deep to deep (100 to 300 centimetres), with red earths and yellow earths overlying laterite gravels and clays on crests and upper slopes; yellow earths and earthy sands occur on mid slopes; grey earths, leached sands and siliceous sands on lower slopes and drainage lines; gleyed podzolic soils in low lying poorly drained areas. **Limitations** – Somersby soils have localised, permanently high water tables, areas of laterite, and stony soil. The soils have very low soil fertility and are highly permeable.



Legend

Operational features
- Beaches Link
- Gore Hill Freeway Connection

Connecting projects
- Western Harbour Tunnel
- Warringah Freeway

Soil landscape
- Blacktown
- Deep Creek
- Disturbed terrain
- Faulconbridge
- Glenorie
- Gymea
- Gymea/Lambert
- Hawkesbury
- Lambert
- Lucas Heights
- Newport
- Oxford Falls
- Somersby
- Warriewood
- West Pennant Hills
- Woy Woy

Figure 16-2 Soil landscapes

Marine sediments

Sediments infilling Middle Harbour comprise Pleistocene and Holocene age alluvial, colluvial, estuarine and marine deposits to about 30 metres thick. 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 Middle Harbour along the proposed harbour crossing is shown in Figure 16-3.

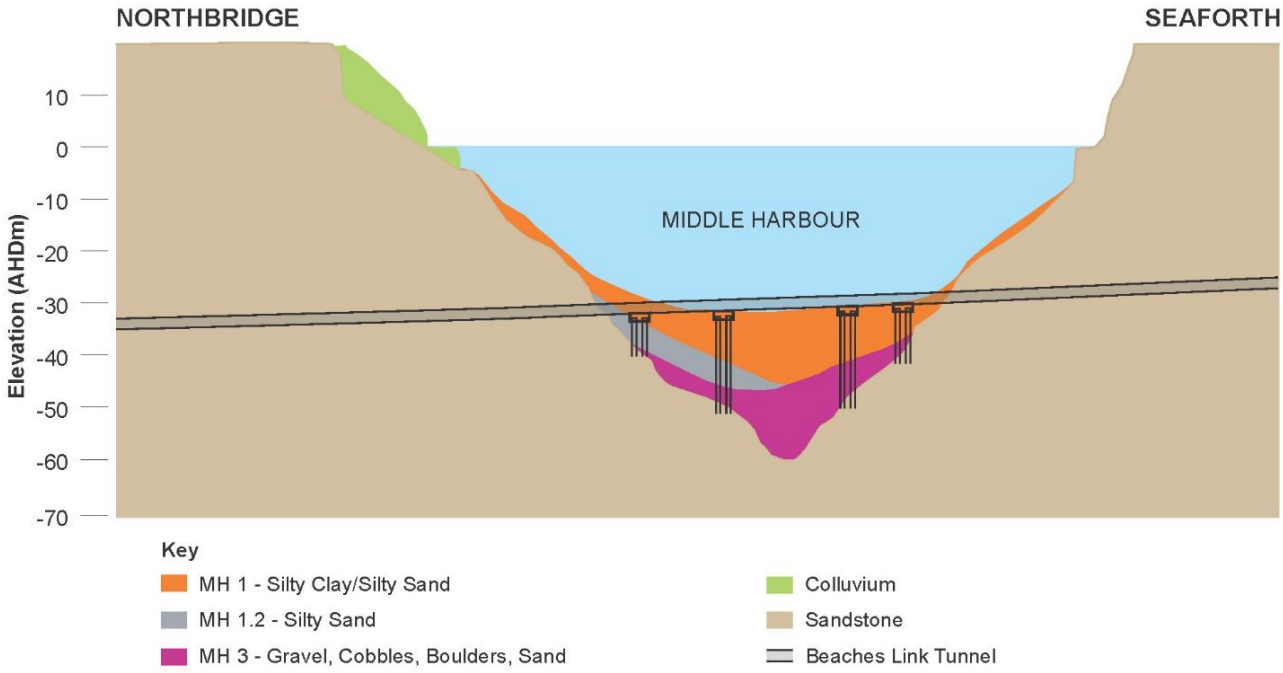


Figure 16-3 Middle Harbour marine sediment and geology profile

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 ascertain the probability of acid sulfate soil being present across the project area. Based on this information, the generalised acid sulfate soil probability across the project area has been assessed as follows:

- Cammeray to Naremburn – (B4) low probability/very low confidence
- Naremburn to Northbridge – (C4) extremely low probability/very low confidence
- Middle Harbour – (A4) high probability/confidence unknown
- Seaforth to Balgowlah – (C4) extremely low probability/very low confidence
- North Balgowlah to Frenchs Forest – (C4) extremely low probability/very low confidence
- Artarmon to Naremburn – (B4) low probability/very low confidence

A review of the acid sulfate soil risk maps from *the Willoughby Local Environmental Plan 2012* (NSW Government, 2012a) and the *Manly Local Environmental Plan 2013* (NSW Government, 2013b) indicate that the project would be located within areas of Class 5 acid sulfate risk or areas with no probable acid sulfate risk (unclassified). The *Mosman Local Environmental Plan 2012* (NSW Government, 2012b) identified areas underlying The Spit as an acid sulfate soil area (land

up to 5 metres AHD) but did not provide an acid sulfate soil class for this area. The acid sulfate soil risk maps from the *Warringah Local Environmental Plan 2011* (NSW Government, 2011) did not classify the project area as an acid sulfate risk. The *North Sydney Local Environmental Plan 2013* (NSW Government, 2013a) does not contain acid sulfate risk maps. The respective local environmental plans do not cover acid sulfate soil risk within Middle Harbour and associated bays.

The local environmental plans state 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 5 – Work within 500 metres of nearby Class 1, 2, 3 or 4 land that is below five metres AHD and by which the water table is likely to be lowered below one metre AHD on nearby Class 1, 2, 3 or 4 land.

Areas with a high probability of acid sulfate soil occurrence along the project alignment for marine environments are illustrated in Figure 16-5.

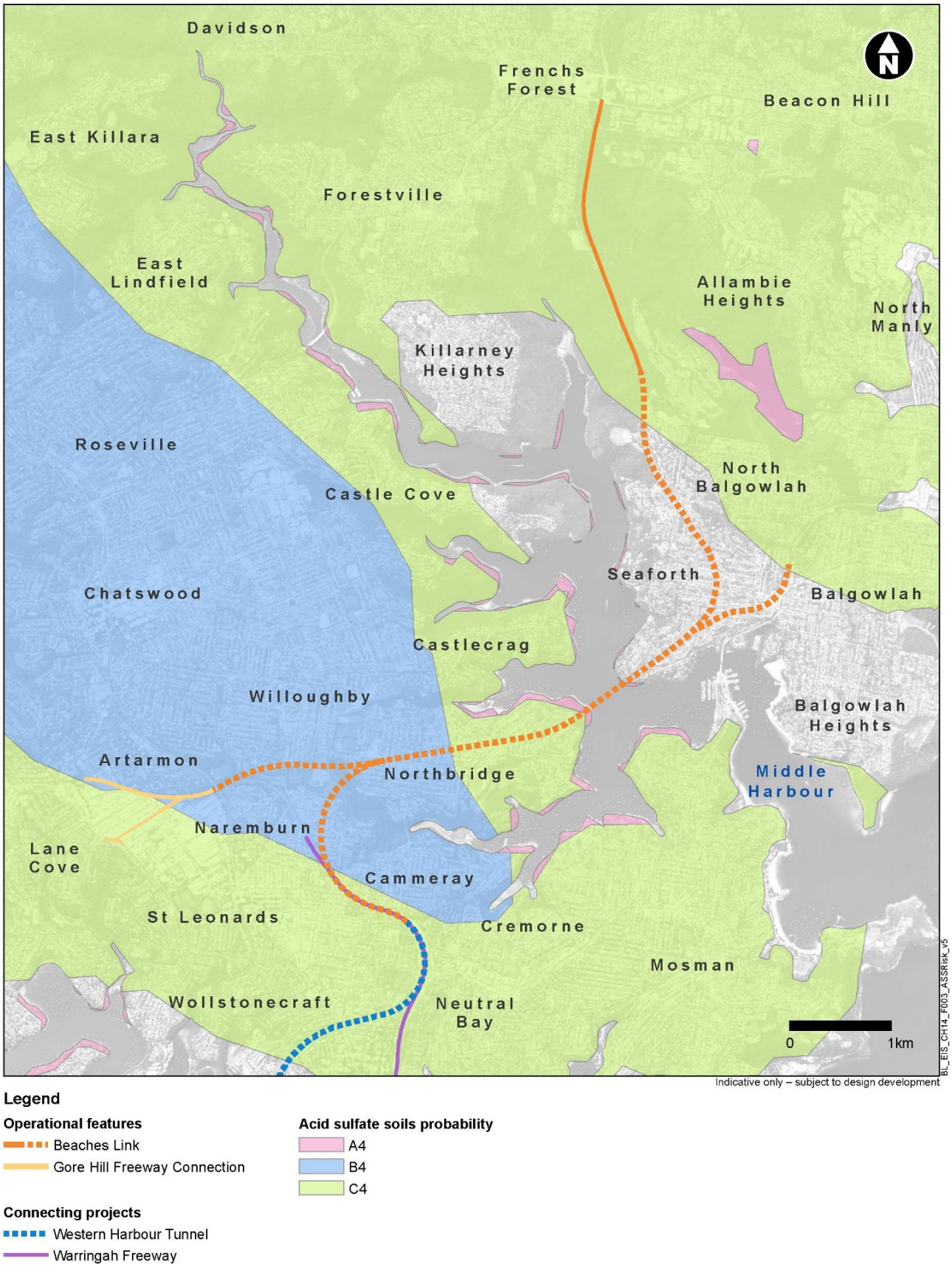


Figure 16-4 Landform acid sulfate soil risk classification

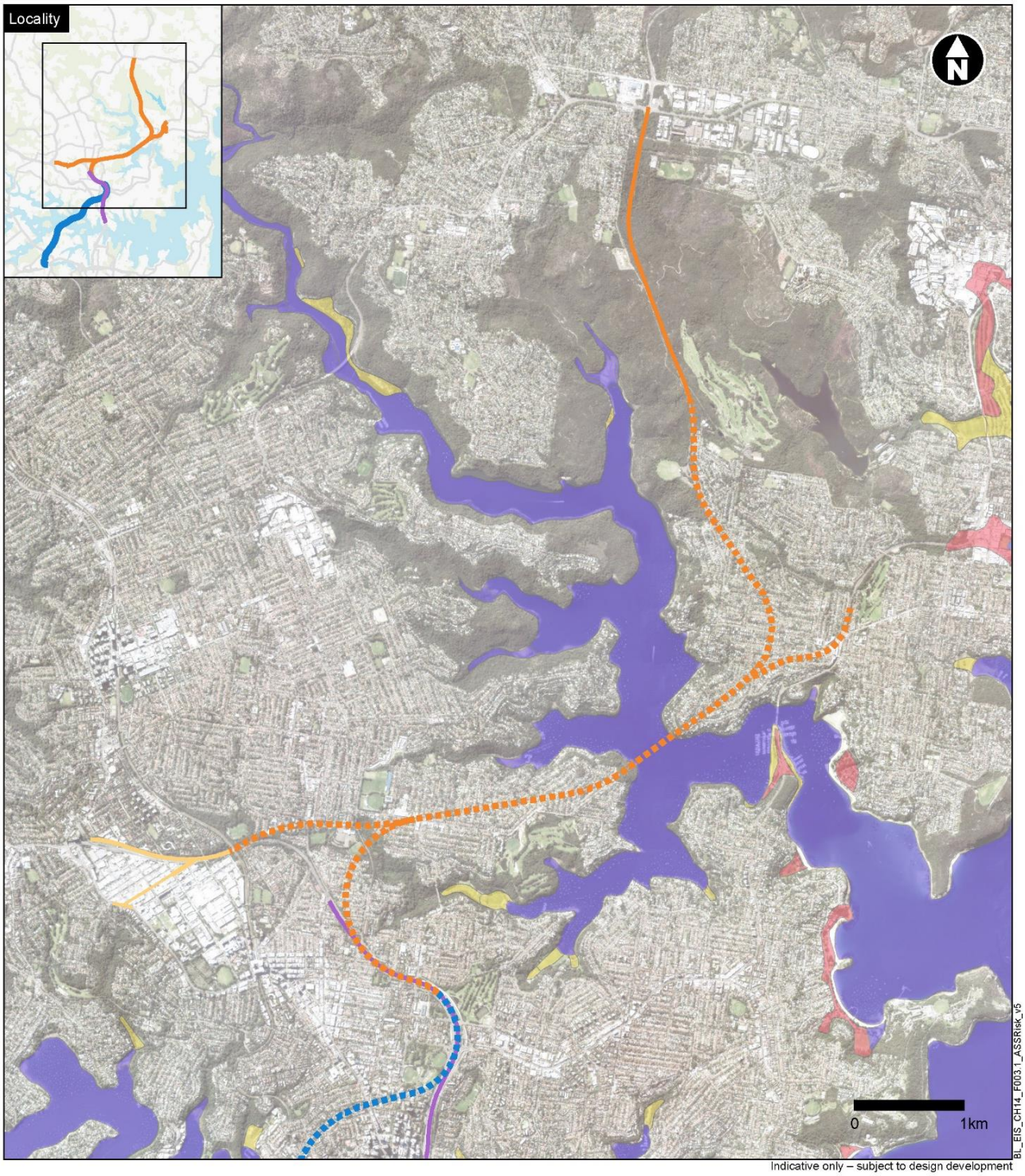


Figure 16-5 Marine environment acid sulfate soil risk classification

Soil salinity

With reference to the *Salinity Potential in Western Sydney 2002* 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 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).

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:

- Quaternary alluvium
- Hawkesbury Sandstone
- Ashfield Shale
- Manmade 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 Middle 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 Middle Harbour, there are only limited occurrences of mapped Quaternary sediments along the alignment. Key occurrences of mapped Quaternary sediments that might influence or be influenced by the project are near Flat Rock Creek.

Overall, the 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).

Hawkesbury sandstone aquifer

The most extensive aquifer in the project area is the Hawkesbury Sandstone, which is up to 250 metres thick in the Sydney region and outcrops over most of the Beaches Link project area. 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 dependent on the distribution of structural defects including fractures, joints and bedding planes.

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.

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. Therefore, the Ashfield Shale formations are not considered to form a significant groundwater system within the project area.

Ashfield Shale is only present along the alignment at ridgelines and outcrops in the area from Willoughby to Neutral Bay Junction. The Warringah Freeway cuts through the Ashfield Shale, exposing the underlying Hawkesbury Sandstone at Naremburn, Cammeray, and the Warringah Freeway.

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 sulfides, the groundwater can be corrosive to tunnel and infrastructure building materials.

Manmade fill

Manmade fill can act as a water bearing unit supporting perched aquifers (aquifers 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.

At Flat Rock Creek there is a known history of dumping industrial and domestic waste in both whole and incinerated form. Interpretation of historical records indicate that up to 40 metres of fill have been placed along Flat Rock Creek while the landscaped area on the east side of Flat Rock Drive is situated on about 30 metres of fill. The existing creek in the area has been placed in a box culvert which is now at depth and was covered with waste over time. The surface water in the area flows along a manmade creek line before re-joining the original creek to the east of the proposed Flat Rock Drive construction support site (BL2).

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, ultimately discharging to the surface drainage features and the harbour. 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.

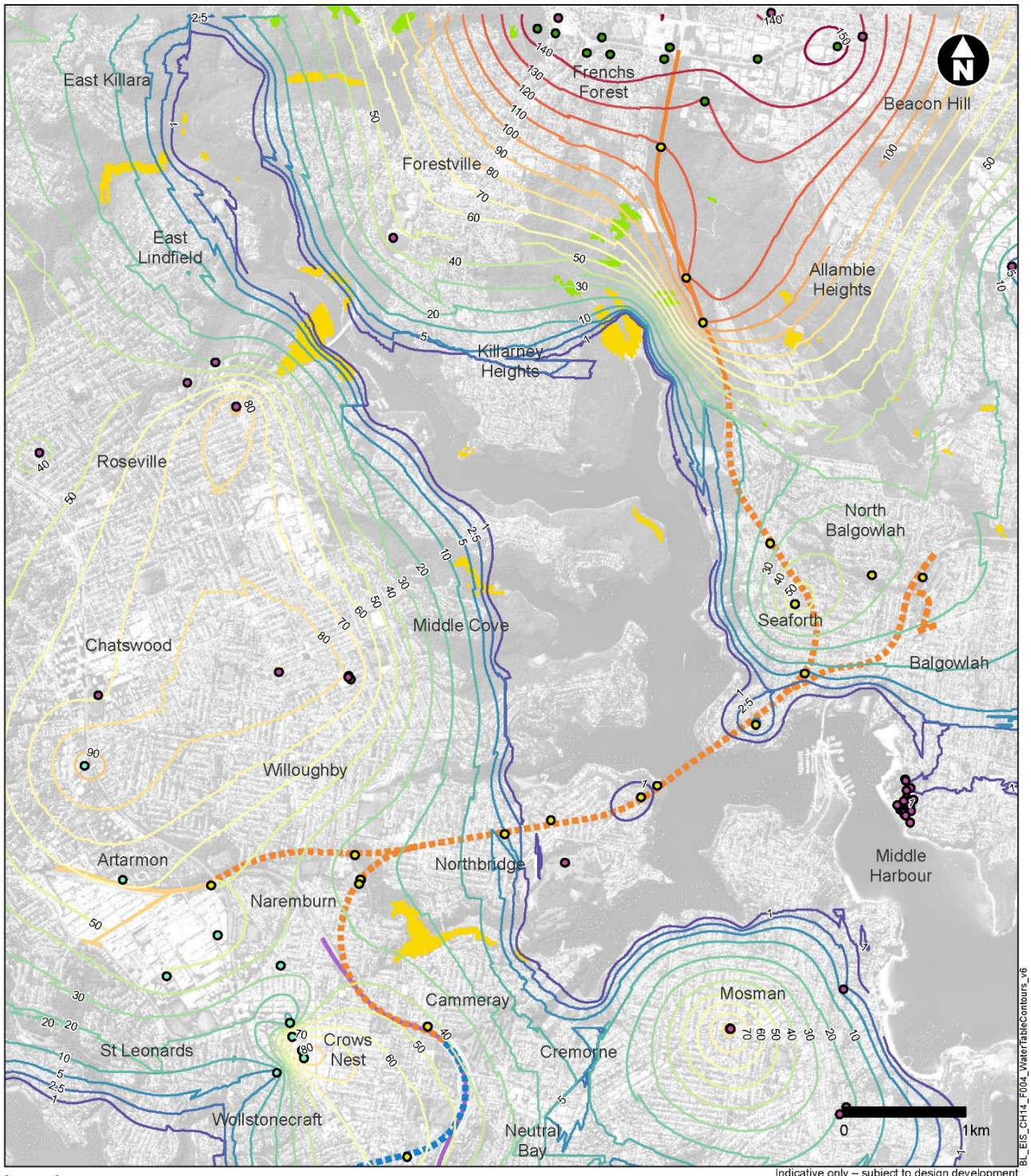
A composite water table contour map for the study area is presented in Figure 16-6. These contours were created using baseline groundwater data from the groundwater monitoring network installed for the project, as well as water levels from the Department of Planning, Industry and Environment (Water) Pinneena database, and water levels obtained from other nearby projects, including Northern Beaches Hospital Road Upgrade (Roads and Maritime Services, 2014a) and Sydney Metro City & Southwest (Chatswood to Sydenham) (Jacobs, 2016). The contours provide a general overview of key groundwater flow directions and trends along the alignment.

The water level contours shown in Figure 16-6 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 testing 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).



Legend

Operational features
- Beaches Link
- Gore Hill Freeway Connection

Connecting projects
- Western Harbour Tunnel
- Warringah Freeway

Groundwater monitoring bores
- Sydney Metro & Southwest (Chatswood to Sydenham)
- Western Harbour Tunnel and Beaches Link
- Northern Beaches Hospital Road Upgrade
- Public works

Groundwater dependent ecosystems
- Ecosystem that relies on subsurface presence of groundwater
- Coastal Upland Swamp - mapped by OEH (2016) with some additional ground truthing

Water table contour (mAHD)
150 m
1 m

Figure 16-6 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 Beaches Link tunnel. These average drainage 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

Tunnel	Opened	Type	Width (metres)	Length (kilometres)	Reported/ predicted inflow (L/sec/km)
Existing tunnels – reported inflow					
Eastern Distributor	1999	Twin 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
Recently completed tunnels – predicted inflow					
M4 East	2019	Twin three lane road		5.5	1.5
M8	2020	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).

Groundwater quality

The groundwater assessment for the Sydney Metro Chatswood to Sydenham environmental impact statement (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 is slightly acidic. 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 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, 2020) did not identify any groundwater dependent ecosystems within the construction footprint (refer to Chapter 19 (Biodiversity)). However, three areas of groundwater dependent ecosystems with potential reliance on subsurface groundwater associated with local waterways were identified within or close to the construction footprint as identified in Table 16-5.

Table 16-5 Groundwater dependent ecosystems

Ecosystems mapped	Location and type of potential groundwater dependent ecosystem	Receptor	Distance from construction footprint
Coastal Sandstone Gully Forest Sandstone Riparian Scrub Coastal Sand Forest	Upper reaches of Flat Rock Creek at Munro Park, Cammeray/Northbridge – Moderate to high potential for terrestrial groundwater dependent ecosystem	Vegetation at Flat Rock and Quarry Creeks	About 280 metres southeast of the tunnel alignment and the Flat Rock Drive construction support site (BL2)
Estuarine Mangrove Forest Seagrass Meadow Coastal Sandstone Gully Forest	Bates Creek, Killarney Heights – Moderate to high potential for terrestrial groundwater dependent ecosystem	Vegetation at Bates Creek Coastal Upland Swamp at Bates Reserve/Garigal National Park	About 550 metres west of the Wakehurst Parkway surface works
Coastal Sandstone Gully Forest Coastal Sandstone Plateau Heath	Manly Dam Reserve, Allambie Heights – Moderate potential for terrestrial groundwater dependent ecosystem	Vegetation at Manly Dam Reserve	About 650 metres east of the Wakehurst Parkway surface works

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 listed in the Department of Planning, Industry and Environment (Water) database (WaterNSW, 2020) as being for the purpose of supply/irrigation/recreational/industrial use, and located within the vicinity of the predicted extent of groundwater level drawdown are shown in Figure 16-7.

There are 17 registered groundwater bores within one kilometre of the project, including:

- Seven bores for household use
- Seven for recreation use
- Two for irrigated agriculture
- One for water supply.

Figure 16-7 Existing groundwater bores within one kilometre of the proposed 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 and 2005 were reviewed with a focus on the key surface disturbance areas and temporary 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 16-6.

Table 16-6 Summary of potential contamination issues at surface disturbance areas

Surface disturbance area	Potential contamination issue
Temporary construction support sites	
Cammeray Golf Course (BL1)	• Inappropriate handling and disposal of building materials during demolition of buildings for construction of the Warringah Freeway • Filling with material of unknown quality during construction of the Warringah Freeway • Particulate matter deposition from vehicles using the Warringah Freeway • Chemical use and storage at golf course
Flat Rock Drive (BL2)	• Infilling with manmade waste material.
Punch Street (BL3)	• Commercial/industrial use of site and surrounding areas • Degradation of building materials used in bridge structure • Demolition - Inappropriate handling and disposal of building materials during demolition of bridge structure • Filling with material of unknown quality during creek realignment • Filling with material of unknown quality during construction of Gore Hill Freeway.
Dickson Avenue (BL4)	• Commercial/industrial use of site and surrounding areas.
Barton Road (BL5)	• Demolition - Inappropriate handling and disposal of building materials during demolition of buildings for construction of Gore Hill Freeway.
Gore Hill Freeway median (BL6)	• Filling with material of unknown quality during redevelopment of quarry • Demolition - Inappropriate handling and disposal of building materials during demolition of buildings for construction of Gore Hill Freeway.

Surface disturbance area	Potential contamination issue
Middle Harbour south cofferdam (BL7)	• Contamination of Middle Harbour sediments (discussed below in the Middle Harbour contamination section).
Middle Harbour north cofferdam (BL8)	• Contamination of Middle Harbour sediments (discussed below in the Middle Harbour contamination section).
Spit West Reserve (BL9)	• Land reclamation.
Balgowlah Golf Course (BL10)	• Filling with material of unknown quality during golf course construction works • Demolition – Inappropriate handling and disposal of building materials during demolition of buildings for construction of Burnt Bridge Creek Deviation • Chemical use and storage at golf course.
Kitchener Street, Balgowlah (BL11)	• Filling with material of unknown quality during construction of Burnt Bridge Creek Deviation.
Wakehurst Parkway south (BL12)	• Contamination resulting from degradation of asphalt road surface • Degradation of hazardous building materials from structures currently present on site.
Wakehurst Parkway east (BL13)	• Contamination resulting from degradation of asphalt road surface • Degradation of paint from use of the adjacent site as water reservoirs.
Wakehurst Parkway north (BL14)	• Stockpiling of material of unknown quality.
Other surface construction sites	
Gore Hill Freeway surface works	• Commercial/industrial use of site and surrounding areas • Demolition - Inappropriate handling and disposal of building materials during demolition of buildings for construction of Gore Hill Freeway.
Balgowlah connection surface works	• Demolition - Inappropriate handling and disposal of building materials during demolition of buildings for construction of Burnt Bridge Creek Deviation • Filling with material of unknown quality during construction of Burnt Bridge Creek Deviation.
Wakehurst Parkway surface works	• Contamination resulting from degradation of asphalt road surface • Potential historical illegal dumping of waste.
Motorway Control Centre	• Commercial/Industrial use of site and surrounding areas.

Review of recent aerial imagery of the study area identified 18 sites, with activities or operations which could potentially represent potential contamination sources. These sites were located in Cammeray (three), North Sydney (one), Crows Nest (three), Naremburn (one), Artarmon (three), Middle Harbour (one), Balgowlah (two), Seaforth (three) and Frenchs Forest (one). Sites that may be contaminated included those used for commercial and industrial purposes and areas subject 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, 2020) and the list of contaminated sites notified to the NSW EPA indicated that there are seven 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 service station activities and are listed in Table 16-7.

Table 16-7 Regulated/notified sites within 500 metres of the project

Suburb	Regulated/notified	Site and address	Distance from project
Neutral Bay	Notified (Section 60)	Caltex service station – 16-38 Military Road	About 150 metres south of the project
Neutral Bay	Notified (Section 60)	Shell Coles service station – 200-204 Ben Boyd Road	About 300 metres south east of the project
Cammeray	Notified (Section 60)	Coles Express service station – 477-483 Miller Street	About 300 metres north of the project
Artarmon	Notified (Section 60)	7-Eleven Service station – 477 Pacific Highway	About 200 metres north west of the project
Lane Cove North	Notified (Section 60)	BP Service station – 432 Pacific Highway	About 300 metres west of the project
Willoughby	Notified (Section 60)	Shell Coles service station – 616-626 Willoughby Road	About 500 metres north of the project
Balgowlah	Notified (Section 60)	BP service station – Corner of Sydney Road and Maretimo Street	Less than 100 metres south of the project

Contamination exposure risk from service stations located in the vicinity of surface works and temporary 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 surface works construction activities at around four to 10 metres below ground level).

Yellow Pages business directory search

The Yellow Pages business directory search identified 74 sites within or adjacent to the project area whose activities may cause contamination. These sites were located in Cammeray (two), Crows Nest (nine), Naremburn (one), Artarmon (43), Willoughby (four), Northbridge (one), Seaforth (one), Balgowlah (seven) and Frenchs Forest (six). The businesses were predominantly comprised of service stations, paint and chemical manufacturers, 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), 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 at Wakehurst Parkway. Guideline exceedances for nickel were reported in soils along Wakehurst Parkway, Frenchs Forest and Gore Hill Freeway, Artarmon.

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 Artarmon, Willoughby, Northbridge, Balgowlah, and Wakehurst Parkway exceeded the Australian and New Zealand Environment and Conservation Council (ANZG) water quality guidelines for marine and freshwater ecosystems (95 per cent level of protection). The concentrations of contaminants above guideline levels may represent contamination, especially those contaminants and associated concentrations reported at Willoughby which may be associated with historical landfill.

Middle Harbour contamination

A review of the technical report *Sydney Harbour: A systematic review of the science* (Hedge et al., 2013) indicated that sediments in Sydney Harbour (Middle Harbour being a sub catchment) 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 including OCP, PAH 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 of input 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 (Hedge et al., 2013).

Sediment samples were collected as part of the geotechnical investigations carried out for the project in Middle Harbour. Sediment samples were collected from a range of depths and analysed for a range of contaminant compounds including heavy metals, hydrocarbon compounds (TRH, BTEX, PAH), OCP, polychlorinated biphenyls, tributyltin (TBT), per- and 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* (ISQG), that form a part of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018)
- *National Assessment Guidelines for Dredging* (NAGD) (Department of Environment, Water, Heritage and the Arts, 2009).

The results of the sediment sampling in Middle Harbour indicated a range of guideline exceedances including mercury, zinc, silver, lead, 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 provided in Appendix M (Technical working paper: Contamination).

Elutriate testing provides an indication of the potentially soluble contaminants that are susceptible to migration and assesses the risk to the environment from these soluble contaminants. Two rounds of elutriate testing have been carried out for sediments samples from Middle Harbour. A total of seven samples were tested. The testing focussed on cooper, lead, zinc, silver, mercury and dioxins. The majority of analytes were below laboratory detection and relevant ANZG (2018) water quality trigger values for marine water. However, exceedances were recorded for each analyte in at least one of the samples tested.

16.4 Assessment of potential construction impacts

16.4.1 Soils

Erosion and sedimentation

The proposed construction associated with the tunnel works, temporary construction support site establishment works and road upgrade works, would involve surface excavation and earthmoving (as described in Chapter 6 (Construction work)). 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 and 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 temporary 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, which is most likely to occur at temporary construction support sites. The majority of temporary construction support sites are not located in areas with steep terrain, reducing the potential for soil erosion. Higher soil erosion impact potential would be associated with surface work construction sites located adjacent to more environmentally sensitive areas (eg Garigal National Park and Manly Dam Reserve).

Uncompacted or unconsolidated materials (such as excavated and stockpiled soils) have the potential to leave construction areas during rain (through surface water run off) causing 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

The excavation of actual and potential acid sulfate soils and lowering of the groundwater table in the vicinity of acid sulfate soils during construction could cause the oxidation of sulfidic compounds within these soils which in turn could generate acid run off, leachate and mobilise other contaminants (namely heavy metals) into the environment. Acidic run off, leachate and contaminant mobilisation could potentially impact upon the following:

- Contaminant exposure risk to project personnel and the general public
- Contaminant exposure to environmental receivers
- Degradation of terrestrial and aquatic ecosystems
- Damage to existing structures.

Class 5 acid sulfate soil risks have been mapped in the Manly and Willoughby local environmental plans. Based on the classification scheme presented in the *Acid Sulfate Soils Assessment Guidelines* (Ahern, Stone and Blunden, 1998), areas classified as Class 5 are located within 500 metres on adjacent Class 1, 2, 3 or 4 land. It is noted that they are not typically found within Class 5 areas. Based on the information reviewed, the risk of acid sulfate soils being present within

the project area is low to negligible, with the exception of soils within Spit West Reserve and sediments within Middle Harbour and The Spit, which have been identified as potential acid sulfate soils. Measures to assess and manage potential and actual acid sulfate soils in these areas are contained in Section 16.7. 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 managed in accordance with the *Acid Sulfate Soil Manual* (ASSMAC, 1998). 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 temporary construction support sites, which can restrict groundwater flow and result in a concentrate of salt in one area.

As outlined in Section 16.3.3, naturally occurring soil salinity is not considered to be 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

An assessment of ground settlement induced by tunnel excavation due to both stress redistribution in the surrounding ground (due to the removal of subsurface materials during tunnelling activities) and groundwater drawdown around drained tunnels has been carried out (Arup & WSP, 2020). The assessment approach and findings are summarised in Appendix N (Technical working paper: Groundwater).

Ground movement may occur as a result of:

- Tunnel induced movement caused by the relief of stress from the removal of intact rock during tunnelling
- Settlement induced by 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 16-8 provides typical impacts which would be expected in relation to potential ground movement values and typical associated impacts for settlement.

Table 16-8 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 millimetre) 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.
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 and maximum slope of ground (angular distortion) >1:50	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 1: Degree 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, based on unconstrained groundwater inflows into the tunnel, is provided in Table 16-9 and shown in Figure 16-8 and Figure 16-9.

Table 16-9 Maximum predicted surface settlement

Location	Maximum stress redistribution induced settlement (mm)	Maximum groundwater drawdown induced settlement (mm)	Maximum total settlement (mm)
Warringah Freeway portal	25 – 30	Less than five	30+
Cammeray ventilation tunnel	25 – 30	Less than five	25 – 30
Flat Rock Drive access decline	5 – 10	Less than five	10 – 15
Flat Rock Creek Reserve	Less than five	80	85
Gore Hill Freeway ventilation tunnel	20 – 25	Less than five	20 – 25
Lane Cove Tunnel exit/entry	20 – 25	Less than five	20 – 25
Middle Harbour crossing, west (Northbridge)	25 – 30	5 - 10	25 – 30
Mainline tunnels between Warringah Freeway and Middle Harbour	20 – 25	10 - 15	20 – 25
Middle Harbour crossing, east (Seaforth)	25 – 30	Less than five	25 – 30
Mainline and ramp tunnels between Middle Harbour Burnt Bridge Creek Deviation/Wakehurst Parkway	15 – 20	Less than five	15 – 20
Balgowlah ventilation tunnel/access decline	35	Less than five	35
Burnt Bridge Creek Deviation portal	35 – 40	Less than five	35 – 40
Wakehurst Parkway portal	35 – 40	Less than five	35 – 40

Preliminary ground movement predictions indicate that there may be potential settlement of up to 40 millimetres around the Burnt Bridge Creek Deviation and Wakehurst Parkway portals. This would be assessed as ‘slight’ severity under relevant guidelines.

Total settlement of 85 millimetres is predicted at Flat Rock Reserve, primarily due to the groundwater induced settlement. There are, however, no buildings present at this location. This prediction assumes that groundwater inflows into the tunnel beneath Flat Rock Reserve are unconstrained. Additional modelling and settlement predictions were completed at this location. The additional modelling included tunnel linings to preclude groundwater inflows beneath Flat Rock Reserve. When the reduced inflows and reduced groundwater drawdown were taken into account, the maximum predicted settlement reduced to 35 millimetres. This demonstrates that appropriate choice of linings can be used to minimise groundwater drawdown induced settlement at this location.

No buildings were predicted to be in the ‘slight’ to ‘very severe’ damage categories. Sixty-one buildings are categorised as potentially within the ‘very slight’ damage category. These buildings are mainly in the vicinity of locations where the tunnel would have shallow cover near portals and larger span caverns, including:

- The Warringah Freeway portal
- Northbridge, east of the Flat Rock Creek area

- Seaforth Bluff
- Seaforth at the junction of the mainline and ramp tunnels
- Wakehurst Parkway cavern and portal.

'Very slight' damage (fine cracks) would be easily treated during normal decoration. Damage would generally be 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 (refer to environmental management measure SG7 in Table 16-19).

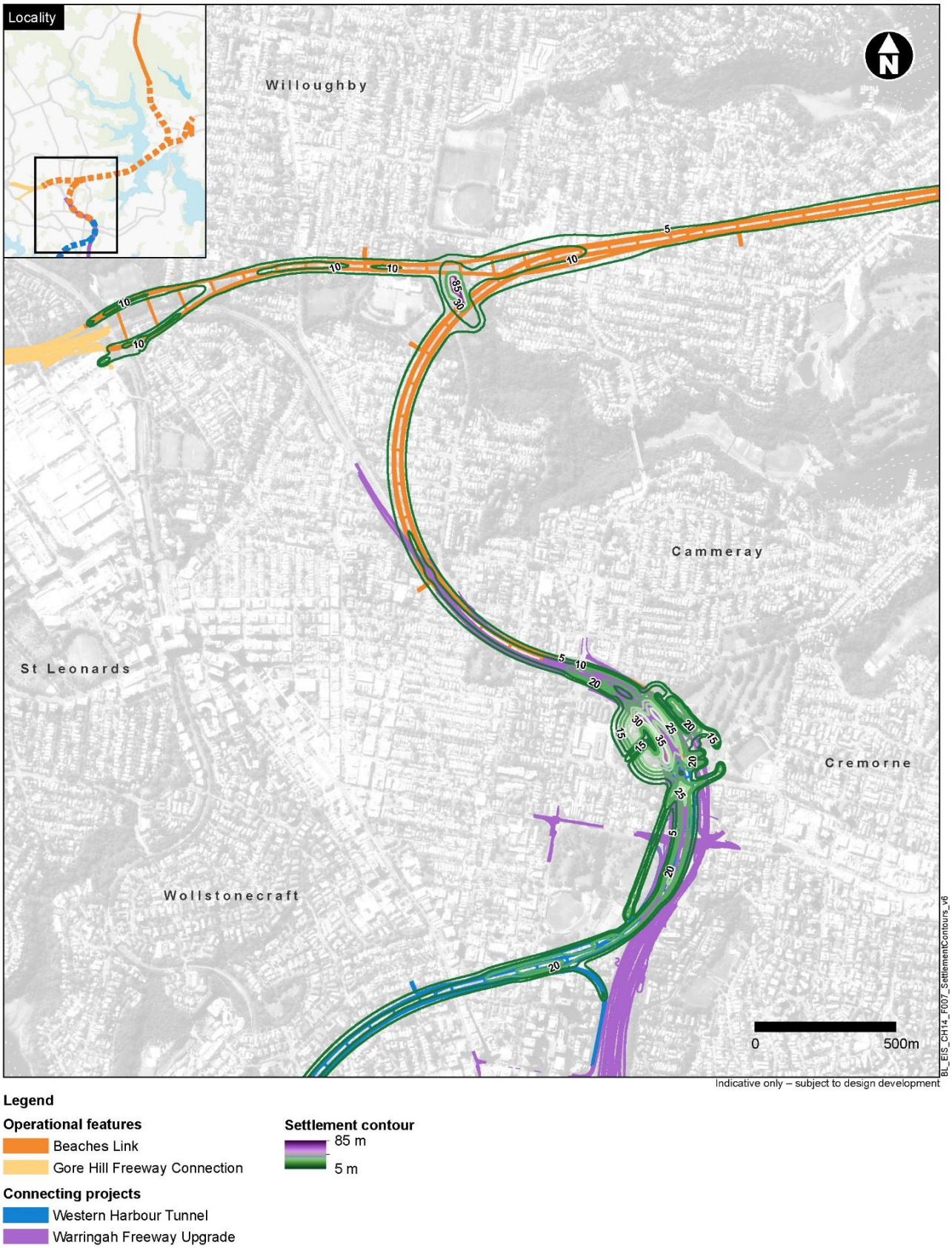


Figure 16-8 Settlement contours – Cammeray, Willoughby

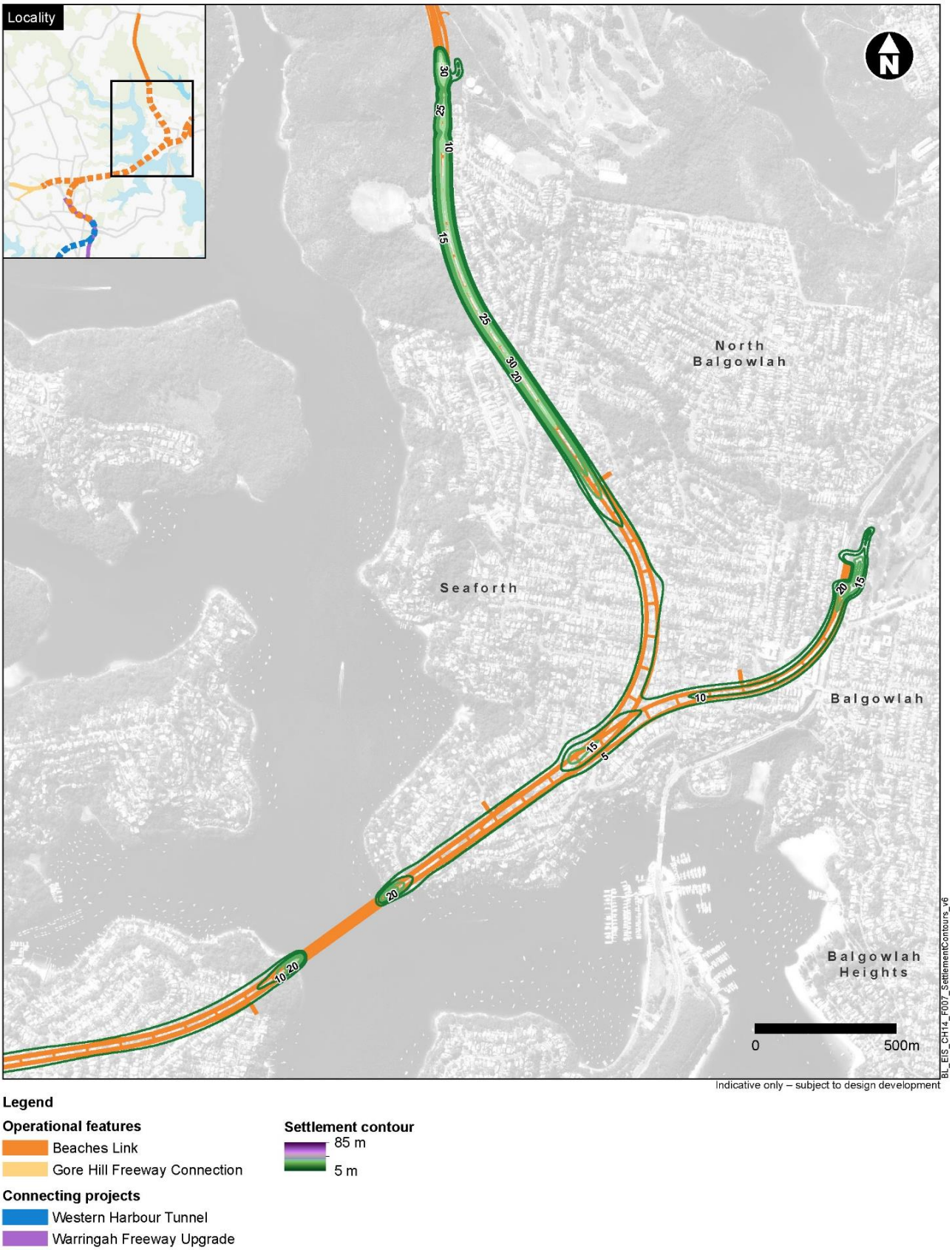


Figure 16-9 Settlement contours – Middle Harbour, Seaforth, Balgowlah

16.4.3 Land contamination

Areas of environmental interest

A Stage 1 contamination investigation was carried out to identify potential areas of environmental interest which would assist in identifying construction limitations/constraints and management options for the project with respect to contamination.

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. Thirteen locations were assessed as having a moderate to high risk rating for contamination 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 16-10.

Warringah Freeway, North Sydney to Cammeray [B1 to B6]

Potentially contaminated soils may be presented within unsealed areas next to the Warringah Freeway between the Cammeray Golf Course at Cammeray and Willoughby Road at Naremburn. The contamination could be associated with the inappropriate handling and disposal of building materials or filling of some of the areas with material of unknown quality during the construction of the Warringah Freeway or even potentially from particulate matter deposition from large volume traffic flows using the Warringah Freeway since its opening. Contaminants could consist of a variety of heavy metals, hydrocarbons and particulate matter as well as asbestos. These areas pose a moderate contamination risk to construction given that contamination is potentially present within soils which are likely to be excavated and exposed during the carrying out of surface works and construction of the temporary construction support site at the Cammeray Golf Course (BL1).

Punch Street, Artarmon [B7]

The area along Punch Street may be contaminated with heavy metals, asbestos and pesticides as a result of the degradation of hazardous building materials contained within the old bridge structure and the potential inappropriate demolition and waste disposal practices used during the demolition of the bridge. In addition, possible infilling of the site with material of unknown quality (potentially contaminated with common contaminant compounds including but not limited to heavy metals, hydrocarbons, pesticides, polychlorinated biphenyls and asbestos) during construction of the Gore Hill Freeway may be present across the site. 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 activities at the Punch Street construction support site (BL3).

Freeway Hotel site, Reserve Road, Artarmon [B8]

The site of the proposed Motorway control centre (Freeway Hotel site), Reserve Road in Artarmon, could be contaminated from current and historical commercial/industrial use of the site and adjacent areas. 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.

Flat Rock Reserve, Northbridge [B9]

The location of the proposed Flat Rock Drive construction support site (BL2) has the potential for contamination risks given the history of landfill activities in the area. Information reviewed as part of the Stage 1 Contamination Investigation carried out for this project (Appendix M (Technical working paper: Contamination)) indicated that building type wastes are situated in the upper layers of the former landfill, with the possible presence of putrescible materials located at greater depths of the waste mass. Soils/wastes and groundwater beneath this site may be contaminated with a variety of contaminant compounds.

It is possible that the waste mass beneath this site and the adjacent Willoughby Leisure Centre and Bicentennial Reserve may present a source of landfill gas. With specific regard to the possible presence of landfill gas beneath the site and the adjacent Willoughby Leisure Centre and Bicentennial Reserve, there is the potential for landfill gas to migrate towards the proposed Flat Rock Drive (BL2) construction support site as a result of formation pressure due to ground disturbance from construction activities associated with the project. It is not known whether the road embankment restricts gas flow (if any) between the two areas. Sub-surface structures (where present) beneath the road embankment between the two areas may act as conduits for gas movement (if gas is present).

This area poses a moderate potential contamination risk associated with the possible presence of contamination beneath Flat Rock Drive construction support site (BL2) and known groundwater contamination in adjoining areas (Willoughby Leisure Centre and Bicentennial Reserve).

Willoughby Leisure Centre and Bicentennial Reserve, Willoughby [B10]

The historical landfill activities carried out within the areas surrounding the Willoughby Leisure Centre and Bicentennial Reserve are likely to contain soil, groundwater contamination sources within the buried waste mass. Soils may be contaminated with a variety of contaminant compounds, including asbestos. This area poses a high potential contamination risk associated with the known presence of contaminated soils/wastes and groundwater as a result of the waste mass in the vicinity of the tunnel alignment, which is likely to be exposed during construction of the tunnel. Construction activities could also create preferential pathways for groundwater contamination to other areas, particularly the adjacent Flat Rock Drive construction support site (BL2).

It is possible that the waste mass beneath Flat Rock Drive construction support site (BL2) and the adjacent Willoughby Leisure Centre and Bicentennial Reserve may present a source of landfill gas. Although not encountered during borehole investigations in the area, there remains the potential for pockets of landfill gas to be present within this area. Should landfill gas be present, there is the potential for it to migrate towards the proposed Flat Rock Drive construction support site (BL2) as a result of formation pressure gradients due to ground disturbance from construction activities associated with the project.

Spit West Reserve, Mosman [B11]

Spit West Reserve is located on partially reclaimed land. The source and the quality of the material used to reclaim this land is not known and may be impacted with common contaminant compounds including, but not limited to, 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 soil which is likely to be excavated and exposed during construction of the Spit West Reserve construction support site (BL9).

Middle Harbour and the Spit [B12]

Contamination has been reported in sediments present within Middle Harbour and west of Spit West Reserve. Contamination is likely to be associated with inputs from the surrounding urbanised catchments and general maritime use within the harbour. 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 the construction of the cofferdams in Middle Harbour, Middle Harbour south cofferdam (BL7) construction support site and Middle Harbour north cofferdam (BL8) construction support site as well as the construction of the Spit West Reserve (BL9) construction support site itself.

Balgowlah Golf Course, Balgowlah [B13]

Soil contamination is anticipated to be present within soils adjacent to and within the Balgowlah Golf Course. The potential contamination could be associated with the inappropriate demolition and waste disposal practices of structures historically present within this area as well as the unknown quality of fill used in the construction of the Burnt Bridge Creek Deviation and the golf course. Further contamination risks could be associated with the degradation of hazardous building materials which may have potentially been used in structures currently situated in the area. This area poses a moderate contamination risk during construction given that soils are expected to be excavated and exposed during construction of the Balgowlah Golf Course (BL10) construction support site, the Balgowlah connection surface works and the new open space and recreation facilities.

Dudley Street, Balgowlah [B14]

Potential soil contamination may be present within surface soils adjacent to the existing residential premises located along Dudley Street at Balgowlah. The potential contamination could be associated with the degradation of hazardous building materials which may have potentially been used in these structures. These areas pose a moderate contamination risk to construction given the potential for contamination and that soils are expected to be excavated and exposed during construction of the Balgowlah Golf Course construction support site (BL10), the Balgowlah connection surface works and the new open space and recreation facilities.

Residential properties, Judith Street & Kirkwood Street, Seaforth [B15]

Potential soil contamination may be present within surface soils adjacent to the existing residential premises located at the corners of Judith Street and Kirkwood Street with Wakehurst Parkway at Seaforth. The potential contamination could be associated with the degradation of hazardous building materials which may have been used in these structures. These areas pose a moderate contamination risk to construction given the potential for contamination and that soils are expected to be excavated and exposed during construction of the Wakehurst Parkway south construction support site (BL12).

Sydney Water Bantry Bay Reservoir site, Killarney Heights [B16]

There is the potential for possible contaminated soils at the Sydney Water Bantry Bay Reservoir site at Killarney Heights from the deposition of degraded materials from the surface of the reservoir. These areas pose a moderate contamination risk to construction given the potential for contamination and that soils are expected to be excavated and exposed during construction of the Wakehurst Parkway east support site (BL13).

Wakehurst Parkway, Seaforth to Frenchs Forest [B17]

Isolated contamination has been reported in surface soils adjacent to the Wakehurst Parkway (Seaforth to Frenchs Forest). The contamination is likely to be associated with the degradation of asphaltic road surfaces. The absence of formalised kerb and guttering along some sections of the Wakehurst Parkway may have caused asphalt to enter surface soils along these sections. These areas pose a high contamination risk to construction given the presence known soil contamination and that soils are expected to be excavated and exposed during the upgrade works to Wakehurst Parkway and adjacent construction of the support sites, Wakehurst Parkway south (BL12) and Wakehurst Parkway north (BL14).

The non-urbanised areas immediately surrounding the Wakehurst Parkway may have been historically subject to the small-scale illegal dumping of waste. Illegally dumped waste presents a moderate contamination risk to construction given the potential for contamination and that soils/wastes are expected to be excavated and exposed during the upgrade works to the Wakehurst Parkway.

Waverton Park – Woolcott Road, Waverton [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. This area poses a high contamination risk to operation given that contamination is known within fill material which could impact upon groundwater. Groundwater could migrate during operation of the tunnel due to groundwater drawdown. No direct construction works associated with the project would occur in Waverton Park. Further information on the Waverton Park site is provided in the *Western Harbour Tunnel and Warringah Freeway Upgrade Technical Working Paper: Contamination* (Jacobs, 2020)

Potential contamination risks

As indicated above, seventeen sites would have a moderate to high risk rating and are considered to be potential areas of environmental interest. Table 16-10 identifies the potential contamination, impacts and associated risks. Management and mitigation measures to address the potential risks are discussed in Section 16.7.

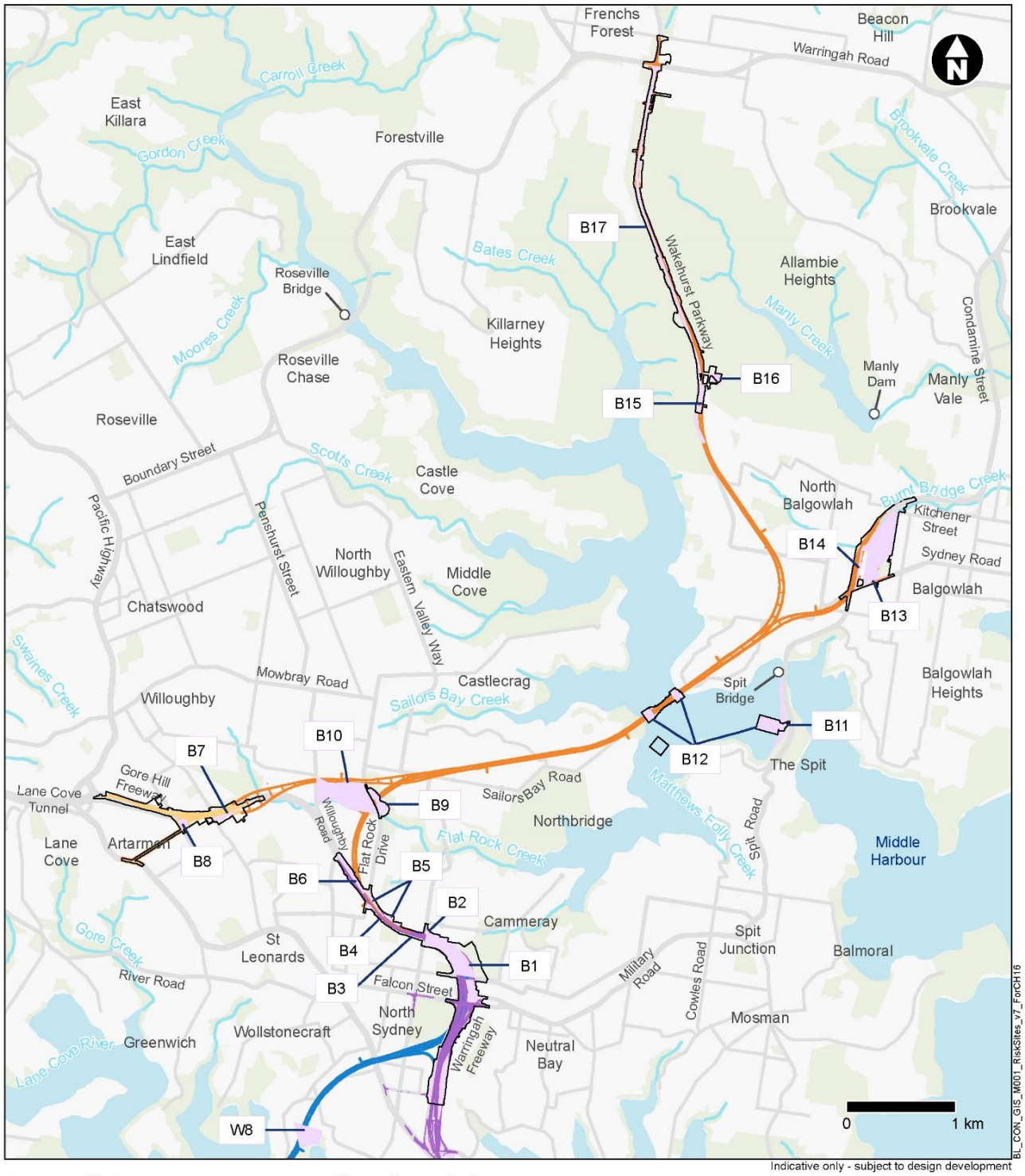


Figure 16-10 Areas of environmental interest and contaminated sites

Table 16-10 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
Warringah Freeway, North Sydney to Cammeray [B1 – B6]	Within construction footprint. Above proposed tunnel alignment and within Cammeray Golf Course construction support site (BL1).	• Temporary construction support site establishment works • Tunnelling and associated excavation and stockpiling.	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 since its opening. Contaminants, including heavy metals, asbestos and pesticides, may be present within the fill material that was used in the construction of the Warringah Freeway. 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 spoil/unexpected finds • Excavation activities may mobilise and spread buried contaminants • Accidental leaks and spills during use of the temporary construction support site • Erosion and off site transport of sediment and contamination via overland flow and stormwater runoff, affecting the water quality of local waterways.	**Moderate** Possible contamination/ excavation activities within site footprint and within potential contamination distribution range (laterally and vertically – surface works only) Potential contamination distribution unlikely to impact upon tunnelling (based on depth of tunnel).	**Moderate** Groundwater quality data indicate potentially elevated heavy metals, ammonia and hydrocarbons at depth

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
Punch Street, Artarmon [B7]	Within construction footprint and Punch Street construction support site (BL3).	• Temporary construction support site establishment works.	The site of the proposed Punch Street construction support site (BL3) may be contaminated with heavy metals, asbestos and pesticides as a result of the degradation of hazardous building materials contained within the old bridge structure and the potential inappropriate demolition and waste disposal practices used during demolition of the bridge. In addition, possible infilling of the site with material of unknown quality (potentially contaminated with common contaminant compounds including but not limited to heavy metals, hydrocarbons, pesticides, polychlorinated biphenyls and asbestos) during construction of the Gore Hill Freeway may be present across the site. If contamination is present and not appropriately controlled, there is the potential for: • Excavation activities may mobilise and spread buried contaminants • 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 spoil/unexpected finds • Accidental leaks and spills during use of the temporary construction support site.	**Moderate** Possible contamination/ excavation activities within site footprint and within potential contamination distribution range (surface work only).	**Moderate** Moderate potential for land contamination migration to groundwater due to groundwater depths.

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
Freeway Hotel site, Reserve Road, Artarmon [B8]	Within footprint of Motorway control centre	• Motorway control centre (surface)	Commercial/industrial use of site and surrounding areas (ie manufacturing, chemical use and storage, etc.) may have resulted in contaminated soils. If contamination is present and not appropriately controlled, there is the potential for: • Excavation activities may mobilise and spread buried contaminants • 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 spoil/unexpected finds • Accidental leaks and spills during use of the temporary construction support site.	**Moderate** Possible contamination/ excavation activities within the site footprint and within potential contamination distribution range (surface work only).	**Low** Low potential for land contamination migration to groundwater due to groundwater depths.

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
Flat Rock Reserve, Northbridge [B9]	Within footprint of construction site.	• Flat Rock Drive construction support site (BL2), access portal (approximately 7 metres below site surface level)	Potential for contamination risks given the history of landfill activities in the area. Information provided indicates that putrescible materials could be present at depth beneath Flat Rock Drive construction support site (BL2). Soils and groundwater beneath this site could be contaminated with a variety of contaminant compounds. It is possible that the waste mass beneath this site and the adjacent Willoughby Leisure Centre and Bicentennial Reserve to the west may present a source of landfill gas. These contamination risks could impact construction elements within the formation of the temporary construction support site and access decline. If contamination is present and not appropriately controlled, there is the potential for: • Mobilisation and spread of buried contaminants as a result of excavations • 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 spoil/unexpected finds • Accidental leaks and spills during use of the temporary construction support site • Erosion and off site transport of sediment and contamination via overland flow and stormwater runoff, affecting the water quality of local waterways.	**Moderate** Known contamination adjacent to site/possible contamination beneath site, within compound and access portal as well as within the potential contamination distribution range (laterally and vertically). Potential contamination distribution has potential to impact formation of the temporary construction support site and associated access decline.	**Moderate** Groundwater quality data indicate the presence of contamination. Depth to groundwater is estimated to be greater than 10 metres.

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
Willoughby Leisure Centre/ Bicentennial Reserve, Willoughby [B10]	Above tunnel and adjacent to footprint of temporary construction support site and tunnel portal	• Tunnelling and associated excavation	The historical landfill activities carried out within and around the areas surrounding the Willoughby Leisure Centre and Bicentennial Reserve are likely to contain soil, groundwater and possible landfill gas contamination sources associated with the buried waste mass Soils/wastes may be contaminated with a variety of contaminant compounds, including asbestos. Construction activities could also create preferential pathways for groundwater contamination and landfill gas (if present) to other areas, particularly the adjacent Flat Rock Drive construction support site (BL2). If contamination is present and not appropriately controlled, there is the potential for: • Excavation activities may mobilise and spread buried contaminants • 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 spoil/unexpected finds • Accidental leaks and spills during use of the temporary construction support site.	**High** Known considerable contamination beneath and possibly adjacent to site footprint and within contamination distribution range (vertically). Potential contamination distribution unlikely to impact upon tunnelling (based on depth of tunnel).	**High** 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
Spit West Reserve, Mosman [B11]	Within Spit West Reserve construction support site (BL9).	• Temporary construction support site establishment works.	The site of the proposed Spit West Reserve construction support site (BL5) may be contaminated with common contaminant compounds including, but not limited to heavy metals, hydrocarbons, pesticides, polychlorinated biphenyls, phenols, organotins and asbestos. If contamination is present and not appropriately controlled, there is the potential for: • Excavation activities may mobilise and spread buried contaminants • 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 spoil/unexpected finds • Accidental leaks and spills during use of the temporary construction support site • Erosion and off site transport of sediment and contamination via overland flow and stormwater runoff, affecting the water quality of local waterways.	**Moderate** Possible contamination/ excavation activities for construction compound within site footprint and within potential contamination distribution range (surface work only).	**Low** Low potential for land contamination migration to groundwater due to coastal location.

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
Middle Harbour and the Spit [B12]	Within construction footprint. Above proposed tunnel alignment and within Middle Harbour south (BL7) and north (BL8) coffer dams and Spit West Reserve construction support site (BL9).	• Temporary construction support site establishment works • Tunnelling and associated excavation and stockpiling.	Contamination has been reported in sediments present within Middle Harbour and The Spit. Contamination is likely to be associated with inputs from the surrounding urbanised catchments 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 Spit West Reserve construction support site (BL9) and the Middle Harbour south and north cofferdams (BL7 and BL8). If contamination is present and not appropriately controlled, there is the potential for: • Excavation activities may mobilise and spread buried contaminants • 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 spoil/unexpected finds • Accidental leaks and spills during use of the temporary construction support site.	**High** Known contamination/ excavation activities within the site footprint and within potential contamination distribution range (vertically).	**Low** Low potential for land contamination migration to groundwater due to coastal location.

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
Balgowlah Golf Course, Balgowlah [B13]	Within Balgowlah Golf Course construction support site (BL10) and wider Balgowlah Golf course area.	• Temporary construction support site establishment works, Motorway facility and new open space and recreation facilities.	A number of houses and buildings were demolished during the construction of Burnt Bridge Creek Deviation. Inappropriate demolition and waste disposal practices may have resulted in demolition wastes and associated contamination (including heavy metals, asbestos and pesticides) remaining in areas adjacent to the road corridor (including within the wider Balgowlah Golf Course). If contamination is present and not appropriately controlled, there is the potential for: • Excavation activities may mobilise and spread buried contaminants • 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 spoil/unexpected finds • Accidental leaks and spills during use of the temporary construction support site • Erosion and off site transport of sediment and contamination via overland flow and stormwater runoff, affecting the water quality of local waterways.	**Moderate** Possible contamination/ excavation activities for construction compound within site footprint and within potential contamination distribution range (surface work only).	**Moderate** Depth to groundwater is estimated to be less than two metres across a portion of the site and groundwater quality monitoring data indicates low pH and the presence of heavy metals at depth.

Location	Location relative to construction footprint	Construction works	Potential contaminants and associated impacts	Risk of land contamination	Risk of existing groundwater contamination
Residential properties, Dudley Street, Balgowlah [B14]	Above tunnel and adjacent to footprint of construction support site (BL10).	• Temporary construction support site establishment works • Tunnelling and associated excavation and stockpiling • Surface roadworks • Construction of new open space and recreational facilities.	Localised contamination may be present as a result of the degradation of hazardous building materials from structures present on site. If contamination is present and not appropriately controlled, there is the potential for: • Excavation activities may mobilise and spread buried contaminants • 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 spoil/unexpected finds • Accidental leaks and spills during use of the temporary construction support site.	**Moderate** Possible contamination/ excavation activities for tunnel portal and construction compound within site footprint, within potential contamination distribution range (laterally and vertically). Potential contamination distribution unlikely to affect tunnelling below surface levels (based on depth of tunnel).	**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
Residential properties – Judith Street/ Kirkwood Street and Wakehurst Parkway at Seaforth. [B15]	Above tunnel and adjacent to footprint of construction support site (BL12).	• Temporary construction support site establishment works • Tunnelling and associated excavation and stockpiling • Surface roadworks.	Localised contamination may be present as a result of the degradation of hazardous building materials from structures present on site. If contamination is present and not appropriately controlled, there is the potential for: • Excavation activities may mobilise and spread buried contaminants • 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 spoil/unexpected finds • Accidental leaks and spills during use of the temporary construction support site.	**Moderate** Possible contamination/ excavation activities for tunnel portal and construction compound within site footprint, within potential contamination distribution range (laterally, not vertically). Potential contamination distribution unlikely to affect tunnelling below surface levels (based on depth of tunnel).	**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
Sydney Water Bantry Bay Reservoir site (and surrounding areas), Killarney Heights [B16]	Area within and adjacent to Wakehurst Parkway east construction support site (BL13) footprint and tunnel (laterally, not vertically)	• Temporary construction support site establishment works • Tunnelling and associated excavation and stockpiling • Roadworks.	Potential soil contamination may be present within the surface soils at the location of the Wakehurst Parkway east construction support site (BL13) and the areas adjacent to it. The potential contamination could be associated with the degradation of painted surfaces on the reservoirs and windblown deposition of paints on adjoining areas. Contamination could also be potentially associated with the demolition of waste material observed across the surface of the site.	**Moderate** Possible contamination/ excavation activities for construction compound and roadwork within site footprint and within potential contamination distribution range (laterally, not vertically) Potential contamination distribution unlikely to affect tunnelling (based on depth of tunnel).	**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
Wakehurst Parkway, Seaforth to Frenchs Forest [B17]	Within construction footprint and Wakehurst Parkway south construction support site (BL12). Above proposed tunnel alignment.	• Temporary construction support site establishment works • Tunnelling and associated excavation and stockpiling • Surface roadworks.	Localised contamination as a result of degrading asphalt road surfaces may be present along the length of Wakehurst Parkway from Seaforth to Frenchs Forest. Hydrocarbon contamination may be present in the surface soils along the road way. The non-urbanised areas immediately surrounding the Wakehurst Parkway may have been historically subject to the illegal dumping of waste. Illegally dumped waste may include heavy metals, hydrocarbons, pesticides and/or asbestos. If contamination is present and not appropriately controlled, there is the potential for: • Excavation activities may mobilise and spread buried contaminants • Cross contamination associated with the incorrect handling or disposal of spoil/unexpected finds • Accidental leaks and spills during use of the temporary construction support site • Erosion and off site transport of sediment and contamination via overland flow and stormwater runoff, affecting the water quality of local waterways.	**High** Known contamination/ excavation activities for construction compound and roadwork within site footprint and within potential contamination distribution range (laterally and vertically) Potential contamination distribution unlikely to affect tunnelling below surface levels (based on depth of tunnel).	**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
Waverton Park – Woolcott Road, Waverton [W8]	About 1900 metres south west from construction footprint.	• None	Known contamination (TRH) likely to be the result of historical infilling and reclamation adjacent to the shoreline. Potential for contamination migration due to groundwater drawdown. Contamination likely present at surface and depth (less than 20 metres) associated with various depths of infilling. Due to low depth of groundwater (less than four metres) there is the potential for contaminated groundwater to migrate to surrounding areas from groundwater drawdown due to the project.	**High** Known contamination (which could impact upon groundwater)	**High** Depth to likely contaminated groundwater is estimated to be less than four metres across this site

Potentially contaminated sites identified in Table 16-10 would be subject to further investigation, remediation and/or management. 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*.

Any contaminated material disturbed during construction would be separated from uncontaminated material on site to prevent cross contamination. Contaminated material would be encapsulated on site where possible, and in accordance with relevant regulatory requirements. Any material that is not suitable for encapsulation would be loaded into sealed and covered trucks for disposal at a suitably licensed facility. Further site investigations during the design development and construction planning phases would inform contamination management including determining where encapsulation is appropriate.

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 (Standards Australia, 2001).

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

16.4.4 Marine contamination

The sediments in Middle 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 the dredging activities required for the installation of the immersed tube tunnel and associated piling works. Piling would also be required to establish temporary construction support site wharf structures at Spit West Reserve construction support site (BL9) and the temporary mooring facility for immersed tube tunnel units in Middle Harbour. 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 Agriculture, Water and the Environment. The appropriateness of offshore disposal would be assessed in accordance with the *National Assessment Guidelines for Dredging* (NAGD) (Department of Environment, Water, Heritage and the Arts, 2009). Offshore disposal would only be appropriate for material that meets the requirements outlined in the NAGD
- Landfill disposal – Marine sediments unsuitable for offshore disposal and requiring disposal to landfill would be assessed in accordance with the *Waste Classification Guidelines* (NSW EPA, 2014a) and disposed of at an appropriately licensed waste facility.

Dredging has the potential to disturb and resuspend sea bed sediments, some of which may be contaminated. While suspended sediment would be subject to tidal water movement that can affect dispersion, the particles settle back to the bed of the harbour. The potential for dispersion can also be restricted through the use of control measures such as silt curtains.

The resuspension of sediments during dredging has the potential to result in the introduction of contaminants into the dissolved phase of the water column. Once in the dissolved phase, released contaminants can be subject to migration, by tidal currents for example, and can therefore result in different exposures and risks compared to the release of contaminants attached to suspended sediment particles. Based on the elutriate test results carried out for the project and the assessed

available natural dilution, however, water quality impacts at the dredging site due to contaminants in resuspended sediments entering the dissolved phase would not be expected.

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 bucket (environmental clamshell) and the use of silt curtains to minimise the spread of potentially contaminated material. Specific environmental 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 impacts for:
  - Saltwater intrusion
  - Contaminant migration from contaminated sites
  - Groundwater dependent ecosystems
  - 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

Maximum groundwater inflow rates would generally occur when new sections of the tunnels are excavated and measures to mitigate inflows (such as tunnel linings) have not yet been installed. Greatest inflow rates are predicted to occur either side of the harbour crossing before the lining of the surrounding tunnel in 2025.

Groundwater inflows into the tunnel (ie tunnel inflows) were calculated for five time periods during the construction phase, as shown in Table 16-11. These predicted flows are unconstrained, in that no tunnel linings to reduce groundwater inflow have been assumed in the modelling. Peak inflows of 1.39 litres per second per kilometre (L/s/km) averaged over the whole tunnel were predicted to occur in 2025. The largest predicted inflows would be associated with the caverns at Flat Rock Drive and Northbridge, due to inflows from a palaeovalley at this location, and the transition structures connecting to the immersed tube tunnels in Middle Harbour. Total inflows over the construction period would be around 2817 megalitres (ML), with annual inflows during construction peaking at around 899 ML/year in 2025.

It is a design requirement of the project that groundwater inflows be limited to no more than one litre per second per kilometre on average and measures to achieve this requirement would be progressively installed during construction. Proposed measures to reduce, collect and dispose of tunnel inflows during construction are summarised in Section 16.7.

Table 16-11 Summary of modelled average tunnel inflows during construction (cumulative scenario)

Year	Cammeray/ Artarmon to Middle Harbour	Middle Harbour to Balgowlah/ Wakehurst Parkway	Entire project		Total annual inflows
	(L/s/km)	(L/s/km)	(L/s/km)	(ML/day)	(ML/year)
2023	0.70	0.12	0.41	0.75	275
2024	1.14	0.33	0.73	1.34	488
2025	1.54	1.23	1.39	2.46	899
2026	1.01	0.84	0.93	1.64	598
2027	0.90	0.83	0.87	1.53	557

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 seven 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 the tunnel construction (end of 2027) and are presented in Figure 16-11.

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, the maximum drawdown is predicted to be around 28 metres immediately overlying the tunnel centreline in the Northbridge area. Predicted drawdown propagates away from the tunnels, with the drawdown extending up to around 0.5 kilometres northwards in the Willoughby/Chatswood area, and extending southwards up to around 0.4 kilometres in the Crows Nest area. North of Middle Harbour, the drawdown would be slightly lower, with the maximum predicted drawdown of 16 metres between Seaforth and Balgowlah. It is noted that these groundwater drawdown predictions are conservatively based on unconstrained inflows into the tunnel. As measures would be installed to restrict groundwater inflow to no more than one litre per second per kilometre, actual drawdown levels and extents would likely be less than these predictions.

A review of current groundwater use has been conducted to identify registered groundwater users within the vicinity of the predicted extent of groundwater level drawdown (refer to Figure 16-11). Of the 17 groundwater bores all but three bores (GW107970, GW108224 and GW108991) are predicted to experience less than one metre of drawdown during construction and would therefore not be impacted by the project.

Modelling predicts that the maximum drawdown would be seven metres at GW107970, up to five metres at GW108224 and up to three metres at GW108991 for the cumulative (including the Sydney Metro City & Southwest and the Western Harbour Tunnel and Warringah Freeway Upgrade project) case. The drawdown at these bores (for the cumulative case) exceeds the minimal impact consideration of the NSW Aquifer Interference Policy (a drawdown impact of more than two metres at any water supply works). In accordance with the NSW Aquifer Interference Policy, further assessment is required and would be carried out to fully assess the predicted impact and identify any required make good provisions.

The first bore, GW107970, is 199 metres deep with a water level of 110 metres below ground level. Modelling predicts that the cumulative maximum drawdown at the bore would be up to seven metres in 2028, which equates to about eight per cent of available drawdown and is therefore not anticipated to cause significant impact to the groundwater supply.

The second bore, GW108224, is 132 metres deep and may be targeting a horizon of the Hawkesbury Sandstone from around 70 metres deep to the base of the bore. The interpreted pre-project groundwater table lies at about 42 metres below ground level in the vicinity of this bore. Therefore, a groundwater head of 90 metres is expected to be available within the bore. A groundwater level depressurisation of five meters equates to a change in of less than six per cent of the available head at the bore and is therefore anticipated to cause negligible impact to the groundwater supply.

The third bore, GW108991 is about 168 metres deep and may also be targeting a horizon of the Hawkesbury Sandstone. The interpreted pre-project groundwater table lies at about three metres below ground level in the vicinity of this bore. Therefore, a groundwater head of 165 metres is expected to be available within the bore. A groundwater level depressurisation of three metres at the bore equates to a change of less than two per cent of the available head and is therefore anticipated to cause negligible impact to the groundwater supply.

Measures to manage impacts at these bores are outlined in Section 16.7.

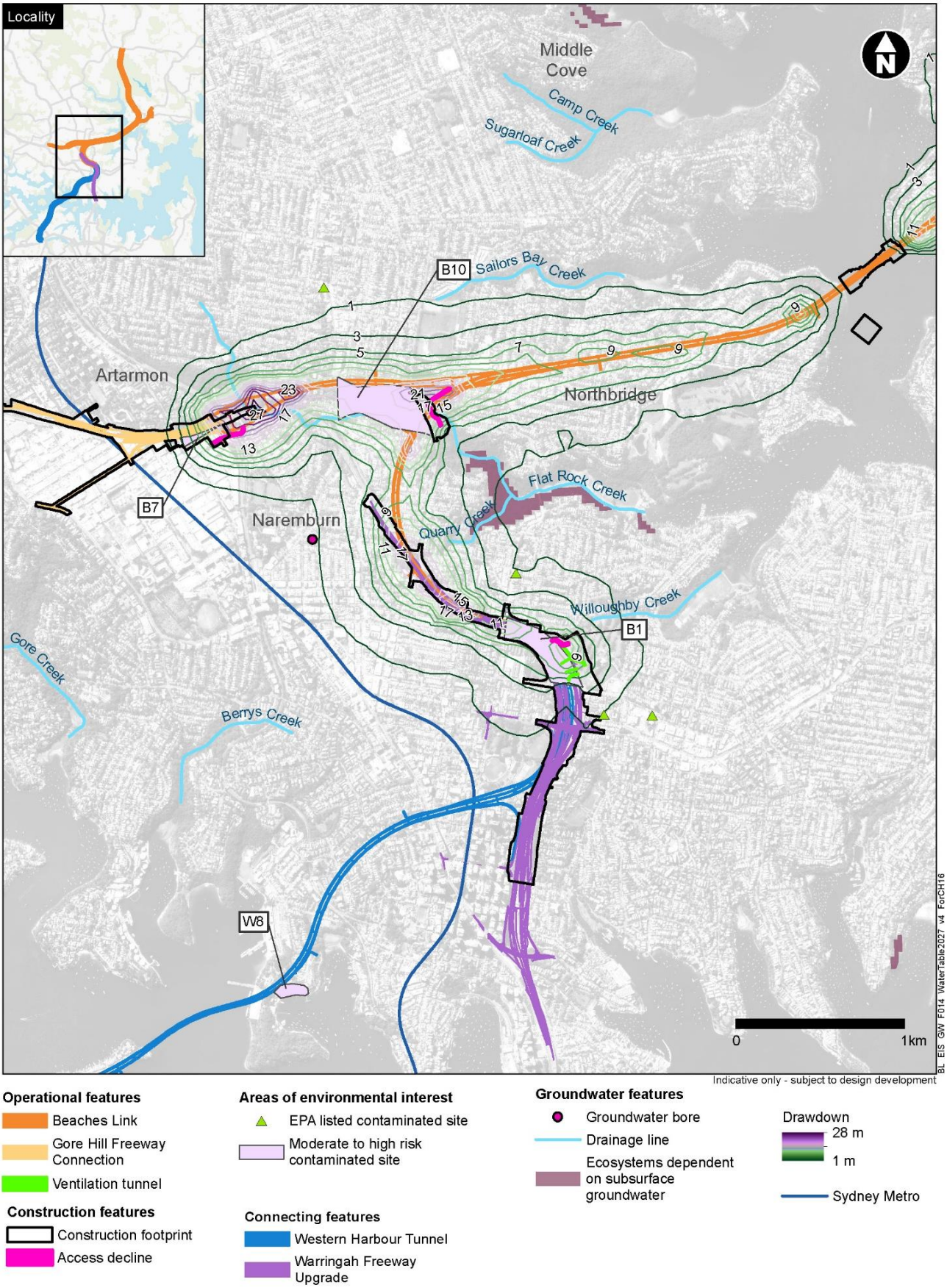


Figure 16-11 Predicted groundwater drawdown contours for the project at the end of tunnel construction (2028) – South of Middle Harbour

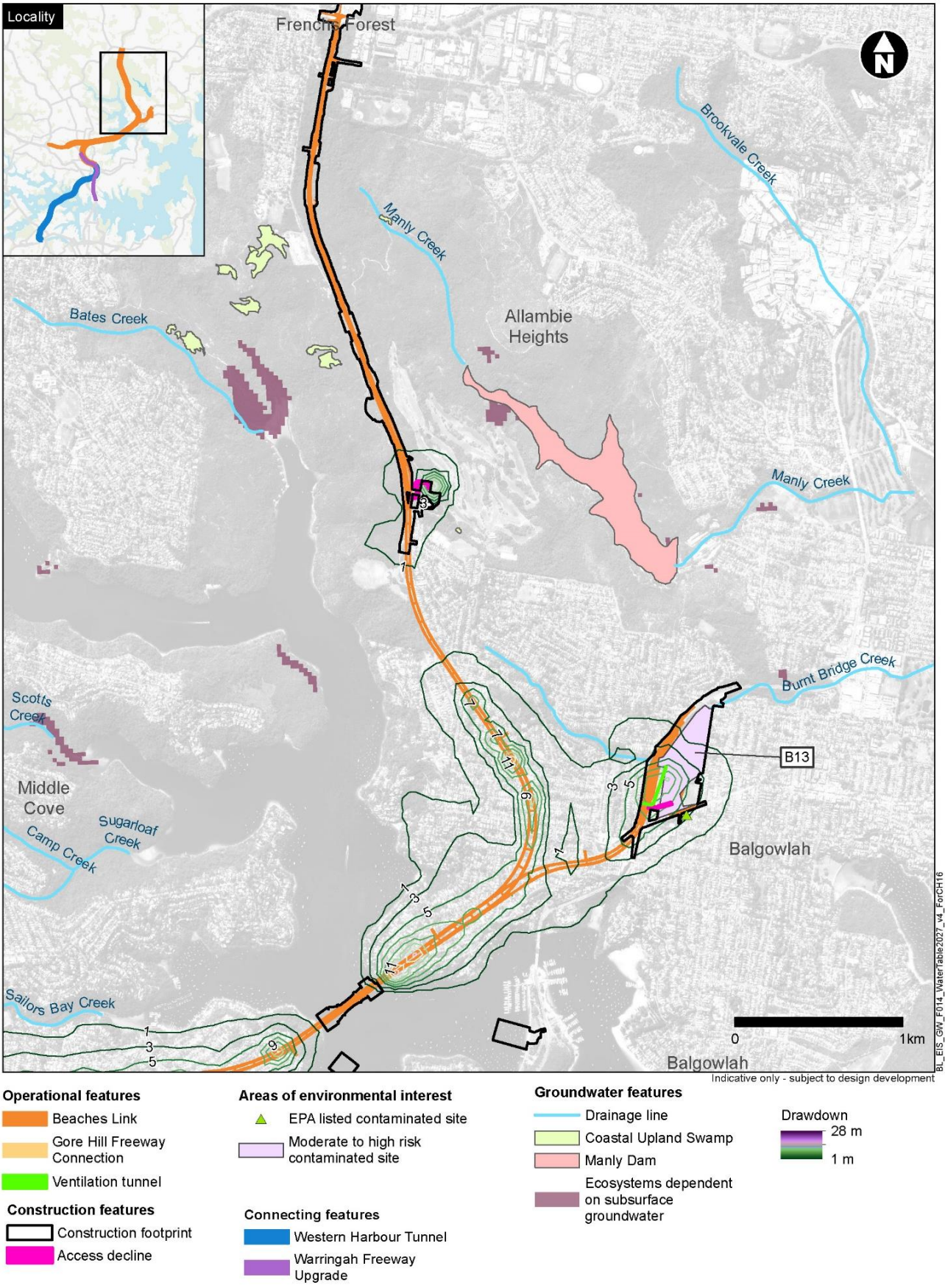


Figure 16-12 Predicted groundwater drawdown contours for the project at the end of tunnel construction (2028) – North of Middle Harbour

Saltwater intrusion

Aquifers adjacent to the harbour foreshore might experience saltwater intrusion as the hydraulic pressure between the aquifer and the harbour is reduced during drawdown, allowing saltwater to enter the aquifer. Depending on the extent of saltwater intrusion it could reduce the beneficial uses of the aquifer for existing users.

Additionally, saltwater intrusion into tunnels could occur during construction, which would increase saltwater loads requiring management and disposal.

Groundwater quality impacts due to saltwater intrusion, however, 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 impact to the groundwater bores (GW108224 and GW108991) located in Naremburn and Lane Cove respectively, which are separated from the shoreline by the tunnel, and the groundwater dependent ecosystem identified at Flat Rock Creek/Munro Park (Section 16.3.4).

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. Drawdown at potentially contaminated sites is shown in Table 16-12 and is based on the water quality guidelines from the NSW Aquifer Interference Policy (NSW DPI, 2012a), 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 Beaches Link and Gore Hill Freeway Connection project in isolation) and 'cumulative' (Beaches Link and Gore Hill Freeway Connection project and other neighbouring proposed construction projects) scenarios are presented in Table 16-12 for areas of environmental interest for contamination within 500 metres of the project alignment with moderate or high risk.

Table 16-12 Predicted drawdown at areas of environmental interest for contamination at the end of tunnel construction (2028)

Area of environmental interest	Predicted drawdown – project only (metres)	Predicted drawdown – cumulative (metres)
Unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray	Up to 13	Up to 17
Punch Street at Artarmon	Up to 19	Up to 19
Flat Rock Reserve at Northbridge	Up to 21	Up to 21
Willoughby Leisure Centre and Bicentennial Reserve at Willoughby	Up to 22	Up to 22
Balgowlah Golf Course at Balgowlah	Up to 11	Up to 11
Waverton Park – Woolcott Road, Waverton	Less than 1	Up to 12

If contaminants are mobilised from unsealed areas next to Warringah Freeway (eastern side by Cammeray Golf Course) at Cammeray; the Willoughby Leisure Centre and Bicentennial Reserve; Punch Street, Artarmon; or Balgowlah Golf Course at Balgowlah, they would travel towards the tunnel during construction. During construction, groundwater inflows would be collected and treated at the construction wastewater treatment plants.

Predicted drawdown is highest at the Willoughby Leisure Centre and Bicentennial Reserve, within both the 'project only' and 'cumulative' scenarios, and is up to approximately 22 metres as parts of this site are located immediately above the proposed tunnel centrelines. There is potential for contaminants associated with the former use of the land as a waste disposal area to migrate into areas of good quality groundwater and reduce the possible benefits of its use in such areas.

The levels of drawdown at Waverton Park during construction would be minor for the 'project only' scenario and would not be expected to cause significant migration of contaminants and contaminant migration into areas of good quality groundwater is unlikely to occur. Under the cumulative scenario, drawdown at Waverton Park would be largely due to the effect of the Western Harbour Tunnel and Warringah Freeway Upgrade project. The movement of groundwater would be towards the Western Harbour Tunnel and would be collected and treated at the water treatment plants established for that project.

The rate of contaminant migration would depend predominantly on the hydraulic conductivity at the area of environmental interest for contamination, contaminant viscosity and the hydraulic gradient at the site, but over the construction period a drawdown of this magnitude would cause migration of contaminants.

Given the relatively small predicted change in total water head within bores GW107970, GW108224 and GW108991, and the fact that these bores lie upgradient of direction of potential contaminant migration towards the tunnels from areas of environmental interest, the groundwater quality at these bores is not expected to be changed due to the project.

Contaminant migration caused by drawdown from the tunnel has the potential to degrade water quality more than 40 metres from the tunnel. The only groundwater dependent ecosystem in the vicinity of these areas of environmental interest is that which is present at the upper reaches of Flat Rock Creek and Quarry Creek in the vicinity of the Willoughby Leisure Centre and Bicentennial Reserve. This groundwater dependent ecosystem is not expected to be impacted by contaminant migration since the potentially contaminated fill area at this area of environmental interest is immediately overlying the tunnels and would therefore drain towards the tunnels and away from the groundwater dependent ecosystem, which would therefore satisfy the requirements of the NSW Aquifer Interference Policy (NSW DPI, 2012a).

Groundwater dependent ecosystems and sensitive environments

Four groundwater dependent ecosystems or sensitive environments occur within the area of predicted drawdown as shown in Table 16-13. Within the exception of the vegetation at Flat Rock and Quarry Creek, groundwater drawdown is predicted to be less than one metre at all these locations. Drawdown for the vegetation at Flat Rock and Quarry Creek is predicted to be less than five metres, however, has the potential to impact the groundwater dependent ecosystems at that location. The potential magnitude of these impacts is discussed further in Chapter 19 (Biodiversity) and Appendix S (Technical working paper: Biodiversity development assessment report). It is noted that these predicted drawdowns are based on unconstrained tunnel inflows and a model containing limited data which assumes full hydraulic connection in the hydrogeological layers between the identified groundwater dependent ecosystems and the underlying rock, which may not be the case. Additionally, due to the very low existing baseflows along Quarry Creek and the existing geomorphologies, the predicted baseflow reductions are unlikely to have any substantial ecological impacts.

Further studies will occur during development of the detailed design to confirm potential groundwater drawdown at Flat Rock Creek and associated potential impacts to the groundwater dependent ecosystem. Where unacceptable ecological impacts are predicted, feasible and reasonable mitigation measures to address the impacts will be identified, incorporated into the detailed design, and implemented during construction(refer to Section 16.7 and Chapter 19 (Biodiversity)).

Table 16-13 Predicted drawdown and impact at groundwater dependent ecosystems and sensitive environments at the end of tunnelling construction (2028)

Receptor	Location	Drawdown – project only (m)	Drawdown – cumulative (m)
Vegetation at Flat Rock and Quarry Creek	Northbridge	Up to 4	Up to 5
Vegetation at Bates Creek	Bates Reserve/Garigal National Park, Killarney Heights	Less than 1	Less than 1
Manly Dam Reserve	Manly Dam Reserve, Allambie Heights	Less than 1	Less than 1
Coastal Upland Swamp[1]	Bates Reserve/Garigal National Park, Killarney Heights	Less than 1	Less than 1

Note 1: Coastal Upland Swamp is not a groundwater dependent ecosystem but is considered a sensitive environment for the purposes of this assessment.

Activation of acid sulfate soils

Lowering of the groundwater table has the potential to expose acid sulfate soils top oxygen, which might result in oxidation and acid generation. Activation of acid sulfate soil has potential to alter groundwater quality by lowering pH and elevating heavy metal content. Acidic groundwater might impact the integrity of underground structures and the tunnel structure itself. The acidity and associated heavy metal content might also affect the quality of groundwater inflow to the tunnels which would be managed through the wastewater disposal process.

Outside of the harbour areas, potential areas of acid sulfate soil risk would be associated with low lying and estuarine sediments in the lower reaches of Flat Rock Creek and in Middle Harbour. Predicted drawdown extents during the construction period do not reach any areas of potential acid sulfate soil risk.

16.4.6 Groundwater quality

Potential construction impacts on groundwater quality due to saltwater intrusion, mobilisation of contaminants and potential acidification are discussed in Section 16.4.5.

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 road header
- Particulate material from tunnelling activities leading to an increase in suspended solids
- Cement pollution arising from shotcrete application, grouting or in-situ casting of concrete.

These potential contaminant sources are low risk and groundwater inflows are predicted to be generally towards and into the tunnel, limiting the potential for contamination of groundwater adjacent to the tunnel due to the tunnels. 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.

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 following requirements:

- The relevant physical and chemical stressors set out in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality ANZECC/ARMCANZ, 2000), and

- The ANZG (2018) 90 per cent species protection levels for toxicants generally, with the exception of those toxicants known to bioaccumulate, which will be treated to meet the ANZG (2018) 95 per cent species protection levels, and
- The draft ANZG default guideline values for iron (in fresh and marine water) and zinc (in marine water) for which public comments are under consideration as of November 2020.

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 environmental management measures implemented on site and the nature of the receiving environment.

Further discussion on accidental spills is included in Chapter 23 (Hazard 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 levels 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 for:
  - Saltwater intrusion
  - Contaminant migration from contaminated sites
  - Groundwater dependent ecosystems
  - 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).

The modelling of operational impacts has assumed that the tunnels are not lined (except for a 125 metre section on either side of Middle Harbour) and therefore provides a relatively conservative estimate of groundwater inflows to the tunnels and associated groundwater level drawdown.

Tunnel inflows

Inflows during operation were calculated for two time periods the first year of operation in 2028, and after 100 years of operation (2128) (refer to Table 16-14). Tunnel inflows would diminish over time as the groundwater system reaches equilibrium.

Peak operational inflows of 0.86 litres per second per kilometre averaged over the whole tunnel are predicted to occur at the beginning of operation (2028). After 100 years of operation, inflows would decline to 0.69 litres per second per kilometre. This would be below the adopted criterion of one litre per second per kilometre. Predicted annual inflows would be around 551 megalitres per year in the first year of operation (2028), falling to 436 megalitres per year after 100 years. The predicted peak annual tunnel inflows would be less than two per cent of the water unassigned under the long term average annual extraction limit.

Table 16-14 Summary of modelled average tunnel inflow during operation

Year	Cammeray to Middle Harbour	Middle Harbour to Wakehurst Parkway	Entire project		Total annual inflows
	(L/s/km)	(L/s/km)	(L/s/km)	(ML/day)	(ML/year)
2028	0.88	0.83	0.86	1.51	551
2128	0.58	0.80	0.69	1.20	436

Groundwater Drawdown

Groundwater modelling has been used to predict groundwater levels after 100 years of operation (2128). Predicted groundwater drawdown at the commencement of operation is the same as that at the end of construction and therefore not reported here (refer to Table 16-11 for more information).

After 100 years of operation, the drawdown increases in comparison to the 2028 case (refer to Figure 16-13) in the Northbridge area, where predicted drawdown would be up to 36 metres, while in and around Seaforth and Balgowlah it would be up to 16 metres. Additional modelling was carried out for the tunnel beneath Flat Rock Reserve. The additional modelling assumed a lined section of tunnel with no inflows to reduce potential drawdown in the fill materials present along Flat Rock Creek. With the linings assumed, the predicted water table drawdown is predicted to be up to eight metres less than predicted without the lining (ie up to 28 metres).

With the exception of six bores identified below, other groundwater bores within the vicinity of the project footprint are predicted to experience less than one metre of drawdown during operation and would therefore not be impacted by the project.

Predicted drawdown at the following six bores is predicted to exceed the minimal impact consideration of the NSW Aquifer Interference Policy, as follows:

- GW023150 is recorded as less than two metres deep which may be an error in the record. Modelling predicts that drawdown at this bore would be up to three metres in 2128 (cumulative case). If this bore were to rely on shallow groundwater, water availability at this bore could be impacted
- GW026513 is about 64 metres deep with a water level of about 6 metres. Modelling predicts that the cumulative maximum drawdown at this bore would be up to two metres in 2128, which equates to about three per cent of available drawdown (water head) within the bore and is therefore anticipated to cause negligible impact to the groundwater supply.
- GW072478 is around 180 metres deep with a water level of about 48 metres below ground level. Modelling predicts that drawdown at this bore would be up to three metres in 2128 (cumulative case), which equates to about five per cent of available drawdown and is therefore anticipated to cause negligible impact to the groundwater supply
- GW107970 is 199 metres deep with a water level of 110 metres. Modelling predicts that the cumulative maximum drawdown at the bore would be up to 13 metres in 2128, which equates to about 15 per cent of available drawdown and is therefore not anticipated to cause significant impact to the groundwater supply.
- GW108224 is 132 metres deep with a water level of 35 metres below ground level. Modelling predicts that drawdown at the bore would be up to 11 metres in 2128 (cumulative case), which equates to about 11 per cent of available drawdown and is therefore anticipated to cause negligible impact to the groundwater supply
- GW108991 is 168 metres deep with a water level about 13 metres below ground level. Modelling predicts that drawdown at this bore would be up to four metres in 2128 (cumulative case), which equates to less than three per cent of available drawdown and is therefore anticipated to cause negligible impact to the groundwater supply.

It is, therefore, unlikely that the predicted drawdown at GW026513, GW072478, GW107970, GW108224 and GW108991 would detrimentally affect the operation of the bores. Further investigations are required to determine the potential for impact to GW023150 and to identify appropriate mitigation and rectification measures for implementation as required.

There are no groundwater dependent culturally sensitive sites within the predicted drawdown extents, therefore drawdown from the project would not affect these receptors and they have not been assessed further. Impacts to groundwater dependent ecosystems are discussed below.

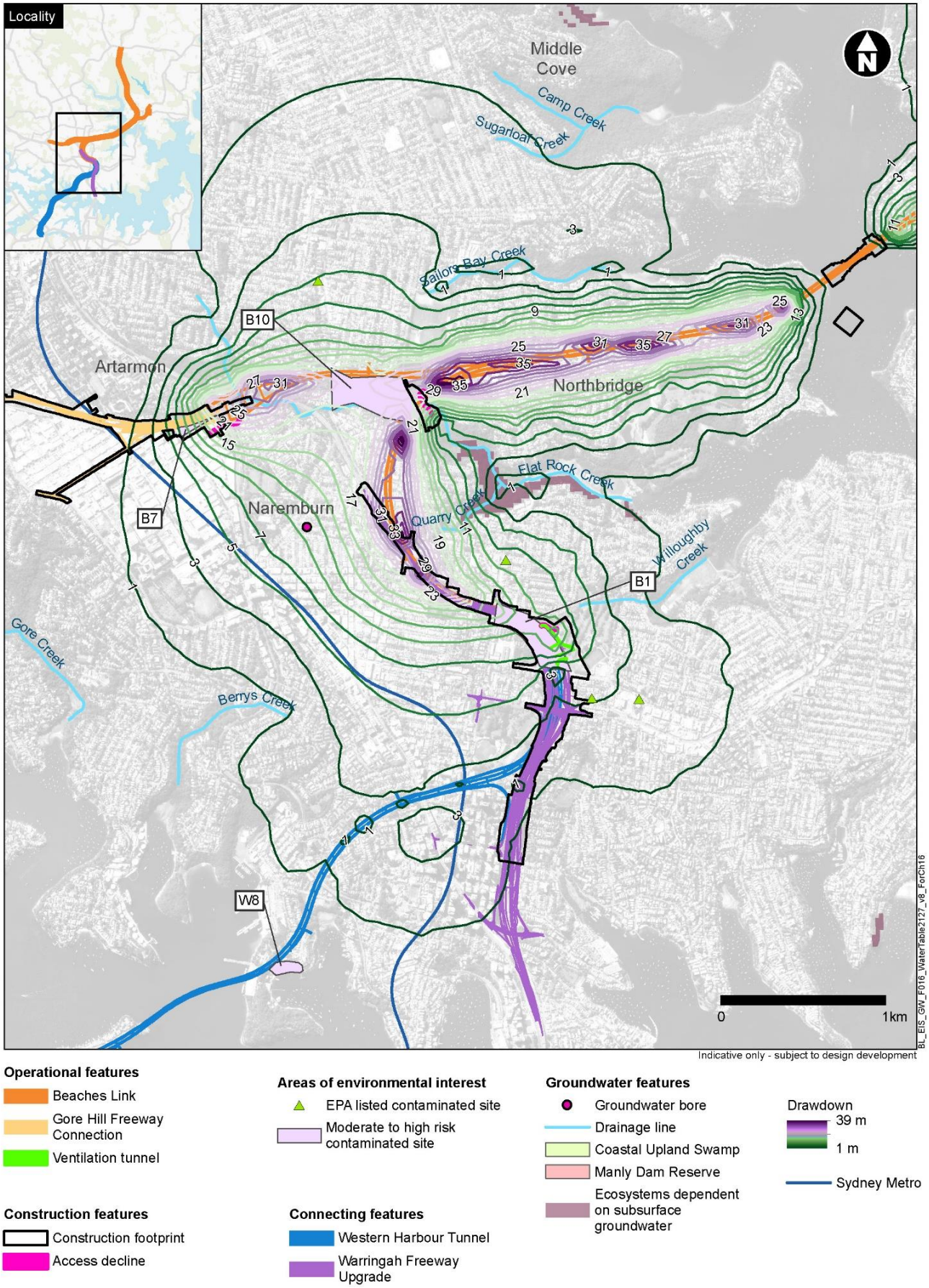


Figure 16-13 Groundwater drawdown contours for the project during operation in 2128 – South of Middle Harbour

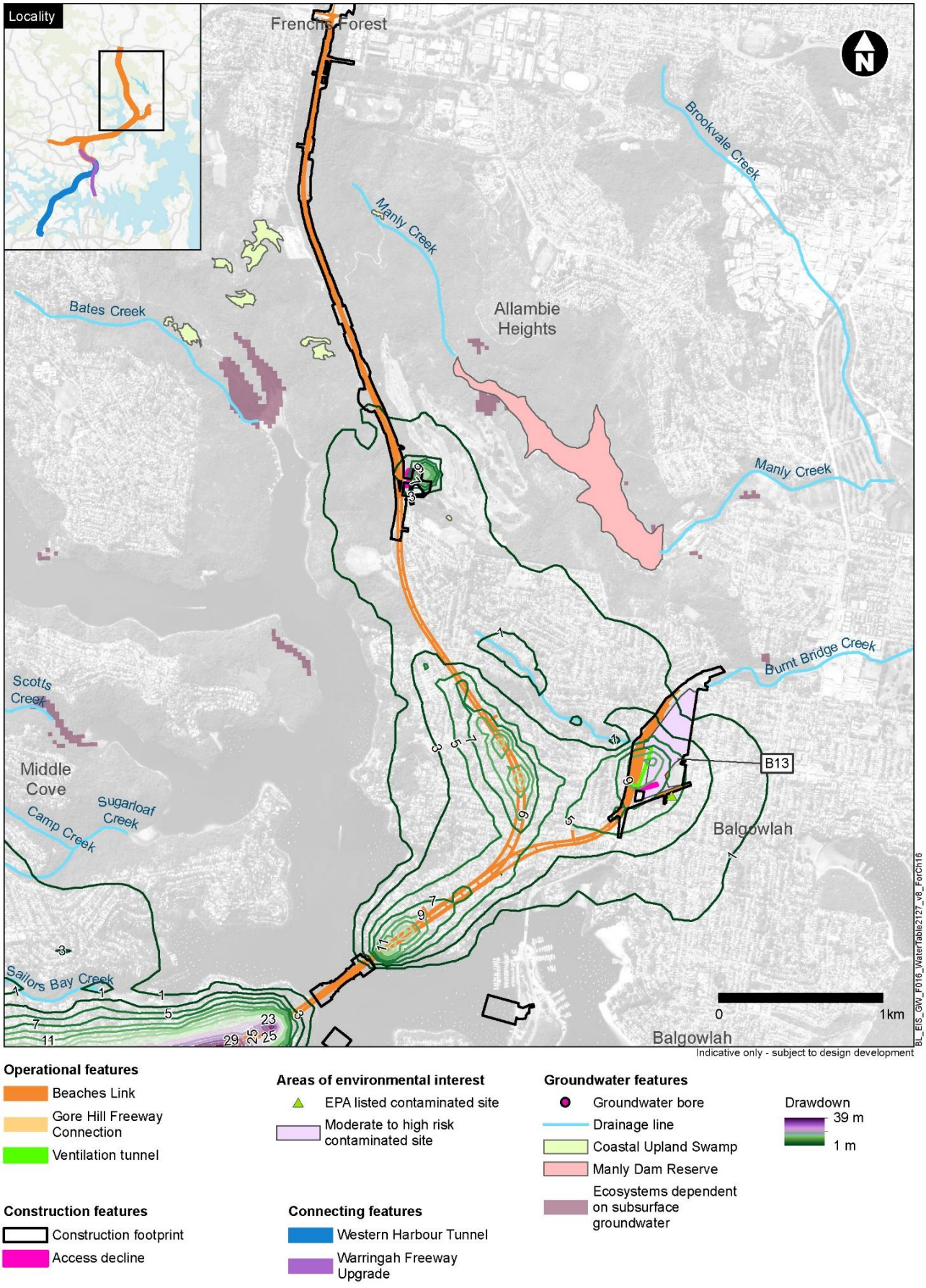


Figure 16-14 Groundwater drawdown contours for the project during operation in 2128 – North of Middle Harbour

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.

Both the lateral and upward movement of the saline interface along the modelled cross-section is predicted to be negligible after 100 years of project operation. Therefore, impacts to groundwater users, groundwater dependent ecosystems and the beneficial use of the aquifer as a result of saltwater intrusion are not expected.

Contaminant migration from contaminated sites

Predicted drawdown at areas of environmental interest for contamination during operation in 2028 (first year of operation) and 2128 (100 years after operation commencement) are shown in Table 16-15.

Table 16-15 Predicted drawdown at areas of environmental interest for contamination during operation in 2028 and 2128

Area of environmental interest	Drawdown – project only 2028 (m)	Drawdown – project only 2128 (m)	Drawdown – cumulative 2028 (m)	Drawdown – cumulative 2128 (m)
Unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray	Up to 13	Up to 13	Up to 17	Up to 19
Punch Street at Artarmon	Up to 19	Up to 21	Up to 19	Up to 21
Willoughby Leisure Centre and Bicentennial Reserve at Willoughby	Up to 22	Up to 27	Up to 22	Up to 27
Balgowlah Golf Course at Balgowlah	Up to 11	Up to 11	Up to 11	Up to 11
Waverton Park – Woolcott Road, Waverton	Less than 1	Less than 1	Up to 12	Up to 13

The rate of migration would depend predominantly on the hydraulic conductivity at the contaminant location, contaminant viscosity and the hydraulic gradient at the site.

Contaminant migration caused by drawdown from the tunnel has the potential to degrade water quality more than 40 metres from the tunnel. Given the relatively small predicted change in total water head within bores GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991, and the fact that these bores lie upgradient of direction of potential contaminant migration towards the tunnels from areas of environmental interest, the groundwater quality at these bores is not expected to be modified due to the project.

The only groundwater dependent ecosystem in the area is at the upper reaches of Flat Rock Creek and Quarry Creek. This location is not expected to be impacted by contaminant migration since the potentially contaminated fill area is immediately overlying the project tunnels and would therefore drain towards the tunnels and away from the groundwater dependent ecosystem, which would satisfy the requirements of the NSW Aquifer Interference Policy (NSW DPI, 2012a).

If contaminants are mobilised towards the tunnel during operation, the quality of groundwater inflows would pose a potential human health risk and could impact the integrity of the construction materials. This risk would be managed through the ongoing monitoring of groundwater inflow quality and groundwater levels and quality. All groundwater inflows would be collected and treated at the Gore Hill Freeway wastewater treatment plant.

Groundwater dependent ecosystems and sensitive environments

As shown in Table 16-16, drawdown is predicted to be less than one metre at the Coastal Upland Swampland, the vegetation at Bates Creek and Manly Dam Reserve. Potential cumulative drawdown is predicted to be up to 12 metres for parts of the groundwater dependent ecosystem at Flat Rock Creek and Quarry Creek. Groundwater inflows to the tunnels would however be collected, treated and discharged into Flat Rock Creek which would partially offset the predicted baseflow reduction.

The predicted groundwater drawdown in the vicinity of Flat Rock Creek and Quarry Creek has the potential to impact the groundwater dependent ecosystem at that location. The potential magnitude of these impacts is discussed further in Chapter 19 (Biodiversity) and Appendix S (Technical working paper: Biodiversity development assessment report). It is noted that these predictions are based on unconstrained groundwater inflows into the tunnels and a model containing limited data which assumes full hydraulic connection in the hydrogeological layers between the identified groundwater dependent ecosystems and the underlying rock, which may not be the case. Additionally, due to the very low existing baseflows along Quarry Creek and the existing geomorphologies, the predicted baseflow reductions are unlikely to have any substantial ecological impacts.

The other groundwater dependent ecosystems in the project area are outside the predicted drawdown extents.

Further studies will occur during development of the detailed design to confirm potential groundwater drawdown at Flat Rock Creek and associated potential impacts to the groundwater dependent ecosystem. Where unacceptable ecological impacts are predicted, feasible and reasonable mitigation measures to address the impacts will be identified, incorporated into the detailed design, and implemented during construction (refer to Section 16.7 and Chapter 19 (Biodiversity)).

The closest listed Ramsar wetland of international importance is the Towra Point Nature Reserve, located 17 kilometres south of the project. Towra Point Nature Reserve and would not be impacted by the project.

Table 16-16 Predicted drawdown and impact at groundwater dependent ecosystems and sensitive environments during operation (2028 and 2128)

Receptor	Location	Drawdown – project only 2028 (m)	Drawdown – project only 2128 (m)	Drawdown – cumulative 2028 (m)	Drawdown – cumulative 2128 (m)
Vegetation at Flat Rock and Quarry Creek	Northbridge	Up to 4	Up to 11	Up to 4	Up to 12
Vegetation at Bates Creek	Bates Reserve/Garigal National Park, Killarney Heights	Less than 1	Less than 1	Less than 1	Less than 1

Receptor	Location	Drawdown – project only 2028 (m)	Drawdown – project only 2128 (m)	Drawdown – cumulative 2028 (m)	Drawdown – cumulative 2128 (m)
Manly Dam Reserve	Manly Dam Reserve, Allambie Heights	Less than 1	Less than 1	Less than 1	Less than 1
Coastal Upland Swamp	Bates Reserve/Garigal National Park, Killarney Heights	Less than 1	Less than 1	Less than 1	Less than 1

Activation of acid sulfate soils

Modelling indicates that water table drawdown could occur within sediments immediately adjacent to the waters of Middle Harbour, where the tunnel alignment crosses Middle Harbour. However, these sediments are expected to remain saturated (due to constant recharge from harbour waters) and are not expected to experience oxidation due to the project beyond historical levels.

Therefore, impacts to groundwater dependent ecosystems, sensitive sites and groundwater users from acid sulfate soils are considered unlikely.

16.5.3 Groundwater quality

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

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

During operation groundwater inflows would be transferred to a wastewater treatment plant prior to disposal to stormwater. For operation, the project would be designed to comply with the following discharge criteria:

- The relevant physical and chemical stressors set out in of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000), and
- The ANZG (2018) 95 per cent species protection levels for toxicants generally, with the exception of those toxicants known to bioaccumulate, which will be treated to meet the ANZG (2018) 99 per cent species protection levels, and
- The draft ANZG default guideline values for iron (in fresh and marine water) and zinc (in marine water) for which public comments are under consideration as of November 2020.

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 (NSW DPI, 2012a) have been used for the purposes of assessment (refer to Table 16-17).

Table 16-17 Minimal harm criteria assessment

Minimal harm criteria	Assessment
Water table	
Level 1 Less than or equal to 10 per cent cumulative variation in the water table, allowing for typical climatic "post water sharing plan" variations, 40 metres from any: • 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.	Schedule 4 of the *Water Sharing Plan for the greater Metropolitan Region Groundwater Sources 2011* (NSW DPI, 2011a) 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 drawdown could exceed two metres at bores GW107970, GW108224 and GW108991 during both construction and operation (refer to sections 16.4 and 16.5). Impact minimisation measures are discussed below.
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.	Groundwater modelling has predicted that drawdown could exceed two metres at bores GW107970, GW108224, GW108991 during both construction and operation and GW023150, GW026513 and GW072478 during operation. The initial assessment, however, indicates that predicted drawdown due to the project would have a negligible impact on water availability at affected bores. Environmental management measures are detailed in Section 16.7.
Water pressure	
Level 1 A cumulative pressure head decline of not more than a two metre decline, at any water supply work.	Investigation and environmental management measures to address impacts at the bores GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991 are proposed in Section 16.7.

Minimal harm criteria	Assessment
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.	The current viability of the bores is uncertain, but if it is proven, monitoring would be carried out. If impacts are realised, the make good provisions would be applied (if required) to either maintain the long term viability of the bores or to provide an alternative supply or compensation.
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 from the project activities would be minor, and as the tunnel inflows create a hydraulic gradient towards the tunnel, and any contamination mobilised or caused by the works would flow back towards the tunnel rather than away from it. Contaminants associated with the project would therefore remain within 40 metres of the tunnel. Drawdown caused by the tunnel may cause contamination of groundwater more than 40 metres 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 NSW Aquifer Interference Policy (NSW DPI, 2012a) would not be satisfied. Impact minimisation measures are discussed in Section 16.7.
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 are not likely to impact the long term viability of groundwater dependent ecosystems or culturally significant sites as no sites exist within the area of drawdown surrounding the tunnel.
Additional considerations	
… any advice provided to a gateway panel, the Planning and Assessment Commission or the Minister for Planning 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	The level of predicted drawdown does not present a substantial risk of 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 additional areas of acid sulfate soils are identified, measures to mitigate impacts will be needed.

Minimal harm criteria	Assessment
• 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.	There is no risk of water logging or water table rise since the tunnel would be drained during both construction and operation. The only tanked structures would be short distances either side of the harbour. Waterlogging or damming of groundwater flow is not expected to occur since the hydraulic gradient by the time the sections of the tunnel are tanked would cause flow towards the drained sections of the tunnel

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 16-18).

Table 16-18 Compliance with water sharing plan rules

Water sharing plan rule	Assessment
Part 7 – Rules for granting 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 899 ML/year during construction, and up to 551 ML/year during operation need to be assigned under the long term average annual extraction limit.
Part 8 – Rules for managing access licences	
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 four bores (GW023150, GW072478, GW108224 and GW108991) that may be impacted by drawdown. Viability of water access at these bores is not expected to be impacted, with the potential exception of bore GW023150 if it is found to be viable and it relies on shallow groundwater.
Distance restriction from the property boundary is 50 metres	The project is within 50 metres of property boundaries and would result in drawdown at adjacent 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 adjacent properties.

Water sharing plan rule	Assessment
Distance restriction from an approved water supply work is 100 metres	There are no approved water supply works within 100 metres of the project. Supply bores GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991 are within the area of drawdown, but make good provisions would apply where required, as discussed above.
Distance restriction from a Department observation bore is 200 metres	The Department of Regional NSW does not have any observation bores within 200 metres of the project, or within the area of drawdown surrounding the project.
Distance restriction from an approved work nominated by another access licence 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 Appendix M (Technical Working Paper: Contamination) the NSW Environment Protection Authority notified contaminated sites have been identified as relevant to the project under the description of contaminated sites in Schedule 3 of the Water Sharing Plan. A water supply works approval must not be granted within: • 250 metres of contaminant plumes associated with these sites • 250 to 500 metres of these sites as long as no drawdown would 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. 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.
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: • 200 metres of a high priority groundwater dependent ecosystem • 500 metres of a karst groundwater dependent ecosystem • 40 metres from a lagoon or escarpment (Section 4.3). The project is within 40 metres of a first/second order stream (Flat Rock Creek/Quarry Creek), but as it is more than 30 metres deep and within the underlying parent material it satisfies the requirements of the Water Sharing Plan.

Water sharing plan rule	Assessment
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 distance restrictions	As the potential supply bores (GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991) and the areas of environmental interest for contamination may be within restricted distances, the proponent must not take more water than specified 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 16-19.

Table 16-19 Environmental management measures - geology, soils and groundwater

Ref	Phase	Impact	Environmental management measure	Location
SG1	All phases	Groundwater drawdown and quality	The existing groundwater monitoring program for both groundwater levels and quality will be continued through construction. Outcomes of updated groundwater modelling (environmental management measure SG2) will identify any requirements for further groundwater monitoring during the operational phase.	BL/GHF

Ref	Phase	Impact	Environmental management measure	Location
SG2	All phases	Groundwater drawdown	As more information becomes available on groundwater levels through ongoing groundwater monitoring, groundwater modelling will be updated to refine the predictions. Inflow predictions will be updated prior to finalising detailed design and will include designed tunnel linings, and the detailed design will be updated based on the updated operational inflow and impact predictions. If refined predictions of groundwater levels and drawdown indicate that impacts would be greater than the impacts presented in the environmental impact statement, feasible and reasonable mitigation measures will be incorporated into the detailed design and implemented. Groundwater modelling will be conducted considering A*ustralian Groundwater Modelling Guidelines* (Barnett et al., 2012), including sensitivity analysis and consideration of future climate change, as required.	BL/GHF
SG3	All phases	Impact to registered groundwater bores	The viability of the following domestic bores will be confirmed prior to construction. • GW023150 • GW026513 • GW072478 • GW107970 • GW108224 • GW108991 If drawdown at the bore exceeds two metres (in accordance with the NSW Aquifer Interference Policy (NSW DPI, 2012a)) and impacts to the ongoing use of the bores are unacceptable, 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 impacts to the bore 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.	BL/GHF

Ref	Phase	Impact	Environmental management measure	Location
SG4	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.	BL/GHF
SG5	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 requirements.	BL/GHF
SG6	Pre-construction	Water table drawdown impact on baseflow and groundwater dependent ecosystems	A focussed study will be carried out to confirm potential groundwater drawdown and associated baseflow reductions at Burnt Bridge Creek, Flat Rock Creek and Quarry Creek due to tunnelling, and confirm potential impacts on freshwater ecology in the affected watercourses and nearby groundwater dependent ecosystems. The study will consider how existing site features affect the interaction between surface water and groundwater along the affected reaches of these watercourses, and the hydraulic connectivity in the underlying geology. Where unacceptable ecological impacts are predicted, feasible and reasonable mitigation measures to address the impacts will be identified, incorporated into the detailed design, and implemented during construction. The mitigation measures considered will include tunnel linings.	BL

Ref	Phase	Impact	Environmental management measure	Location
SG7	Pre-construction, construction	Ground movement impacts	Pre-construction building structure condition surveys will be offered and prepared (where the offer is accepted by the owner) for properties (and heritage assets) within the zone of influence of tunnel settlement where the degree of severity has been assessed as 'slight' or above and within the minimum working distances for cosmetic and structural damage due to vibration. The surveys will be carried out by a suitably qualified person prior to the commencement of the tunnelling and vibration intensive activities in the vicinity with the potential to affect the building/structure. Within three (3) months of the completion of construction activities that have the potential to cause settlement or vibration-related damage to the subject surface/subsurface structure, all property owners of buildings for which a pre-construction building condition survey was carried out will be offered a second building condition survey. Where an offer is accepted, a post-construction building condition survey will be carried out by a suitably qualified person. The results of the survey will be documented in a post-construction building condition survey report for each building surveyed. Copies of building condition survey reports will be provided to the owners of the buildings surveyed within one (1) month of the survey being completed. Any building and/or property damage from settlement caused by the project will be repaired at no cost to the owner. Any repairs to listed heritage items required as a result of the settlement damage, will be carried out under the guidance of a suitably qualified and experienced heritage professional.	BL/GHF

Ref	Phase	Impact	Environmental management measure	Location
SG8	Pre-construction and 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 further 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 environmental interest in the project footprint, including: • Warringah Freeway (from North Sydney to Cammeray) • Punch Street, Artarmon • Willoughby Leisure Centre and Bicentennial Reserve, Willoughby • Flat Rock Reserve, Northbridge • Spit West Reserve, Mosman • Balgowlah Golf Course, Balgowlah • Wakehurst Parkway (from Seaforth to Frenchs Forest). Subject to the outcomes of the investigations, a Remediation Action Plan will be implemented in the event that site remediation is warranted. The Remediation Action Plan will be prepared in accordance with *Managing Land Contamination: Planning Guidelines SEPP 55 – Remediation of Land* (Department of Urban Affairs and Planning and Environment Protection Authority, 1998). If Remediation Action Plan(s) are required for works at Flat Rock Drive (BL2), Balgowlah Golf Course (BL10) construction support sites and surface works and construction support site locations along the Wakehurst Parkway (BL12, BL13 and BL14) these will be developed with consideration of environmental management measure WM6. An independent NSW EPA Accredited Site Auditor will be engaged where contamination is complex to review applicable contamination reports and evaluate the suitability of sites for a specified use as part of the project.	BL/GHF

Ref	Phase	Impact	Environmental management measure	Location
SG9	Construction	Erosion and sedimentation	Erosion and sediment control measures will be implemented at all work sites and surface road upgrades in accordance with the principles and requirements in *Managing Urban Stormwater – Soils and Construction, Volume 1* (Landcom 2004), *Managing Urban Stormwater: Volume 2D Main Road Construction* (NSW Department of Environment and Climate Change, 2008) and relevant guidelines, procedures and specifications of Transport for NSW. A soil conservation specialist will be engaged for the duration of construction of the project to provide advice regarding erosion and sediment control including review of Erosion and Sediment Control Plans.	BL/GHF
SG10	Construction	Impacts on site workers and/or local community through disturbance and mobilisation of contaminated material	Asbestos handling, management and disposal will be carried out in accordance with relevant legislation, codes of practice and Australian standards.	BL/GHF
SG11	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 structures. Demolition works will be carried out in accordance with the relevant Australian Standards and relevant NSW WorkCover Codes of Practice, including the Work Health and Safety Regulation 2011 (NSW) to minimise potential exposure of construction personnel and the public to hazardous materials.	BL/GHF
SG12	Construction	Impacts on site workers and/or local community through disturbance and mobilisation of contaminated material	A Construction Waste Management Plan will be prepared and implemented during construction. The plan will include but not be limited to procedures for handling and storing potentially contaminated substances.	BL/GHF

Ref	Phase	Impact	Environmental management measure	Location
SG13	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 contamination discovery procedure, as outlined in the *Guideline for the Management of Contamination* (Roads and Maritime Services, 2013).	BL/GHF
SG14	Construction	Impacts from disturbance of acid sulfate soils	Prior to ground disturbance in high risk acid sulfate areas at Spit West Reserve and Middle Harbour, 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, 1998).	BL
SG15	Construction	Ground gas impacts	Ground gas investigations will be carried out in Flat Rock Reserve to further assess the potential presence of 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, 2012).	BL
SG16	Construction	Groundwater drawdown during operation	Measures will be implemented during tunnel construction to ensure that groundwater inflows during the operation phase do not exceed 1L/s/km on average over the entire tunnel length.	BL
SG17	Construction	Marine contamination impacts	The appropriateness of offshore disposal will be assessed in accordance with the Australian Government Department of Agriculture, Water and the Environment's *National Assessment Guidelines for Dredging* (Department of Environment, Water, Heritage and the Arts, 2009). Offshore disposal will only occur for material that meets the criteria provided in the guidelines.	BL

Ref	Phase	Impact	Environmental management measure	Location
SG18	Construction and operation	Groundwater drawdown	The groundwater monitoring program will consider additional locations for monitoring that are 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.	BL/GHF
SG19	Construction and operation	Groundwater quality impacts	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.	BL/GHF
SG20	Construction and operation	Contamination due to leakage or spills	Emergency procedures, including material bunding and appropriately sized spill containment kits, 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.	BL/GHF

Note: BL = Beaches Link, GHF = Gore Hill Freeway