NSW GOVERNMENT

Transport for NSW

Beaches Link and Gore Hill Freeway Connection

Chapter 14

Non-Aboriginal heritage

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DECEMBER 2020

14 Non-Aboriginal heritage

This chapter describes the potential non-Aboriginal heritage impacts associated with the project and identifies measures which address these impacts. Detailed non-Aboriginal heritage assessments have been carried out for the project and are included in Appendix J (Technical working paper: Non-Aboriginal heritage) and Appendix K (Technical working paper: Maritime heritage).

The Secretary's environmental assessment requirements as they relate to non-Aboriginal heritage, and where in the environmental impact statement these have been addressed, are detailed in Table 14-1 (Secretary's environmental assessment requirements checklist).

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 proposed environmental management measures relevant to non-Aboriginal heritage are included in Section 14.5.

Table 14-1 Secretary's environmental assessment requirements – Non-Aboriginal heritage

Secretary's requirement	Where addressed in EIS
1. The Proponent must identify and assess any direct and/or indirect impacts (including cumulative, vibration and visual impacts) to the heritage significance of listed (and nominated) heritage items inclusive of: c. environmental heritage, as defined under the *Heritage Act 1977* (including potential items of heritage value, conservation areas, open space heritage landscapes, build heritage landscapes and archaeology); d. items listed on the State, National and World Heritage lists; e. heritage items and conservation areas identified in local regional planning environmental instruments covering the project area; and f. marine items of potential heritage significance within Middle Harbour, such as any shipwrecks.	A summary of listed heritage items within the study area is presented in **Section 14.3**. Consideration of direct and/or indirect impacts (including potential item of heritage value, conservation areas, open space heritage landscapes, built heritage landscapes and archaeology) to the heritage significance of listed (and nominated) heritage items are presented in **Section 14.4.2**. Further details are provided in **Appendix J** (Technical working paper: Non-Aboriginal heritage). **Section 14.4.3** includes assessment of maritime items of potential heritage significance within Middle Harbour. Further details are provided in **Appendix K** (Technical working paper: Maritime heritage).
2. Where impacts to State or locally significant heritage items or archaeology are identified, the assessment must: a. Include a significance assessment and statement of heritage impact for all heritage items (including any unlisted places that are assessed of heritage value); b. Provide a discussion of alternative locations and design options that have	Significance assessment and statements of heritage impact are presented in **Section 14.4**, and **Section 4** of **Appendix J** (Technical working paper: Non-Aboriginal heritage). A discussion of alternative locations and design options are outlined in **Section 14.4.1,** and **Section 5.1**, **Section 5.2** and **Section 5.4** of **Appendix J** (Technical working paper: Non-Aboriginal heritage) and **Section 4.4** and

Secretary's requirement	Where addressed in EIS
been considered to reduce heritage impacts; c. in areas identified as having potential archaeological significance, undertake a comprehensive archaeological assessment and management plan in line with Heritage Council guidelines which includes a methodology and research design to assess the impact of the works on the potential archaeological resource and to guide physical archaeological test excavations and include the results of these excavations. This is to be carried out by a suitably qualified archaeologist and is to discuss the likelihood of significant historical, maritime and Aboriginal archaeology on the site, how this may be impacted by the project, and includes measures to mitigate any impacts; d. consider impacts to the item of significance caused by, but not limited to, vibration, demolition, archaeological disturbance, altered historical arrangements and access, increased traffic, visual amenity, landscape and vistas, curtilage, subsidence and architectural noise treatment (as relevant); e. provide a comparative analysis to inform the rarity and representative value of any heritage places proposed for demolition; f. outline mitigation measures to avoid and minimise identified impacts in accordance with the current guidelines; and g. be undertaken by a suitably qualified heritage consultant(s) (note: where archaeological excavations are proposed the relevant consultant must meet the NSW Heritage Council's Excavation Director criteria).	**Section 4.5** of **Chapter 4** (Project development and alternatives). Mitigation measures are presented in **Section 14.5** which includes consideration of areas identified as having potential archaeological significance. Discussion of impacts as a result of vibration, demolition, archaeological disturbance, altered historical arrangements and access, increased traffic, visual amenity, landscape and vistas, curtilage, subsidence and architectural noise treatment (as relevant) are provided in **Section 14.4** and **Section 5.2** to **Section 5.4** of **Appendix J** (Technical working paper: Non-Aboriginal heritage). A comparative analysis is not required for the reasons stated in **Appendix J** (Technical working paper: Non-Aboriginal heritage). This is summarised in **Section 14.4.2**. Environmental management measures are presented in **Section 14.5**. **Section 14.2** and **Section 1.4** of **Appendix J** (Technical working paper: Non-Aboriginal heritage) provides details of qualification held by heritage consultants.

14.1 Legislative and policy framework

The *Heritage Act 1977* (the Heritage Act) is the primary piece of State legislation affording protection to all items of environmental heritage (natural and cultural) in NSW. Under the Heritage Act, "items of environmental heritage" include places, buildings, works, relics, moveable objects and precincts identified as having heritage significance based on historical, scientific, cultural, social, archaeological, architectural, natural or aesthetic values. Items of identified heritage at a level of State significance are listed on the NSW State Heritage Register and are afforded automatic protection against any activities that may damage an item or affect its heritage significance under the Heritage Act.

The Heritage Act also provides protection for 'relics', which includes archaeological material or deposits. Sections 139 to 145 of the Heritage Act prevent the excavation or disturbance of land known or likely to contain relics, unless under an excavation permit. However, the project is subject to Division 5.2 (State significant infrastructure) provisions of the *Environmental Planning and Assessment Act 1979*, and therefore excavation or exception permits would not be required.

For the purposes of the Heritage Act, the State of NSW also includes the bed of the harbour and the water column up to three nautical miles from the coast. Shipwrecks currently under the jurisdiction of the Heritage Act are identified in the Historic Shipwrecks Register, maintained by the NSW Heritage Council. Part 3C of the Heritage Act also contains specific provisions for the protection of shipwrecks more than 75 years old. This section is included in the Act to provide a link to and consistency with the *Historic Shipwrecks Act 1976* (Commonwealth).

The *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) (Commonwealth) applies to those items which are of World, Commonwealth or National heritage significance. Significant impact to World or National heritage items constitute a matter of national environmental significance and require a referral to the Minister for Environment and Energy.

The *Environmental Planning and Assessment Act 1979* establishes the framework for cultural heritage values to be formally assessed in the land use planning and development consent process. The *Environmental Planning and Assessment Act 1979* requires that environmental impacts are considered before land development; this includes impacts on cultural heritage items and places as well as archaeological sites and deposits.

The requirement to consider potential impacts on Non-Aboriginal heritage is given effect through the following guidelines:

- United Nations Educational, Scientific and Cultural Organisation Convention on the Protection of the Underwater Cultural Heritage (UNESCO, 2001)
- Australia International Council on Monuments and Sites *Charter for Places of Cultural Significance (Burra Charter)* (Australia ICOMOS, 2013)
- *NSW Heritage Manual* (NSW Heritage Office and Department of Urban Affairs and Planning, 1996) including the following sections:
    - *Investigating History* – used in carrying out research into historical context and history of individual heritage items
    - *Investigating Fabric* – used in surveying and recording individual heritage items
- *Assessing Heritage Significance* (NSW Heritage Office, 2001) – updated section of 1996 *NSW Heritage Manual* used to review existing significance assessment and carry out significance assessment for new heritage items
- *Investigating Heritage Significance* (draft guideline) (NSW Heritage Office, 2004) – updated section of *NSW Heritage Manual* used to carry out significance assessment for new heritage items
- *Statements of Heritage Impact* (NSW Heritage Office, 2002) – used in preparation of Statements of Heritage Impact
- *Guidelines for the Management of Australia's Shipwrecks* (Australian Institute for Maritime Archaeology Inc. and the Australian Cultural Development Office, 1994)
- *Criteria for the Assessment of Excavation Directors* (NSW Heritage Council, 2011)
- *Cultural Heritage Guidelines* (Roads and Maritime Services, 2015a).

14.2 Assessment methodology

Impacts on heritage are defined as either:

- Direct impacts, resulting in a planned and intentional physical change to a heritage item from project activities within the heritage item boundary
- Potential direct impacts, resulting from incidental physical impacts occurring as a result of activities adjacent to or within the heritage item boundary
- Indirect impacts, resulting in changes to the heritage item or its surroundings from project activities outside of the heritage boundary, such as vibration, settlement, visual impacts, social impacts, impacts to landscapes and vistas, changes to ongoing use, changed associations, or change to access.

The level of impact on the heritage significance of each heritage item in the study area has been assessed as major, moderate, minor or negligible based on the definitions and framework for assessing severity of impacts from the *EPBC Act Significant Impact Guidelines 1.2* (Department of Sustainability Environment Water Population and Communities, 2013). Where the heritage significance of an item is unknown, such as for potential maritime heritage items identified during field surveys and investigations, items have been assigned a heritage sensitivity level which combines heritage potential of the item with its potential significance.

A Statement of Heritage Impact has been prepared for each State or locally significant terrestrial heritage item impacted by the project in accordance with the *Statements of Heritage Impact guidelines* (NSW Heritage Office, 2002). Where relevant, the impact assessment has incorporated Commonwealth heritage guidelines including *Matters of National Environmental Significance Significant Impact Guidelines 1.1* (Commonwealth of Australia Department of the Environment, 2013).

For the purpose of the heritage assessments, all areas within 50 metres of the project construction footprint have been considered (the study area). The maritime heritage assessment is limited to the immersed tube tunnel alignment between Northbridge and Seaforth, the area around the Middle Harbour south and Middle Harbour north cofferdams (BL7 and BL8), the area around the Spit West Reserve construction support site (BL9) and the temporary mooring facility east of Clive Park in Middle Harbour (refer to Chapter 6 (Construction work)).

The terrestrial and maritime heritage assessments have been informed by searches of NSW and Commonwealth heritage registers and supplemented by a literature review of previous assessments and heritage studies. Heritage items and areas of archaeological potential not already identified on registers are also identified as part of the assessment. Field surveys were carried out in May, June, September and December 2017, August 2018, and March 2020 by qualified heritage specialists to inspect items of known heritage value and areas of potential heritage value.

Further detail on the assessment methodology is provided in Appendix J (Technical working paper: Non-Aboriginal heritage) and Appendix K (Technical working paper: Maritime heritage).

14.3 Existing environment

14.3.1 Historical context of the project area

North Sydney to Cammeray

At the time of European arrival, the North Shore area of Sydney was inhabited by the *Cammeraygal* (also known as *Gamaraigal* and *Kameragal*) with groups camped at Milsons Point, Manly and Lane Cove (Morris, 1986). The first record of contact with Aboriginal people in this area was on the Lane Cove River in 1788 and later in Middle Harbour.

Between the 1790s and 1831, thousands of hectares of land were granted to politicians, merchants, ex-convicts, and settlers (North Sydney Council, n.d.-a). The Township of St Leonards (now North Sydney) was gazetted in 1838, and its town centre was established in the same year. By the mid-1880s, the township had a commercial and civic centre, a tramline, and a ferry wharf at Milsons Point, which boosted development. A tramline extension was added along Falcon Street

from North Sydney to Crows Nest in 1893, which was replaced by an electric tramline in 1898, attracting a larger population to the area (Godden Mackay, 1994).

The opening of the Sydney Harbour Bridge in 1932 transformed the township into a large commercial area and a popular shopping destination, and saw a marked increase in land values (City of Sydney, 2016a; Warne, 2005). By the 1960s, many townhouses and apartments were built in an effort to house the population. During the 1970s and 1980s, commercial growth accompanied residential development, and the 1990s and 2000s saw a substantial increase in population (City of Sydney, 2016a).

The Cammeray area was slow to develop due to its steep topography and remote location, with little growth in the area until the early 1900s when the tramline was extended along Miller Street (North Sydney Council, 2012a; 2012b; n.d.-b). In 1886, the mayor of St Leonards dedicated a portion of land as a reserve, comprising present-day Cammeray Park, Cammeray Golf Course, Green Park, and ANZAC Park (North Sydney Council, 2016).

Cammeray and Artarmon to Northbridge

The first land grant in Artarmon was made in 1810, with new settlers establishing farms, market gardens, and orchards in the area during the 1850s. Brick making began in the area in 1828 and laid the foundation for the 1950s establishment of the Artarmon Industrial Area (City of Sydney, 2016b; Fallowfield, 2008).

The Municipality of North Willoughby was formally proclaimed in October 1865 and by the 1880s, several tanneries and brickworks had been established in the area (LandArc Pty Limited, 2002; Willoughby District Historical Society Inc, 2011a). Land near Naremburn was one of the first areas settled from 1853, followed by land on the Northbridge Peninsula in the vicinity of Sailors Bay Road in 1855 and 1856 (Willoughby District Historical Society Inc, 2011c).

In the late 19th century and early 20th century, subdivision and development took off first around Artarmon, predominantly driven by the opening of the North Shore Railway (City of Sydney, 2016b; Willoughby District Historical Society Inc, 2011b). Development around Naremburn, Northbridge and Willoughby during the 1920s was driven by the prospective opening of the Sydney Harbour Bridge (Willoughby District Historical Society Inc, 2011c; Willoughby Leisure, n.d.).

More intensive development in the area occurred from the 1960s, and in response, the Willoughby Council initiated the West Artarmon Residential Area Redevelopment Plan to open the way for 0medium and high density buildings, including high-rise residential towers and public housing developments (City of Sydney, 2016b; Willoughby District Historical Society Inc, 2011b). The opening of the Gore Hill Freeway in 1992 separated Artarmon's industrial area in the south from its residential area in the north (Willoughby City Library Services, 2013).

Middle Harbour

The first recorded European visitation of Middle Harbour occurred soon after the arrival of the First Fleet, however settlement in the surrounding area was slow to develop as it was not attractive for agricultural activities (Godden Mackay, 1991).

The waterway gradually became a thoroughfare and crossing point for people travelling between Sydney and settlements in the Manly area in the 19th century, and for the transportation of goods such as timber logs and harvested oysters (Technical working paper: Maritime heritage (2020); Godden Mackay, 1991). The first ferry service across Middle Harbour from The Spit to Clontarf was established in 1849 and was taken over by the Government in the late 1880s (Sturrock, 1982). The first Spit Bridge was constructed in 1924 and was later replaced with the present bridge in 1958 as development on the northern side of Middle Harbour increased.

Modest commercial maritime activities in Middle Harbour developed through the second half of the 19th century but slowly declined as rail and road networks diverted trade away from small jetties and landings along the foreshore. At this time, the upper areas of Middle Harbour around Bantry Bay were largely undeveloped and were used by the Government as an explosives storage area. From the early 20th century until the mid-1970s, explosives were regularly towed in lighters or

barges to and from a storage facility at Bantry Bay to a specially dedicated wharf at The Spit (Godden Mackay, 1991).

In the early 20th century, Middle Harbour became popular for recreational purposes, with a corresponding increase in the presence of recreational boats, timber jetties, slips, boatsheds and swimming enclosures (Godden Mackay, 1991).

Seaforth to Balgowlah and Frenchs Forest

Initial land grants were made in the 1810s and were typically used for farming. Settlements had been developed around Manly Cove and North Harbour by the 1820s (City of Sydney, 2016c; Manly and Northern Beaches, 2017). Balgowlah was used for the village of North Harbour as early as 1828, although the population remained minimal until the 1880s (City of Sydney, 2016d; 2016e; MacRitchie, 2008). The first Manly Wharf was built in 1856 with a regular ferry service from 1859. Rapid growth took place in the 1880s, and the area became a popular seaside resort (City of Sydney, 2016d).

Settlement in the Frenchs Forest area first began in the 1850s, driven by major timber and milling operations around Bantry Bay (City of Sydney, 2016f; City of Sydney, 2017; City of Sydney, 2016g). Traces of the 1856 bullock track used to haul logs from the sawmills to the wharf are still extant today along a bushwalking track within the Garigal National Park between Bantry Bay and the Wakehurst Parkway (NSW National Parks and Wildlife Service, 2017).

Land within the Warringah area remained rural until the 1880s when some growth occurred and Warringah Council established in 1906 (Warringah Council, 1998). Growth in this area primarily consisted of subdivision for weekenders and holiday homes for tourism and recreational purposes, which was further driven by the early 1900s extension of the tramline and the construction of the Spit and Roseville bridges in 1924 (City of Sydney, 2016h).

There was population expansion in the 1920s after the opening of the Spit Bridge, and the Balgowlah Golf Course was formed in 1925 (Jobling IF, 1996; Manly Library, n.d). Significant development did not occur in the area until the post-war years of the 1950s, when the remaining dairy farms disappeared as the area urbanised (MacRitchie, 2008).

Many apartments and units were constructed in the 1960s and 1970s, and industrial development centred around Frenchs Forest (City of Sydney, 2016g; 2016h). New buildings were established during the mid-1990s, attracting a larger population, (City of Sydney, 2016i).

14.3.2 Heritage items and conservation areas

Listed terrestrial heritage items and conservation areas

Seventy-three items with heritage listings were identified within the study area. This includes four items listed on the State Heritage Register (North Sydney Sewer Vent and St Leonards Park at North Sydney, Tarella (house) at Cammeray, and the Walter Burley Griffin Incinerator at Willoughby), with the remainder being of local heritage significance. There are no heritage items listed on the World Heritage List, National Heritage List or Commonwealth Heritage List in or adjacent to the study area. Heritage items listed within the study area are shown in Figure 14-1 to Figure 14-3. Further detail on heritage items and heritage listings of each item are provided in Appendix J (Technical working paper: Non-Aboriginal heritage).

Additional potential terrestrial heritage items

Four additional items of potential heritage significance were identified during the field investigations. These were ANZAC Park at Cammeray, Henry Lawson's Cave within Flat Rock Gully, Balgowlah Golf Course and Burnie (House) at Balgowlah. ANZAC Park was assessed as being of social value due to the location of the war memorial within the park, and its association with the former North Sydney Tramway Depot and its personnel who served during World Wars I and II. Henry Lawson's Cave was assessed as being of historical and social value due to its association with Henry Lawson and as an amphitheatre for recreational community use. Balgowlah Golf Course was assessed as being of historical value as an example of Sydney's post-World War

I suburban expansion and community desire for recreational activities, and its association with one if its founders, James Sydney Wallace Eve, an Olympic swimmer and Australian sports administrator. The impact of the project on these items is assessed in Section 14.4.2. Burnie (House) did not meet the thresholds for heritage significance for local or state listing.

No additional areas of archaeological potential were identified during the field surveys.

Listed maritime heritage items

Two of the listed heritage items identified within the study area have a maritime heritage component. These are Clive Park Tidal Pool, listed on the Willoughby Local Environment Plan 2013, and Harbour foreshores (Seaforth), listed on the Manly Local Environment Plan 2012.

Further detail on heritage items and heritage listings of each item are provided in Appendix K (Technical working paper: Maritime heritage).

Additional potential maritime heritage items

Three unidentified shipwrecks of potential heritage significance were identified during field surveys at Clive Park, Pearl Bay and Middle Harbour (refer to Figure 14-3). These are considered to be of local heritage significance for their rarity and research potential. As such, the impact of the project on these items has been assessed in Section 14.4.3.

Seven unverified anomalies were identified between Northbridge and Seaforth through review of remote sensing data from field surveys and from review of existing sources (refer to Figure 14-3). These are considered to have low to medium potential heritage sensitivity. As the heritage significance cannot be verified, the impact of the project on these items has been assessed in Section 14.4.3 for completeness.

There is potential within the project construction footprint for archaeological remains to occur, associated with maritime infrastructure, shipwrecks and vessel activity that were not identified during the field surveys due to the limitations of visual and remote sensing investigations. A summary of maritime archaeological potential is provided in Table 14-2.

Table 14-2 Maritime archaeological potential within the study area

Potential archaeological site type	Location		
	Middle Harbour between Northbridge and Seaforth	Middle Harbour and Pearl Bay, west of The Spit	Middle Harbour between Northbridge and Beauty Point
Maritime infrastructure	Certain	Certain	Very unlikely
Shipwrecks	Certain	Certain	Unlikely
Discard	Certain	Certain	Very likely

14.4 Assessment of potential impacts

14.4.1 Impact avoidance and minimisation

As detailed in Chapter 4 (Project development and alternatives), the project has avoided or minimised impacts to heritage in the following ways:

- The majority of the project would be constructed and located underground, avoiding impacts through the subsurface tunneling of the project

- At Cammeray, the construction and permanent footprint for the program of works has been designed to utilise as much as possible the existing Warringah Freeway corridor and to enable the remaining land to continue to function as a recreational area (golf course). Residual land (ie outside operational requirements) would be returned to enable incorporation into the golf course at the completion of constructionAt Middle Harbour, the construction methodology for the project has been selected to avoid direct impacts on foreshore areas, such as Clive Park. Specifically, the use of cofferdams has minimised temporary and permanent impacts to the shoreline and avoids direct impacts to the park
- At the Wakehurst Parkway, project work has been contained within the existing road reserve to avoid direct impact to Bantry Bluff, which is listed on the Manly Local Environmental Plan 2013 as locally significant, and Upper Middle Harbour Area and the Narrabeen Catchment Lagoon, which are listed on the Register of the National Estate for landscape values
- The Wakehurst Parkway east construction support site (BL13) has been designed to avoid direct impacts to key heritage elements of the Bantry Bay Water Pumping Station and the Bantry Bay Reservoir
- Permanent direct impacts to the Manly Dam and surrounds have been avoided. Less than one per cent of the heritage item would be impacted during a short period of the construction phase to reconnect the upgrade works to an existing fire trail / high voltage powerline maintenance access track.

14.4.2 Potential terrestrial heritage impacts

Of the 76 heritage items identified within the study area, 48 items have been identified as not being impacted by the project. These items are located within 50 metres of surface works for the project along the Warringah Freeway corridor and Balgowlah connections in proximity to minor works within the existing road reserve. Impacts on these 48 items would be limited to temporary noise, vibration and/or visual impacts during construction, and managed through the implementation of minimum working distances for vibration intensive construction activities and other standard construction management measures. As such, impacts to these heritage items have not been carried forward for further detailed assessment.

Of the 28 heritage items that would be potentially impacted:

- Three heritage items (Henry Lawson's Cave, Commercial building, and Grant's Wharf (remains)) would be in the vicinity of low impact work and impact to these items from settlement and vibration would be negligible. There would be no impact to one item in the vicinity of low impact work. Temporary and permanent visual impact is also unlikely as the distance to permanent infrastructure and the retained mature vegetation provides a visual barrier to the majority of the project-related infrastructure
- Three heritage items (Bantry Bluff, The Upper Middle Harbour Area, and The Narrabeen Catchment Lagoon) within the study area, that are listed for landscape and natural values, have been identified as subject to negligible impact by the construction or operation of the project. In each case, the work is outside, or just within the curtilage of the item and work would be contained within previously disturbed areas. Mature vegetation would be retained between the construction footprint and heritage curtilage and any impact on the heritage items and their significance would be negligible.

As such, impact to these heritage items has not been carried forward for further detailed assessment.

A heritage assessment for the remaining 22 heritage items and conservation areas that would be potentially impacted is included in Table 14-3, with items shown in Figure 14-1. Heritage items situated above the tunnel alignment or adjacent to surface works have been assessed as groups of heritage items due to their proximity to each other, the similarity of impacts and similarity of mitigation measures.

Two terrestrial heritage items considered in Table 14-3 have maritime heritage elements. These items include:

- Clive Park Tidal Pool
- Harbour foreshores (Seaforth).

These items have been considered in their entirety in Table 14-3, and do not appear in the maritime heritage assessment in Section 14.4.3.

It is noted that as no whole heritage places are proposed for demolition, no comparative analysis was carried out.

Table 14-3 Potential impacts on terrestrial heritage items

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
1	ANZAC Park, Cammeray	Unlisted	Local	Direct impacts: • Planned physical impacts to the heritage item due to the construction of permanent operational infrastructure within the heritage boundary as part of the Western Harbour Tunnel and Warringah Freeway Upgrade project and Beaches Link and Gore Hill Freeway Upgrade program of works.	**Negligible** All work within the heritage boundary would be contained within previously disturbed areas associated with the Western Harbour Tunnel and Warringah Freeway Upgrade project, and would be minor in nature. Views of permanent operational infrastructure would be partially filtered by vegetation and would not affect the visual setting around the war memorial within the park. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be negligible.
				Potential direct impacts: • Potential physical impacts to the heritage item due to operation of construction vehicles and equipment within and in proximity to the heritage boundary.	
				Indirect impacts: • Temporary vibration impacts due to construction activities within the heritage boundary • Temporary and permanent visual impacts due to the construction of permanent operational infrastructure within and adjacent to the heritage boundary.	

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
2	Cammeray Park (including Golf Course), Cammeray	North Sydney Local Environmental Plan 2013	Local	Direct impacts: • Planned physical impacts to the heritage item due to the construction of permanent operational infrastructure within the heritage boundary. Potentially direct impacts: • Potential physical impacts to the heritage items due to operation of construction vehicles and equipment within and in proximity to the heritage boundary. Indirect impacts: • Temporary and permanent visual impacts due to the construction of permanent operational infrastructure within the heritage boundary • Permanent social impacts due to the repurposing of a large section of the heritage item for permanent operational infrastructure • Temporary vibration impacts due to construction activities within the heritage boundary • Slight permanent settlement and ground movement impacts to the heritage item caused by tunnel excavation.	**Moderate** Direct impacts of the project would be contained within areas previously disturbed by the Western Harbour Tunnel and Warringah Freeway Upgrade project. The proposed works would be of small-medium scale and of moderate intensity, with the changes to the heritage item being permanent and irreversible. The heritage item would lose a large portion of its significance as a relatively intact open space. The implementation of the management measures described in Section 14.5 would provide landscape treatments to screen views to operational infrastructure, however the level of impact would still be moderate.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
3	Cammeray Conservation Area, Cammeray	• North Sydney Local Environmental Plan 2013 • Register of the National Estate.	Local	Direct impacts: • Planned physical impacts to the heritage item due to the construction of permanent road infrastructure within and adjacent to the heritage boundary. Potential direct impacts: • Potential physical impacts to the heritage item due to operation of construction vehicles and equipment within and in proximity to the heritage boundary. Indirect impacts: • Temporary and permanent visual impacts due to the construction of permanent operational infrastructure within and adjacent to the heritage boundary • Temporary vibration impacts due to construction activities within and adjacent to the heritage boundary • Very slight permanent settlement and ground movement impacts to the heritage item caused by tunnel excavation.	**Minor** Direct impacts of the project to the heritage item would be minor and would be contained within areas previously disturbed by the Western Harbour Tunnel and Warringah Freeway Upgrade project. However, temporary and permanent visual impacts along the boundary of the conservation area would be moderate to high due to landscape impacts at Cammeray Golf Course and the presence of project-related infrastructure. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be minor.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
4	Tarella, Cammeray	• State Heritage Register • North Sydney Local Environmental Plan 2013 • Register of the National Estate • National Trust of Australia (NSW) Register.	State	Direct impacts: • Physical impact due to the implementation of architectural noise treatments for the heritage item. No potential direct impacts Indirect impacts: • Temporary and permanent visual impacts due to the construction of permanent operational infrastructure within and adjacent to the heritage boundary • Temporary vibration impacts due to construction activities within and adjacent to the heritage boundary • Very slight permanent settlement and ground movement impacts to the heritage item caused by tunnel excavation.	**Negligible** Eligibility for architectural noise treatment for the heritage item would be confirmed during further design development and in consultation with the landowner. Should architectural noise treatment be required, this would be done in such a way to minimise heritage impacts, while preserving owner amenity and heritage values of the item. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be negligible.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
5	St Thomas Rest Park, Crows Nest	• North Sydney Local Environmental Plan 2013 • National Trust of Australia (NSW).	Local	No direct impacts No potential direct impacts Indirect impacts: • Temporary vibration impacts due to construction activities within and adjacent to the heritage boundary • Very slight permanent settlement and ground movement impacts to the heritage item caused by tunnel excavation.	**Negligible** With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be negligible, as the proposed works would remain outside the heritage boundary.
6	Holtermann Estate A Conservation Area, Crows Nest	• North Sydney Local Environmental Plan 2013 • Register of the National Estate.	Local	Direct impacts: • Physical impact due to the implementation of architectural noise treatments for a number of residences within the conservation area. No potential direct impacts Indirect impacts: • Temporary and permanent visual impacts due to the construction of permanent operational infrastructure in proximity to the conservation area • Very slight to slight permanent settlement and ground movement impacts to heritage item within the conservation area caused by tunnel excavation.	**Negligible** Eligibility for architectural noise treatment at a number of residences within the conservation area would be confirmed during further design development and in consultation with the landowner. Should architectural noise treatment be required, this would be done in such a way to minimise heritage impacts, while preserving owner amenity and heritage values of the conservation area. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be negligible.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
7	Artarmon heritage conservation area, Artarmon	Willoughby Local Environmental Plan 2012	Local	Direct impacts: • Physical impacts to the conservation area due to the construction of permanent infrastructure within the heritage boundary. No potential direct impacts Indirect impacts: • Temporary and permanent visual impacts due to the construction of permanent operational infrastructure within and adjacent to the heritage boundary • Temporary vibration impacts due to construction activities within and adjacent to the heritage boundary • Settlement and ground movement impacts to the heritage item caused by tunnel excavation.	**Negligible** Temporary and permanent works within the heritage conservation area would be limited to minor pavement and drainage works and be restricted to previously disturbed areas. Areas impacted by vibration and settlement would be vegetated open space (Artarmon Reserve), with no structures relevant to the heritage listing present. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be negligible.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
8	Clive Park and Tidal Pool, Northbridge	Willoughby Local Environmental Plan 2012	Local	No direct impacts Potential direct impacts • Potential physical impact to the heritage item from anchoring of project maritime vessels on or around the item. Indirect impacts: • Temporary visual impacts due to the construction infrastructure in Middle Harbour in proximity to the heritage item, including cofferdams, cranes and maritime construction vessels • Temporary vibration impacts due to construction activities (eg piling) adjacent to the heritage boundary • Slight permanent settlement and ground movement impacts to heritage item within the conservation area caused by tunnel excavation.	**Minor** The construction methodology for the project has been selected to avoid direct impacts on Clive Park and its immediate foreshore. There is potential for the site to be physically impacted from anchoring by construction related vessels, however this is highly improbable as the area would be marked as a restricted zone. Indirect impacts would occur due to vibration, settlement and temporary changes to the visual setting of the item. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be minor.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
9	Harbour foreshores	Manly Local Environmental Plan 2012	Local	No direct impacts Potential direct impacts: • Potential physical impact to the heritage item from anchoring of project marine vessels on or around the item. Indirect impacts: • Temporary visual impacts due to the construction infrastructure in Middle Harbour in proximity to the heritage item, including cofferdams, cranes and marine construction vessels • Temporary vibration impacts due to construction activities (eg piling) adjacent to the heritage boundary • Slight permanent settlement and ground movement impacts to heritage item within the conservation area caused by tunnel excavation.	**Minor** The construction methodology for the project has been selected to avoid direct impacts on the heritage item. There is potential, for the site to be physically impacted from anchoring by construction related vessels, however this is highly improbable as the harbour foreshores would be marked as restricted zones. Indirect impacts would occur due to vibration, settlement and temporary changes to the visual setting of the item. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be minor.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
10	Balgowlah Golf Course, Balgowlah	Unlisted	Local	Direct impacts: • Physical impacts to significant portions of the heritage item due to the temporary establishment and operation of the Balgowlah Golf Course construction support site (BL10) and the construction of permanent road infrastructure and operational facilities and new and improved open space and recreation facilities. No potential direct impacts Indirect impacts: • Temporary and permanent visual impacts due to the location of the Balgowlah Golf Course construction support site (BL10) and the location of permanent operational facilities within the heritage boundary • Permanent social impacts due to repurposing of the heritage item for construction and operational use, and for use as new and improved open space and recreation facilities.	**Major** The proposed works would be of large scale and major intensity, with portions of the golf course being modified through the construction of the permanent access road, operational infrastructure and new and improved open space and recreation facilities. Changes to the heritage item would be permanent and irreversible as the heritage item would potentially no longer demonstrate its original character as an interwar period golf course. It is noted that for the purposes of the non-Aboriginal heritage impact assessment (see Appendix J (Technical working paper: Non-Aboriginal heritage)), a worst-case scenario approach of demolition has been assumed for the Golf Course club house building. However, further opportunities to retain and repurpose the club house would be investigated through the dedicated consultation process jointly led by Transport for NSW and Northern Beaches Council during further design development which would give the community the opportunity to provide input on the final layout of the new and improved open space and recreation facilities at Balgowlah. The implementation of the management measures described in Section 14.5 would ensure information about the physical nature of the heritage item is recorded, however the level of impact would still be major.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
11	Frenchs Bullock Track, Killarney Heights	Warringah Local Environmental Plan 2011	Local	Direct impacts: • Physical impacts to part of the heritage item due to the construction of permanent road infrastructure within the heritage boundary. Potential direct impacts: • Potential physical impacts to the heritage item due to operation of construction vehicles and equipment within and in proximity to the heritage boundary. Indirect impacts: • Temporary and permanent visual and aesthetic impacts to the heritage item due to roadworks within and in proximity to the heritage boundary • Vibration impacts to the heritage item due to construction activities within the heritage boundary.	**Minor** The proposed works would be of small and localised scale, and low intensity, with a small section of the Frenchs Bullock Track potentially being permanently modified by a slope associated with roadworks extending into the curtilage of the item. If required, works could result in a permanent and irreversible change of up to 20 per cent of the track, the changes would not detrimentally impact the historical and aesthetic significance of the heritage item as the greater majority of the track remains in-situ and would continue to display its historical and aesthetic significance. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be minor. During detailed design and construction planning, the impacts would be re-assessed with a view to redesign shared path connections to the track, thereby minimising the level of impact.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
12	Bantry Bay Water Pumping Station (WPS 122), Killarney Heights	• Warringah Local Environmental Plan 2011 • Sydney Water Section 170 Heritage and Conservation Register	Local	Direct impacts: • Physical impacts within the heritage boundary due to site establishment works and operation of the Wakehurst Parkway east construction support site (BL13). Potential direct impacts: • Potential physical impacts to the heritage item due to operation of construction vehicles and equipment within proximity to the pumping station building. Indirect impacts: • Temporary visual impacts due to the location of the Wakehurst Parkway east construction support site (BL13).	**Minor** The proposed works would be restricted to avoid direct impact to the historic pumping station building. Within the heritage boundary the proposed works would be restricted to small to medium scale low-intensity temporary and reversible activities. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be minor.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
13	Bantry Bay Reservoir (WS 0008), Killarney Heights	• Warringah Local Environmental Plan 2011 • Sydney Water Section 170 Heritage and Conservation Register	Local	Direct impacts: • Physical impacts within the heritage boundary due to site establishment works and operation the Wakehurst Parkway east construction support site (BL13). Potential direct impacts: • Potential physical impacts to the heritage item due to operation of construction vehicles and equipment within and in proximity to the heritage boundary. No indirect impacts	**Minor** The proposed works would be restricted to avoid direct impact to the significant concrete reservoir which is the key heritage element of the heritage item. Within the heritage boundary, the proposed works would be of small-medium scale of low intensity, with the majority of the area being subject to works which are temporary and reversible. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be minor.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
14	Manly Dam and Surrounds, Allambie Heights	• Warringah Local Environmental Plan 2011 • Register of the National Estate.	Local	Direct impacts: • Physical impacts within the heritage boundary due to the construction of permanent road infrastructure within and adjacent to the heritage boundary. Potential direct impacts: • Potential physical impacts within the heritage boundary due to operation of construction vehicles and equipment within and in proximity to the heritage boundary. Indirect impacts: • Temporary and permanent visual impacts due to the location of the Wakehurst Parkway South construction support site (BL13) and the location of permanent operational facilities adjacent to the heritage boundary • Temporary vibration impacts due to construction activities within and adjacent to the heritage boundary • Slight permanent settlement and ground movement impacts within the heritage boundary caused by tunnel excavation.	**Negligible** The vast majority of the heritage item would not be impacted by the project, beyond the single small section of the boundary along the Wakehurst Parkway. Additionally, none of the significant built heritage elements are within close proximity to the Wakehurst Parkway east construction support site (BL13) and are not predicted to experience vibration impacts. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be negligible, as there would be little or no physical impact to the heritage item.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
n/a	Three heritage items situated above the tunnel alignment with potential settlement impacts – Naremburn Central Township (Conservation Area), Walter Burley Griffin Incinerator, street trees along Alan Avenue within Seaforth	Various	State (Walter Burley Griffin Incinerator) / Local (all other items)	No direct impacts No potential direct impacts Indirect impacts: • Temporary vibration impacts due to construction activities within and adjacent to the heritage boundaries • Slight permanent settlement and ground movement impacts to heritage items caused by tunnel excavation.	**Negligible** With the implementation of the management measures described in Section 14.5, the level of impact on the heritage items would be negligible.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
n/a	Five heritage items situated immediately adjacent to surface works – five houses on Ernest Street in Neutral Bay	Various	Local	No direct impacts Potential direct impacts: • Potential physical impacts to the heritage items due to operation of construction vehicles and equipment within and in proximity to the heritage boundary. Indirect impacts: • Temporary and permanent visual impacts due to changes in land use and the construction of permanent operational infrastructure in the vicinity of the heritage items • Temporary vibration impacts due to construction activities within and adjacent to the heritage boundary.	**Negligible** Temporary and permanent visual impacts along the boundary of the conservation area would be moderate to high due to landscape impacts at Cammeray Golf Course and the presence of project-related infrastructure. Permanent impacts would likely reduce over time as replacement landscape planting matures. It is noted there may be direct impacts to the heritage items due to the implementation of architectural noise treatments however, these would be carried out as part of the Western Harbour Tunnel and Warringah Freeway Upgrade project. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage items would be negligible.

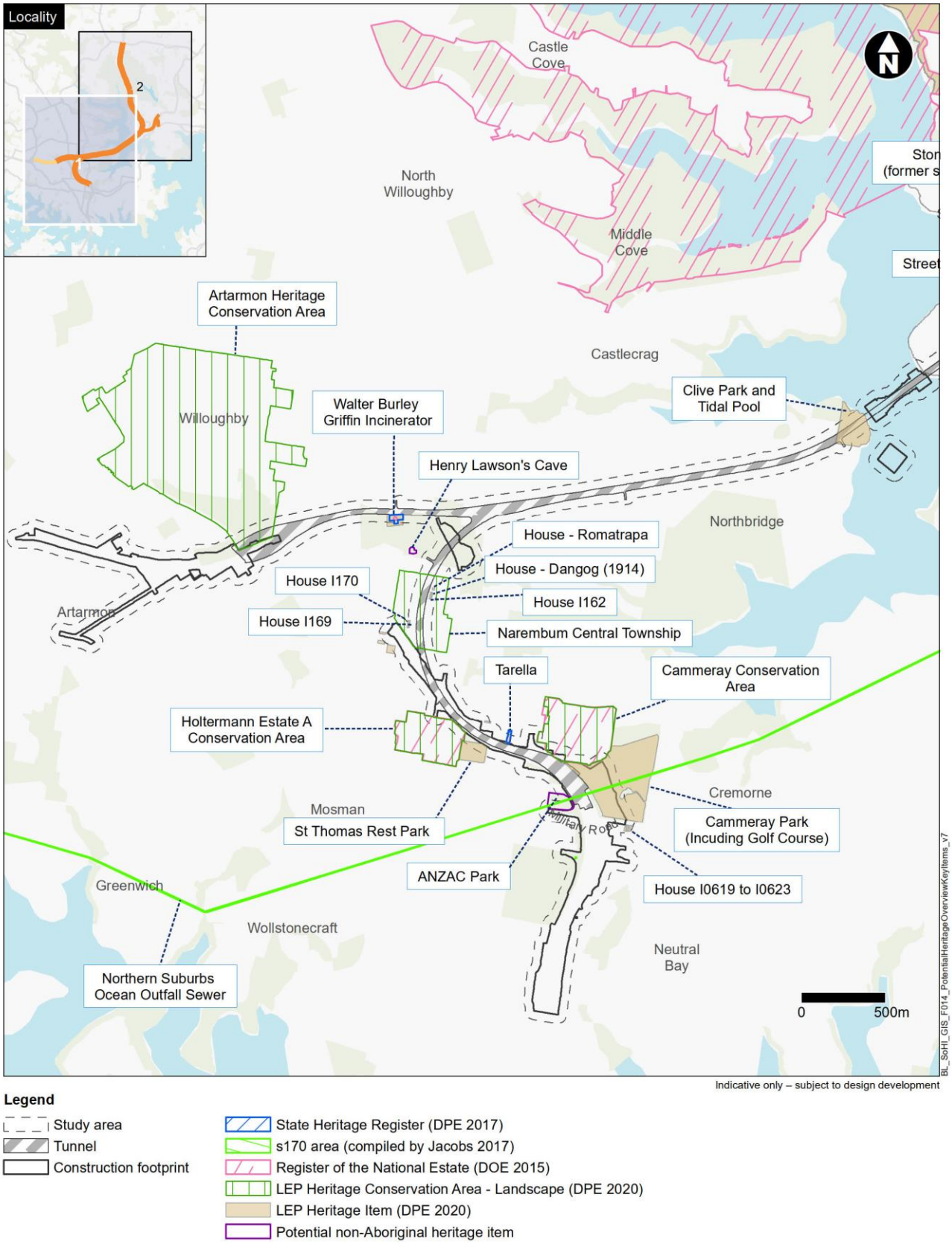

Figure 14-1 Location of terrestrial heritage items impacted by the project

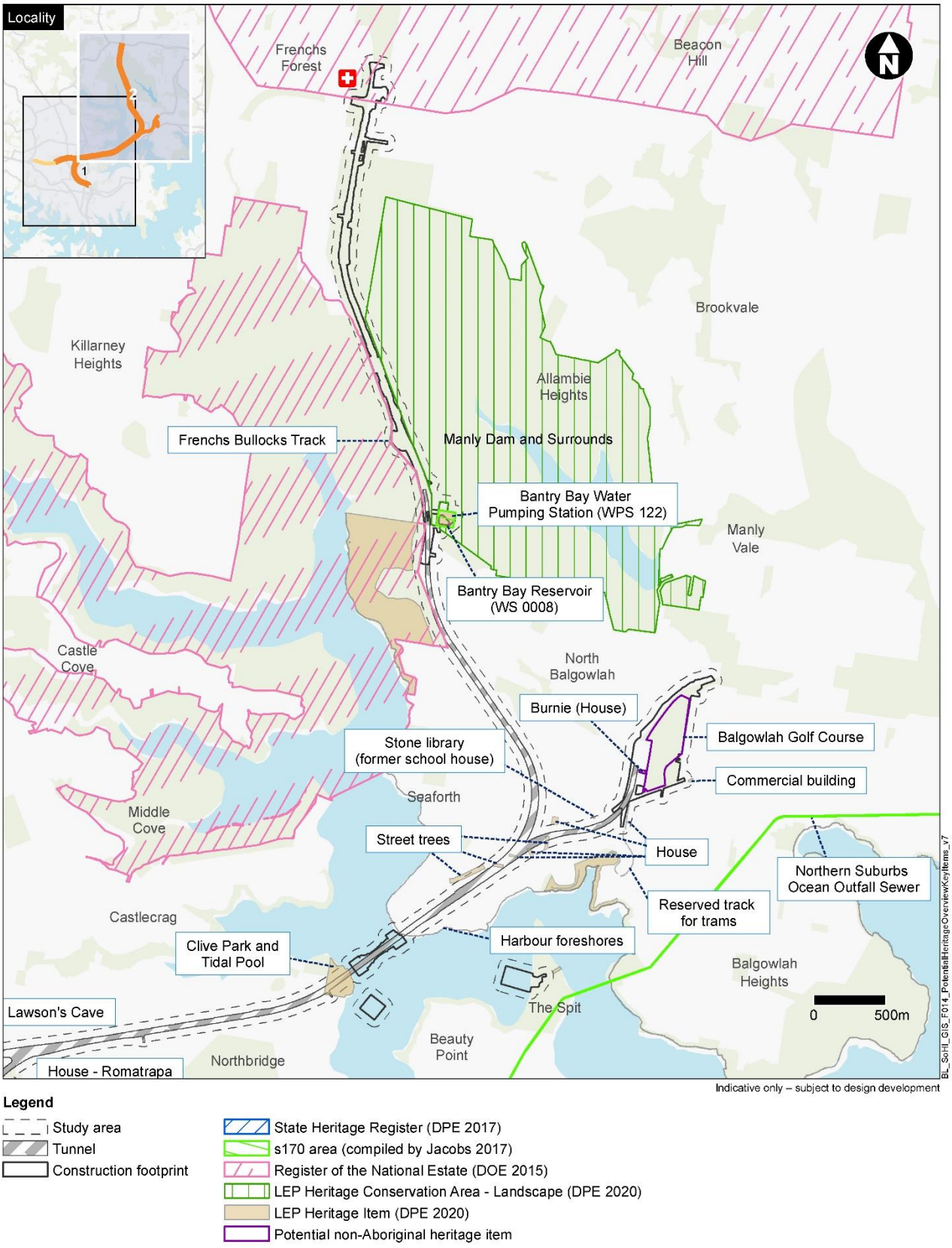

Figure 14-2 Location of terrestrial heritage items impacted by the project

14.4.3 Potential maritime heritage impacts

Of the 10 maritime heritage items identified within the study area with cultural heritage significance, one item, the Side scan sonar anomaly (18W-003), would not be impacted by the project (refer Figure 14-3).

A heritage assessment for the remaining nine heritage items that would be potentially impacted is included in Table 14-4 and shown in Figure 14-3. Areas of archaeological potential have also been assessed (Items 10, 11 and 12).

Note that Clyde Park Tidal Pool and Harbour foreshores (Seaforth) have been assessed as terrestrial items in Section 14.4.2.

Table 14-4 Potential impacts on maritime heritage sites

Item	Item name	Listing	Heritage	Impact type	Impact rating (with mitigation)
Heritage items					
1	Clive Park Unidentified Shipwreck No. 1	Unlisted	Local	No direct impacts	**Minor** The proposed works may result in loss of site integrity and reduction in heritage values. Potential direct and indirect impacts to the heritage item would be minimised with the implementation of the management measures described in Section 14.5 to collect archaeological information from the site before construction.
				Potential direct impacts: • Physical impact to the heritage item from anchoring of project vessels on or around the item • Physical impact to the heritage item by propeller jet turbulence of project vessels.	
				Indirect impacts: • Temporary vibration impacts to the heritage item due to the construction of the Middle Harbour south cofferdam (BL7).	
2	Middle Harbour Unidentified Shipwreck No. 1	Unlisted	Local	No direct impacts	**Negligible** With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be negligible.
				No potential direct impacts	
				Indirect impacts: • Temporary vibration impacts to the heritage item due to the construction of the Middle Harbour south cofferdams (BL7).	

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating (with mitigation)
3	Pearl Bay Unidentified No. 1 Shipwreck (18W-01)	Unlisted	Local	Direct impacts: • Physical impact to the heritage item from piling activities associated with the construction of the Spit West Reserve construction support site (BL9). Potential direct impacts • Physical impact to the heritage item from anchoring of project vessels on or around the item. No indirect impacts	**Minor** The proposed works may result in loss of site integrity and reduction in heritage values. Potential direct and indirect impacts to the heritage item would be minimised with the implementation of the management measures described in Section 14.5 to collect archaeological information from the site before construction and to establish a restricted zone before construction to avoid potential direct impacts.
Unverified anomalies – potential heritage items					
4	'Barge'	Unlisted	Unknown – low heritage sensitivity	No direct impacts No potential direct impacts Indirect impacts: • Temporary vibration impacts to the heritage item due to the construction of the Middle Harbour south cofferdam (BL7).	**Negligible** It is expected there would be no discernible change to the existing natural and human impacts to this site. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be negligible.
5	Side scan sonar anomaly 16W-06	Unlisted	Unknown – low heritage sensitivity	Direct impacts: • Planned physical impacts to the entire item due to dredging for the immersed tube tunnels. No potential direct impacts No indirect impacts	**Minor** The proposed dredging works for the immersed tube tunnels would result in loss of site integrity and reduction in heritage values. As the expected heritage sensitivity of the site is low, the implementation of the pre-dredge management measures described in Section 14.5 would result in a minor impact.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating (with mitigation)
6	Magnetic anomaly 1	Unlisted	Unknown – low heritage sensitivity	Direct impacts: • Physical impacts to the entire item due to dredging for the immersed tube tunnels. No potential direct impacts No indirect impacts	**Minor** The proposed dredging works for the immersed tube tunnels would result in loss of site integrity and reduction in heritage values. As the expected heritage sensitivity of the site is low, the implementation of the pre-dredge management measures described in Section 14.5 would result in a minor impact.
7	Magnetic anomaly 2	Unlisted	Unknown – low heritage sensitivity	Direct impacts: • Physical impacts to the entire item due to dredging for the immersed tube tunnels. No potential direct impacts No indirect impacts	**Minor** The proposed dredging works for the immersed tube tunnels would result in loss of site integrity and reduction in heritage values. As the expected heritage sensitivity of the site is low, the implementation of the pre-dredge management measures described in Section 14.5 would result in a minor impact.
8	Magnetic anomaly 3	Unlisted	Unknown – medium heritage sensitivity	No direct impacts Potential direct impacts: • Physical impact to the heritage item from anchoring of project vessels on or around the item • Physical impact to the heritage item by propeller jet turbulence of project vessels. Indirect impacts: • Temporary vibration impacts to the heritage item due to the construction of the Middle Harbour south and Middle Harbour north cofferdams (BL7 and BL8).	**Minor** The proposed works may result in loss of site integrity and reduction in heritage values, which is suspected to be associated with the Clive Park Unidentified Shipwreck No 1. Potential direct and indirect impacts to the heritage item would be minimised with the implementation of the management measures described in Section 14.5 to collect archaeological information from the site before construction.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating (with mitigation)
9	Side scan sonar anomaly 18W-002	Unlisted	Unknown – low heritage sensitivity	Direct impacts: • Physical impact to the heritage item from piling activities associated with the construction of the Spit West Reserve construction support site (BL9).	**Minor** The proposed works may result in loss of site integrity and reduction in heritage values. Potential direct and indirect impacts to the heritage item would be minimised with the implementation of the management measures described in Section 14.5.
				Potential direct impacts: • Physical impact to the heritage item from anchoring of project vessels on or around the item • Physical impact to the heritage item by propeller jet turbulence of project vessels.	
				No indirect impacts	

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating (with mitigation)
Potential archaeological sites					
10	Potential archaeological sites in Middle Harbour between Northbridge and Seaforth	Unlisted	Unknown – low heritage sensitivity	Direct impacts: • Physical impacts to the bed of the harbour in this area due to dredging for the immersed tube tunnels and construction of the Middle Harbour south and Middle Harbour north cofferdams (BL7 and BL8).	**Minor** The proposed works may result in loss of site integrity and reduction in heritage values of potential archaeological sites. Impacts to potential archaeological sites would be minimised with the implementation of the management measures described in Section 14.5 to identify any further heritage items before construction.
				Potential direct impacts: • Physical impact to the bed of the harbour in this area from anchoring of project vessels on or around the item • Physical impact to the bed of the harbour in this area by water turbulence from the operation of project vessels.	
				Indirect impacts: • Temporary vibration impacts to the bed of the harbour in this area due to the construction of the Middle Harbour south and Middle Harbour north cofferdams (BL7 and BL8).	

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating (with mitigation)
11	Potential archaeological sites in Middle Harbour and Pearl Bay, west of The Spit	Unlisted	Unknown – low to medium heritage sensitivity	Direct impacts: • Physical impact to the bed of the harbour in this area from piling activities associated with the construction of the Spit West Reserve construction support site (BL9).	**Minor** The proposed works may result in loss of site integrity and reduction in heritage values of potential archaeological sites. Impacts to potential archaeological sites would be minimised with the implementation of the management measures described in Section 14.5 to identify any further heritage items before construction.
				Potential direct impacts: • Physical impact to the bed of the harbour in this area from anchoring of project vessels on or around the item • Physical impact to the bed of the harbour in this area by water turbulence from the operation of project vessels.	
				No indirect impacts	
12	Potential archaeological sites in Middle Harbour between Northbridge and Beauty Point	Unlisted	Unknown – low heritage sensitivity	No direct impacts	**Minor** The proposed works may result in loss of site integrity and reduction in heritage values of potential archaeological sites. Impacts to potential archaeological sites would be minimised with the implementation of the management measures described in Section 14.5 to identify any further heritage items before construction.
				Potential direct impacts: • Physical impact to the bed of the harbour in this area from anchoring of project vessels on or around the item.	
				No indirect impacts	

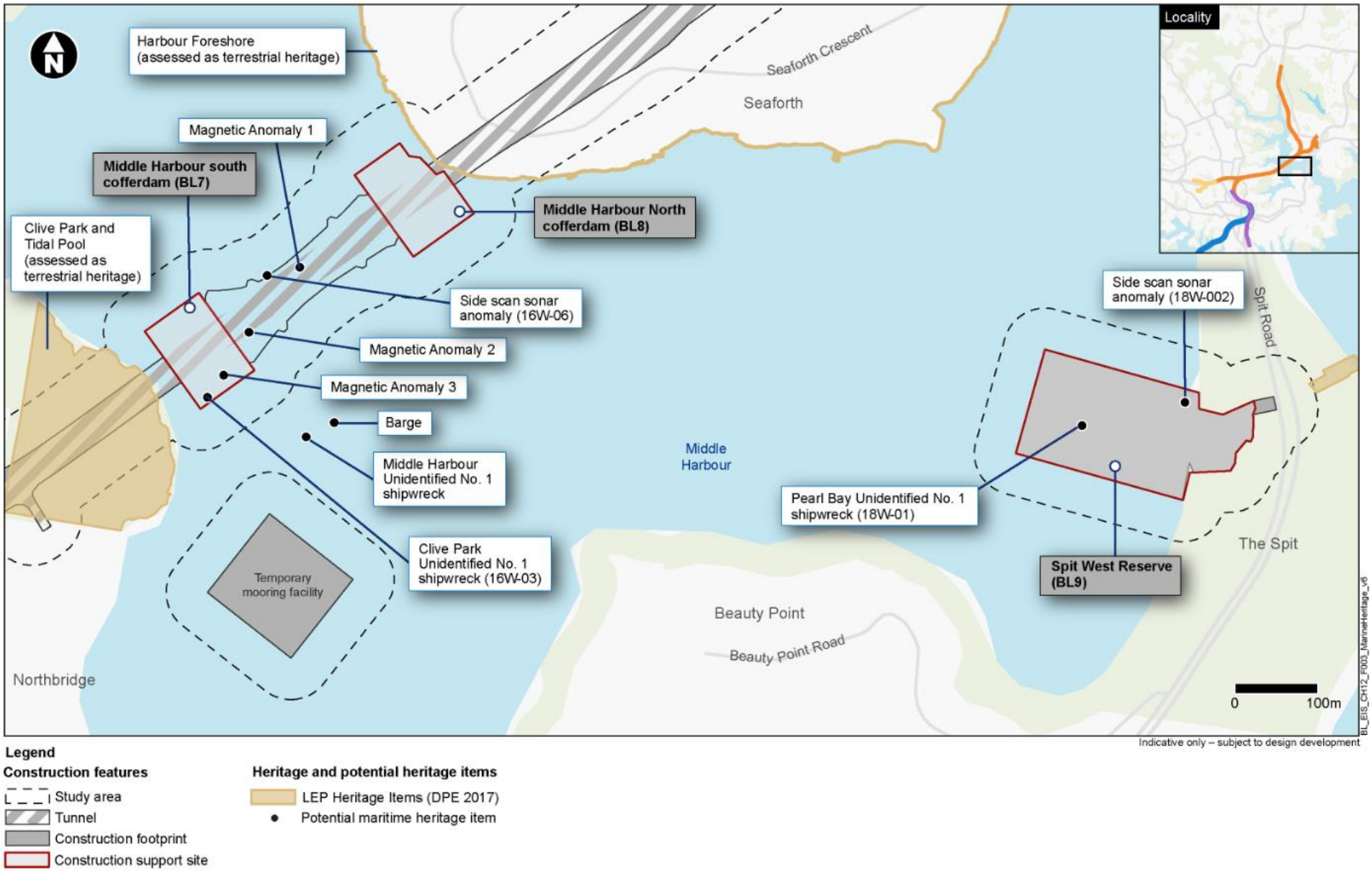

Figure 14-3 Location of maritime heritage items impacted by the project

14.5 Environmental management measures

Environmental management measures relating to non-Aboriginal heritage for the project are outlined in Table 14-5.

Table 14-5 Environmental management measures – Non-Aboriginal heritage

Ref	Phase	Impact	Environmental management measure	Location
NAH1	Design	Ongoing non-Aboriginal heritage impacts	Appropriate heritage interpretation will be incorporated into the urban design for the project in accordance with the *NSW Heritage Manual* (NSW Heritage Office and Department of Urban Affairs and Planning, 1996), *Interpreting Heritage Places and Items: Guidelines* (NSW Heritage Office, 2005), and the *Heritage Interpretation Policy* (NSW Heritage Council, 2005).	BL/GHF
NAH2	Pre-construction	Impacts on specific non-Aboriginal heritage items	Archival recording will be carried out in accordance with the *Photographic Recording of Heritage Items Using Film or Digital Capture* guideline for areas/items subject to change within the following items, in accordance with Appendix J (Technical working paper: Non-Aboriginal heritage): • Item 10: Balgowlah Golf Course, Balgowlah • Item 11: Frenchs Bullock Track, Killarney Heights (pending further detailed survey and detailed design development confirming direct impact). Archival recording will be completed prior to any works that have the potential to impact upon the items and deposited with appropriate stakeholders as determined during further design development (eg local councils).	BL/GHF
NAH3	Pre-construction	Maritime non-Aboriginal heritage impacts	A Maritime Heritage Management Plan that details the objectives and methodologies to conserve maritime heritage and mitigate impacts will be prepared in consultation with a qualified and experienced maritime archaeologist. The Maritime	BL

Ref	Phase	Impact	Environmental management measure	Location
			Heritage Management Plan will specify: a. Unexpected finds protocols relevant to each type of activity such as dredging or piling b. Artefact management procedures, including identification of approved submerged reburial locations c. Relevant work method requirements and maritime heritage inductions tailored for each type of work activity such as dredging or piling d. Restricted zone, archival, baseline and periodic monitoring protocols including before and during construction, and final site inspections within three months of completion of works for the following maritime heritage sites: • Clive Park Tidal Pool • Clive Park Unidentified No. 1 • Pearl Bay Unidentified No. 1. e. An archaeological research design to guide the investigation of Clive Park Unidentified No 1.	
NAH4	Pre-construction	Maritime non-Aboriginal heritage impacts	Any pre-dredge bed of the harbour clearance by divers in Middle Harbour will be carried out in the presence of a maritime archaeologist, who will identify any additional inspection or documentation that should be carried out during the clearance dive. This may include inspecting the locations of known or potential submerged maritime heritage sites and items, either recording in situ or recovery and/or relocation.	Middle Harbour
NAH5	Pre-construction	Maritime archival recording	An archival recording of Clive Park Unidentified No. 1 will be carried out to mitigate the likely loss of information resulting from a breakdown of site integrity. The archival recording will have the	Clive Park Unidentified No. 1

Ref	Phase	Impact	Environmental management measure	Location
			following objectives or research questions: • Identifying and recording the extent of the site • Identifying the type and function of the vessel (which would mean determining its construction) • Identifying what the vessel was carrying at the time of loss • Re-assessing the cultural heritage significance of the site. The archival recording of the wreck would require limited excavation of the site to recover and examine its contents. This excavation will be carried out in accordance with the research design (refer to NAH3) and any artefacts recovered from the site will be buried, after analysis, in an approved location nearby.	
NAH6	Pre-construction	Maritime archival recording	A detailed archival recording of the following maritime heritage items will be prepared, consistent with relevant NSW Heritage Council approved standards and guidelines: • Clive Park Tidal Pool • Pearl Bay Unidentified No. 1. The archival records will also capture any relevant information needed to serve as a baseline for monitoring during the project, as identified in the Maritime Heritage Management Plan (see NAH3). The final archival record will be updated with any changes identified during monitoring or investigation prior to lodgement.	Clive Park Tidal Pool, Pearl Bay Unidentified No.1
NAH7	Pre-construction	Maritime non-Aboriginal heritage impacts	A side scan sonar survey will be carried out for the following areas, where they are not already covered by existing surveys: • Project construction footprint between Northbridge and	Middle Harbour south cofferdam (BL7), Middle Harbour

Ref	Phase	Impact	Environmental management measure	Location
			Seaforth in the vicinity of the immersed tube tunnels and the Middle Harbour cofferdams (BL7 and BL8) • Project construction footprint in the vicinity of the Spit West Reserve construction support site (BL9). A qualified maritime archaeologist will assess the results of the side scan survey to identify any additional potential heritage items requiring investigation and assessment.	north cofferdam (BL8), Spit West Reserve construction support site (BL9)
NAH8	Pre-construction	Maritime non-Aboriginal heritage impacts	A dive team under the supervision of a maritime archaeologist will inspect the location of each proposed piled mooring to assess the maritime heritage value of any cultural object present and either relocate the object or, if significant, relocate the proposed mooring.	Temporary mooring facility east of Clive Park in Middle Harbour
NAH9	Pre-construction	Non-Aboriginal heritage impacts to Frenchs Bullock Track	The northern section of the Frenchs Bullock Track potentially impacted directly by construction works will be reformed if impacted, as close as possible to the existing alignment. Further detailed survey will be completed to confirm the heritage curtilage of the southern section of Frenchs Bullock Track prior to construction to determine if this section will be directly impacted. Where the heritage curtilage of the Frenchs Bullock Track is within the construction footprint or boundary of proposed permanent infrastructure, impacts to the track will be avoided where possible through further design development.	BL
NAH10	Pre-construction and construction	Vibration impacts to non-Aboriginal heritage	A structural survey will be prepared for all maritime infrastructure within the Seaforth 'Harbour Foreshores' that could be subject to vibrational impact to determine minimum working distances and vibration limits to be observed to prevent cosmetic damage. Vibration	Harbour foreshores (Seaforth)

Ref	Phase	Impact	Environmental management measure	Location
			monitoring will be carried out during works to ensure vibration levels do not exceed appropriate limits. The recommended actions in Appendix G (Technical working paper: Noise and vibration) will be followed.	
NAH11	Construction	Non-Aboriginal heritage impacts during construction	Delineation of restricted zones will be implemented to avoid inadvertent works occurring within the curtilage of heritage items.	BL/GHF
NAH12	Construction	Unexpected discovery of historical heritage materials, features or deposits	If at any time during construction of the project, historical materials, features and/or deposits are encountered, the *Standard Management Procedure: Unexpected Heritage Items* (Roads and Maritime Services, 2015d) will be followed.	BL/GHF
NAH13	Construction	Unexpected discovery of human remains	In the event that construction of the project reveals possible human skeletal material (remains), *Standard Management Procedures – Unexpected Heritage Items* (Roads and Maritime Services, 2015d) will be implemented.	BL/GHF
NAH14	Construction	Non-Aboriginal heritage impacts during construction	Non-Aboriginal heritage awareness training will be provided for contractors prior to commencement of construction works to ensure understanding of potential heritage items that may be impacted during the project, and the procedure required to be carried out in the event of discovery of non-Aboriginal heritage materials, features or deposits, or the discovery of human remains. This includes relevant work method requirements and maritime heritage inductions tailored for each type of work activity such as dredging or piling.	BL/GHF

Ref	Phase	Impact	Environmental management measure	Location
NAH15	Construction	Non-Aboriginal heritage impacts	Should at-property noise treatment be required at a premise that is heritage listed, this will be carried out in a manner to minimise heritage impact, and advice of a heritage conservation architect will be sought prior to carrying out the works. Any treatments will be sympathetic to the heritage values of the item, designed with heritage architect input and be reversible where feasible.	BL/GHF

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

Environmental management measures identified in previous sections of this environmental impact statement will also mitigate potential impacts to non-Aboriginal heritage. These are identified in Table 14-6.

Table 14-6 Environmental management measures for non-Aboriginal heritage impacts identified in other sections of the environmental impact statement

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 surveys will be carried out by a suitably qualified person. The results of the surveys 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
CNV7	Construction	Construction vibration impacts	Vibration generating activities will be managed through the establishment of minimum buffer distances to achieve screening levels. Where vibration levels are predicted to exceed the screening levels, a more detailed assessment of the impacted structure will be carried out to assess the susceptibility of the structure to damage from vibration due to the project. Appropriate mitigation and management measures, such as equipment substitution and alternative methods, will be identified and implemented to avoid damage. Attended vibration monitoring will be carried out during vibration intensive activities in the vicinity to ensure vibration levels remain below appropriate limits for that structure. For heritage items, the more detailed assessment will specifically consider the heritage values of the structure in consultation with a heritage specialist to ensure sensitive heritage fabric is adequately monitored and managed. Pre-construction building structure condition surveys will be carried out in accordance with environmental management measure SG7. Any building and/or structure damage from vibration caused by the project would be repaired at no cost to the owner.	BL/GHF

There are environmental management measures that would contribute to the mitigation and management of non-Aboriginal heritage impacts associated with the Western Harbour Tunnel and Beaches Link program of works, which are committed to within the Submissions report for the Western Harbour Tunnel and Warringah Freeway Upgrade project. The implementation of these management measures would also mitigate potential non-Aboriginal heritage impacts associated with this project. These include:

- A thematic heritage study of golf courses in Sydney will be prepared for the region north of the Sydney Harbour. This study will assist in identifying other potential heritage items in the region that demonstrate the same or similar significance as the Cammeray Golf Course (Revised environmental management measure NAH8)
- Archival recording will be carried out in accordance with the *Photographic Recording of Heritage Items Using Film or Digital Capture* guideline for areas/items subject to change within the following items, in accordance with Appendix J (Technical working paper: Non-Aboriginal heritage):
  - f) Cammeray Park (including the Golf Course), Cammeray
  - g) Cammeray Conservation Area, Cammeray (Revised environmental management measure NAH5).

Transport for NSW

Beaches Link and Gore Hill Freeway Connection

Chapter 15

Aboriginal cultural heritage

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15 Aboriginal cultural heritage

This chapter outlines the potential Aboriginal cultural heritage impacts associated with the project and identifies measures which address these impacts. A detailed Aboriginal cultural heritage assessment has been carried out for the project and is included in Appendix L (Technical working paper: Aboriginal cultural heritage assessment report).

The Secretary's environmental assessment requirements as they relate to Aboriginal cultural heritage, and where in the environmental impact statement these have been addressed, are detailed in Table 15-1.

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 proposed environmental management measures relevant to Aboriginal cultural heritage impacts are included in Section 15.5.

Table 15-1 Secretary's environmental assessment requirements – Aboriginal heritage

Secretary's requirement	Where addressed in EIS
1. The Proponent must identify and assess any direct and/or indirect impacts (including cumulative and visual impacts) to the heritage significance of listed (and nominated) heritage items includes of: a. Aboriginal places and objects, as defined under the *National Parks and Wildlife Act 1974* and in accordance with the principles and methods of assessment identified in the current guidelines;	**Section 15.4** identifies and assesses all Aboriginal places and objects. The legislative and policy framework used for this assessment is outlined in **Section 15.1**, which includes reference to the guidelines used to consider potential impacts.
b. Aboriginal places of heritage significance, as defined in the Standard Instrument – Principal Local Environmental Plan;	**Section 15.3.3** identifies Aboriginal places of heritage significance as defined in the Standard Instrument – Principal Local Environmental Plan.
d. items listed on the State, National and World Heritage lists	**Section 15.3.3** identifies search results from relevant Aboriginal heritage databases. Listed non-Aboriginal heritage items are identified in **Chapter 14** (Non-Aboriginal heritage).
e. heritage items and conservation areas identified in local and regional planning environmental instruments covering the project area; and	**Section 15.3.3** identifies search results relevant Aboriginal heritage databases including relevant local environmental plans.
f. marine items of potential heritage significance within Middle Harbour, such as any shipwrecks.	**Section 15.3.4** discusses potential submerged Aboriginal sites. Non-Aboriginal maritime heritage sites are discussed in **Chapter 14** (Non-Aboriginal heritage).

Secretary's requirement	Where addressed in EIS
2. Where impacts to State or locally significant heritage items or archaeology are identified, the assessment must: a. include a significance assessment and statement of heritage impact for all heritage items (including any unlisted places that are assessed of heritage value);	Significance assessments are presented in **Section 15.3**.
b. provide a discussion of alternative locations and design options that have been considered to reduce heritage impacts;	A discussion of alternative locations and design options is provided in **Appendix L** (Technical working paper: Aboriginal cultural Heritage assessment report) and **Section 4.4** and **Section 4.5** of **Chapter 4** (Project development and alternatives).
c. in areas identified as having potential archaeological significance, undertake a comprehensive archaeological assessment and management plan in line with Heritage Council guidelines which includes a methodology and research design to assess the impact of the works on the potential archaeological resource and to guide physical archaeological test excavations and include the results of these excavations. This is to be carried out by a suitably qualified archaeologist and is to discuss the likelihood of significant historical, maritime and Aboriginal archaeology on the site, how this may be impacted by the project, and includes measures to mitigate any impacts;	Details of test excavations carried out are presented in **Section 15.3** and Annexure D of **Appendix L** (Technical working paper: Aboriginal cultural Heritage assessment report).
d. consider impacts to the item of significance caused by, but not limited to, vibration, demolition, archaeological disturbance, altered historical arrangements and access, increased traffic, visual amenity, landscape and vistas, curtilage, subsidence and architectural noise treatment (as relevant);	Discussion of impacts to items of significance as a result of vibration, demolition, archaeological disturbance, altered historical arrangements and access, increased traffic, visual amenity, landscape and vistas, curtilage, subsidence and architectural noise treatment (as relevant) are provided in **Section 15.4** and further discussed in **Chapter 10** (Construction noise and vibration)
e. provide a comparative analysis to inform the rarity and representative value of any heritage places proposed for demolition;	No sites are proposed for demolition.
f. outline mitigation measures to avoid and minimise identified impacts in accordance with the current guidelines; and	Mitigation and management measures are presented in **Section 15.5**.

Secretary's requirement	Where addressed in EIS
g. be undertaken by a suitably qualified heritage consultant(s) (note: where archaeological excavations are proposed the relevant consultant must meet the NSW Heritage Council's Excavation Director criteria).	**Appendix L** (Technical working paper: Aboriginal cultural heritage assessment report) provides details of qualifications held by archaeologists.
3. Where archaeological investigations of Aboriginal objects are proposed these must be conducted by a suitably qualified archaeologist, meeting the minimum qualification requirements specified in section 1.6 of the *Code of Practice for Archaeological Investigation of Aboriginal Objects in NSW* (DECCW 2010).	**Appendix L** (Technical working paper: Aboriginal cultural heritage assessment report) provides details of qualifications held by archaeologists. **Section 15.2** provides details of attendance for site surveys.
4. The Proponent must identify and describe the Aboriginal cultural heritage values that exist across the whole area that would be affected by the development and document these in an Aboriginal cultural heritage assessment report (ACHAR). This may include the need for surface survey and test excavation. The identification of cultural heritage values must be conducted in accordance with *Code of Practice for Archaeological Investigations of Aboriginal Objects in NSW* (OEH 2010), and guided by the *Guide to Investigating, Assessing and Reporting on Aboriginal Cultural Heritage in NSW* (Office of Environment and Heritage (OEH), 2011a).	**Appendix L** (Technical working paper: Aboriginal cultural heritage assessment report) documents Aboriginal cultural heritage values and details are summarised in **Section 15.3.3** and **Section 15.3.7**.
5. Consultation with Aboriginal people must be undertaken and documented in accordance with the *Aboriginal cultural heritage consultation requirements for proponents 2010* (DECCW). The significance of cultural heritage values for Aboriginal people who have a cultural association with the land must be documented in the ACHAR.	Aboriginal stakeholder consultation was carried out in accordance with the *Procedure for Aboriginal Cultural Heritage Consultation and Investigation* (Roads and Maritime, 2011) and is discussed in **Chapter 7** (Stakeholder and community engagement) and **Appendix L** (Technical working paper: Aboriginal cultural assessment heritage report). Aboriginal cultural significance was assessed through consultation and is summarised in **Section 15.3.7**.
6. Impacts on Aboriginal cultural heritage values are to be assessed and documented in the ACHAR. The ACHAR must demonstrate attempts to avoid impact upon cultural heritage values and identify any conservation outcomes. Where impacts are unavoidable, the ACHAR must outline measures proposed to mitigate impacts. Any objects recorded as part of the assessment must be documented and notified to the Environment, Energy and Science Group in the Department of Planning, Industry and Environment.	**Appendix L** (Technical working paper: Aboriginal cultural heritage assessment report) documents potential impacts and management recommendations. These are summarised in **Section 15.4** and **Section 15.5**.

Secretary's requirement	Where addressed in EIS
Note that due diligence is not an appropriate assessment, and an ACHAR is required	**Appendix L** (Technical working paper: Aboriginal cultural heritage assessment report)

15.1 Legislative and policy framework

The primary legislation relevant to Aboriginal cultural heritage in NSW is the *National Parks and Wildlife Act 1974* (NPW Act) and its supporting regulation, which provides for the management of Aboriginal land, objects and places. Although an Aboriginal heritage impact permit would not be required for the project under section 90 of the NPW Act (refer to Chapter 2 (Assessment process)), an equivalent level of assessment and consultation has been carried out.

The requirement to consider potential impacts on Aboriginal cultural heritage, including objects and places, is given effect through the following guidelines:

- *Code of Practice for Archaeological Investigation of Aboriginal Objects in New South Wales* (DECCW, 2010d)
- *Guide to Investigating, Assessing and Reporting on Aboriginal Cultural Heritage in NSW* (OEH, 2011a)
- *Aboriginal Cultural Heritage Consultation Requirements for Proponents* (DECCW, 2010b)
- *Due Diligence Code of Practice for the Protection of Aboriginal Objects in NSW* (DECCW, 2010c).

The *Procedure for Aboriginal Cultural Heritage Consultation and Investigation* (PACHCI) (Roads and Maritime Services, 2011a) specifically tailors and applies the requirements of these guidelines to its road projects.

The *Native Title Act 1993* (Commonwealth) and *Aboriginal Land Rights Act 1983* (NSW) provide a framework for the protection of native title rights on certain Crown lands. There are no Crown lands subject to a native title claim within the footprint of the project.

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (Commonwealth) aims to recognise the role of Indigenous people in the conservation and ecologically sustainable use of Australia's biodiversity, and to promote the use of Indigenous peoples' knowledge of biodiversity with the involvement of, and in cooperation with, the owners of the knowledge. The EPBC Act establishes both the National Heritage List, which includes natural, Indigenous and historic places that are of outstanding heritage value to the nation, and the Commonwealth Heritage List, which includes places on Commonwealth lands and waters or under Australian Government control that have Indigenous heritage significance. There are no Aboriginal heritage items in the detailed investigation area that are registered on either the National or Commonwealth lists.

The *Aboriginal and Torres Strait Islander Heritage Protection Act 1984* (Commonwealth), provides for the protection of Aboriginal cultural property that are of particular significance to Aboriginals in accordance with Aboriginal tradition and may apply to Aboriginal cultural property as well as ancient sites.

15.2 Assessment methodology

The Aboriginal cultural heritage assessment was carried out in accordance with the PACHCI (Roads and Maritime Services, 2011a). The PACHCI applies the requirements of other relevant guidelines (refer to Section 15.1) to road projects.

The PACHCI provides Aboriginal people with the opportunity to participate in the decision making process regarding the management of their cultural heritage, by providing Transport for NSW with information regarding cultural significance as well as providing input into management options, if required. The PACHCI includes up to four stages of assessment, all of which are relevant and have been applied to the project:

- Stage 1 – a desktop risk assessment was carried out to determine whether the project may potentially impact on Aboriginal cultural heritage and require further assessment or investigation. The desktop risk assessment considered relevant registers and databases, including but not limited to the Aboriginal Heritage Information Management System (AHIMS)
- Stage 2 – because Stage 1 identified a risk of impact on Aboriginal cultural heritage, site surveys of relevant areas were carried out in consultation with the Metropolitan Local Aboriginal Land Council
- Stage 3 – because Stage 2 identified that there may be an impact on Aboriginal cultural heritage, an Aboriginal cultural heritage assessment report (ACHAR) was prepared and formal consultation with Aboriginal stakeholders was carried out
- Stage 4 – the outcomes and recommendations from the ACHAR, including mitigation and management measures, would be implemented during construction and operation of the project.

For the purpose of the Aboriginal cultural heritage assessment, all areas within 300 metres of the project's construction footprint were considered. As project refinements were made during the Stage 3 PACHCI process, this search area was refined to 50 metres (see Figure 15-1). Searches of AHIMS, relevant local environmental plans and State and Commonwealth heritage registers were carried out on 1 May 2017. A further search of AHIMS sites was carried out on 8 April 2020 to determine if any additional sites were apparent. No new AHIMS sites were determined from those identified in the 2017 search.

Site surveys were carried out in May, June and August 2017 by a qualified archaeologist accompanied by a representative of the Metropolitan Local Aboriginal Land Council. Aboriginal site officers were also engaged for archaeological field inspections in January 2018. Additional assessments were carried out with nominated site officers representing the Metro Metropolitan Local Aboriginal Land Council in August 2018, February 2020 and September 2020. During these surveys, site officers were provided an opportunity to comment on the potential for Aboriginal cultural material to be present within the study area, the cultural significance of any Aboriginal cultural heritage sites identified during the survey and proposed management recommendations, including recommendations for further assessment. Feedback from Registered Aboriginal Parties has also been incorporated into the assessment.

Registered Aboriginal Parties were identified in accordance with the DECCW guidelines (2010b) and invited to an Aboriginal focus group (AFG) meeting on the project, held on 28 September 2017. A second AFG was held on 3 November 2020. Through these meetings Registered Aboriginal Parties have been provided an opportunity to review site surveys and assessment methodology. Feedback from Registered Aboriginal Parties has been incorporated into the ACHAR.

Aboriginal stakeholder consultation was carried out in accordance with the PACHCI and is discussed in Chapter 7 (Stakeholder and community engagement) and Appendix L (Technical working paper: Aboriginal cultural heritage assessment report).

In conjunction with the PACHCI process, an assessment of potential submerged Aboriginal sites was carried out within the marine environment of the project area. Where possible, the assessment of potential submerged Aboriginal sites was coordinated with the PACHCI process.

The potential submerged Aboriginal sites assessment included:

- Review of existing information and remote sensing data
- Field survey, carried out as part of the maritime archaeological dive inspections in December 2017 at two locations where rock outcrops indicated the potential for the presence of rock overhangs which could have associations with past human occupation
- Establishing a predictive model of maritime heritage potential to guide the assessment of significance and sensitivity
- Assessing potential impacts and providing appropriate mitigation and management measures.

15.3 Existing environment

15.3.1 Ethnographic and archaeological context

The Sydney area has a rich indigenous heritage. Aboriginal occupation focused on accessing resources from diverse ecological areas, seasons and conditions. Occupation sites, hunting, travel and inter-clan contact would have been associated with coastal areas, smaller rivers, creeks and swamps.

Aboriginal occupation in the Sydney area is known to have extended beyond the Last Glacial Maximum (about 21,000 years ago). Evidence of Aboriginal occupation in NSW dates back to around 50,000 to 60,000 years ago at Lake Mungo, up to 30,000 years ago at Parramatta, and is increasingly identified at other locations in the Sydney Basin.

Until the most recent ice age, about 12,000 years ago, sea levels were about 100 metres below their current level and the eastern coastline of Australia was about 25 to 30 kilometres further east. As the climate grew warmer and the sea level began to rise, these freshwater creeks and rivers were gradually drowned, and the lower-middle slopes of the ancient valleys were slowly inundated. The sea eventually flooded the area that became Port Jackson, and food resources would have changed dramatically. The sea level stabilised about 6000 to 8000 years ago which allowed the development of the foreshore maritime resource economy that then operated until after the arrival of the First Fleet in 1788.

Numerous open and rockshelter sites with shell middens and remains of fish and land mammals dating to the past 4500 years are known around Port Jackson, including Middle Harbour (Attenbrow, 2010). The material culture of Aboriginal people reflected a reliance on organic materials, using an intimate understanding of timber, plant and animal products to make utensils, tools and weapons. Igneous stone suitable for hatchet heads and stone for flaking, cutting and scraping were not naturally available in the area and could be traded from long distances.

Historically, Aboriginal people lived in small family or clan groups that were associated with particular territories or places. The project would be located on land within the boundaries of the Darug linguistic group. The two dialects of *Darug* are suggested to have been used: the coastal dialect (area between Sydney Harbour and Botany Bay, and west to Parramatta), and the hinterland dialect (area to the west of the Cumberland Plain) (Attenbrow, 2010).

Rock shelters appear to have been widely used by Darug-speaking peoples in coastal areas at the time of European contact. Existing data suggests that dominant site types for this region include rock shelters, artefact scatters and isolated artefacts, with middens present in the coastal areas further north. Applied art in rock shelters and engravings on sandstone platforms were common in this part of Sydney, although their fragility means that many have been lost in the past two centuries.

There is evidence of Aboriginal occupation throughout the study area, with areas of plentiful food resources associated with shorelines, riparian zones and adjacent areas including Clive Park, Burnt Bridge Creek and Flat Rock Creek. During urban development, many of these areas have been covered by fill, concealing original formations. Some evidence of Aboriginal occupation may also be present along movement pathways, meeting and camping sites, which were often associated with ridgelines.

15.3.2 Environmental and landscape context

The lower North Shore landscape region is a highly urbanised and developed landscape with only very small pockets of unmodified landscape remaining. The lower North Shore portion of the study area includes several parks and reserves including St Leonards Park, ANZAC Park, Cammeray Golf Course, Artarmon Park and Artarmon Reserve, as well as the Flat Rock Reserve and the surrounding alluvial terraces and exposed sandstone outcrops. These parks and reserves have been subject to less intensive disturbance and may have increased potential for Aboriginal sites.

The Middle Harbour and Balgowlah landscape region is also a highly urbanised landscape with only very small pockets of unmodified landscape remaining. The landscape region is characterised by 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. A gentler gradient at Clive Park descends from Northbridge into a shallower portion of Middle Harbour with the Spit Bridge located where a long, narrow sandbar once formed. Middle Harbour is bordered by steep headlands of exposed Hawkesbury Sandstone with some low hills and rises on Triassic and later sediments. The study area traverses the low gradient at Clive Park towards Seaforth and Balgowlah, where Burnt Bridge Creek is situated in Hawkesbury Sandstone bedrock.

At the Wakehurst Parkway landscape region, there are sections of undisturbed remnant landscapes in two locations within or in close proximity to the project (Garigal National Park and Manly Dam Reserve). The Wakehurst Parkway is located within an erosional landscape comprising undulating to rolling low hills on Hawkesbury Sandstone, broad ridges, gently to moderately inclined slopes, wide rock benches with low broken scarps, small hanging valleys and areas of poor drainage. The landscape region is characterised by rugged, rolling to very steep hills on Hawkesbury Sandstone with local reliefs of 40 to 200 metres with rock outcrops and shallow, stony, highly permeable soils. The Wakehurst Parkway landscape region is particularly significant because of the Hawkesbury Sandstone and its association with known Aboriginal rock engravings.

15.3.3 Database search results

AHIMS sites in the region around the project are shown in Figure 15-1. Of these, 11 sites have been identified within 50 metres of the project construction footprint including:

- One artefact scatter
- Four art sites (engraving and pigment)
- Three rock shelters (with middens)
- Three potential archaeological deposits (PADs).

The location and condition of one of the sites (45-6-0662) was unable to be confirmed during field inspection and the Aboriginal Heritage Office has advised that the site was likely covered by gravel/vegetation. As such, a desktop assessment of this site was carried out, basing findings on settlement and vibration modelling.

The site Wakehurst Engraving MAN 104 (45-6-3032) was observed to be significantly damaged during field inspection in September 2020. This resulted in notification to the Department of Premier and Cabinet (Heritage) (also known as Heritage NSW).

A further three additional AHIMS sites, 45-5-2222 (Clive Park 4; Northbridge) 45-6-0994 (Chatswood) and 45-6-1587 (Seaforth) were initially identified within the study area but were later confirmed as being incorrectly mapped and were determined to sit outside the study area. These sites do not form part of the eleven sites identified within the study area and have not been considered further in this assessment.

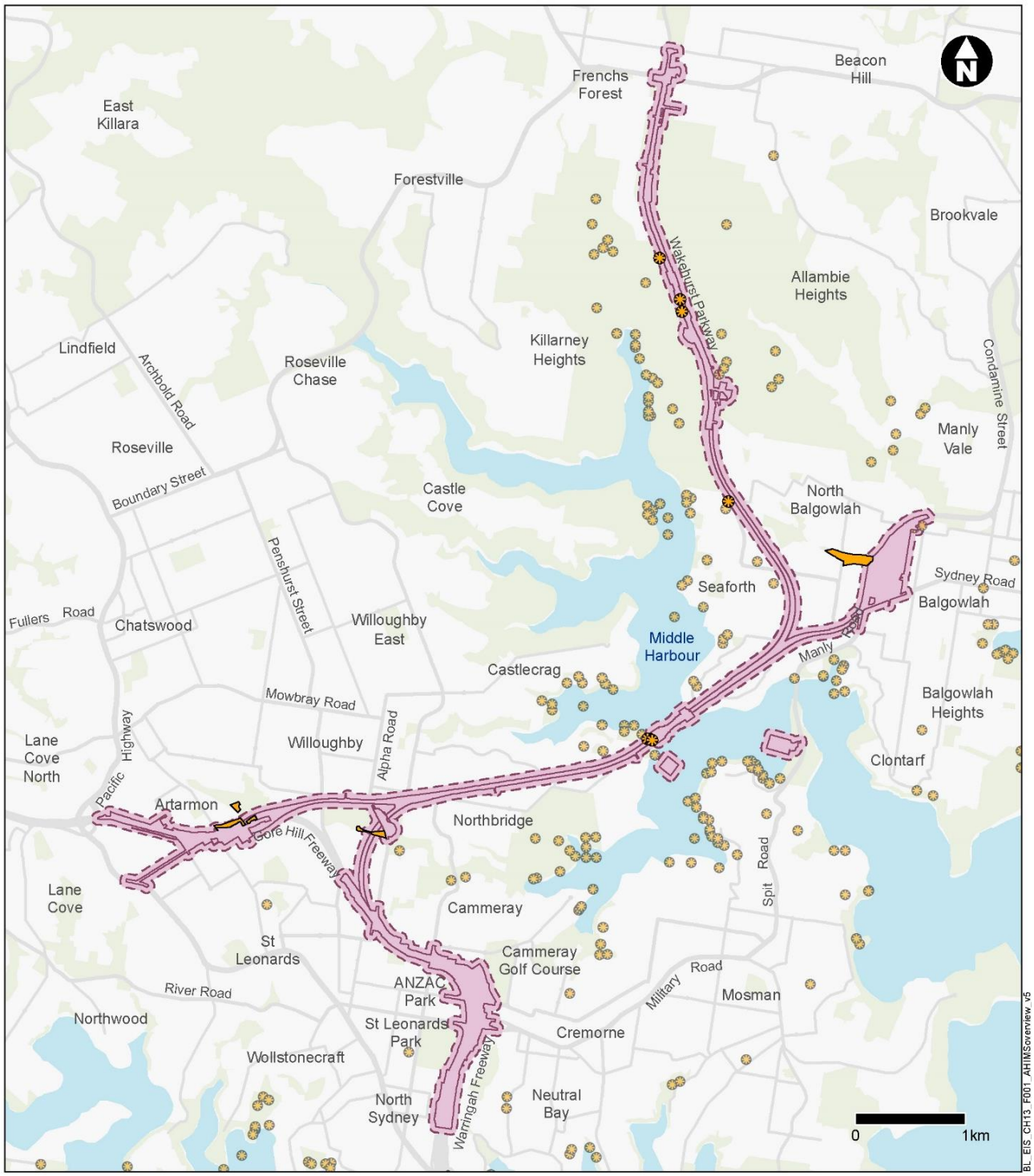
Details of the AHIMS sites, including Aboriginal cultural values identified through consultation with knowledge holders, are summarised in Table 15-2. The proximity of these sites to the construction footprint is shown in Figure 15-2 to Figure 15-5. The location of Aboriginal sites presented in Figure 15-2 to Figure 15-5 is based on the results of extensive AHIMS searches. Where possible, the location of these sites was confirmed during the archaeological survey.

No relevant items were identified in schedule 5 of the *North Sydney Local Environmental Plan 2013*, the *Willoughby Local Environmental Plan 2012* or the *Warringah Local Environment Plan 2011*.

Table 15-2 AHIMS sites within 50 metres of the project construction footprint

AHIMS site ID	Site name	Site type	Proximity to the project	Cultural value description
45-6-3599	Artarmon Park artefact scatter	Sub-surface artefact scatter	Within 50 metres of surface works at the Gore Hill Freeway Connection.	Part of cultural area and occupation site
45-6-3362	Artarmon Park potential archaeological deposit (PAD)	Potential archaeological deposit	Within 50 metres of surface works and the ramp tunnels at the Gore Hill Freeway Connection and Beaches Link on-ramp (portal).	Part of cultural area and occupation site
45-6-3361	Flat Rock Creek PAD	Potential archaeological deposit	Within 50 metres of surface works and above the alignment of the mainline tunnels at Flat Rock Drive construction support site (BL2).	Part of cultural area and occupation site
45-6-3012	Clive Park 8, Shelter and Midden	Shelter and midden (rock shelter is less than 50 m^3 in size)	Located above the mainline tunnels at Clive Park and within 50 metres of the Middle Harbour south cofferdam construction support site (BL7).	Part of cultural area and occupation site
45-6-0654	Clive Park 1; Northbridge	Shelter with midden, art, burial/s and artefact scatter (rock shelter is less than 50 m^3 in size)	Located above the mainline tunnels at Clive Park and within 50 metres of the Middle Harbour south cofferdam construction support site (BL7).	Part of cultural area and occupation site
45-6-0996	Clive Park 2; Taplin's Cicada Pupa Cave	Shelter with art and midden (rock shelter is less than 50 m^3 in size)	Located above the mainline tunnels at Clive Park and within 50 metres of the Middle Harbour south cofferdam construction support site (BL7).	Part of cultural area and occupation site
45-6-3363	Burnt Bridge Creek PAD	Potential archaeological deposit	Within 50 metres of surface works at Balgowlah and the ramp tunnels.	Part of cultural area and occupation site
45-6-3032	Wakehurst Engraving MAN 104	Rock engraving on outcrop	Within 50 metres of the ramp tunnels at Seaforth. Damage to the site was observed during field inspection in September 2020.	Part of cultural area and occupation site
45-6-2940	Rock engraving (Garigal National Park)	Rock engraving	Within 50 metres of surface works on Wakehurst Parkway (Killarney Heights).	Part of cultural area and occupation site

AHIMS site ID	Site name	Site type	Proximity to the project	Cultural value description
45-6-0662	Frenchs Forest; Bantry Bay; Wakehurst Parkway	Rock engraving	Potentially within 50 metres of surface works on Wakehurst Parkway (Killarney Heights). Location and condition of site could not be confirmed during field inspection as site is likely covered by gravel/vegetation.	Part of cultural area and occupation site
45-6-0655	Bantry Bay Aboriginal Engraving Site	Large rock engraving site with multiple engravings	Within 50 metres of surface works on Wakehurst Parkway (Killarney Heights).	Part of cultural area and occupation site



Legend

Construction features

- 50 metre area around construction footprint
- Construction footprint
- Tunnel

AHIMS sites

- AHIMS site within 50 metres of the construction footprint
- AHIMS site over 50 metres from the construction footprint
- Potential Archaeological Deposit

Figure 15-1 AHIMS sites in the region around the project

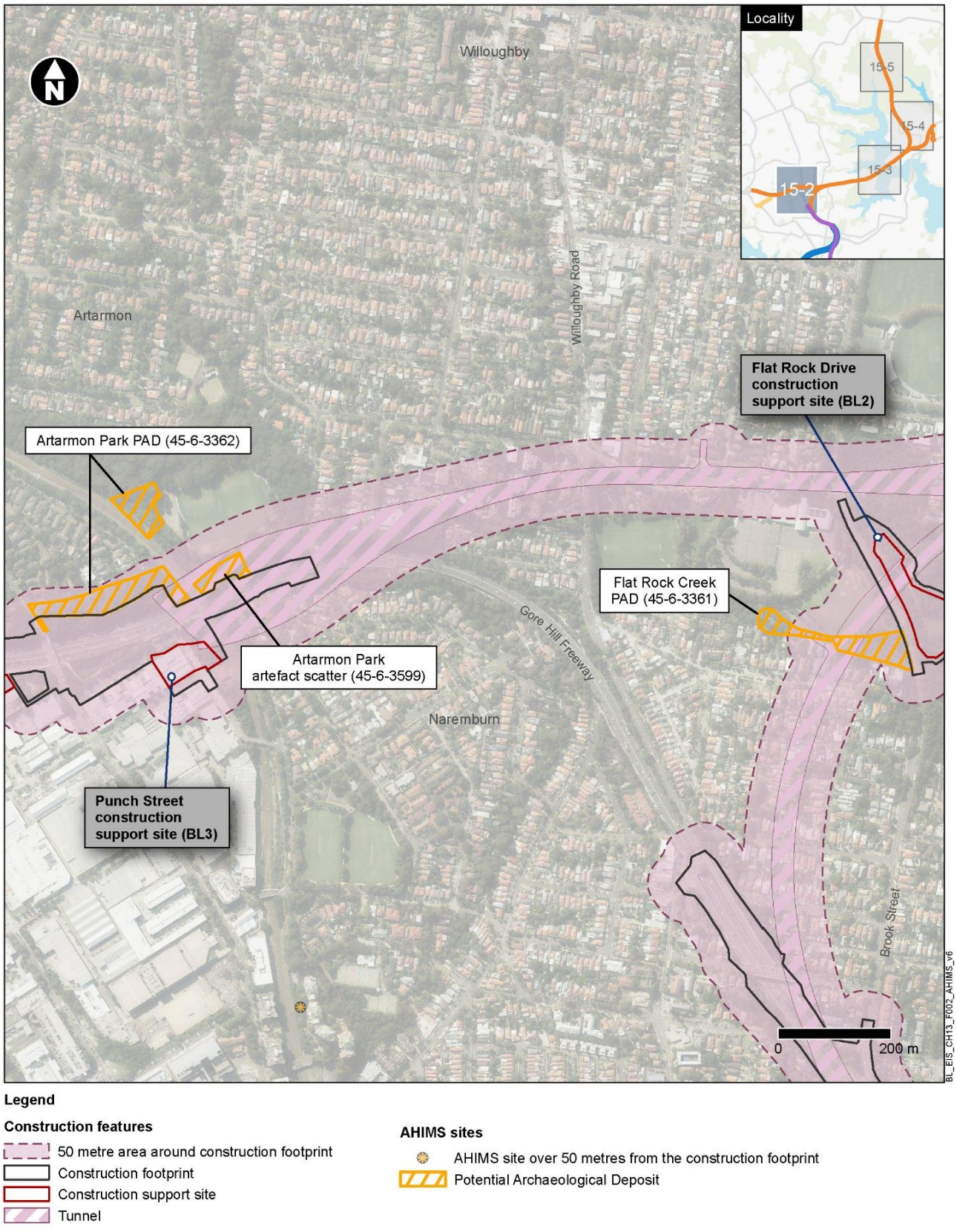


Figure 15-2 AHIMS sites within 50 metres of the project construction footprint (Gore Hill Freeway and Flat Rock Creek)

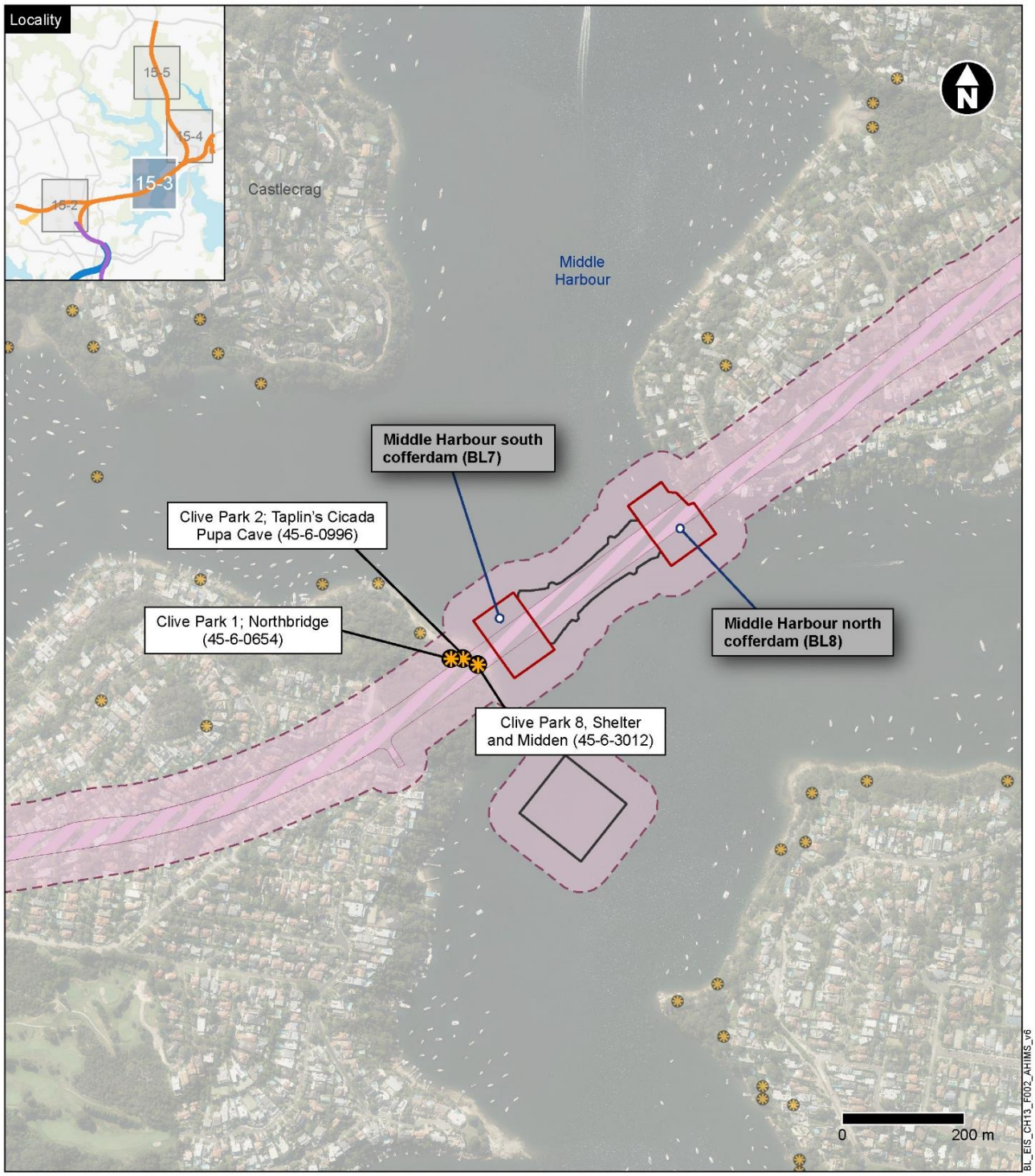


Figure 15-3 AHIMS sites within 50 metres of the project construction footprint (Middle Harbour)

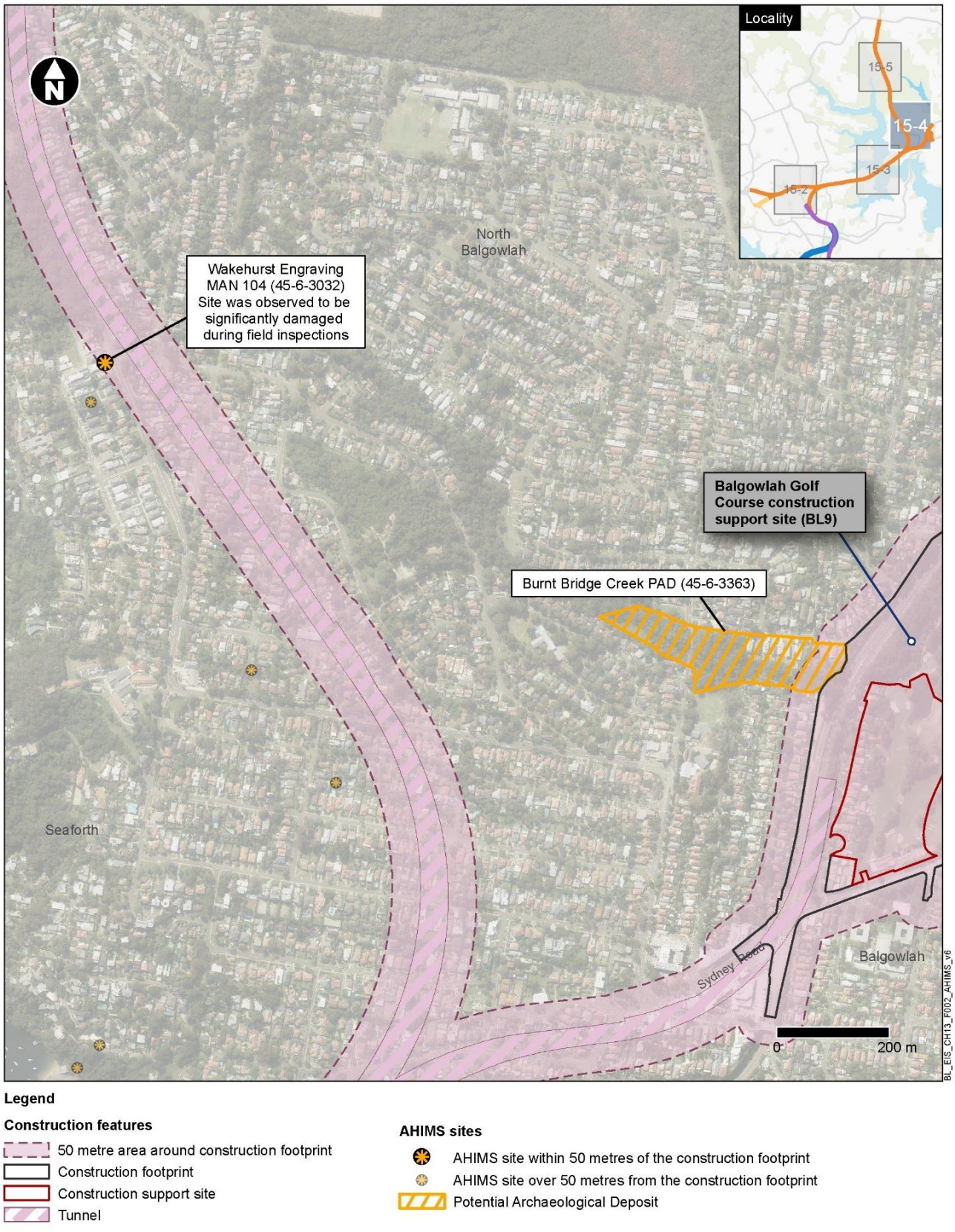


Figure 15-4 AHIMS sites within 50 metres of the project construction footprint (Seaforth to Balgowlah)

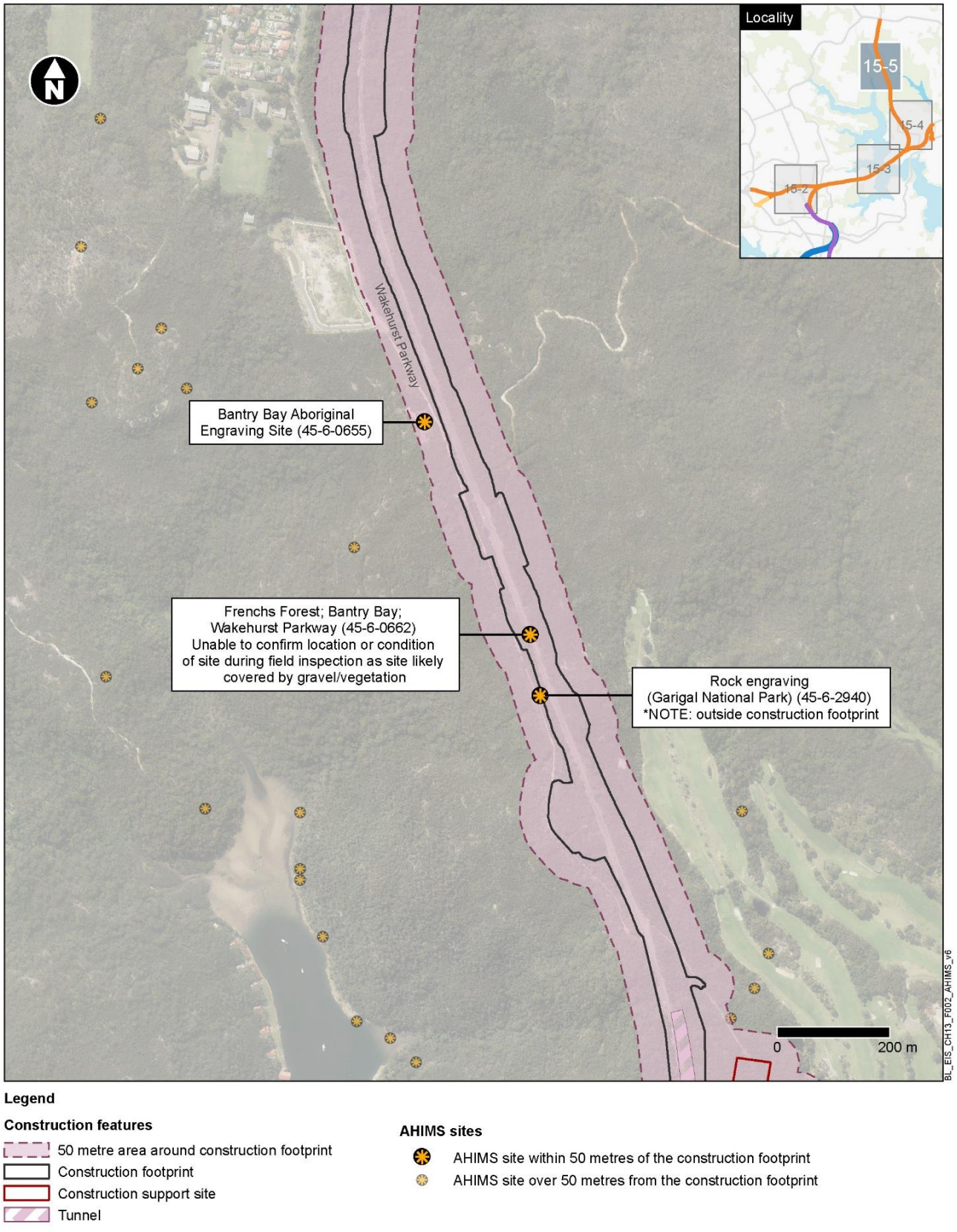


Figure 15-5 AHIMS sites within 50 metres of the project construction footprint (Wakehurst Parkway)

15.3.4 Potential submerged Aboriginal sites

Potential submerged Aboriginal archaeological sites refers to archaeological sites inundated since around 17,000 years ago, when the sea level began to rise, eventually flooding the river valley and forming a flood tide delta (Sydney Institute of Marine Sciene 2014). Aboriginal archaeological sites that could occur in inundated areas of the study area include:

- Rock shelters with occupation evidence and deposit
- Art and grinding grooves on sandstone ledges and faces
- Middens and/or stone artefact scatters on sandstone platforms and elevated area
- Fish traps on shallow, wide and gently sloping sandstone platforms.

The probability of these surviving intact, or at all depends on how the sea rose – gradually or as an encroaching active shoreline with wave and tidal action, and the subsequent pattern of tidal flow. The pronounced rock outcrops at about 20 metres depth close to Seaforth Bluff are considered to have moderate to high potential for the presence and survival of inundated rock shelters, more so than smaller rock overhangs closer to Clive Park which have been assessed as having low potential. At 30 metres below the current bed of the harbour, peat deposits present along the ancient watercourse that formed Middle Harbour have the greatest potential to contain well-preserved archaeological objects. There is a moderate to high potential for all identified site types listed above to be present in the Pearl Bay (west of Spit West Reserve) and the area between Clive Park and Beauty Point.

Potential rock overhangs are submerged and concealed by marine sediments, so they cannot be readily accessed and assessed. The assessment of impacts to submerged Aboriginal archaeological sites is therefore based on the potential for such sites to exist, using available geophysical information and an understanding of site formation processes.

Areas where submerged Aboriginal archaeological sites could occur have been considered based on a combination of the likelihood of the site occurring and the likelihood of it surviving inundation. Table 15-3 presents how archaeological potential has been defined, based on the likelihood of a site's presence.

Table 15-3 Defining Aboriginal archaeological potential

Archaeological potential	Likelihood of presence
Moderate to high	50–100 per cent
Low	25–49 per cent
Very Low	2–24 per cent
Remote	Less than 0–1 per cent

Table 15-4 summarises areas of submerged Aboriginal archaeological potential relevant to the project.

Table 15-4 Summary of areas of submerged Aboriginal archaeological potential

Location	Potential Aboriginal site type	Archaeological potential	Predicted potential location within study area
Between Northbridge and Seaforth	Stone artefacts, midden deposits and fish traps	Moderate to high	Formed along the ancient watercourse (as shown from geotechnical investigations).
	Rock shelters	Moderate to high	Along the sloping bed of the harbour on the Seaforth side of Middle Harbour.
	Rock shelters	Low	Along the sloping bed of the harbour on the Clive Park side of Middle Harbour.
	Rock shelters, art, grinding grooves, middens, stone artefact scatters, quarry sites and fish traps	Very low	Across the remainder of the study area.
Pearl Bay (west of Spit West Reserve)	Rock shelters, grinding grooves, middens and/or stone artefact scatters, stone quarry sites, fish traps	Moderate to high	In potential residual soils and/or sandstone overhangs/ledges, creek lines that may occur buried beneath Holocene marine sediments, up to up 30 metres thick below the current surface bed of the harbour.
Between Clive Park and Beauty Point)	Rock shelters, grinding grooves, middens and/or stone artefact scatters, stone quarry sites, fish traps.	Moderate to high	In potential residual soils and/or sandstone overhangs/ledges, creek lines that may occur buried beneath Holocene marine sediments which are assumed to comprise at least the first few metres of the current bed of the harbour.

15.3.5 Archaeological survey results

Targeted archaeological surveys were carried May, June and August 2017 to confirm the location of registered AHIMS sites and to assess areas identified as having potential Aboriginal archaeological sensitivity based on particular landforms. Additional assessments were undertaken with nominated site officers representing the Metropolitan Local Aboriginal Land Council in August 2018, February 2020 and September 2020. During these surveys, site officers were provided an opportunity to comment on the potential for Aboriginal cultural material to be present within the study area, the cultural significance of any Aboriginal cultural heritage sites identified during the survey and proposed management recommendations, including recommendations for further assessment. These areas of potential Aboriginal archaeological sensitivity and archaeological survey results are described in Table 15-5.

The archaeological surveys verified the presence of 10 of the 11 identified AHIMS sites. The location and condition of one of the sites (45-6-0662, Frenchs Forest; Bantry Bay; Wakehurst Parkway) could not be confirmed during field inspection and the Aboriginal Heritage Office has advised that the site was likely covered by gravel and vegetation.

The site Wakehurst Engraving MAN 104 (45-6-3032) was observed to be significantly damaged during field inspection in September 2020. An extensive area of bedrock from the horizontal rock

engraving appeared to have been cut back, with a significant portion missing, exceeding one square metre in extent. Transport for NSW has notified Heritage NSW of the damage.

No previously unrecorded Aboriginal cultural heritage places or objects were identified during the surveys.

Table 15-5 Outcomes of the archaeological surveys

Survey area	Aboriginal archaeological sensitivity	Archaeological survey results
St Leonards Park, North Sydney	Low	No Aboriginal cultural heritage was identified.
Cammeray Golf Club, Cammeray	Low	No Aboriginal cultural heritage was identified.
ANZAC Park, Cammeray	Low	No Aboriginal cultural heritage was identified.
Artarmon Park, Artarmon	Low	Potential archaeological deposit: several large sandstone outcrop areas and intact deposits: • Artarmon Park PAD (45-6-3362) • Artarmon Park artefact scatter (45-6-3599).
Punch Street, Artarmon	Low	No Aboriginal cultural heritage was identified.
Flat Rock Creek, Willoughby	Low	Historically significant area (Henry Lawson Cave) outside study area. One potential archaeological deposit identified near large sandstone outcrop areas with potentially intact deposit: • Flat Rock Creek PAD (45-6-3361).
Clive Park, Northbridge	High	Registered AHIMS sites inspected: • Clive Park 2; Taplin's Cicada Pupa Cave (45-6-0996) • Clive Park 1; Northbridge (45-6-0654) • Clive Park 8, Shelter and Midden (45-6-3012). No further Aboriginal cultural heritage was identified.
Spit West Reserve, Mosman	Low	No Aboriginal cultural heritage was identified.
Balgowlah Golf Course and Burnt Bridge Creek, Balgowlah	Low	High levels of disturbance across the site. Two recorded AHIMS sites were unable to be located (note these sites have now been documented as being destroyed and Heritage NSW have updated AHIMS to reflect this). Areas of potential archaeological deposit were noted where intact landforms remain adjacent to the creek. There is the potential for grinding grooves and engravings in the sandstone bedrock. Location of Burnt Bridge Creek PAD (45-6-3363). No further Aboriginal cultural heritage was identified.

Survey area	Aboriginal archaeological sensitivity	Archaeological survey results
Wakehurst Parkway, Seaforth to Frenchs Forest	High	Registered AHIMS sites inspected: • Bantry Bay Aboriginal Engraving Site (45-6-0655) • Wakehurst Engraving MAN 104 (45-6-3032) This site was observed to be significantly damaged during field inspection carried out in September 2020 • Rock engraving (Garigal National Park) (45-6-2940) • The location and condition of Frenchs Forest; Bantry Bay; Wakehurst Parkway (45-6-0662) was not able to be confirmed as the site was likely covered by gravel/vegetation.

15.3.6 Test excavation

During the archaeological survey, three areas of potential archaeological deposit were identified.

Further assessment and impact modelling was carried out to determine whether these sites had the potential to be directly impacted by the project. Based on this impact modelling, only the Artarmon Park potential archaeological deposit required test excavation as it is within the construction footprint that could be directly impacted by construction activities.

Test excavation at Balgowlah and Flat Rock Creek was not required because the areas of potential archaeological deposit are outside the immediate construction footprint. Although they are within the broader 50 metre area from the construction footprint being considered for indirect impacts (vibration and settlement), areas of potential archaeological deposit would not be impacted.

The test excavation at Artarmon Park consisted of:

- 17 shovel test pits (500 millimetres x 500 millimetres)
- One test pit (1000 millimetres x 1000 millimetres).

During the test excavations an artefact scatter consisting of 15 sub-surface stone artefacts (chert, silcrete, quartzite and mudstone material) were identified in association with Artarmon Park PAD (45-6-3362). This has been recorded as Artarmon Park artefact scatter (45-6-3599).

15.3.7 Significance assessment

The significance of those Aboriginal sites within 50 metres of the project construction footprint is summarised in Table 15-6, and has been assessed based on the four values of the Australia ICOMOS (International Council on Monuments and Sites) *Burra Charter* (Australia ICOMOS 2013):

- Social values
- Historical values
- Scientific values
- Aesthetic values.

Aboriginal cultural significance was assessed through consultation with the relevant Registered Aboriginal Parties during the archaeological survey and consultation process.

Potential archaeological deposits do not have a statement of significance below as they have not been extensively excavated and their significance is not able to be determined. It is noted that project refinements have allowed potential archaeological deposits to be avoided, removing the need to excavate in these areas during construction.

Any potential submerged Aboriginal archaeological sites could potentially have very high scientific significance due to the potential to yield information that would contribute to an understanding of New South Wales' natural and cultural history. Submerged Aboriginal archaeological sites and Pleistocene Aboriginal archaeological sites are both, on their own, rare site types within a New South Wales context and the identification of submerged Pleistocene landscapes and associated Aboriginal archaeological resources would be an extremely rare discovery within Australia.

Table 15-6 Significance of Aboriginal sites within 50 metres of the project construction footprint

Name and AHIMS ID	Significance value				Overall significance
	Social	Historical	Scientific	Aesthetic	
Artarmon Park artefact scatter (45-6-3599)	High	N/A	Moderate	Low	Low-moderate
Clive Park 8, Shelter and Midden (45-6-3012)	High	N/A	High	High	High
Clive Park 1; Northbridge (45-6-0654)	High	N/A	Moderate-high	High	High
Clive Park 2; Taplin's Cicada Pupa Cave (45-6-0996)	High	N/A	Moderate-high	Moderate	Moderate-high
Rock engraving (Garigal National Park) (45-6-2940)	High	High	Moderate-high	High	High
Bantry Bay Aboriginal Engraving Site (45-6-0655)	High	High	High	High	High

Name and AHIMS ID	Significance value				Overall significance
	Social	Historical	Scientific	Aesthetic	
Wakehurst Engraving MAN 104 (45-6-3032)	High	N/A	Low	Low	Low The site was observed to be damaged during field inspection in September 2020. Prior to the field inspection, the site had low overall significance. Following the September 2020 inspection, the significance rating of low is retained.
Frenchs Forest; Bantry Bay; Wakehurst Parkway (45-6-0662)	The location and condition of this site could not be confirmed during field inspection as the site was likely covered by gravel/vegetation. As such, a desktop assessment of this site was carried out, and no significance assessment has been carried out. The Aboriginal Heritage Office were the last agency to have conducted a condition assessment of the site.				

15.4 Assessment of potential impacts

15.4.1 Potential impacts to terrestrial Aboriginal heritage sites

Most potential impacts to Aboriginal sites would occur during construction, and may include:

- Direct impacts such as the removal or destruction of an Aboriginal site
- Indirect impacts associated with construction vibration generated by surface works in proximity to Aboriginal sites.

Potential impacts during operation are expected to be limited and may include indirect impacts associated with Aboriginal site setting (visual impacts, changes to vistas/landscapes), changes to ongoing use or environmental association.

The potential for these impacts to occur at known Aboriginal sites is summarised in Table 15-7. Based on the results of this assessment and in consultation with the Registered Aboriginal Parties, it is anticipated that:

- The location and condition of one Aboriginal site Frenchs Forest; Bantry Bay; Wakehurst Parkway (45-6-0662) could not be confirmed during field inspection but is considered likely to be within the construction footprint. This site could have partial/potential direct impact but this would need to be determined through further consultation/inspection
- Five Aboriginal sites (45-6-0655, Bantry Bay Aboriginal Engraving Site; 45-6-2940, Rock engraving (Garigal National Park); 45-6-3362, Artarmon Park PAD; 45-6-3361, Flat Rock Creek PAD and 45-6-3363, Burnt Bridge Creek PAD) are located within 50 metres of surface works including two sites that may be subject to indirect impacts associated with vibration and settlement (45-6-0655, Bantry Bay Aboriginal Engraving Site and 45-6-2940, Rock engraving (Garigal National Park))

- Five Aboriginal sites (45-6-3032, Wakehurst Engraving MAN 104; 45-6-3012, Clive Park 8, Shelter and Midden; 45-6-0654, Clive Park 1; Northbridge; 45-6-0996, Clive Park 2; Taplin's Cicada Pupa Cave and 45-6-3599, Artarmon Park artefact scatter) are located above or within 50 metres of the tunnel alignment and may be subject to indirect impacts associated with vibration and settlement
- Operational impacts are considered to be negligible.

Table 15-7 Assessment of potential impacts to known Aboriginal cultural heritage sites

Site	Site type	Overall site significance	Potential impact and description	Risk of potential impacts
Artarmon Park artefact scatter (45-6-3599)	Sub-surface artefact scatter	Low-moderate	Site is a sub-surface artefact scatter and would not be impacted by the project.	No impact
Artarmon Park PAD (45-6-3362)	Potential archaeological deposit	N/A	Site is a potential archaeological deposit and would not be impacted by the project.	No impact
Flat Rock Creek PAD (45-6-3361)	Potential archaeological deposit	N/A	Site is a potential archaeological deposit and would not be impacted by the project.	No impact
Clive Park 8, Shelter and Midden (45-6-3012)	Shelter and midden	High	Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible
			Indirect – settlement Settlement is predicted to be between 25-30 millimetres.	Negligible
Clive Park 1; Northbridge (45-6-0654)	Shelter with art, burial/s, shelter with midden, artefact scatter	High	Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible
			Indirect – settlement Settlement is predicted to be between 20-25 millimetres. Large overhang and high significance of this site increased significance outcome of potential impact.	Minor

Site	Site type	Overall site significance	Potential impact and description	Risk of potential impacts
Clive Park 2; Taplin's Cicada Pupa Cave (45-6-0996)	Shelter with art, shelter with midden	Moderate-high	Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible
			Indirect – settlement Settlement is predicted to be 10-15 millimetres.	Negligible
Burnt Bridge Creek PAD (45-6-3363)	Potential archaeological deposit	N/A	Site is a potential archaeological deposit and would not be impacted by the project. Rock shelter is less than 50 cubic metres in size.	No impact
Wakehurst Engraving MAN 104 (45-6-3032)	Rock engraving on outcrop	High	Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible
			Indirect – settlement Settlement at this location is predicted to be 10-15 millimetres, which poses a minor risk, however the existing site is already significantly impacted/damage and risk is therefore considered negligible.	Negligible
Rock engraving (Garigal National Park) (45-6-2940)	Rock engraving	High	Indirect – change to environmental setting and access There is the potential for changes to the visual setting and surrounding landscape due to the removal of mature native trees during construction. There is the potential for changes to the site access during construction works.	Negligible
			Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible

Site	Site type	Overall site significance	Potential impact and description	Risk of potential impacts
Frenchs Forest; Bantry Bay; Wakehurst Parkway (45-6-0662)	Rock engraving	Not assessed	Direct (partial/potential) Location and condition not confirmed during site inspection as site was likely covered by gravel/vegetation.	Minor
Bantry Bay Aboriginal Engraving Site (45-6-0655)	Large rock engraving site with multiple engravings	High	Indirect – change to environmental setting and access There is the potential for changes to the visual setting and surrounding landscape due to the removal of mature native trees during construction. There is the potential for changes to the site access during construction works.	Negligible
			Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible

Note: Each AIHMS site has been assessed for indirect impacts associated with settlement. With the exception of Clive Park 8, Shelter and Midden (45-6-3012), Clive Park 1; Northbridge (45-6-0654), Clive Park 2; Taplin's Cicada Pupa Cave (45-6-0996) and Wakehurst Engraving MAN 104 (45-6-3032) all sites within the study area are outside of the zone of potential settlement impacts.

15.4.2 Impacts to potential submerged Aboriginal sites

Potential rock overhangs are submerged and concealed by marine sediments, so they cannot be readily accessed and assessed. The assessment of impacts to submerged Aboriginal archaeological sites is therefore based on the potential for such sites to exist, using available geophysical information and an understanding of site formation processes.

The predictive model provides a basis for assessing potential impacts and identified that there is documented evidence of Aboriginal occupation and land use patterns along the Port Jackson shoreline and the broader Sydney Basin.

The extent to which sites may have survived inundation is dependent on the length and intensity of exposure to water movement and wave action. It is predicted that most submerged sites are likely to be identified in peat deposits which have formed above residual subsoils, some of which may be beneath at least 10 metres of marine sediment.

Construction activities associated with excavation within the cofferdams, dredging and piling may have direct and indirect impacts on potential submerged Aboriginal archaeological sites. The construction of the immersed tube tunnels would require dredging of the bed of the harbour to create a trench for the installation of the immersed tube tunnel. The slopes of the trench would generally be about 14 degrees (25 per cent) to maximise the stability of the trench and minimise the risk of slumping. The tunnel trench would be designed to provide a solid and safe place for the immersed tube tunnel to be placed.

Most of the potential impacts to submerged Aboriginal archaeological sites would likely occur during construction rather than operation, and may include:

- Direct impacts from construction activities such as dredging, piling and excavation within the cofferdams
- Indirect impacts associated with construction vibration generated by construction activities in proximity to Aboriginal sites.

Indirect impacts such as vibration would have a negligible impact, because any submerged Aboriginal archaeological sites would be buried, and movement of individual objects would be minimal.

Further investigation would be required to confirm the presence of sites and their condition. If confirmed, the identification and documentation of such Aboriginal archaeological sites would demonstrate that such sites could be present across Sydney Harbour / Middle Harbour, and the information obtained in this project would be valuable in managing this resource.

A summary of potential impacts to submerged Aboriginal heritage is provided in Table 15-8.

Table 15-8 Assessment of potential impacts to submerged Aboriginal sites

Location	Potential Aboriginal site type	Archaeological potential	Significance of direct impacts	Risk of indirect impacts
Between Northbridge and Seaforth	Stone artefacts, midden deposits and fish traps	Moderate to high	Moderate to major (before mitigation) due to dredging	Negligible
	Rock shelters – Seaforth side of Middle Harbour	Moderate to high	N/A as likely below construction depth	Negligible
	Rock shelters – Clive Park side of Middle Harbour	Low	N/A	Negligible
	Rock shelters, art, grinding grooves, middens, stone artefact scatters, quarry sites and fish traps (across remainder of study area)	Very low	Negligible to moderate (before mitigation) due to dredging and excavation	Negligible
Pearl Bay (west of Spit West Reserve)	All forms identified – rock shelters, grinding groves, middens and/or stone artefact scatters, stone quarry sites, fish traps	Moderate to high	Potential impacts to submerged Aboriginal sites unlikely in this location as the depth of piling for the temporary wharf would not reach below bed of the harbour strata containing Aboriginal archaeological sites. Potential impacts are therefore considered negligible to minor.	
Between Clive Park and Beauty Point)	All forms identified – rock shelters, grinding groves, middens and/or stone artefact scatters, stone quarry sites, fish traps	Moderate to high	Potential impacts to submerged Aboriginal sites unlikely in this location as the depth of piling for the temporary wharf would not reach below bed of the harbour containing Aboriginal archaeological sites. Potential impacts are therefore considered negligible.	

15.5 Environmental management measures

Measures to avoid, minimise or manage Aboriginal cultural heritage impacts as a result of the project are detailed in Table 15-9.

Table 15-9 Environmental management measures – Aboriginal cultural heritage

Ref	Phase	Impact	Environmental management measure	Location
Terrestrial Aboriginal heritage				
AH1	Pre-construction and construction	Aboriginal heritage – vibration, and settlement impacts	Before the start of construction, further consultation with Heritage NSW, the Metropolitan Local Aboriginal Land Council, the Aboriginal Heritage Office and the Registered Aboriginal Parties will be carried out to decide an appropriate course of action for the Aboriginal site 45-6-0662 on Wakehurst Parkway, as the location of this site could not be confirmed during field inspection (site is likely covered by gravel/vegetation). If considered appropriate, an archaeological investigation may be carried out at the possible site location to carefully remove the gravel/vegetation, to confirm its presence and record the underlying site condition. If new information regarding site condition is identified during consultation suggesting the site may be subject to impacts due to vibration and settlement, environmental management measures AH2, AH3 and AH4 will apply. In the absence of confirming the site, if during construction works a site is located, the unexpected finds protocol prescribed in AH5 would apply. Further, Heritage NSW, an appropriately qualified archaeologist and the Metropolitan Local Aboriginal Land Council will be contacted and the site will be re-recorded in situ.	Frenchs Forest; Bantry Bay; Wakehurst Parkway (45-6-0662)
AH2	Pre-construction and construction	Aboriginal heritage – vibration impacts	The following process will be carried out to confirm where vibration monitoring at those terrestrial sites within 50 metres of the project corridor will be required: a) Terrestrial Aboriginal site condition surveys of sites will be completed by an appropriately qualified person using those techniques appropriate in determining which sites are considered to be structurally unsound b) Where this determination cannot be made, as a precaution the site will be considered to be structurally unsound c) A screening of vibration intensive activities within 50 metres of structurally unsound sites will be carried out to identify activities	All registered AHIMS sites subject to vibration intensive activities determined to be structurally unsound (see AH2).

Ref	Phase	Impact	Environmental management measure	Location
			that have the potential to exceed vibration levels of 2.5 millimetres per second d) Sites identified as being both structurally unsound and having potential for exceedance in vibration levels of 2.5 millimetres per second will be identified as requiring vibration monitoring where this cannot be reduced at the source.	
AH3	Construction	Aboriginal heritage – vibration impacts	Vibration monitoring will be carried out at sites that have been identified as requiring monitoring in accordance with the process outlined in environmental management measure AH2. The monitoring process will: • Be developed by a suitably qualified person • Be risk-based • Include appropriate frequency and duration of monitoring including adequate benchmark recording before works commence • Include appropriate management protocols for any exceedances. Where possible, project works will be conducted in a manner to minimise vibration levels, to less than 2.5 millimetres per second at all structurally unsound AHIMS sites.	All registered AHIMS sites located subject to vibration intensive activities determined to be structurally unsound (see AH2).
AH4	Construction	Aboriginal heritage – vibration impacts	Where monitoring identifies that vibration levels exceed 2.5 millimetres per second, or following vibration intensive activities, subsequent condition survey of sites that are subject to monitoring in AH3 will be carried out. The subsequent condition surveys will record any changes to the integrity of the site that may have resulted from construction vibration. Additional surveys must be carried out by a suitably qualified person and include a Metropolitan Local Aboriginal Land Council representative. AHIMS site cards will be updated accordingly where any changes are observed. Condition surveys may include further photogrammetry and 3D-capture techniques, in which case comparison against the baseline will be carried out.	All registered AHIMS sites subject to vibration monitoring (see AH3)

Ref	Phase	Impact	Environmental management measure	Location
AH5	Construction	Unexpec-ted discovery of historical heritage materials, features, or deposits	If at any time during construction of the project, any items of potential Aboriginal archaeological or cultural heritage conservation significance or Ancestral remains are discovered they will be managed in accordance, the *Standard Management Procedure: Unexpected Heritage Items* (Roads and Maritime Services, 2015d).	BL/GHF
AH6	Construction	Aboriginal heritage – impacts	Cultural and historic heritage awareness training will be carried out for personnel engaged in work that may impact heritage items before commencing works for the project.	BL/GHF
AH7	Pre-construction and construction	Aboriginal heritage – impacts	As part of the project urban design and landscape plan, an Aboriginal heritage interpretation strategy will be developed for the project in consultation with Registered Aboriginal Parties and other relevant Stakeholders. Appropriate Aboriginal heritage interpretation will be incorporated into the project urban design and landscape plan in accordance with the interpretation strategy.	BL/GHF
Maritime Aboriginal heritage				
AH8	Pre-construction	Potential Aboriginal submerge-ed sites heritage impacts	The effectiveness of using high resolution geophysical survey to identify rock overhangs concealed by marine sediments will be assessed. If it is determined that a high resolution geophysical survey could produce the desired results, then the survey will be carried out. If the geophysical survey conclusively shows that there are no rock overhangs measuring at least 1.5 metres in height (from the rock base to the rock ceiling), there would be no further archaeological work carried out and any residual risk will be managed through an unexpected finds procedure. However, if the geophysical survey is inconclusive or distinct rock overhangs are identified, then an archaeological dive investigation will be implemented. Much of the diving will be done in near zero visibility and will therefore be limited to what a diver can feasibly and safely do.	Potential rock shelter(s) at Seaforth located outside of Middle Harbour north construction support site (BL8) cofferdam footprint but within the dredge footprint

Ref	Phase	Impact	Environmental management measure	Location
AH9	Pre-construction and construction	Potential Aboriginal submerge-ed sites heritage impacts	The effectiveness of using high resolution geophysical survey to identify rock overhangs concealed by marine sediments will be assessed. If it is determined that a high resolution geophysical survey could produce the desired results, then the survey will be carried out. If the geophysical survey conclusively shows that there are no rock overhangs measuring at least 1.5 metres in height (from the rock base to the rock ceiling), there would be no further archaeological work carried out and any residual risk will be managed through an unexpected finds procedure. However, if the geophysical survey is inconclusive or distinct rock overhangs are identified, then onsite visual monitoring within the cofferdam will be carried out during the construction period, after the cofferdam has been de-watered. The aim of the monitoring will be to identify voids within the bedrock close to the interface with marine sediments. In the event that a void in the bedrock appears that displays the characteristics of a potential rock shelter, then the marine sediments will be removed by pump. Should the marine sediments bottom out onto the rock no further action would be taken. If the characteristics of the marine sediments change or if fissures are evident, then samples of the sediments will be taken, preferably as an intact core sample. In consultation with a suitably experienced geomorphologist a set of criteria will be established for the identification of pre-inundation soil deposits (peat, charcoal, roots, etc). If pre-inundation soil deposits are evident within samples, a controlled archaeological investigation to recover any artefacts will take place. However, the extent of the archaeological investigation and method of recovery will be determined by the constraints of the bed rock conditions and workplace health and safety protocols and constraints within the cofferdams, including safety protocols for handling of potentially contaminated sediment. Environmental, engineering and workplace health and safety factors such as operating space within an overhang, viscosity of the pre-inundation soil and elevated contamination levels will have an influence on the method of archaeological investigation, which will nonetheless aim to retain spatial and stratigraphic control if at all feasible.	Within the footprint of Middle Harbour south and north cofferdams construct-ion support sites (BL7 and BL8)

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

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Chapter 16

Geology, soils and groundwater

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DECEMBER 2020

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.

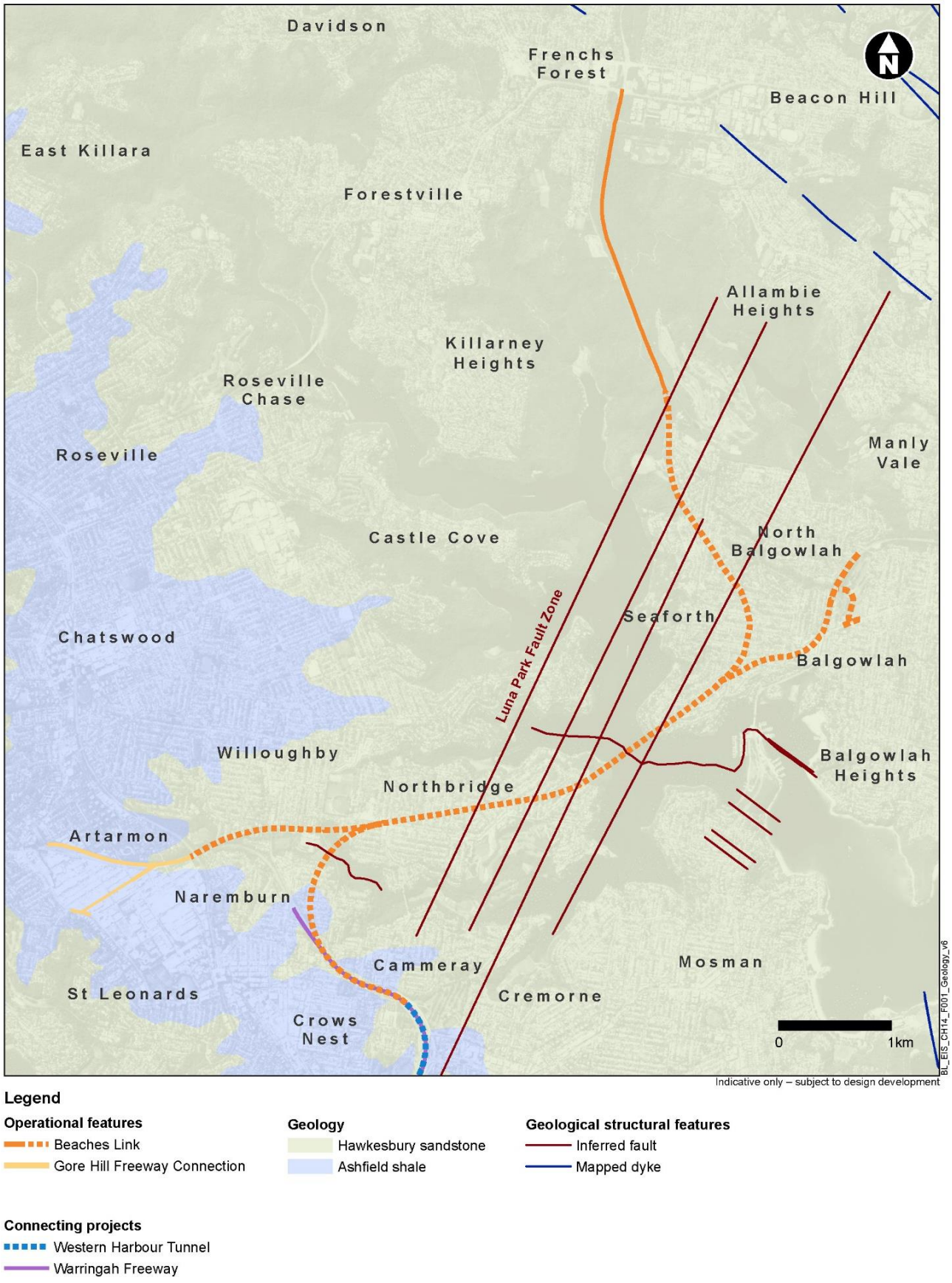


Figure 16-1 Regional geological context

16.3.3 Soils

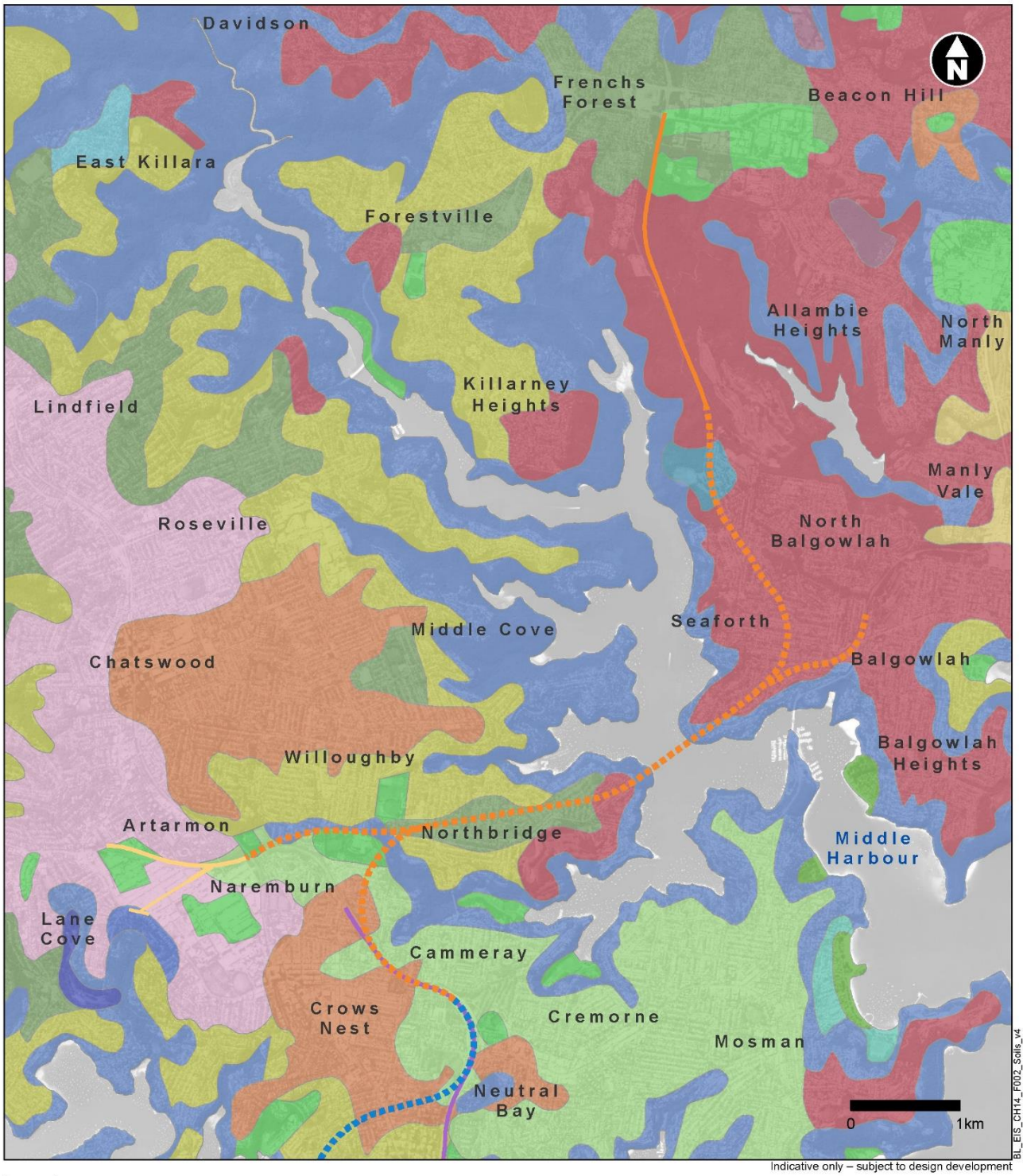
Soil groups and erosion potential

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.

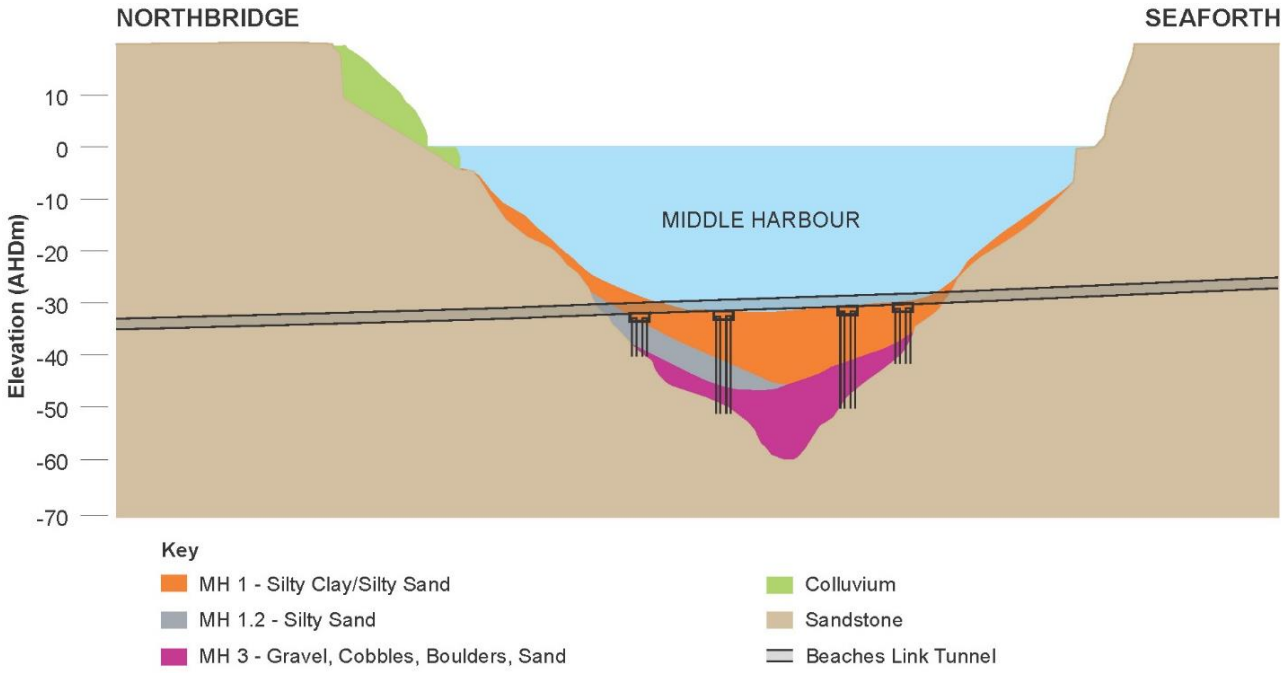


Figure 16-3 Middle Harbour marine sediment and geology profile

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.

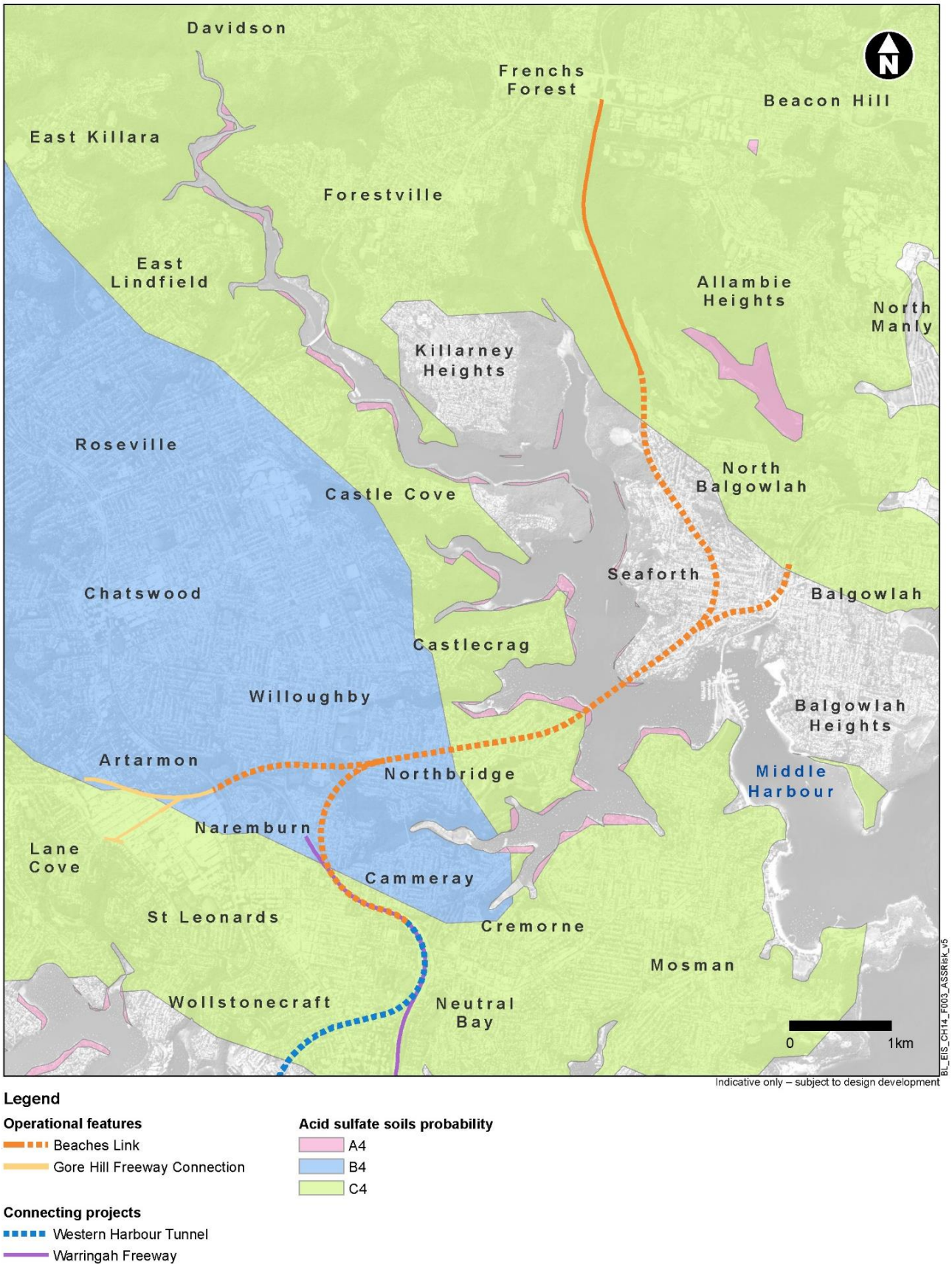


Figure 16-4 Landform acid sulfate soil risk classification

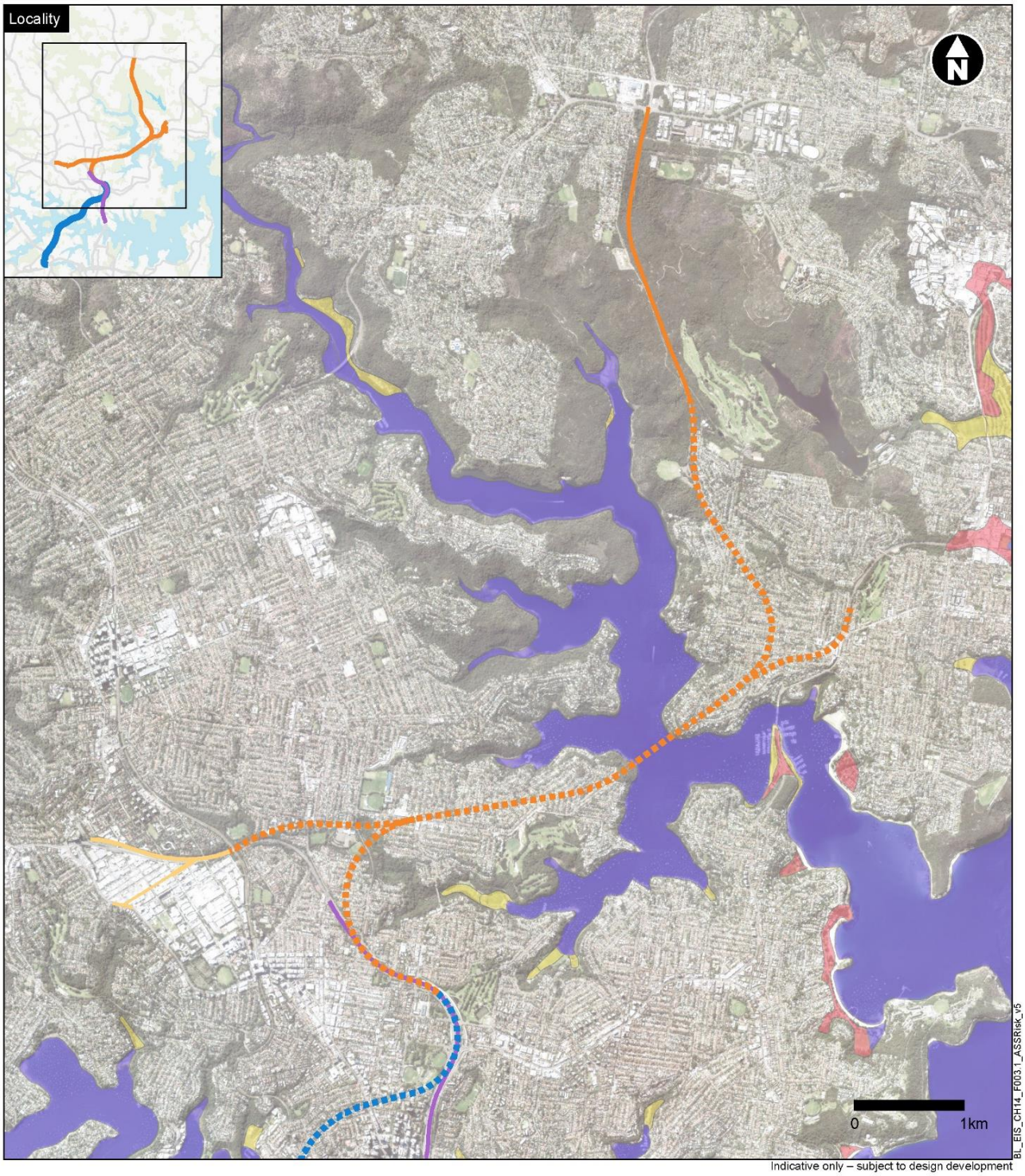


Figure 16-5 Marine environment acid sulfate soil risk classification

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.

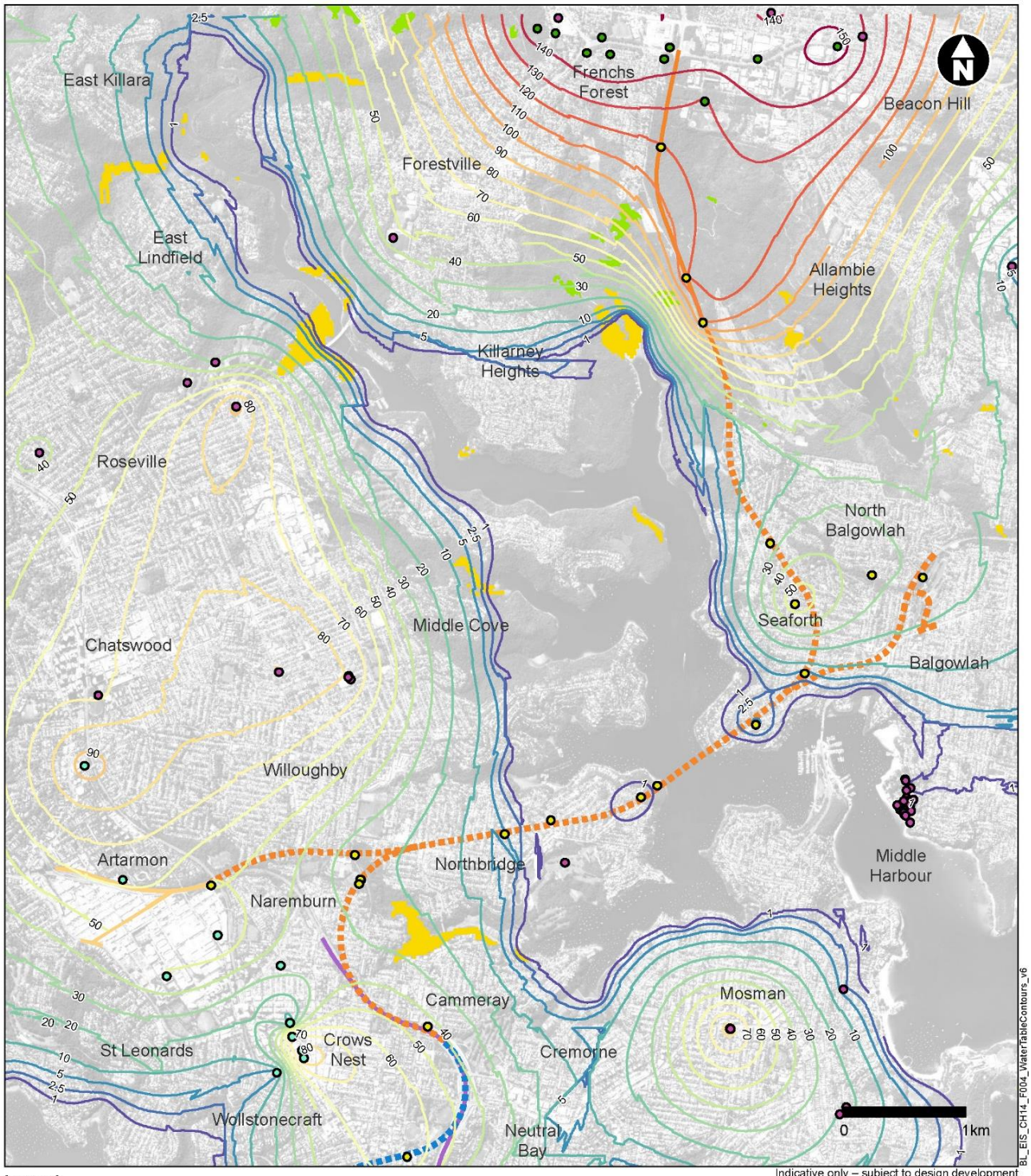
A composite water table contour map for the study area is presented in Figure 16-6. These contours were created using baseline groundwater data from the groundwater monitoring network installed for the project, as well as water levels from the Department of Planning, Industry and Environment (Water) 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).

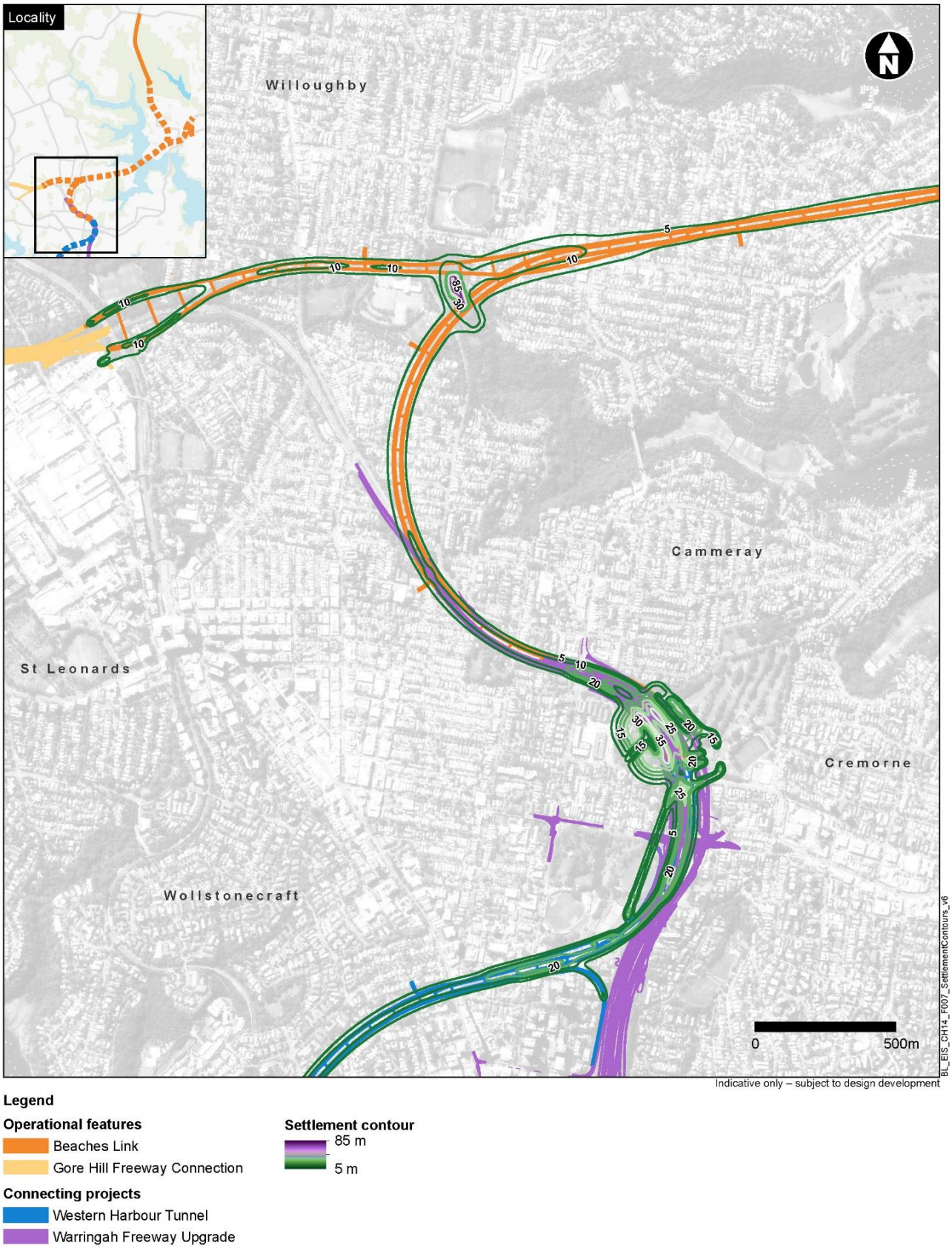


Figure 16-8 Settlement contours – Cammeray, Willoughby

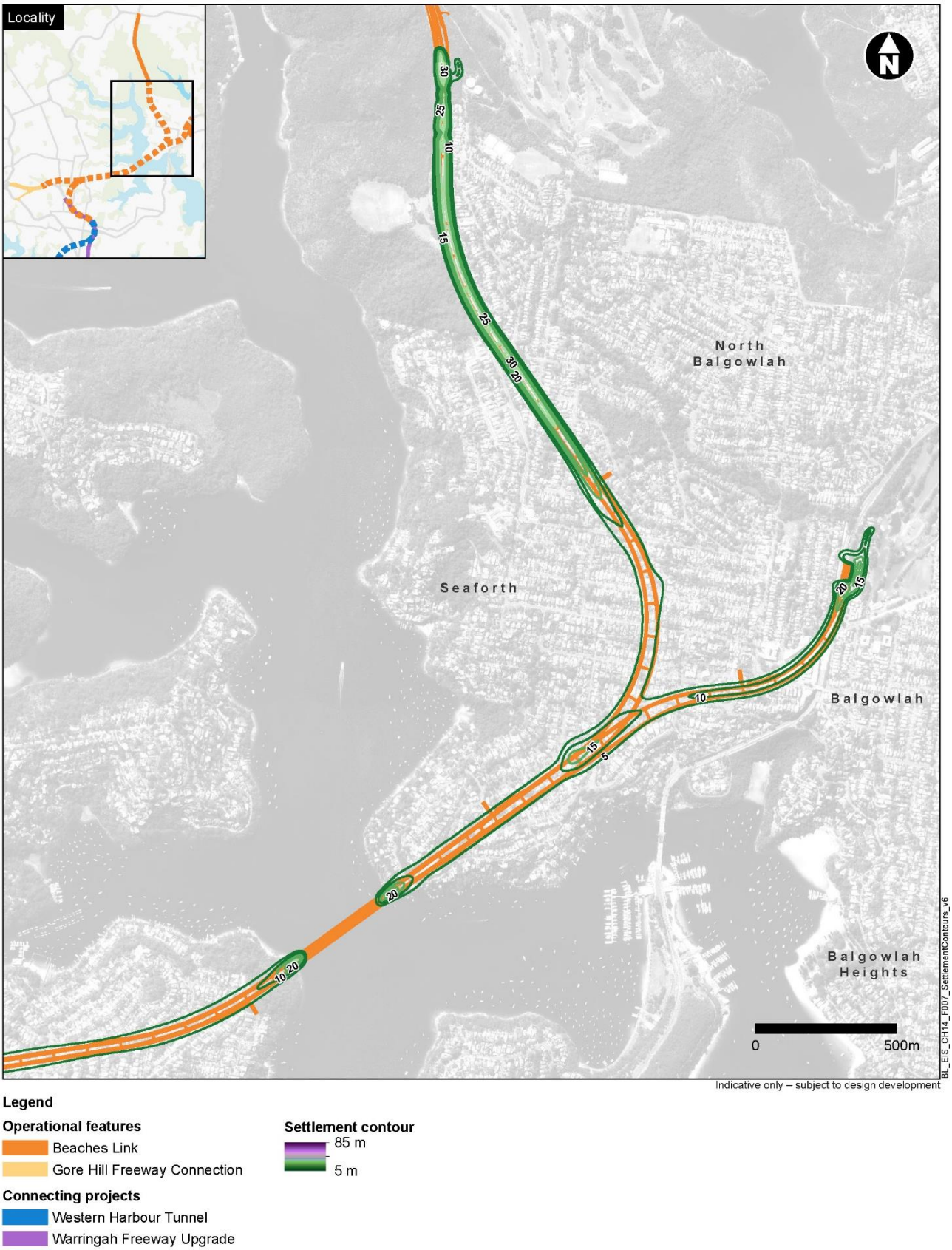


Figure 16-9 Settlement contours – Middle Harbour, Seaforth, Balgowlah

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.

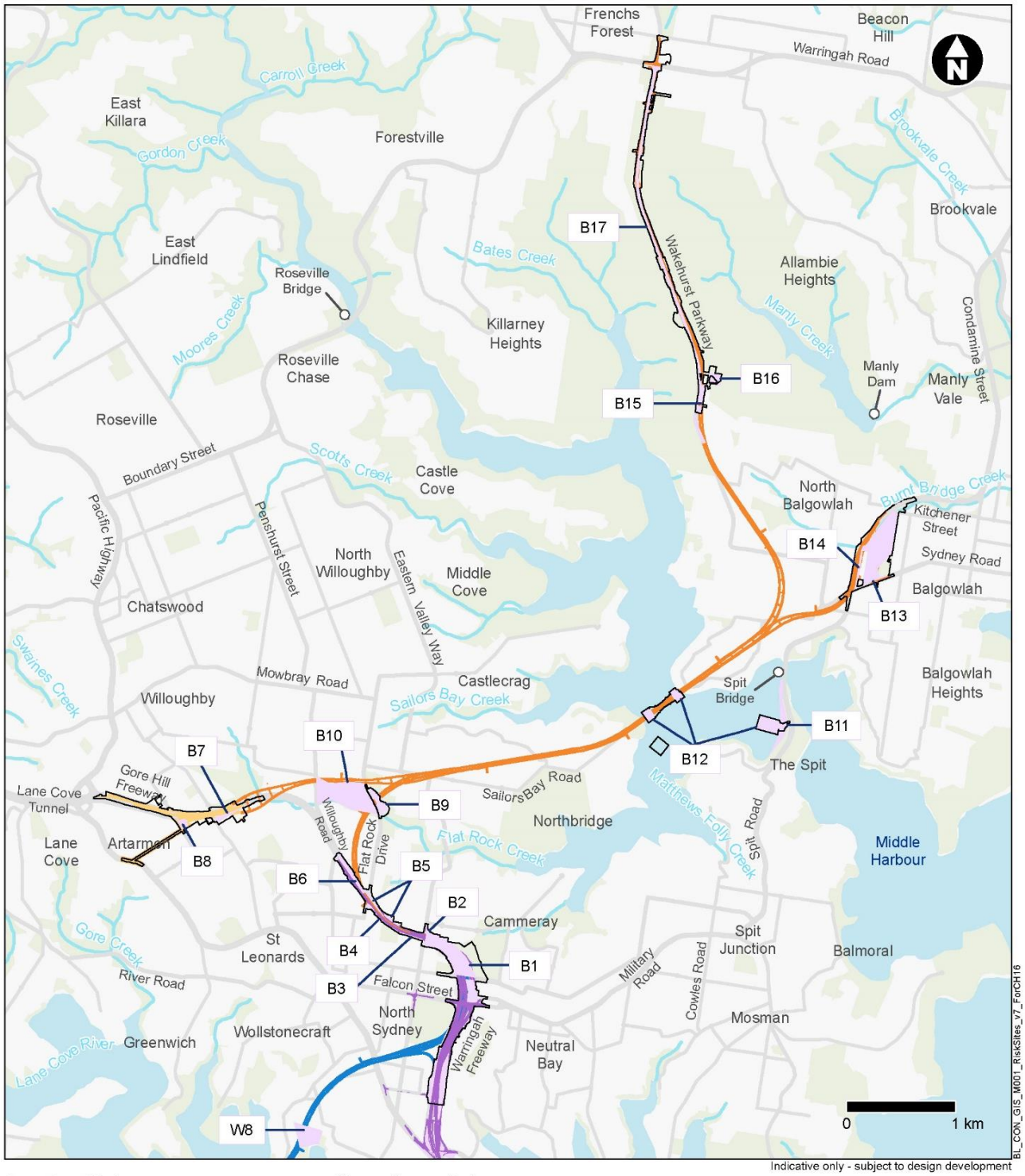


Figure 16-10 Areas of environmental interest and contaminated sites

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.

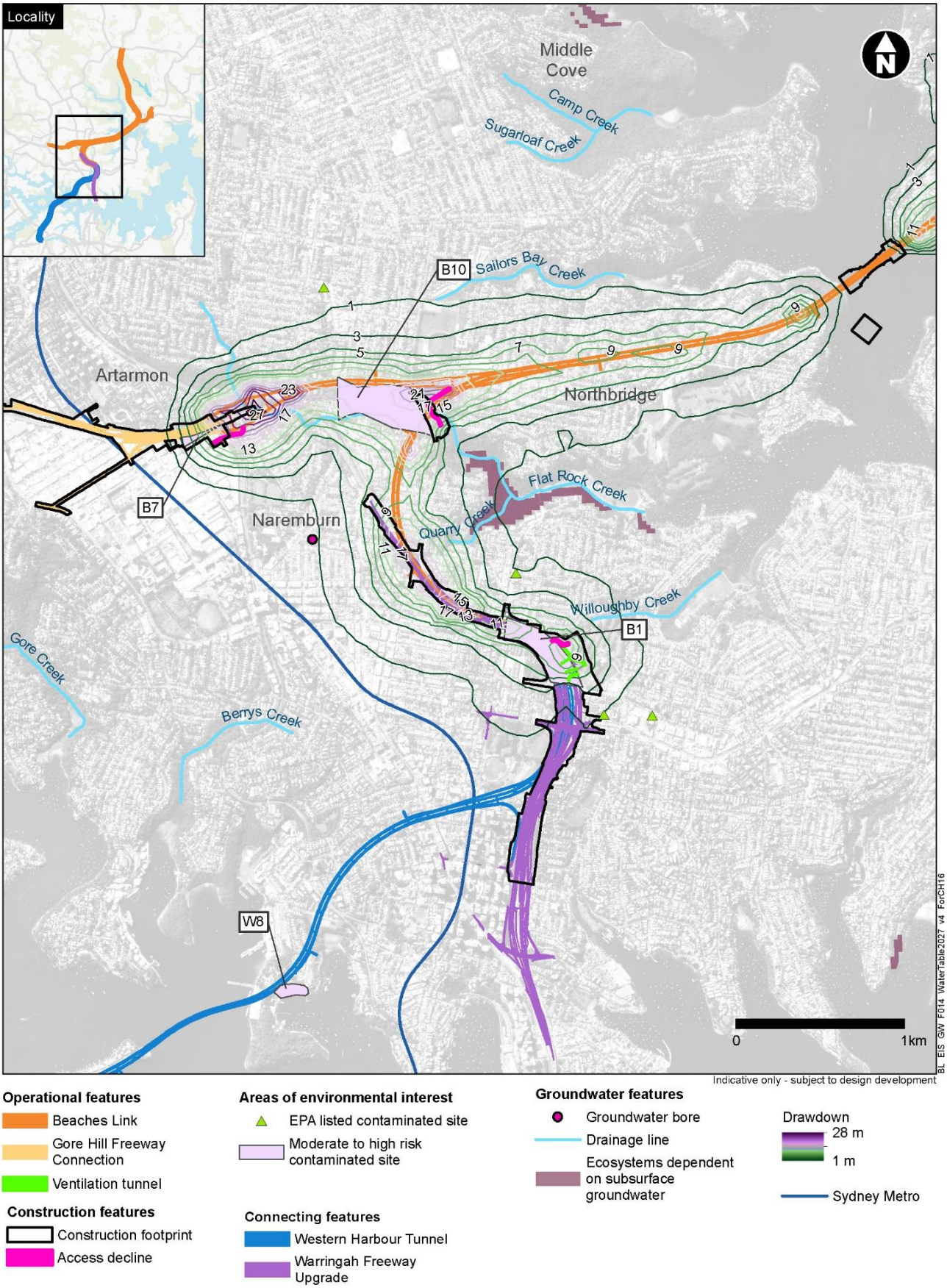


Figure 16-11 Predicted groundwater drawdown contours for the project at the end of tunnel construction (2028) – South of Middle Harbour

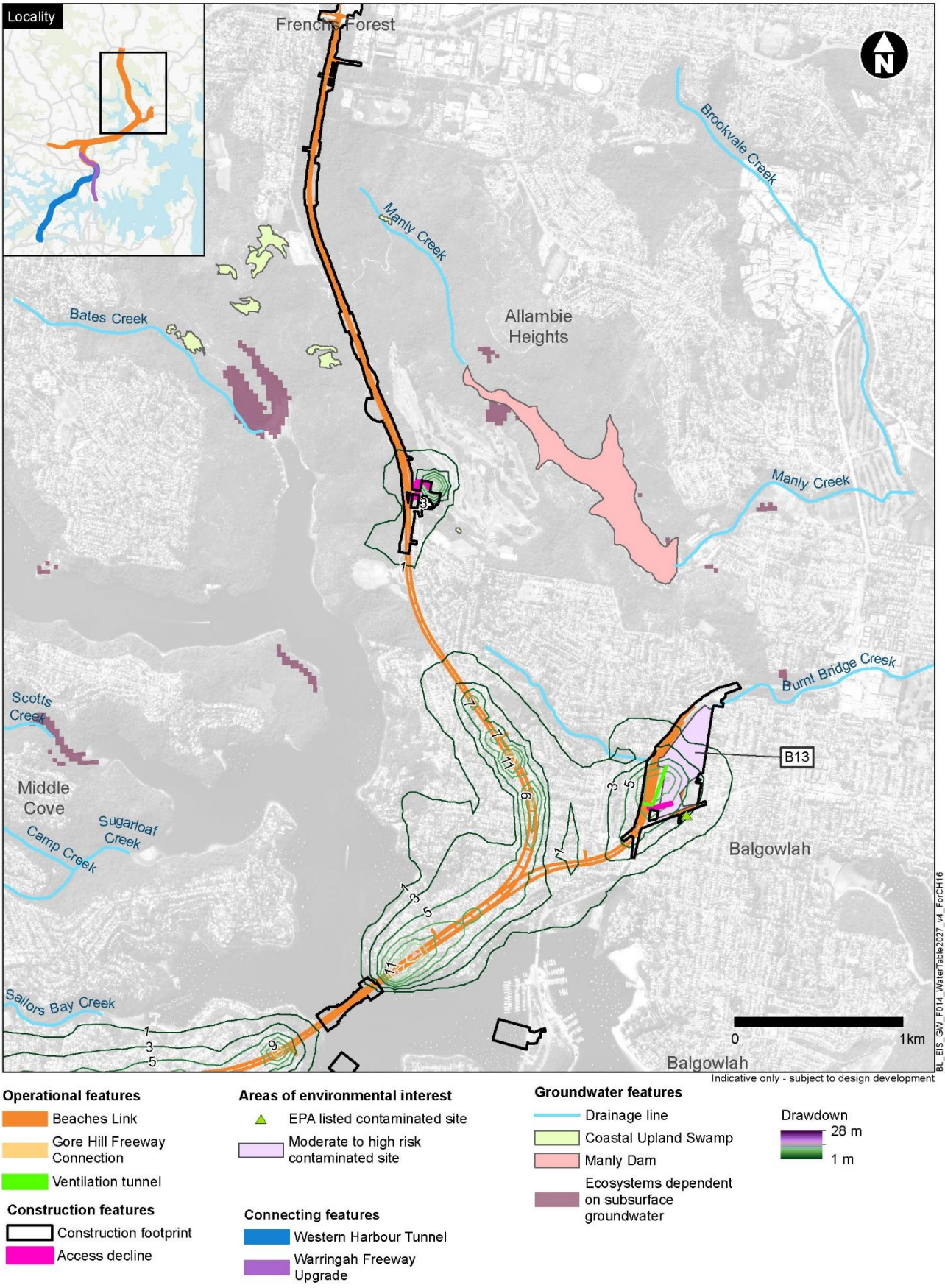


Figure 16-12 Predicted groundwater drawdown contours for the project at the end of tunnel construction (2028) – North of Middle Harbour

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.

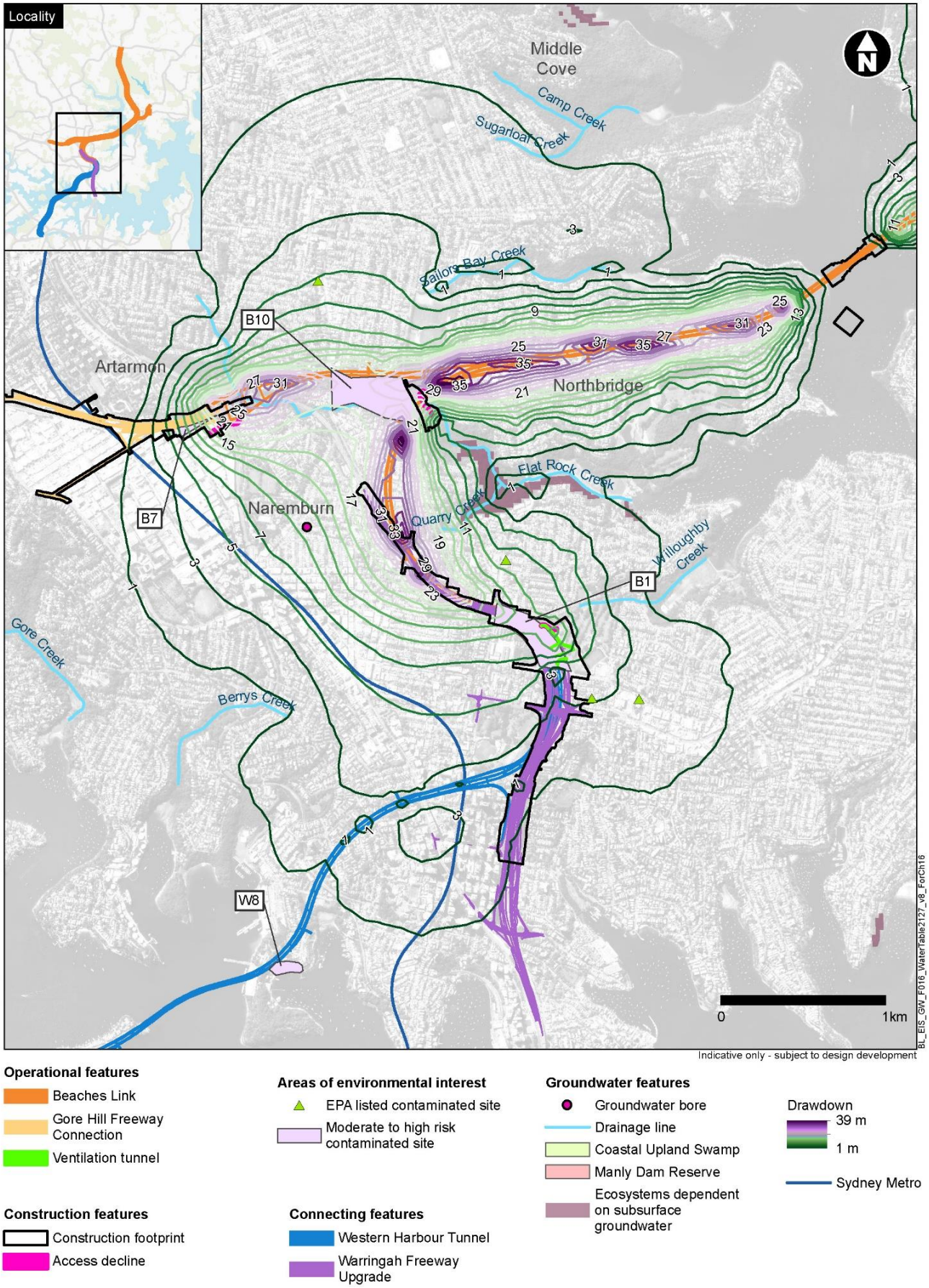


Figure 16-13 Groundwater drawdown contours for the project during operation in 2128 – South of Middle Harbour

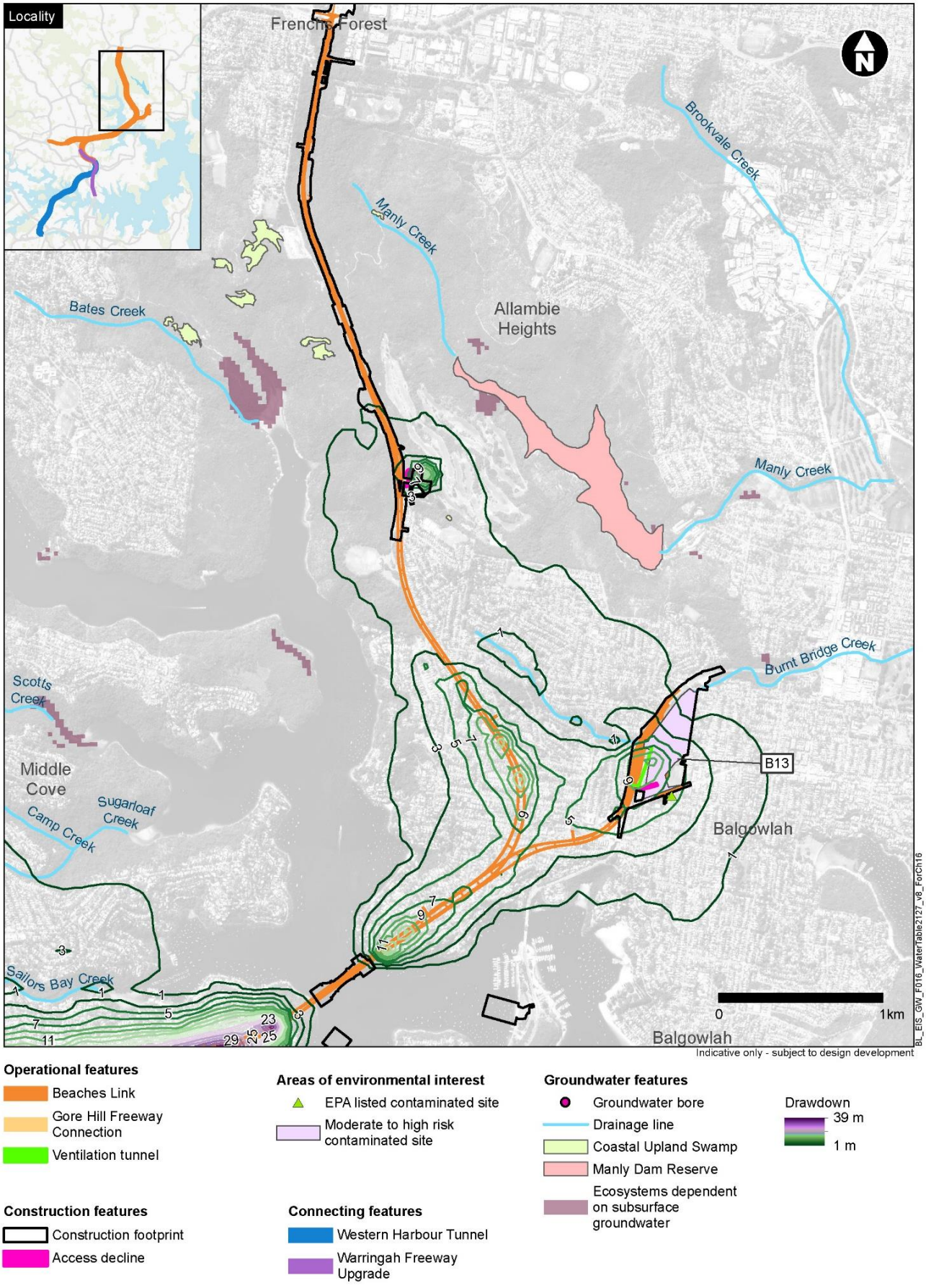


Figure 16-14 Groundwater drawdown contours for the project during operation in 2128 – North of Middle Harbour

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

Transport for NSW

Beaches Link and Gore Hill Freeway Connection

Chapter 17

Hydrodynamics and water quality

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DECEMBER 2020

17 Hydrodynamics and water quality

This chapter provides an assessment of the construction and operational impacts associated with hydrodynamics and (surface) water quality and identifies measures which address these impacts.

A detailed surface water quality and hydrology assessment has been carried out for the project and is included in Appendix O (Technical working paper: Surface water quality and hydrology). Hydrodynamic and dredge plume modelling has also been carried out and is detailed in Appendix P (Technical working paper: Hydrodynamic and dredge plume modelling). A marine water quality assessment is provided in Appendix Q (Technical working paper: Marine water quality). The impacts associated with flooding are detailed in Chapter 18 (Flooding), while assessments of contamination and groundwater impacts are included in Chapter 16 (Soils, geology and groundwater).

The Secretary's environmental assessment requirements as they related to hydrodynamics and water quality, and where in the environmental impact statement these have been addressed, are detailed in Table 17-1.

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 hydrodynamics and water quality are included in Section 17.6.

Table 17-1 Secretary's environmental assessment requirements – hydrodynamics and water quality

Secretary's requirement	Where addressed in EIS
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* (OEH, 2014).	The existing hydrological regime for surface water resources is described in **Section 17.3**. Details of water resources likely to be impacted by the project is presented in **Section 17.3.1**. Biodiversity considerations are outlined in **Chapter 19** (Biodiversity) and the hydrological regime for groundwater is considered in **Chapter 16** (Soils, geology and groundwater).
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.	A surface water balance for construction and operation is provided in **Section 17.4.5** and **Section 17.5.6** respectively. Further details, including wastewater treatment plants and associated discharge locations, are provided in **Section 17.4.3**. Refer to **Chapter 5** (Project description) for locations of permanent water quality basins proposed for the project.

Secretary's requirement	Where addressed in EIS
	Refer to **Chapter 16** (Geology, soils and groundwater) for groundwater inflow predictions.
3. The Proponent must assess (and model if appropriate) the impact of the construction and operation of the project and any ancillary facilities (both built elements and discharges) on surface and groundwater hydrology in accordance with the current guidelines, including: a. natural processes within rivers, wetlands, estuaries, marine waters and floodplains that affect the health of the fluvial, riparian, estuarine or marine system and landscape health (such as modified discharge volumes, durations and velocities), aquatic connectivity, water-dependent fauna and flora and access to habitat for spawning and refuge;	Surface water hydrological impacts and impacts on natural processes are included in **Section 17.4** and **Section 17.5**. Groundwater hydrological impacts are included in **Chapter 16** (Geology, soils and groundwater). Impacts on flooding are included in **Chapter 18** (Flooding). 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 are included in **Chapter 19** (Biodiversity).
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;	Groundwater hydrological impacts are included in **Chapter 16** (Geology, soils and groundwater). Implications for groundwater dependent ecosystems and species are included 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;	An assessment of the changes to environmental water availability and flows (including the stormwater harvesting scheme implemented by North Sydney Council at the storage dam at Cammeray Golf Course) is included in **Section 17.4.5** and **Section 17.5.6**.
d. direct or indirect increases in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses;	Potential impacts on surface water with regard to erosion, siltation, and bank stability are assessed in **Section 17.4** and **Section 17.5**. Impacts from scour and erosion on geomorphology are discussed in **Section 17.4.4** and **Section 17.5.4**. Impacts on riparian vegetation are included in **Chapter 19** (Biodiversity).
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	The effects of proposed stormwater and wastewater management on surface water quality are assessed in **Section 17.4.3** and **Section 17.5.3**. Information on wastewater discharge, including volumes and rates of discharge, are included in **Section 17.4.3** and **Section 17.5.3**.

Secretary's requirement	Where addressed in EIS
systems where discharges are proposed through such systems;	
f. measures to mitigate the impacts of the proposal and manage the disposal of produced and incidental water; and	Environmental management measures relating to surface water are detailed in **Section 17.6**. Water drainage and management infrastructure is detailed in **Chapter 5** (Project description) and **Chapter 6** (Construction work).
4. The assessment must provide details of the final landform of the sites to be excavated or modified (eg portals), including final void management and rehabilitation measures.	Details of the final landforms and rehabilitation for the project are provided in **Chapter 22** (Urban design and visual amenity). Landscape treatments for the project are detailed in **Chapter 5** (Project description).
5. The Proponent must identify any requirements for baseline monitoring of hydrological attributes.	A description of surface water monitoring carried out to inform this environmental impact statement, and requirements for operational monitoring are provided in **Section 17.2.3** and **Section 17.6** respectively. Proposed surface water monitoring locations are presented in **Section 17.2.2**.
6. The assessment must include details of proposed surface and groundwater monitoring.	A description of surface water monitoring carried out to inform this environmental impact statement, and requirements for operational monitoring are provided in **Section 17.2.3** and **Section 17.6** respectively. Proposed groundwater monitoring is identified in **Chapter 16** (Geology, soils and groundwater).
7. The Proponent must identify design approaches to minimise or prevent drainage of alluvium in the paleochannels.	Palaeochannels near the project are described in **Chapter 16** (Geology, soils and groundwater). Details of tunnel design are provided in **Chapter 5** (Project description) and **Chapter 6** (Construction work).
Water – Quality	
1. The Proponent must: a. describe the background conditions for any surface or groundwater resource likely to be affected by the development	A description of the background surface water and groundwater conditions is included in **Section 17.3** and **Chapter 16** (Geology, soils and groundwater) respectively.
b. state the ambient NSW Water Quality Objectives (NSW WQO) (as endorsed by the NSW Government [see www.environment.nsw.gov.au/ieo/index.htm]) and environmental values for the receiving waters (including groundwater where appropriate) relevant to the project and that represent the community's uses and values for those receiving waters, including the	A list of the ambient NSW water quality objectives for receiving waters within the project area is included in **Section 17.1.2**. Environmental values for the receiving waters are discussed in **Section 17.3.9**. The ANZG (2018) and ANZECC/ARMCANZ (2000) default trigger values are provided in **Appendix O** (Technical working paper: Surface water quality and hydrology).

Secretary's requirement	Where addressed in EIS
indicators and associated trigger values or criteria for the identified environmental values in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government;	
c. identify and estimate the quality and quantity of all pollutants that may be introduced into the water cycle by source and discharge point and describe the nature and degree of impact that any discharge(s) may have on the receiving environment, including consideration of all pollutants that pose a risk of non-trivial harm to human health and the environment;	Potential pollutants of concern are identified in **Section 17.4**, **Section 17.5** and **Appendix O** (Technical working paper: Surface water quality and hydrology). An assessment of the potential for construction to introduce pollutants into receiving waterways is provided in **Section 17.3.5**. Discharge quantities and locations are provided in **Section 17.4.3** and **Section 17.5.3**.
d. identify the rainfall event that the water quality protection measures will be designed to cope with;	**Section 17.1.3** identifies design standards, targets and considerations to be adopted during construction and operation, including criteria to which water quality protection measures would be designed for.
e. assess the significance of any identified impacts including consideration of the relevant ambient water quality outcomes;	The significance of identified impacts on ambient water quality outcomes is assessed in **Section 17.4** and **Section 17.5**.
f. demonstrate how construction and operation of the project (including mitigating effects of proposed stormwater and wastewater management) would, to the extent that the project can influence, ensure that: - where the NSW WQOs for receiving waters are currently being met they would continue to be protected; and - where the NSW WQOs are not currently being met, activities would work toward their achievement over time;	Discussion of whether the NSW water quality objectives are currently met is included in **Section 17.3.5**. An assessment on how construction and operation of the project would impact on the NSW water quality objectives is included in **Section 17.1.2**. Management measures relevant to surface water quality impacts are provided in **Section 17.6**. The ability of the project to meet the NSW water quality objectives is discussed in **Section 17.4.3** and **Section 17.5.3**.
g. justify, if required, why the WQOs cannot be maintained or achieved over time;	Treatment of wastewater to meet ANZG (2018) and ANZECC/ARMCANZ (2000) would maintain or improve existing water quality. The ability of the project to meet the NSW WQOs is discussed in **Section 17.4.3** and **Section 17.5.3**.
h. demonstrate that all practical measures to avoid or minimise water pollution and protect human health and the environment from harm are investigated and implemented;	Practical management measures to be adopted for the project are provided in **Section 17.6**. The project has been designed to avoid or minimise environmental impacts. Relevant

Secretary's requirement	Where addressed in EIS
	environmental controls are detailed in **Chapter 5** (Project description) and **Chapter 6** (Construction work). Management measures to ensure the protection of human health are outlined in **Chapter 13** (Human health).
i. identify sensitive receiving environments (which may include estuarine and marine waters downstream including Quarry Creek and its catchment) and develop a strategy to avoid or minimise impacts on these environments; and	Sensitive receiving environments are identified and described in **Section 17.3.8**. Management measures to avoid (or minimise) impacts are provided in **Section 17.6**. The project has been designed to avoid or minimise environmental impacts, relevant environmental controls are detailed in **Chapter 5** (Project description) and **Chapter 6** (Construction work).
j. identify proposed monitoring locations, monitoring frequency and indicators of surface and groundwater quality.	Surface water monitoring locations are discussed in **Section 17.2.3**. Proposed surface water monitoring is included in **Section 17.6**. **Appendix O** (Technical working paper: Surface water quality and hydrology) provides further detail on the proposed surface water quality monitoring for the project. It is anticipated that the same monitoring sites detailed in **Section 17.2.3** and indicators detailed in Section 3.2, Annexure A and Annexure B of the **Appendix O** (Technical working paper: Surface water quality and hydrology) would be monitored in the future. Details relating to the proposed groundwater monitoring are provided in **Chapter 16** (Geology, soils and groundwater).
k. identify how the development meets the objectives of the *Coastal Management Act 2016* and management objectives of relevant Coastal Management Areas defined under the *Coastal Management Act 2016.*	Consistency with the objectives of the *Coastal Management Act 2016* is outlined in **Section 17.1.1** and discussed further in **Appendix O** (Technical working paper: Surface water quality and hydrology).
l. demonstrate consistency with any relevant certified Coastal Management Program (or Coastal Zone Management Plan).	Consistency with the vision and objectives presented in the Greater Sydney Harbour Estuary Coastal Management Program Scoping Study which are consistent with the *Coastal Management Act 2016* is outlined in **Section 17.1.1** and discussed further in **Appendix O** (Technical working paper: Surface water quality and hydrology).
2. The assessment should consider the results of any current water quality studies, as available, in the project catchment.	Water quality studies considered for this assessment are listed in **Section 17.2.2**.

17.1 Legislative and policy framework

17.1.1 Relevant legislation

Chapter 2 (Assessment process) describes the environmental impact assessment and approval process for the project, including relevant NSW and Commonwealth legislation applicable to the project. Legislative requirements specific to water quality and hydrodynamics are provided in Table 17-2.

Table 17-2 Legislation relevant to the project

Legislation	Relevance to project
Protection of the Environment Operations Act 1997	Environment protection licences are issued for a broad range of activities listed in Schedule 1 of the *Protection of the Environment Operations Act 1997* and aim to address air, noise, waste, land contamination and water pollution issues created by those activities. An environment protection licence for road construction and road tunnel emissions under Chapter 3 of the Act would be required for construction of the project.
Fisheries Management Act 1994	In accordance with section 199 of the *Fisheries Management Act 1994*, notification to the Department of Planning, Industry and Environment (Regions, Industry, Agriculture and Resources) is required if dredging or reclamation works are required in water land classed as Key Fish Habitat.
Water Management Act 2000, Water Management Amendment Act 2014, and Water Management (General) Regulation 2011	The project is located within an area covered by the *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources* (NSW DPI, 2011b). This plan applies to surface water sources and includes rules for protecting the environment, water extraction, managing licence holders' water accounts, and water trading within the plan area. Under Schedule 4, Part 1, clause 2 of the Water Management (General) Regulation 2011, roads authorities are exempt from the requirement to hold a water access licence to take water for road construction and road maintenance.

Legislation	Relevance to project
Coastal Management Act 2016 and the related State Environmental Planning Policy (Coastal Management) 2018	The objects of the *Coastal Management Act 2016* are to manage the coastal environment in a manner consistent with the principles of ecologically sustainable development for the social, cultural and economic well-being of the people of the State. State Environmental Planning Policy (Coastal Management) 2018 promotes an integrated and coordinated approach to land use planning in the coastal zone, consistent with the objects of the *Coastal Management Act 2016*. It provides development controls for four coastal management areas – coastal wetlands and littoral rainforests areas, coastal vulnerability areas, coastal environment areas and coastal use areas. Management objectives are listed in the *Coastal Management Act 2016* for each of the four coastal management areas. The construction footprint is located on land mapped as "proximity area for coastal wetlands" and "proximity area for littoral rainforest", "coastal environment area" and "coastal use area". As described in Chapter 2 (Assessment process), environmental planning instruments do not apply to State significant infrastructure; however, consideration has been given to the management objectives of the coastal management areas through which the project passes. The applicable management objectives are established in the *Greater Sydney Harbour Estuary Coastal Management Program Scoping Study* (BMT WBM, 2018), which was prepared in 2018 to facilitate the development of the Coastal Management Program coastal management program for Greater Sydney Harbour. This program will soon supersede the *Clontarf/Bantry Bay Estuary Management Plan* (Manly Council, 2008) and provide more coverage over the study area. The objectives presented in the scoping study are consistent with the *Coastal Management Act 2016* and are proposed for inclusion in the development of the Greater Sydney Harbour Coastal Management Program. The vision and objectives of the program and relevance to marine water quality are presented in Section 17.1.2 and Appendix O (Technical working paper: Surface water quality and hydrology) and Appendix Q (Technical working paper: Marine water quality).
Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005	The Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005 covers all the waterways of the harbour, the foreshores and entire catchment. It provides an improved and clearer planning framework and better environmental outcomes for Sydney Harbour and its tributaries.

17.1.2 Relevant policies and guidelines

The water quality assessment has been prepared in accordance with a number of policies and guidelines as described below.

Australian and New Zealand Guidelines for Fresh and Marine Water Quality

The Australian and New Zealand Environment and Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ, 2000) provide guidelines for water quality, taking into account their environmental values. The guidelines were updated in 2018 to incorporate new science and knowledge developed over the past 18 years (ANZG, 2018).

The study area would typically fall under the ANZG (2018) and ANZECC/ARMCANZ (2000) water quality guidelines for 'South-east Australia slightly disturbed lowland rivers and estuaries'. Wastewater treatment plants during construction and operation would be designed such that discharges comply with these guidelines.

NSW Water Quality and River Flow Objectives

Water quality objectives have been developed for the Sydney Harbour and Parramatta River and Northern Beaches Lagoons catchments (DECCW, 2006a; DECCW, 2006b). The water quality objectives are 'primarily aimed at maintaining and improving water quality, for the purposes of supporting aquatic ecosystems, recreation and where applicable, water supply'. Waterways relevant to this assessment (Willoughby Creek, Quarry Creek, Flat Rock Creek, Burnt Bridge Creek, Manly Creek and Trefoil Creek) have been classified as 'waterways affected by urban development'. Based on this classification, the water quality objectives and nominated environmental values relevant to the project include:

- Protection of aquatic ecosystems – ecological condition of waterways and the riparian zone (lower and upper estuary)
- Protection of visual amenity – aesthetic qualities of waters (lower and upper estuary)
- Protection of primary contact recreation – water quality for activities, such as swimming (lower and upper estuary)
- Protection of secondary contact recreation – water quality suitable for activities, such as boating and wading (lower and upper estuary)
- Aquatic foods (cooked), which refers to protecting water quality so that it is suitable for the production of aquatic foods for human consumption and aquaculture activities.

Environmental values, as identified by the Department of Planning, Industry and Environment (Environment, Energy and Science), for the Sydney Harbour and Parramatta River and Northern Beaches Lagoon catchments are discussed further in Section 17.3.9.

Guidelines for Managing Risks in Recreational Water

The *Guidelines for Managing Risks in Recreational Water* (NHMRC, 2008b) aim to protect the health of humans from threats posed by the recreational use of coastal, estuarine and fresh waters. The guidelines have been applied in the background research for the project to understand the current recreational water quality and threat to public health of waterways relevant to the project.

Sydney Harbour Water Quality Improvement Plan

The *Sydney Harbour Water Quality Improvement Plan* (Greater Sydney Local Land Services, 2015) provides a coordinated management framework to improve the future health of Sydney Harbour and its catchments. This plan applies to the majority of the construction footprint, which ultimately drains to Sydney Harbour. While the plan itself does not include pollutant reduction targets for individual developments, catchment load and estuary condition targets have been

developed for some sub-catchments and local government areas using feasible scenario options for both the management of stormwater and improvements in sewer outflow performance.

Greater Sydney Harbour Estuary Coastal Management Program Scoping Study

As described above, the *Greater Sydney Harbour Estuary Coastal Management Program Scoping Study* (BMT WBM, 2018) was prepared in 2018 to facilitate the development of the coastal management program for Greater Sydney Harbour. A vision and objectives were presented in the scoping study that are consistent with the *Coastal Management Act 2016* for inclusion in the Greater Sydney Harbour Coastal Management Program. The objectives of the program relevant to marine water quality and references to applicable parts of this environmental impact statement are outlined in Table 17-3. Other coastal management objectives are deemed not applicable to the project.

Table 17-3 Relevant Greater Sydney Harbour coastal management objectives

Relevant coastal management objectives	Consideration
To protect and enhance natural processes and environmental values of the Greater Sydney Harbour coastal zone.	Section 17.3 with respect to the protection of environmental values of the estuary.
To support the social and cultural values of the Greater Sydney Harbour and maintain public access, amenity, use and safety.	Section 17.3 with respect to the maintenance of the estuary as a public amenity and for public use and safety.
To acknowledge Aboriginal peoples' spiritual, social, customary and economic connection with and use of the Greater Sydney Harbour coastal zone.	Chapter 15 (Aboriginal heritage) discusses the potential impacts of the project on Aboriginal heritage including potential submerged Aboriginal sites.
To recognise the Greater Sydney Harbour coastal environment is a vital economic zone, the maritime gateway to Australia's largest city.	Chapter 21 (Socio-economics) outlines the potential economic impacts of the project.
To facilitate ecologically sustainable development in the Greater Sydney Harbour coastal zone and promote strategic, coordinated and sustainable land use planning decision-making.	Chapter 25 (Sustainability) outlines how the project would meet the principles of ecologically sustainable development.
To mitigate current and future risks from coastal hazards, taking into account the effects of climate change, including impacts from extreme storm events.	Chapter 26 (Climate change and greenhouse gas) outlines how the project would mitigate current and future climate risks.

17.1.3 Design standards, targets and considerations

Construction

Construction erosion and sediment controls would be designed in accordance with:

- *Managing Urban Stormwater: Soils and Construction*, Volume 1, 4th Edition (Landcom, 2004) (known as the Blue Book Volume 1)
- *Managing Urban Stormwater: Soils and Construction,* Volume 2D Main Road Construction (DECC, 2008) (known as the Blue Book Volume 2)
- Guideline for Construction Water Quality Monitoring (RTA, 2003a)
- Road Design Guideline, Section 8 Erosion and Sediment (RTA, 2003b)
- Erosion and Sediment Management Procedure (RTA, 2009)

- Code of Practice for Water Management – Road Development and Management (RTA, 1999)
- QA Specification G38 – Soil and Water Management, Edition 2/Revision 4 (Transport for NSW, 2020f).

The ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines would be used for designing temporary construction wastewater treatment plants and setting their discharge criteria.

Operation

Impervious surfaces and stormwater discharges

New or modified drainage would be provided along the Gore Hill Freeway, and along modified or new surface roads at Balgowlah, North Balgowlah, Killarney Heights, Seaforth and Frenchs Forest. Also, new water quality basins would be provided at Balgowlah Golf Course and along Wakehurst Parkway.

The project would provide water quality treatment that meets the design targets listed in Table 17-4 where feasible and reasonable. These targets are as based on typical requirements for pollutant reduction described in the *Draft Managing Urban Stormwater – Council Handbook* (NSW EPA, 1997). Where the design targets cannot be met due to site constraints, the project would provide water quality treatment to meet or improve existing conditions to ensure that there is no impact on surface water quality as a result of the project.

The design targets listed in Table 17-4 require annual average pollutant reduction as opposed to pollutant reduction levels for a specific rainfall event. Long term impacts are best described by the use of long term rainfall data which has been expressed as average annual pollutant loads.

The type and design of specific stormwater treatment measures would be refined during further design development including confirmation of performance with modelling, if required.

Table 17-4 Operational water quality design targets

Issue	Design target
Total nitrogen	45 per cent annual average pollutant load reduction
Total phosphorus	65 per cent annual average pollutant load reduction
Total suspended solids	85 per cent annual average pollutant load reduction
Grease	No visible grease
Water quality	Neutral or beneficial impacts where percentage design targets cannot be practicably met
Spills	Spill containment of up to 40 cubic metres where possible for environmentally sensitive areas
Existing infrastructure	Minimise impacts to existing water quality infrastructure and performance as a result of the design

It is noted that these targets largely align to the stormwater quality targets established in Sydney Water's *Stormwater quality targets (Version 2)* (Sydney Water, 2020), with the exception of phosphorus, for which the project exceeds the Sydney Water stormwater quality target of a 60 per cent average annual pollutant load reduction. If stormwater discharge from the project is required to connect to Sydney Water's stormwater assets, the project would install and operate water treatment devices during operation to achieve the Sydney Water pollutant load reduction targets where feasible and reasonable.

Wastewater treatment plant discharges

The Gore Hill Freeway wastewater treatment plant would be designed to achieve the following discharge criteria:

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

17.2 Assessment methodology

17.2.1 Overview

The methodology for the assessment included:

- A review of the existing environment including water quality data and reporting from previous monitoring activities
- Water quality monitoring and visual condition assessment at selected locations in the study area
- Site classification as sensitive receiving environments, identification of environmental values and assessment of existing geomorphic characteristics
- Hydrodynamic modelling to assess the potential hydrodynamic impacts on Middle Harbour during project construction and operation
- Dredge plume modelling to assess potential water quality impacts as a result of dredging activities during construction of the immersed tube tunnels
- Assessment of potential impacts during construction and operation to water quality with reference to the ANZG (2018) and ANZECC/ARMCANZ (2000) water quality guidelines and with regard to the relevant environmental values
- MUSIC (Model for Urban Stormwater Improvement Conceptualisation) modelling to assess the operational impacts against the water quality design targets and standards
- Assessment of changes to the North Sydney Council and Balgowlah Golf Course stormwater harvesting schemes
- Identification of appropriate management measures to mitigate potential hydrology and water quality impacts.

17.2.2 Desktop review

The desktop review involved a review of existing information that was available for the surface water environment upstream and downstream of the construction footprint and marine water quality information for Middle Harbour and Sydney Harbour. The review was carried out to develop an understanding of the existing environment and the potential impacts of the project. The review of information included data collected by Willoughby City Council, North Sydney Council and Northern Beaches Council, as well as the following sources:

- *Sydney Harbour Catchment Coastal Zone Management Plan Scoping Study*. Literature and Data Review – Management and Use of Sydney Harbour (Sydney Coastal Council Group, 2015)

- *Sydney Harbour: A systematic review of the science*, Sydney Institute of Marine Science (Hedge et al., 2013)
- *Flat Rock Creek Catchment Flood Study and Overland Flow Mapping Volume 1. Draft Report for Public Exhibition* (Lyall and Associates, 2017)
- *Water Quality Monitoring Program for Willoughby City Council. Spring 2015-Autumn 2016* (Sydney Water, 2016)
- The National Atlas of Groundwater Dependent Ecosystems to identify the location and groundwater dependence of surface water systems and vegetation (Bureau of Meteorology, 2018)
- *Water Sharing Plan for the Greater Metropolitan Region groundwater sources 2011* (NSW DPI, 2011a)
- Water quality data collected between 2014 and 2016 as part of Transport for NSW's Northern Beaches Hospital road upgrade project (SMEC, 2017)
- *The chemistry of suspended particulate material in a highly contaminated embayment of Port Jackson (Australia) under quiescent, high-wind and heavy-rainfall conditions*. Environmental Geology (Birch & O'Hea, 2007)
- *Parramatta River Estuary Data Compilation and Review Study* (Cardno Lawson Treloar, 2008)
- *Trace metal and total suspended solids concentrations in freshwater: the importance of small-scale temporal variation*. Journal of Environmental Monitoring (Hatje et al., 2001)
- *Dissolved trace metal distributions in Port Jackson estuary (Sydney Harbour), Australia.* Marine Pollution Bulletin (Hatje et al., 2003)
- *Water Quality of the Upper Parramatta River. Analysis of data collected between 1990 and 1996* (Laxton, 1997)
- *Mid Parramatta (North) River Stormwater Management Plan* (Robinson GRC Consulting, 1999)
- *Water Quality Sampling of Parramatta River - Methods & Sampling Protocol*. Sydney Institute of Marine Science (Harrison, 2012)
- *Contaminant dynamics in offchannel embayments of Port Jackson, New South Wales*. AGSO Journal of Australian Geology and Geophysics (Taylor & Birch, 1999)
- The Barangaroo project's monthly water quality reports 2012 to 2017 (Lend Lease, 2017).

17.2.3 Monitoring

Hydrodynamic monitoring of Middle Harbour

Hydrodynamic monitoring was carried out between August and November 2017 to measure variability in hydrodynamic conditions within Middle Harbour due to tidal and non-tidal influences. Specifically:

- An acoustic doppler current profiler type instrument was used at two locations to take continuous measurements of water level, current speed, current direction, and acoustic backscatter. The monitoring sites also measured water quality parameters (primarily turbidity)
- Vessel-based monitoring using a mounted acoustic doppler current profiler was carried out along two transects across Middle Harbour near the proposed location of the immersed tube tunnel crossing during spring tidal conditions to determine the spatial variability in currents and discharge throughout a tidal cycle
- Opportunistic surface sediment samples were collected from the bed of the harbour and analysed for particle size distribution.

Water quality monitoring of Middle Harbour

Water quality monitoring was carried out as part of the marine water quality assessment in two discrete sampling periods:

- Sampling period 1 – an eight week period from 5 December 2017 to 31 January 2018
- Sampling period 2 – a five week period from 17 April 2020 to 1 June 2020.

Sampling period 1 focused on collecting information about the effects of turbidity on underwater light that would assist interpretation of the potential effects of dredging. Data were collected at a high temporal resolution using the following methods:

- Two water quality monitoring moored loggers deployed from 5 December 2017 to 31 January 2018 to monitor turbidity, photosynthetically available radiation, chlorophyll-*a*, salinity, pressure and temperature in shallow waters near areas of known benthic primary producers, namely seagrass and rocky reef habitats
- Water sampling and water column vertical profiling carried out at eight sites over two days (18 and 31 January 2018) to monitor water quality parameters (turbidity, photosynthetically available radiation, conductivity, temperature, depth, fluorometric chlorophyll-*a*, pH and dissolved oxygen) through the water column from the bed of the harbour to the surface. Water samples were also collected at a depth of 1.5 metres below the water surface at each site for laboratory testing of total suspended solids (turbidity) and chlorophyll-*a* concentrations
- The collation of meteorological and oceanographic data to provide information on the weather and ocean conditions that are key drivers of the estuary water quality response.

Sampling period 2 was designed to better understand dissolved oxygen concentration variability within the deep water to assist with understanding the potential impacts of the Middle Harbour crossing, and included the following methods:

- Two water quality moored loggers deployed from 27 April 2020 to 1 June 2020
- Water column profiling carried out on six days in 2020 (17 April, 4, 14, 23 and 27 May and 1 June)
- The collation of meteorological and oceanographic data to provide information on the weather and ocean conditions that are key drivers of tidal flushing and the water quality response.

The locations of monitoring sites for sampling period 1 were informed by preliminary predictions of the dredge plume footprint in Middle Harbour (Royal HaskoningDHV, 2020). Sites for sampling period 2 were spread further apart to better understand upstream and downstream potential variability in tidal flushing.

Table 17-5 details the Middle Harbour water quality monitoring locations for the project, including the two sites monitored as part of the hydrodynamic assessment. These monitoring locations are shown in Figure 17-1.

Table 17-5 Middle Harbour hydrodynamic and water quality monitoring sites

Site Name	Location	Monitoring activity
Sampling period 1		
BL1	Pickering Point, Seaforth	Fixed water quality monitoring mooring and profiling site
BL2	Clive Park, Northbridge	Fixed water quality monitoring mooring and profiling site
BLP1	Yeoland Point, Castle Cove	Water quality profiling site

Site Name	Location	Monitoring activity
BLP2	Peach Tree Bay, Seaforth	Water quality profiling site
BLP3	Seaforth Bluff, Seaforth	Water quality profiling site
BLP4	Hallstrom Point, Northbridge	Water quality profiling site
BLP5	Beauty Point, Mosman	Water quality profiling site
BLP6	The Spit, Mosman	Water quality profiling site
MH1	Seaforth Bluff, Seaforth	Hydrodynamic monitoring location
MH2	Southwest of Spit Bridge	Hydrodynamic monitoring location
Sampling period 2		
BM1/B1	Clontarf Point, Clontarf	Fixed water quality monitoring mooring and profiling site
BM2/B5	Seaforth Bluff, Seaforth	Fixed water quality monitoring mooring and profiling site
B2	The Spit, Mosman	Water quality profiling site
B3	Shell Cove, Clontarf	Water quality profiling site
B4	Seaforth Bluff, Seaforth	Water quality profiling site
B6	Quakers Hat, Mosman	Water quality profiling site
B7	Fig Tree Point, Northbridge	Water quality profiling site
B8	Sailors Bay, Northbridge	Water quality profiling site
B9	Seaforth Bluff, Seaforth	Water quality profiling site
B10	Peach Tree Bay, Seaforth	Water quality profiling site
B11	Pickering Point, Seaforth	Water quality profiling site
B12	Yeoland Point, Castle Cove	Water quality profiling site
B13	Bantry Bluff, Seaforth	Water quality profiling site

Surface water quality monitoring

Site visits were carried out between October 2017 and February 2018 to monitor surface water quality and visually assess the conditions of waterways relevant to the project.

Nine monitoring locations were selected immediately upstream and downstream of the project alignment, except for sites where access was prevented. It is noted only one wet weather event was captured, with the results representing mainly dry weather events. Dry weather is classified as less than 15 millimetres of rainfall recorded at the Bureau of Meteorology rainfall gauge (Gauge #066011) in the 24 hours prior to sampling, with wet weather classified as 15 millimetres or more of rainfall recorded. Monitoring locations are provided in and Table 17-6 and shown in Figure 17-1.

Table 17-6 Water quality monitoring sites in waterways

Site	Waterway	Location
2b	Willoughby Creek downstream	Primrose Park, Cremorne
3a	Burnt Bridge Creek upstream	Footbridge near Worrobil Street, North Balgowlah
3b	Burnt Bridge Creek downstream	Kitchener Street, Balgowlah
5a	Flat Rock Creek upstream	Grandview Street, Naremburn
5b	Flat Rock Creek downstream (upstream of Quarry Creek inflow)	Flat Rock Reserve, Northbridge
5c	Flat Rock Creek downstream (downstream of Quarry Creek inflow)	Tunks Park, Long Gully bridge, Northbridge
6b	Manly Dam mid (downstream)	Mid dam – Section 4 picnic area, Allambie Heights
6c	Manly Dam downstream	Dam wall, Allambie Heights
7b	Manly Creek downstream	Allambie Heights

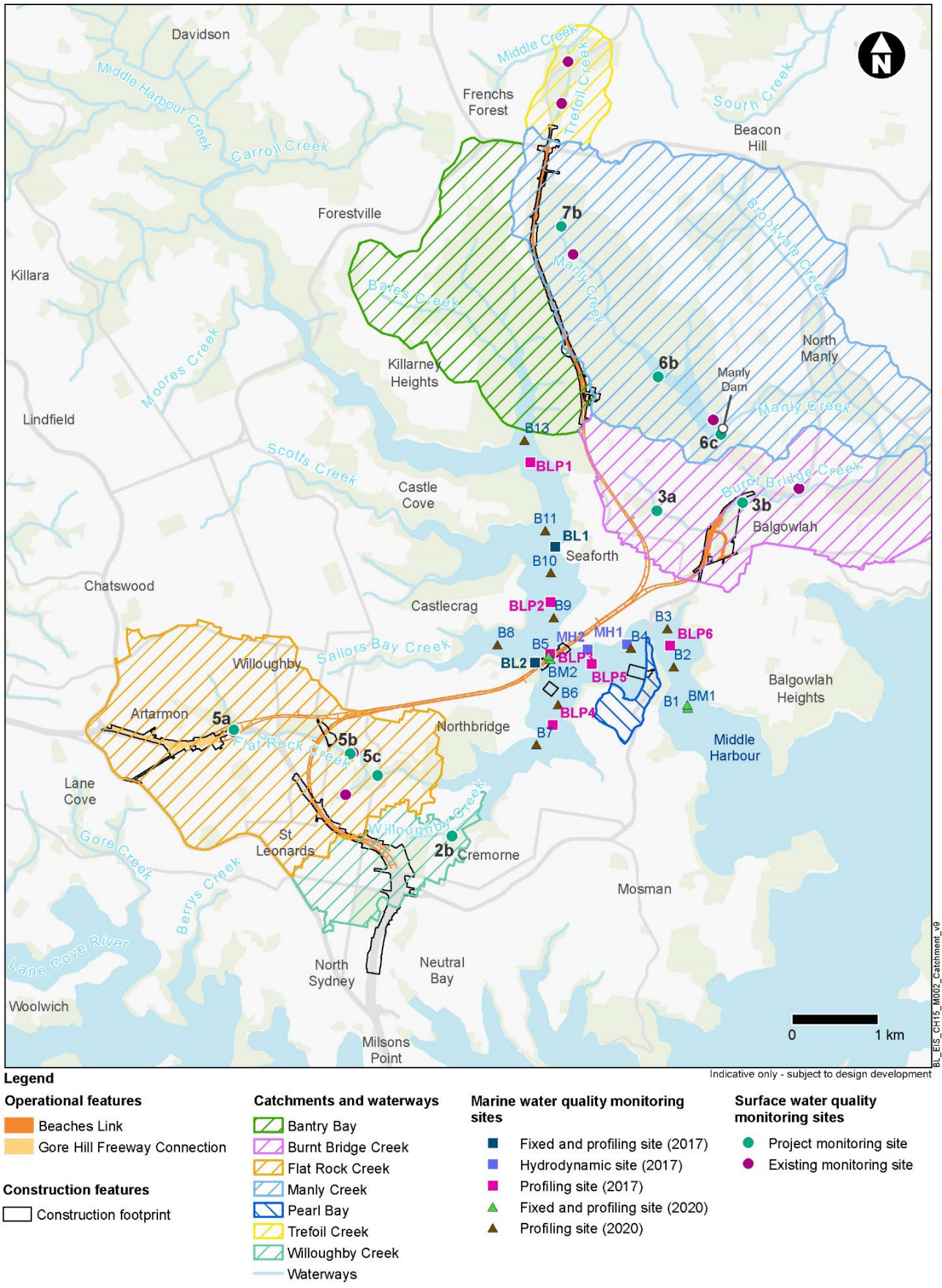


Figure 17-1 Catchments, waterways and hydrodynamic and water quality monitoring locations

17.2.4 Model development

Hydrodynamic model development

A three-dimensional hydrodynamic model of Middle Harbour was developed using MIKE 3 software which simulated currents, water levels and flow characteristics to:

- Provide a realistic representation of the existing marine environment within Middle Harbour near the project, as it relates to hydrodynamic characteristics
- Understand the potential impacts of the construction and operation of an immersed tube tunnel on the hydrodynamic characteristics within Middle Harbour.

Plume model development

Construction of the project would involve dredging of the bed of Middle Harbour to create the trench within which the immersed tube tunnel units would be placed (refer to Chapter 6 (Construction work) for more information relating to dredging).

Numerical modelling was used to determine the likely movement of sediments released into the water column (known as a plume) from dredging. Plume modelling simulates the dispersal of suspended sediment by ambient currents in Middle Harbour, as well as the subsequent deposition of these sediments. The modelling was carried out using the hydrodynamic model of Port Jackson.

The plume modelling was applied to fine sediments only, as these would be the most mobile within the water column. The modelling was based on the sequence of dredging activities (both the dredge plant and sediment types) and the location of sediment types within the dredging footprint, for four sizes of fine sediment (clay, fine silt, medium silt and coarse silt). Plume modelling incorporated the use of the two proposed 12 metre deep draft silt curtains, however, did not consider the proposed floating silt curtain enclosures (sometimes referred to as a ‘moon pool’) that would be attached to the dredge or the additional shallow draft silt curtains that would be installed along the shorelines at the crossing location to provide protection to nearby ecologically sensitive areas (eg seagrass and rocky reef habitat).

Sydney Harbour Ecological Response Model

The Sydney Harbour Ecological Response Model simulates numerous physical, nutrient, algal and biological processes in response to tidal forcing, river inflows, wind, waves and atmospheric heat fluxes.

The model was not run specifically for this project, however adopted simulation results that were available for a 12 month simulation period from April 2012 to March 2013 have been used to inform the assessment on marine water quality.

Surface water quality modelling

A Model for Urban Stormwater Improvement Conceptualisation (MUSIC) was carried out to assess the operational impact of the project and performance of the proposed water quality management strategy against the water quality design targets and standards. The MUSIC modelling results are presented in Appendix O (Technical working paper: Surface water quality and hydrology) for the main locations where stormwater would be discharged (Gore Hill Freeway Connection, surface connections at the Burnt Bridge Creek Deviation, Balgowlah as well as the surface connection and integration works along the Wakehurst Parkway and the realigned and upgraded Wakehurst Parkway).

17.3 Existing environment

17.3.1 Catchments and waterways

The project is within the broader Sydney Harbour and Parramatta River catchment and the Northern Beaches Lagoons catchment.

The Sydney Harbour and Parramatta River catchment is comprised of three harbours: North Harbour, Middle Harbour and Sydney Harbour (the main branch of the estuary). The Middle Harbour region of Sydney Harbour is the north western branch of the estuary, and is one of the three main tributaries; the other two being Parramatta River (Western Harbour) and Lane Cove River.

The Sydney Harbour and Parramatta River catchment is a highly urbanised catchment (86 per cent) which results in rapid runoff during high rainfall events. The catchment is heavily influenced by human factors which have altered the frequency, volume and seasonality of stream flows.

The Northern Beaches Lagoons catchment consists of Narrabeen Lagoon and catchment, Dee Why Lagoon and catchment, Curl Curl and Manly lagoons and their catchments and Manly Dam (within the Manly Lagoon catchment). Relevant sub-catchments to the project include Narrabeen Lagoon, Manly Lagoon and Manly Dam. Narrabeen Lagoon is the largest of the coastal lagoons within the Northern Beaches local government area and an important environmental and recreational area (SMEC, 2011). Manly Lagoon is a small shallow coastal lagoon in the Northern Beaches local government area and is considered of poor water quality due to local pollution sources including urban stormwater runoff, sewage overflows, former landfill leachate and illegal discharge and dumping of industrial and trade waste (Cardno, 2010).

The project and surroundings are dominated by residential areas (ranging from low to high density), with some industrial and commercial developments in Artarmon, St Leonards and Willoughby. At the northern end of the project, the Garigal National Park and Manly Dam War Memorial Park are located to the west and east of Wakehurst Parkway respectively. The main bodies of water surrounding the project area are Middle Harbour and Manly Dam. The main waterways in proximity to the project include Willoughby Creek, Flat Rock Creek, Burnt Bridge Creek, Manly Creek and Trefoil Creek. Burnt Bridge Creek is a first order stream that discharges to Manly Lagoon via Manly Creek. Trefoil Creek is also a first order stream that feeds into Middle Creek which discharges to Narrabeen Lagoon. Manly Creek feeds into Manly Dam. Willoughby Creek and Flat Rock Creek are first order streams that discharge directly into Middle Harbour.

The waterways and associated catchments within the study area are shown in Figure 17-1. Table 17-7 outlines the catchments that form part of the Sydney Harbour and Parramatta River and Northern Beaches Lagoons catchments as relevant to the project and provides a description of the key waterways relevant to the project.

Some areas of the project would be located on catchments dominated by drainage lines, rather than watercourses and would include:

- Spit West Reserve construction support site (BL9) has drainage lines which drain towards Middle Harbour
- Wakehurst Parkway south (BL12) and Wakehurst Parkway east (BL13) construction support sites drain towards Burnt Bridge Creek and Manly Dam, respectively
- The eastern edge of the connections to and from the Wakehurst Parkway has drainage lines which drain towards Burnt Bridge Creek and Manly Dam
- The western edge of the connections to and from the Wakehurst Parkway has drainage lines which traverse Garigal National Park and drain into Bantry Bay.

Table 17-7 Description of key waterways and catchments relevant to the project

Waterway/catchment	Description	Relevant project features
Middle Harbour (Sydney Harbour and Parramatta River catchment)	• The Middle Harbour region of Sydney Harbour is the north western branch of the estuary, and is one of the three main tributaries; the other two being Parramatta River and Lane Cove River • It drains a large catchment of about 7700 hectares of a wide variety of land-uses • The main channel of Middle Harbour features a relatively shallow, constricted, sharp bend between The Spit and Seaforth, which controls the volume of tidal waters that propagate upstream beyond The Spit • The channel is surrounded by a number of bays (including Quakers Hat Bay to the south, Sailors Bay to the west and Fig Tree Cove to the north) which act as reservoirs for the tidal waters • The immersed tube tunnel crossing of Middle Harbour would be located in a low energy hydrodynamic environment with relatively low current speeds and little to no expected transport of sediment from the bed of the harbour • The surface currents in the vicinity of the Spit West Reserve construction support site (BL9) are relatively slow, with the exception of the shoreline area associated with a return eddy that forms in Pearl Bay during the flood tide. During both the flood and the ebb current speeds reduce slightly with depth • The immersed tube tunnel crossing of Middle Harbour would be located in a low energy or mild wave environment. Waves are mainly derived from local winds and vessels (generally recreation craft) • Fresh and saline waters are typically well mixed due to low fresh water discharges and turbulent tidal mixing.	• Gore Hill Freeway Connection western edge drains into Bantry Bay • Crossing of Middle Harbour • Middle Harbour south cofferdam (BL7) • Middle Harbour north cofferdam (BL8) • Spit West Reserve construction support site (BL9) • Upgrade and integration works along the Wakehurst Parkway western edge drains into Bantry Bay.

Waterway/catchment	Description	Relevant project features
Willoughby Creek (Willoughby Creek catchment) 	• Willoughby Creek is a small modified concrete and rock channel which drains a catchment of around 150 hectares that includes the suburbs of Neutral Bay and Cammeray directly into Willoughby Bay at Cremorne • The development of impervious surfaces within the catchment has increased the volume and rate of runoff, which has in turn necessitated flood mitigation measures • Willoughby Bay and Long Bay are popular boating and swimming areas for local residents.	• Southern portion of Beaches Link. • Cammeray Golf Course construction support site (BL1).
Quarry Creek (part of Flat Rock Creek catchment) 	• Quarry Creek is a small natural estuarine tributary of Flat Rock Creek which drains Cammeray • The creek has steep embankments on both sides now densely vegetated by weeds and has limited accessibility.	• Southern portion of Beaches Link.

Waterway/catchment	Description	Relevant project features
Flat Rock Creek (Flat Rock Creek catchment)  	• Flat Rock Creek is predominantly a concrete lined (open drain and closed box culvert) stormwater channel which drains a catchment of around 390 hectares that include Artarmon, Willoughby and Naremburn. • The upper reaches of Flat Rock Creek in Artarmon consist of a covered concrete lined drain and vegetated floodway associated with the Artarmon Reserve detention basin. The creek is a concrete lined channel as it crosses the Gore Hill Freeway for the first time and continues in an open lined channel as it meanders east and crosses back under the Gore Hill Freeway. • As the creek continues east, it enters a concrete box culvert near Willoughby Road and flows underground until it reaches a point in Flat Rock Reserve around 150 metres east of Flat Rock Drive where the box culvert outlets into a human made (naturalised) excavated bedrock channel followed by a natural bedrock stream until it enters Tunks Park, where it again flows through an underground box culvert. The various surface water linings of Flat Rock Creek are shown in Figure 17-2 • The natural drainage characteristics of Flat Rock Creek have been altered by residential, commercial and industrial development • At its downstream reach the creek drains a relatively steep catchment characterised by rocky riffle and runs. The downstream reaches are surrounded by native Coachwood forests with popular walking tracks and give access to large sporting fields at Tunks Park, Cammeray • The end point of the creek is a tidally influenced naturalised estuary at the base of Flat Rock Gully discharging into Long Bay.	• Beaches Link and Gore Hill Freeway Connection • Flat Rock Drive construction support site (BL2) • Punch Street construction support site (BL3) • Dickson Avenue construction support site (BL4) • Barton Road construction support site (BL5) • Gore Hill Freeway median construction support site (BL6).

Waterway/catchment	Description	Relevant project features
Burnt Bridge Creek (Burnt Bridge Creek catchment  	• Burnt Bridge Creek is an urban intermittent waterway which flows through Seaforth, North Balgowlah, Balgowlah and Manly Vale into Manly Lagoon. It is a freshwater first order stream receiving multiple inflows of stormwater. The various surface water linings of Burnt Bridge Creek are shown in Figure 17-3 • It drains a catchment of about 380 hectares of a wide variety of land-uses including residential areas, the Balgowlah Industrial Estate, golf courses and roads • The creek is naturalised upstream with rock, sand and mud substrate with narrow vegetated buffer zones. Downstream it is a combination of concrete and rock fill construction, which is present at the Kitchener Road crossing in Balgowlah • The creek has been heavily modified due to urban pressure (ie sewage and sewer outfalls) resulting in poor water quality, extensive weed infestation, erosion of creek banks, build-up of sediment and reduced biodiversity • The Balgowlah Golf Course Stormwater Harvesting Dam was installed in 2013 and has allowed the golf course to extract water from the dam rather than Burnt Bridge Creek allowing creek water to remain as environmental flows which has improved the ecological conditions in the creek (Manly Council, 2014) • Surface runoff discharging into Burnt Bridge Creek between Sydney Road and north of Kitchener Street currently does not receive any water quality treatment • The section of creek through the Balgowlah Golf Course has been modified and realigned in the past and is known to experience hazardous flooding.	• Northern portion of Beaches Link (Balgowlah) • Balgowlah Golf Course construction support site (BL10) • Kitchener Street construction support site (BL11).

Waterway/catchment	Description	Relevant project features
Manly Dam (Manly Creek catchment) 	• Manly Dam drains a catchment of 510 hectares of predominantly open space (bushland), and some commercial, industrial and residential areas • The catchment is characterised by sandstone slopes, rock platforms and gullies, as well as some shale areas. Over half of the catchment has gradients steeper than 10 degrees and soils have very high to severe erosion potential • The steep terrain and urban interface pose challenges to water quality, including occurrence of blue-green algal blooms due to external nutrient loading • One of the largest freshwater lakes in Sydney which provides a valued facility for swimming, fishing, water-skiing, canoe/kayaking and boating • The dam is no longer used as a source of drinking water by Sydney Water • Immediately downstream of the dam, the creek is polluted and heavily infested with weeds.	• Northern portion of Beaches Link (upgrade and integration works along the Wakehurst Parkway) • Wakehurst Parkway south construction support site (BL12) • Wakehurst Parkway east construction support site (BL13).

Waterway/catchment	Description	Relevant project features
Manly Creek (Manly Creek catchment) 	• Manly Creek drains a catchment in the urban areas of French Forest and flows into Manly Dam via War Memorial Park • The creek channel is formed of bedrock shelves, boulder and cobble runs and riffles, and pools that hold some sediment. Its banks are generally low and stable • During storm events, the creek is likely to experience high velocity flows. Riparian vegetation creates greater bank stability; however, natural scouring is likely to occur during high rainfall events.	• Northern portion of Beaches Link (upgrade and integration works along the Wakehurst Parkway).
Trefoil Creek (Trefoil Creek catchment) 	• Narrow natural waterway, engorged through a gully located near the corner of Frenchs Forest Road and Wakehurst Parkway • Drains through the suburbs of Frenchs Forest and Oxford Falls and underneath Wakehurst Parkway into Middle Creek (which flows to Narrabeen Lagoon) • The area consists of low density housing and substantial bushland, which is susceptible to flooding and road closures • The creek line is characterised by dense native and exotic vegetation, sediment substrate and rocky outcrops.	• Northern portion of Beaches Link (Frenchs Forest) • Wakehurst Parkway north construction support site (BL14).

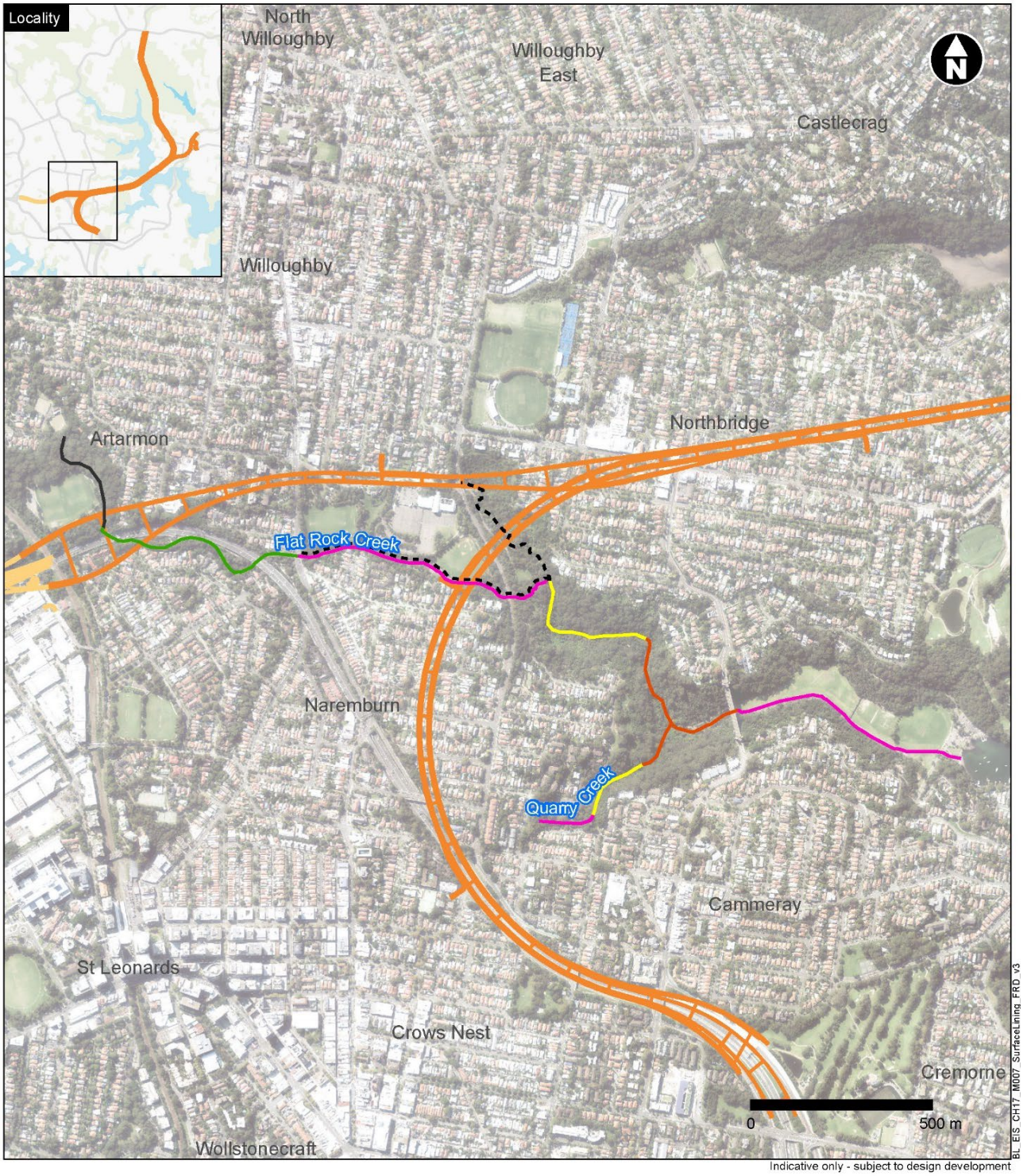


Figure 17-2 Surface water lining of Flat Rock Creek

Figure 17-3 Surface water lining of Burnt Bridge Creek

17.3.2 Hydrodynamic features

Bathymetry

The bed of Middle Harbour is made up of many deep holes, basins, shoals and reefs. At the proposed location of the immersed tube tunnel crossing of Middle Harbour, there is a deep 'U' shaped channel reaching a depth of 32 metres. Other key bathymetry features near the crossing of Middle Harbour include:

- The main channel of Middle Harbour, between The Spit and Seaforth is relatively shallow in comparison to the main reaches of Middle Harbour directly downstream. The Spit along with Spit Bridge and its associated piers act as a constriction to tidal flows
- There is a near 180 degree bend in the main channel as it passes between The Spit and Seaforth. This acts to control the volume of tidal waters that propagate upstream beyond The Spit
- Bays near the proposed immersed tube tunnels act as large reservoirs for tidal waters including Quakers Hat Bay, Sailors Bay and Fig Tree Cove.

Tides and currents

Port Jackson is a semi-diurnal estuary meaning that it has two high tides and two low tides per day. It has a small tidal range (less than two metres) and the ebb (outgoing), and flood (incoming) tidal discharges are the dominant cause of water movement.

Current patterns in Middle Harbour are influenced by the complex shape of the harbour, the relatively deep U-shaped channel, and the constriction at The Spit. Tidal current speeds at the proposed Middle Harbour crossing location are substantially lower than those at Spit Bridge due to increased depth. The Spit experiences faster peak flood currents than ebb currents. Spatial measurements and monitoring show little change in current speed with changes in depth.
A summary of the current speeds observed as part of the hydrodynamic monitoring is shown in Table 17-8.

Table 17-8 Current speeds near the Middle Harbour crossing

Monitoring location	Parameter	Maximum	95th percentile	Average
Southwest of Spit Bridge (MH9)	Flood current speed (m/s)	0.72	0.42	0.17
	Ebb current speed (m/s)	0.37	0.21	0.09
Seaforth Bluff, Seaforth (MH8)	Flood current speed (m/s)	0.15	0.07	0.03
	Ebb current speed (m/s)	0.21	0.08	0.04

Wind

The wind statistics from the Bureau of Meteorology's weather station at Fort Denison (1990 to 2017) were considered to be the most representative of overwater wind conditions at the proposed immersed tube tunnel crossing of Middle Harbour and indicate that:

- Easterly winds are the prominent wind direction in the spring/summer months, with westerly winds dominating during autumn/winter months
- Wind speeds during the year range from 4.2 to 4.7 metres per second (50th percentile) to 6.7 to 8.3 metres per second (90th percentile)
- Wind speeds are slightly higher during spring/summer compared to autumn/winter.

Waves

Ocean swells that enter Middle Harbour are deflected by the complex bathymetry and shoreline formation such that most of Middle Harbour is affected only by locally derived wind and vessel generated waves. Most vessels in Middle Harbour are relatively small recreational craft, resulting in limited vessel wakes. The wave climate near the proposed immersed tube tunnel crossing of Middle Harbour is a low energy wave climate with wave heights typically less than 0.3 metres and wave periods of less than four seconds.

The bathymetry near the proposed immersed tube tunnel crossing of Middle Harbour is relatively deep, meaning that the potential effect of waves (either wind waves or vessel wakes) on hydrodynamic or sediment plumes at the bed of the harbour is minimal.

Rainfall and freshwater runoff into Middle Harbour

Rainfall in Sydney varies substantially both year-to-year and month-to-month. Much of the variability in precipitation is due to large-scale climate variations, with El Niño Southern Oscillation being the most important. Weather data recorded at Observatory Hill; Sydney indicates that average annual rainfall is 1215 millimetres. Average monthly rainfall between the years 1859 and 2017 ranged from a minimum of 67.9 millimetres in September to a maximum of 133.2 millimetres in June.

Middle Harbour has a catchment area of around 7700 hectares. While there are no major rivers flowing into Middle Harbour there are many small creeks including Middle Harbour Creek, Rocky Creek, Carroll Creek, Gordon Creek, Moores Creek, Bates Creek, Scotts Creek, Willoughby Creek and Flat Rock Creek.

Suspended sediments

Turbidity is typically used as an indicator of suspended sediment concentrations. A review of historical data for turbidity of the waters in Port Jackson identifies a noticeable gradient from high turbidity in the shallower upper reaches of the Parramatta River and longer bays, to low turbidity in the lower reaches of the harbour where tidally driven ocean exchange influences water quality.

As there is limited existing turbidity data for Middle Harbour, a summary of measured turbidity for the waters around Balls Head (about six kilometres south west of the Middle Harbour crossing) is provided in Table 17-9 to provide a reference for expected turbidity levels in Middle Harbour during dry and wet weather events.

Table 17-9 Ambient measured turbidity near Balls Head

Weather	Ambient turbidity (Nephelometric Turbidity Units (NTU))
Dry weather	less than 1 to 4 NTU
Wet weather	4 to 20 NTU – short-lived events, less than two days with higher values on ebb tide

Project specific turbidity data recorded during monitoring for the project near the Middle Harbour crossing identified similar low ambient turbidity levels (less than 5 NTU) (Table 17-10).

Table 17-10 Instantaneous turbidity statistics (in NTU) at Middle Harbour site BL2

Statistical parameter	Ambient total suspended solids (NTU)
95th percentile	1.0
90th percentile	0.9
50th percentile (median)	0.5
10th percentile	0.3
5th percentile	0.3

An example of the high turbidity which occurs within Middle Harbour following heavy rainfall is shown in Figure 17-4 (near Clive Park, near the Middle Harbour crossing in Northbridge) for an event in February 2020.

17.3.3 Marine water quality

A review of historical marine water quality data and project specific monitoring of Middle Harbour indicates that:

- The complex interactions between rainfall/runoff, mixing within the broader Sydney Harbour and Parramatta River regional catchment and exchange with ocean waters, leads to seasonal variations in temperature and salinity that in turn influence the mixing of the Middle Harbour deep waters
- Total suspended solids concentrations are generally low (below one milligram per litre) during extended dry periods with peaks up to 30 milligrams per litre after heavy rainfall events (refer to Figure 17-4). During the wetter months, total suspended solids concentrations are elevated at around three to five milligrams per litre
- Low dissolved oxygen levels can occur at the bed of the harbour, however vertical mixing maintains high dissolved oxygen content of the overall water column
- Good light penetration occurs through the water column. The euphotic depth, where light decreases to one per cent of its surface value, is typically greater than 15 metres depth.

17.3.4 Existing road surface water quality infrastructure

Existing infrastructure related to road surface water quality control relevant to the project includes:

- Drainage from the existing Warringah Freeway road surface and nearby road networks in North Sydney and Willoughby local government areas discharges to local stormwater drainage systems, and ultimately to Sydney Harbour or Middle Harbour. The Warringah Freeway does not have any specific spill risk management devices
- Drainage from the Gore Hill Freeway discharges to existing water quality basins located at Punch Street and Artarmon Oval. Basin discharges then travel in local drainage systems into Flat Rock Creek which ultimately discharges into Middle Harbour
- Water quality treatment is not provided at Burnt Bridge Creek Deviation between Sydney Road and north of Kitchener Street however the weir located within the golf course provides some water quality treatment by default, capturing some coarse sediment. Stormwater runoff is collected through a pit and pipe network that discharges into Burnt Bridge Creek via several cross drainage pipes without treatment
- Water quality treatment is not provided along Wakehurst Parkway aside from the operational water quality infrastructure that was recently constructed as part of the Northern Beaches Hospital road upgrade project. Road runoff is collected through natural drainage lines before reaching the receiving waterways. Flows travelling to the west reach Middle Harbour while flows travelling to the east reach Manly Dam.

Figure 17-4 Evidence of increased turbidity at Clive Park (looking north) after heavy rain in February 2020

17.3.5 Surface water quality

The water quality of waterways relevant to the project is influenced by several factors including:

- Current and former polluting land uses within the catchments
- Stormwater and sewage overflows and leachate from contaminated and/or reclaimed land
- Urbanisation of the catchments and subsequent reduction in permeable area, increasing run-off and pollutant loads entering waterways

A review of the existing water quality data and site-specific water quality monitoring indicates that the waterways in the study area are in very poor condition and are representative of a heavily urbanised system. The water quality at each assessed waterway is summarised in Table 17-11.

Table 17-11 Existing water quality conditions in the project area

Waterway	Commentary on ANZG (2018) and ANZECC/ARMCANZ (2000) indicators	Monitoring sites/source data
Willoughby Creek	• High levels of heavy metals • High nutrient concentrations • Low dissolved oxygen levels.	• Site 2b
Quarry Creek	• High levels of heavy metals • High nutrient concentrations • High pH (ie alkaline conditions) • High dissolved oxygen levels • Very high faecal coliform counts indicating microbial contamination.	• North Sydney Council
Flat Rock Creek	• High concentrations of heavy metals • Very high nutrient concentrations, indicating eutrophic conditions • Microbiological contamination • High pH (ie alkaline conditions) in some areas • Varied dissolved oxygen levels.	• Sites 5a, 5b, 5c • Willoughby City Council
Burnt Bridge Creek	• High levels of heavy metals • High nutrient concentrations • Low dissolved oxygen levels • Low chlorophyll-*a* levels.	• Sites 3a, 3b • Northern Beaches Council
Manly Dam	• Dissolved oxygen levels just below the recommended limit • High concentrations of total nitrogen and oxidised nitrogen • Total phosphorus levels were compliant	• Sites 6b, 6c • Northern Beaches Council

Waterway	Commentary on ANZG (2018) and ANZECC/ARMCANZ (2000) indicators	Monitoring sites/source data
	• Low concentrations of heavy metals.	
Manly Creek	• Low dissolved oxygen levels • High levels of heavy metals • Varied nutrient levels • Low chlorophyll-a levels.	• Site 7b • Northern Beaches Council
Trefoil Creek	• High concentrations of heavy metals • High nutrient concentrations (total nitrogen).	• Northern Beaches Hospital road upgrade project • Northern Beaches Council

17.3.6 North Sydney Council stormwater harvesting scheme

North Sydney Council has established an extensive stormwater harvesting scheme, which includes a storage dam at Cammeray Golf Course of about 45 metres by 35 metres in size. The dam receives stormwater harvested from the surrounding catchments that is then used to irrigate a number of community parks and the golf course itself. Harvested water is also piped through the existing stormwater system back to St Leonards Park, which is used to irrigate the public parklands and North Sydney Oval. The dam also serves as a sediment settlement pond which improves the quality of water re-entering the catchment and harbour. The dam has become habitat for wildlife such as ducks and saves about 30 million litres of clean water each year. The dam would be directly impacted by the proposed Western Harbour Tunnel and Warringah Freeway Upgrade project prior to the Beaches Link project using the Cammeray Golf Course construction support site (BL1).

17.3.7 Balgowlah Golf Course stormwater harvesting dam

The construction of the Balgowlah Golf Course stormwater harvesting project was completed in 2013. The stormwater harvesting project involved construction of a four megalitre pond/dam with a maximum nominal water depth of 2.5 metres and installation of a gross pollutant trap in Balgowlah Oval upstream of Balgowlah Golf Course. Dam storage of four megalitres allows for around 60 million litres per year of captured stormwater to be used for irrigation. The dam and the underground gross pollution trap treat 100 per cent of the stormwater flowing through the golf course. A key outcome of the Balgowlah Golf Course stormwater harvesting project is the golf course no longer extracts water from Burnt Bridge Creek for irrigation. As such, creek water remains as environmental flows, which re-creates the natural creek conditions.

17.3.8 Sensitive receiving environments

A sensitive receiving environment is an environment that has high conservation or community value, or that supports ecosystem or human uses of water and is particularly sensitive to pollution or degradation of water quality.

The classification of the waterways within the study area regarding their status as sensitive receiving environments is shown in Table 17-12.

Table 17-12 Sensitive receiving environments

Waterway	Sensitive receiving environment	Reason for classification
Middle Harbour	Yes	• Considered a Type 1 Key Fish Habitat (due to known presence of several species of seagrass) • Potential habitat for vulnerable species such as the Black Rockcod which is listed under the *Fisheries Management Act 1994* and *Environment Protection and Biodiversity Conservation Act 1999* • Includes endangered populations of the seagrass *Posidonia Australis* which is listed under the *Fisheries Management Act 1994* • Is a primary contact recreation area.
Willoughby Creek	No	• Considered a Type 3 minimally sensitive Key Fish Habitat • Is a highly urbanised stormwater channel containing limited natural features.
Quarry Creek	Yes	• Downstream Flat Rock Creek characterised as Type 1 highly sensitive Key Fish Habitat (NSW DPI, 2013) due to potential fish refuge.
Flat Rock Creek	Yes	• Downstream Flat Rock Creek characterised as Type 1 highly sensitive Key Fish Habitat (NSW DPI, 2013) due to potential fish refuge • Is a secondary contact recreation area.
Burnt Bridge Creek	No	• Considered a Type 2 moderately sensitive Key Fish Habitat (NSW DPI, 2013) due to limited aquatic habitat and urbanisation of the channel.
Manly Dam	Yes	• Considered a Type 1 highly sensitive Key Fish Habitat (NSW DPI, 2013) due to potential fish refuge • Located within 100 metres of the Coastal Sandstone Gully Forest groundwater dependent ecosystem • Located near patches of endangered ecological community Coastal Upland Swamp in the Sydney Basin Bioregion, as listed under the Biodiversity Conservation Act 2016 • Is a primary contact recreation area.
Manly Creek	Yes	• Considered a Type 1 highly sensitive Key Fish Habitat (NSW DPI, 2013) due to potential fish refuge • Located within 100 metres of the Coastal Sandstone Gully Forest groundwater dependent ecosystem • Located near patches of endangered ecological community Coastal Upland Swamp in the Sydney Basin Bioregion, as listed under the *Biodiversity Conservation Act 2016* • Is a secondary Contact Recreation area.
Trefoil Creek	Yes	• Potential habitat for the Red-Crowned Toadlet which is listed as Vulnerable under the *Biodiversity Conservation Act 2016* • Is a secondary contact recreation area.

17.3.9 Environmental values

The Department of Planning, Industry and Environment (Environment, Energy and Science) identifies a number of environmental values for the Sydney Harbour and Parramatta River catchment (which includes Middle Harbour) and Northern Beaches Lagoons catchment including relevant indicators and guideline levels. Environmental values relevant to the regional catchment are:

- Aquatic ecosystems – which signal physical and chemical water quality stressors that cause degradation of aquatic ecosystems. For the purpose of this assessment, indicators include nutrient levels, dissolved oxygen, pH, metals, salinity and turbidity
- Visual amenity – the aesthetic appearance of a waterbody. For the purpose of this assessment, indicators include transparency, odour and colour
- Primary and secondary contact recreation – where primary contact recreation implies direct contact with the water via bodily immersion or submersion with a high potential for ingestion (eg swimming, diving and water skiing), and secondary contact recreation implies some direct contact with the water would be made but ingestion is unlikely (eg boating, fishing and wading). Bacteriological indicators are used to assess the suitability of water for recreation
- Aquatic foods (cooked) – which refers to protecting water quality so that it is suitable for the production of aquatic foods for human consumption and aquaculture activities. This objective applies to all waters where aquatic foods are taken for non-commercial and commercial harvesting. For this assessment this includes turbidity, metals and organochlorines.

These environmental values have been assigned to each waterway within the study area as shown in Table 17-13. Aquatic ecosystems and visual amenity apply to all waterways within the study area.

Table 17-13 Assigned environmental values

Waterway	Environmental value				
	Aquatic ecosystems	Visual amenity	Primary contact recreation	Secondary contact recreation	Aquatic foods (cooked)
Middle Harbour	✓	✓	✓	✓	
Willoughby Creek	✓	✓		✓	
Burnt Bridge Creek	✓	✓			
Flat Rock Creek	✓	✓		✓	
Manly Dam	✓	✓	✓	✓	✓
Manly Creek	✓	✓		✓	✓
Trefoil Creek	✓	✓		✓	✓

17.4 Assessment of potential construction impacts

17.4.1 Hydrodynamic features of Middle Harbour

Construction of the immersed tube tunnel has the potential to affect tidal and current flows within Middle Harbour due to:

- The establishment of Middle Harbour south cofferdam (BL7) and Middle Harbour north cofferdam (BL8)
- The establishment of deep draft silt curtains at either side of the proposed immersed tube tunnel crossing location where most of the dredging works would occur
- The establishment of the Spit West Reserve construction support site (BL9).

Each cofferdam would be constructed using steel tubular piles, which would act as a temporary but complete barrier to the flow of water.

The modelling of hydrodynamic impacts has identified that during the ebb (outgoing) tide, the Middle Harbour north cofferdam (BL8) would cause a reduction in current speeds around Seaforth Bluff at all water depths. There would be an increase in current speeds in the middle of the channel and at the bed of the harbour (ie beneath the silt curtain). Current speeds would also increase at the upper layers of the water column between the bank near Clive Park and the Middle Harbour south cofferdam (BL7).

During the flood tide (recharging of the estuary), there would be a decrease in current speed at both cofferdams as well as within and surrounding the silt curtains. There would also be a decrease in current speed along Seaforth Bluff upstream of the Middle Harbour north cofferdam (BL8). An increase in current speed along the bank upstream of the Middle Harbour south cofferdam (BL7) would occur.

A general reduction in current speeds adjacent to the shoreline is predicted near the Spit West Reserve construction support site (BL9), in particular during the flood tide. The reduced current speeds result from the temporary structures impeding the eddy that forms in this area. The eddy would be redirected, particularly in the surface layers, towards the west resulting in a small area of current speed increase to the west of the immersed tube tunnel unit casting facility.

Due to the existing low energy hydrodynamic environment, the changes in current speeds observed during ebb and flood tides are not expected to have a substantial impact on the surrounding environment.

During both ebb and flood tide, the current reductions would be more pronounced in the surface layer due to the effect of the silt curtains on the upper water column. As these changes are more pronounced in the surface layer it is not expected that any major erosion or accretion of the bed of the harbour would occur in this area. The localised increases in current speeds near the bed of the harbour are not expected to result in a substantial change to the sediment dynamics in this area.

17.4.2 Marine water quality

Construction of the immersed tube tunnels would require dredging of the bed of Middle Harbour, which would result in sediments being released into the water column. Other construction activities within and adjacent to the harbour would also have the potential to impact marine water quality including:

- Dredging, excavating and piling activities associated with the establishment of the Middle Harbour south cofferdam (BL7), Middle Harbour north cofferdam (BL8) and immersed tube tunnel support piles, as well as adjacent land based activities at the Spit West Reserve construction support site (BL9) have the potential to reduce water quality and disturb contaminated sediments

- Construction vessel movements have the potential to generate localised plumes of suspended sediments associated with vessel wash in shallower waters, generally less than five to ten metres water depth
- Maintenance or refuelling of construction plant and equipment resulting in spills or leaks of fuels and chemicals that could be discharged directly or indirectly to the marine environment
- Transport of dredged and excavated material that is unsuitable for offshore disposal to a suitable shore-based load out facility prior to disposal at a licensed land-based facility. This would be at a shore-based location outside Middle Harbour
- Land based activities involving the exposure or handling of soils may result in possible soil erosion and off-site transport of sediment via air or runoff to receiving marine waterways.

Potential marine water quality impacts from these activities would include:

- Increases in turbidity resulting in a visible plume and reducing light penetration into the water column
- Increases in turbidity resulting in lowered dissolved oxygen levels and increased nutrients
- Transfer of sediment deposits onto the bed of the harbour
- Mobilisation of contaminants associated with the transportation and dispersion of disturbed sediments
- Direct impacts from discharges, runoff, spills and leaks.

These are discussed in more detail below.

Increases in turbidity

Water quality impacts as a result of the dispersion of sediments released during dredging was assessed using dredge plume modelling, which identified the following:

- The extent of the dredge plume (two milligrams per litre suspended sediment concentration) would be relatively small. It would spread further at the bed of the harbour than at the surface
- Deep draft silt curtains would effectively contain the surface layer suspended sediments and to a lesser degree the deeper suspended sediments. Additional shallow draft silt curtains are proposed and would further reduce potential impacts and protect near shore ecologically sensitive areas
- Suspended sediment concentrations would be generally low (less than five milligram per litre) for areas outside of the silt curtains. Concentrations would be highest in the bottom layer
- Suspended sediment in the lower layers would be transported via relatively slow upstream and to a greater extent downstream currents within a tidal stream adjacent to the Seaforth shoreline
- Suspended sediment concentrations in the waters next to Seaforth would peak (up to eight milligrams per litre) during the first four weeks of dredging due to the removal of soft surface sediments. For the majority (95 per cent) of the dredge time the concentrations are predicted to be less than 2.5 milligrams per litre
- Brief periods of increased suspended sediment concentrations (up to 3.5 milligrams per litre) are predicted at the surface layer immediately outside the silt curtain surrounding the Middle Harbour south cofferdam (BL7) near Clive Park. For the majority (99 per cent) of the dredge time, surface layer concentrations are predicted to be less than 1.7 milligrams per litre.

Figure 17-5 shows the results of the dredge plume modelling for the 95th percentile (ie the value that is predicted to be exceeded for only five per cent of the time, or 8.4 hours in a week) for the 37 week dredging program for the bottom, middle and surface layers of Middle Harbour.

The results indicate that the dredging program would not have a substantial impact on marine water quality. The dredging and construction activities for the project are likely to cause short term

increases in suspended sediment concentrations but due to the rapid dispersion of suspended sediments in Middle Harbour, impacts on water quality would be temporary and minimal in nature. Monitoring during the dredging activities would provide data to assess the compliance of the activities with this assessment.

Although there is limited existing data for turbidity during high rainfall events in Middle Harbour, the expected dredge plumes are likely to result in less impact than turbidity that occurs due to ongoing high rainfall events. One such high rainfall event occurred in February 2020 (refer to Figure 17-4) resulting in an increase in turbidity in Middle Harbour.

Along with the use of several shallow and deep draft silt curtains around cofferdams and dredging activities, shallow draft silt curtains would be installed along the shorelines where appropriate to mitigate potential impacts to nearby ecologically sensitive areas (eg seagrass and rocky reef habitat).

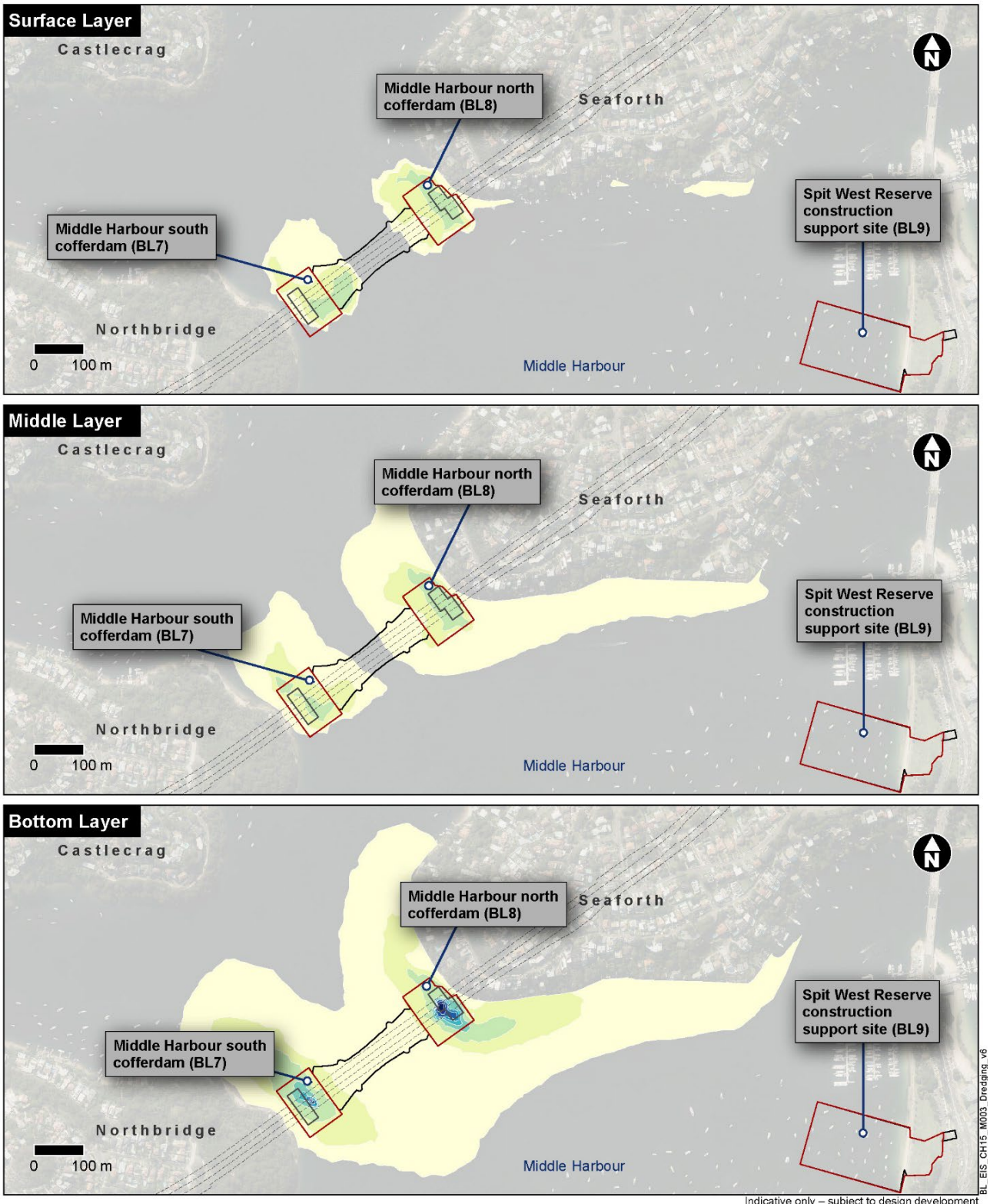


Figure 17-5 Dredge plume impacts within Middle Harbour during dredging activities

Deposition of mobilised sediment

Deposition of dredged material would be contained within the silt curtains proposed to be used during dredging activities and limited to a thickness of less than five millimetres.

Modelling of sediment deposition on the bed of the harbour two weeks after the completion of dredging activities indicated the following (refer to Figure 17-6):

- The majority of deposition would occur within and adjacent to the dredging footprint due to the low current speeds throughout the area and the use of deep draft silt curtains. Deposits would be concentrated in front of each cofferdam where most of the rock dredging and rehandling would occur
- Low levels of sedimentation (one to five millimetres) would mostly occur downstream of the dredge footprint due to stronger currents during the ebb tide, with some deposition reaching beyond Spit Bridge near Clontarf. Low level sedimentation would occur upstream about 600 metres from the immersed tube tunnel crossing of Middle Harbour
- Deposition is not predicted to accumulate in the area around Spit Bridge where tidal currents and bed shear stresses are high
- Deposition rates at the Middle Harbour south cofferdam (BL7) would remain low throughout the dredge period, despite its location close to the dredge footprint, due to the effectiveness of the deep and shallow draft silt curtains.

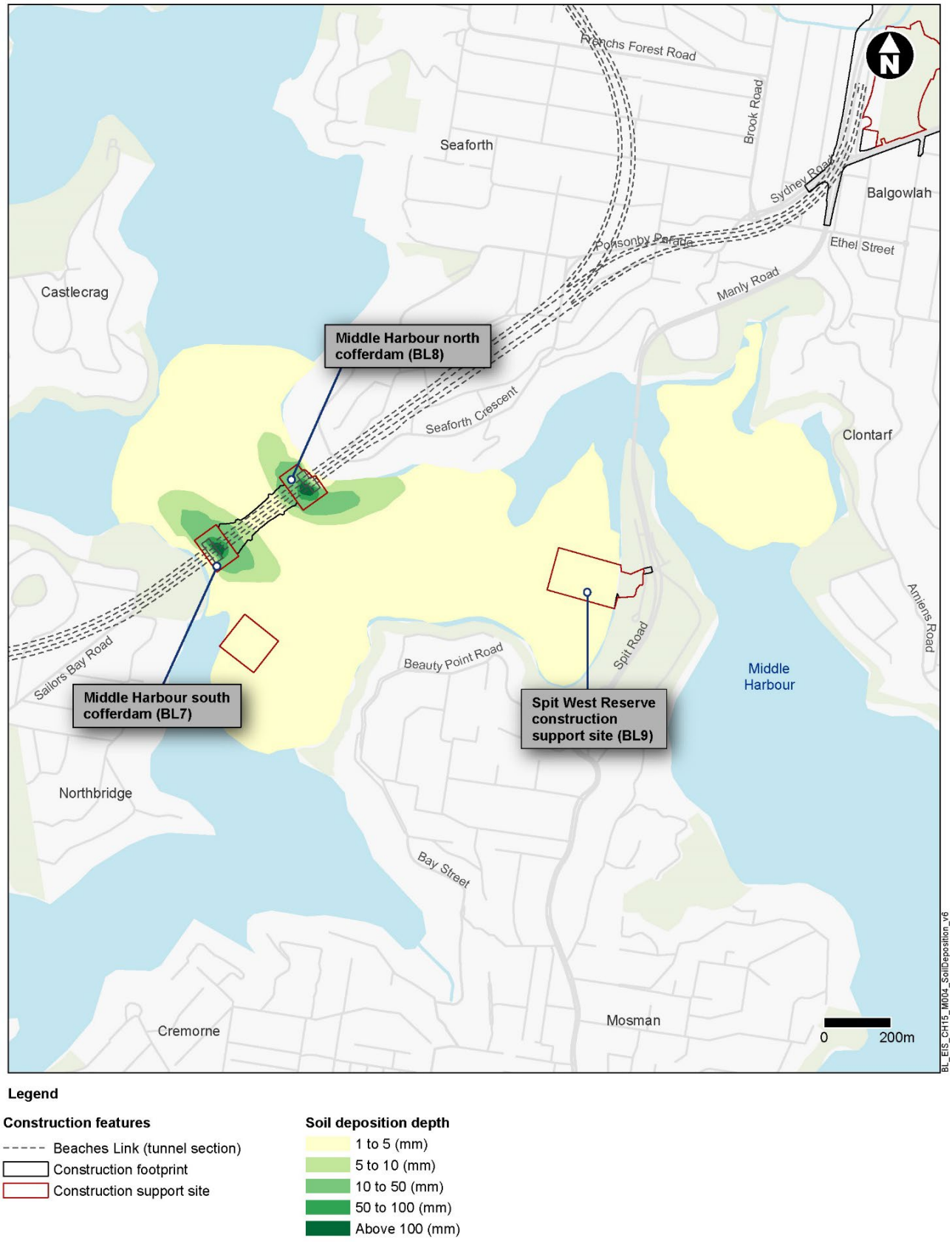
In summary, the effects of sedimentation as a result of dredging are expected to be minor. Short term effects of turbidity and deposition would likely be less than the effects from significant rainfall events.

Mobilisation of contaminants

Sediment sampling carried out for the project within Middle Harbour identified levels of selected contaminants within the top 0.5 metres to one metre of sediments from the bed of the harbour, which would, if mobilised, exceed guideline criteria. Dredging and other construction activities within Middle Harbour have the potential to mobilise these contaminants.

The behaviour of sediment-bound contaminants when resuspended into the water column has been previously assessed (Geotechnical Assessments, 2015) for other construction projects (Sydney Metro City & Southwest) which determined that contaminants are likely to remain bound to sediment particles and not be released into the water column.

A backhoe dredge with a closed environmental clamshell bucket would be used to remove the top layer of sediment. This would reduce the potential for release of contaminated sediments into the water (refer to Chapter 6 (Construction work)). On the basis of this proposed methodology, plume modelling has shown it is therefore unlikely that marine water quality would be substantially affected.



Legend

Construction features

- Beaches Link (tunnel section)
- Construction footprint
- Construction support site

Soil deposition depth

- 1 to 5 (mm)
- 5 to 10 (mm)
- 10 to 50 (mm)
- 50 to 100 (mm)
- Above 100 (mm)

Figure 17-6 Sediment deposition two weeks after completion of dredging activities

Discharges, runoff, spills and leaks

Land based construction activities occurring immediately adjacent to Middle Harbour could result in of the release of sediment via runoff to the harbour. There is also potential for spills or leaks of fuels and/or oils from maintenance or re-fuelling of construction plant or equipment or vehicle incidents, which could result in discharges to surrounding waterways and Middle Harbour. The discharge of treated water from onshore construction areas may also affect water quality in Middle Harbour.

These potential impacts would be effectively managed through the implementation of environmental management measures and procedures such that impacts on marine water quality would be minimised.

17.4.3 Surface water quality

Surface activities

A summary of potential impacts to surface water quality as a result of surface construction works is provided in Table 17-14. Identified surface water quality impacts would be managed via standard erosion and sediment control management and mitigation measures for all work sites including surface works areas.

Table 17-14 Summary of potential surface construction impacts on surface water quality

Construction activities/ incidents	Potential impacts
Temporary construction support sites	Establishment of temporary construction support sites may result in erosion and mobilisation of exposed soils by stormwater runoff and wind leading to sedimentation of waterways. Temporary construction support sites may include activities that have a high potential to impact downstream water quality, if unmitigated, through spills of pollutants flowing to downstream watercourses. Typical activities that pose a risk include: • Storage of chemicals • Vehicle wash down areas • Vehicle refuelling areas. Further, the movement of construction vehicles may transfer soil and pollutants to adjacent roads, which may then be conveyed via stormwater runoff into waterways.
Earthworks	Exposure of soils during earthworks (including stripping of topsoil, excavation, removal of existing paved areas, stockpiling and transport of materials) can result in soil erosion and off-site movement of eroded sediments by wind and/or stormwater into receiving waterways. Once sediments enter waterways, they can directly and indirectly impact on the aquatic environment. If not appropriately managed, direct impacts would include reducing light penetration (limiting the growth of macrophytes), clogging fish gills, altering stream geomorphology, smothering benthic organisms and reducing visibility for fish. Indirect impacts of increased sediments occur over the longer term and include accumulation and the release of attached pollutants such as nutrients and heavy metals. The waterways at most risk of being impacted by earthworks would be: • Willoughby Creek • Flat Rock Creek • Burnt Bridge Creek

Construction activities/ incidents	Potential impacts
	• Manly Creek and Manly Dam.
Stockpiling	Storage of earthworks materials, crushed rock, mulch and vegetation in stockpiles on construction sites and within temporary construction support sites have the potential to impact water quality and impact the aquatic environment if not appropriately managed. Stockpiles within 500 metres of a waterway that could potentially present a risk to water quality would be located at: • Flat Rock Drive (BL2) and Punch Street (BL3) construction support sites (Flat Rock Creek) • Balgowlah Golf Course (BL10) and Kitchener Street (BL11) construction support sites (Burnt Bridge Creek) • Wakehurst Parkway south and east construction support sites (BL12 and BL13) (Manly Creek and Manly Dam) • Wakehurst Parkway north (BL14) construction support site (Trefoil Creek) • Surface connection at Balgowlah (Burnt Bridge Creek) • Realignment and upgrade of Wakehurst Parkway (Manly Creek and Trefoil Creek).
Demolition	Demolition works have the potential to disturb and/or spread sources of pollutants including asbestos and other building materials, pollutant-laden soils, or heavy metals and chemicals that could affect water quality if not appropriately managed. Demolition can also generate dust and airborne pollutants. These pollutants once mobilised can be picked up by stormwater runoff and distributed to downstream receiving waterways via the drainage network.
Contamination and acid sulfate soils	If not appropriately managed, disturbance of contaminated land or groundwater, or acid sulfate soils during construction could result in the mobilisation of contaminants or acid sulfate soils by stormwater runoff and subsequent transportation to downstream waterways, potentially increasing contaminant concentrations in the receiving environment (refer to Chapter 16 (Geology, soils and groundwater)). The project is located within areas of low or extremely low probability of acid sulfate soils (refer to Appendix M (Technical Working Paper: Contamination)). There is the possibility of acid sulfate soils being present within sediments within Middle Harbour and/or The Spit.
Spills and leaks	If not appropriately managed, accidental spills or leaks could occur from spillage of diesel during refuelling, and leakage of hydraulic and lubricating oil from plant and equipment. Washdown water from plant washing and concrete slurries also have the potential to enter waterways if not appropriately managed.
Relocation of utilities	The relocation of utilities would involve soil disturbance as a result of trench excavation and underboring and construction of new utility routes. The disturbance of soil by machinery would increase the potential for soil erosion which has the potential to impact on downstream water quality if not appropriately managed.

Construction activities/ incidents	Potential impacts
Removal of vegetation	The removal of vegetation has the potential to increase the risk of erosion and sedimentation within the surrounding waterways if not appropriately managed. The majority of vegetation that would be removed for the project is located along the Wakehurst Parkway. Additionally, a small area of riparian vegetation and instream habitat would be removed for the localised adjustment and drainage works at Burnt Bridge Creek and the existing aboveground watercourse within the northern extent of Flat Rock Reserve. The removal of riparian vegetation and instream habitat at both creeks has the potential to impact bank stability and surface water quality if environmental management measures are not implemented. Vegetation removal for the localised adjustment of a small section of Burnt Bridge Creek would be mitigated by constructing a naturalised channel comprising of new plantings and retaining walls.

Tunnelling activities

Sources of wastewater

During construction, tunnelling works would result in large volumes of wastewater being generated from the following sources:

- Groundwater infiltration into tunnelling works
- Rainfall runoff into tunnel portals and ventilation outlet tunnels
- Wash down runoff
- Heat and dust suppression water.

Most of this wastewater would be collected from groundwater infiltration into the tunnelling works. Estimated volumes of construction wastewater are included in Section 17.4.5. Water volumes generated during the construction of the project would vary based on construction activities both above and below the ground surface, the amount of groundwater infiltrating into the tunnels and the length of tunnels that have been excavated. Groundwater infiltration into tunnelling works has been estimated as a worst case without consideration of the progressive installation of tunnel linings designed to reduce infiltration to an average of one litre per second per kilometre of tunnel.

The reuse of wastewater would be maximised during construction works (eg dust suppression and compaction of earthworks and pavements). Despite this reuse, there is expected to be a surplus of wastewater, which would need to be treated appropriately before discharge to the local stormwater system or directly to a local surface watercourse.

Wastewater treatment

The wastewater collected from tunnelling activities would be tested and treated at construction wastewater treatment plants prior to reuse or discharge. Discharges from construction wastewater treatment plants would be required to meet the following discharge criteria:

- 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 would 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) of which public comments are under consideration as of November 2020.

Temporary construction wastewater treatment plants would generally consist of settling tanks/ponds, flocculation tanks (which bind small particles suspended in the water together to make them easier to remove) and filtration.

Indicative construction wastewater treatment discharges and approximate duration of operation of the treatment plants are presented in Table 17-15. Discharge quantities are presented as a worst case, excluding progressive installation of tunnel linings to reduce infiltration to below one litre per second per kilometre. Therefore, the predicted tunnel infiltration, and discharge volumes, would be less than predicted by the modelling. Wastewater treatment plants and discharge locations are shown in Figure 17-7.

Table 17-15 Construction wastewater treatment plants

Plant location	Approximate duration of operation	Discharge quantity (kL/d)	Discharge location	Ultimate receiving waters
Cammeray Golf Course construction support site (BL1)	Three years and three months	296	Local stormwater system	Willoughby Creek
Cammeray Golf Course construction support site (BL1) and Western Harbour Tunnel and Warringah Freeway Upgrade project Cammeray Golf Course construction support site (WHT10) (cumulative discharge)[1]	Six months	321	Local stormwater system	Willoughby Creek
Flat Rock Drive construction support site (BL2)	Four years	711	Local stormwater system	Flat Rock Creek
Punch Street construction support site (BL3)	Three years and nine months	308	Local stormwater system	Flat Rock Creek
Balgowlah Golf Course construction support site (BL10)	Four years	428	Local stormwater system	Burnt Bridge Creek
Wakehurst Parkway east construction support site (BL13)	Three years and six months	10	Drainage channel to be formed at the eastern section of the temporary construction support site	Wakehurst Golf Course dam for reuse by the golf course (via overland flow)

Note 1: Cumulative impact during the time the two wastewater treatment plants would be discharging concurrently into the local stormwater system.

The wastewater treatment plants at Cammeray Golf Course (BL1), Flat Rock Drive (BL2), Punch Street (BL3), Balgowlah Golf Course (BL10) and Wakehurst Parkway east (BL13) construction support sites would treat wastewater generated from tunnelling activities to a standard suitable for discharge based on ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines. Construction wastewater treatment plants would be designed to maintain the water quality outcomes of the receiving ambient environment so that water quality objectives are achieved and impacts on water quality of affected catchments would be low compared to the existing pollutant loads.

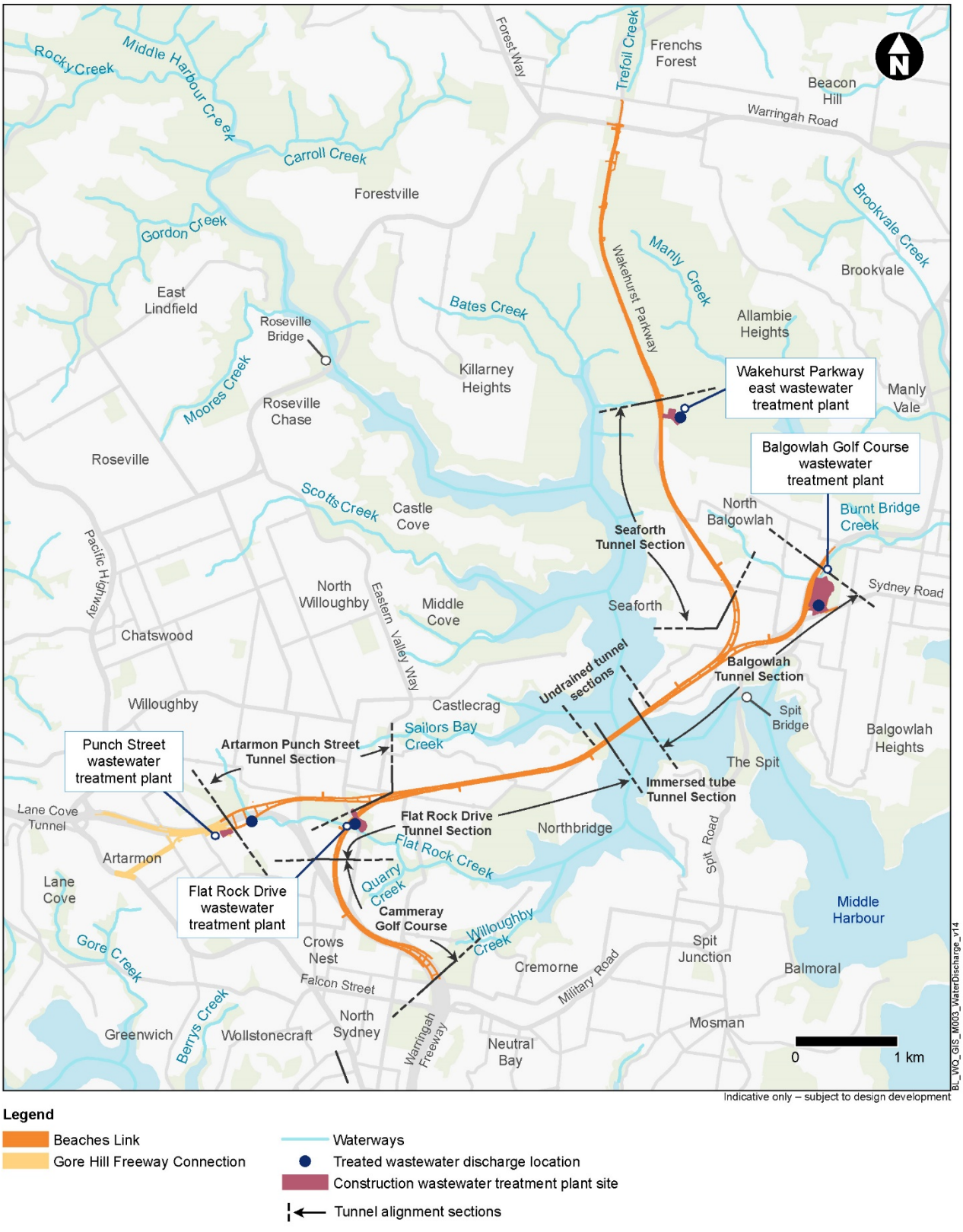


Figure 17-7 Construction wastewater treatment plants and discharge locations

Impacts on NSW water quality objectives during construction

The project would treat wastewater from tunnelling activities and implement standard erosion and sediment control measures for all work sites and surface works areas. With the implementation of these standard, environmental management measures, potential pollutant loading to the receiving waterways is considered to be low compared to the existing pollutant loading from Willoughby Creek, Flat Rock Creek, Burnt Bridge Creek, Manly Creek and Trefoil Creek catchments.

As a consequence, the project construction is likely to have a negligible influence on whether the NSW water quality objectives of receiving waters are protected (if currently met) or achieved (if currently not met).

17.4.4 Impacts on geomorphology

Construction of the project has the potential to impact on geomorphology due to:

- Treated water discharges from construction wastewater treatment plants have the potential to impact creek channel bed and bank conditions due to changes in baseline volumes and velocities
- Temporary changes in downstream creek flows and velocities as a result of increased surface runoff
- Mobilised sediment build up in the streams if not appropriately managed
- Impervious surfaces created by the project increasing the volume and rate of runoff, causing erosion within the instream channel
- Potential subsidence below watercourses, potentially impacting on channel bed and bank conditions.

Groundwater infiltration to the tunnels would be collected, treated and reused as required or discharged to local waterways including Willoughby Creek, Flat Rock Creek and Burnt Bridge Creek. This is expected to largely offset baseflow reduction to these waters, as the additional creek flows could partially feed the surrounding groundwater system.

Treated wastewater discharges into Willoughby Creek are not anticipated to change the creek geomorphology as the modified concrete and rock channel would be able to handle greater flows during frequent flood events. The susceptibility of Willoughby Creek to degradation as a result of increased flows is considered to be low based on assessment of its current stability and the relatively low level of project discharges when compared to existing flows.

Cumulative average daily treated wastewater discharges into Flat Rock Creek would be 0.012 kilolitres per second for about four years. This cumulative flow is considered minor when compared to creek flows experienced during a two-year average recurrence interval (ARI) event (0.02 kilolitres per second). Construction wastewater treatment plant discharges into Flat Rock Creek are not anticipated to change the form of the creek channel and banks as Flat Rock Creek is able to handle greater flows during frequent flood events. The overall predicted maximum total flow reduction in Flat Rock Creek at the end of construction is 20 per cent, increasing to 39 per cent after 100 years of operation, however given the circular nature of water flows (treatment of groundwater infiltration and discharge back into local waterways), discharges may partially offset this impact. There is also little potential for further incision of the concrete-lined sections and rocky riffle/runs at Flat Rock Creek. Baseflow impacts are modelled conservatively without tunnel linings designed and installed to reduce groundwater inflows into the tunnels. Baseflow impacts are therefore likely to be lower than that predicted. Refer to Section 17.4.5 for further discussion on water availability and flows.

Average daily treated wastewater discharges into Burnt Bridge Creek would be about 0.005 kilolitres per second for about four years. This flow is considered negligible when compared to creek flows experienced during a two-year ARI event (29.7 kilolitres per second) and is not expected to change the stability or form of Burnt Bridge Creek channel or banks.

Most of the treated wastewater generated at the Wakehurst Parkway east construction support site (BL13) wastewater treatment plant would be reused. The small amount discharged would be into the drainage channel to be formed at the eastern section of the site which would naturally drain towards Wakehurst Golf Course and the golf course dam. Therefore, geomorphology impacts from treated wastewater discharges at the Wakehurst Parkway east construction support site are not expected.

If not appropriately managed, impacts to geomorphology as a result of increased mobilised sediment or increased surface runoff (volume or velocity) could occur where activities are near watercourses. This includes Willoughby Creek, Flat Rock Creek, Burnt Bridge Creek, Manly Creek and along drainage lines that pass under Wakehurst Parkway. Impacts to Flat Rock Creek are considered to have low potential of occurring given the concrete-lined or piped nature of the creek.

Drainage works associated with an existing aboveground watercourse within Flat Rock Reserve at the Flat Rock Drive construction support site (BL2) and localised adjustment of Burnt Bridge Creek as part of surface connections at Balgowlah would be staged to ensure creek flows and velocities are not substantially changed and to avoid downstream erosion and bed and bank stability impacts. The potential for watercourse geomorphology impacts would be mitigated through environmental management measures outlined in Section 17.6.

Works along the Wakehurst Parkway, the Wakehurst Parkway south construction support site (BL12), Wakehurst Parkway east construction support site (BL13) and Wakehurst Parkway north construction support site (BL14) are unlikely to change the bed and bank conditions of the existing drainage lines within the Garigal National Park and Manly Dam Reserve provided environmental management measures outlined in Section 17.6 are implemented. Refer to Chapter 6 (Construction work) for further details regarding the scope and extent of stormwater drainage works.

17.4.5 Water balance, environmental water availability and flows

Water balance

The expected construction water balance, based on average groundwater infiltration, and the estimated treated discharge quantities are shown in Table 17-16. The actual water usage during construction is expected to show considerable variation during this period depending on the nature and extent of construction activities taking place. Non-potable water uses would include earthworks and pavement compaction, landscape watering, roadheader supply, dust suppression, plant wash-down and rock bolting, amongst other activities. Some activities are consumptive such as concrete batching and the water used in the offices, with some consumptive demand assumed to be discharged directly into the sewerage network. There would also be minor losses in the system due to evaporation. The remainder would be treated and either reused or discharged at the proposed discharge locations listed in Table 17-15.

Non-potable sources (eg treated wastewater and harvested rainwater) may be used to meet construction water demand requirements. The deficit for the non-potable demand and any potable demand would be sought from the Sydney Water supply network. The use of non-potable water over potable would be preferred, however this is dependent on the location and nature of the water use activity as well as the quantity and quality of available water at the time. Water availability would vary as construction progresses as well as seasonally due to climate. It is expected that the potential for treated wastewater reuse would also show variability.

Table 17-16 Construction water balance

Activity[1]	Total water demand (kL/d)	Consumptive use (kL/d)	Groundwater infiltration (kL/d)	Harvested rainwater (kL/d)	Treated wastewater reused (kL/d)	Sydney water supply (kL/d)	Discharge quantity (kL/d)
Surface works[2]	368	368	0	0	185	183	0
Tunnelling							
Cammeray Golf Course (BL1)	159	15	278	1	127	32	296
Flat Rock Drive (BL 2)	635	61	440	1	305	331	711
Punch Street (BL 3)	125	40	347	1	130	0	308
Balgowlah Golf Course (BL 10)	810	457	521	1	263	547	428
Wakehurst Parkway east (BL 13)	548	370	30	1	199	349	10
Total	**2645**	**1311**	**1616**	**5**	**1209**	**1442**	**1753**

Note 1. Middle Harbour south cofferdam (BL7), Middle Harbour north cofferdam (BL8) and Spit West Reserve (BL9) construction support sites are not included in the water demand estimates
Note 2. Surface works estimates include works along the existing Gore Hill Freeway, surface works between the mainline tunnels at Balgowlah and Killarney Heights, and surface works at Wakehurst Parkway.

Water availability and flows

Water extraction from surface water is not proposed during construction. However, surface environmental water availability and flows have the potential to be reduced as a result of groundwater drawdown during construction of the project. Baseflow impacts are modelled conservatively without tunnel linings designed and installed to reduce groundwater infiltration into the tunnels. Baseflow impacts are likely to be lower than that predicted in Appendix N (Technical working paper: Groundwater) due to conservative modelling assumptions.

The assessment of groundwater impacts for the project indicate that the maximum predicted groundwater drawdown at Willoughby Creek during construction is up to three metres in the upper reaches. Baseflow impacts are not expected as the creek is lined in this area. There is the potential for baseflow reductions of more than five per cent to occur at Flat Rock Creek and Quarry Creek at the end of construction. The drawdown beneath Burnt Bridge Creek is estimated to be up to five metres. There would be maximum of 79 per cent reduction in baseflow at the end of construction. Due to the very low existing baseflows along Burnt Bridge Creek and Quarry Creek and the existing geomorphologies, the predicted baseflow reductions are unlikely to have any substantial hydrodynamic or water quality impacts. An estimated drawdown of less than one metre is expected at Manly Dam, resulting in maximum baseflow reduction of two per cent. Other creeks would be unaffected by changes to baseflow conditions. As discussed below, it is expected that the additional creek flows from treated water from the construction wastewater treatment plants could partially feed the surrounding groundwater system. Further details regarding the potential impacts of baseflow reductions and measures to minimise potential impacts on ecological conditions are provided in Chapter, 16 (Geology, soils and groundwater), Chapter 19 (Biodiversity) and Appendix S (Technical working paper: Biodiversity development assessment report).

Stormwater harvesting schemes

The project would not impact the stormwater harvesting scheme implemented by North Sydney Council at the storage dam at the Cammeray Golf Course. However, the existing storage dam at the Cammeray Golf Course would be impacted by the Western Harbour Tunnel and Warringah Freeway Upgrade project.

As part of the Western Harbour Tunnel and Warringah Freeway Upgrade project and subject to a timely agreement with Cammeray Golf Club and North Sydney Council regarding a suitable alternative location, Transport for NSW would install a new permanent replacement storage dam (and associated infrastructure) within the golf course prior to decommissioning of the existing dam.

The reinstatement and management of impacts to North Sydney Council prior to the reinstatement of the permanent solution form part of the Western Harbour Tunnel and Warringah Freeway Upgrade project.

The project would impact the Balgowlah Golf Course stormwater harvesting dam as part of constructing the new access road between Sydney Road and Burnt Bridge Creek Deviation. The Balgowlah Golf Course Stormwater Harvesting dam will initially be retained and maintained as construction water and irrigation of Balgowlah Oval by Northern Beaches Council. As construction progresses the stormwater harvesting dam would be removed. The ongoing need for a stormwater harvesting water quality basin at Balgowlah would be assessed and determined during further design development. If the stormwater harvesting water quality basin is considered to be required, a suitable alternate location and future use would be determined as part of the dedicated consultation process regarding the final layout of the new and improved public open space and recreation facilities at Balgowlah.

17.4.6 Residual impacts during construction

With the implementation of the management measures outlined in Section 17.6, and in the context of the overall catchment, any potential short-term impacts are unlikely to have any material impact on ambient water quality within the receiving waterways.

The residual risk to sensitive receiving environments and environmental values identified in Section 17.3.8 and Section 17.3.9 is expected be low provided the proposed management measures are implemented, maintained and monitored.

Construction activities are not expected to result in a substantial change to the sediment dynamics in the vicinity the Middle Harbour crossing. The use of floating silt curtain enclosures immediately around dredging plant and associated deep draft silt curtains is expected to effectively contain any mobilised sediments.

17.5 Assessment of potential operational impacts

17.5.1 Hydrodynamic environment of Middle Harbour

The immersed tube tunnels would be installed as a series of pre-cast units. Due to the profile of the harbour bed, the units would sit both partially within a trench closer to the shore and above the bed of the harbour towards the centre of the harbour crossing. The middle sections would be placed with the tops of the tunnel units being about 9.2 metres above the existing level of the bed of the harbour, creating a sill-like feature over a length of around 250 metres and around 40 metres wide. The water depth above the immersed tube tunnels would vary between 16 metres and 22 metres, depending on the distance from the shore.

Hydrodynamic modelling of the potential impacts on tidal currents and tidal flushing indicates:

- The changes to currents for both flood and ebb tides as a result of the project would be small and less than those seen through natural variations such as wind driven circulation
- Water levels upstream of the Middle Harbour crossing would not be affected
- The tidal prism of Middle Harbour (ie the volume of water between mean high tide and mean low tide) would be marginally reduced (0.4 per cent decrease)
- Tidal flushing (replacement of water via tidal fluctuations) would take slightly longer for water located upstream and below the level of the sill; however, flushing would remain relatively rapid.

Due to the existing low energy hydrodynamic environment at the proposed Middle Harbour crossing, little to no bedload transport or resuspension of existing sediment is expected to occur where the immersed tube tunnels would be located above the bed of the harbour. Localised increases in current speed are not expected to result in a change to the sediment dynamics near the proposed Middle Harbour crossing. Figure 17-8 to Figure 17-11 show the changes to tidal flows as a result of the project during peak flood and peak ebb tides at the top of the sill and at the surface.

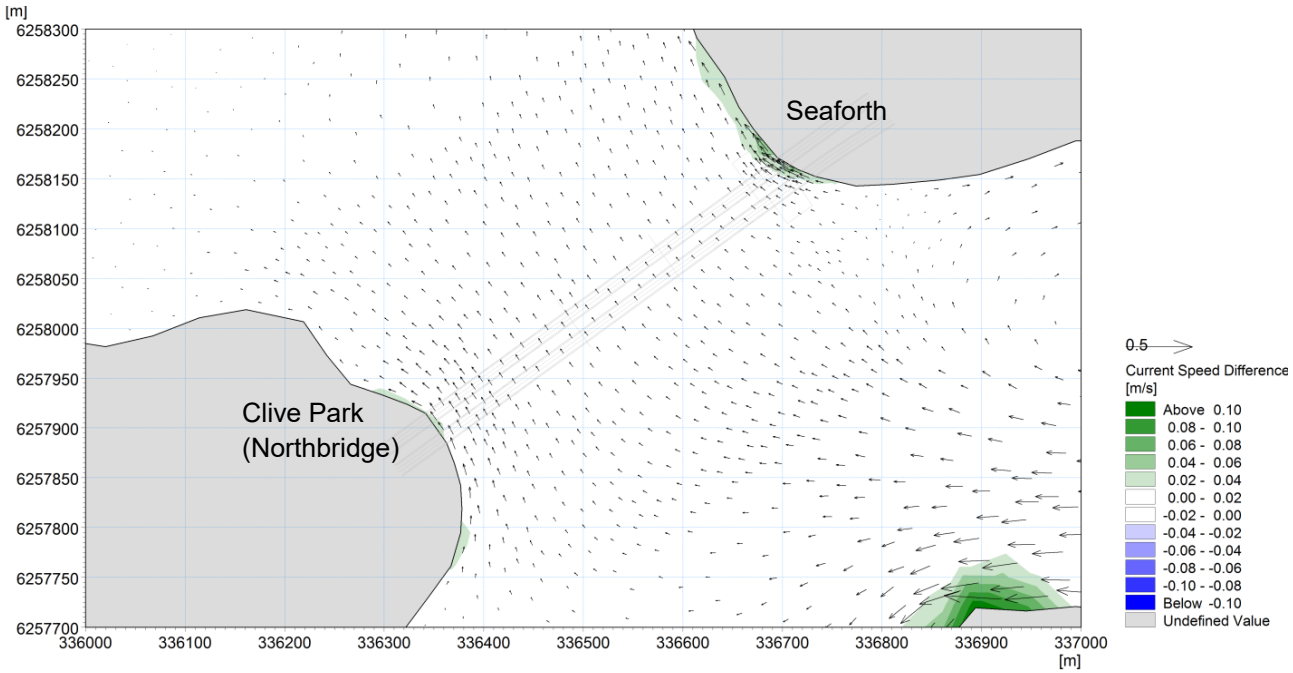


Figure 17-8 Current speed difference: project design less existing conditions (Peak flood tide: surface layer)

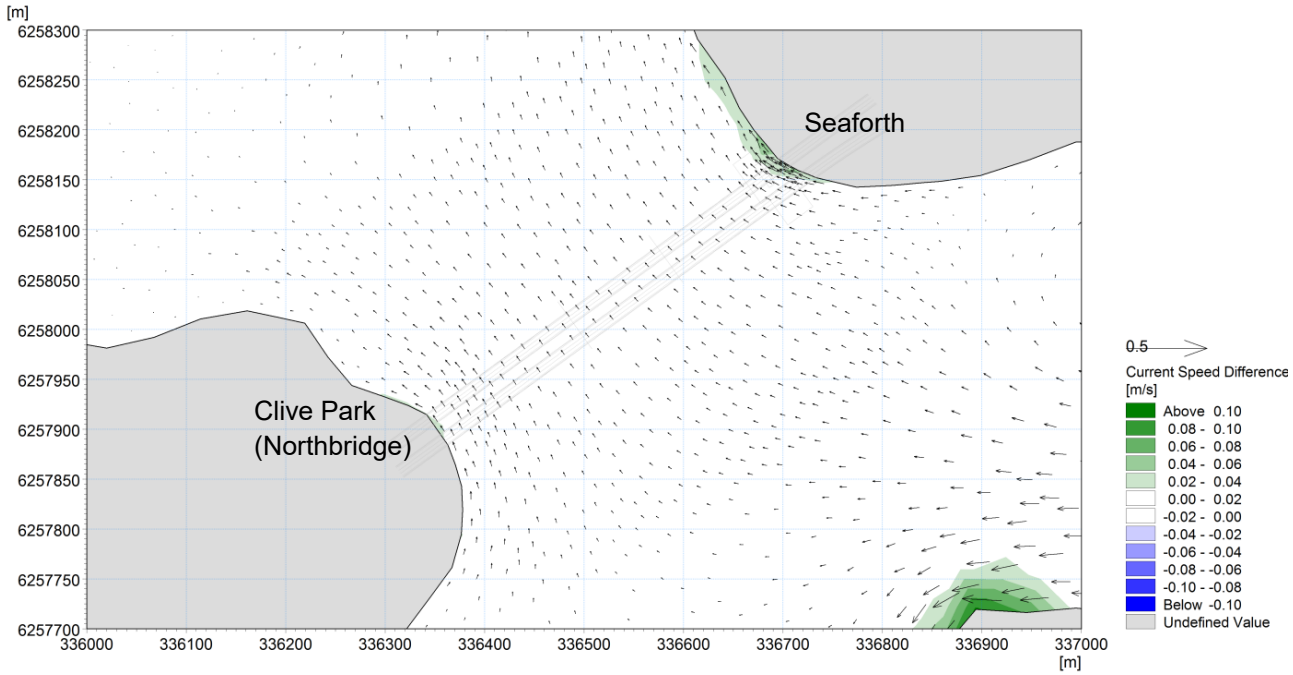


Figure 17-9 Current speed difference: project design less existing conditions (Peak flood tide: layer just above the crown of the tunnel)

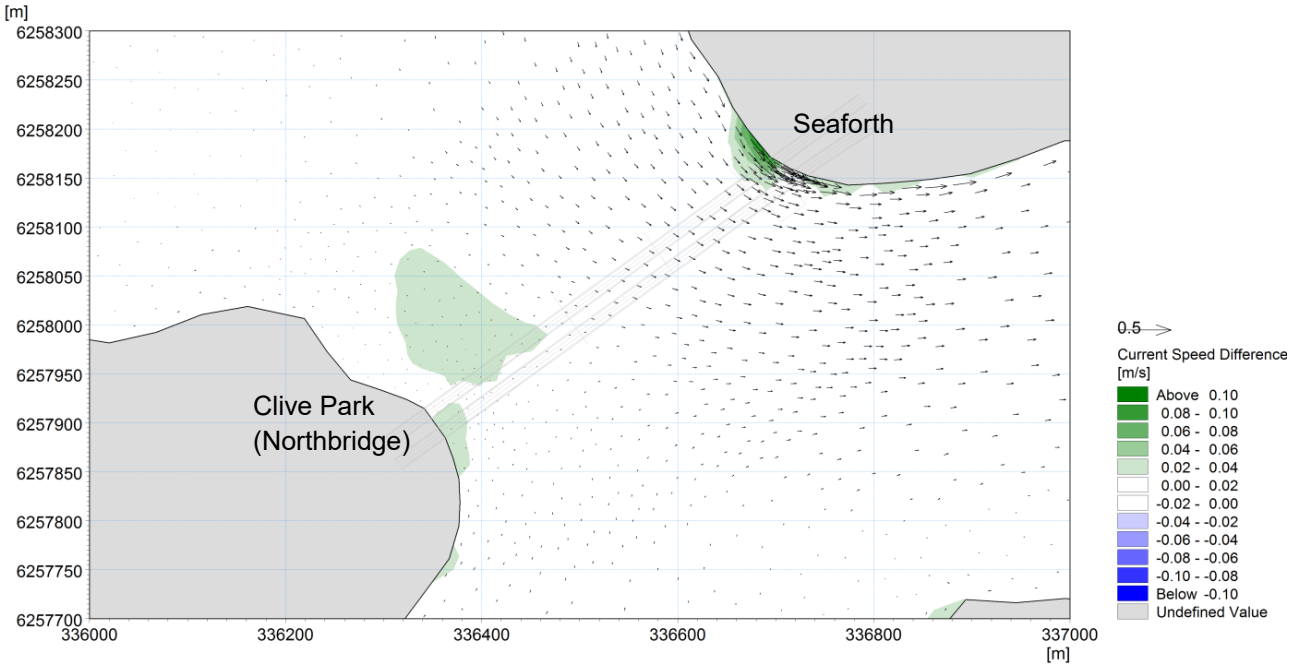


Figure 17-10 Current speed difference: project design less existing conditions (Peak ebb tide: surface layer)

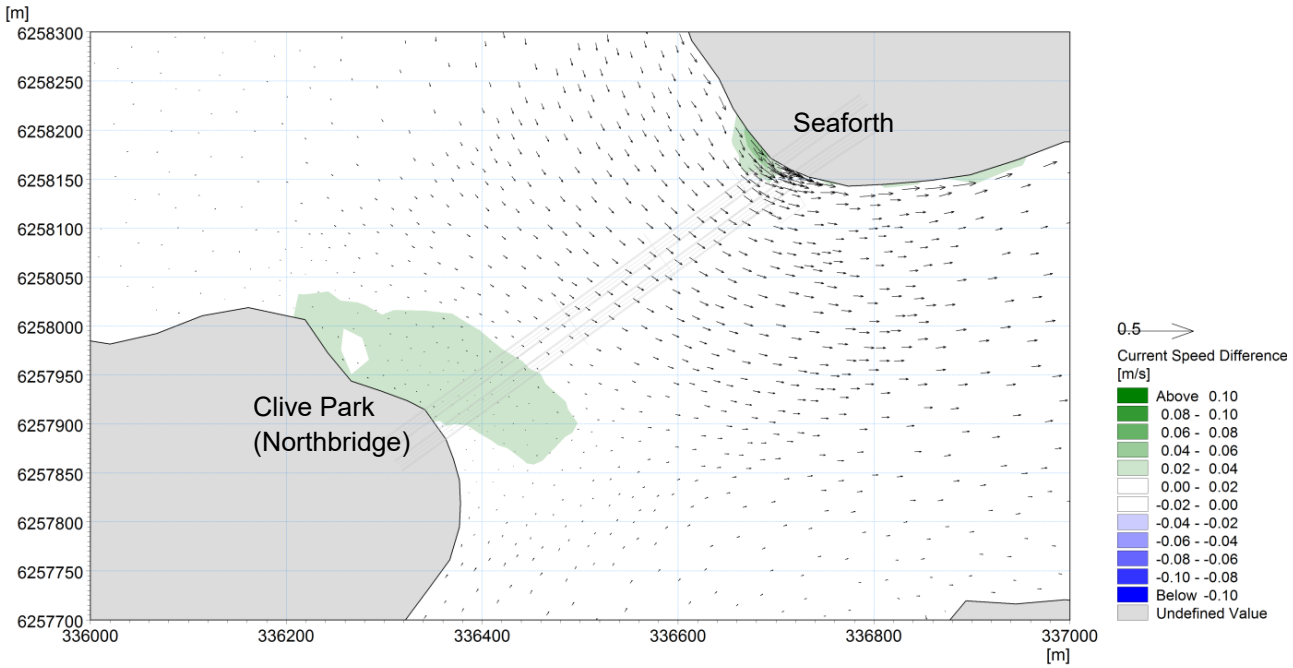


Figure 17-11 Current speed difference: project design less existing conditions (Peak ebb tide: layer just above the crown of the tunnel)

17.5.2 Marine water quality

Tidal flushing upstream of the Middle Harbour crossing has the potential to be affected by the permanent sill-like feature that would be created by the project. The longer term effects of the sill have the potential to reduce water exchange and therefore increase residence times in the near-bed waters for about one kilometre upstream of the sill from 1.6 days to 2.4 days. Increased residence time of the deep water upstream may lead to longer periods of low dissolved oxygen concentrations in the near-bed waters below the sill level and/or increased siltation behind the sill. Lower dissolved oxygen concentrations may lead to a nutrient release from the sediments and its subsequent vertical mixing, potentially stimulating algal growth near the surface.

When dissolved oxygen concentrations are reduced there may be mortality to some benthic infauna and epifauna in soft sediment habitat in the deepest parts of the harbour, but fish and sharks would generally be able to avoid these bottom layers. It would be expected that recolonisation of affected deep water soft sediment habitat would occur through natural processes of recruitment of planktonic larvae and from movement of fauna from shallower unaffected areas of soft sediment.

Based on average annual rainfall patterns, the conditions leading to dissolved oxygen depletion to about 50 per cent saturation concentrations are likely to naturally occur a few times per year, particularly during the warmer late summer and autumn period. While the project would potentially result in low dissolved oxygen events lasting slightly longer at a slightly lower dissolved oxygen concentration than currently occurs, any depletion of dissolved oxygen in deeper waters would be rapidly mixed vertically resulting in the project having a negligible effect on dissolved oxygen in surface waters in which Type 1 and Type 2 Key Fish Habitats are located. The potential impacts of the likely slightly longer periods of low dissolved oxygen concentrations in the deep waters to the marine ecology of Middle Harbour are discussed further in Chapter 19 (Biodiversity).

17.5.3 Surface water quality

Surface water runoff

During operation of the project, all road surfaces would be sealed, and embankments landscaped. Suitable stabilisation and management measures would be implemented during periods of vegetation establishment to minimise the potential for erosion and sedimentation impacts at nearby waterways including Flat Rock Creek and Burnt Bridge Creek. Provided appropriate controls are implemented, short-term impacts during the vegetation establishment period would be expected to be manageable with negligible impacts on receiving water quality.

Runoff from upgraded road pavement would typically contain pollutants such as sediments, litter, nutrients, oils and greases, petrochemicals and heavy metals, which could potentially impact on water quality when discharged into receiving waterways and sensitive receiving environments (Trefoil Creek, Manly Creek, Manly Dam, Burnt Bridge Creek and Flat Rock Creek). Potential impacts on the water quality of nearby watercourses and drainage lines would include increased sedimentation, erosion, and mobilisation of contaminated sediments resulting in potential impacts to aquatic flora and fauna if not appropriately managed.

Where possible, surface water quality controls for the project would be provided so that water is treated to a standard that would meet the design targets for the project. Where the design targets are not able to be met due to site constraints, water quality treatment to meet existing conditions would be provided such that impacts on surface water quality would be minimal.

MUSIC modelling was carried out to assess the performance of the proposed surface water quality treatment measures against the pollutant reduction targets outlined in Section 17.1.3.

The modelling results for the main locations where stormwater would be discharged (ie Gore Hill Freeway Connection, surface connections at Balgowlah and the realigned and upgraded Wakehurst Parkway) indicate that while the project would not meet the design targets in all locations, it would still meet or improve the existing water quality. On this basis impacts on surface water quality are expected to be minimal.

Chapter 5 (Project description) and Appendix O (Technical working paper: Surface water quality and hydrology) provide further details of the stormwater drainage infrastructure and proposed stormwater quality treatment systems.

Tunnel drainage and wastewater treatment

The tunnels, when operational, would include drainage infrastructure to capture groundwater and stormwater ingress, spills, maintenance wastewater, fire suppressant deluge and other potential water sources.

Water intercepted by the tunnel drainage systems would be collected and pumped to the Gore Hill Freeway wastewater treatment plant for treatment. Following treatment, the water would then be discharged into Flat Rock Creek via a new drainage pipe connecting with Flat Rock Creek at a flow rate of about 16 litres per second (refer to Figure 17-12).

The wastewater treatment plant would be designed to meet the following discharge criteria:

- 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) 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) of which public comments are under consideration as of November 2020.

Impacts on NSW water quality objectives during operation

During operation, the project would treat tunnel infiltration and road tunnel runoff at the Gore Hill Freeway operational wastewater treatment plant. The plant would be designed to treat key indicators of concern to a level that is consistent with the ANZG (2018) water quality guidelines and the NHMRC (2008b) recreational water quality guidelines.

Runoff from the Gore Hill Freeway Connection, surface connections at Balgowlah and the realigned and upgraded Wakehurst Parkway is predicted to meet or improve the existing water quality of receiving waters (Flat Rock Creek, Burn Bridge Creek, Manly Dam, Manly Creek or Bantry Bay).

The overall impacts to ambient water quality are likely to be negligible. The project is considered to have a negligible influence on goals to achieve the NSW water quality objectives.

17.5.4 Impacts to the local stormwater system

Treated wastewater from the Gore Hill Freeway operational wastewater treatment plant would discharge into Flat Rock Creek via a new drainage pipe at a flow rate of about 0.016 kilolitres per second (16 litres per second) (refer to Figure 17-12). This discharge rate is unlikely to have a material impact on the operation of the local stormwater system.

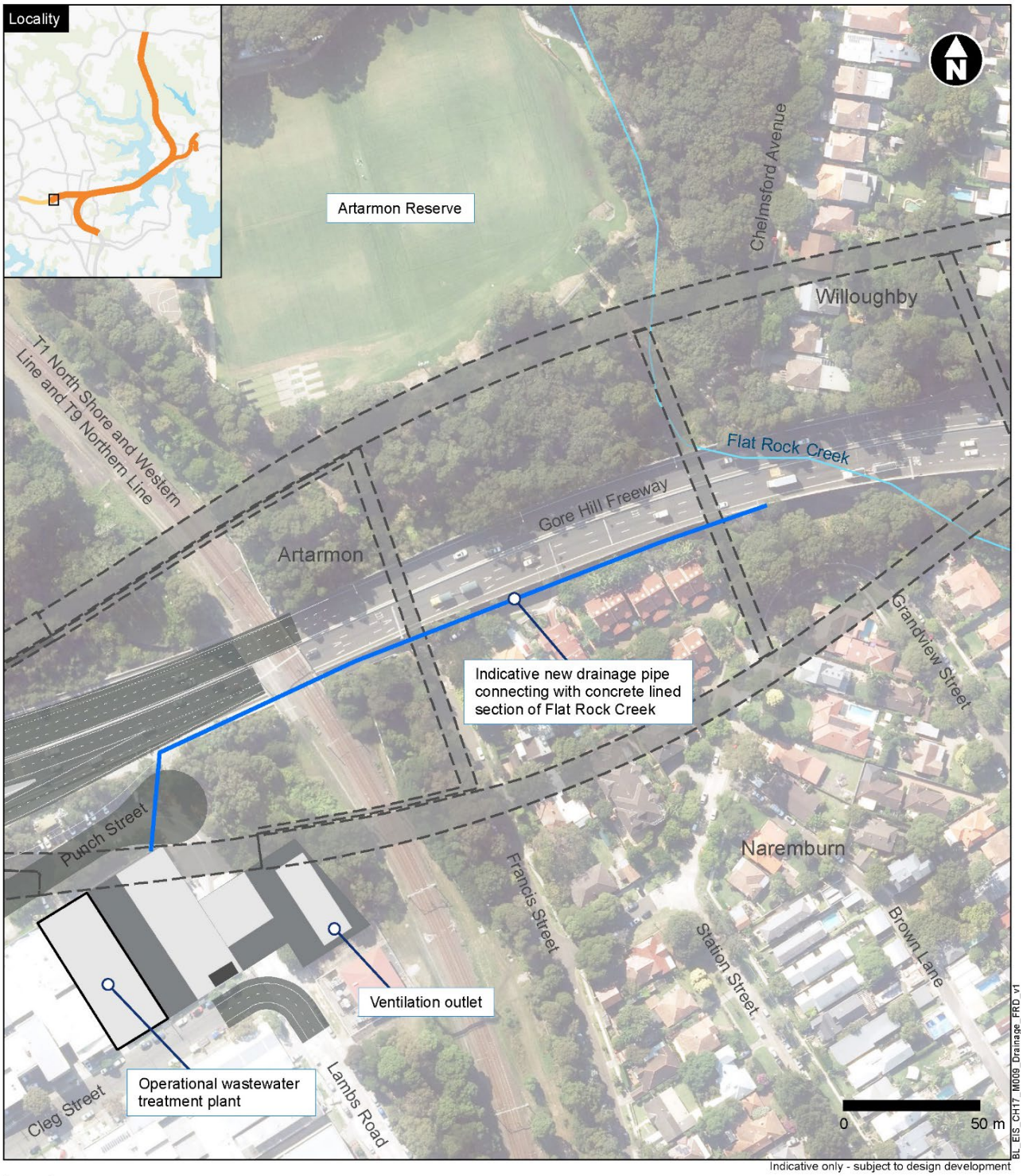


Figure 17-12 Operational wastewater treatment discharge location

17.5.5 Impacts on geomorphology

The potential impact to the geomorphology of watercourses from surface water runoff is considered negligible given that project stormwater discharges would be via the stormwater network. Drainage works would be designed to include velocity flow dissipation structures so as to prevent scouring of creeks and drainage lines.

The Gore Hill Freeway wastewater treatment plant discharge volumes would be ultimately received into Flat Rock Creek via the local stormwater system at a flow rate of about 0.016 kilolitres per second. This rate is lower than the creek flow rate under a two-year ARI flood event (0.02 kilolitres per second). It is therefore considered that Flat Rock Creek bed and banks would be able to handle expected wastewater treatment plant flow rates without impacting the creek form and geomorphic processes.

The upgrade of the concrete lined drainage line between Punch Street and Flat Rock Creek via Chelmsford Avenue would be located on existing flow paths and sized to not restrict the free flow of water. It would be designed with low gradient and scour protection to minimise impacts to geomorphology. Additionally, installation of culverts would be in accordance with the *Temporary Stormwater Drainage for Road Construction technical guideline* (Roads and Maritime Services, 2011b).

The proposed localised adjustment of Burnt Bridge Creek would be designed considering the susceptibility of the creek to scour from increased flow and runoff. The extension to the existing culvert would be designed with low gradient and scour protection to minimise impacts to geomorphology. The extent of scour protection would be minimised during further design development as far as practicable. The gradient, sinuosity and channel capacity would remain consistent with upstream and downstream sections of the creek. Where required, grade controls and bank stabilisation works would be implemented to manage anticipated high velocity conditions.

Cumulative long-term surface settlement from tunnelling works and groundwater drawdown have been assessed for the project (Arup and WSP, 2020). Cumulative long-term surface settlement is expected to be nil or very minor at creeks intersected or in proximity to the tunnels. The risk of rock cracking from such surface settlement is negligible because the ground movement would be insufficient to cause any noticeable change in permeability of the rock cover. The exception to this is the cumulative long-term surface settlement predicted at Flat Rock Creek within poorly consolidated fill beneath Flat Rock Baseball Diamond. At this location, settlement is predicted to be up to 85 millimetres under a worst case (conservative) modelling scenario. With the inclusion of proposed tunnel lining for around 300 metres beneath Flat Rock Reserve, modelling indicates that predicted settlement at Flat Rock Reserve reduces from 85 millimetres without the lined tunnel to 35 millimetres with the lined tunnel.

Contours of calculated surface angular distortion have been developed based on the calculated surface settlement data (Arup and WSP, 2020). The calculated maximum settlement is at the north east section of the link at Balgowlah Connection, Burnt Bridge Creek, Wakehurst Parkway Connection and north of the Warringah Freeway portal with the maximum settlement being 35 to 40 millimetres in these areas.

Settlement is not expected to have noticeable impact on Flat Rock Creek or Burnt Bridge Creek form and geomorphology as the existing creek drainage infrastructure along both these creeks would be designed as culverts and would mitigate some of the predicted settlement impacts.

17.5.6 Water balance, environmental water availability and flows

Water balance

Operation of the project has the potential to alter the water balance of surface and groundwater systems. The Gore Hill Freeway wastewater treatment plant would treat all groundwater infiltration during operation of the project. Any non-potable water demand during operation of the project would be sourced from this facility. The operational stage water balance is shown in Table 17-17.

Table 17-17 Operational water balance

Wastewater treatment plant location	Water demand		Average groundwater infiltration (kL/d)	Treated groundwater re-used (kL/d)	Discharge quantity (kL/d)
	Washdown (kL/d)	Deluge testing (kL/d)			
Gore Hill Freeway	2	8	1435	10	1425

Water availability and flows

Water extraction from waterways is not proposed during operation of the project. However, surface environmental water availability and flows have the potential to be reduced as a result of groundwater drawdown during operation of the project. This has the potential to result in impacts to groundwater dependant ecosystems and other surrounding riparian ecosystems reliant on surface water (refer to Appendix N (Technical working paper: Groundwater)).

The assessment of groundwater impacts for the project identified that the project has the potential to result in a worst case groundwater drawdown of up to 29 metres beneath Flat Rock Creek after 100 years of operation. The modelling indicates that there would be a maximum total flow reduction of about 39 per cent in Flat Rock Creek after 100 years of operation, noting operational wastewater treatment plant discharges to Flat Rock Creek may offset this impact. Potential impacts would also be experienced at Quarry Creek and Burnt Bridge Creek, where maximum total flows would be reduced by 69 and 96 per cent respectively after 100 years of operation.

While these reductions could be considered significant, in particular for Burnt Bridge Creek and Quarry Creek, they are unlikely to result in a complete loss of aquatic habitat. Pools would be retained and there would still be high flows within the waterways immediately after rainfall events. Between rainfall events there would still be some (low) flow along the waterways. Further consideration to the potential impacts of baseflow reduction on aquatic ecosystems is provided in Appendix S (Technical working paper: Biodiversity development assessment report).

It is noted that groundwater modelling provides a conservative assessment which excludes the designed tunnel linings. Additional modelling was carried out for a scenario in which the section of tunnel beneath Flat Rock Creek is lined. With the linings assumed, the predicted water table drawdown after 100 years of operation was predicted to be up to eight metres less than the drawdown predicted without the lining, demonstrating that implementation of tunnel lining would help mitigate potential groundwater drawdown impacts and that potential baseflow impacts would be lower than predicted (refer to Chapter 16 and Appendix N (Technical working paper: Groundwater)).

A minor flow reduction of two per cent would be experienced at Manly Creek/Manly Dam, however other watercourses including Willoughby Creek would be unaffected by changes to baseflow and would experience a negligible total flow reduction after 100 years of operation.

Environmental management measures to minimise potential impacts due to reduced groundwater baseflow to creeks are provided in Chapter 16 (Geology, soils and groundwater). Monitoring of surface water flows and groundwater levels would occur in the vicinity of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, both prior to and during construction to confirm potential baseflow loss to these surface water features.

Stormwater harvesting schemes

The stormwater harvesting scheme implemented by North Sydney Council at the storage dam at Cammeray Golf Course would not be impacted by the project as the storage dam would be reinstated as part of the Western Harbour Tunnel and Warringah Freeway Upgrade project.

The ongoing need for a stormwater harvesting water quality basin at Balgowlah would be assessed and determined during further design development. If a basin is considered to be required, a suitable alternate location and future use will be determined as part of the dedicated consultation process regarding the final layout of the new and improved public open space and recreation facilities at Balgowlah.

17.5.7 Residual impacts on water quality during operation

As discussed in Section 17.3, receiving waterways near the project have existing elevated levels of some heavy metals, nutrients, turbidity and pH, and low dissolved oxygen.

Tunnel water would be treated to comply with (ANZECC/ARMCANZ, 2000) and ANZG (2018) guidelines (refer to Section 17.1.3). MUSIC model results for several areas, including the Gore Hill Freeway Connection stormwater catchment, combined stormwater sub-catchments at Balgowlah and stormwater catchments at Wakehurst Parkway, show that the proposed water quality strategy would achieve general reductions on annual pollutant exports when compared to existing conditions. However, the water quality strategy at Balgowlah would not achieve the operational water quality design targets for total suspended solids and total phosphorus, while the water quality strategy for the Wakehurst Parkway would not achieve the operational water quality design target for nitrogen. Spill controls and water quality monitoring would be implemented to identify and manage operational impacts on ambient water quality within the receiving waterways.

For locations where stormwater would be discharged (ie Gore Hill Freeway, Balgowlah and Wakehurst Parkway), water quality treatment to meet existing conditions would be provided, at a minimum, such that impacts on surface water quality would be minimal.

Impacts to the baseflow of Quarry Creek and Flat Rock Creek would occur because of groundwater drawdown that occurs due to the project. Provided controls are implemented, maintained and monitored, impacts on downstream receivers would be minimal.

With the proposed treatment and management measures, residual impacts on ambient water quality are expected to be negligible.

The residual risk to sensitive receiving environments and environmental values identified in Section 17.3.8 and Section 17.3.9 respectively is expected to be low provided the proposed management measures are implemented, maintained and monitored.

17.6 Environmental management measures

Environmental management measures relating to water quality impacts are outlined in Table 17-18. No specific measures are required for hydrodynamics during construction given the methodology to be implemented during construction; activities in Middle Harbour (refer to Chapter 6 (Construction work)) and the minimal hydrodynamic impacts expected as a result of the project.

Table 17-18 Environmental management measures – hydrodynamics and water quality

Ref	Phase	Impact	Environmental management measure	Location
WQ1	Design	Stormwater harvesting	The need for a stormwater harvesting water quality basin at Balgowlah will be assessed and determined during further design development. If the stormwater harvesting water quality basin is considered to be required, a suitable alternate location and future use will be determined as part of the dedicated consultation process regarding the final layout of the new and improved public open space and recreation facilities at Balgowlah.	BL (Balgowlah)

Ref	Phase	Impact	Environmental management measure	Location
WQ2	Design	Spill containment	Spill containment controls along surface roads will be confirmed during further design development and determined with consideration of: • The environmental sensitivity of the receiving waterways • The likelihood of vehicle accidents, informed by the annual average daily traffic (AADT) loading along the surface road • Where implementation of controls measures may have a negative impact on other areas of environmental importance, such as biodiversity and heritage.	BL/GHF
WQ3	Design and operation	Local stormwater system capacity	The capacity for the local stormwater system to receive operational wastewater treatment plant discharge will be confirmed during further design development. If there is a stormwater infrastructure capacity issue with existing infrastructure, mitigation measures such as storage detention to control water outflow during wet weather events will be implemented within the motorway facility site.	GHF
WQ4	Design and operation	Burnt Bridge Creek geomorphology	The localised adjustment of Burnt Bridge Creek will be designed with consideration of existing channel conditions and an understanding of existing hydrology to minimise alterations to, and erosion of, the bed and banks. The gradient, sinuosity and channel capacity will be consistent with upstream and downstream sections. The extension to the existing culvert will be designed with a low gradient and scour protection to minimise impacts to geomorphology. Where required, the adjustment will include grade controls and bank stabilisation works to manage anticipated high velocity conditions.	BL

Ref	Phase	Impact	Environmental management measure	Location
WQ5	Design and operation	Water sensitive urban design	Opportunities for water sensitive urban design will be considered during the development of the design for the stormwater management system for the new and upgraded road infrastructure and during development of the urban design and landscape plans. Identified water sensitive urban design features will be implemented where practical and with consideration to best management practice guidelines including Transport for NSW's *Water sensitive urban design guideline* (Roads and Maritime Services, 2017d).	BL/GHF
WQ6	Design and operation	Surface water discharge	Water quality treatment controls for stormwater will meet the design targets, where possible. Where the design targets cannot be met due to site constraints, water quality treatment controls will be provided to meet or improve existing surface water quality.	BL/GHF
WQ7	Design and operation	Connection to Sydney Water stormwater assets	The need for direct connection to Sydney Water stormwater assets will be reviewed during further design development and in consultation with Sydney Water. Where direct connection to a Sydney Water stormwater asset is required, the project will install and operate water treatment devices during operation to achieve the Sydney Water pollutant load reduction targets where feasible and reasonable.	BL/GHF
WQ8	Design and construction	Watercourse geomorphology	The potential for scour and erosion of watercourse bed and banks will be considered during the design of new discharge outlets. Construction work activities within or next to the watercourses and drainage lines will be minimised as much as reasonably practical to minimise disturbance of sediments in or near the waterway.	BL/GHF

Ref	Phase	Impact	Environmental management measure	Location
WQ9	Design and construction	Local stormwater system capacity	Further design development will confirm the local stormwater system capacity to receive construction wastewater treatment plant inflows. If there is a stormwater infrastructure capacity issue with existing infrastructure, mitigation measures such as storage detention to control water outflow during wet weather events will be considered and implemented within the construction support site where feasible and reasonable.	BL/GHF
WQ10	Pre-construction and construction	Freshwater quality monitoring	A freshwater quality monitoring program for the construction of the project will be developed and implemented, with consideration of the freshwater monitoring being carried out for the Western Harbour Tunnel and Warringah Freeway Upgrade project and the completed Northern Beaches Hospital road upgrade project. The program will be developed in consultation with the Environment Protection Authority, Department of Planning, Industry and Environment (Natural Resources Access Regulator), Department of Planning, Industry and Environment (Water), and relevant councils. Sampling locations and monitoring methodology including frequency and indicators will be in accordance with the *Guideline for Construction Water Quality Monitoring* (RTA, 2003a) and ANZG (2018). If exceedances of the criteria established under the freshwater monitoring program are detected, a management response will be triggered and appropriate mitigation measures to address the exceedance will be identified and implemented.	BL

Ref	Phase	Impact	Environmental management measure	Location
WQ11	Construction	Wastewater discharge	Discharges from wastewater treatment plants during the construction phase will be required to meet the following discharge criteria: • 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).	BL/GHF
WQ12	Construction	Dredge plumes	Monitoring of dredge plumes will be carried out during dredging activities to validate the dredge plume dispersion predictions. Exceedances of the predicted dredge plume extents and intensities will trigger subsequent management responses that will include a range of strategies including, assessing whether secondary impacts are occurring (eg seagrass stress) and if so then further levels of management actions will be implemented, such as adjustments to the dredging process.	BL
WQ13	Construction	Watercourse geomorphology	During construction, the drainage and adjustment works associated with Burnt Bridge Creek and an existing aboveground constructed drainage line within Flat Rock Reserve will be staged to ensure creek flows and velocities are not substantially changed and to avoid downstream erosion and bed and bank stability impacts.	BL/GHF
WQ14	Construction	Sediment basin discharge	Sediment basin discharge impact assessments, commensurate with the potential risk and consistent with the *National Water Quality Guidelines* (ANZG (2018)) and *Managing Urban Stormwater – Soils and Construction, Volume 1* (Landcom, 2004) will be prepared to inform the criteria for discharge from sediment basins.	BL/GHF

Ref	Phase	Impact	Environmental management measure	Location
WQ15	Construction	Erosion and sedimentation	Disturbed floodplain environments next to the watercourses and/or along overland drainage lines should be stabilised as soon as practical following disturbance.	BL/GHF
WQ16	Construction	Marine water quality	Management measures that will be implemented during dredging activities to minimise impacts on marine water quality, vegetation and habitats will include: • Use of a backhoe dredge with a closed environmental clamshell bucket operated within a localised floating silt curtain enclosure to a depth of two to three metres to dredge the top layer of marine sediments • Implementation of 10 to 12 metre deep-draft silt curtains around the dredge works • Implementation of silt curtains in accordance with environmental management measures B31 to B33.	BL
WQ17	Operation	Wastewater discharge	The Gore Hill Freeway wastewater treatment plant will be designed to treat wastewater generated from tunnel groundwater ingress and rainfall runoff in tunnel portals and the following discharge criteria: • 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) 95 per cent species protection levels for toxicants generally, with the exception of those toxicants known to bioaccumulate, which would 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).	BL/GHF

Ref	Phase	Impact	Environmental management measure	Location
WQ18	Operation	Operational monitoring	Operational phase monitoring of surface water quality of sensitive receiving environments will be described in the operational surface water quality monitoring program and carried out in line with the post construction phase requirements of the *Roads and Maritime Guideline for Construction Water Quality Monitoring* (RTA, 2003a). As a minimum, monthly monitoring will be carried out for the first year of operation or until a suitably qualified and experienced independent expert determines that a site has adequately stabilised and stormwater basin discharge criteria are achieved. Should discharge criteria from operational stormwater basins be exceeded, a management response will be triggered and appropriate mitigation measures to address the exceedance will be identified and implemented.	BL/GHF

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

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Chapter 18

Flooding

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DECEMBER 2020

18 Flooding

This chapter outlines the potential flooding impacts associated with the project and identifies measures to address these impacts. Detailed flooding assessments have been carried out for the project and are included in Appendix R (Technical working paper: Flooding).

The Secretary's environmental assessment requirements as they relate to flooding, and where in the environmental impact statement these have been addressed, are detailed in Table 18-1.

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. The environmental management measures proposed to minimise the potential impacts in relation to flooding are included in Section 18.8.

Table 18-1 Secretary's environmental assessment requirements – flooding

Secretary's requirement	Where addressed in EIS
1. The EIS must map the following features relevant to flooding as described in the *NSW Floodplain Development Manual 2005* (NSW Government, 2005) including: a. Flood prone land; b. Flood planning areas, the area below the flood planning level; c. Hydraulic categorisation (floodways and flood storage areas); d. Flood Hazard.	Figures containing maps of features relevant to flooding are listed below: a. Flood prone land – Figure 4.4 of **Appendix R** (Technical working paper: Flooding) b. Flood planning areas, the area below the flood planning level – Figure 4.7 of **Appendix R** (Technical working paper: Flooding) c. Hydraulic categorisation (floodways and flood storage areas) – Figure 4.5 of **Appendix R** (Technical working paper: Flooding) d. Flood Hazard – Figure 4.6 of **Appendix R** (Technical working paper: Flooding).
2. The Proponent must assess (and model where required), the impacts on flood behaviour during construction and operation for a full range of flood events up to the probable maximum flood (taking into account sea level rise and storm intensity due to climate change) including:	**Section 18.3** sets out the approach that was adopted to assess the impact the project would have on flood behaviour during both its construction and operation. **Section 18.5** and **Section 18.6** detail the findings of the impact assessment for construction and operation respectively.
a. How the tunnel entries and cut-and-cover sections of the tunnels would be protected from flooding during construction works;	**Section 18.5.1** summarises the findings of the assessed flood risk at the temporary construction support sites that would be used to support tunnel excavation and the construction of cut and cover sections of tunnel, while **Section 18.8** contains a set of measures which are aimed at managing the flood risk during tunnel construction.

Secretary's requirement	Where addressed in EIS
b. Any detrimental increases in the potential flood affectation of the project infrastructure and other properties, assets and infrastructure;	**Sections 18.5** and **Section 18.6** present the findings of an assessment of the potential impacts on flood behaviour during the construction and operational phases of the project, respectively.
c. Consistency (or inconsistency) with applicable Council floodplain risk management plans;	**Section 18.6.3** presents the findings of a review of the project in terms of its consistency with council floodplain risk management plans.
d. Compatibility with the flood hazard of the land;	**Section 18.4** describes the existing flood behaviour in the vicinity of the project, including an overview of the provisional flood hazard for a 1% Annual Exceedance Probability (AEP) flood. **Section 18.5.1** includes discussion on the potential flood hazard at proposed temporary construction support sites, **Section 18.5.2** includes discussion of potential flood risk at temporary construction support sites, while **Section 18.6** includes discussion on the findings of the assessment in terms of the impact that the operation of the project would have on the hazard categorisation of the floodplain.
e. Compatibility with the hydraulic functions of flow conveyance in flood ways and storage areas of the land;	**Section 18.4** describes the existing flood behaviour in the vicinity of the project, including the hydraulic categorisation of the floodplain into floodways, flood storage and flood fringe for a 1% AEP flood. **Sections 18.5** and **Section 18.6** describe the impacts on flood behaviour as a result of changes to flow conveyance and flood storage across the floodplain.
f. Whether there will be adverse effect to beneficial inundation of floodplain environment, on, or adjacent to or downstream of the site;	Due to the urbanised nature of the floodplain, no areas have been identified where there would be an adverse effect caused by a reduction in inundation. **Section 18.5** and **Section 18.6** present the findings of an assessment of more general impacts of the project on flood behaviour, including changes in the extent of inundation.
g. Downstream velocity and scour potential;	**Section 18.5** identifies potential impacts that the construction of the project could have on velocity and scour potential, while **Section 18.6** presents the findings of the assessment of impacts during the operation of the project.
h. Impacts the development may have upon existing community emergency management arrangements for flooding. These matters must be discussed with the	**Section 18.6** provides an assessment of the proposed works and its impact on transport infrastructure that may be relied upon as part of community emergency management arrangements.

Secretary's requirement	Where addressed in EIS
State Emergency Services and Council;	**Section 18.8** sets out environmental management measures, including consultation with State Emergency Services and relevant councils and incorporation of flood emergency management measures into the relevant project environmental and/or safety documentation. **Appendix E** (Community consultation framework) identifies councils and State Emergency Services as key stakeholders, with engagement to continue into the next phases of the project.
i. Any impacts the development may have on the social and economic costs to the community as consequence of flooding;	**Section 18.5** and **Section 18.6** present the findings of an assessment of the potential impacts on flood behaviour during the construction and operational phases of the project respectively, including consideration of social impacts (such as impacts on emergency response arrangements and disruption to the community) and economic impacts (such as the potential for increases in flood damages in adjacent development due to an increase in above floor inundation).
j. Whether there will be direct or indirect increase in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses; and	**Section 18.5** identifies potential impacts that the construction of the project could have on erosion, siltation and the stability of watercourses, while **Section 18.6** presents the findings of an assessment of the corresponding impacts during the operation of the project.
k. Any mitigation measures required to offset potential flood risks attributable to the project (these mitigation measures must be discussed with the State Emergency Services and Council where appropriate).	**Section 18.8** outlines potential measures to mitigate construction and operational related impacts of the project on flooding conditions (and therefore the potential for increased flood risk) in adjacent development and to manage the risk of flooding to the project. **Appendix E** (Community consultation framework) identifies councils and State Emergency Services as key stakeholders, with engagement to continue into the next phases of the project.
3. The assessment should take into consideration any flood studies undertaken by local government councils, as available.	**Section 18.3** identifies the flood studies used in the assessment of flooding impacts.
4. The EIS must assess and model the effect of the proposed development (including fill) on current flood behaviour for the 1 in 200 and 1 in 500 year flood events as proxies for assessing sensitivity to an increase in	**Section 18.6.5** provides an assessment of the impact the project would have on flood behaviour under future climate change conditions.

Secretary's requirement	Where addressed in EIS
rainfall intensity of flood producing rainfall events due to climate change.	

18.1 Flooding terminology and concepts

18.1.1 Annual exceedance probability

The frequency of floods is generally referred to in terms of their Annual Exceedance Probability (AEP). For example, for a flood magnitude having 10% AEP, there is a 10 per cent probability (or 1 in 10 chance) that there would be floods of greater magnitude each year. Similarly, for a flood magnitude having 1% AEP, there is a one per cent probability (or 1 in 100 chance) that there would be floods of greater magnitude each year.

18.1.2 Probable maximum flood

The Probable Maximum Flood (PMF) occurs as a result of the Probable Maximum Precipitation on the study catchments. The PMF is the result of the optimum combination of the available moisture in the atmosphere and the efficiency of the storm mechanism in regard to rainfall production. Meaning, the PMF is defined as the upper limiting value of floods that could reasonably be expected to occur and defines the extent of flood prone land (ie the floodplain).

18.2 Legislative and policy framework

The assessment of potential flooding impacts of the project on existing flood regimes has been conducted in accordance with relevant national, state and local government legislation, policies and technical guidelines. The assessment has adhered to:

- National-level:
  - *Australian Rainfall Runoff* (ARR) 1987 (Institution of Engineers Australia, 1987), with a sensitivity analysis of the recently released ARR 2019 edition (Ball et al., 2019)
  - *Australian Disaster Resilience Handbook 7: Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia* (AIDR) 2017 edition (Australian Institute for Disaster Resilience, 2017)
- State-level:
  - *Floodplain Development Manual* (FDM) 2005 (NSW Government, 2005)
  - *Guideline on Development Controls on Low Risk Flood Areas* 2007 (Department of Planning, 2007)
  - *Environmental Planning and Assessment Act 1979*
  - *Floodplain Risk Management Guidelines: Practical Considerations of Climate Change* 2007 (DECC, 2007)
- Local-level:
  - Warringah Local Environmental Plan (LEP) 2011
  - Manly LEP 2013
  - Willoughby LEP 2012
  - North Sydney LEP 2013
  - Mosman LEP 2012.

18.3 Assessment methodology

The key tasks comprising the flooding and drainage assessment are broadly described as follows:

- Review of available data including existing flood studies and associated hydrologic and hydraulic models (collectively referred to as 'flood models') within the catchment that are crossed by the project, including:
  - Manly Lagoon Floodplain Risk Management Study and Plan (WMA, 2018)
  - *Flat Rock Creek Catchment Flood Study and Overland Flow Mapping Volume 1* (Lyall and Associates, 2018)
  - North Sydney Flood Study (WMA, 2016)
  - Fort Denison Sea Level Rise Vulnerability Study (Watson & Lord, 2008)
- Update of the existing flood models where required to more accurately define flooding and drainage behaviour in the vicinity of the project
- Application of the ARR 1987 methodology (and recently released 2019 ARR sensitivity analysis) for design flood estimation
- Preparation of figures showing flood behaviour under present day conditions for design floods with AEPs of 10%, 1%, 0.5% and 0.2%, as well as the PMF
- Assessment of the potential flood risks during construction and the operational features of the project
- Assessment of the impact future climate change would have on flood behaviour while under construction and during operational conditions
- Assessment of the impact a partial blockage of the local stormwater drainage system would have on flood behaviour under operational conditions
- Assessment of potential measures which are aimed at mitigating the risk of flooding to the project and its impact on existing flood behaviour
- Development of hydrologic models to assess the impact the upgrade of the Wakehurst Parkway would have on peak flows and hence scour potential in the receiving drainage lines that drain to Bantry Bay and Manly Creek
- Assessment of potential measures which are aimed at mitigating the risk of scour in the aforementioned receiving drainage lines.

Further detail and information in respect to the methodology for each of the key tasks above is outlined in Appendix R (Technical working paper: Flooding).

18.4 Existing environment

18.4.1 Overview

The following catchments contribute runoff to the existing drainage systems and waterways that are located within the project footprint (Figure 18-1):

- Willoughby Creek
- Flat Rock Creek
- Pearl Bay (within Middle Harbour)
- Burnt Bridge Creek (a sub-catchment of Manly Lagoon)
- Bantry Bay
- Manly Creek (a sub-catchment of Manly Lagoon)

- Trefoil Creek (a sub-catchment of Narrabeen Lagoon).

The catchments outlined above drain to either Middle Harbour, Manly Lagoon or Narrabeen Lagoon. Section 18.4.2 provides a brief overview of each catchment, while Section 18.4.3 provides a description of the nature of mainstream flooding and major overland flow in the vicinity of the project under present day (ie pre-project) conditions. Mainstream flooding, major overland flow and ocean storm tide flooding have collectively been termed 'flooding' within this chapter.

Figure 18-1 Catchment areas

A general description of the geomorphology and water quality of the existing catchment and watercourse environments is provided in Chapter 17 (Hydrodynamics and water quality). Chapter 17 (Hydrodynamics and water quality) also details the existing drainage infrastructure and surface water and surface water management infrastructure of the study area. This section outlines:

- Catchments and their drainage characteristics
- The existing flood behaviour of each catchment.

18.4.2 Catchment areas

The following sections provide an overview of each catchment that drains to and from the project corridor, including information regarding key drainage features, as well as the source of flows for the existing drainage lines that cross the project.

Figure 18-1 shows an overview of the catchment areas subject to the project, while Figure 4.1 of Appendix R (Technical working paper: Flooding) shows more detail of the existing drainage systems and catchment features along the project corridor and should be read in conjunction with the information detailed below.

Willoughby Creek

The Willoughby Creek catchment drains in a north-easterly direction, extending from the Pacific Highway in North Sydney and has a total catchment area of about 1.5 square kilometres (150 hectares) at Grafton Street. The catchment is located within the North Sydney local government area and includes the suburbs of North Sydney, Crows Nest, Neutral Bay, Cremorne and Cammeray.

The Warringah Freeway runs north-south through the middle reaches of the catchment, which predominantly comprises medium density residential development with areas of higher density residential and commercial development also present within its upper reaches. Areas of open space in the catchment include St Leonards Park, ANZAC Park, Cammeray Golf Course and Green Park. ANZAC Park School is located on the western (upstream) side of the Warringah Freeway, immediately north of ANZAC Park.

A series of drainage systems comprising pipe and box culvert sections control runoff from the catchment upstream of the Warringah Freeway and converge at ANZAC Park where they discharge into twin 2000 millimetre wide by 1500 millimetre high box culvert where the drainage line crosses under the Warringah Freeway. A series of piped drainage systems that control runoff from the Warringah Freeway discharge directly into the box culvert. This drainage line continues downstream through Cammeray Golf Course as a 2500 millimetre wide by 1500 millimetre high box culvert. At Grafton Street the box culvert outlets into a steep gully in the north-east corner of Primrose Park where it runs along the northern side of the park as a grassed channel before ultimately discharging into Middle Harbour.

Flat Rock Creek

The Flat Rock Creek catchment drains in an easterly direction from the Pacific Highway in Artarmon and has a total catchment area of about 3.9 square kilometres (390 hectares) at Willoughby Road. The catchment is located within the Willoughby local government area and includes the suburbs of Artarmon, St Leonards, Naremburn, Willoughby, Northbridge and Cammeray.

The catchment is completely urbanised and the natural drainage characteristics have been altered by industrial, residential and commercial development. The construction of the Gore Hill Freeway in 1991 along the route of the original creek has altered the natural drainage system and its flood storage characteristics. The T1 North Shore and Western Line and T9 Northern Line runs north-south through the middle reaches of the catchment.

A new trunk drainage system was constructed in conjunction with the Gore Hill Freeway, extending from the Pacific Highway to the T1 North Shore and Western Line and T9 Northern Line. The Gore Hill Freeway and its drainage system were later upgraded as part of the Lane Cove Tunnel project in 2006.

The trunk drainage system is piped where it runs along the southern side of Gore Hill Freeway from Marsden Street and crosses under the freeway at Hampden Road, via an existing transverse drainage structure. This drainage structure discharges into an open channel that continues along the northern side of the Gore Hill Freeway to a brick arch culvert under the T1 North Shore and Western Line and T9 Northern Line. Two existing transverse drainage structures control runoff from the north of the Gore Hill Freeway discharge into the trunk drainage system along this section. Two existing drainage structures that control runoff from the southern side of Gore Hill Freeway discharge into an open channel between Hampden Road and the T1 North Shore and Western Line (refer to Figure 17-2 of Chapter 17 (Hydrodynamics and water quality) for further details on the characteristics of Flat Rock Creek).

The trunk drainage system downstream of the T1 North Shore and Western Line and T9 Northern Line culvert to Willoughby Road was constructed in the 1930's and was not altered by the construction of the freeway. Between the railway and Chelmsford Avenue, the trunk drainage comprises a low level conduit running beneath a vegetated floodway which caters for surcharge (overflow) flows. A concrete and brick lined channel with a waterway area of 6.5 to 7.3 square metres comprises the main arm of Flat Rock Creek where it runs from Chelmsford Avenue to Willoughby Road.

As part of the trunk drainage for the Gore Hill Freeway, Artarmon Reserve was converted to a dual purpose playing field/retarding basin. The objective was to reduce the peaks of major stormwater flows which originate from the northern portion of the catchment, to offset the increase in peak flows generated by the freeway. The retarding basin was later modified as part of the Lane Cove Tunnel project to offset the impact that the widening of the Gore Hill Freeway would otherwise have had on peak flows in Flat Rock Creek.

At Willoughby Road, flows are conveyed through a stone arch bridge. During major flood events, the Willoughby Road bridge conveys flows derived from the Flat Rock Creek catchment, as well as surcharges from one of its tributaries. A major box culvert commences at the downstream face of the bridge and runs beneath Hallstrom Park before discharging to an open channel 150 metres to the east of Flat Rock Drive.

Pearl Bay

The Pearl Bay catchment drains in a westerly direction, extending from Spit Road in Mosman and has a total catchment area of about 0.27 square kilometres (27 hectares). The catchment is located within the Mosman local government area.

The Spit West Reserve construction support site (BL9) is proposed to be located at the northern end of the catchment within Spit West Reserve.

Burnt Bridge Creek

The Burnt Bridge Creek catchment drains in an easterly direction from the Wakehurst Parkway and has a total catchment area of about 3.4 square kilometres (340 hectares) at Condamine Street. The catchment covers the Northern Beaches local government area and includes the suburbs of Seaforth, North Balgowlah, Balgowlah, Manly Vale and Fairlight.

Burnt Bridge Creek Deviation runs north-south from Sydney Road to Condamine Street through the middle reaches of the catchment which predominantly comprises low and medium density residential development. Commercial development is mainly located along Condamine Street and Sydney Road. Open space is predominantly located within the middle and lower reaches of the catchment and includes Balgowlah Golf Course, Manly Golf Club, Manly West Park and LM Graham Reserve.

The main arm of Burnt Bridge Creek comprises a vegetated channel that extends from Clontarf Street in the west to Condamine Street in the east and includes culvert crossings at Brook Road, Burnt Bridge Creek Deviation and Kitchener Street. The culvert crossing of Burnt Bridge Creek Deviation comprises twin 3600 millimetre wide by 3600 millimetre high box culverts and twin 2400 millimetre wide by 2400 millimetre high box culverts. East (downstream) of Condamine Street the creek is drained by a box culvert that discharges into a vegetated channel that runs along the northern side of Manly West Park and through the Manly Golf Club before discharging into Manly Lagoon at Pittwater Road (refer to Figure 17-3 of Chapter 17 (Hydrodynamics and water quality) for further details on the characteristics of Burnt Bridge Creek).

A series of piped drainage lines cross Burnt Bridge Creek Deviation between Serpentine Crescent and Abingdon Street. The piped drainage lines control runoff from the catchment to the north of Burnt Bridge Creek Deviation and discharge into Burnt Bridge Creek along its northern bank.

Bantry Bay

The Bantry Bay catchment drains in a southerly direction from Warringah Road and has a total catchment area of about 4.8 square kilometres (480 hectares). Residential development is located in the upper northern and western portions of the catchment, while the Garigal National Park covers the majority of the middle and lower portions of the catchment.

The section of the project that runs along the Wakehurst Parkway between Grattan Crescent and Kirkwood Street generally follows the catchment divide between Bantry Bay and Manly Creek. Three minor drainage lines presently control runoff from this section of the Wakehurst Parkway which would be upgraded as part of the project.

Manly Creek

The Manly Creek catchment drains in a south easterly direction, extending from Warringah Road in the north and has a total catchment area of about 18.2 square kilometres (1820 hectares) at Manly Lagoon.

Manly Creek runs in a southerly direction to the east of Wakehurst Parkway. A series of piped crossings along the Wakehurst Parkway control runoff from the residential development and nature reserve to the west of the road. The largest of these piped drainage systems comprises a 2400 millimetre wide by 1800 millimetre high box culvert and a 750 millimetres diameter pipe located about 140 metres south of Warringah Road, and a 1200 millimetre diameter pipe located immediately south of Yarraman Avenue. The piped crossings discharge into receiving drainage lines that feed into Manly Creek.

Manly Dam was originally constructed across Manly Creek in the late 1800’s to supply drinking water to the local area. The dam continued to supply drinking water until 1936, after which time it became an important recreational facility for the local area and beyond. The dam has a capacity of approximately 2000 megalitres and its water body is sheltered and deep (in most parts) with a surface area of approximately 0.3 square kilometres (30 hectares).

Trefoil Creek

A relatively small section of the project along the Wakehurst Parkway at its connection to Frenchs Forest Road East is located within the headwaters of the Trefoil Creek catchment, runoff from which discharges into Middle Creek. The Trefoil Creek catchment is about 0.97 square kilometres (97 hectares) at its confluence with Middle Creek.

Trefoil Creek is fed by several piped drainage systems which discharge to the steep sided valley to the east of the Wakehurst Parkway and north of Frenchs Forest Road East. These piped drainage systems control runoff from sections of Frenchs Forest Road East, the Wakehurst Parkway and Bantry Bay Road, as well as the north east portion of the Northern Beaches Hospital.

18.4.3 Existing flooding and drainage characteristics

A brief description of patterns of both mainstream flooding and major overland flow is provided below with respect to present day (ie pre-project) conditions within areas in the vicinity of construction and/or operational components of the project.

The patterns of mainstream flooding and major overland flow are classified using Annual Exceedance Probability and Probable Maximum Flood which, as outlined in Section 18.1 above, are defined as follows:

- Annual Exceedance Probability (AEP)
  - 10% AEP – there is a 10 per cent probability (or 1 in 10 chance) that there would be floods of greater magnitude each year
  - 1% AEP – there is a one per cent probability (or 1 in 100 chance) that there would be floods of greater magnitude each year
- Probable Maximum Flood (PMF) – the upper limiting value of floods that could reasonably be expected to occur (the result of the most severe combination of meteorological conditions) and defines the extent of flood prone land (ie the floodplain).

Flooding behaviour has been defined using the hydrologic and hydraulic models that were developed as part of the studies informing this assessment (see Appendix R (Technical working paper: Flooding) for more information). It should be noted the discussion below considers flooding patterns for the AEP and PMF in catchment areas for which impacts are predicted. As such, the existing AEP and PMF flood impacts are not reported for all catchment areas. A discussion of flooding patterns is provided for those catchments where the AEP and PMF flood impacts are not reported.

Figure 18-2 to Figure 18-8 show the flooding behaviour for each of the catchments in the 1% AEP event (for the existing flooding behaviour in the 10% AEP, 1% AEP and PMF events for all catchments, refer to Figures 4.2 to 4.4 in Appendix R (Technical working paper: Flooding)).

Willoughby Creek

Up to 1% AEP

During a 10% AEP event, flow would surcharge the trunk drainage system that forms the main arm of Willoughby Creek and overtop the sag in Ernest Street to the east of Lytton Street to a maximum depth of about 0.5 metres, increasing to 0.7 metres during a 1% AEP. Existing residential development located on the southern side of Ernest Street is also affected by flooding due to surcharge of the trunk drainage system. The main flow path which runs between St Leonards Park and ANZAC Park principally operates as a low hazard floodway, although high hazard areas are located near ANZAC Park, principally due to the depth of ponding that occurs in this area.

Flow that surcharges the tributary branch of Willoughby Creek that runs between Miller Street and ANZAC Avenue along the northern boundary of ANZAC Park Public School would overtop ANZAC Avenue to a maximum depth of about 0.2 metres during a 10% AEP event, increasing to 0.5 metres during a 1% AEP event.

Overland flow from Ernest Street and ANZAC Avenue would collect at the low point in ANZAC Park before entering the trunk drainage system that runs under the Warringah Freeway. The depth of ponding in ANZAC Park would occur to a maximum of 2.1 metres and 3.5 metres during a 10% and 1% AEP event, respectively, which is sufficient to result in hazardous flooding conditions to persons and property.

Floodwaters that collect in ANZAC Park would pond against the noise wall that runs along the western side of the Warringah Freeway to a maximum depth of about three metres during a 1% AEP event. If the noise wall were to fail under this weight of water, then floodwater would inundate the Miller Street off-ramp to a maximum depth of about two metres and extend across the northbound carriageways of the freeway.

During a 1% AEP storm event, a low and high hazard floodway would form to the north (downstream) of the road corridor near Cammeray Golf Course. The floodway area also extends east into an existing residential development which is located along Fall Street and Grafton Street.

PMF

Floodwaters that collect in ANZAC Park would build up to a level that overtops the noise wall that is located along the western side of the Warringah Freeway, where it would pond across the full width of the freeway before surcharging across its eastern side and into Cammeray Golf Course.

ANZAC Park would be inundated to a maximum depth of seven metres, while the carriageways of the Warringah Freeway would be inundated over a length of about 350 metres and to a maximum depth of five metres. The flood walls associated with the Western Harbour Tunnel and Warringah Freeway Upgrade project (subject to separate environmental impact assessment and approval) would prevent the ingress of floodwater to the road tunnels for events up to the PMF.

Flat Rock Creek

Up to 1% AEP

During a 10% AEP event flow in excess of the capacity of the existing stormwater drainage system would pond in the cul-de-sac of George Place to a maximum depth of about one metre. During a 1% AEP event, flow would pond to a maximum depth of 1.5 metres before discharging in a south-easterly direction through the adjoining industrial development and onto the eastbound carriageway of the Gore Hill Freeway.

The eastbound carriageway of the Gore Hill Freeway acts as an overland flowpath during a 1% AEP event, conveying flows that surcharge the existing transverse drainage structures located in the vicinity of George Place and Reserve Road. Depths of overland flow would typically be less than 0.2 metres but would reach up to 0.4 metres at two locations.

During a 10% AEP event, flow that surcharges the trunk drainage system in McLachlan Avenue would travel in an easterly direction along the shared bicycle path to the south of the Gore Hill Freeway before discharging onto the westbound carriageway north of Hotham Street.

The westbound carriageway of the Gore Hill Freeway acts as an overland flowpath during a 1% AEP event, conveying flow that surcharges the drainage systems in McLachlan Avenue, Hotham Parade and Whiting Street. Flow along the eastbound carriageway would collect at the sag below the Reserve Road overpass and ponds to a maximum depth of 0.7 metres before continuing in a southerly direction.

During a 1% AEP event, flow that surcharges the existing transverse drainage structures located between Herbert Street and the T1 North Shore and Western Line and T9 Northern line also contributes to overland flow travelling east along the eastbound carriageway of the Gore Hill Freeway.

PMF

The main carriageways and various existing entry and exit ramps of the Gore Hill Freeway are inundated by floodwater that discharges from the north at George Place, Reserve Road, and Simpson Street, and from the south at McLachlan Avenue, Hotham Parade Whiting Street, Herbert Street and Punch Street.

While the majority of flow that discharges from George Place is conveyed in an easterly direction along the eastbound carriageway, a portion of this flow discharges onto the central carriageways where it enters the Lane Cove Tunnel.

Similarly, while the majority of flow that discharges from McLachlan Avenue is conveyed in an easterly direction along the westbound carriageway, a portion of the flow discharges onto the central carriageways where it would enter the Lane Cove Tunnel.

The section of Gore Hill Freeway between Reserve Road and the T1 North Shore and Western Line and T9 Northern Line is inundated across its full width. Depths of flow are typically 1.2 metres or less but would reach a maximum of 1.8 metres at one location.

Flood levels upstream (west) of the T1 North Shore and Western Line and T9 Northern Line are controlled by the rail underpass, which constricts overland flow travelling along the Gore Hill Freeway.

Pearl Bay

The area of Spit West Reserve where the Spit West Reserve construction support site (BL9) is proposed to be located would be inundated by overland flow that is conveyed along the southbound carriageway of Spit Road and discharges into the reserve via the carpark entry from Spit Road for events up to the PMF.

Burnt Bridge Creek

Up to 1% AEP

The existing culvert crossing of Burnt Bridge Creek at Burnt Bridge Creek Deviation has a hydrologic standard in excess of 1% AEP under ideal flow conditions.

While flow would generally be confined to the incised valley through which Burnt Bridge Creek runs between Brook Road and Kitchener Street, residential development located on the southern overbank of the creek in Brook Road, Hope Street and Burnt Bridge Creek Deviation would be inundated by floodwater during a 1% AEP event.

Flow that surcharges existing transverse drainage structures would pond behind the noise wall located along the western side of Burnt Bridge Creek Deviation between Serpentine Crescent and Kitchener Street, with a portion of this flow discharging onto Burnt Bridge Creek Deviation via openings which are present in the noise wall adjacent to Kitchener Street during a 10% AEP event.

Flow would overtop the western bank of Burnt Bridge Creek immediately upstream of Kitchener Street and discharge onto the southbound carriageway of Burnt Bridge Creek Deviation during a 10% AEP event.

PMF

Flow in excess of the existing transverse drainage structure (culvert crossing of Burnt Bridge Creek at Burnt Bridge Creek Deviation) would overtop Burnt Bridge Creek Deviation to a maximum depth of about one metre. A portion of this flow would re-enter Burnt Bridge Creek to the east of the road corridor, while the remaining flow would travel in a northerly direction along both the northbound and southbound carriageways.

Flow that surcharges the existing transverse drainage structures would pond behind the noise wall that runs along the western side of Burnt Bridge Creek Deviation before discharging onto the road in the vicinity of the Kitchener Street bridge.

Flow would overtop the western bank of Burnt Bridge Creek immediately upstream of Kitchener Street where it discharges onto both the northbound and southbound carriageways of Burnt Bridge Creek Deviation. The depth of flow along Burnt Bridge Creek Deviation would reach a maximum of about two metres near the Kitchener Street bridge.

Bantry Bay

The section of the Wakehurst Parkway between Grattan Crescent and Kirkwood Street generally follows the catchment divide between Manly Creek and Bantry Bay and is not affected by mainstream flooding or major overland flow.

Manly Creek

Up to 1% AEP

During a 1% AEP event, flow that surcharges the piped drainage system in the Wakehurst Parkway at its intersection with Warringah Road would inundate the road to relatively shallow depths that are typically 0.1 metres or less.

Flow that discharges from the drainage system at the northern end of Bantry Bay Road would pond at the inlet of the 1050 millimetre diameter pipe that crosses the Wakehurst Parkway about 140 metres south of Warringah Road. During a 1% AEP event, this ponding would have a maximum depth of over two metres but would not surcharge onto the road.

During a 1% AEP event, flow that surcharges the two pipe crossings of the Wakehurst Parkway between Garner Avenue and Yarraman Avenue would inundate the road to depths typically 0.2 metres or less.

Flow that discharges from the drainage system at the eastern end of Yarraman Avenue would pond at the inlet of the 1200 millimetre diameter pipe that crosses Wakehurst Parkway immediately to its south. During a 1% AEP event, this ponding would have a maximum depth of over two metres but would not surcharge onto the road.

PMF

The hydraulic model developed as part of the Manly Lagoon Floodplain Risk Management Study and Plan (WMA, 2018) has been configured in a way that applies inflows downstream of Wakehurst Parkway and therefore does not show flooding to the road corridor or any of the areas upstream during a PMF event. Flow would, however, inundate the Wakehurst Parkway at the locations described above to a greater depth during more extreme storm events.

Trefoil Creek

The section of the project along the Wakehurst Parkway that is located within the Trefoil Creek catchment is not impacted by mainstream flooding or major overland flow.

The Wakehurst Parkway was recently upgraded as part of the Northern Beaches Network Connectivity and Enhancements project. Figure 4.1 of Appendix R (Technical working paper: Flooding) shows the layout of the upgraded drainage system along the Wakehurst Parkway, which has been designed to control runoff from the local catchment during storms up to 10% AEP in magnitude. During a 1% AEP event, overland flow would occur along the kerbside lanes of the Wakehurst Parkway due to surcharge of the drainage system.

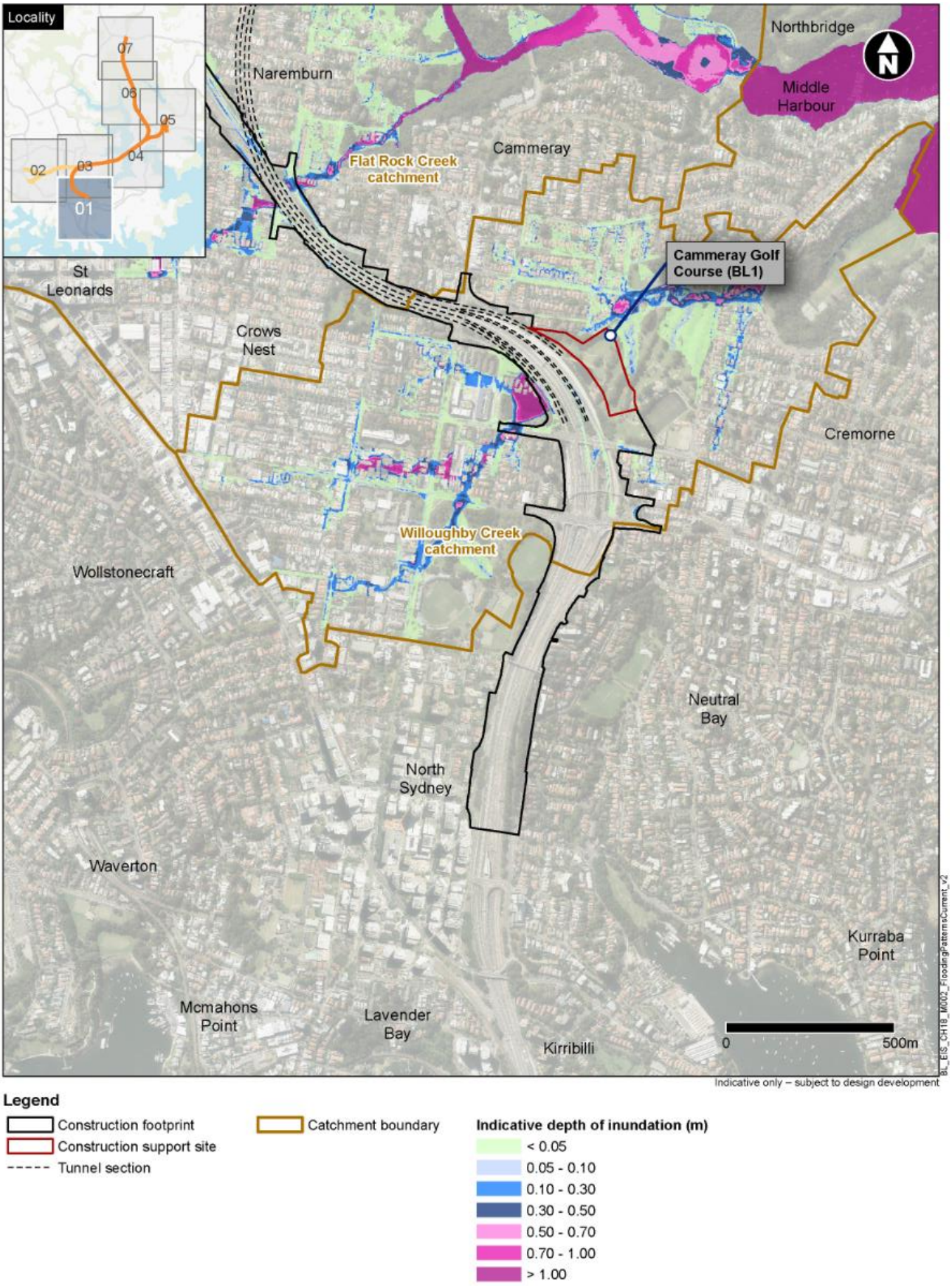

Figure 18-2 Flood behaviour under present day conditions – 1% AEP event (map 1)

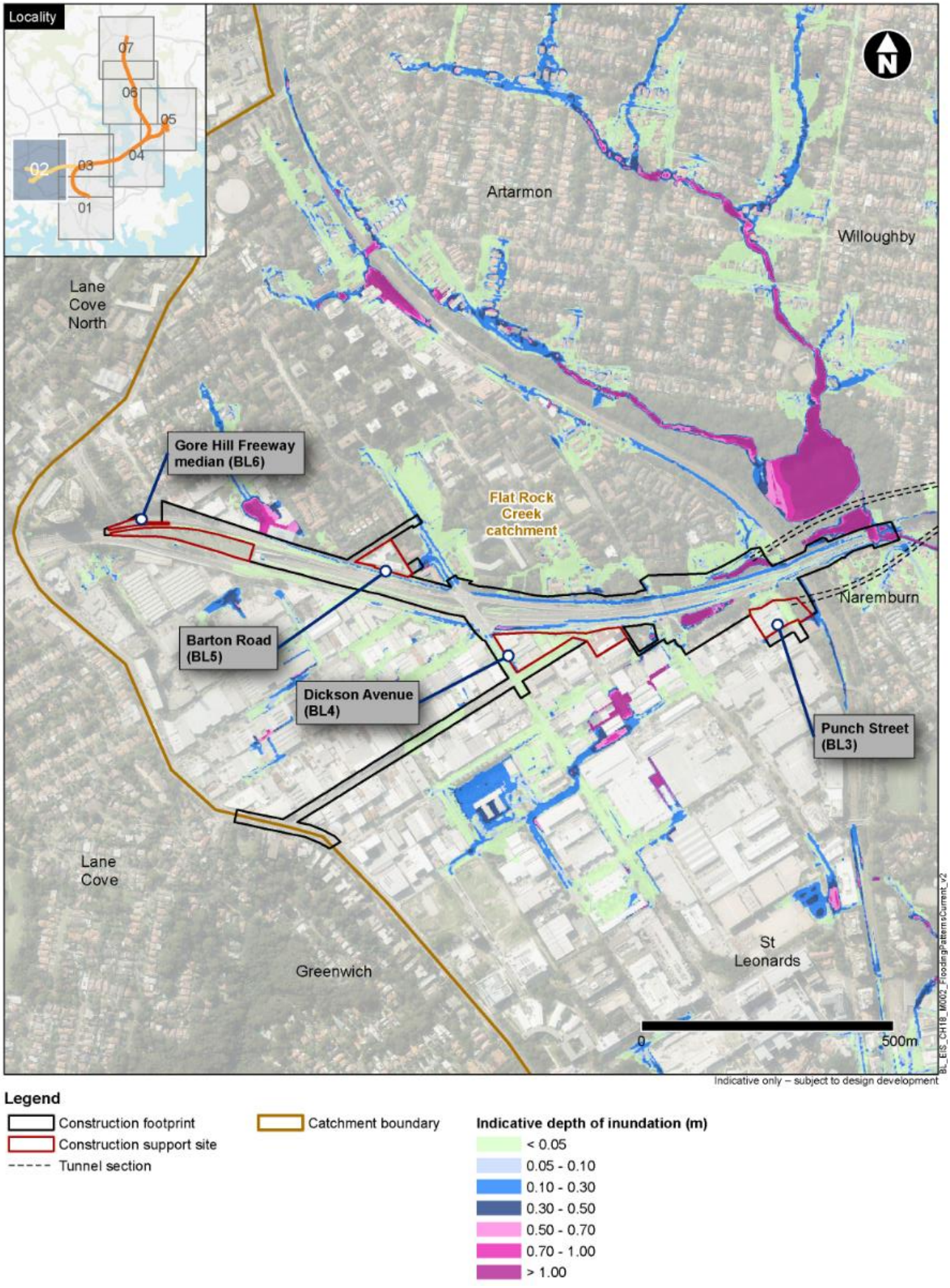

Figure 18-3 Flood behaviour under present day conditions – 1% AEP event (map 2)

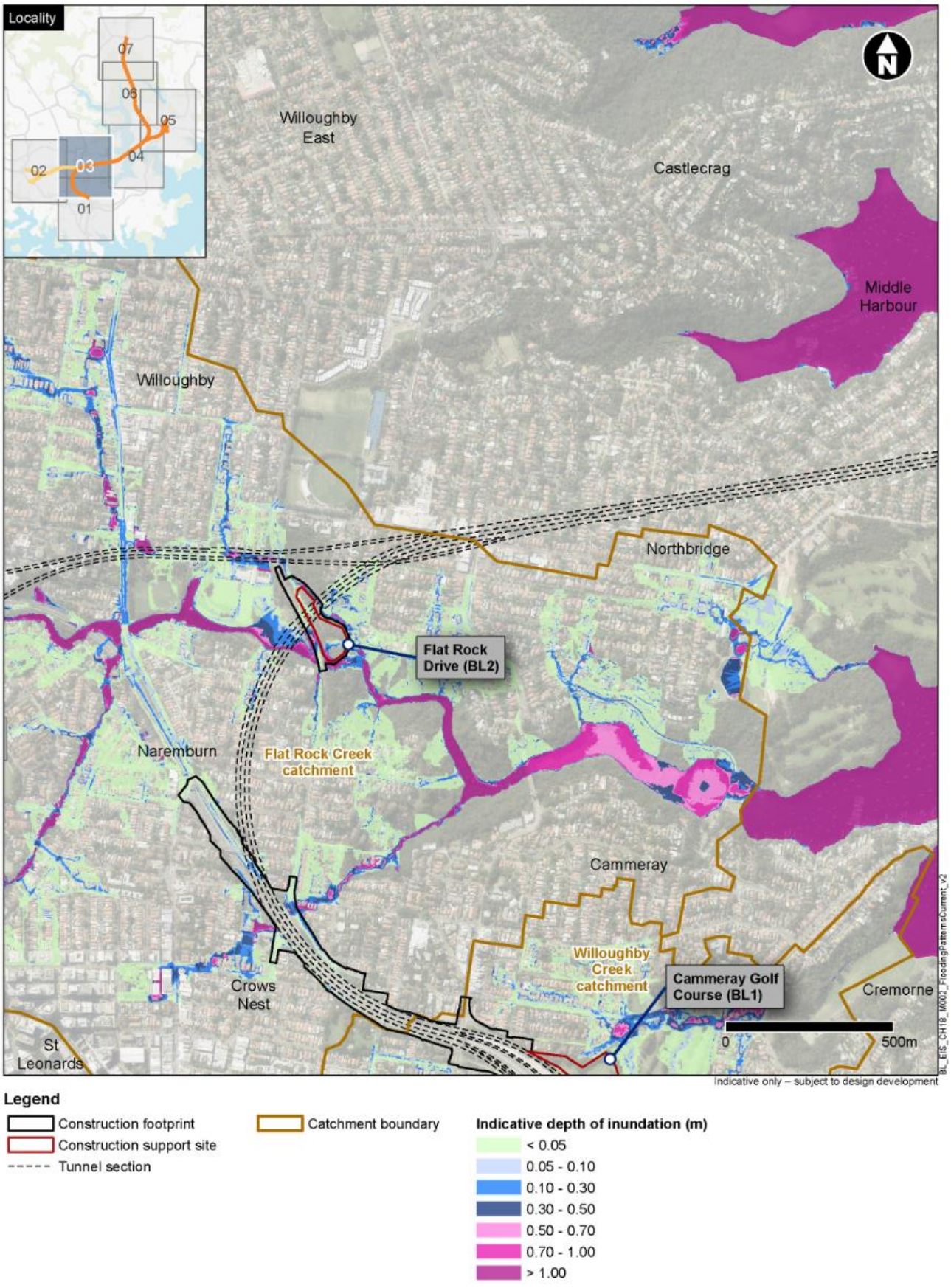

Figure 18-4 Flood behaviour under present day conditions – 1% AEP event (map 3)

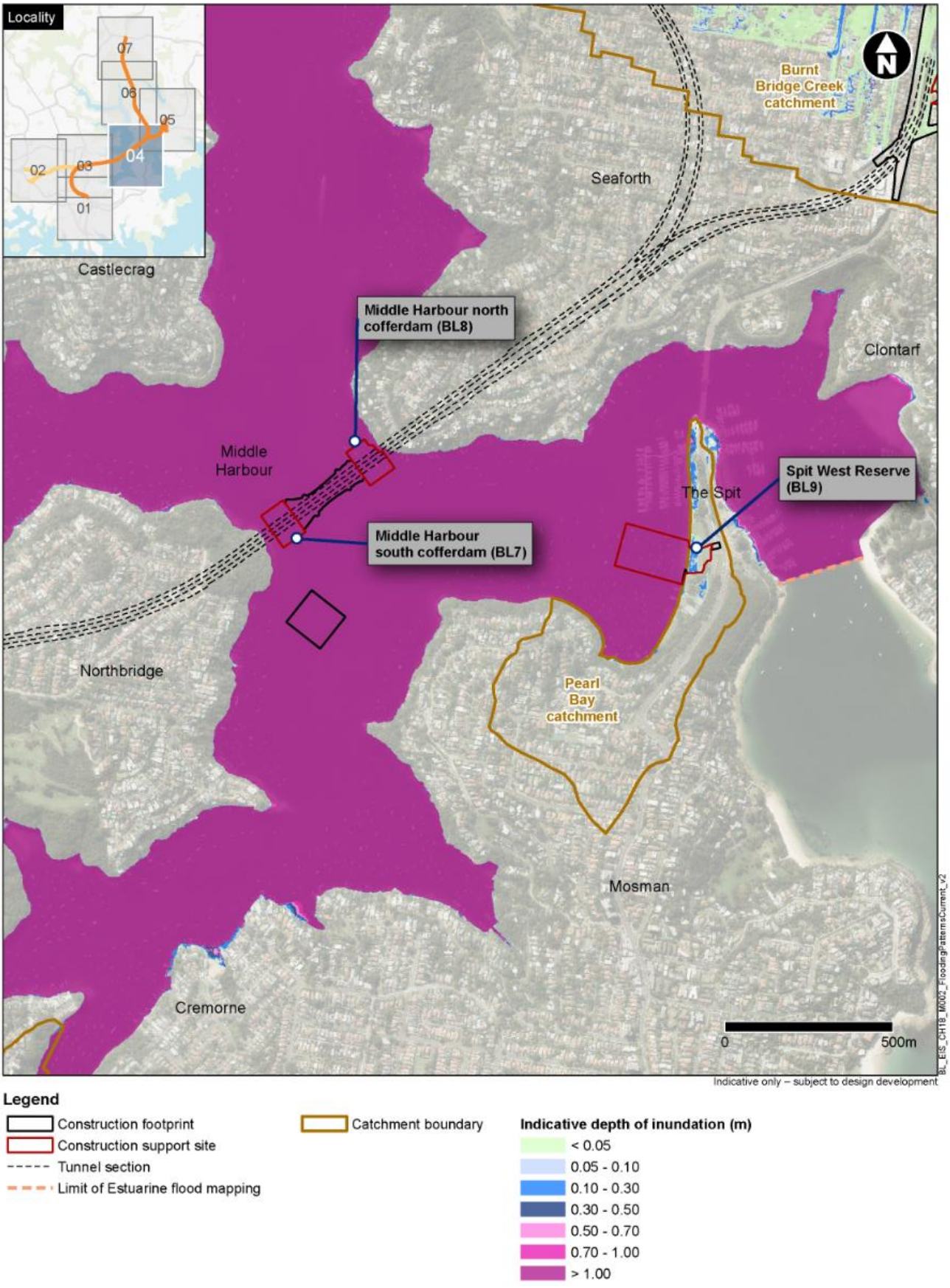

Figure 18-5 Flood behaviour under present day conditions – 1% AEP event (map 4)

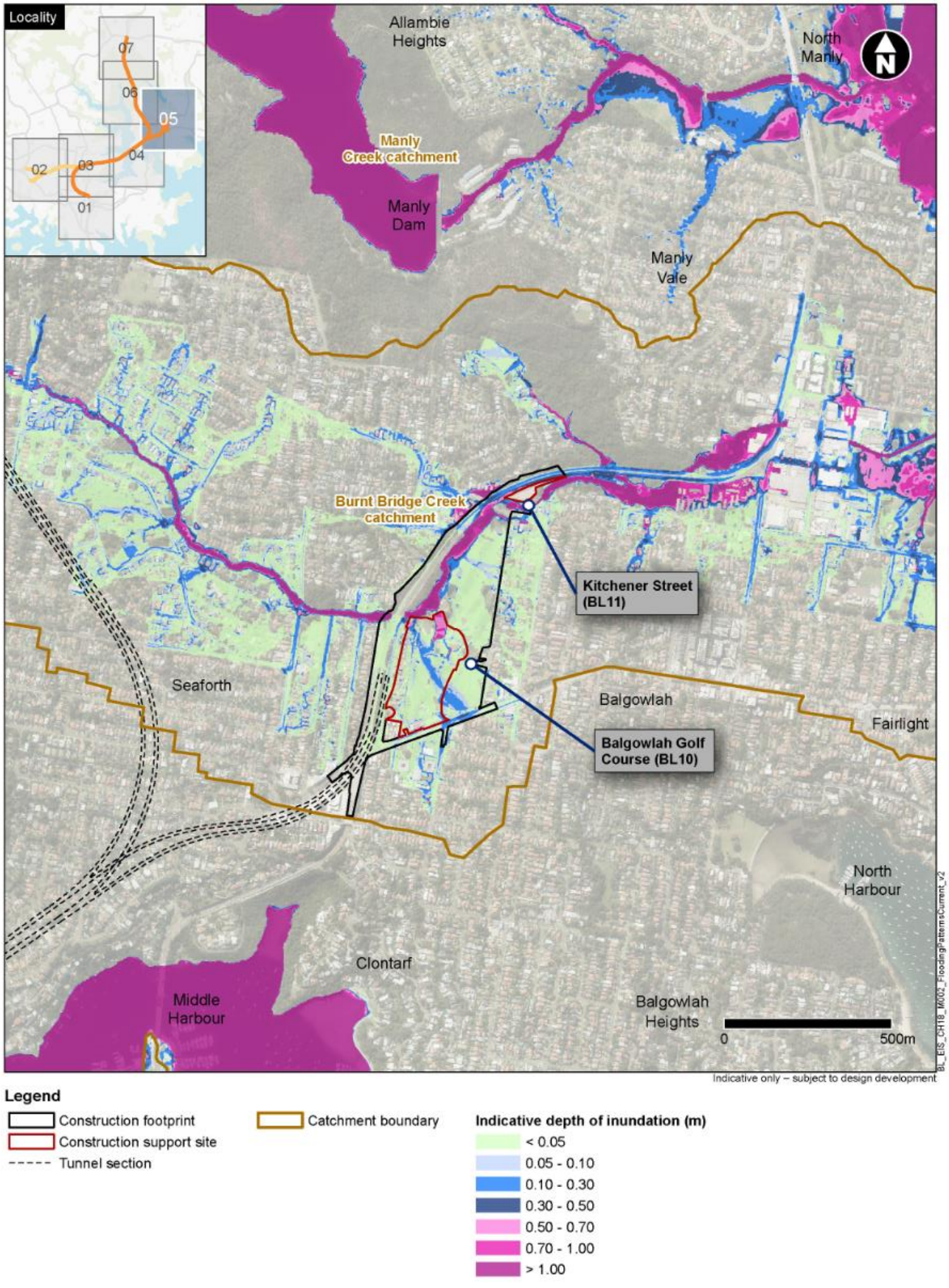

Figure 18-6 Flood behaviour under present day conditions – 1% AEP event (map 5)

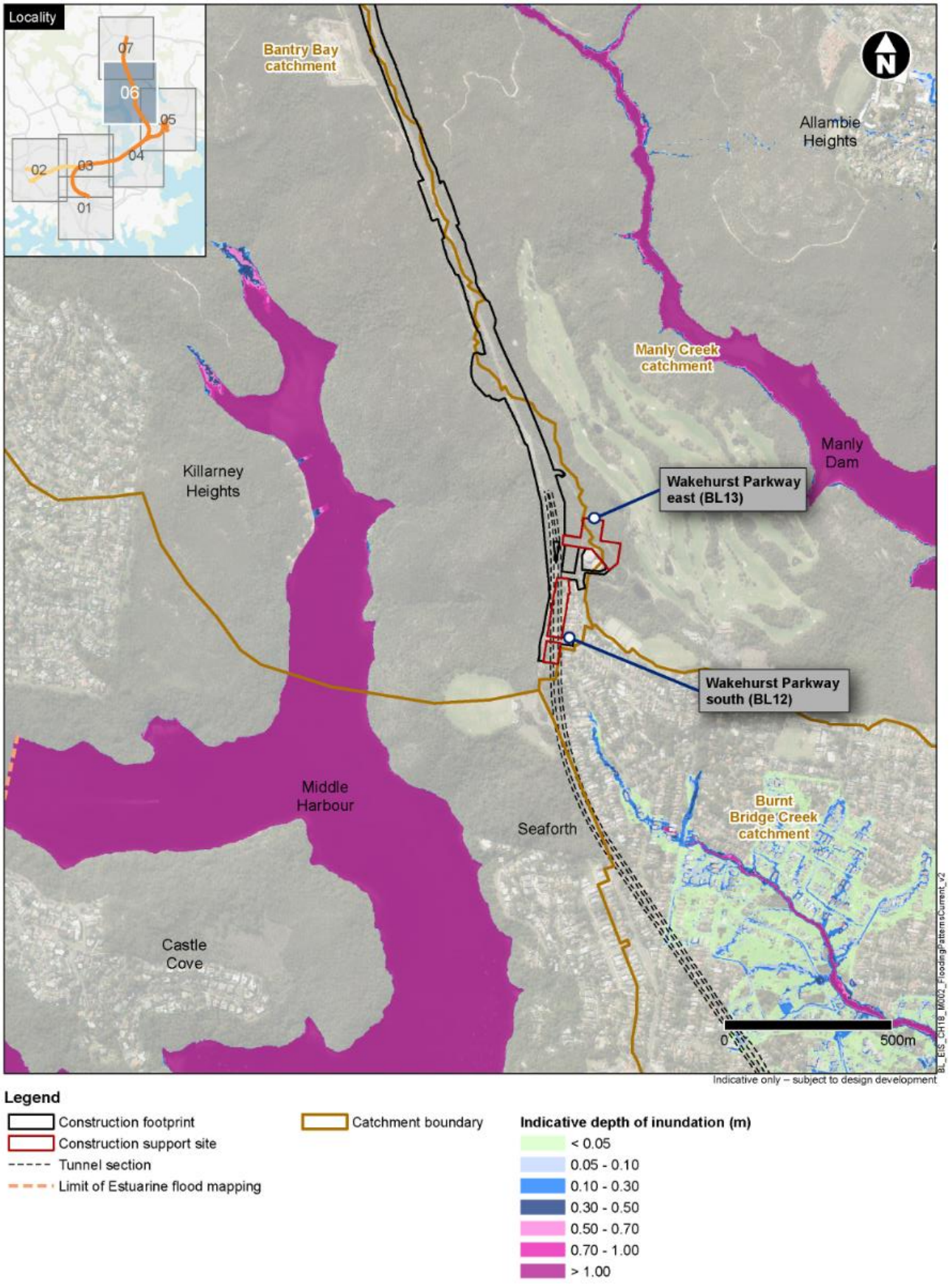

Figure 18-7 Flood behaviour under present day conditions – 1% AEP event (map 6)

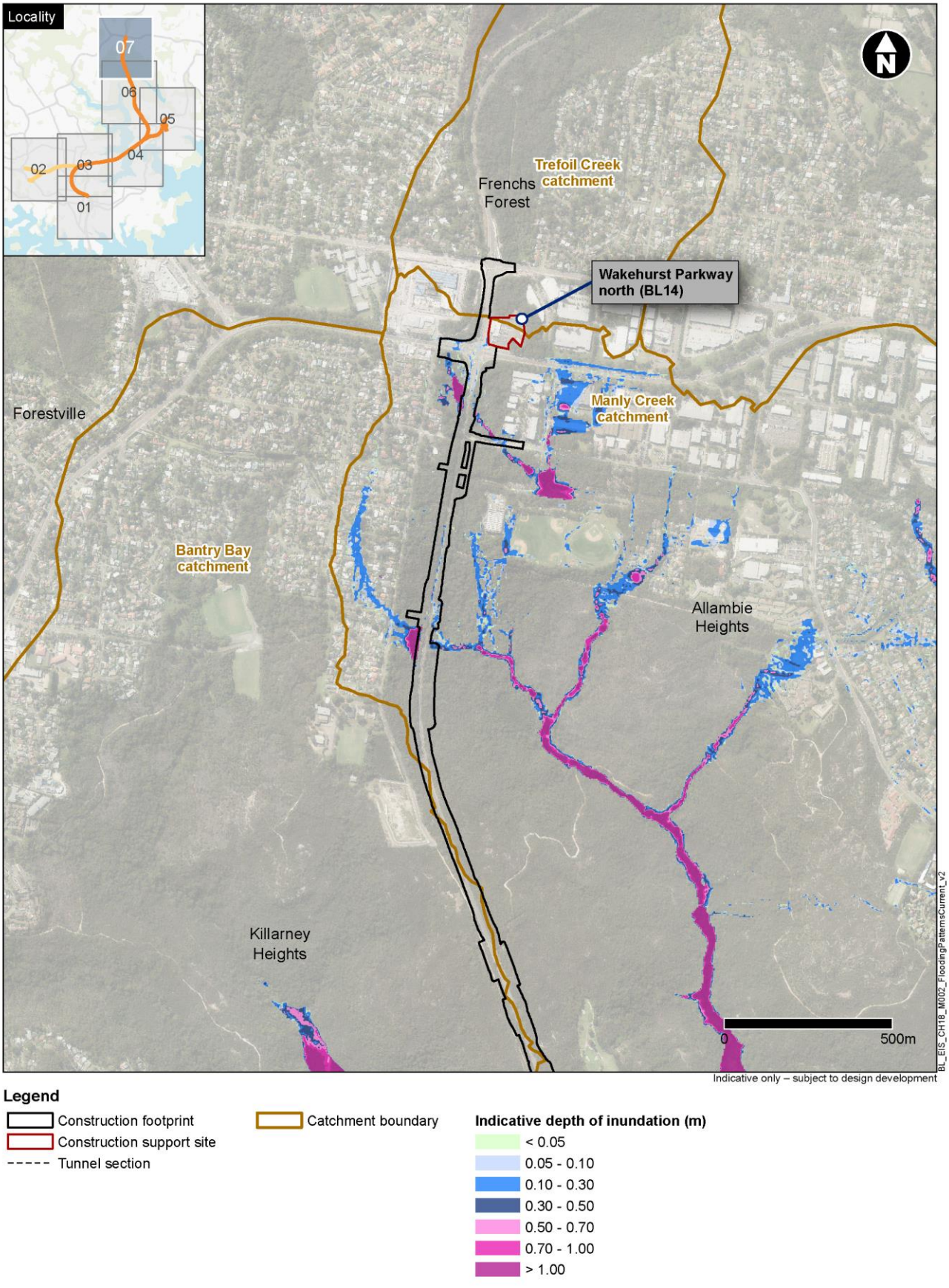

Figure 18-8 Flood behaviour under present day conditions – 1% AEP event (map 7)

18.5 Assessment of potential construction impacts

This section provides an assessment of the flood risk at the proposed temporary construction support sites which are associated with the construction of the Beaches Link and Gore Hill Freeway project. Details of the proposed temporary construction support sites, including proposed activities are outlined in Chapter 6 (Construction works).

This section also provides an overview of the potential impacts that the proposed construction activities could have on flood behaviour.

18.5.1 Potential impacts of construction activities on flood behaviour

Construction activities have the potential to exacerbate flooding conditions when compared to both present day and operational conditions. This is because the construction activities typically impose a larger footprint on the floodplain due to the need to provide temporary structures outside the operational project footprint which would be removed following the completion of construction activities.

A qualitative assessment was carried out of the potential impacts construction activities could have on flood behaviour, the key findings of which are summarised in Table 18-2.

While the majority of the temporary construction support sites would involve works within the floodplain that would need to be managed, the assessment found that the greatest potential for adverse impacts on flood behaviour in adjacent development is associated with Balgowlah Golf Course construction support site (BL10) and the adjacent new and improved public open space and recreation facility works. There is also the potential for construction activities to impact local catchment runoff, which would be managed through appropriate local stormwater management controls to be implemented during the construction phase of the project.

Without mitigation the construction of the project has the potential to result in changes in flood behaviour that may result in social and economic cost impacts to the community by exacerbating the impact of flooding to property and infrastructure as well as disruption to the community.

While the findings of the assessment provide an indication of the potential impacts of construction activities on flood behaviour, further investigation would need to be carried out during further design development and construction planning. Consideration would also be given to setting an appropriate hydrologic standard for mitigating the impacts of construction activities on flood behaviour, taking into account their temporary nature and therefore the likelihood of a flood of a given AEP occurring during the construction period.

Prior to construction, further investigation would be carried out to develop measures which are aimed at mitigating the impacts of construction activities on flood behaviour. A range of measures which would be implemented to mitigate the potential construction related impacts of the project are outlined in Section 18.8.

Temporary construction support site facilities

A range of site facilities including offices, staff amenities, stores and laydown, workshops and parking are proposed at the temporary construction support sites associated with the project, with the exception of Middle Harbour south cofferdam (BL7) and Middle Harbour north cofferdam (BL8) construction support sites located on Middle Harbour.

Most of the locations that have been identified for the proposed construction support sites are affected by flooding, whether as a result of main stream flooding, overland flow or ocean storm tides (refer to Table 18-2), with the exception of Gore Hill Freeway median (BL6), Wakehurst Parkway south (BL12), Wakehurst Parkway east (BL13) and Wakehurst Parkway north (BL14) construction support sites.

While the majority of the temporary construction support sites would be subject to flooding during a 10% AEP storm event, depths of inundation are generally shallow and of a short duration nature. The exception is Flat Rock Drive construction support site (BL2), where depths of flow are greater

than 0.5 metres in a 10% AEP flood event. Elevated water levels in Middle Harbour could also result in the partial inundation of Spit West Reserve construction support site (BL9).

Site facilities located on the floodplain, particularly in areas of high hazard, pose a safety risk to construction personnel. It would be necessary to locate site facilities outside high hazard areas with safe evacuation routes. All temporary construction support sites include land located outside areas of high hazard that would be suitable for site facilities.

Tunnel construction

The key activities associated with tunnel construction carried out from the Beaches Link temporary construction support sites, include:

- Tunnel excavation
- Cut and cover structures.

The tunnel excavation would involve the use of pumps at the tunnel low points, and potentially mobile sumps at the cutting face to collect tunnelling water, groundwater ingress and stormwater runoff from the tunnel openings. While the tunnel excavation arrangement would be designed to accommodate a nominal amount of stormwater runoff, the potential for the ingress of floodwater to the tunnel excavations during their construction poses a significant risk to personal safety and has the potential to cause damage to machinery and delays in the project timetable if not adequately managed. The flood standard adopted at each tunnel opening during construction would be developed during further design development.

Similar to the construction of the driven tunnels, the potential for ingress of floodwater into the open excavations poses a safety risk to construction workers, as well as having the potential to cause damage to machinery and construction delays. Potential impacts to cut and cover structures that are part of the project, include:

- The ability for floodwater which ponds in ANZAC Park in the Willoughby Creek catchment to discharge onto the Warringah Freeway near the proposed cut and cover sections of the tunnel is constrained by the presence of the noise wall which runs along its southern side. Any leakage of floodwater through, or overtopping of, the noise wall (for example in a PMF event), could cause flooding of the freeway in excess of one metre in the vicinity of the cut and cover sections of tunnel
- Stormwater which surcharges the existing drainage system at the Flat Rock Creek and Burnt Bridge Creek catchments has the potential to impact cut and cover operations.

Cut and cover works at the Wakehurst Parkway are not subject to flooding due to the road being located along a natural ridgeline.

The provision of temporary barriers in combination with the permanent solid barriers/flood walls which are proposed around tunnel portals, would be required to prevent floodwater entering the open excavations.

Refer to Table 18-2 for details on the potential impacts of flooding behaviour resulting from tunnel construction activities.

Spoil management and stockpile areas

The construction of the project would generate a significant amount of spoil which, in some situations, may need to be temporarily stored in stockpile areas. Stockpiles located on the floodplain have the potential to obstruct floodwater and alter flooding patterns. Inundation of stockpile areas by floodwater can also lead to significant quantities of material being washed into receiving drainage lines and waterways.

Some stockpiling of spoil material is proposed at all temporary construction support sites with the exception of Middle Harbour south cofferdam (BL7) and Middle Harbour north cofferdam (BL8) construction support sites. Tunnel spoil is generally stockpiled within an acoustic shed. External stockpiles are generally avoided. While the majority of these sites are affected by flooding to

varying degrees, there would typically be suitable areas outside the 10% AEP flood extent that could be used to stockpile material.

Surface earthworks

While surface earthworks are associated with activities within the confines of most temporary construction support sites, the main area of surface earthworks is associated with the Gore Hill Freeway Connection component as well as the upgrades of Burnt Bridge Deviation and the Wakehurst Parkway.

Surcharge of the existing drainage along the Gore Hill Freeway occurs during a 1% AEP, when the depth of flow along the northern and southern sides of the freeway exceed about 0.3 metres.

While floodwater is generally confined to the main channel of Burnt Bridge Creek and its immediate overbank area near the project, several major overland flow paths develop during storms which result in the surcharge of the existing stormwater drainage system.

As the Wakehurst Parkway generally runs along the top of a natural ridge line, it is not subject to flooding. Rather, the road corridor is impacted by surface runoff which is generated by a number of relatively small catchments which are located on its eastern and western sides.

The inundation of the surface earthworks by floodwater has the potential to cause scouring of disturbed surfaces and transport sediment and construction materials into the receiving waterways. It would be necessary to plan, implement and maintain measures which are aimed at managing the diversion of floodwater either through or around the construction areas.

Bridge construction

New bridge works are limited to pedestrian and shared user bridge upgrades along the Wakehurst Parkway, the construction of which would be managed from the Wakehurst Parkway north construction support site (BL14).

The proposed pedestrian footbridge works along the Wakehurst Parkway are not at risk of being flooded during construction.

18.5.2 Potential flood risk at temporary construction support sites

Without the implementation of appropriate management measures, inundation of the temporary construction support sites by floodwater has the potential to:

- Cause damage to the project works and delays in construction programming
- Pose a safety risk to construction workers
- Detrimentally impact the downstream waterways through the transport of sediments and construction materials by floodwaters
- Obstruct the passage of floodwater and overland flow through the provision of temporary infrastructure such as site sheds, stockpiles, noise walls and flood walls, which in turn, could exacerbate flooding conditions at developments located outside the construction footprint.

Table 18-2 provides a summary of the proposed activities, as well as the assessed flood risk at the temporary construction support sites associated with the construction of the Beaches Link and Gore Hill Freeway Connection project. Figure 5.1 of Appendix R (Technical working paper: Flooding) shows the extent to which floods of varying magnitude affect each temporary construction support site. Figure 5.2 shows the indicative depth and extent of inundation in the vicinity of each temporary construction support site for the 10% AEP and 1% AEP flood events. Figure 5.3 of Appendix R (Technical working paper: Flooding) shows the provisional flood hazard and preliminary hydraulic categorisation of the floodplain near each temporary construction support site for a 1% AEP flood event. Further details of each temporary construction support site and its associated facilities and activities is provided in Chapter 6 (Construction work). A range of measures which would be implemented to mitigate the potential construction related impacts of the project are outlined in Section 18.8.

Table 18-2 Summary of assessed flood risks and potential impacts associated with proposed temporary construction support sites

Temporary construction support site	Catchment	Threshold of flooding[1]	Site facilities [2]	Spoil management [2]	Tunnel launch and support [2]	Cut and cover structures [2]	Surface earthworks [2]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
Cammeray Golf Course (BL1)	Willoughby Creek	PMF	✓	✓	✓	✓	✓	The Cammeray Golf Course construction support site (BL1) would be subject to very shallow sheet flow during heavy rainfall events, principally due to runoff generated from within its extent. Overland flow discharging through the Cammeray Golf Course construction support site (BL1) during storms up to 1% AEP in intensity is classified as low hazard flood fringe. During a PMF event, floodwater would surcharge the Warringah Freeway where it would discharge through the Cammeray Golf Course construction support site (BL1) at depths of up to 0.5 metres. Refer to Figures 5.1 (Sheet 2), 5.2 (Sheet 1) and 5.3 (Sheet 1) of Appendix R (Technical working paper: Flooding).	If appropriate connections to existing trunk drainage system are not incorporated into the design of the project, then the provision of hard stand areas within the confines of the Cammeray Golf Course construction support site (BL1) has the potential to exacerbate flooding conditions in existing residential development that is located along Warringa Road, Falls Street, Cammeray Road and Grafton Street. Construction activities within the confines of the Cammeray Golf Course construction support site (BL1) have the potential to obstruct flow which surcharges the Warringah Freeway during a PMF, thereby exacerbating flooding conditions in existing development that is located on the western side of the freeway. Floodwater originating from ANZAC Park, as well as from

Temporary construction support site	Catchment	Threshold of flooding[1]	Site facilities [2]	Spoil management [2]	Tunnel launch and support [2]	Cut and cover structures [2]	Surface earthworks [2]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
									within the Warringah Freeway corridor has the potential to impact tunnel works that are proposed adjacent to Cammeray Golf Course.
Flat Rock Drive (BL2)	Flat Rock Creek	More frequent than 10% AEP	✓	✓	✓		✓	The Flat Rock Drive construction support site (BL2) would be subject to flooding during storms more frequent than 10% AEP. Flooding occurs in the south-west corner of the Flat Rock Drive construction support site (BL2) during storms which result in the surcharge of the existing transverse drainage of Flat Rock Drive. The Flat Rock Drive construction support site (BL2) also spans an incised natural watercourse which drains from the north. Refer to Figures 5.1 (Sheet 3), 5.2 (Sheet 1) and 5.3 (Sheet 1) of Appendix R (Technical working paper: Flooding).	Changes in natural surface levels within the confines of the Flat Rock Drive construction support site (BL2) have the potential to alter flooding patterns in the area, which in turn could impact on construction activities, as well as the hydrologic standard of Flat Rock Drive. Flooding has the potential to impact the covered section of the decline and the spoil shed, both of which are located across the incised natural watercourse which drains from the north. Construction activities within the Flat Rock Drive construction support site (BL2) would not have an impact on flood behaviour in existing development.

Temporary construction support site	Catchment	Threshold of flooding[1]	Site facilities [2]	Spoil management [2]	Tunnel launch and support [2]	Cut and cover structures [2]	Surface earthworks [2]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
Punch Street (BL3)	Flat Rock Creek	More frequent than 10% AEP	✓	✓	✓	✓	✓	Shallow overland flow discharges in a northerly direction along Lambs Road which it is intercepted by a series of kerb inlet pits that are located at the eastern end of Punch Street. Refer to Figures 5.1 (Sheet 4), 5.2 (Sheet 2) and 5.3 (Sheet 2) of Appendix R (Technical working paper: Flooding).	Alterations to existing road levels to facilitate access to the Punch Street construction support site (BL3) has the potential to cause minor flooding within the proposed acoustic shed and access decline. Due to the topography in the area, activities within the Punch Street construction support site (BL3) would not have an impact on flood behaviour in adjacent residential development.
Dickson Avenue (BL4)	Flat Rock Creek	More frequent than 10% AEP	✓	✓	✓	✓	✓	Parts of the Dickson Avenue construction support site (BL4) are subject to relatively shallow sheet flow during storms which result in the surcharge of the existing stormwater drainage system. Refer to Figures 5.1 (Sheet 4), 5.2 (Sheet 2) and 5.3 (Sheet 2) of Appendix R (Technical working paper: Flooding).	Due to the relatively shallow nature of the flow, activities within the confines of the Dickson Avenue construction support site (BL4) would not have an impact on flood behaviour in adjacent commercial and industrial development.

Temporary construction support site	Catchment	Threshold of flooding[1]	Site facilities [2]	Spoil management [2]	Tunnel launch and support [2]	Cut and cover structures [2]	Surface earthworks [2]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
Barton Road (BL5)	Flat Rock Creek	Less frequent than 1% AEP	✓				✓	The Barton Road construction support site (BL5) is subject to relatively shallow overland flow during very rare and extreme storm events. Refer to Figures 5.1 (sheet 4), 5.2 (sheet 2) and 5.3 (sheet 2) of Appendix R (Technical working paper: Flooding).	Due to the relatively shallow nature of the flow, activities within the Barton Road construction support site (BL5) would not have an impact on flood behaviour in adjacent residential development.
Gore Hill Freeway median (BL6)	Flat Rock Creek	Not flooded	✓				✓	Refer to Figures 5.1 (Sheet 4), 5.2 (Sheet 2) and 5.3 (Sheet 2) of Appendix R (Technical working paper: Flooding). The Gore Hill Freeway median construction support site (BL6) is generally flood free.	Activities within the Gore Hill Freeway median construction support site (BL6) would not have an impact on flood behaviour in adjacent residential development.
Middle Harbour south cofferdam (BL7)	-	Potentially subject to wave action during elevated water levels in Middle Harbour			✓		✓	Flooding of the Middle Harbour south cofferdam construction support site (BL7) is principally limited to elevated water levels in Middle Harbour. Wave action due to coincident high winds could exacerbate flooding conditions at the Middle Harbour south cofferdam construction support site (BL7)	Activities within the confines of the Middle Harbour south cofferdam construction support site (BL7) would not have an impact on water levels in Middle Harbour.

Temporary construction support site	Catchment	Threshold of flooding[1]	Site facilities [2]	Spoil management [2]	Tunnel launch and support [2]	Cut and cover structures [2]	Surface earthworks [2]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
								during periods of elevated water levels in Middle Harbour. Refer to Figures 5.1 (sheet 5), 5.2 (sheet 3) and 5.3 (sheet 3) of Appendix R (Technical working paper: Flooding).	
Middle Harbour north cofferdam (BL8)	-	Potentially subject to wave action during elevated water levels in Middle Harbour			✓		✓	Flooding of the Middle Harbour north cofferdam (BL8) construction support site is principally limited to elevated water levels in Middle Harbour. Wave action due to coincident high winds could exacerbate flooding conditions at the Middle Harbour north cofferdam construction support site (BL8) during periods of elevated water levels in Middle Harbour. Refer to Figures 5.1 (Sheet 5), 5.2 (Sheet 3) and 5.3 (Sheet 3) of Appendix R (Technical working paper: Flooding).	Activities within the confines of the Middle Harbour north cofferdam construction support site (BL8) would not have an impact on water levels in Middle Harbour.

Temporary construction support site	Catchment	Threshold of flooding[1]	Site facilities [2]	Spoil management [2]	Tunnel launch and support [2]	Cut and cover structures [2]	Surface earthworks [2]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
Spit West Reserve (BL9)	-	Potentially subject to wave action during elevated water levels in Middle Harbour	✓	✓	✓			Flooding of the Spit West Reserve construction support site (BL9) is principally limited to elevated water levels in Middle Harbour. Wave action due to coincident high winds could exacerbate flooding conditions at the Spit West Reserve construction support site (BL9) during periods of elevated water levels in Middle Harbour. Refer to Figures 5.1 (Sheet 5), 5.2 (Sheet 4) and 5.3 (Sheet 4) of Appendix R (Technical working paper: Flooding).	Activities within the confines of the Spit West Reserve construction support site (BL9) would not have an impact on water levels in Middle Harbour.
Balgowlah Golf Course (BL10)	Burnt Bridge Creek	More frequent than 10% AEP	✓	✓	✓	✓	✓	The Balgowlah Golf Course construction support site (BL10) is also impacted by major overland flow which discharges through Balgowlah Oval from Sydney Road. Flooding is of a low hazard nature along the major overland flow path which forms in Balgowlah Golf Course.	Activities within the extent of the Balgowlah Golf Course construction support site (BL10) have the potential to impact flooding behaviour along Sydney Road and in adjoining parts of the golf course. Activities external to the Balgowlah Golf Course construction support site (BL10) have the potential to impact flood

Temporary construction support site	Catchment	Threshold of flooding[1]	Site facilities [2]	Spoil management [2]	Tunnel launch and support [2]	Cut and cover structures [2]	Surface earthworks [2]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
								Refer to Figures 5.1 (Sheet 6), 5.2 (Sheet 5) and 5.3 (Sheet 5) of Appendix R (Technical working paper: Flooding).	behaviour in existing development that is located immediately upstream of the Burnt Bridge Creek Deviation crossing of Burnt Bridge Creek and along the eastern side of the Balgowlah Golf Course.
Kitchener Street (BL11)	Burnt Bridge Creek	More frequent than 10% AEP	✓	✓				The Kitchener Street construction support site (BL11) is located on land which generally lies above peak 1% AEP flood levels. It would be subject to shallow inundation during extreme storm events. Refer to Figures 5.1 (Sheet 6), 5.2 (Sheet 5) and 5.3 (Sheet 5) of Appendix R (Technical working paper: Flooding).	Activities within the extent of the Kitchener Street construction support site (BL11) would have a minimal effect on flood behaviour.

Temporary construction support site	Catchment	Threshold of flooding[1]	Site facilities [2]	Spoil management [2]	Tunnel launch and support [2]	Cut and cover structures [2]	Surface earthworks [2]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
Wakehurst Parkway south (BL12)	Manly Creek and Bantry Bay	Not flooded	✓	✓		✓	✓	The Wakehurst Parkway south construction support site (BL12) is not subject to flooding. Refer to Figures 5.1 (Sheet 7), 5.2 (Sheet 6) and 5.3 (Sheet 6) of Appendix R (Technical working paper: Flooding).	The provision of hard stand areas within the confines of the Wakehurst Parkway south construction support site (BL12) would increase the runoff potential of the area, which in turn would increase the rate at which flow discharges to the adjacent bushland and golf course.
Wakehurst Parkway east (BL13)	Bantry Bay	Not flooded	✓	✓	✓		✓	The Wakehurst Parkway east construction support site (BL13) is not subject to flooding. Refer to Figures 5.1 (Sheet 8), 5.2 (Sheet 6) and 5.3 (Sheet 6) of Appendix R (Technical working paper: Flooding).	The provision of hard stand areas within the confines of the Wakehurst Parkway east construction support site (BL13) would increase the runoff potential of the area, which in turn would increase the rate at which flow discharges to the adjacent bushland and golf course.

Temporary construction support site	Catchment	Threshold of flooding[1]	Site facilities [2]	Spoil management [2]	Tunnel launch and support [2]	Cut and cover structures [2]	Surface earthworks [2]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
Wakehurst Parkway north (BL14)	Manly Creek	Not flooded	✓	✓			✓	Refer to Figures 5.1 (Sheet 10), 5.2 (Sheet 6) and 5.3 (Sheet 6) of Appendix R (Technical working paper: Flooding). The Wakehurst Parkway north construction support site (BL14) is not subject to flooding. Refer to Figures 5.1 (Sheet 8), 5.2 (Sheet 6) and 5.3 (Sheet 6) of Appendix R (Technical working paper: Flooding).	The provision of hard stand areas within the confines of the Wakehurst Parkway north construction support site (BL14) would increase the runoff potential of the area, which in turn would increase the rate at which flow discharges to the pavement drainage system of Warringah Road.

Note 1: The assessed threshold of flooding is based on present day conditions
Note 2: Proposed construction activities

18.6 Assessment of potential operational impacts

This section provides an assessment of the flood risk to the project and the impact it would have on flood behaviour during operation. Consistency of the impacts with state government and local council flood plans and policies has also been carried out (Section 18.6.3). The findings of an assessment of the potential impact of future climate change and impacts of a partial blockage of the local stormwater drainage system on flooding behaviour under operational conditions are also presented. Furthermore, the application of the ARR 2019 methodology to the design flood estimation is also detailed below in Section 18.6.6.

While the project incorporates measures that are aimed at mitigating the impact that it would have on flood behaviour, there are a number of residual impacts that would need to be investigated during further design development. This section identifies and describes the nature of the residual impacts, while a range of potential measures which are aimed at managing the flood risk and further mitigating the residual impacts of the project on flood behaviour are discussed in Section 18.8.

18.6.1 Potential flood risk to the project

Tunnel portals

While a series of measures have been incorporated into the design of the project in the vicinity of the tunnel portals for all events up to the PMF, a sensitivity analysis identified that there is the potential for floodwater to enter the tunnel system via the Gore Hill Freeway and Burnt Bridge Deviation portals should the stormwater drainage system experience a partial blockage during an extreme storm event. Further details of the sensitivity analysis and studies to be carried out during further design development are set out in Section 18.6.6.

At all other tunnel locations, the ingress of floodwater would be controlled through a combination of grade changes and standard barrier types. Design of the project also includes upgrades to the existing stormwater drainage to divert local catchment runoff around the proposed tunnel portals.

Road and pedestrian bridges

The existing road bridges, upgraded as part of the project, are all high level structures that would only be subject to relatively shallow sheet flow during storms which surcharge the pavement drainage system.

The proposed pedestrian and shared user bridges over the Wakehurst Parkway are high level structures that would not be subject to flooding.

Surface road works

Willoughby Creek Catchment

Major flooding of the Warringah Freeway during storms up to 1% AEP in intensity is prevented by the presence of a continuous solid concrete noise wall which runs along the northern side of ANZAC Park (refer to Figure 6.5 (Sheet 2) of Appendix R (Technical working paper: Flooding)). Depths of ponding in ANZAC Park increase from a maximum of about two metres during a 10% AEP storm event to a maximum of about 3.2 metres during a 1% AEP storm event. Overtopping of the noise wall would occur during a PMF event, when floodwater would pond to a maximum depth of about five metres and extend across the full width of the Warringah Freeway.

Flat Rock Creek Catchment

Flooding of the surface road works during storms up to 1% AEP in intensity would occur at the location where both the Gore Hill Freeway westbound off ramp to Epping Road and Pacific Highway, and the Gore Hill Freeway eastbound entry ramp to the Beaches Link tunnel runs under Reserve Road. Depths of ponding across the westbound and eastbound lanes of the Gore Hill

Freeway at these two locations would exceed one metre and 0.6 metres, respectively, during a 1% AEP storm event.

Floodwater which ponds across the Gore Hill Freeway eastbound entry ramp to the Beaches Link tunnel would eventually reach a depth where it would commence to flow in a southerly direction beneath the Reserve Road eastbound on ramp to the Gore Hill Freeway via a new bridge structure, where it would discharge onto the eastbound carriageway of the Lane Cove Tunnel. Flow discharging onto the eastbound carriageway of the Lane Cove Tunnel at this location would discharge in an easterly direction, where it would gradually be intercepted by the proposed pavement drainage system.

Burnt Bridge Creek Catchment

The surface road works would be subject to relatively shallow sheet flow as a result of flow which surcharges the existing pavement drainage system to the south of the crossing of Burnt Bridge Creek. Greater depths of inundation would be experienced further to the north of the tunnel portals as a result of flow which surcharges both the existing and proposed stormwater drainage system. Floodwater would also discharge onto Burnt Bridge Creek Deviation at the location of the Burnt Bridge Creek crossing during storms that are more intense than about 0.2% AEP.

It is noted the Burnt Bridge Creek Deviation is subject to flooding immediately to the north of the project as a result of floodwater which surcharges Burnt Bridge Creek during storms that are more frequent than 1% AEP.

Trefoil Creek, Manly Creek and Bantry Bay Catchments

Inundation of the Wakehurst Parkway during storms up to 1% AEP would be limited to flow which surcharges the new pavement drainage system given the road generally follows the natural divide between the Manly Creek and Bantry Bay catchments.

Tunnel support facilities

Tunnel support facilities are to be constructed as part of the project at Waltham Street, Artarmon and the Wakehurst Parkway, Frenchs Forest, with finished ground levels raised above the level of the PMF.

Motorway control centre

The proposed motorway control centre at the Gore Hill Freeway, Artarmon in the Flat Rock Creek catchment is located on land which generally lies above the level of the PMF. Provision would be incorporated into the design of the motorway control centre to prevent the ingress of floodwater to the building for events up to the PMF.

18.6.2 Potential impacts of the project on flood behaviour

The changes to flood behaviour external and internal to the road corridor as a result of the project in the 1% AEP event are discussed in the subsections below, and shown in Figure 18-9 to Figure 18-14. Changes in flood depth as a result of the project, in the 1% AEP event are shown in Figure 18-15 to Figure 18-20. Appendix R (Technical working paper: Flooding) provides discussion regarding the project's effect on flood behaviour for storm events more intense than 1% AEP. Refer to Figures 6.1 to 6.6 in Appendix R (Technical working paper: Flooding) for the changes to flood behaviour resulting from the project in the 10% AEP, 1% AEP and PMF events, for all catchments.

The proposed upgrade of the Wakehurst Parkway is located in the upper reaches of the Trefoil Creek, Manly Creek and Bantry Bay catchments. Due to the minor nature of the receiving drainage lines which control runoff from the road corridor, combined with the available LiDAR survey data, the assessment for these catchments was limited to a comparative peak flow analysis, the results of which were used to identify where the project has the potential to increase the rate of flow and hence scour potential in the affected drainage lines. For this reason, flood mapping is not provided

for these areas. Refer to Appendix R (Technical working paper: Flooding) for further details on assessment methodology.

Given the minor impact that the project would have on flood behaviour under operational conditions, it is not expected that changes in flooding patterns would result in significant change to the social and economic costs of flooding.

External to the road corridor

External to the road corridor, the project would generally result in a neutral or beneficial effect on flood behaviour external to the road corridor for storm events up to 1% AEP in intensity, with the following exceptions:

- Along the main arm of Burnt Bridge Creek downstream of the Kitchener Street bridge where peak 10% AEP flood levels would be increased at six residential properties in the range 10-50 millimetres
- While peak flows could potentially be increased in a number of the receiving drainage lines which run west toward Bantry Bay, there is no existing development that would be impacted by the change in flow regime
- While peak flows could potentially be increased in a number of the receiving drainage lines which run east toward the main arm of Manly Creek, there is no existing development other than the Wakehurst Golf Course that would be impacted by the change in flow regime. Increases in the rate and volume of runoff discharging to the receiving drainage lines that run through the Wakehurst Golf Course have the potential to cause prolonged inundation of parts of the golf course during periods of heavy rain
- Increases in the rate of runoff has the potential to increase the frequency of surcharge of the existing stormwater drainage system which runs across Aquatic Drive and under Aquatic Reserve, thereby increasing the frequency and depth of overland flow that is experienced across the road and in the reserve during periods of heavy rain.

In the above cases, a floor level survey would be required to determine whether the minor increase in peak flood levels attributable to the project would result in an increase in above floor inundation in existing habitable areas.

The project would have the following impacts on flow velocities and the duration of inundation external to the road corridor for storms up to 1% AEP:

- Maximum flow velocities would be increased along the main arm of Flat Rock Creek downstream of the T1 North Shore and Western Line and T9 Northern Line crossing, where maximum flow velocities would be increased by a maximum of about 0.1 metres per second
- The extension of the existing transverse drainage structure under Burnt Bridge Creek Deviation in combination with minor works within the main channel of the watercourse immediately downstream of the road crossing has the potential to increase flow velocities by up to one metre per second. The duration of inundation along the main arm of Burnt Bridge Creek Deviation would be reduced slightly when compared to present day conditions. It is noted that changes in landform in this area would also alter the nature of flows
- The concentration of flow at discrete locations along the widened section of the Wakehurst Parkway has the potential to increase peak flows, and hence flow velocities and the duration of inundation, in a number of receiving drainage lines which run to the east of the road corridor. Conversely, in a number of different receiving drainage lines which run to the east of the road corridor, the upgrade of the Wakehurst Parkway also has the potential to decrease peak flows.

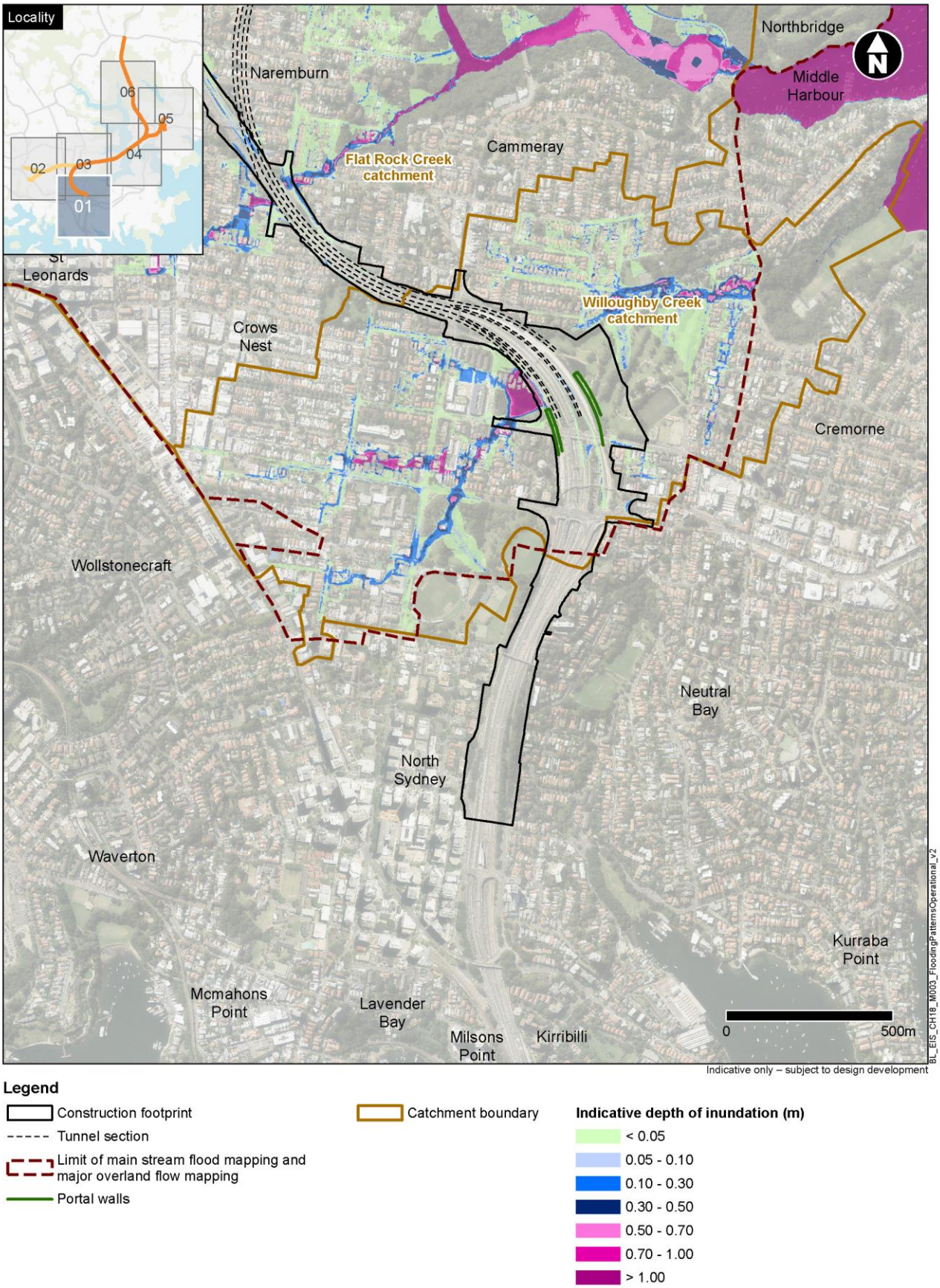

Figure 18-9 Flood behaviour under operational conditions – 1% AEP event (map 1)

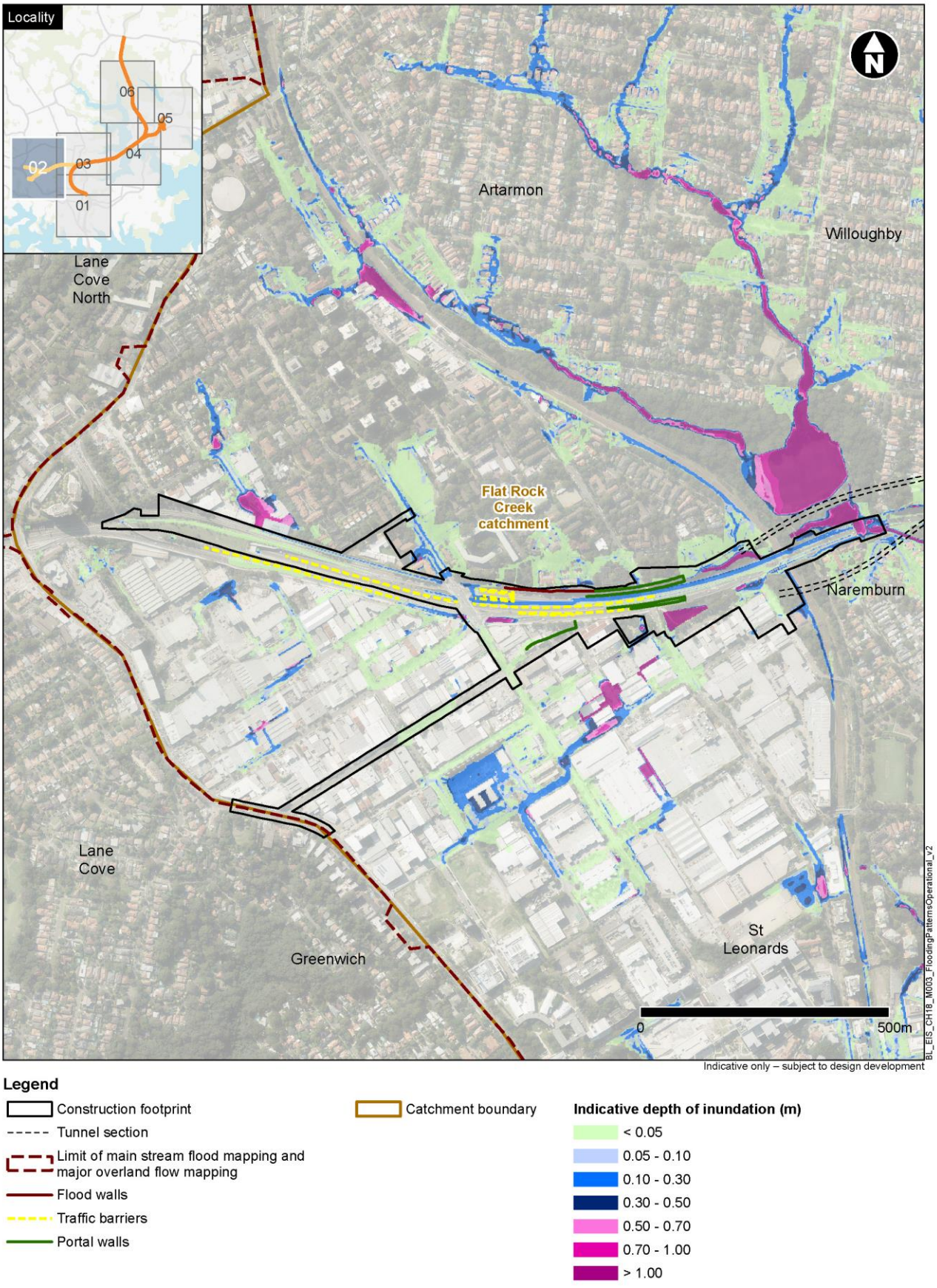

Figure 18-10 Flood behaviour under operational conditions – 1% AEP event (map 2)

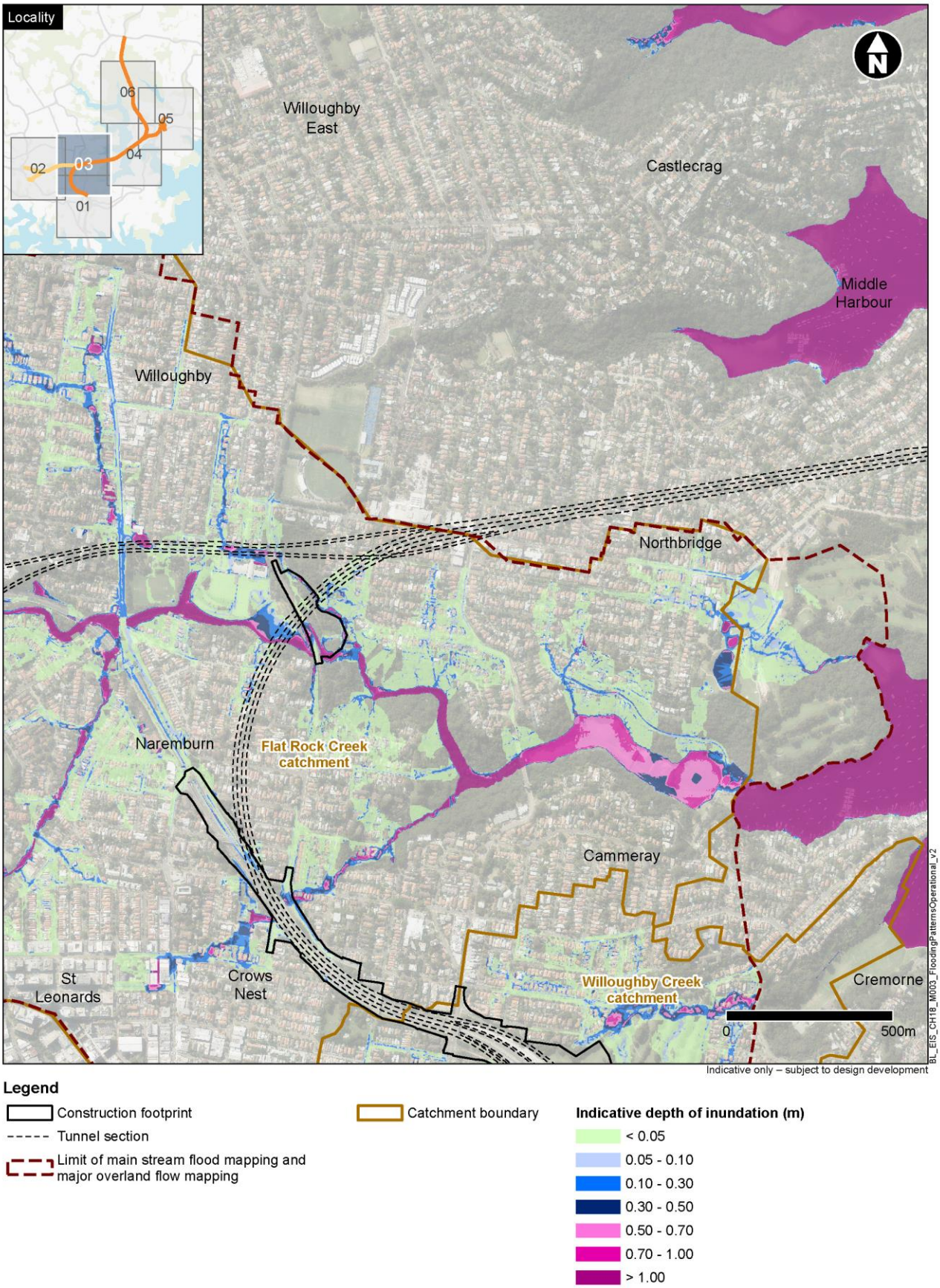

Figure 18-11 Flood behaviour under operational conditions – 1% AEP event (map 3)

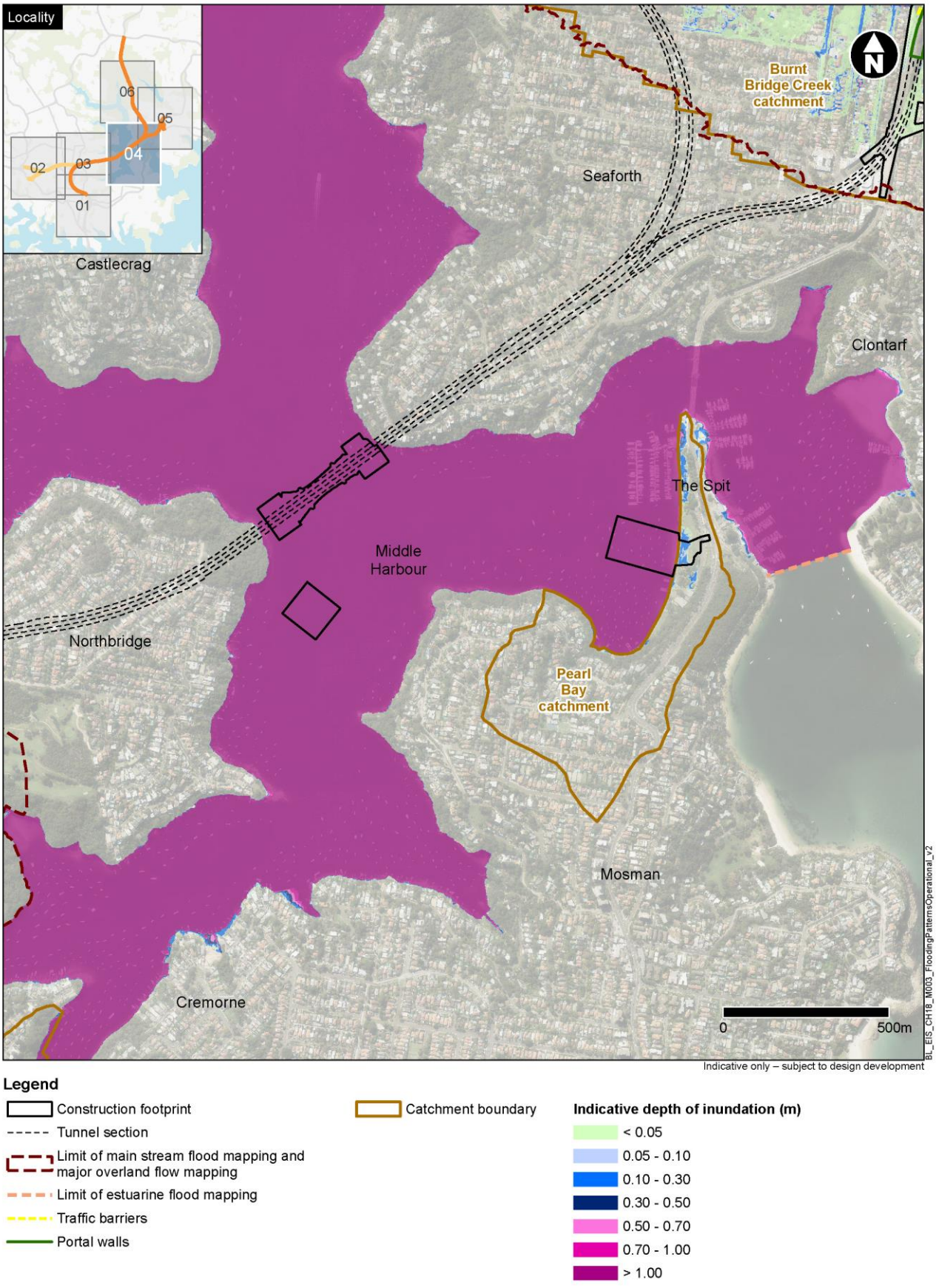

Figure 18-12 Flood behaviour under operational conditions – 1% AEP event (map 4)

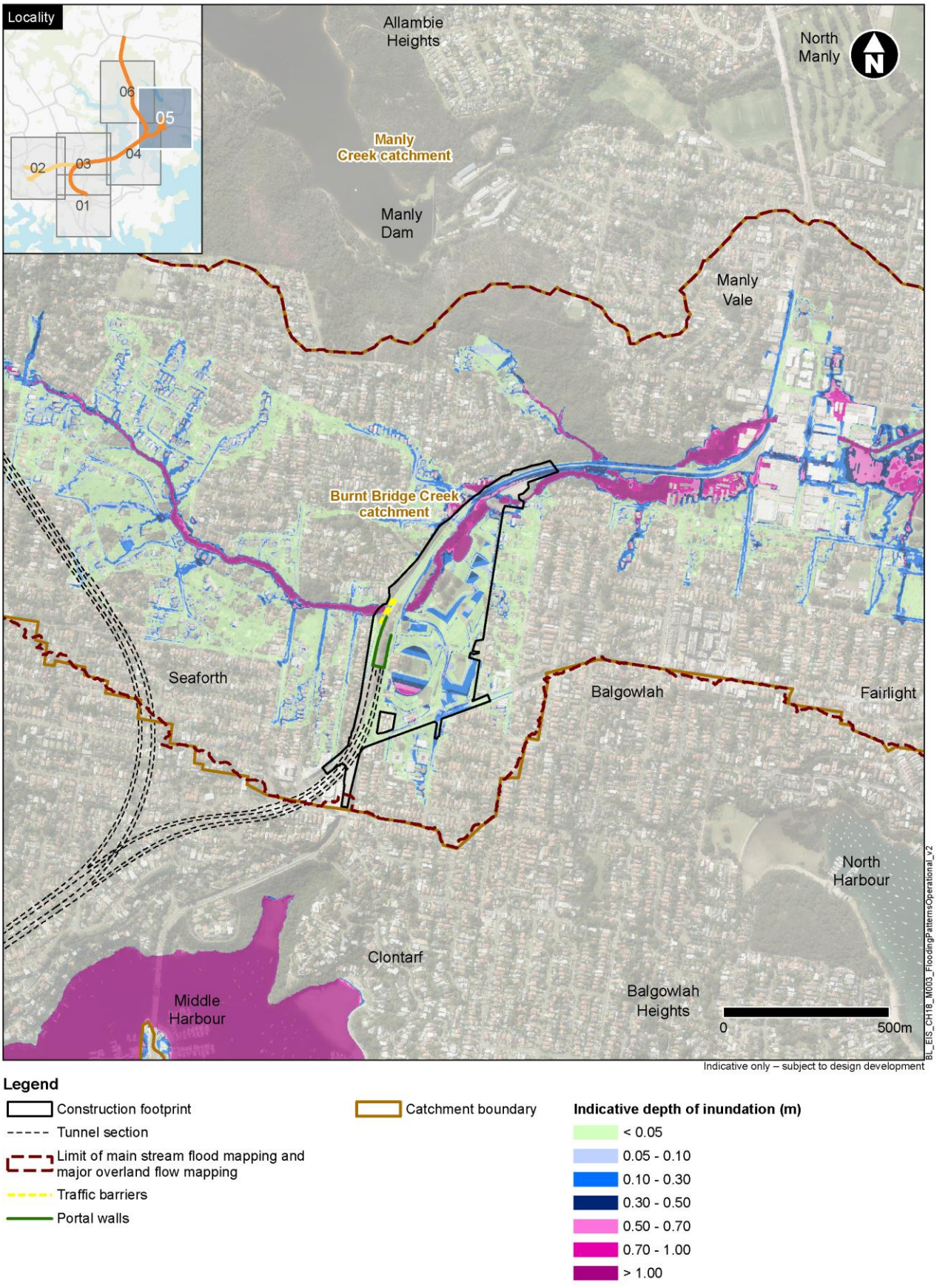

Figure 18-13 Flood behaviour under operational conditions – 1% AEP event (map 5)

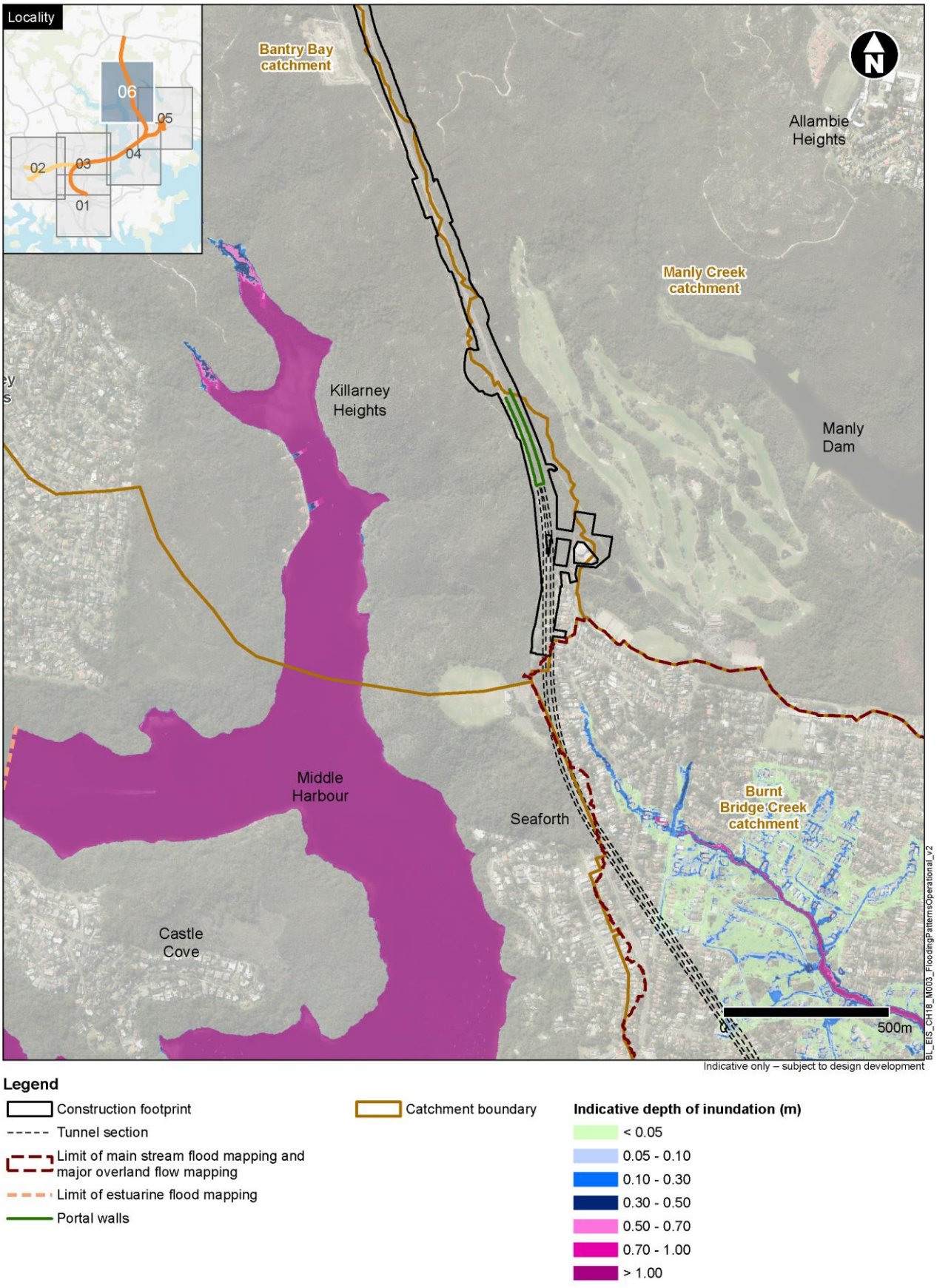

Figure 18-14 Flood behaviour under operational conditions – 1% AEP event (map 6)

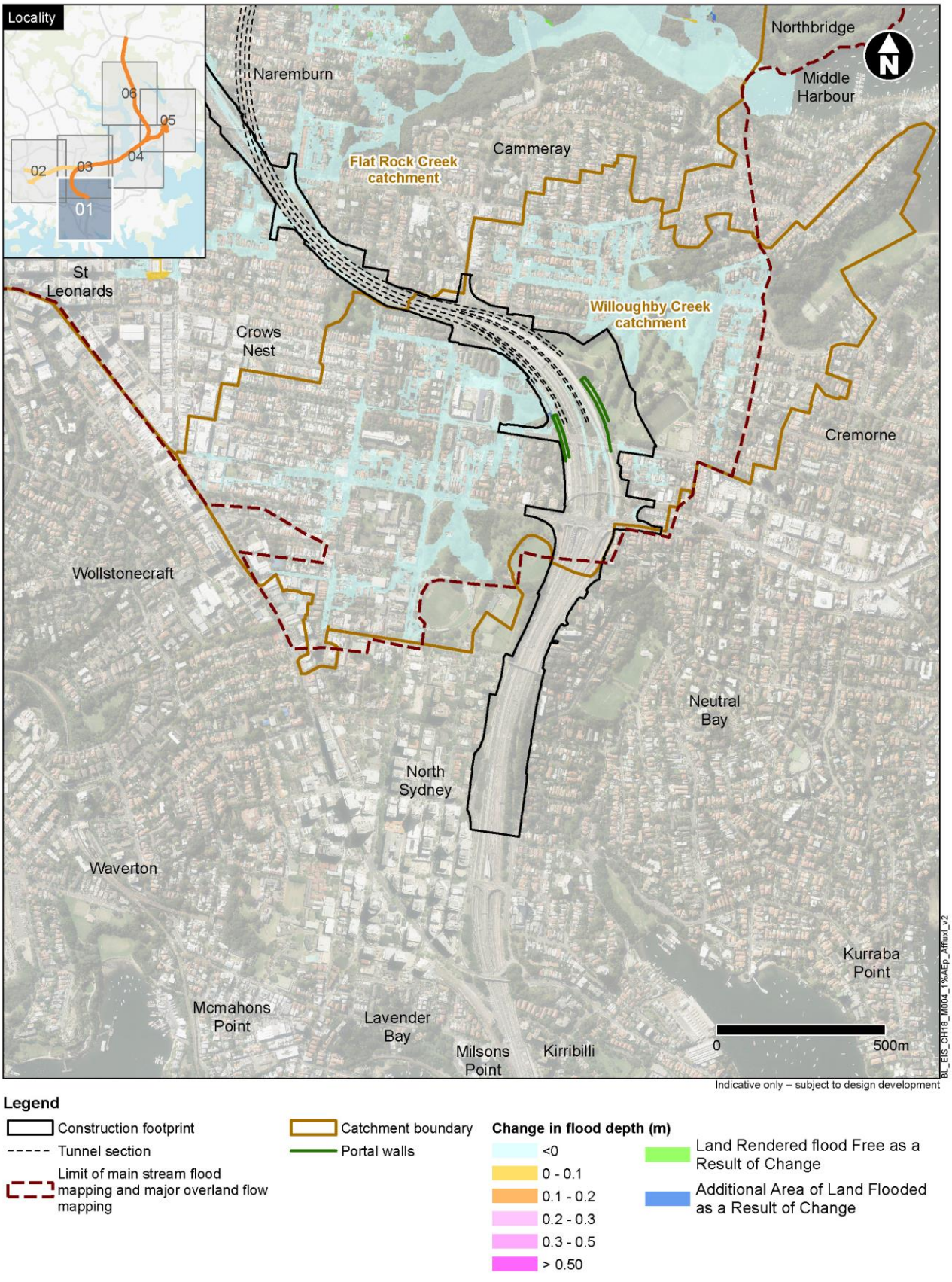

Figure 18-15 Change in flood depth under operational conditions – 1% AEP event (map 1)

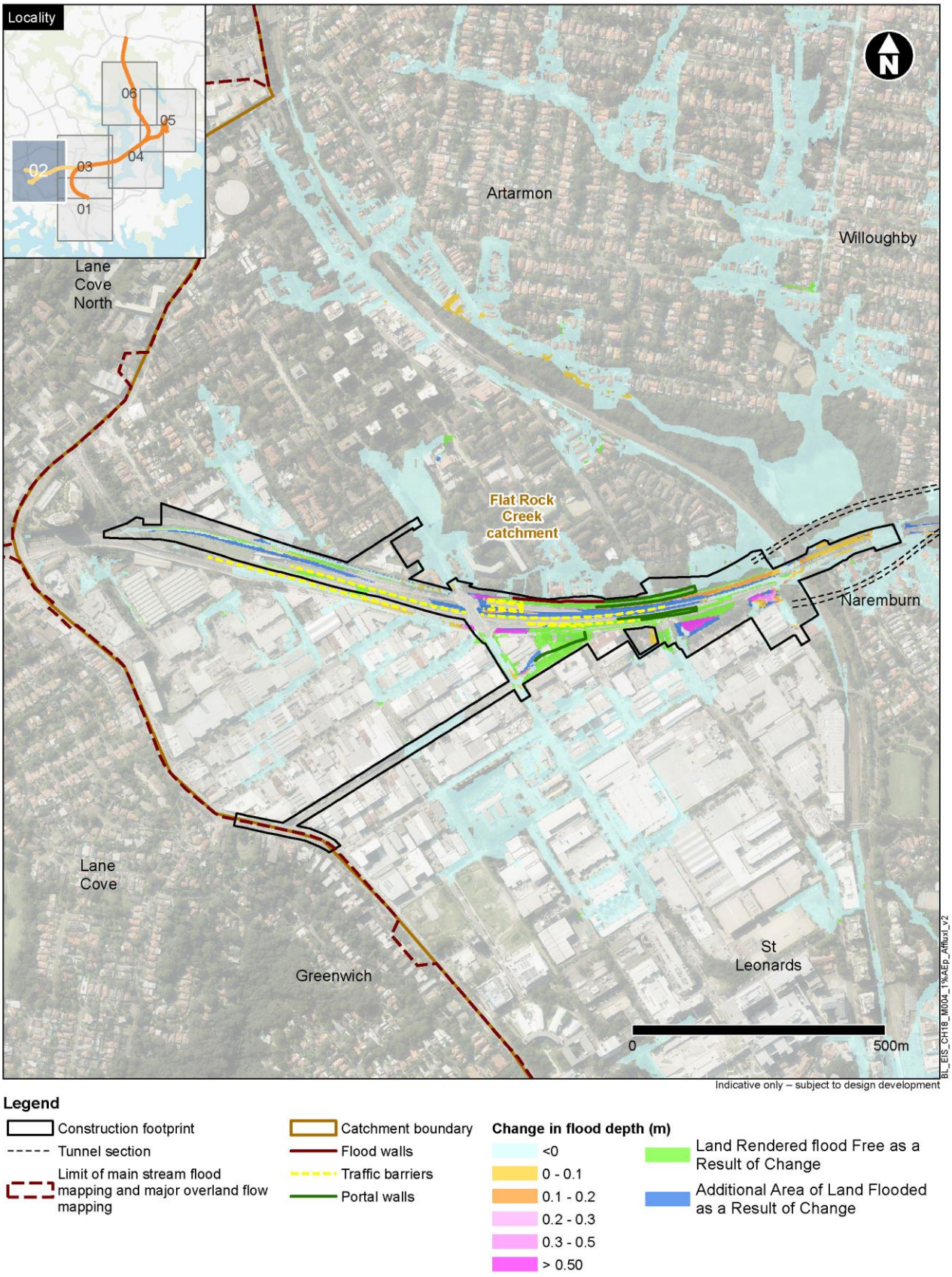

Figure 18-16 Change in flood depth under operational conditions – 1% AEP event (map 2)

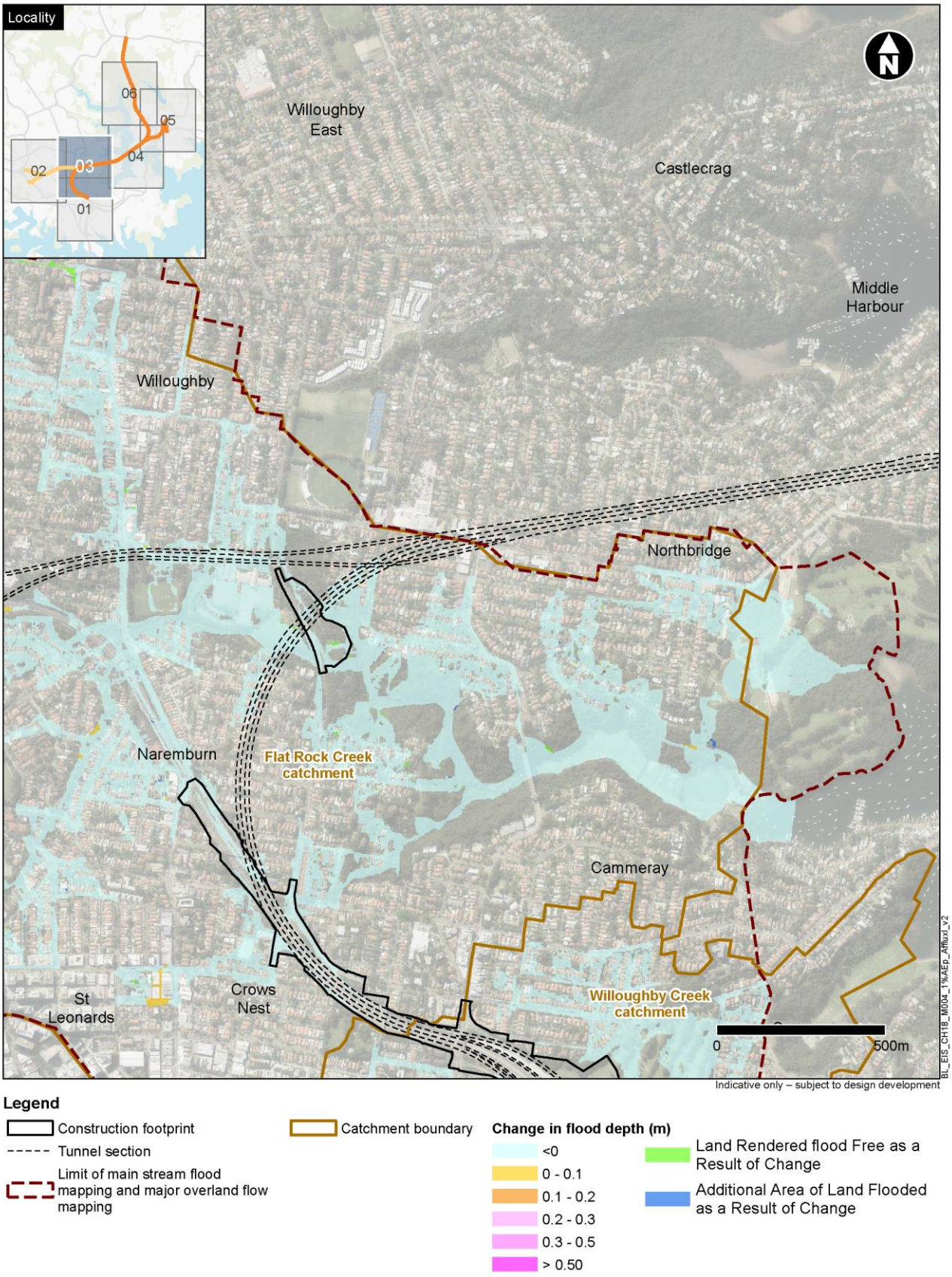

Figure 18-17 Change in flood depth under operational conditions – 1% AEP event (map 3)

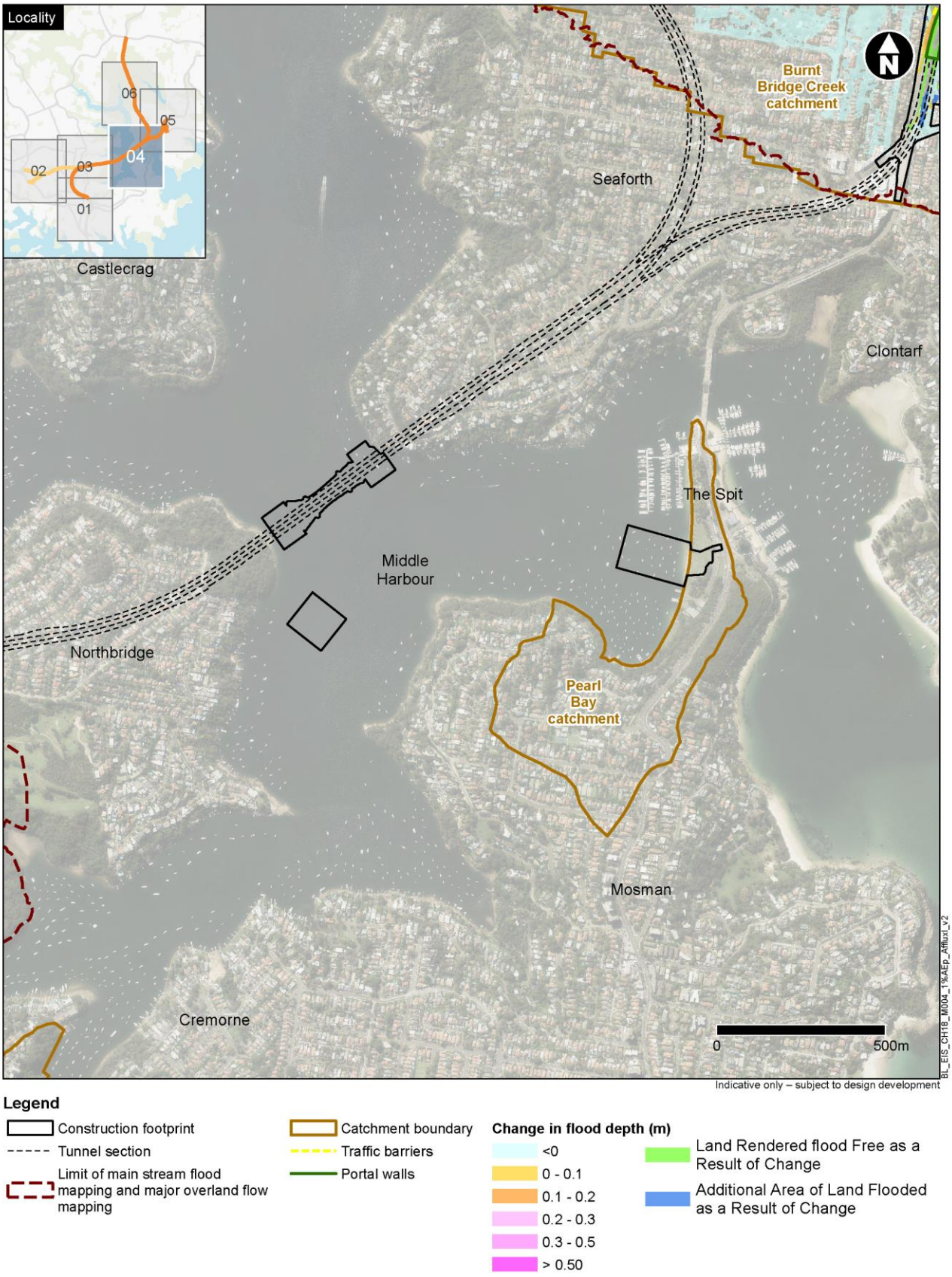

Figure 18-18 Change in flood depth under operational conditions – 1% AEP event (map 4)

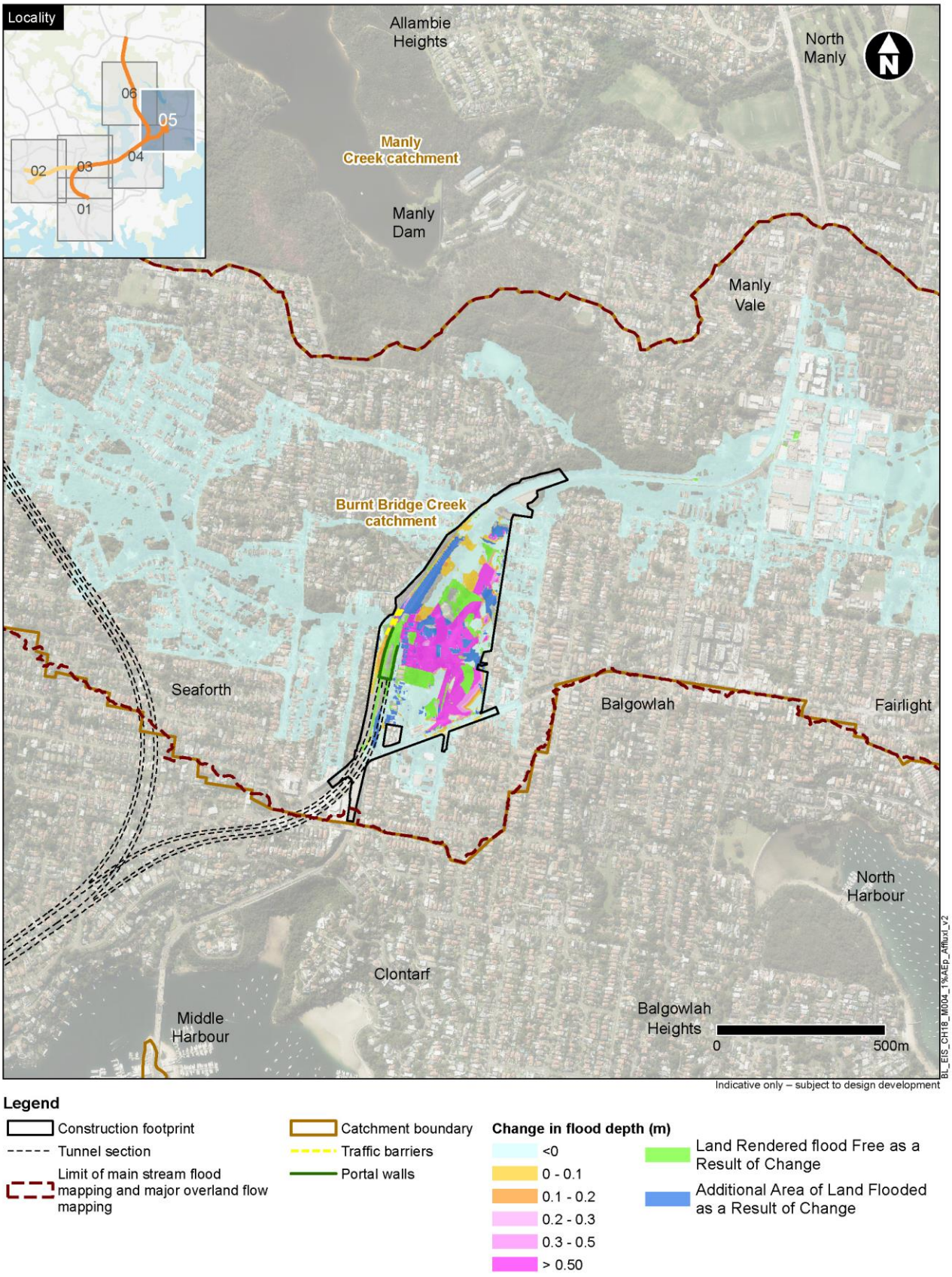

Figure 18-19 Change in flood depth under operational conditions – 1% AEP event (map 5)

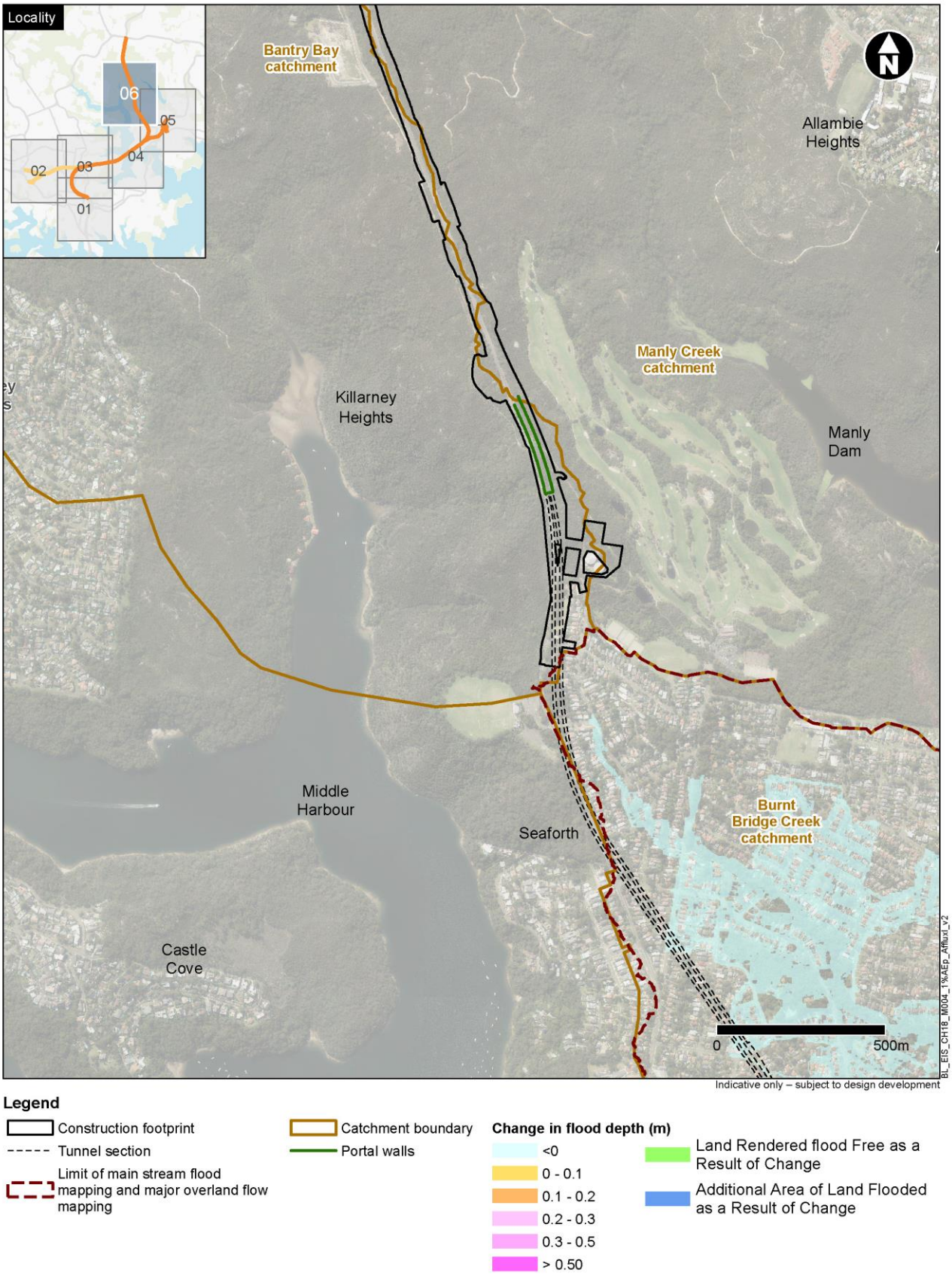

Figure 18-20 Change in flood depth under operational conditions – 1% AEP event (map 6)

Internal to the road corridor

Internal to the road corridor, the project would exacerbate flooding conditions during storms up to 1% AEP in intensity at the following locations:

- Flat Rock Creek Catchment:
  - At the location of a newly formed sag which would be located beneath the Reserve Road overpass on the Gore Hill Freeway westbound off ramp to Epping Road and the Pacific Highway. During a 1% AEP storm event, floodwater would pond across the two lane carriageway to a maximum depth of about 1.6 metres
  - At the location of a newly formed sag which would be located beneath the Reserve Road overpass on the Gore Hill Freeway eastbound on ramp to the Beaches Link tunnel. During a 1% AEP storm event, floodwater would pond across the two lane carriageway to a maximum depth of about 0.6 metres
  - Along the eastbound lanes of the Lane Cove Tunnel and Gore Hill Freeway carriageways extending from the Reserve Road interchange to a location east of the T1 North Shore and Western Line and T9 Northern Line overpass. Depths of flow along the two carriageways would be a maximum of about 300 millimetres in a 1% AEP storm event
- Burnt Bridge Creek Catchment:
  - While the flood modelling carried out as part of this study indicates that the depth of flow in the road corridor would be increased as part of the project, improvements to the existing pavement drainage system, the features of which were not incorporated in the flood models, would be aimed at controlling runoff under post-upgrade conditions.

Internal to the road corridor flow velocities and durations of inundation would generally be increased in the areas where increases in the depth and extent of inundation would be increased.

18.6.3 Potential impacts of the project on scour potential

The project has the potential to cause scouring in Burnt Bridge Creek, as well as the receiving drainage lines that are located along the Wakehurst Parkway due to the following:

- Increases in the rate of flow (and hence the depth and velocity of flow) associated with:
  - The enlargement of transverse drainage structures
  - The discharge of runoff from the widened carriageway
  - Changes in the distribution of flow along the project corridor
- Increases in the velocity of flow where it discharges from pipe outlets or newly lined sections of channel
- The concentration of flow resulting from the formalisation of the drainage system within the project corridor.

Increases in the rate of flow in the receiving drainage lines could result in a lowering of the stream bed through a process of headwater erosion, as well as a possible widening of the watercourse through a process of bank erosion. The lining of channels and the concentration of flow could also result in localised scour in the receiving drainage lines at the downstream limit of the drainage works.

Scour of Burnt Bridge Creek and the receiving drainage lines that are located along the Wakehurst Parkway has the potential to increase the turbidity of flow discharging to Bantry Bay and Manly Dam and to a lesser extent, Manly Lagoon.

18.6.4 Consistency with state government and local council flood plans and policies

The Warringah Local Environmental Plan 2011, the Manly Local Environmental Plan 2013 and the Willoughby Local Environmental Plan 2012 each contain flood planning clauses that apply to land at or below the Flood Planning Level, which is defined in all documents as equal to the peak 1% AEP flood level plus 0.5 metres. It is noted that both the North Sydney Local Environmental Plan 2013 and the Mosman Local Environmental Plan 2012 do not include a definition of the Flood Planning Level.

In accordance with the Secretary's environmental assessment requirements, a flood planning area has been defined by the current assessment through mapping the extent of land which lies below the peak 1% AEP flood level plus 0.5 metres under present day conditions. The flood planning area shown on Figure 4.7 of Appendix R (Technical working paper: Flooding) is based on mainstream flooding along the major creeks and tributaries that are crossed by the project, as well as the main paths associated with major overland flow. It should be noted that the flood modelling carried out for the assessment was developed for the specific purpose of assessing the flood risks and impacts associated with the project and therefore should be taken as preliminary only in terms of defining the flood planning area across the broader extent of flood prone land within the catchments that are crossed by the project.

The findings of the assessment presented in Section 18.6.2, show that the project would have only a minor impact on peak 1% AEP flood levels. As a result, the project would have no significant impact on the extent of the flood planning area and therefore the area of land to which clause 6.3 of Manly Local Environmental Plan 2013, Warringah Local Environmental Plan 2011 and Willoughby Local Environmental Plan 2012 would apply. While North Sydney Local Environmental Plan 2013 and Mosman Local Environmental Plan 2012 do not contain a definition of the flood planning level, the project would have no significant impact on the extent of the flood planning area were the two councils to adopt the same definition as set out in clause 6.3 of Manly Local Environmental Plan 2013, Warringah Local Environmental Plan 2013 and Willoughby Local Environmental Plan 2012.

While a floodplain risk management study and plan has only been prepared for the Manly Creek catchment, the findings of the assessment (Section 18.6.2) show that the project would have only a minor impact on peak flood levels external to the road corridor.

NSW State Emergency Service maintains two local units located on Station Street, Naremburn and Quirk Road, Balgowlah, both of which are located outside the project footprint and would not be affected by the project related flood impacts. Provided the flood mitigation measures set out in Section 18.8 are incorporated into the design of the project, the project would not increase the flood hazard in existing development for all events up to the 1% AEP event. The project would not have an adverse impact on NSW State Emergency Service's emergency response arrangements.

18.6.5 Impact of future climate change on flood behaviour

Impact of future climate change on flooding to the project

Annexure B of Appendix R (Technical working paper: Flooding) contains a series of figures which show flood behaviour under present day and project operation conditions for design storms with AEPs of 0.5% and 0.2%. Also included are a series of figures which show the impact that an increase in the intensity of a 1% AEP storm event would have on flooding patterns under project operation conditions. The 0.5% AEP and 0.2% AEP storms have been used as proxies to assess the impact that a 10 per cent and 30 per cent increase in 1% AEP rainfall intensities would have on flood behaviour in the vicinity of the project.

Impacts on flood behaviour associated with a potential increase in the rainfall intensities are summarised below.

Willoughby Creek Catchment

- While depth of ponding would be increased in ANZAC Park, it would not be deep enough to overtop the continuous concrete noise wall which runs along its northern side
- As a series of measures have been incorporated into the design of the project to prevent the ingress of floodwater to the tunnel portals for events up to the PMF, increases in peak flood levels associated with future climate change would not increase the flood risk to the project
- As the motorway facilities and ventilation outlet at the Warringah Freeway would be designed to prevent the ingress of floodwater to the tunnels during a PMF event, increases in peak flood levels associated with future climate change would not increase the flood risk to the project.

Flat Rock Creek Catchment

- The rate at which flow approaches the Gore Hill Freeway from the urbanised catchments which lie to its north and south would increase, resulting in an increase in the depth of flow along several of its lanes
- As the operational facilities and ancillary infrastructure at the Gore Hill Freeway would be designed to prevent the ingress of floodwater to the building during a PMF event, increases in peak flood levels associated with future climate change would not increase the flood risk to the project
- As a series of measures have been incorporated into the design of the project that would prevent the ingress of floodwater to the tunnel portals for events up to the PMF, increases in peak flood levels associated with future climate change would not increase the flood risk to the project.

Burnt Bridge Creek Catchment

- Floodwater would surcharge the existing transverse drainage structure on Burnt Bridge Creek during storms that are more intense than about 0.2% AEP
- As a series of measures have been incorporated into the design of the project that would prevent the ingress of floodwater to the tunnel portals for events up to the PMF, increases in peak flood levels associated with future climate change would not increase the flood risk to the project
- As the motorway facilities and ventilation outlet at the Burnt Bridge Creek Deviation would be designed to prevent the ingress of floodwater to the tunnels during a PMF event, increases in peak flood levels associated with future climate change would not increase the flood risk to the project.

Bantry Bay Catchment

- As a series of measures have been incorporated into the design of the project that would prevent the ingress of floodwater to the tunnel portals for events up to the PMF, increases in peak flood levels associated with future climate change would not increase the flood risk to the project
- As the motorway facilities and ventilation outlet at the Wakehurst Parkway would be designed to prevent the ingress of floodwater to the tunnels during a PMF event, increases in peak flood levels associated with future climate change would not increase the flood risk to the project.

Manly Creek Catchment

- Surcharge of the new pavement and transverse drainage could occur as a result of an increase in rainfall intensities. As the project generally runs along the catchment divide, surcharge of the proposed drainage is unlikely to result in an increase in the flood risk to road users
- As the operational facilities and ancillary infrastructure at Frenchs Forest and Killarney Heights at the Wakehurst Parkway would be designed to prevent the ingress of floodwater to the

tunnels during a PMF event, increases in peak flood levels associated with future climate change would not increase the flood risk to the project.

Trefoil Creek Catchment

- Surcharge of the new pavement drainage could occur as a result of an increase in rainfall intensities. As the project is located on the catchment divide, surcharge of the proposed drainage is unlikely to result in an increase in the flood risk to road users.

Impact of the project on flood behaviour under future climate change conditions

While the project would generally have a similar impact on flood behaviour to that described in Section 18.6.2 for a 1% AEP storm event under present day conditions for the assessed climate change scenarios, it would increase peak post-climate change 1% AEP flood levels, as described below.

Increases in sea level were not included in the assessment of climate change impacts on the basis that the surface works associated with the project operation are located above Reduced Level (RL) 10 metres Australian Height Datum (AHD) and are therefore well above areas that would be impacted by an increase in sea level due to climate change.

Burnt Bridge Creek Catchment

- Immediately upstream of the Burnt Bridge Creek Deviation crossing of Burnt Bridge Creek, peak post-climate change 1% AEP flood levels could be increased by up to 250 millimetres, with the impacts extending into eleven residential properties located on either side of the watercourse
- Immediately downstream of the Burnt Bridge Creek Deviation crossing of Burnt Bridge Creek, peak post-climate change 1% AEP flood levels could be increased by up to 200 millimetres, noting that no existing or future development would be impacted as a result of these changes.

18.6.6 Impact of a partial blockage of the local stormwater drainage system on flood behaviour

The mechanism and geometrical characteristics of blockages in the piped system are difficult to quantify and would be different for each storm event. Realistic scenarios would be limited to one or two pipes becoming partially blocked during a storm event. However, for the purposes of the flooding impact assessment, analyses were carried out with the cross sectional areas of all pipes and conduits reduced by 50 per cent for the 1% AEP storm event. This represents a case which is well beyond a blockage scenario which could reasonably be expected to occur and is presented for illustrative purposes.

Annexure C (Figure C.1) of Appendix R (Technical working paper: Flooding) shows the impact a partial blockage of the local stormwater drainage system and the extended culverts under the Burnt Bridge Creek Deviation would have on peak 1% AEP flood levels in the vicinity of the proposed tunnel portals, bridges and surface road works. The key findings of the assessment are outlined below.

While the tunnel system would not be impacted by flooding should the existing stormwater drainage system experience a partial blockage during storms up to 1% AEP in intensity, there is the potential for floodwater to enter the tunnels should a partial blockage occur during more extreme storm events. For example, a partial blockage of the stormwater drainage system during a PMF event would result in flow discharging to the tunnel system at the location of the Gore Hill Freeway connection, while floodwater would commence to enter the tunnels via the Burnt Bridge Creek Deviation tunnel portals. During further design development, a risk assessment would be carried out to assess the flood risk in the tunnel system should the stormwater drainage system experience a partial blockage during storms that are more intense than 1% AEP.

Willoughby Creek Catchment

- While peak 1% AEP flood levels would be increased by about 1.5 metres in ANZAC Park, they would not be high enough to overtop the proposed flood walls which would border the proposed tunnel portals.

Flat Rock Creek Catchment

- While peak 1% AEP flood levels would be increased in the road corridor, they would not be high enough to cause floodwater to enter the proposed tunnel portals.

Burnt Bridge Creek Catchment

- Flow would surcharge the existing Burnt Bridge Creek transverse drainage structure on Burnt Bridge Creek Deviation, where it would discharge across both the northbound and southbound lanes before re-entering the creek on the eastern (downstream) side of the road corridor
- There would be a minor increase in the depth of overland flow discharging north along the access road.

Bantry Bay Catchment

- A partial blockage of the new pavement drainage system would result in the minor inundation of the Wakehurst Parkway at the major sag in the road which is located a short distance to the north of the tunnel portals. For example, flow would pond across the road until it reached the height of the adjacent footpath before discharging into the adjacent bushland.

Manly Creek Catchment

- A partial blockage of the new pavement drainage system would result in the minor inundation of the Wakehurst Parkway at the location of the two major sags in the road. For example, flow would pond across the road at these two locations until it reached the height of the adjacent footpath before discharging into the adjacent bushland
- A partial blockage of the transverse drainage may result in floodwater discharging onto the surface of the Wakehurst Parkway where it would pond at the location of the two major sags in the road. In this instance, flow would pond across the road until it reached the height of the adjacent footpath before discharging into the adjacent bushland.

Refer to Table 6.1 and 6.2 of Appendix R (Technical working paper: Flooding) for further details on the assessment findings outlined above.

18.6.7 Application of Australian Rainfall and Runoff 2019 to design flood estimation

The ARR 2019 was released during the preparation of the environmental impact statement. As a result, the procedures set out in ARR 1987 have been used as the basis of carrying out the flooding investigation for the project, noting the approach is consistent with the flood studies that have been carried out to date in the catchments through which it runs.

As the procedures set out in ARR 2019 would be used by councils to carry out new flood studies and to also update previous studies, a sensitivity study was carried out as part of the present investigation to assess the likely changes that would occur in predicted flood behaviour in the vicinity of the project where it runs through the Willoughby Creek catchment.

The procedures set out in ARR 2019 were applied to the hydrologic model that relate to the Willoughby Creek, Bantry Bay and Manly Creek (upper reaches only) catchments, and both them and the hydraulic model in the case of the Willoughby Creek catchment run for the 1% AEP storm event. The investigation found that there would be a reduction in the rate of runoff which would be generated by the catchment which in turn would result in a reduction in peak flood levels. This finding would apply to the adjacent catchments through which the project runs given the similar level of development in the area.

Based on the above finding, it was concluded that the adoption of the procedures set out in ARR 1987 represents a worse-case scenario in terms of assessing flood behaviour in the vicinity of the project.

18.7 Assessment of cumulative impacts

This section presents the findings of an assessment of the potential impacts the project would have on flood behaviour in combination with other nearby projects. The assessment was based on impacts during the operation of the project only, given the short term nature of exposure to potential flood impacts during the construction of the project together with the general requirement to manage adverse impacts on existing development.

18.7.1 Other motorway projects

Western Harbour Tunnel and Warringah Freeway Upgrade

The flood impact assessment set out in this technical working paper assumes that the Western Harbour Tunnel and Warringah Freeway Upgrade project forms part of baseline (ie pre-project) flooding conditions (ie it assumes that construction of the Western Harbour Tunnel and Warringah Freeway Upgrade project precedes that of the project).

While the present investigation found that the project would not exacerbate flooding conditions in existing development located in the Willoughby Creek catchment, a similar investigation found that the Western Harbour Tunnel and Warringah Freeway Upgrade project would increase peak 1% AEP flood levels by up to 16 millimetres in nine residential properties located along Cammeray Road, Park Avenue, Fall Street and Grafton Street in Cammeray.

18.7.2 Other projects

There are no other proposed non-motorway projects that are of a scale that would influence flood behaviour in the vicinity of the project.

18.8 Environmental management measures

The project has aimed to limit its impact in respect to flooding, both in terms of impacts on the project itself and the areas surrounding it. Project elements have been designed with consideration of the surrounding areas and management measures are proposed in order to reduce the impacts of flooding brought on by the project. Environmental management measures relating to flooding impacts are outlined in Table 18-3.

Table 18-3 Environmental management measures - flooding

Reference	Phase	Impact	Environmental management measure	Location
F1	Design	Impact of the project on flood behaviour	Where flood levels in the 1% AEP event are predicted to increase at any residential, commercial and/or industrial buildings as a result of operation of the project, a floor level survey will be carried out. If the survey indicates existing buildings would experience above floor inundation during a 1% AEP event as a result of the project, further refinements will be made (as required) to the design of permanent project components to minimise the potential for impacts.	BL/GHF
F2	Design	Operational flooding impacts	Impact of the project on flood behaviour during operation will be confirmed during further project development. This will include the consideration of future climate change and a partial blockage of the local stormwater drainage system.	BL/GHF
F3	Design	Impact of flooding on the project	Flood emergency management measures for construction and operation of the project will be prepared in consultation with State Emergency Services and relevant councils and incorporated into relevant environmental and/or safety management documentation.	BL/GHF
F4	Design	Impact of the project on scour potential	Measures will be assessed during further design development which are aimed at reducing as far as is practical the risk of increased scour in the receiving drainage lines that are located along the Wakehurst Parkway. Scour countermeasures will also be provided at the outlet of new or upgraded transverse and longitudinal drainage lines.	BL/GHF

Reference	Phase	Impact	Environmental management measure	Location
F5	Design and construction	Impacts of construction sites on flood behaviour	Detailed construction planning will consider flood risk at construction sites and construction support sites. This will include: • A review of site layout and staging of construction activities to avoid or minimise obstruction of overland flow paths and limit the extent of flow diversion required • Identification of measures to not worsen flood impacts on the community and on other property and infrastructure during construction up to and including the 1% AEP flood event where reasonable and feasible • Measures to mitigate alterations to local runoff conditions due to construction activities.	BL/GHF
F6	Construction	Flooding impacts to tunnel excavation	Entries to tunnel excavations, including cut and cover sections of tunnel, will be protected against frequent flooding by locating openings outside flood prone areas, and/or the provision of local bunding and flood protection barriers.	BL/GHF
F7	Construction	Flooding impacts to tunnel excavation	The flood standard adopted at each tunnel entry during construction will be developed taking into consideration the duration of construction, the magnitude of inflows and the potential risks to personal safety and the project works.	BL/GHF
F8	Construction	Flood impacts to construction sites	Spoil stockpiles will be located in areas which are not subject to frequent inundation by floodwater, ideally outside the 10% AEP flood extent. The exact level of flood risk accepted at stockpile sites will depend on the duration of stockpiling operations, the type of material stored, the nature of the receiving drainage lines and also the extent to which it would impact flooding conditions in adjacent development.	BL/GHF
F9	Operation	Flood impacts to construction sites	Site facilities will be located outside high flood hazard areas based on a 1% AEP flood.	BL/GHF

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