Chapter 14

Non-Aboriginal heritage

January 2020

14 Non-Aboriginal heritage

This chapter outlines the potential non-Aboriginal heritage impacts associated with the project. 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).

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, built heritage landscapes and archaeology); d. items listed on the State, National and World Heritage lists (including Cockatoo Island); e. heritage items and conservation areas identified in local and regional planning environmental instruments covering the project area; and f. marine items of potential heritage significance within Sydney Harbour, such as any shipwrecks within proximity to the Balls Head Coal Loader wharf.	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 items 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 14.4.1**. **Section 14.4.2** includes assessment of maritime items of potential heritage significance within Sydney Harbour. Further details are provided in **Appendix K** (Technical working paper: Maritime heritage). Cockatoo Island is located outside of the study area defined in **Appendix J** (Technical working paper: Non-Aboriginal heritage), and the maritime heritage values of this site would not be impacted (direct or indirectly).
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 been considered to reduce heritage	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 Section 5.1, Section 5.2 and Section 5.4 of **Appendix J** (Technical working paper: Non-Aboriginal heritage) and **Section 4.4** and **Section 4.5** of **Chapter 4** Mitigation measures are presented in **Section 14.5** which includes consideration of

Secretary's requirement	Where addressed in EIS
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 potential impacts to the Balls Head Coal Loader particularly associated with vibration and disturbance as part of the ongoing works. Due to the potential significance of this site, options to ensure that it is not impacted must be considered; e. 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); f. provide a comparative analysis to inform the rarity and representative value of any heritage places proposed for demolition; g. outline mitigation measures to avoid and minimise identified impacts in accordance with the current guidelines; and h. 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).	areas identified as having potential archaeological significance. Potential impacts to Balls Head Coal Loader are discussed in **Section 14.4** and **Section 14.5**. 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 14.4.1**. 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 *NSW 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* (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:

- UNESCO *Convention on the Protection of the Underwater Cultural Heritage* (2001)
- *Australia ICOMOS 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 undertaking 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 carried 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, 2015c).

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* (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 Birchgrove and Waverton, the area around the Sydney Harbour south and Sydney Harbour north cofferdams (WHT5 and WHT6), the temporary construction support site at Berrys Bay (WHT7), and around the White Bay construction support site (WHT3) (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 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

Rozelle to Birchgrove

The original people to occupy the Balmain area were part of the Darug language group, who occupied the region for about 20,000 years prior to European occupation. The local Aboriginal population was substantially reduced following the arrival of European settlers, caused by an epidemic of smallpox from 1789-1790 and violent conflicts over resources between settlers, convicts, soldiers and the Aboriginal population.

Between 1790 and 1819, land grants were made within the Balmain area to civilians, the military and the clergy. Increased subdivision occurred within the region in the early 1800s, along with an improvement in transportation to the area (Tanner Architects, 2011). During the Depression in the 1920s-1930s, many of the 'fine old homes' were taken over by government departments as institution offices, hostels and boarding houses (Tanner Architects, 2011).

The waterfront of Rozelle, Glebe, and Balmain was used for maritime industry, and was fundamental to the development of these suburbs through much of the mid-19th and twentieth centuries (Tanner Architects, 2011). By the 1990s, the population expanded as the area's industrial zones underwent extensive redevelopment to become residential zones (Australian Bureau of Statistics, 2011; Inner West Council, 2013).

Sydney Harbour

The First Fleet arrived in Sydney Harbour on 26 January 1788 and settled in Sydney Cove (Godden Mackay, 1991). The Sydney Cove settlement developed in the mid-19th century as a major port and trade centre, with residential and industrial development expanding into the Glebe, Balmain and Ultimo areas. Small maritime industries and wharves for dockyards, ship building, light industrial, gas works and power stations were developed along the foreshores of these areas, and continued into the early 20th century (Godden Mackay, 1991).

The industrial character of Sydney Harbour declined from the 1960s onwards when Port Botany was developed as Sydney's main container terminal and cargo handling port. However, the waterway remained busy into the 21st century with passenger ferries and a range of recreational functions.

Maritime development on the North Shore around Berrys Bay began in the early to mid-19th century, with the foreshore occupied by various industrial companies and government occupants such as the NSW Torpedo Corps, the Anglo-Persian Oil Refineries (subsidiary of British Petroleum (BP)), Woodley's Shipyard, a Commonwealth Department of Health Quarantine Station, timber works and a range of boat builders. These uses resulted in the construction of various maritime infrastructure along the foreshore, including slipways, wharves, mooring facilities, cranes, storage tanks, sea walls and industrial buildings. Industrial activities were wound down in the 1990s, with the northern and western section of Berrys Bay, associated with Carradah Park and former coal loader site, converted to recreational open space and some of the southern section reserved for waterfront industrial use.

Waverton 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) people 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, 2016; 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, 2016).

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 tramway was extended along Miller Street (North Sydney Council, 2012; 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, 2016a).

Bushland on Berrys Island and Balls Head Reserve was declared public parkland in 1926 and protected from surrounding maritime industrial and commercial development, and by the 1980s the land opened as public foreshore parkland (Hoskins, 2010; Spindler, 2011; North Sydney Council, 2016a; 2016b; n d-c).

14.3.2 Heritage items and conservation areas

Listed heritage items and conservation areas

Two hundred and forty-six items with heritage listings were identified within the study area. These include one of world heritage significance (Sydney Opera House buffer zone), one of national heritage significance, 10 of state heritage significance, and the remainder of local heritage significance. Six of the listed heritage items have maritime heritage elements. Heritage listed items within the study area are shown in Figure 14-1 to Figure 14-4. In addition, one indicative place, the Sydney Harbour Landscape Area, is located within the study area. This item is not listed on any of the statutory registers, and so no additional assessment was carried out. 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

Two additional items of potential heritage significance were identified during the field investigations. These were ANZAC Park at Cammeray and a seating area at the eastern end of Ridge Street in North Sydney.

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. The impact of the project on ANZAC Park is assessed in Section 14.4.1.

The seating area was not considered to meet the significance criterion thresholds for local or state listings and has not been considered further in this assessment.

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

Overall, one additional item, ANZAC Park, was included in this assessment, bringing the total number of heritage items identified within the study area to 247.

Additional maritime heritage items

Three unidentified shipwrecks of potential heritage significance were identified at Balls Head in database searches (refer to Figure 14-5). 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.

Nine unverified anomalies were identified between Yurulbin Park and Balls Head through review of remote sensing data from field surveys and from review of existing sources (refer to Figure 14-5). 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 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 project construction footprint

Potential archaeological site type	Location		
	Sydney Harbour between Birchgrove and Waverton	Berrys Bay	White Bay, Johnstons Bay and Glebe Island
Maritime heritage infrastructure (and associated deposits)	Certain	Certain	Very likely
Shipwrecks (and associated deposits)	Certain	Very likely	Not applicable
Discard	Certain	Certain	Likely
Built heritage	Not applicable	Not applicable	Certain

14.4 Assessment of potential impacts

14.4.1 Potential terrestrial heritage impacts

Of the 247 heritage items identified within the study area, 134 items would either have no impact or a negligible impact from the project due to either the low impact activities proposed or the distances between these items and the project construction works. These items are located within 50 metres of surface works in Annandale and Rozelle, in North Sydney, and in the vicinity of the Warringah Freeway Upgrade. Impacts on these 134 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.

A heritage assessment for the remaining 113 heritage items and conservation areas that would be potentially impacted is included in Table 14-3, with items shown in Figure 14-1. The following items have been assessed as groups due to their proximity, the similarity of impacts and similarity of mitigation measures:

- Three items including St Leonards Park, W. Tunks Memorial Fountain and the War Memorial (Item 10)
- 93 heritage items situated above the tunnel alignment (Item 19).

Six terrestrial heritage items considered in Table 14-3 have maritime heritage elements. These items are:

- Glebe Island Bridge
- Yurulbin Park
- Former Balls Head Coal Loader
- Railway Electricity Tunnel
- Former BP Site
- Former Woodleys Shipyard.

These items have been considered as terrestrial items in their entirety in Table 14-3, and do not appear in the maritime heritage assessment in Section 14.4.2.

Within Heritage Conservation Areas (Items 2, 15 and 18), demolition of a small number of buildings is proposed. These building are situated on the margins of the Heritage Conservation Areas and would not equate to demolition of the entire heritage place. As such comparative analysis to determine the rarity of the buildings to be demolished have not been prepared.

Table 14-3 Potential impacts on terrestrial heritage items

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
1	Glebe Island Bridge, Pyrmont	• State Heritage Register • Roads and Maritime Section 170 Register • Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005 • Register of the National Estate • National Trust of Australia (NSW).	State	No direct impacts Potential direct impacts: • Potential physical impacts to the heritage item due to operation of construction vehicles and equipment in close proximity to the heritage item. Indirect impacts • Temporary vibration impacts due to construction activities in the vicinity of the heritage item • Temporary visual impacts due to construction activities in the vicinity of the heritage item.	**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.
2	The Valley heritage conservation area	Leichhardt Local Environmental Plan 2013	Local	No direct impacts Potential direct impacts: • Potential physical impacts to the conservation area due to operation of construction vehicles and equipment in close proximity to the heritage boundary. Indirect impacts: • Temporary and permanent visual impacts due to the demolition of buildings adjacent to the conservation area, and temporary	**Minor** The proposed project works would be of small scale and of low intensity. 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
				establishment and operation of the Victoria Road construction support site (WHT2) • Temporary vibration impacts due to construction activities adjacent to the conservation area • Slight permanent settlement and ground movement impacts to the heritage item caused by tunnel excavation.	
3	Railway electricity tunnel under Sydney Harbour, Birchgrove and Greenwich	• State Heritage Register • Leichhardt Local Environmental Plan 2013 • Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005 • Transport for NSW Section 170 Heritage and Conservation Register.	State	No direct impacts No potential direct impacts Indirect impacts: • Temporary vibration impacts due to construction activities in the vicinity of the heritage item at the Sydney Harbour south and Sydney Harbour north cofferdams (WHT5 and WHT6) • Very slight permanent settlement and ground movement impacts to the heritage item.	**Negligible** With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be negligible.
4	Yurulbin Park, Birchgrove	Leichhardt Local Environmental Plan 2013	Local	Direct impacts: • Planned physical impacts to the heritage item due to the temporary establishment and operation of the Yurulbin Park construction support site (WHT4) and the Sydney	**Major** The proposed works would be of medium-large scale and of moderate intensity, with some changes being permanent and

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
				Harbour south cofferdam (WHT5) • Planned physical impacts to areas of archaeological potential due to the temporary establishment and operation of WHT4 and WHT5. Potential direct impacts: • Physical impacts to the heritage item due to operation of construction equipment within the heritage boundary • Physical impacts to elements of the heritage item due to the temporary establishment of the Yurulbin Park construction support site (WHT4) • Physical impact to maritime elements of the heritage item from anchoring of project vessels on or around the item • Physical impact to the heritage item from potential collision of project vessels • Physical impact to maritime elements of the heritage item by water turbulence from the operation of project vessels. Indirect impacts: • Temporary visual impacts due to the temporary establishment and operation of the Yurulbin Park construction support site (WHT4)	irreversible. The design of the project works at Yurulbin Park have been developed in consultation with Bruce Mackenzie AM, the original designer of the park. This has resulted in a design that minimises impacts to significant features and changes to the permanent landform at Yurulbin Park. Some mature trees within the park would be directly impacted, but areas of exclusion have been identified and replacement plantings would be provided on completion of construction as part of the redesign. Opportunities to temporarily remove, store and reinstate certain elements such as stone flagging, stone walls and steps would be investigated and implemented if these elements need to be temporarily removed. While permanent impacts would occur to areas of archaeological potential during site establishment, specialist investigations would provide an opportunity to obtain information about the archaeology and history of the site not available from other sources. Reinstatement works following the completion of

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
				and the Sydney Harbour south cofferdam (WHT5) • Temporary vibration impacts due to construction activities within and adjacent to the heritage boundary • Slight permanent settlement and ground movement impacts to the heritage item caused by tunnel excavation.	construction would be designed in consultation with Bruce Mackenzie. The new design would seek to retain and enhance the existing character and the original design intent as much as possible. These works would also improve the quality and long-term viability of landscaping and useability of the park. The implementation of the management measures described in Section 14.5 and Chapter 20 (Land use and property) will ensure that direct impacts are minimised and that disturbed areas would be reinstated following the completion of construction in a manner that is consistent with the heritage values of the item.
5	Former coal loader, Waverton	• North Sydney Local Environmental Plan 2013 • Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005 • Register of the National Estate.	Local	No direct impacts Potential direct impacts: • Permanent physical impacts to the heritage item due to operation of construction equipment in close proximity to maritime elements of the heritage item • Permanent physical impacts to elements of the heritage item due to the temporary installation of the	**Minor** With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be minor. Visual impacts would be temporary, and vibration and settlement risks minimised.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
				Sydney Harbour north cofferdam (WHT6) • Permanent physical impact to maritime elements of the heritage item from anchoring of project vessels on or around the item • Permanent physical impact to the heritage item from potential collision of project vessels • Permanent physical impact to maritime elements of the heritage item by water turbulence from the operation of project vessels.	
				Indirect impacts: • Temporary visual impacts due to the temporary establishment and operation of the Sydney Harbour north cofferdam (WHT6) • Temporary vibration impacts due to construction activities adjacent to the heritage item • Slight permanent settlement and ground movement impacts to the heritage item caused by tunnel excavation.	
6	Woodleys Shipyard, Waverton	• North Sydney Local Environmental Plan 2013 • Roads and	Local	Direct impacts: • Planned temporary impacts to existing structures within the heritage boundary due to the temporary establishment and	**Minor** The proposed works would be of medium-large scale and of low intensity. The implementation of the management measures described

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
		Maritime Section 170 Register • Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005.		operation of the Berrys Bay construction support site (WHT7) • Planned impacts to maritime heritage elements and areas of archaeological potential within the heritage boundary due to the construction of a temporary wharf at the Berrys Bay construction support site (WHT7). Potential direct impacts: • Physical impacts to structures within the heritage boundary due to operation of construction vehicles and equipment in close proximity to maritime elements of the heritage item • Physical impacts to elements of the heritage item due to the temporary establishment and operation of the Berrys Bay construction support site (WHT7) • Physical impact to maritime elements of the heritage item from anchoring of project vessels on or around the item • Physical impact to maritime elements of the heritage item by water turbulence from the operation of project vessels. Indirect impacts: • Temporary visual impacts due to	in Section 14.5 will ensure that impacts to the heritage item are temporary and reversible, and that any maritime archaeology is salvaged prior to construction.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
				the temporary establishment and operation of the Berrys Bay construction support site (WHT7) • Temporary vibration impacts due to construction activities within the heritage boundary • Very slight permanent settlement and ground movement impacts to the heritage item caused by tunnel excavation.	
7	BP site, Waverton	• North Sydney Local Environmental Plan 2013 • Roads and Maritime Section 170 Register • Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005.	Local	Direct impacts: • Temporary and permanent impacts to existing structures and areas of archaeological potential within the heritage boundary due to the temporary establishment and operation of the Berrys Bay construction support site (WHT7) • Permanent impacts to maritime heritage elements and areas of archaeological potential within the heritage boundary due to the construction of a temporary wharf at the Berrys Bay construction support site (WHT7). Potential direct impacts: • Physical impacts to structures within the heritage boundary due to operation of construction vehicles and equipment in close proximity to maritime elements of the heritage	**Minor** The proposed project works would be of medium-large scale and of low intensity. While the changes to the subsurface archaeology of the heritage item would be permanent and irreversible, changes to the heritage significance would be temporary and reversible, subject to the implementation of the mitigation measures described in Section 14.5. Mitigation measures would protect existing heritage components, record information about the physical nature of the heritage item as it currently exists and salvage any land-based and maritime archaeology prior to construction.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
				item • Physical impacts to elements of the heritage item due to the temporary establishment and operation of the Berrys Bay construction support site (WHT7) • Physical impact to maritime elements of the heritage item from anchoring of project vessels on or around the item • Physical impact to maritime elements of the heritage item by water turbulence from the operation of project vessels.	
				Indirect impacts: • Temporary visual impacts due to the temporary establishment and operation of the Berrys Bay construction support site (WHT7) • Temporary social impacts due to limited access to the heritage item during construction • 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.	

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
8	Sydney Harbour Bridge, approaches and viaducts (road and rail), Milsons Point/Dawes Point	• National Heritage List • State Heritage Register • North Sydney Local Environmental Plan 2013 • Roads and Maritime Section 170 Heritage and Conservation Register • Register of the National Estate • National Trust of Australia (NSW) Register.	National	Direct impacts within the National listing boundary: • Permanent impacts to the heritage item due to road upgrade works within the heritage boundary. Direct impacts within the State listing boundary: • Planned temporary impacts to the heritage item due to the temporary establishment and operation of the Blue Street construction support site (WFU1). No potential direct impacts within the National listing boundary. Potential direct impacts within the State listing boundary: • Physical impacts to the heritage item due to operation of construction vehicles and equipment within and in close proximity to the State heritage boundary. Indirect impacts within the National listing boundary: • Temporary visual impacts due to road upgrade activities within the heritage boundary • Temporary social impacts due to limited access to the heritage item	**Minor** The proposed works would be of small-medium scale and of moderate intensity. Works associated with the establishment and operation of the Blue Street construction support site (WFU1) would be temporary and reversible. While the road upgrade works within the heritage boundary would be permanent and irreversible, they would not impact the heritage significance of the item and would allow for continued use of the heritage item as a major road and rail connection. Implementation of the mitigation measures described in Section 14.5 would ensure that the level of impact on this heritage item would be minor.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
				during construction. Indirect impacts within the State listing boundary: • Permanent visual impacts due to the potential construction of a toll gantry within the heritage boundary and noise barrier adjacent to the boundary • Temporary visual impacts due to the temporary establishment and operation of the Blue Street construction support site (WFU1).	
9	North Sydney Bus Shelters BS008 'Falcon' – Miller Street, North Sydney BS010 'Miller' – corner of Miller and Falcon Streets, North Sydney BS025 'Berrys Bay' – Woolcott Street, Waverton BS038 'St Johns' – Brought Street, Kirribilli BS050 'St Leonards	North Sydney Local Environmental Plan 2013	Local	Direct impacts: • Temporary relocation of BS008, BS010 and BS050 during construction due to construction works directly adjacent to the heritage items. Potential direct impacts: • Potential physical impacts to BS038 due to operation of construction vehicles and equipment in close proximity. Indirect impacts: • Temporary visual impacts due to the relocation of BS008, BS010 and BS050 during construction • Temporary vibration impacts to heritage items remaining in situ due	**Negligible** The proposed works would be of small/localised scale, low intensity, and temporary. With the implementation of the management measures described in Section 14.5, the level of impact on BS008, BS010 and BS050 would be minor. Impacts to BS025 and BS038 would be negligible.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
	Park' – corner of Falcon and Miller Streets, North Sydney			to construction activities in close proximity • Very slight permanent settlement and ground movement impacts to BS025 caused by tunnel excavation.	
10	St Leonards Park (including W. Tunks Memorial Fountain, War Memorial, and North Sydney Oval), North Sydney	• State Heritage Register • North Sydney Local Environmental Plan 2013 • Register of the National Estate • National Trust of Australia (NSW) Register.	State	Direct impacts: • Physical impacts to the heritage item due to the temporary establishment and operation of the Ridge Street north construction support site (WHT9) • Addition of operational infrastructure within the heritage boundary. Potential direct impacts: • Physical impacts to the heritage item due to operation of construction vehicles and equipment within and in close proximity to the heritage boundary. Indirect impacts: • Temporary and permanent visual impacts due to the construction of permanent operational infrastructure within and in the vicinity of the heritage boundary • Temporary vibration impacts due to construction activities within and in	**Minor** The proposed works would be of small scale and of low intensity. While impacts associated with the establishment and operation of Ridge Street north construction support site (WHT9) would be temporary, those associated with road upgrade works to the Warringah Freeway would be permanent and irreversible. Kerb and footpath adjustment works would occur on Miller Street southbound around the intersection with Falcon Street. These works would provide a new dedicated lane for left turning traffic from Falcon Street westbound to Miller Street southbound. Further review of the impacts in this area is currently being carried out and permanent impacts to St Leonards Park would be minimised or, where possible eliminated. The implementation of the

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
				the vicinity of the heritage boundary • Slight permanent settlement and ground movement impacts to the heritage item caused by tunnel excavation.	management measures described in Section 14.5 will minimise disturbance and ensure that disturbed areas are reinstated to retain as much of the existing character and design as possible.
11	North Sydney Sewer Vent, North Sydney	• State Heritage Register • North Sydney Local Environmental Plan 2013 • Sydney Water Section 170 Heritage and Conservation Register • Register of the National Estate • National Trust of Australia (NSW) Register.	State	No direct impacts Potential direct impacts: • Physical impacts to the heritage item due to operation of construction vehicles and equipment in close proximity to the heritage item. Indirect impacts: • Temporary and permanent visual impacts due to the construction of permanent operational infrastructure in the vicinity of the heritage item • Temporary vibration impacts due to construction activities in the vicinity of the heritage item • Very slight permanent settlement and ground movement impacts to the heritage item caused by tunnel excavation.	**Negligible** The proposed works would be of small scale and of low intensity. While some permanent and irreversible changes would occur on the roadways adjacent to the heritage item, they are not planned to impact the heritage item.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
12	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. Potential direct impacts: • Potential physical impacts to the heritage item due to operation of construction vehicles and equipment within and in close 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.	**Negligible** The proposed works would be restricted to a small area along the south, southeast and eastern boundary of the park. While changes would be permanent and irreversible, they would not impact significant heritage components or the overall heritage significance 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.
13	Northern Suburbs Ocean Outfall Sewer, Blacktown to Manly	Sydney Water Section 170 Register	Local	Direct impacts: • Planned permanent adjustment to the maintenance access to the heritage item due to the construction of permanent operational infrastructure. Potentially direct impacts:	**Negligible** The proposed works would be of small scale and of low intensity, with the changes to the heritage item being permanent and irreversible. The changes would affect a small portion of the heritage item and are necessary for the continued

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
				• Potential physical impacts to the heritage item due to operation of construction vehicles and equipment within and in close proximity to the heritage boundary. Indirect impacts: • Temporary vibration impacts due to construction activities within and adjacent to the heritage boundary • Slight permanent settlement and ground movement impacts to the heritage item caused by tunnel excavation.	operation of the heritage item. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be negligible.
14	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 item due to operation of construction vehicles and equipment within and in close proximity to the heritage boundary. Indirect impacts: • Temporary and permanent visual impacts due to the construction of	**Moderate** 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. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be moderate.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
				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.	
15	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 demolition of two buildings 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 close proximity to the heritage boundary. Indirect impacts: • Temporary and permanent visual impacts due to the removal of heritage fabric and the construction	**Minor** The proposed works would be of small scale and of low intensity, with the direct impacts to the heritage item being permanent and irreversible. 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
				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.	
16	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: • Planned physical impact due to the implementation of architectural noise treatments for the heritage item. No potential direct impacts Indirect impacts: • Temporary vibration impacts due to construction activities in close proximity to the heritage boundary.	**Negligible** Eligibility for architectural noise treatment for the heritage item would be confirmed during detailed design 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.
17	St Thomas Rest Park, North Sydney	• 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 in close proximity to the heritage boundary.	**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.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
18	Holtermann Estate A Conservation Area, Crows Nest	• North Sydney Local Environmental Plan 2013 • Register of the National Estate.	Local	Direct impacts: • Planned 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.	**Negligible** Eligibility for architectural noise treatment at a number of residences within the conservation area would be confirmed during detailed design 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.
19	Heritage items situated above the tunnel alignment – including various commercial premises (shops and hotels), civic buildings (court house, post office, police station, council chambers), churches, schools, a theatre, trees and streetscapes, parks,	Various	State ('Raywell' House) / Local (all other items)	No direct impacts No potential direct impacts Indirect impacts: • Slight or very slight permanent settlement and ground movement impacts to heritage items within the conservation area 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
	railway station, Birchgrove Colliery, and Former Quarantine Boat Depot.				

Figure 14-1 Location of all heritage items and potential heritage items within the study area (map 1)

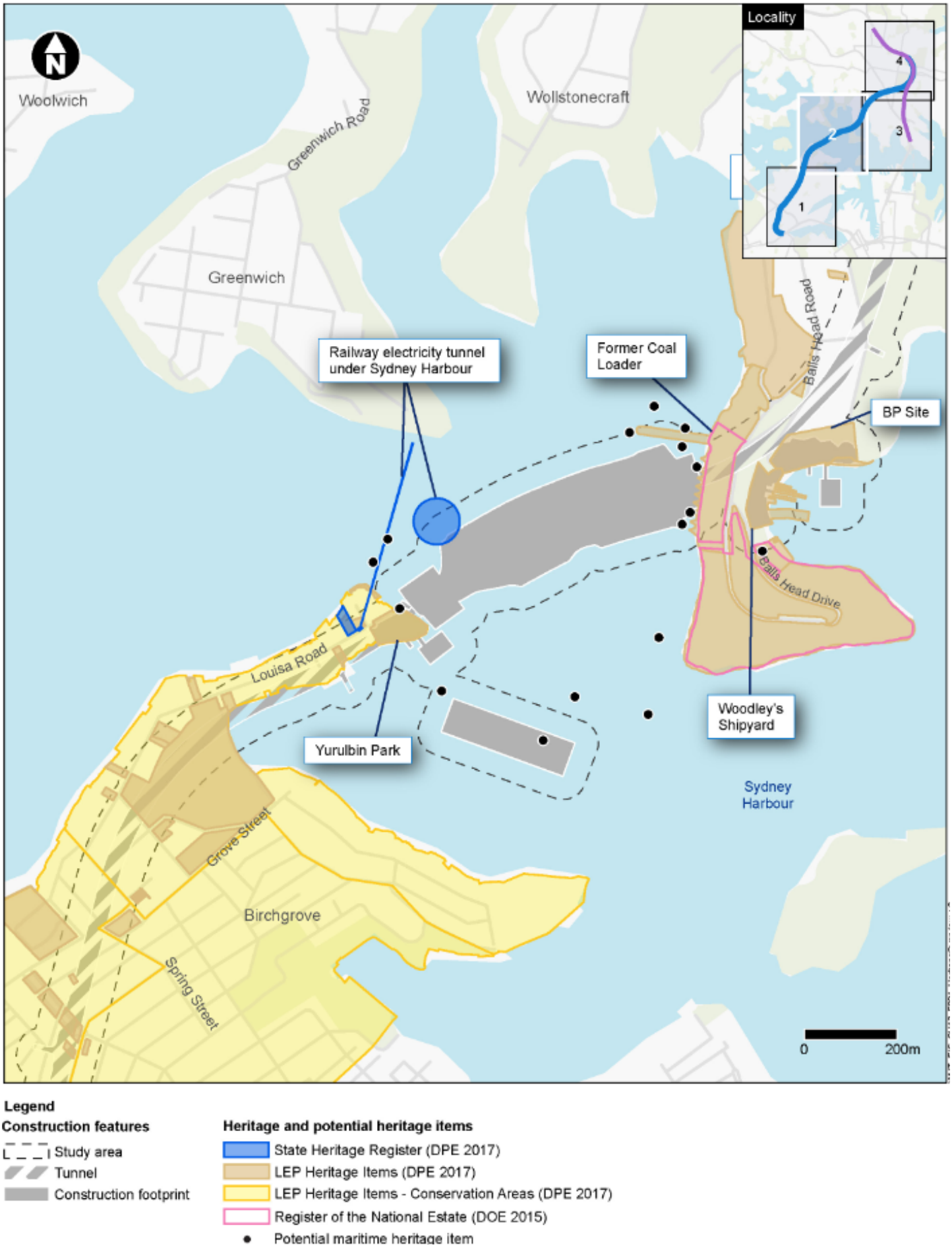
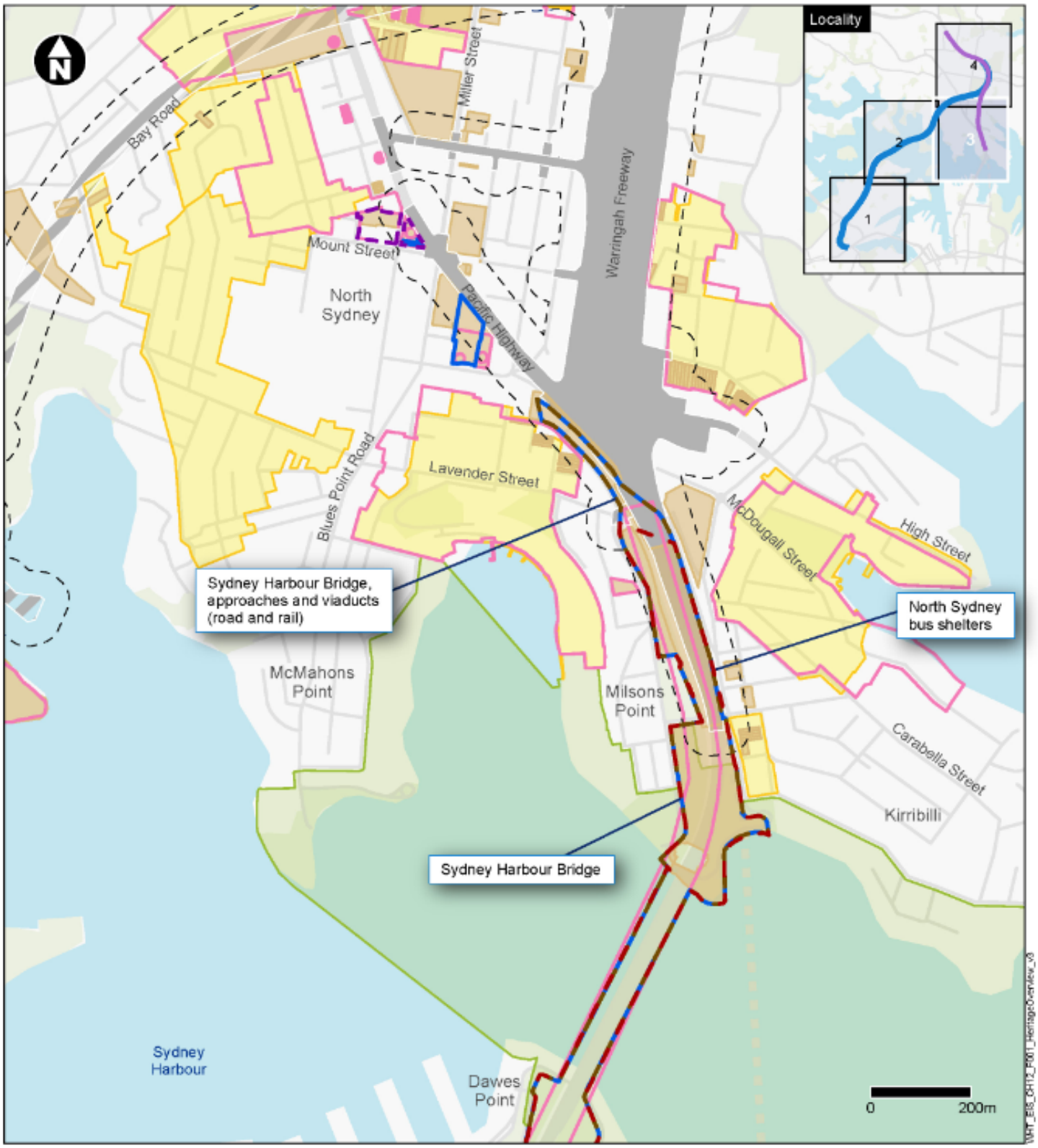


Figure 14-2 Location of all heritage items and potential heritage items within the study area (map 2)



Legend

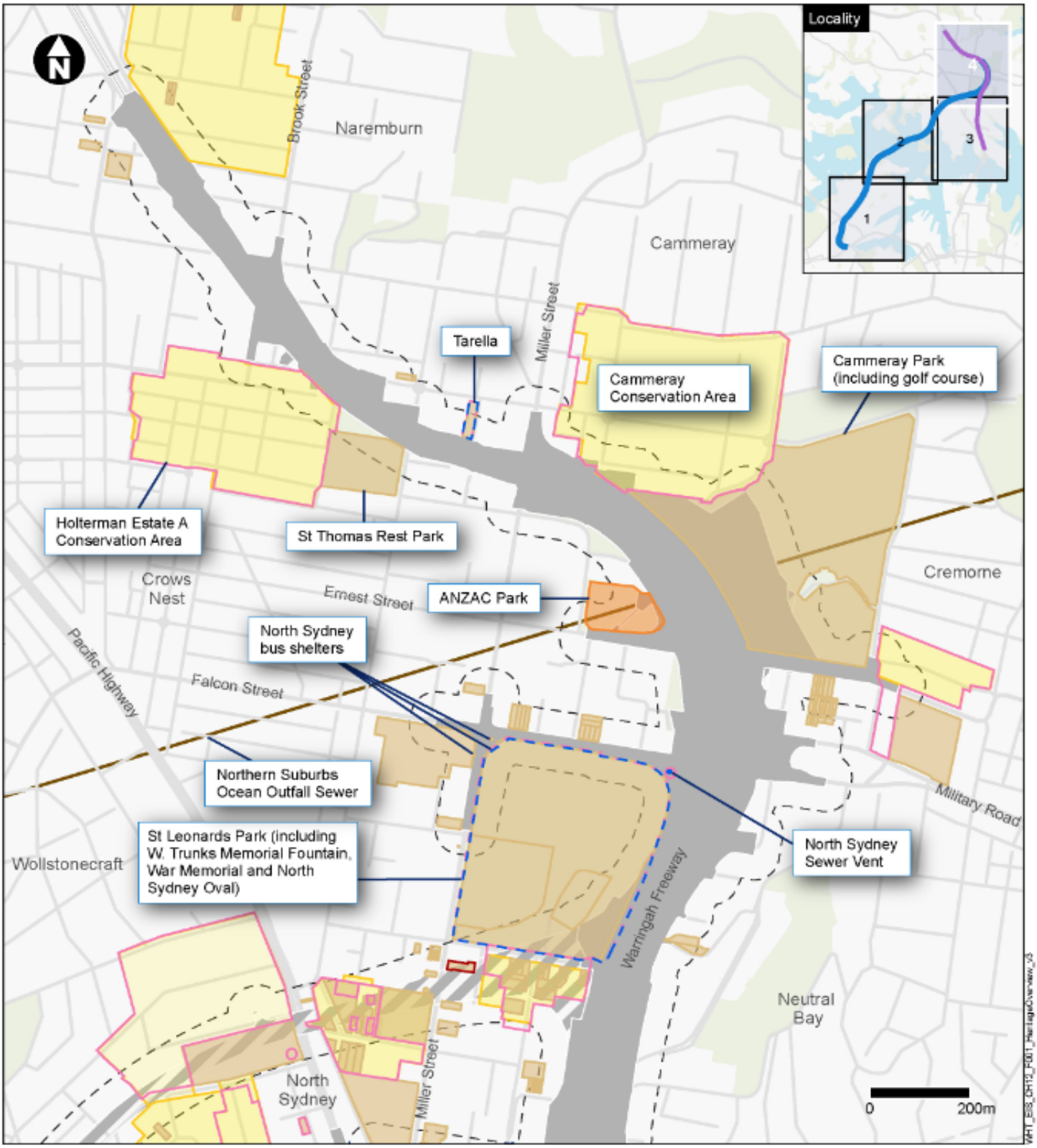
Construction features

- Study area
- Tunnel
- Construction footprint

Heritage and potential heritage items

- World Heritage List (DOE 2015)
- Commonwealth Heritage List (DOE 2017)
- National Heritage List (DOE 2015)
- State Heritage Register (DPE 2017)
- s170 area (compiled by Jacobs 2017)
- LEP Heritage Items (DPE 2017)
- LEP Heritage Items - Conservation Areas (DPE 2017)
- Register of the National Estate (DOE 2015)

Figure 14-3 Location of all heritage items and potential heritage items within the study area (map 3)



Legend

Construction features

- Study area
- Tunnel
- Construction footprint

Heritage and potential heritage items

- State Heritage Register (DPE 2017)
- s170 area (compiled by Jacobs 2017)
- LEP Heritage Items (DPE 2017)
- LEP Heritage Items - Conservation Areas (DPE 2017)
- Register of the National Estate (DOE 2015)
- Potential non-Aboriginal heritage items
- National Heritage List (DOE 2015)
- Potential maritime heritage item

Figure 14-4 Location of all heritage items and potential heritage items within the study area (map 4)

14.4.2 Potential maritime heritage impacts

Of the 18 maritime heritage items identified within the study area, 12 items would not be impacted by the project, including (refer to Figure 14-5):

- Balls Head Reserve, western foreshore
- Unidentified Balls Head Bay 1 shipwreck
- Balls Head #1 Unknown shipwreck
- ANZAC Bridge
- Wreck 1241
- Sidescan Sonar anomalies 1 to 7.

A heritage assessment for the remaining six heritage items that would be potentially impacted is included in Table 14-4 and shown in Figure 14-5. Areas of archaeological potential have also been assessed (Items 7, 8 and 9).

Table 14-4 Potential impacts on maritime heritage sites

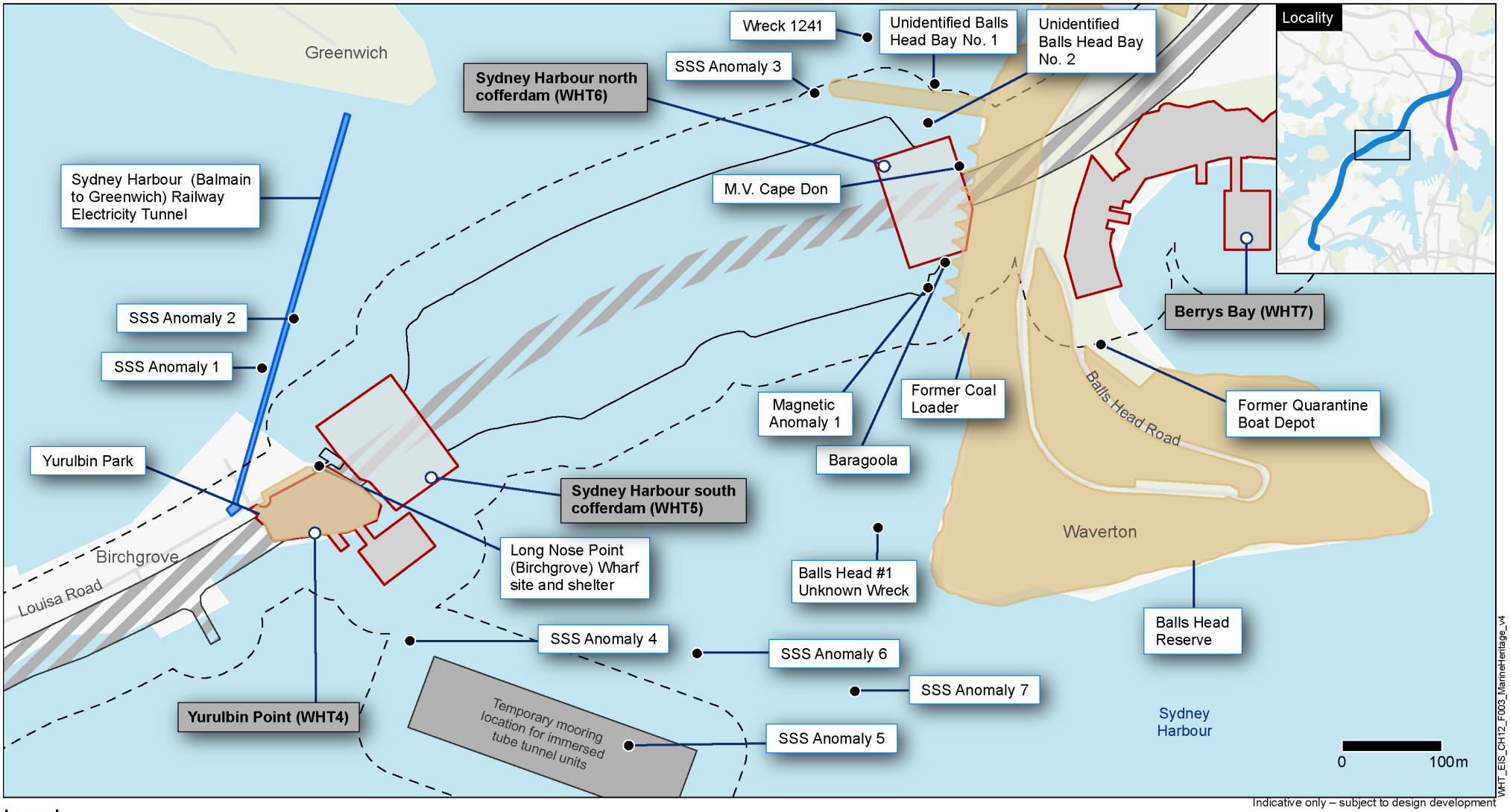
Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
Heritage items					
1	Long Nose Point (Birchgrove) Wharf site and shelter	Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005	Local	Direct impacts: • No planned direct impacts. Potential direct impacts: • Permanent physical impact to the heritage item from anchoring of project vessels on or around the item • Permanent physical impact to the heritage item from potential collision of project vessels • Permanent physical impact to the heritage item by water turbulence from the operation of project vessels. Indirect impacts: • Temporary vibration impacts to the heritage item due to the construction of the Sydney Harbour south cofferdam (WHT5) • Temporary visual impacts due to the location of the Sydney Harbour south cofferdam (WHT5) • Permanent settlement impacts to the heritage items due to the construction of the immersed tube tunnels.	**Minor** The proposed works may result in partial 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.
2	Unidentified Balls Head Bay 2	NSW Maritime Heritage Sites	Local	No direct impacts No potential direct impacts	**Minor** The proposed works may result in partial loss of site integrity and

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
				Indirect impacts: • Temporary vibration impacts to the heritage item due to the construction of the Sydney Harbour north cofferdam (WHT6).	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 an exclusion zone before construction.
3	*Baragoola*	Australian Register for Historic Vessels	State	Direct impacts: • Relocation of vessel to a different berthing facility. No potential direct impacts Indirect impacts: • Ability to maintain and repair the vessels could be reduced if relocated to unsuitable berth facilities.	**Negligible** With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be negligible. Vessel owners would be provided with reasonable notice to find a suitable alternate berthing within Sydney Harbour before construction commences. Transport for NSW should take no action that results in the degradation of the heritage significance of the items until relocation occurs.
4	M.V. *Cape Don*	Australian Register for Historic Vessels	State	Direct impacts: • Relocation of vessel to a different berthing facility.	**Negligible** With the implementation of the management measures described in

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
				No potential direct impacts Indirect impacts: • Ability to maintain and repair the vessels could be reduced if relocated to unsuitable berth facilities.	Section 14.5, the level of impact on the heritage item would be negligible. Vessel owners would be provided with reasonable notice to find a suitable alternative berthing within Sydney Harbour before construction commences. Transport for NSW should take no action that results in the degradation of the heritage significance of the items until relocation occurs.
5	Former Quarantine Boat Depot	North Sydney Local Environmental Plan 2013	Local	No direct impacts No potential direct impacts Indirect impacts: • Temporary visual impacts due to the location of construction equipment and infrastructure at Berrys Bay construction support site (WHT7).	**Minor** Impacts to the heritage item would be limited to temporary indirect visual impacts. With the implementation of the management measures described in Section 14.5, the level of impact on the heritage item would be minor.
Unverified anomalies – potential heritage items					
6	Magnetic anomaly 1	Unlisted	Unknown – low heritage sensitivity	Direct impacts: • Planned permanent physical impacts to the entire item due to dredging for the immersed tube tunnels. No potential direct impacts	**Minor** Assuming the magnetic anomaly has heritage value, the proposed dredging works for the immersed tube tunnels would result in loss of site integrity and reduction in

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
				No indirect impacts	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 if any.
Potential archaeological sites					
7	Potential archaeological sites in Sydney Harbour between Birchgrove and Waverton	Unlisted	Unknown – low to medium heritage sensitivity	Direct impacts: • Planned permanent physical impacts to the bed of the harbour in this area due to dredging for the immersed tube tunnels and construction of the Sydney Harbour south and Sydney Harbour north cofferdams (WHT5 and WHT6). Potential direct impacts: • Permanent physical impact to the bed of the harbour in this area from anchoring of project vessels on or around the item • Permanent 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 potential archaeological remains in this area due to the construction of the Sydney Harbour south and Sydney Harbour north cofferdams (WHT5 and WHT6).	**Minor** The proposed works may result in partial 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.

Item No.	Item name	Listing	Heritage significance	Impact type	Impact rating
8	Potential archaeological sites in the western portion of Berrys Bay	Unlisted	Unknown – low to medium heritage sensitivity	• No direct impacts Potential direct impacts: • Permanent physical impacts to the bed of the harbour in this area due to the construction of temporary wharves at Berrys Bay construction support site (WHT7) • Permanent physical impact to the bed of the harbour in this area from anchoring of project vessels on or around the item • Permanent physical impact to the bed of the harbour in this area by water turbulence from the operation of project vessels. No indirect impacts	**Minor** The proposed works may result in partial 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.
9	Potential archaeological sites in White Bay	Unlisted	Unknown – low heritage sensitivity	No direct impacts Potential direct impacts: • Permanent physical impacts to the bed of the harbour in this area due to the construction of a temporary wharf at the White Bay construction support site (WHT3). No indirect impacts	**Minor** The proposed works may result in partial 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.



Legend

Construction features

- Study area
- Tunnel
- Surface features
- Construction support site

Heritage and potential heritage items

- State Heritage Register (DPE 2017)
- LEP Heritage Items (DPE 2017)
- Potential maritime heritage item

Figure 14-5 Location of maritime heritage items impacted by the project

14.5 Environmental management measures

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

Table 14-5 Environmental management measures for non-Aboriginal heritage impacts

Ref	Phase	Impact	Environmental management measure	Location
Terrestrial heritage				
NAH1	Design	Sydney Harbour Bridge	The Lavender Street toll gantry will be designed to avoid direct impact with the heritage item and to minimise visual obstruction of the Lavender Street arch in consultation with relevant stakeholders. All works potentially affecting the Sydney Harbour Bridge will be carried out in accordance with *Sydney Harbour Bridge Conservation Management Plan 2007.*	WFU - Sydney Harbour Bridge
NAH2	Design	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* (Roads and Maritime, 2005f), and the *Heritage Interpretation Policy* (NSW Heritage Council, 2005).	WHT/WFU
NAH3	Design / construction	ANZAC Park	Impacts to areas of archaeological potential will be avoided by the project. In the event that works are required in the location of the air raid trenches, an archaeological excavation will be required with a test excavation methodology prepared in consultation with relevant stakeholders prior to the disturbance of this area.	WFU - ANZAC Park
NAH4	Pre-construction	Ongoing non-Aboriginal heritage impacts	Should at-property noise treatment be required at a premises 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 undertaking the works. Any treatment will be sympathetic to the heritage values of the item, designed with heritage architect input and be reversible where feasible and reasonable.	WHT/WFU

Ref	Phase	Impact	Environmental management measure	Location
NAH5	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 terrestrial items, in accordance with Appendix J (Non-Aboriginal heritage working paper): a) Item 2: The Valley Heritage Conservation Area, Rozelle and Balmain b) Item 4: Yurulbin Park, Birchgrove c) Item 7: BP site, Waverton d) Item 9: North Sydney Bus Shelters e) Item 10: St Leonards Park (including W. Tunks Memorial Fountain, War Memorial, and North Sydney Oval), North Sydney f) Item 14: Cammeray Park (including Golf Course), Cammeray g) Item 15: Cammeray Conservation Area, Cammeray. 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 detailed design (eg local councils).	WHT/WFU - Specific sites listed
NAH6	Pre-construction	Yurulbin Park	A condition survey will be completed prior to works commencing. Opportunities to temporarily remove, store and reinstate these elements on completion of construction work will be investigated and implemented if these elements need to be temporarily removed.	WHT - Yurulbin Park
NAH7	Pre-construction	Woodleys Shipyard	Should heritage buildings be changed externally, such as by adding cladding or extensions, further assessment will be carried out to identify approaches to avoid heritage fabric and/or minimise impact on heritage significance. This will include consideration of how works can be carried out to facilitate subsequent adaptive reuse or to minimise incremental impacts.	WHT - Woodleys Shipyard
NAH8	Pre-construction	Cammeray Golf Course	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	WFU – Cammeray Golf Course

Ref	Phase	Impact	Environmental management measure	Location
			heritage items in the region that demonstrate the same or similar significance as the Cammeray Golf Course.	
NAH9	Pre-construction / construction	Impacts on archaeology	Archaeological investigations will be carried out at: a) Item 4: Yurulbin Park, Birchgrove b) Item 7: BP site, Waverton.	WHT
NAH10	Construction	Unexpected discovery of historical heritage materials, features, or deposits	If at any time during construction of the project, historical heritage materials, features and/or deposits are encountered, the *Standard Management Procedure: Unexpected Archaeological Finds* (Roads and Maritime, 2015d) will be followed.	WHT/WFU
NAH11	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, 2015e) will be implemented.	WHT/WFU
NAH12	Construction	Heritage impacts during construction	Non-Aboriginal historical 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 historical heritage materials, features or deposits, or the discovery of human remains.	WHT/WFU
NAH13	Construction	BP Site	The heritage item will be rehabilitated and returned to an equivalent state as soon as practicable. Reinstatement of the site will include investigating the adaptive reuse of the site for the wider community.	WHT - BP Site
NAH14	Construction	Impacts to North Sydney bus shelters	The North Sydney bus shelters (Item 9) will be temporarily removed, stored and relocated on completion of construction work with council.	WFU
Maritime heritage				
NAH15	Design and Construction	Maritime non-Aboriginal	Investigation into the potential to relocate or redesign the temporary wharves at the proposed temporary construction facility	WHT – Berrys Bay

Ref	Phase	Impact	Environmental management measure	Location
		heritage impacts – Berrys Bay	WHT7 in Berrys Bay will be carried out to minimise impact on maritime heritage. Where this is not feasible then appropriate mitigation will be implemented before construction in accordance with the *Maritime Heritage Management Plan* (Mitigation Measure NAH16). Such mitigation will include carrying out archaeological excavation and documentation under the direction of a qualified archaeologist across all areas of impact at the site.	
NAH16	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 by a qualified and experienced maritime archaeologist. The Maritime Heritage Management Plan should 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) Exclusion 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: • Balls Head Coal Loader wharf • Yurulbin Park maritime infrastructure • Unidentified Balls Head Bay 2 wreck • Collapsed wharf, BP site, Berrys Bay e) Requirements for any mitigation recovery or archaeological excavations.	WHT
NAH17	Pre-construction	Maritime non-Aboriginal heritage	Any pre-dredge clearance of the bed of the harbour in Sydney Harbour will be carried out in the presence of a qualified maritime archaeologist who will identify any additional inspection or	WHT

Ref	Phase	Impact	Environmental management measure	Location
		impacts	documentation that should be carried out during the clearance dives. This may include inspecting the locations of known or suspected submerged cultural heritage, detailed recording, or recovery and relocation of heritage objects.	
NAH18	Pre-construction	Maritime non-Aboriginal heritage impacts	Archival recording of the following maritime heritage sites will be carried out prior to works commencing in order to mitigate against predicted or potential impacts, and to establish a baseline against which to measure any changes to these sites due to works at: a) Balls Head Coal Loader wharf b) Unidentified Balls Head Bay 2 wreck c) Yurulbin Park maritime infrastructure d) Collapsed timber wharf, BP site, Berrys Bay e) Slipway No. 1, former Woodleys Shipyard, Berrys Bay. The archival recording will include: a) Creation of a detailed site plan by a surveyor for Balls Head Coal Loader, Yurulbin Park maritime infrastructure, collapsed timber wharf and Slipway No. 1, former Woodley's shipyard b) Detailed recording and inventory of all site elements c) Detailed diver survey and recording of submerged sites and site elements, primarily in the form of video and photography. All archival recordings are to be prepared consistently with the current NSW Heritage Council endorsed standards and guidelines.	WHT
NAH19	Pre-construction	Maritime non-Aboriginal heritage impacts	A sidescan sonar survey will be prepared for sections of the Sydney Harbour crossing not already included in the sidescan sonar coverage in Area A in Appendix K (Technical working paper: Maritime heritage*)*. A qualified maritime archaeologist will assess the results of the sidescan survey to identify any additional potential heritage items requiring investigation and assessment.	WHT
NAH20	Pre-construction	Maritime non-Aboriginal heritage	Transport for NSW will give reasonable time and notice for the owners of the historic vessels *M.V Cape Don* and *Baragoola* to find a suitable alternate	WHT

Ref	Phase	Impact	Environmental management measure	Location
		impacts	berthing within Sydney Harbour before construction commences. Transport for NSW will take no action that results in the degradation of the heritage items until relocation occurs.	
NAH21	Construction	Maritime non-Aboriginal heritage impacts	An exclusion zone will be established around the former Balls Head Coal Loader wharf extending at least 15 metres from the edge of the wharf apron and thus also covering the Unidentified Balls Head Bay 1 and 2 wrecks.	WHT - Balls Head Coal Loader Wharf

Western Harbour Tunnel = WHT, Warringah Freeway Upgrade = WFU

Chapter 15

Aboriginal cultural heritage

January 2020

15 Aboriginal cultural heritage

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

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
Heritage	
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: 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** identifies Aboriginal places of heritage significance as defined in the Standard Instrument – Principal Local Environmental Plan.
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 15.4**.
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: Cultural Heritage assessment report) and in **Section 4.4** and **Section 4.5** of **Chapter 4** (Project development and alternatives).
c. in areas identified as having potential archaeological significance, undertake	Details of test excavations carried out are presented in **Section 15.3** and **Appendix E** of

Secretary's requirement	Where addressed in EIS
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;	**Appendix L** (Technical working paper: Cultural heritage assessment report).
e. 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**.
f. provide a comparative analysis to inform the rarity and representative value of any heritage places proposed for demolition	No sites are proposed for demolition.
g. 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.**
h. be undertaken by a suitably qualified heritage consultant (note: where archaeological excavations are proposed the relevant consultant must meet the NSW Heritage Council's Excavation Director criteria).	**Appendix L** (Technical working paper: 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 2010d).	**Appendix L** (Technical working paper: Cultural Heritage assessment report) provides details of qualifications held by archaeologists. **Section 15.2** provides details of attendance for site surveys.

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* (Office of Environment and Heritage, 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, 2011) specifically tailors and applies the requirements of these guidelines to its road projects.

The *Native Title Act 1993* (Cth) 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.

15.2 Assessment methodology

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

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 took into account 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 50 metres of the project's construction footprint have been considered. Searches of AHIMS, relevant local environmental plans and State and Commonwealth heritage registers were carried out in March 2018. Feedback from Registered Aboriginal Parties has been incorporated into the ACHAR.

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.

Registered Aboriginal Parties were identified in accordance with the DECCW guidelines (2010b) and invited to focus group meetings (September 2017 and October 2019) on the project, and have been provided an opportunity to review the survey and assessment methodology. Feedback from Registered Aboriginal Parties has been incorporated into the ACHAR. Aboriginal site officers were engaged for archaeological fieldwork in January 2018.

Aboriginal stakeholder consultation was carried out in accordance with the PACHCI and is discussed in Chapter 7 (Stakeholder and community engagement).

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
- 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 8000 to 6000 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 Sydney 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. 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 people 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 along and around the project alignment, with areas of plentiful food resources associated with shorelines, riparian zones and adjacent areas including Berrys Bay, Yurulbin Park and the Sydney Harbour foreshore. During urban development, many of these areas were 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 project is located in a region bordered by steep headlands of exposed Hawkesbury Sandstone with some low hills and rises on later sediments.

The project is underlain by Hawkesbury Sandstone across the majority of the project alignment, with isolated occurrences of Ashfield Shale in the north-eastern portion of the project alignment, around North Sydney and Neutral Bay. During the glacial maximum, the area would have resembled the flat-topped, steeply stepped river valleys still seen in the Blue Mountains, creating plateaus with sandstone exposures exploited for engraved art, but which held little water or complex vegetation. Rockshelters, seeps and little creeks formed repeatedly down the cascading cliff sides, now largely drowned, while the ancient Parramatta River itself was probably narrow and fast-flowing.

Most of the project alignment is underlain by soils of the Gymea landscape group. Hawkesbury landscape group soils surround the shorelines of Sydney Harbour and there are isolated occurrences of the Blacktown landscape group soils around North Sydney. In the drowned river valley, there is evidence of more extensive open soil development, which would have created yet another resource and subsistence zone for occupation by Aboriginal people.

After rising sea levels began to stabilise about 8000 years ago, the now-familiar Sydney Harbour foreshore environments began to develop. These provided environments for different types of fish, shellfish and other marine resources to be exploited. Below the water surface, sedimentation began to fill up and smooth the tumbled rocky cliffsides, masking their appearance and possibly burying evidence of former Aboriginal occupation.

The present landscape is highly urbanised and is characterised by planted native vegetation mixed with exotic or invasive species. Vegetation within built-up areas is generally limited to planted street trees and vegetation within public parks and reserves, such as at Yurulbin Park, Birchgrove and St Leonards Park.

Urban development has resulted in a high level of disturbance across the region. This has included extensive vegetation clearance, landscape modification and infrastructure development. This level of disturbance means that most Aboriginal deposits that were present are likely to have been destroyed.

15.3.3 Database search results

Aboriginal Heritage Information System (AHIMS) sites in the region around the project are shown in Figure 15-1. Of these, nine sites have been identified within 50 metres of the project construction footprint:

- Seven rock shelters (with middens and engravings)
- One midden site
- One art site (engravings).

Details of these 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 project construction footprint is shown in Figure 15-2. The location of Aboriginal sites presented in Figure 15-2 is based on the results of extensive AHIMS searches. Where possible, the location of these sites were confirmed during the archaeological survey. As discussed in Section 15.3.5, the location of four sites could not be verified due to private property access constraints.

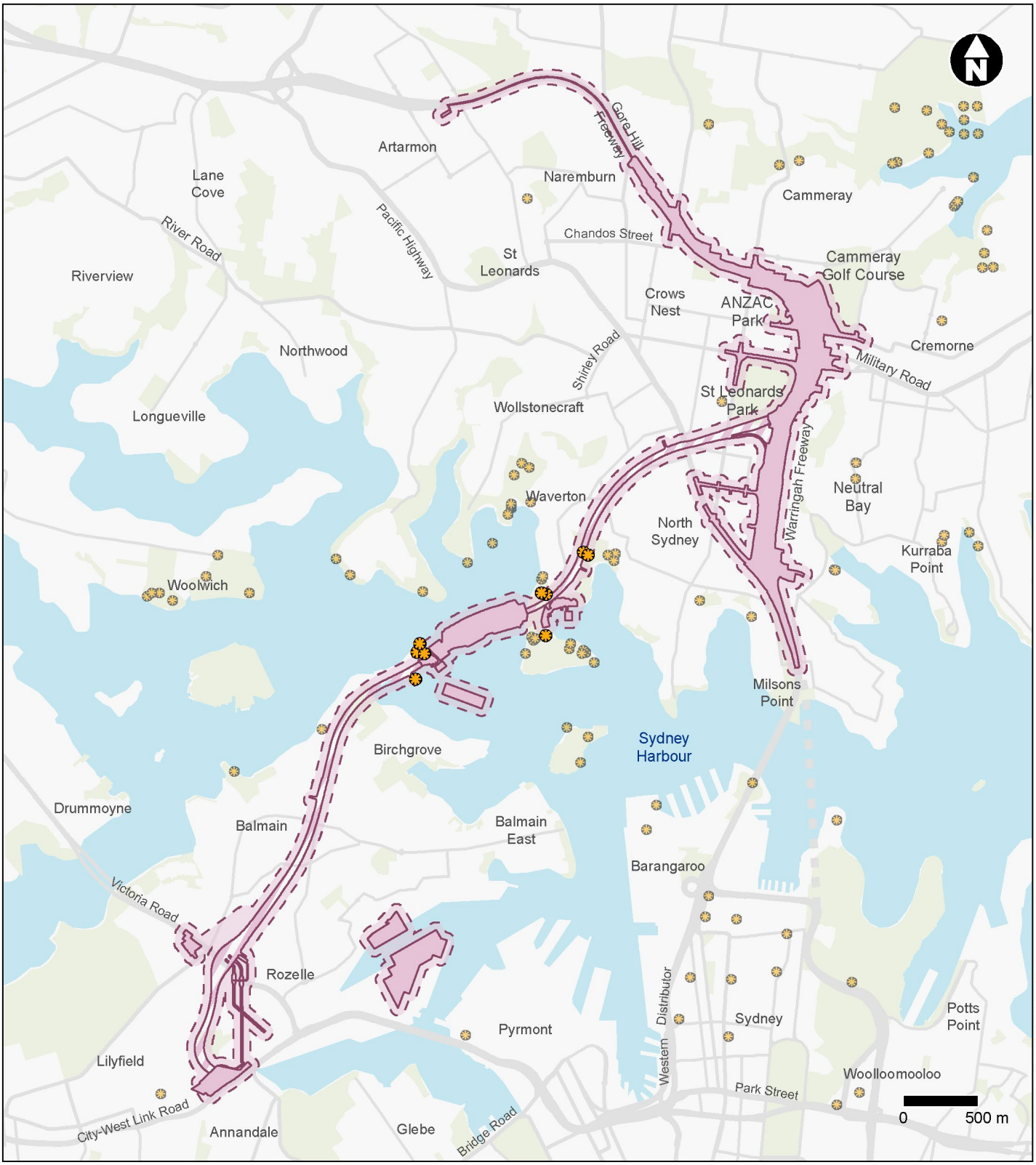
Four of the AHIMS sites within 50 metres of the project construction footprint are also listed under the *Leichhardt Local Environmental Plan 2013*:

- LEP item A4: Aboriginal midden and rock shelter, 144 Louisa Road at Birchgrove
- LEP item A8: Aboriginal middens and rock shelter, Numa Street (public reserve) at Birchgrove
- LEP item A6: Aboriginal middens and rock shelter, 7 Numa Street at Birchgrove
- LEP item A7: Aboriginal middens and rock shelter, 9 Numa Street at Birchgrove.

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

AHIMS site ID/LEP item	Site name	Site type	Proximity to the project	Cultural value description
45-6-2180	Quarantine Cave: Waverton	Shelter with midden (rock shelter is less than 50 m^3 in size)	Within 50 metres of the surface works at the Berrys Bay construction support site (WHT7).	Part of cultural area and occupation site.
45-6-2762	Coal Loader 1	Shelter with midden (rock shelter is less than 50 m^3 in size; shell is non-human bone and organic material)	Within 50 metres of the driven tunnel alignment and over 50 metres from surface works at the Berrys Bay construction support site (WHT7).	Part of cultural area and occupation site.
45-6-1270	Waverton Park	Midden	Within 50 metres of the driven tunnel alignment and over 50 metres from surface works at the Berrys Bay construction support site (WHT7).	Part of cultural area and occupation site.
45-6-2181	Waverton Park Cave	Shelter with midden (rock shelter is less than 50 m^3 in size)	Directly above the driven tunnel alignment and over 50 metres from surface works at the Berrys Bay construction support site (WHT7).	Part of cultural area and occupation site.
45-6-0026	Whale Rock	Rock engravings	Within 50 metres of the driven tunnel alignment and over 50 metres of surface construction works at the Berrys Bay construction support site (WHT7).	Part of cultural area and occupation site. Vantage point looking toward harbour. Likely a place of spiritual significance. Multiple engravings including large whale with human figures. This engraving was recorded as early as the 1840s.
45-6-1901 LEP item A7	Long Nose Point 1	Shelter with midden and art (rock shelter is less than 50 m^3 in size)	Assumed to be within 50 metres of driven tunnel alignment and potentially within 50 metres of surface construction works at Yurulbin Point construction support site (WHT4). Further investigation and	Part of cultural area and occupation site.

AHIMS site ID/LEP item	Site name	Site type	Proximity to the project	Cultural value description
			consultation would be carried out to confirm site location.	
45-6-2287 LEP item A6	Yerroulbin Cave	Shelter with midden and art (rock shelter is less than 50 m^3 in size)	Assumed to be within 50 metres of the driven tunnel alignment and potentially within 50 metres of surface construction works at the Yurulbin Point construction support site (WHT4). Further investigation and consultation would be carried out to confirm site location.	Part of cultural area and occupation site. Vantage point looking toward harbour. Likely a place of spiritual significance. Hand stencils recorded as being present.
45-6-2672 LEP item A4	Shed Cave	Shelter with midden and art (rock shelter is less than 50 m^3 in size)	Assumed to be within 50 metres of the driven tunnel alignment (based on a hand drawn map provided on the AHIMS site card) and potentially within 50 metres of surface construction works at the Yurulbin Point construction support site (WHT4). Further investigation and consultation would be carried out to confirm site location.	Part of cultural area and occupation site.
45-6-2967 LEP item A8	5 Hands Shelter	Shelter with midden and art (rock shelter is less than 50 m^3 in size)	Assumed to be within 50 metres of the driven tunnel alignment and potentially within 50 metres of surface construction works at the Yurulbin Point construction support site (WHT4). Further investigation and consultation would be carried out to confirm site location.	Part of cultural area and occupation site.



Legend

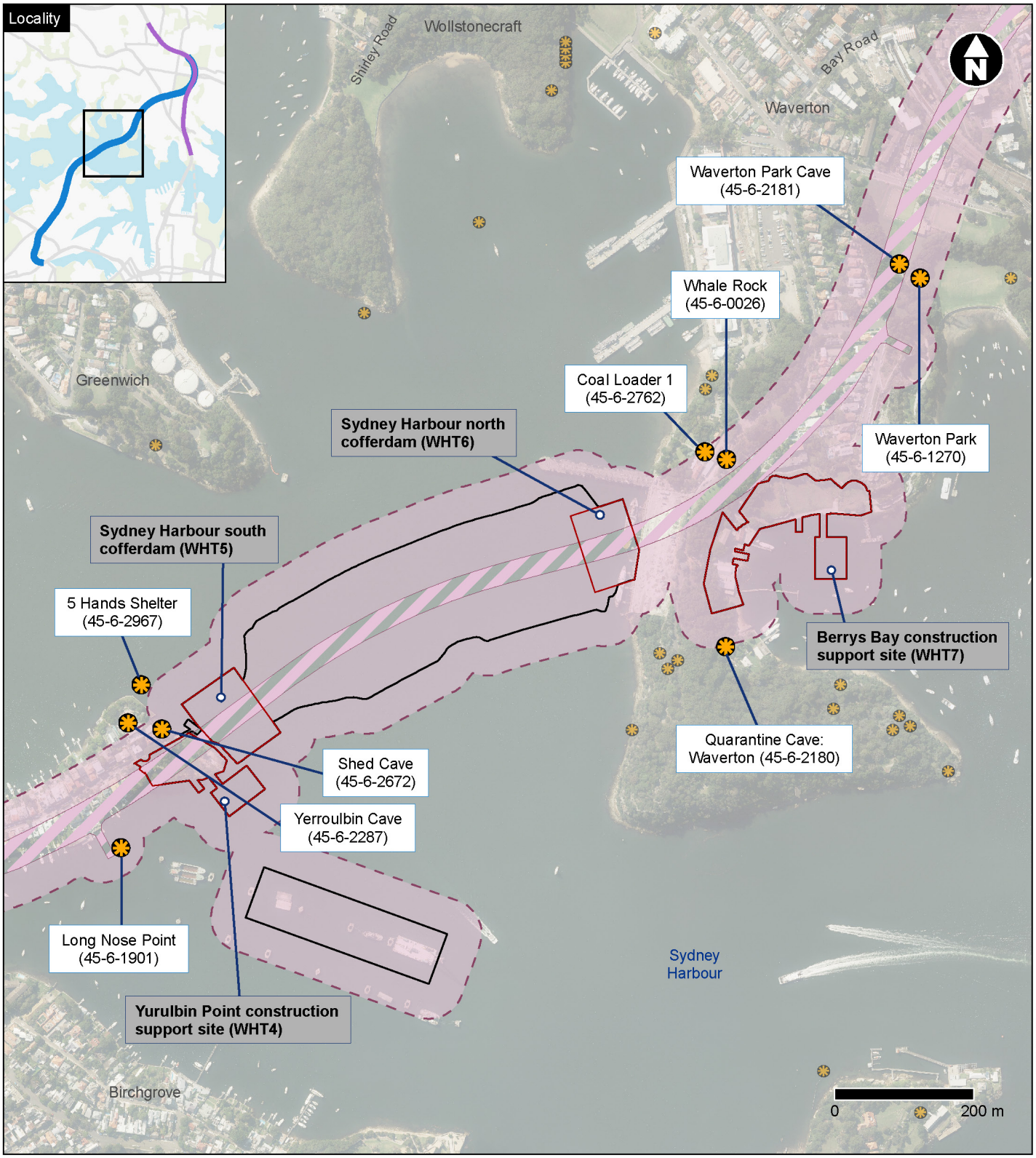
Construction features

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

AHIM sites

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

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



Legend

Construction features

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

AHIMS sites

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

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

15.3.4 Potential submerged Aboriginal sites

Potential submerged Aboriginal sites refer to archaeological sites inundated since the rise in sea levels that occurred in Port Jackson (including Sydney Harbour) after 18,000 years ago. Aboriginal sites that could occur in inundated areas of the study area include:

- Rock shelters with occupation evidence and deposit
- Engraving and applied pigment art and axe grinding grooves on sandstone ledges and faces
- Middens and/or stone artefact scatters on sandstone platforms and within soil profiles
- 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. Between Yurulbin Point and Balls Head Aboriginal sites may have a lesser likelihood of surviving inundation due to present strong tidal flows. Elsewhere in the area, data collected from geotechnical drilling for the project indicates that for a time during the latest sea level rise, water flow was sufficiently slow to allow sedimentary build-up that was potentially capable of trapping, burying and effectively protecting archaeological sites and deposits.

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 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%
Low	25–49%
Very Low	2–24%
Remote	>0–1%

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 Yurulbin Point and Waverton	Stone artefacts, midden deposits and fish traps	Moderate to high (in one localised area)	In identified peat deposits formed above residual soils (as shown from geotechnical investigations).
	Stone artefacts and	Low	In identified residual soils.

Location	Potential Aboriginal site type	Archaeological potential	Predicted potential location within study area
	midden deposits		
	Rock shelters, art, grinding grooves, middens, stone artefact scatters, quarry sites and fish traps	Very low	Buried beneath at least 10 metres of marine sediment.
Berrys Bay	Rock shelters, grinding grooves, middens and/or stone artefact scatters, 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 20 metres thick below the current bed of the harbour surface.
White Bay	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 20 metres thick below the current bed of the harbour surface as well as under reclamation.

15.3.5 Archaeological survey results

Targeted archaeological surveys were carried out in January 2018 to confirm the location of registered AHIMS sites and LEP items and to assess areas identified as having potential Aboriginal archaeological sensitivity based on particular landforms. These areas of potential Aboriginal archaeological sensitivity and archaeological survey results are described in Table 15-5.

The archaeological surveys verified the presence of five of the nine identified AHIMS sites. The location of the remaining four sites could not be verified due to private property access constraints. Further investigation and consultation with Department of Premier and Cabinet (Heritage), the Metro Local Aboriginal Land Council (LALC) and the RAPs would be carried out to confirm the location of these four remaining sites.

No previously unrecorded Aboriginal cultural heritage places, objects or areas of potential archaeological deposits were identified during the surveys.

Table 15-5 Outcomes of the archaeological surveys

Survey area	Aboriginal archaeological sensitivity	Archaeological survey results
Yurulbin Park, Birchgrove	Moderate	Sites not accessed due to private property access constraints: • 5 Hands Shelter (45-6-2967) • Yerroulbin Cave (45-6-2287) • Long Nose Point 1 (45-6-1901) • Shed Cave (45-6-2672).

Survey area	Aboriginal archaeological sensitivity	Archaeological survey results
		No further Aboriginal cultural heritage was identified.
Balls Head and surrounds, Waverton Peninsula	High	Registered AHIMS sites inspected: • Waverton Park Cave (45-6-2181) • Waverton Park (45-6-1270) • Coal Loader 1 (45-6-2762) • Whale Rock (45-6-0026) • Quarantine Cave: Waverton (45-6-2180). No further Aboriginal cultural heritage was identified.
St Leonards Park, North Sydney (south east section of the park between The Greens Bowling Club and the Warringah Freeway)	Low	No Aboriginal cultural heritage was identified.
ANZAC Park, Cammeray	Low	No Aboriginal cultural heritage was identified.
Cammeray Golf Course, Cammeray (western edge of the Cammeray Golf Course site between the Warringah Freeway and Ernest Street)	Low	No Aboriginal cultural heritage was identified.

15.3.6 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 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.

Any potential submerged Aboriginal archaeological sites are likely to 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	
Waverton Park Cave (45-6-2181)	High	N/A	Moderate to high	Moderate	Moderate to high
Waverton Park (45-6-1270)	High	N/A	Moderate to high	Low	Moderate to high
Coal Loader 1 (45-6-2762)	High	N/A	Moderate	N/A	Moderate to high
Whale Rock (45-6-0026	High	High	High	High	High
Quarantine Cave: Waverton (45-6-2180)	High	N/A	Moderate to high	Moderate	Moderate to high
5 Hands Shelter (45-6-2967)	The sites were unable to be inspected due to private property access constraints and have been assumed to hold 'high' overall significance for the purpose of this assessment.				
Yerroulbin Cave (45-6-2287)					
Long Nose Point 1 (45-6-1901)					
Shed Cave (45-6-2672)					

15.4 Assessment of potential impacts

15.4.1 Potential impacts to terrestrial Aboriginal heritage sites

The majority of potential impacts to Aboriginal sites would likely occur during construction rather than operation of the project, 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
- Indirect impacts associated with vibration and settlement from tunnelling works beneath or near to Aboriginal sites
- Indirect impacts associated with Aboriginal site setting (visual impacts, changes to vistas/landscapes), dust, 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:

- No verified Aboriginal heritage sites are located within the surface construction footprint of the project, and therefore no known sites would be directly impacted by the project
- One archaeological site (45-6-2180, Quarantine Cave: Waverton) is located within 50 metres of surface works and may be subject to indirect impacts associated with vibration and settlement
- One archaeological site (45-6-2181, Waverton Park Cave) is located directly above the tunnel alignment and may be subject to indirect impacts associated with vibration and settlement
- Three archaeological sites (45-6-1270, Waverton Park; 45-6-2762, Coal Loader 1; and 45-6-0026, Whale Rock) are located within 50 metres of the tunnel alignment and may be subject to indirect impacts associated with vibration and settlement.

The four archaeological sites at Long Nose Point, Birchgrove that could not be inspected (45-6-2967, 45-6-2287, 45-6-1901 and 45-6-2672) are likely to be within 50 metres of the tunnel alignment or surface construction works and could be indirectly impacted by vibration and settlement. No Aboriginal sites were identified within the construction footprint at the surface in this location.

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
Waverton Park Cave (45-6-2181)	Shelter with midden	High	Indirect – vibration Vibration impact would be within the minimum working distance for unsound structures and could pose a risk to the structural integrity of the site if not minimised and managed.	Moderate
			Indirect – settlement Settlement is predicted to be between 15-20 millimetres.	Negligible
Waverton Park (45-6-1270)	Midden	High	Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible
Coal Loader 1 (45-6-2762)	Shelter with midden	Moderate	Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible
Quarantine Cave: Waverton (45-6-2180)	Shelter with midden	High	Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible
Whale Rock (45-6-0026)	Rock engraving	High	Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible
			Indirect – settlement Settlement is predicted to be less than 10 millimetres.	Negligible

Site	Site type	Overall site significance	Potential impact and description	Risk of potential impacts
5 Hands Shelter (45-6-2967)	Shelter with midden and art	Moderate-high	Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible
Yerroulbin Cave (45-6-2287)	Shelter with midden and art	Moderate-high	Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible
Long Nose Point 1, 9 Numa Street, Birchgrove (45-6-1901)	Shelter with midden and art	Moderate-high	Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible
Shed Cave (45-6-2672)	Shelter with midden and art	Moderate-high	Indirect – vibration Vibration impact would be outside the minimum working distance for unsound structures.	Negligible
			Indirect – settlement Settlement is predicted to be less than 10 millimetres.	Negligible

Note: Each AHIMS site has been assessed for indirect impacts associated with settlement. With the exception of Waverton Park Cave (45-6-2181), Shed Cave (45-6-2672) and Whale Rock (45-6-0026) 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 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 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 1:4 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. A rock protection layer would be installed with rock materials to protect the immersed tube tunnels from activities during operation, including falling or dragging anchors.

The majority of potential impacts to submerged Aboriginal 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 remains would be buried and movement of individual artefacts 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 remains would demonstrate that such remains could be present across Sydney 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 Yurulbin Point and Waverton	Stone artefacts, midden deposits and fish traps	Moderate to high (in one localised area)	Moderate (without mitigation)	Negligible
	Stone artefacts and midden deposits	Low	Negligible to moderate	Negligible

Location	Potential Aboriginal site type	Archaeological potential	Significance of direct impacts	Risk of indirect impacts
			(without mitigation)	
	Rock shelters, art, grinding grooves, middens, stone artefact scatters, quarry sites and fish traps	Very low	Negligible to moderate (without mitigation)	Negligible
Berrys Bay	Rock shelters, grinding groves, middens and/or stone artefact scatters, stone quarry sites, fish traps	Moderate to high	Negligible to minor	Negligible
White Bay	Rock shelters, grinding groves, middens and/or stone artefact scatters, stone quarry sites, fish traps	Moderate to high	Negligible to minor	Negligible

15.5 Environmental management measures

Measures to avoid, minimise or manage Aboriginal 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	Prior to construction, further consultation with Department of Premier and Cabinet (Heritage), the Metro LALC and the RAPs will be carried out to decide an appropriate course of action for previously recorded Aboriginal sites not assessed during archaeological surveys due to site accessibility constraints. If new information regarding site condition and location is identified during consultation suggesting the sites may be subject to impacts due to vibration and settlement, then mitigation measures AH2, AH3 and AH4 will apply.	Yerroulbin Cave (45-6-2287) Long Nose Point 1 (45-6-1901) 5 Hands Shelter (45-6-2967) Shed Cave (45-6-2672)

Ref	Phase	Impact	Environmental management measure	Location
			If during construction works a site is located, Department of Premier and Cabinet (Heritage), an appropriately qualified archaeologist and the Metro LALC will be contacted and the site will be re-recorded in situ. If the site is determined to be within the construction footprint, consultation between Department of Premier and Cabinet (Heritage), Transport for NSW, Metro LALC and RAP groups will occur with the aim of avoiding, minimising and managing adverse impacts on the site before construction works at the location recommence.	
AH2	Pre-construction and construction	Aboriginal heritage – vibration impacts	The following process will be carried out to confirm where vibration monitoring at terrestrial AHIMS sites will be required: a) Terrestrial Aboriginal site condition surveys will be completed using photogrammetry and 3D-capture techniques to determine which AHIMS sites are considered to be structurally unsound b) Where this determination cannot be made, the AHIMS 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 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.	All registered AHIMS sites located within 50 metres of the project construction footprint
AH3	Construction	Aboriginal heritage – vibration impacts	Vibration monitoring will be carried out at AHIMS sites that have been identified as requiring monitoring in accordance with the process outlined in mitigation measure AH2. Where possible, works will be	All registered AHIMS sites subject to vibration intensive activities determined to be structurally

Ref	Phase	Impact	Environmental management measure	Location
			conducted in a manner to minimise vibration levels, to less than 2.5 millimetres per second at all structurally unsound AHIMS sites.	unsound (see AH2)
AH4	Construction	Aboriginal heritage – vibration impacts	If vibration monitoring identifies that vibration levels exceed 2.5 millimetres per second at AHIMS sites that have been identified as requiring monitoring, a site visit will be organised with a representative from Metro LALC to record any changes to the integrity of the site that may have resulted from construction vibration, and updated site cards must be prepared accordingly. Condition surveys may include further photogrammetry and 3D-capture techniques.	All registered AHIMS sites subject to vibration intensive activities determined to be structurally unsound (see AH2)
AH5	Construction	Unexpected 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 human remains are discovered they will be managed in accordance with the *Standard Management Procedure: Unexpected Heritage Items* (Roads and Maritime Services, 2015e).	WHT/WFU
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.	WHT/WFU
Maritime Aboriginal heritage				
AH7	Pre-construction	Maritime Aboriginal heritage impacts	The need for further high-resolution geophysical survey/s to identify the presence of submerged rock overhangs concealed by marine sediments will be investigated in consultation with a maritime archaeology advisor. If it is determined that a high resolution geophysical survey could produce the desired results, the geophysical	Sydney Harbour south and north cofferdams (WHT5 and WHT6)

Ref	Phase	Impact	Environmental management measure	Location
			survey will be carried out.	
AH8	Construction	Maritime Aboriginal heritage impacts	The following mitigation measures will be carried out if the geophysical survey described in AH7 is inconclusive or if the geophysical survey identifies rock overhangs at least 1.2 metres in height: a) Excavations will be visually monitored after WHT5 and WHT6 cofferdams have been de-watered in order to identify voids within the bedrock and identify potential rock shelters b) In consultation with a suitably experienced geomorphologist, criteria will be established for the identification of pre-inundation soil deposits (peat, charcoal, roots, etc) and where necessary, samples of marine sediments will be collected to identify if pre-inundation soil deposits are evident c) If pre-inundation soil deposits are evident then a controlled archaeological investigation will be carried out to recover any artefacts, subject to bed rock conditions and safety constraints within the cofferdams.	Sydney Harbour south and north cofferdams (WHT5 and WHT6)
AH9	Pre-construction and construction	Maritime Aboriginal heritage impacts	Prior to construction, determination of whether dredged soil units have potential to contain cultural material will be carried out by a palaeo-geomorphologist through review of existing borehole information. If the potential to encounter cultural material is identified, then an appropriate sampling protocol will be designed so that samples can be collected during construction if feasible.	Dredging works in the immediate vicinity of borehole B215W in Area A, located between Yurulbin Point and Balls Head (Appendix L (Technical working paper: Cultural heritage assessment report))

Western Harbour Tunnel = WHT, Warringah Freeway Upgrade = WFU

Chapter 16

Geology, soils and groundwater

January 2020

16 Geology, soils and groundwater

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

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

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

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

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

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

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

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

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

16.1 Legislative and policy framework

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

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

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

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

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

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

16.2 Assessment methodology

The methodology included:

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

16.3 Existing environment

16.3.1 Topography

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

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

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

16.3.2 Geology

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

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

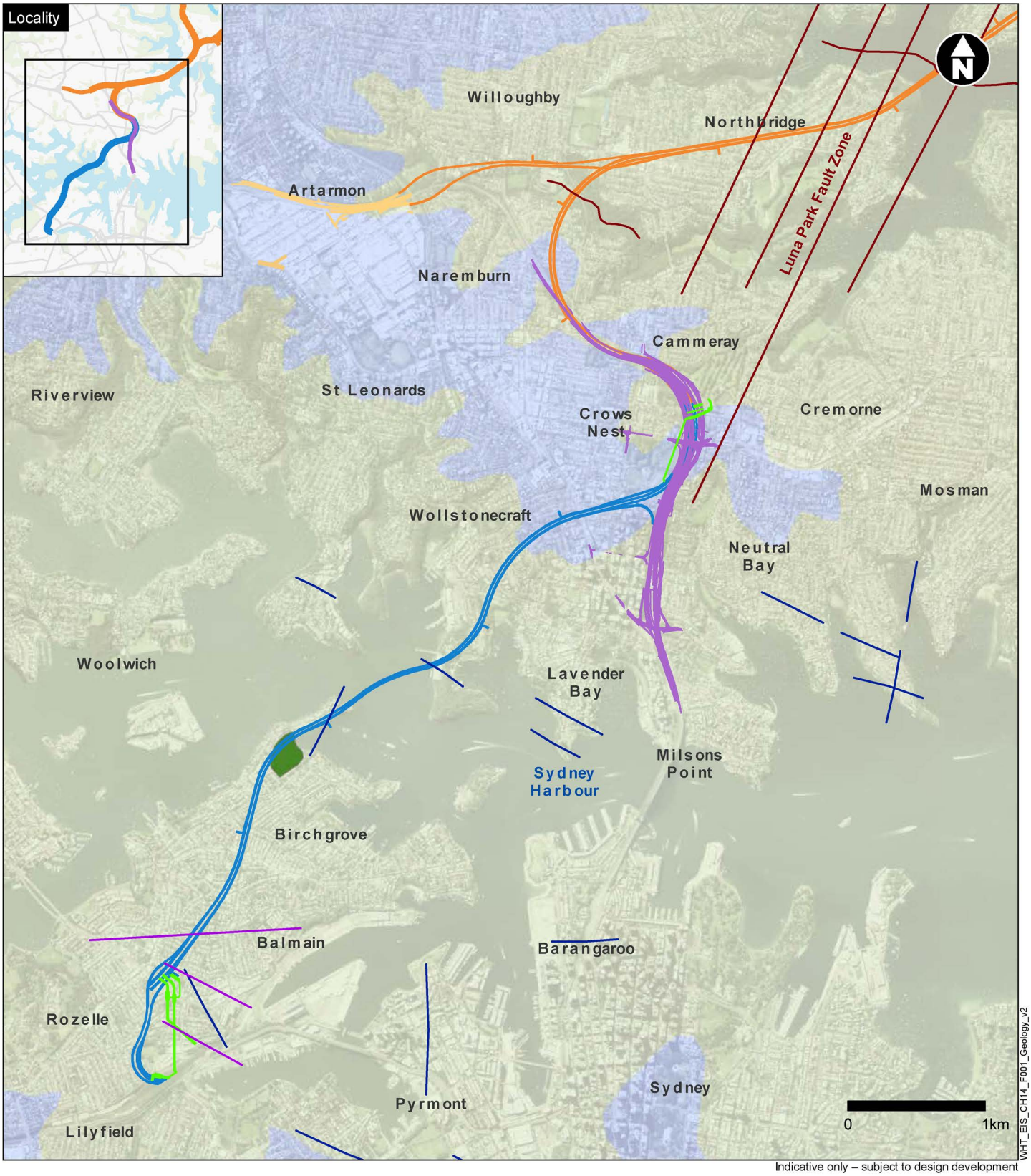
Table 16-2 Geological units underlying the project area

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

Geological structural features

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

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



Legend

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

Connecting projects
- Beaches Link
- Gore Hill Freeway Connection

Geology
- Hawkesbury sandstone
- Ashfield shale
- Anthropogenic Fill

Geological structural features
- Inferred dyke
- Inferred fault
- Mapped dyke

Figure 16-1 Regional geological context

16.3.3 Soils

Soil groups

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

Table 16-3 Soil landscape groups across the project area

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

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

Legend

Operational features

- Western Harbour Tunnel alignment
- Warringah Freeway alignment

Connecting projects

- Beaches Link alignment
- Gore Hill Freeway connection

Soil landscape

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

Figure 16-2 Soil landscapes

Marine sediments

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

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

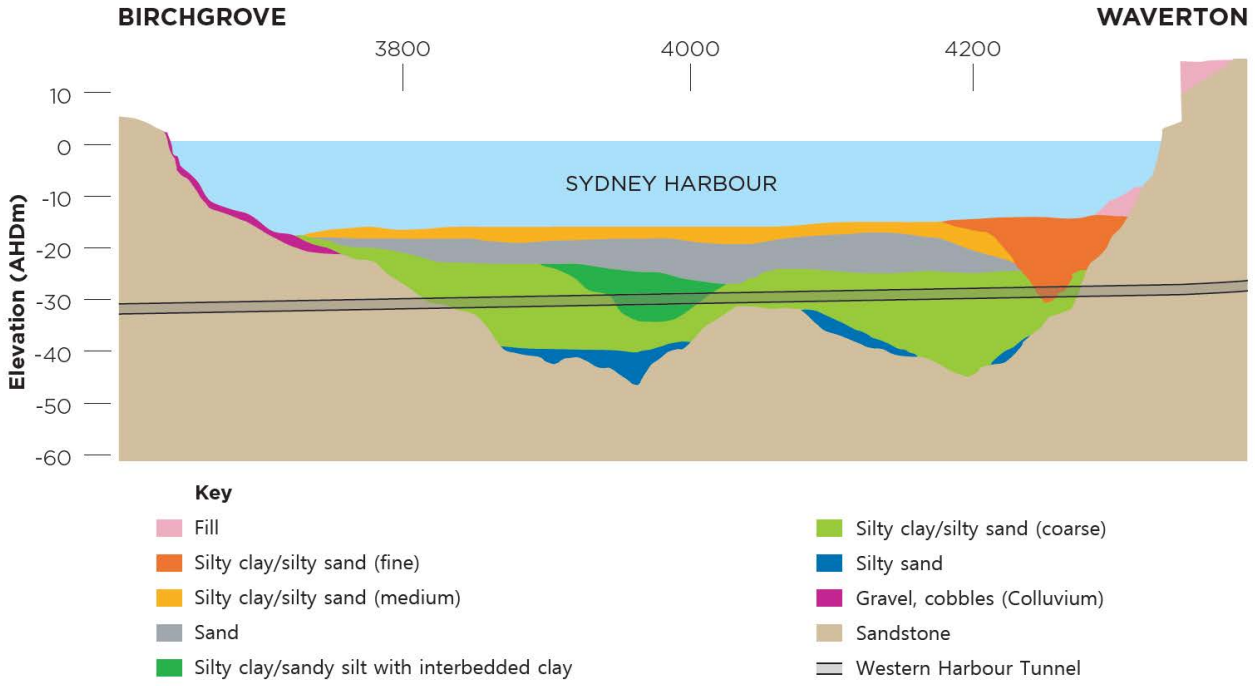


Figure 16-3 Sydney Harbour marine sediment profile

Acid sulfate soils

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

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

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

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

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

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

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

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

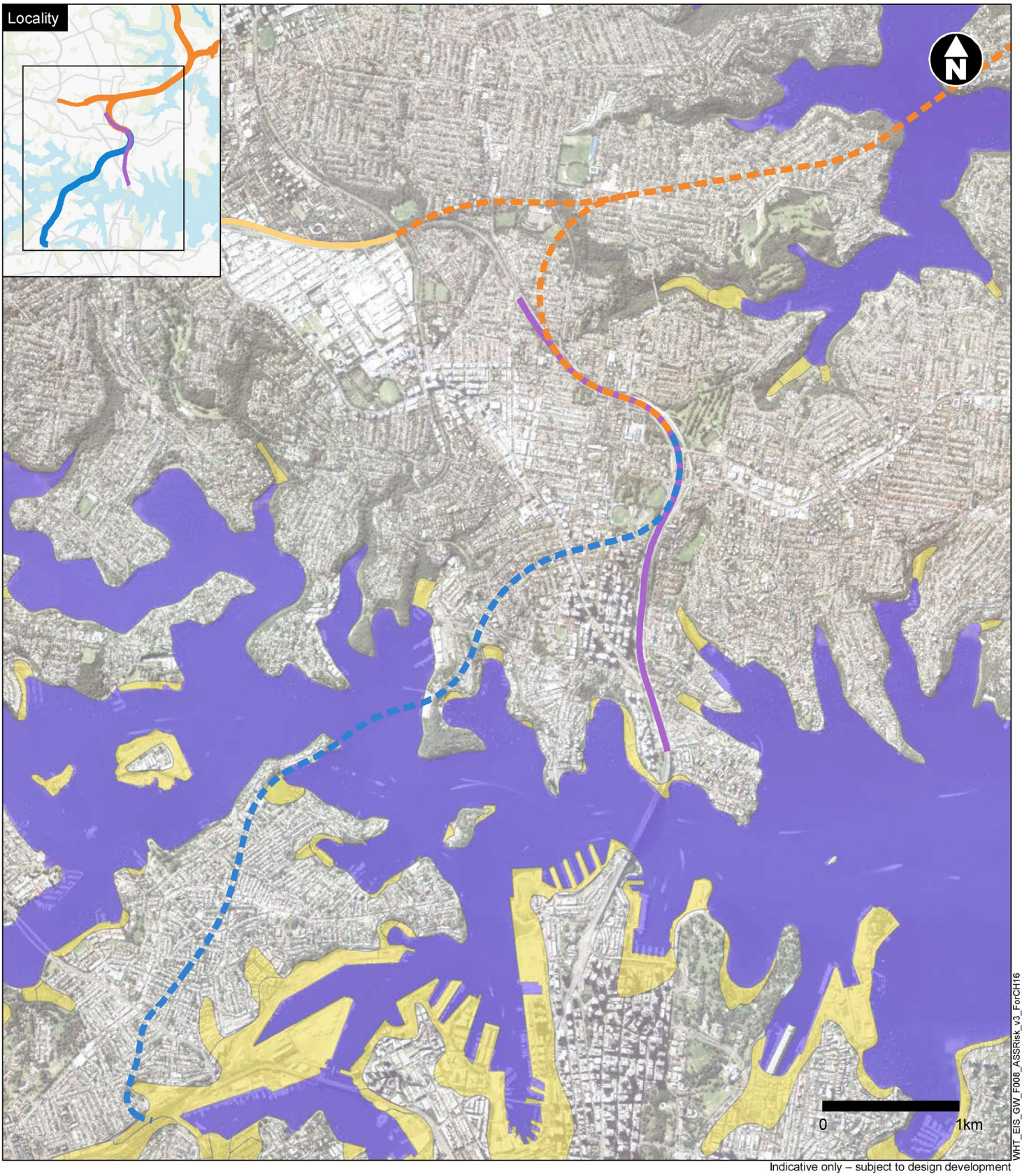


Figure 16-4 Acid sulfate soil risk classification

Soil salinity

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

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

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

16.3.4 Groundwater

Groundwater flow

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

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

Quaternary alluvium

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

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

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

Ashfield shale aquifer

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

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

Hawkesbury sandstone aquifer

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

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

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

Human made fill

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

Groundwater levels and movement

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

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

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

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

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

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

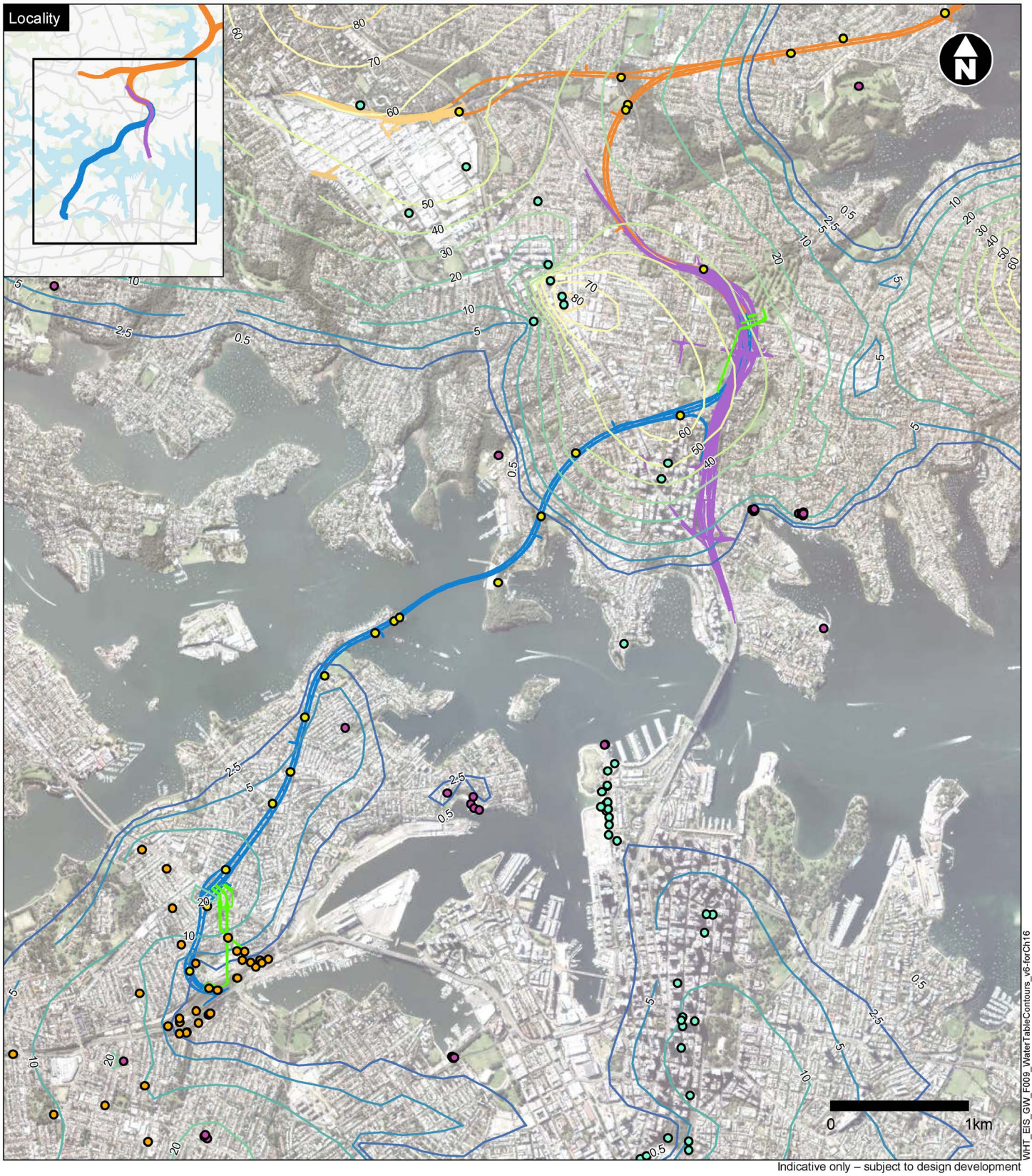


Figure 16-5 Water table contour map and groundwater monitoring network

Groundwater inflow in existing Sydney Tunnels

Rates of water inflows have been monitored in recent years from several unlined tunnels in the Sydney area with similar geology, hydrogeology and construction to that of the proposed Western Harbour Tunnel. These inflow rates are considered long term flow rates throughout the operational life of the infrastructure and are summarised in Table 16-4.

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

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

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

Groundwater quality

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

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

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

Contaminants identified during groundwater monitoring are discussed in Section 16.3.5.

Groundwater dependent ecosystems

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

Groundwater users and extraction

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

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

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

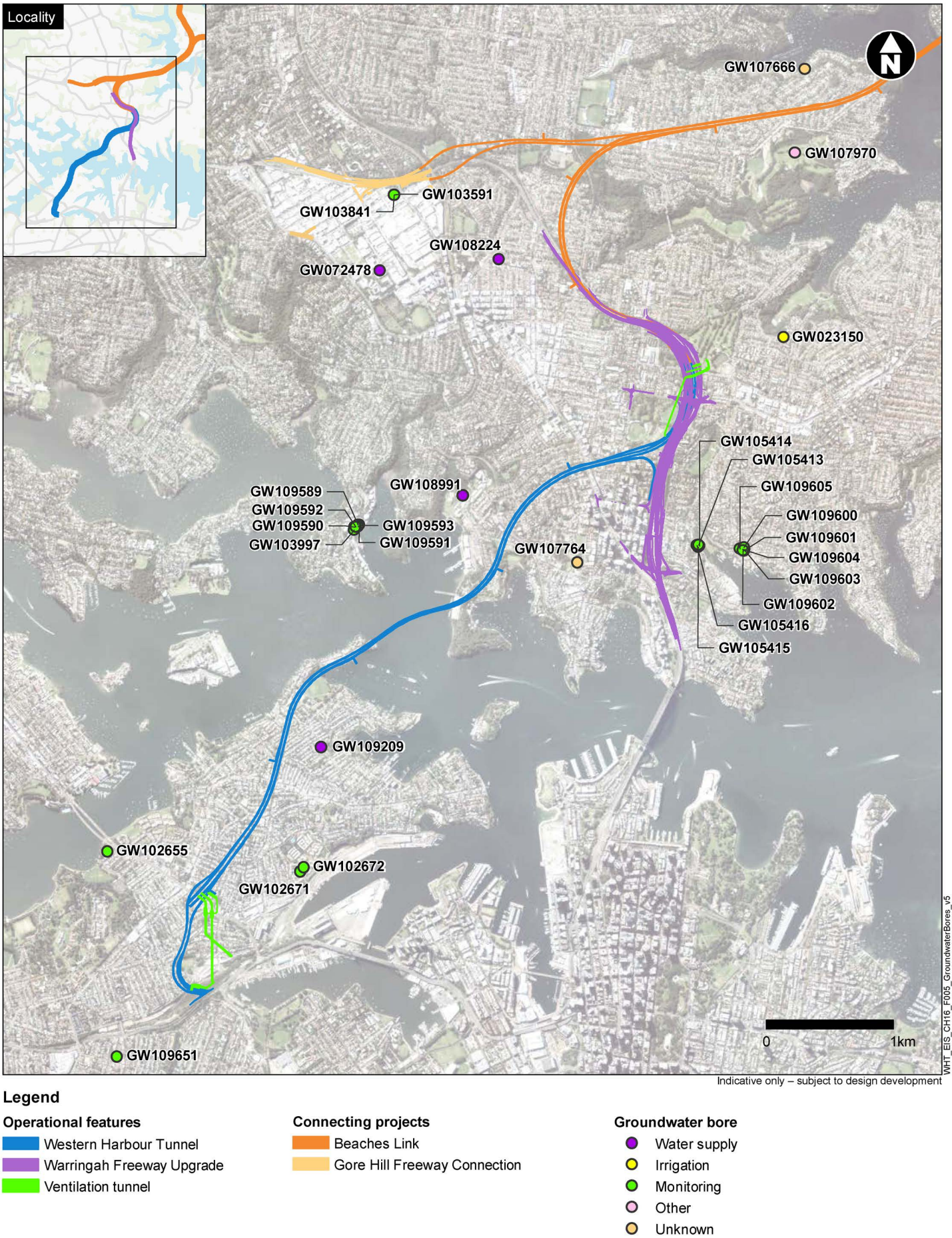


Figure 16-6 Existing groundwater bores within one kilometre of the alignment

16.3.5 Contamination

Land contamination

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

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

Historical and current aerial photographs

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

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

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

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

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

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

NSW EPA Contaminated Sites Register and Records of Notices

An online search of the NSW EPA Contaminated Sites Record of Notices (NSW EPA, 2019) and the list of contaminated sites notified to the NSW EPA indicated that there are eight sites registered with the NSW EPA within 500 metres of the project that are either regulated (current notices) or

have been notified. These sites were associated with industrial and service station activities and are listed in Table 16-6.

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

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

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

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

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

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

Yellow Pages business directory search

The Yellow Pages business directory search identified 23 sites within or adjacent to the study area whose activities may cause contamination. These sites were located in Rozelle (14), Balmain

(three) and North Sydney (six), and comprised service stations, paint manufacturers, explosives industries, vehicle mechanics and dry cleaners.

Contamination investigations

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

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

Groundwater contamination

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

Sydney Harbour contamination

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

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

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

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

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

16.4 Assessment of potential construction impacts

16.4.1 Soils

Erosion and sedimentation

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

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

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

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

Acid sulfate soils

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

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

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

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

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

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

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

Soil salinity

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

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

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

16.4.2 Ground movement

Ground movement may occur as a result of:

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

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

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

Table 16-7 Building and structure settlement damage classification

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

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

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

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

Table 16-8 Maximum predicted surface settlement

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

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

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

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

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

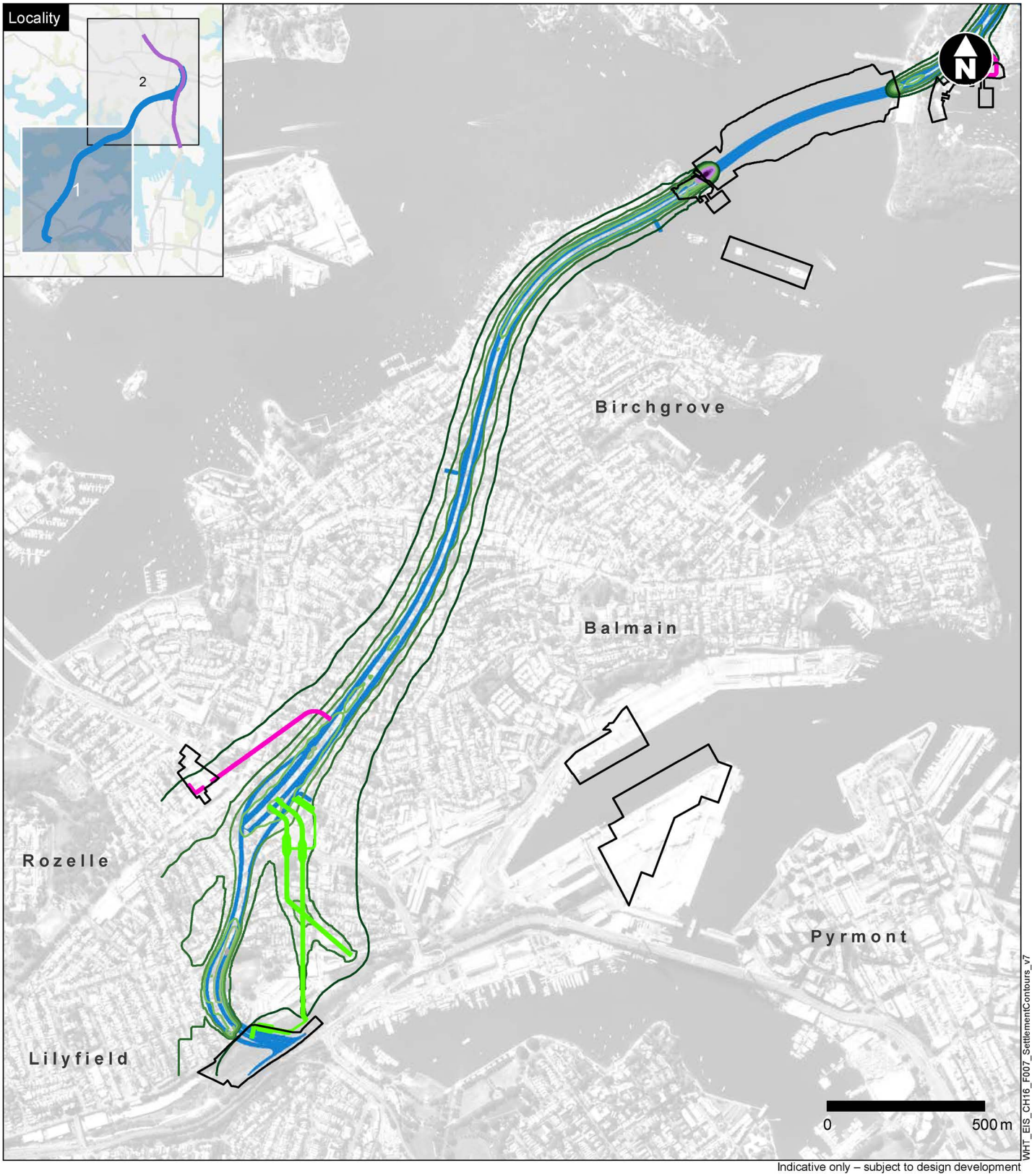


Figure 16-7 Settlement contours (Rozelle to Sydney Harbour, map 1)

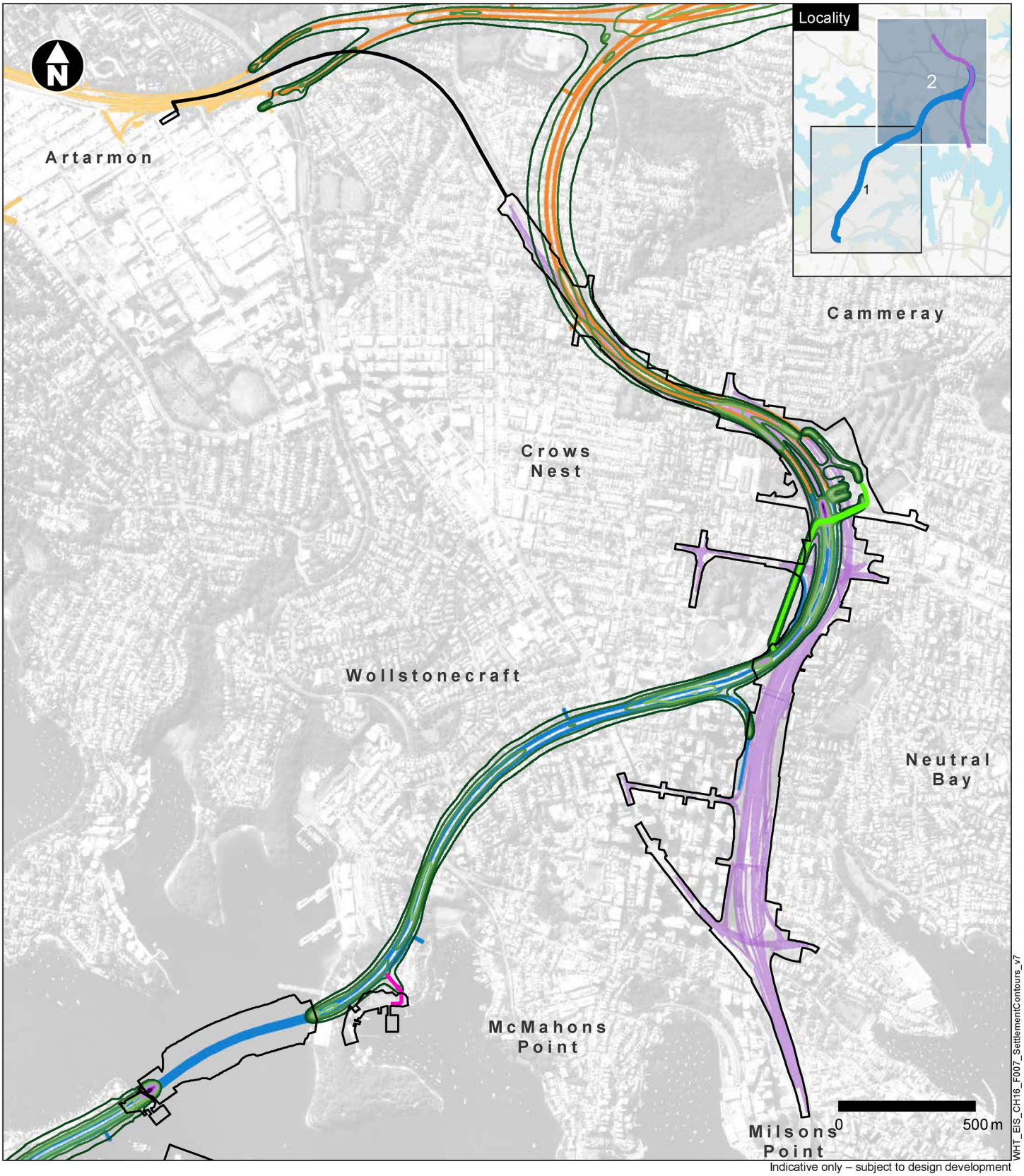


Figure 16-8 Settlement contours (Sydney Harbour to Warringah Freeway, map 2)

16.4.3 Land contamination

Areas of environmental interest

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

Rozelle Rail Yards, Rozelle (AEI1) [W1]

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

Easton Park, Lilyfield (AEI2) [W2]

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

Birchgrove peninsula (AEI3) [W3 and W4]

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

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

Sydney Harbour (AEI4) [W5]

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

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

Balls Head peninsula (AEI5) [W6 and W7]

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

Waverton Park (AEI6) [W8]

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

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

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

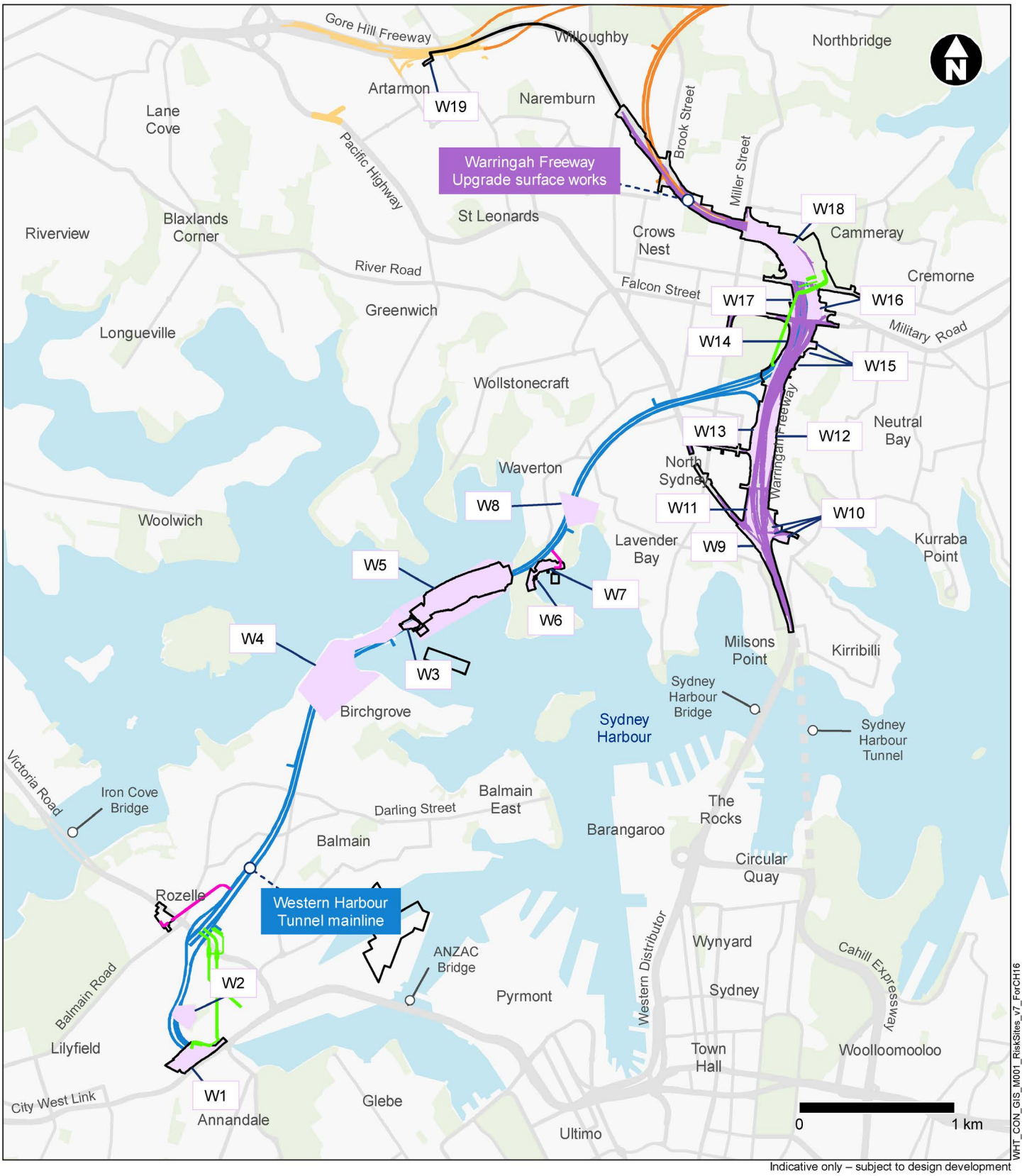
Waltham Street, Artarmon (AEI9) [W20]

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

Potential contamination risks

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

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



Legend

Operational features

- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Ventilation tunnel

Connecting projects

- Beaches Link
- Gore Hill Freeway Connection

Contaminated sites

- Moderate to high risk contaminated site

Construction features

- Construction footprint
- Access decline

Figure 16-9 Areas of environmental interest and contaminated sites

Table 16-9 Potential contamination risks

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

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

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

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

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

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

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

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

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

16.4.4 Marine contamination

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

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

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

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

16.4.5 Groundwater levels

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

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

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

Tunnel inflows

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

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

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

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

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

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

Groundwater level decline (Drawdown)

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

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

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

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

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

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

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

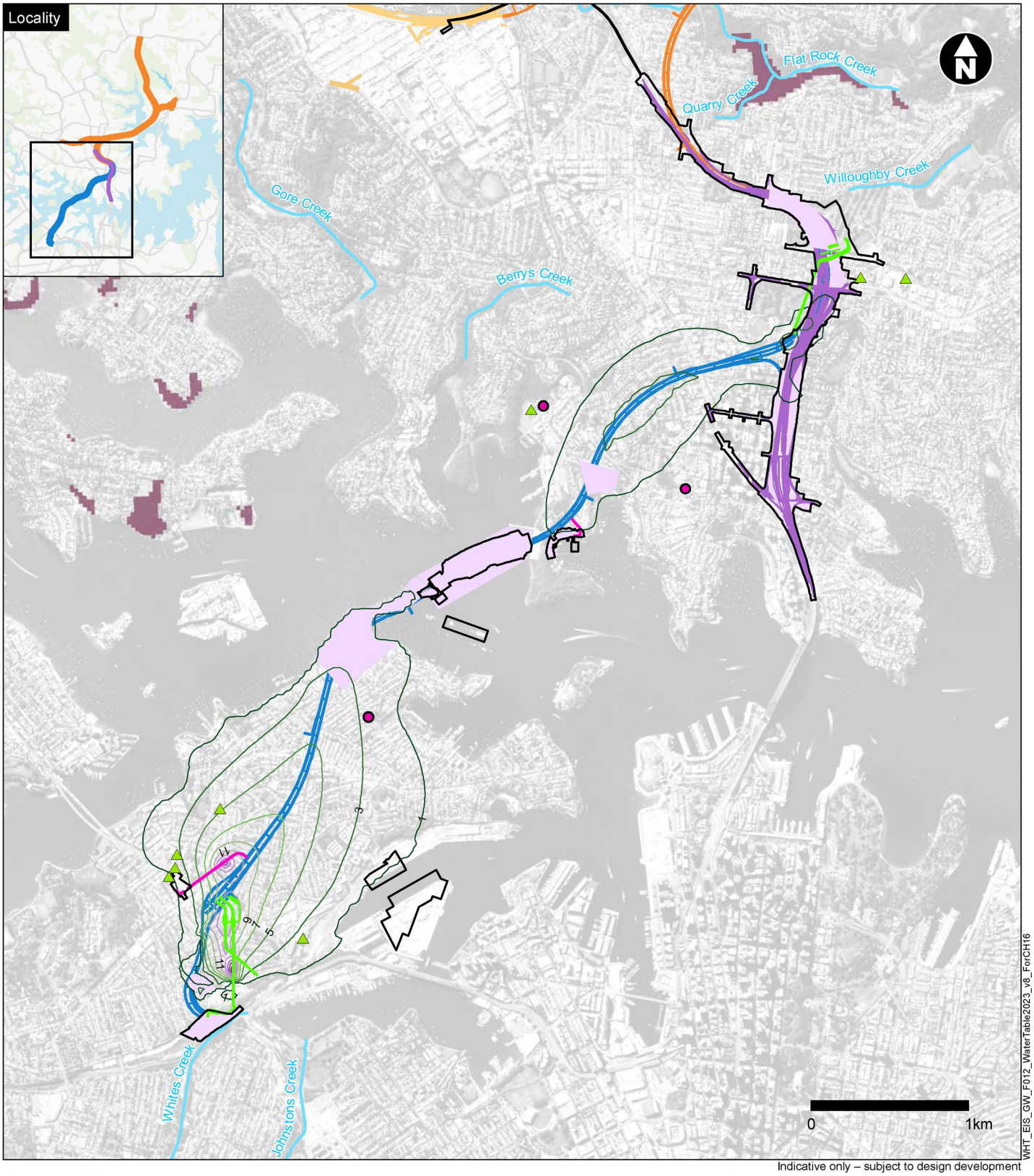


Figure 16-10 Groundwater drawdown contours for the project for the end of tunnel construction (2026)

Saltwater intrusion

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

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

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

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

Contaminant migration from contaminated sites

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

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

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

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

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

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

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

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

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

Activation of acid sulfate soils

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

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

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

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

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

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

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

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

16.4.6 Groundwater quality

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

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

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

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

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

16.5 Assessment of potential operational impacts

16.5.1 Spills and leakages

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

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

16.5.2 Groundwater levels

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

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

Tunnel inflows

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

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

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

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

Groundwater Drawdown

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

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

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

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

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

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

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

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

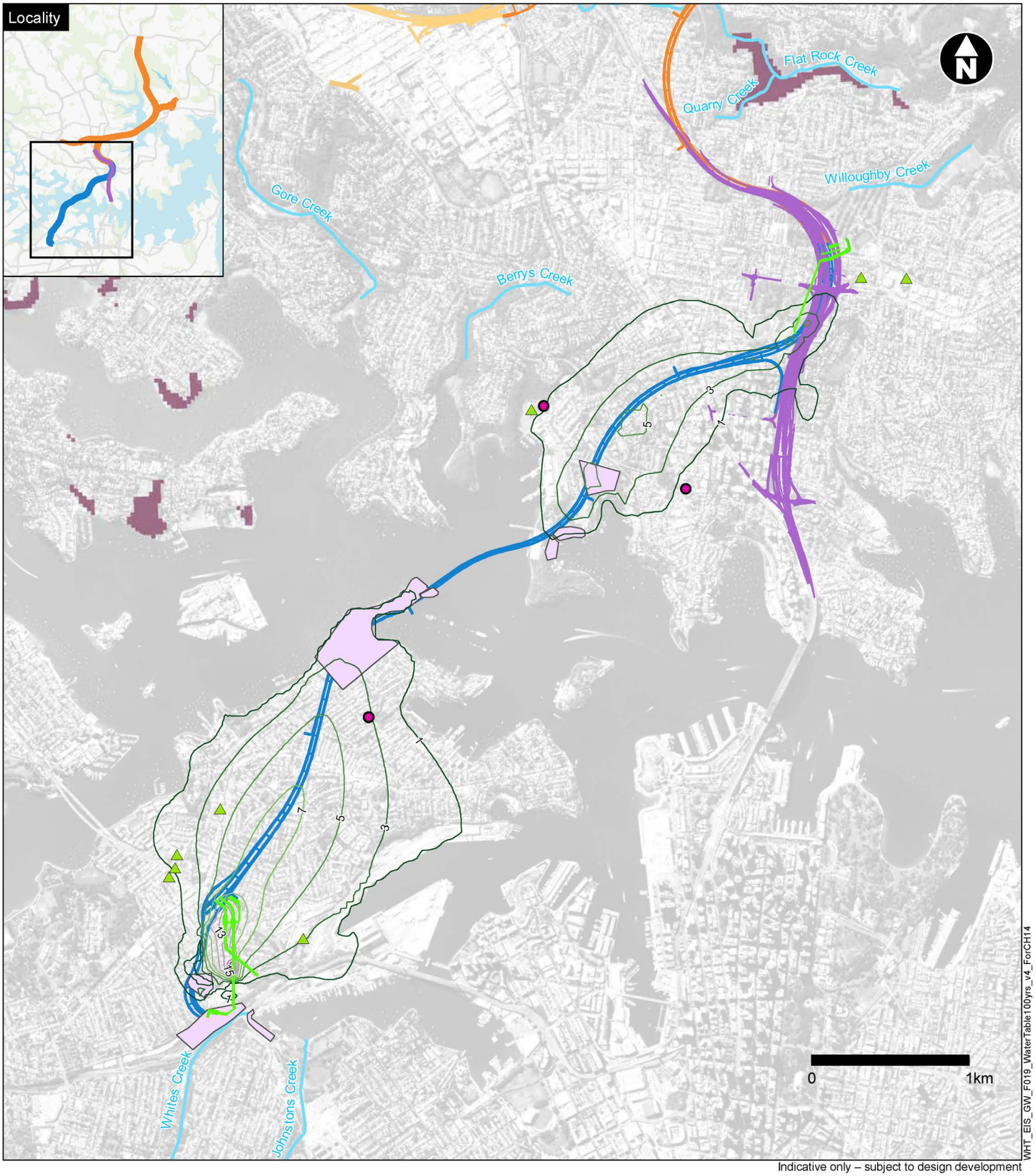


Figure 16-11 Groundwater drawdown elevations for the project during operation in 2126

Saltwater intrusion

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

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

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

Contaminant migration from contaminated sites

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

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

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

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

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

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

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

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

Activation of acid sulfate soils

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

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

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

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

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

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

16.5.3 Groundwater quality

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

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

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

16.6 Policy compliance

16.6.1 Consistency with minimum harm criteria

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

Table 16-16 Minimal harm assessment

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* identifies that within the Hawkesbury Sandstone and Ashfield Shale there are: • No listed high priority groundwater dependent ecosystems (refer to Section 16.3.4) • No listed high priority culturally significant sites (refer to Section 16.4.5). Groundwater modelling has predicted that water table drawdown at bores GW109209 and GW107764 would exceed two metres. Impact minimisation measures are discussed below.
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.	Water table drawdown is predicted to be up to four metres at bore GW109209 and up to two metres at bores GW108991 and GW107764. The approach to 'make good' the predicted impacts would be to first confirm whether the bores still exist and are in a usable condition, and if so, to carry out monitoring and/or further modelling. If impacts are realised, then 'make good' options would be discussed with the owner. Make good provisions would include provision of alternative water supplies (such as mains water), replacing the bore with a deeper bore, or compensation for additional pumping costs.
Water pressure	
Level 1 A cumulative pressure head decline of not more than a two metre decline, at any water supply work.	Investigation and mitigation measures to address impacts at bores GW109209, GW108991 and GW107764 have been proposed.
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 will be carried out and if impacts are realised, the make good provisions will be applied to either maintain the long term viability of the bores or to provide an alternative access or compensation.

Minimal harm criteria	Assessment
Water quality	
Level 1 Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	Impacts to groundwater quality associated with the project would be minor, and as the tunnel inflows create a hydraulic gradient towards the tunnel, any contamination mobilised or caused by the works would flow towards the tunnel rather than away from it. Contaminants associated with the project would therefore remain within 40m of the tunnel. Drawdown caused by the project may cause contamination of groundwater more than 40m away from the tunnel due to: • Inland migration of the saline interface • Migration of contaminated groundwater from existing contaminated sites into areas of fresher groundwater • Potential activation of acid sulfate soils. These processes mean that this requirement of the Aquifer Interference Policy would not be satisfied. Impact minimisation measures are discussed below.
Level 2 If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long term viability of the dependent ecosystem, significant site or affected water supply works.	Intrusion of saline water from the coast into fresher groundwater, and migration of already contaminated groundwater, will not impact the long term viability of dependent ecosystems or significant sites. If impacted, bores GW109209, GW108991 and GW107764 would be affected by reduced yields before any groundwater quality impacts occur. The make good provisions discussed above would be implemented to provide an alternative water source or compensate the user.
Additional Considerations	
… any advice provided to a gateway panel, the Planning and Assessment Commission or the Minister for Planning and Public Spaces on a State significant development or State significant infrastructure will also consider the potential for: Acidity issues to arise, for example exposure of acid sulfate soils; Water logging or water table rise to occur, which could potentially affect land use, groundwater dependent ecosystems and other aquifer interference activities. Specific limits will be determined on a case by case basis, depending on the sensitivity of the surrounding land and groundwater dependent ecosystems to waterlogging and other aquifer interference activities to water intrusion.	The level of predicted drawdown is sufficient to cause activation of acid sulfate soils if present. No work has been carried out so far to identify and test the acid generating potential of soil and rock in the project area. If acid sulfate soils are identified, measures to mitigate impacts would be needed. There is no risk of water logging or water table rise since the tunnel will be drained during both construction and operation. The only tanked structures will be a short distance either side of the harbour. Waterlogging or damming of groundwater flow would not occur since the hydraulic gradient by that time would cause flow towards the drained sections of the tunnel around Rozelle/Balmain in the south, and Waverton in the north.

16.6.2 Consistency with Water Sharing Plan rules

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

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

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

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

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

16.7 Environmental management measures

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

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

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

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

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

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

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

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

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

Chapter 17

Hydrodynamics and water quality

January 2020

17 Hydrodynamics and water quality

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

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).

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.

The proposed environmental management measures relevant 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* (Office of Environment and Heritage, 2014).	Details of surface water resources likely to be impacted by the project are presented in **Section 17.3.1**. Biodiversity consideration 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 **17.5.6** respectively. Refer to **Chapter 16** (Geology, soils and groundwater) for groundwater inflow predictions.

Secretary's requirement	Where addressed in EIS
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 **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 **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 **17.5**. Impacts from scour and erosion on geomorphology are discussed in **Section 17.4.4**. The effects of proposed stormwater and wastewater management on surface water quality are assessed in **Section 17.4.3** and **17.5.3**. Impacts on riparian vegetation are included in **Chapter 19** (Biodiversity).

Secretary's requirement	Where addressed in EIS
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 reuse options) and on the conveyance capacity of existing stormwater systems where discharges are proposed through such systems;	Information on wastewater discharge, including volumes and rates of discharge, is included in **Section 17.4.3** and **17.5.3**.
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 17.2.2** and **17.6** respectively. Proposed groundwater monitoring is identified in **Chapter 16** (Geology, soils and groundwater).
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 17.2.2** and **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.	Tunnel design in relation to drainage resulting from paleochannels is 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.

Secretary's requirement	Where addressed in EIS
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 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;	A list of the ambient NSW Water Quality Objectives (NSW WQO) for receiving waters within the project area is included in **Section 17.1.2**. Environmental values for the receiving waters are discussed in **Section 17.3.8**. The ANZG (2018) and ANZECC/ARMCANZ (2000) default trigger values are provided in **Appendix O** (Technical working paper: Surface water quality and hydrology).
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**, **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 **17.5.3**.
d. identify the rainfall event that the water quality protection measures will be designed to cope with;	**Appendix O** (Technical working paper: Surface water quality and hydrology) outlines water quality protection measures to be adopted during construction and operation, which basins 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 **17.5**.
f. demonstrate how construction and operation of the project (including mitigating effects of proposed stormwater and wastewater management) will, to the extent that the project can influence, ensure that: - where the NSW WQOs for receiving waters are currently being met they will continue to be protected; and - where the NSW WQOs are not currently being met, activities will work toward their achievement over time;	Discussion of whether the NSW WQOs 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 WQOs is included in **Section 17.1.1**. Management measures relevant to surface water quality impacts are provided in **Section 17.6**. The ability of the project to meet the NSW WQOs is discussed in **Section 17.4** and **17.5**.

Secretary's requirement	Where addressed in EIS
g. justify, if required, why the WQOs cannot be maintained or achieved over time;	
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 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 17.3.7**. Management measures to avoid (or minimise) impacts are provided in **Section 17.6**. Proposed surface water monitoring locations are discussed in **Section 17.2.2**. Further details, including monitoring frequency and indicators are provided in **Appendix O** (Technical working paper: Surface water quality and hydrology). 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.	Proposed surface water monitoring locations, frequency and indicators are identified in **Section 17.6**. The proposed monitoring locations, frequency and indicators of groundwater quality are outlined in **Chapter 16** (Geology, soils and groundwater).
2. The assessment should consider the results of any current water quality studies, as available, in the project catchment.	Surface water quality studies considered for this assessment are listed in **Appendix O** (Technical working paper: Surface water quality and hydrology).

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 is 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 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 & Resources) (former Department of Primary Industries (Fisheries)) 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 Regulation (General) 2011	The project is located within an area covered by the *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources* (NSW Department of Primary Industries (DPI), 2011). 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.
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 rainforest areas, coastal vulnerability areas, coastal environment areas and coastal use areas. The project footprint is not located within the coastal wetlands and littoral rainforest area or the coastal vulnerability area. The development controls for coastal environment areas and coastal use areas do not apply to the project, as the project footprint is within

Legislation	Relevance to project
	the catchment of the Sydney Harbour Catchment Regional Environmental Plan 2005 (refer below).
Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005	*The Sydney Harbour Catchment Regional Environmental Plan 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 20 years (ANZG, 2018).

The study area would typically fall under the ANZG (2018) and ANZECC/ARMCANZ (2000) water quality guidelines for 'South-east Australian slightly disturbed lowland rivers and estuaries'. Wastewater treatment plants used during construction and operation would be designed such that discharges would comply with these guidelines. Site-specific trigger values would be used when setting the wastewater treatment plant discharge criteria to ensure wastewater is treated to a level that is representative of background concentrations at the receiving environment.

NSW Water Quality and River Flow Objectives

Water quality objectives have been developed for the Sydney Harbour and Parramatta River catchment (DECCW, 2006). The marine waterbodies relevant to this assessment, have been identified as 'upper estuary' (Iron Cove) and 'lower estuary' (Rozelle Bay, Snails Bay and Berrys Bay). Waterways relevant to this assessment (Whites Creek, Quarry Creek, Flat Rock Creek and Willoughby 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).

Environmental values, as identified by the Department of Planning, Industry and Environment (Environment, Energy and Science) (formerly NSW Office of Environment and Heritage), for the Sydney Harbour and Parramatta River catchment are discussed further in Section 17.3.8.

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 this 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 project 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.

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: Volume 2D Main Road Construction* (Department of Environment and Climate Change, 2008) (known as the Blue Book Volume 2)
- *Road Design Guideline, Section 8 Erosion and Sediment* (RTA, 2003a)
- *Guideline for Construction Water Quality Monitoring* (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 2* (Roads and Maritime Services, 2015g).

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

At Rozelle, the project would include a surface connection to the City West Link. Surface water collected from the Western Harbour Tunnel portals and the road connecting the Western Harbour Tunnel with City West Link would be collected by the tunnel drainage system.

Along the Warringah Freeway, the project would provide drainage infrastructure to convey runoff from the upgraded section of the Warringah Freeway and to maintain drainage performance that is generally consistent with the existing arrangements. Impervious catchment area sizes upstream of the freeway would change marginally (between minus six and 2.3 per cent) and are not expected to change the pollutant load because of the project. For this reason, no formal water quality treatment infrastructure is proposed except for the motorway facilities at the Warringah Freeway, within the existing Cammeray Golf Course, which would have water quality infrastructure to treat runoff before discharge to the existing local stormwater network.

Should further design development identify the need for additional water quality controls, the project would provide water quality treatment that meets the design targets listed in Table 17-3. These targets are described in the *Draft Managing Urban Stormwater – Council Handbook* (NSW EPA, 2007). 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 type and design of specific stormwater treatment measures would be further refined, including confirmation of performance with modelling, if required.

Table 17-3 Operational water quality design targets

Issue	Design target
Total nitrogen	45 per cent mean annual pollutant load reduction
Total phosphorus	65 per cent mean annual pollutant load reduction
Total suspended solids	85 per cent mean annual 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

Wastewater treatment plant discharges

The Rozelle Interchange wastewater treatment plant discharge criteria would comply with ANZG (2018) 95 per cent species protection level and a 99 per cent protection level for contaminants that bioaccumulate (or as otherwise agreed with relevant stakeholders including the EPA, DPI Water and Sydney Water). Discharge criteria for iron would comply with the NHMRC (2008b) recreational guidelines water quality criteria.

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 Sydney Harbour during project construction and operation
- Dredge plume modelling to assess potential water quality impacts as a result of increased dredging activities during construction of the immersed tube tunnel

- 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
- Assessment of changes on the North Sydney Council stormwater harvesting scheme
- Identification of appropriate management measures to mitigate potential hydrology and water quality impacts.

17.2.2 Monitoring

Hydrodynamic monitoring of Sydney Harbour

Hydrodynamic monitoring was carried out between August and November 2017 to measure variability in hydrodynamic conditions within Sydney 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 mounted monitoring using an acoustic doppler current profiler was carried out along three transects across Sydney Harbour near the project 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 Sydney Harbour

Water quality monitoring was carried out as part of the marine water quality assessment at eight locations in Sydney Harbour that could be potentially affected by dredging and construction activities. Monitoring activities involved:

- Four fixed water quality monitoring moorings with a number of sensors to monitor turbidity, photosynthetically available radiation, chlorophyll-a, salinity, pressure and temperature (from 5 December 2017 to 31 January 2018)
- Water sampling and 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 water surface to the harbour bed. 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.

Table 17-4 details the water quality monitoring locations for the project, including the two sites monitored as part of the hydrodynamic assessment. The monitoring locations are shown in Figure 17-1.

Table 17-4 Sydney Harbour hydrodynamic and water quality monitoring sites

Site	Location	Monitoring activity
SH1	Wrights Point, Drummoyne	Fixed water quality monitoring mooring and profiling site
SH2	Pulpit Point, Hunters Hill	Water quality profiling site
SH3	Onions Point, Woolwich	Water quality profiling site

Site	Location	Monitoring activity
SH4	Manns Point, Greenwich	Hydrodynamic monitoring location
SH5	Berry Island Reserve	Hydrodynamic monitoring location
SH6	Manns Point, Greenwich	Water quality profiling site
SH7	Longnose Point, Birchgrove	Fixed water quality monitoring mooring and profiling site
SH8	Berrys Bay, Waverton	Fixed water quality monitoring mooring and profiling site
SH9	Goat Island	Water quality profiling site
SH10	Cremorne Point, Cremorne	Fixed water quality monitoring mooring and profiling site

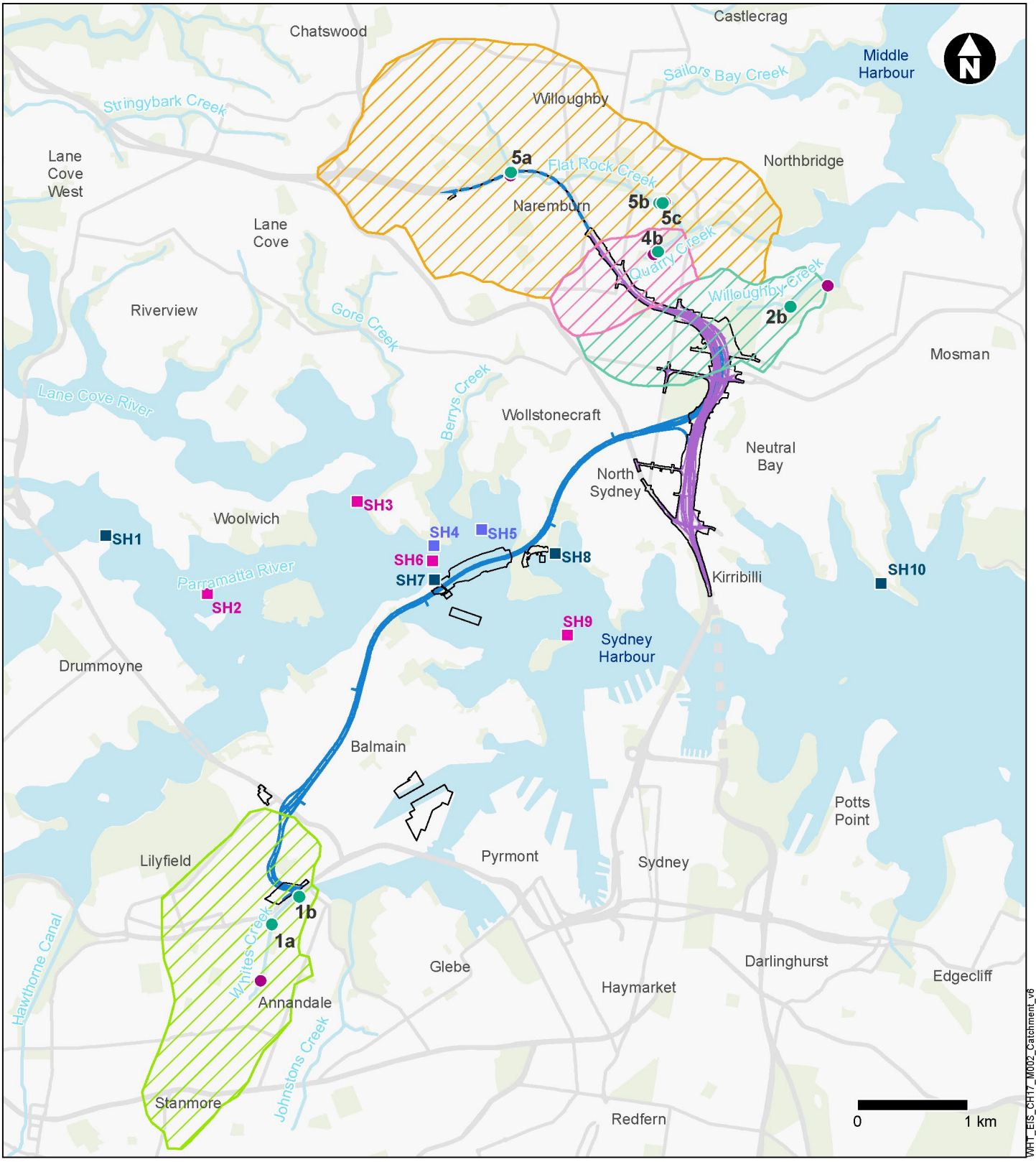
Surface water quality monitoring

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

Seven monitoring locations were selected immediately upstream and downstream of the proposed waterway crossing. It is noted that 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 same Bureau of Meteorology rainfall gauge in the 24 hours prior to sampling, with wet weather classified as 15 millimetres or more of rainfall recorded. Monitoring locations are provided in Table 17-5 and shown in Figure 17-1.

Table 17-5 Water quality monitoring sites in waterways

Site	Waterway	Location
1a	Whites Creek upstream	Brennan Street, Annandale
1b	Whites Creek downstream	Railway Parade, Annandale
2b	Willoughby Creek downstream	Primrose Park, Cremorne
4b	Quarry Creek	Quarry Street, Naremburn
5a	Flat Rock Creek upstream	Grandview Street, Naremburn
5b	Flat Rock Creek downstream (upstream of Quarry Creek inflow)	Flat Rock Gully, Northbridge
5c	Flat Rock Creek downstream (downstream of Quarry Creek inflow)	Tunks Park, Northbridge Suspension bridge



Legend

Operational features

- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Communications cable for motorway control centre
- M4-M5 Link project (indicative)

Construction features

- Construction footprint

Catchments and waterways

- Flat Rock Creek
- Quarry Creek
- Whites Creek
- Willoughby Creek
- Waterways

Marine water quality monitoring sites

- Fixed and profiling site
- Hydrodynamic site
- Profiling site

Surface water quality monitoring sites

- Project monitoring site
- Existing monitoring site

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

17.2.3 Model development

Hydrodynamic model development

A three-dimensional hydrodynamic model of Sydney 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 Sydney Harbour near the project, as it relates to hydrodynamic characteristics
- Understand what impacts the construction of an immersed tube tunnel would have on the hydrodynamic characteristics within Sydney Harbour.

Plume model development

Construction of the project would involve dredging of the bed of Sydney 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 Sydney 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).

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

No water quality model was run for the surface water collected at the Western Harbour Tunnel portals and the road connecting the Western Harbour Tunnel with the City West Link because this surface water would be collected by the tunnel drainage system and treated at the Rozelle wastewater treatment plant.

A water quality model for the Warringah Freeway Upgrade was not warranted because this section of the project would result in negligible change to pavement catchment areas immediately upstream of the project and is therefore not expected to increase pollutant loads.

17.3 Existing environment

17.3.1 Catchments and waterways

The project would be located within the Sydney Harbour and Parramatta River regional catchment, located within Port Jackson. Port Jackson is comprised of three harbours: North Harbour, Middle Harbour and Sydney Harbour (the main branch of the estuary). Sydney Harbour is a drowned river valley, characterised by steep sided banks which have been eroded by up to 85 metres into the Hawkesbury Sandstone and overlying Ashfield Shale. The catchment comprises both natural and urban landscapes rich in cultural, geological and biological diversity and heritage. The regional catchment covers Sydney Harbour, Parramatta River, Lane Cove River and Middle Harbour.

The Sydney Harbour catchment is a highly-urbanised catchment (86 per cent) which results in rapid runoff during high rainfall events.

This catchment is highly urbanised and is influenced by human factors which have altered the frequency, volume and seasonality of streamflows through intermittently flowing watercourses. The waterways in the study area are highly modified, predominantly concrete-lined trenches, and although containing little ecosystem value, they provide good stability during stormwater overflows. Flat Rock Creek differs where it becomes a naturalised creek and forms a ravine at Flat Rock Gully. Willoughby Creek also has entrenched bedrock (constructed) with soil banks for a small section behind Primrose Park at Cremorne.

The main bodies of water surrounding the study area are Middle Harbour and Sydney Harbour, which are estuaries. The main waterways in proximity to the project are Flat Rock Creek, Quarry Creek, Willoughby Creek and Whites Creek. All are first order streams that discharge directly to the harbours.

The waterways and associated catchments within the study area are shown in Figure 17-1. Table 17-6 outlines the catchments that form part of the larger Sydney Harbour and Parramatta River regional catchment as relevant to the project and provides a description of the key waterways relevant to the project.

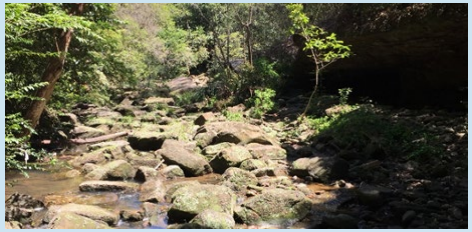
Some areas of the project would be located on catchments dominated by drainage lines that drain towards Sydney Harbour, rather than watercourses, and would include:

- Victoria Road construction support site (WHT2) – drainage lines from this construction support site drain towards Iron Cove
- Yurulbin Point construction support site (WHT4) – drainage lines from this construction support site drain towards Snails Bay
- Berrys Bay construction support site (WHT7) – drainage lines from this construction support site drain towards Berrys Bay
- Warringah Freeway Upgrade – drainage lines from the southern end of the upgrade drain towards Neutral Bay
- Waltham Street construction support site (WHT11) – drainage lines from this construction support site, drain towards Flat Rock Creek.

Table 17-6 Description of key waterways and catchments relevant to the project

Waterway/catchment	Description	Relevant project features
Sydney Harbour (Sydney Harbour and Parramatta River regional catchment)	• Sydney Harbour in the context of the project comprises two main tributaries: Lane Cove River and Parramatta River • The bathymetry near the immersed tube tunnel crossing of Sydney Harbour is complex and irregular with defined channels, shallow bays including Balls Head, Snails Bay and Berrys Bay, and deep holes up to 32 metres deep • The hydrodynamic conditions at the proposed immersed tube tunnel crossing of Sydney Harbour are primarily influenced by astronomical tides with other influences from barometric effects (environmental air pressure), wind and freshwater flows from local creeks and rivers being comparatively small.	• Victoria Road construction support site (WHT2) drains towards Iron Cove • White Bay construction support site (WHT3) drains into White Bay • Yurulbin Point construction support site (WHT4) drains towards Snails Bay • Sydney Harbour south cofferdam (WHT5) • Crossing of Sydney Harbour • Sydney Harbour north cofferdam (WHT6) • Berrys Bay construction support site (WHT7) drains towards Berrys Bay • Southern portion of the Warringah Freeway Upgrade drains towards Neutral Bay.

Waterway/catchment	Description	Relevant project features
Whites Creek (Whites Creek catchment) 	• Small creek (about two kilometres long) in the densely developed inner western suburbs of Sydney. It drains a catchment dominated by residential areas and roads • Headwaters are in the suburbs of Stanmore and Leichhardt, and flows in a northerly direction discharging to Rozelle Bay, Sydney Harbour • The complete length of the creek is a stormwater drain with buried pipes in the upper reaches and open concrete channel for the lower one kilometre • Sydney Water has begun works on naturalising Whites Creek due to its deteriorated condition. It is likely to incorporate features such as sandstone blocks and vegetated benches to provide ecological benefits to the channel.	• Rozelle Rail Yards construction support site (WHT1).
Willoughby Creek (Willoughby Creek catchment) 	• Willoughby Creek is a small modified concrete and rock channel which drains 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.	• Mid portion of Warringah Freeway Upgrade • Cammeray Golf Course (WHT10 and WFU8) and Rosalind Street east (WFU9) construction support sites.

Waterway/catchment	Description	Relevant project features
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.	Northern portion of Warringah Freeway Upgrade.
Flat Rock Creek (Flat Rock Creek catchment)  	• Flat Rock Creek is predominantly a concrete lined (open and closed) stormwater channel which drains the suburbs of Artarmon, Willoughby and Naremburn. It travels underground between Naremburn and Willoughby. 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 steep catchment characterised by rocky riffle and runs. The downstream reaches are surrounded by native Coachwood forests with walking tracks which provide 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.	• Northern portion of the Warringah Freeway Upgrade • Waltham Street construction support site (WHT11). Drainage lines from this construction support site drain towards Flat Rock Creek.

17.3.2 Hydrodynamic features

Bathymetry

The bed of Sydney Harbour is made up of many deep holes, shoals, basins, rocky islands and reefs. At the proposed immersed tube tunnel crossing of Sydney Harbour, there is a defined channel with relatively steep banks, with an average depth of around 15 metres. Other key bathymetry features near the crossing of Sydney Harbour include:

- A hole about 17 metres deep near Birchgrove
- A deep hole to the south of the Sydney Harbour proposed immersed tube tunnel crossing about 32 metres deep
- Shallow bays which act as large reservoirs for tidal waters, including Balls Head Bay, Snails Bay and Berrys Bay.

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 Sydney Harbour are influenced by the complex shape of the harbour with stronger tidal streams in the main channels, weaker currents outside the main channels along with circulating eddies in some of the bays (eg Balls Head Bay). Spatial measurements and monitoring showed little change in current speed with changes in depth. A summary of the current speeds observed as part of hydrodynamic monitoring is shown in Table 17-7.

Table 17-7 Current speeds near the Sydney Harbour crossing

Monitoring location	Parameter	Maximum	95th percentile	Average
Manns Point, Greenwich (SH4)	Flood current speed (m/s)	0.43	0.27	0.12
	Ebb current speed (m/s)	0.41	0.26	0.13
Berry Island Reserve (SH5)	Flood current speed (m/s)	0.18	0.08	0.04
	Ebb current speed (m/s)	0.29	0.12	0.05

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 Sydney 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 range from 4.2 to 4.7 metres per second (50th percentile) and 6.7 to 8.3 metres per second (90th percentile) throughout the year
- Wind speeds are slightly higher during spring/summer compared to autumn/winter.

Waves

Ocean swells that enter Sydney Harbour are deflected by the complex bathymetry and shoreline formation such that most of Sydney Harbour is affected only by locally derived wind- and ship-generated waves. The wave climate near the proposed immersed tube tunnel crossing of Sydney Harbour is a low energy wave climate with wave heights typically less than 0.3 metres and wave periods of less than four seconds. Wave periods associated with Rivercat and Harbourcat ferries can exceed four seconds depending on vessel speed.

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

Rainfall and freshwater runoff into Sydney 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.

The amount of freshwater runoff into Sydney Harbour depends on the amount of rainfall in the local catchment. There are no permanent rivers or streams which discharge into Sydney Harbour. The Parramatta and Lane Cove Rivers are merely arms of the estuary and provide limited to no freshwater flux into the system, except during major rainfall events.

During dry weather conditions (rainfall less than one millimetre per day) freshwater discharge from the Parramatta and Lane Cove catchment is minimal and is estimated to be less than 0.1 cubic metres per second from both catchments (Rochford, 2008; Birch and Rochford, 2010).

Suspended sediments

Turbidity is typically used as an indicator of suspended sediment concentrations. A review of historical data for turbidity of the waters within Port Jackson displays 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.

A summary of measured turbidity for the waters around Balls Head is provided in Table 17-8.

Table 17-8 Ambient measured turbidity near Balls Head

Weather	Ambient turbidity
Dry weather	<1 to 4 NTU
Wet weather	4 to 20 NTU – short-lived events ~<2 days with higher values on ebbing tide

17.3.3 Marine water quality

A review of historical marine water quality data and project specific monitoring of Sydney 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 influences the mixing of the Sydney Harbour deep waters

- Total suspended solids concentrations are generally low (below one milligram per litre) during extended dry periods with peaks up to 40 milligram per litre after heavy rainfall events. During the wetter months, total suspended solids concentrations are elevated at around three to eight milligram per litre
- Good vertical mixing maintains high dissolved oxygen content of the overall water column
- Good light penetration occurs through water column. The euphotic depth, where light decreases to one per cent of its surface value, was typically between seven and 10 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:

- Pavement drainage from Rozelle road network discharges to existing council drainage systems and ultimately to Whites Creek and Rozelle Bay. The M4-M5 Link project would provide road surface water quality infrastructure in this area
- Drainage from the existing Warringah Freeway road surface and nearby road networks in North Sydney and Willoughby local government areas currently discharge to existing local stormwater drainage systems, before discharging to Sydney Harbour or Middle Harbour
- Drainage from Waltham Street construction support site (WHT11) would discharge into the local stormwater system then travel into Flat Rock Creek before discharging into Middle Harbour.

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 are in very poor condition and are representative of a heavily urbanised system. The water quality of each assessed waterway is summarised in Table 17-9.

Table 17-9 Existing water quality conditions in the study area

Waterway	Commentary on ANZG (2018) and ANZECC/ARMCANZ (2000) indicators	Monitoring sites/data source
Whites Creek	• Median faecal coliforms and ammonia concentrations above the recommended limit for protection of aquatic ecosystems • High levels of heavy metals • High nutrient concentrations • Low dissolved oxygen levels • High pH (ie alkaline conditions) • High turbidity.	• Sites1a, 1b • Sydney Water • M4-M5 Link project and Bays Precinct project.

Waterway	Commentary on ANZG (2018) and ANZECC/ARMCANZ (2000) indicators	Monitoring sites/data source
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.	• Site 4b • 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 • North Sydney 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, measuring 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, and 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 provides habitat for wildlife such as ducks and saves about 90 million litres of clean water each year.

17.3.7 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 that 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 17-10.

Table 17-10 Sensitive receiving environments

Waterway	Sensitive receiving environment	Reason for classification
Sydney 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 Rock Cod which is listed under the *Fisheries Management Act 1994* and *Environment Protection and Biodiversity Conservation Act 1999* • Is a primary contact recreation area.

Waterway	Sensitive receiving environment	Reason for classification
Whites Creek	No	• Not identified as Key Fish Habitat based on NSW DPI (2007) mapping.
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.

17.3.8 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 regional 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 nutrients, 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.

These environmental values have been assigned to each waterway within the study area as shown on Table 17-11. Aquatic ecosystems and visual amenity would apply to all waterways within the study area.

Table 17-11 Assigned environmental values

Waterway	Environmental value			
	Aquatic ecosystems	Visual amenity	Primary contact recreation	Secondary contact recreation
Sydney Harbour	✓	✓	✓	✓
Whites Creek	✓	✓		
Willoughby Creek	✓	✓		✓
Quarry Creek	✓	✓		✓
Flat Rock Creek	✓	✓		✓

17.4 Assessment of potential construction impacts

17.4.1 Hydrodynamic features of Sydney Harbour

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

- The establishment of Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6) and associated shallow draft silt curtains. The use of deep draft silt curtains during dredging activities is not proposed due to tidal currents and maritime traffic within Sydney Harbour
- The establishment of the Yurulbin Point (WHT4) and Berrys Bay (WHT7) construction support sites.

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 Sydney Harbour south cofferdam (WHT5) would cause a reduction in the current speed downstream of the structure. This would be offset by a small increase in speeds in the middle of the channel and around Balls Head. During the flood tide, a similar pattern is observed with currents largely reduced downstream of the structure and a corresponding increase in the middle of the channel and along the northern bank (near Birchgrove Wharf). Increased current speeds are expected to occur near Greenwich Baths, however it is not expected to have any notable impact on recreational amenity.

The Sydney Harbour north cofferdam (WHT6) would have a very minor impact on current speeds during the ebb tide. This is because near the Coal Loader Wharf ebb current speeds are relatively low in both existing and with cofferdam scenarios resulting in the structure not significantly impacting on flow conditions. Larger reductions in current speeds are expected near the cofferdam and the Coal Loader Wharf during the flood tide due to the interaction with the eddy in the entrance to Balls Bay.

During both ebb and flood tide the differences would be more pronounced in the surface layer when compared to bottom layers. The bed of the harbour potentially affected is composed of cobbles, boulders, sand and clay, is not expected to be eroded by the higher current speeds. The foreshore area potentially affected is also protected from erosion by seawalls or rocky

shorelines. Overall the changes in tidal currents are unlikely to lead to erosion of the bed of the harbour or adjacent foreshores.

17.4.2 Marine water quality

Construction of the immersed tube tunnel would require dredging of the bed of Sydney 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 and piling activities associated with the establishment of the Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6), as well as adjacent land based activities at White Bay construction support site (WHT3), Yurulbin Point construction support site (WHT4) and Berrys Bay construction support site (WHT7) have the potential to reduce water quality and disturb contaminated sediments
- Vessel movements have the potential to generate localised plumes of excess suspended sediments associated with vessel wash in shallower waters, generally less than five to ten metres water depth
- Potential spills or leaks of fuels and chemicals from maintenance or re-fuelling of construction plant and equipment that could potentially be discharged directly or indirectly to the marine environment
- Potential impacts on marine water quality could be the transport, treatment and temporary storage of dredged material that is unsuitable for offshore disposal while temporarily stored on barges or at the White Bay construction support site (WHT3) (an application for offshore disposal of suitable dredged material has been submitted to the Commonwealth Department of the Environment and Energy)
- Land based activities involving the exposure or handling of soils (eg removal of pavement, vegetation clearance, stripping of topsoil, excavation, disturbance of contaminated soil, stockpiling and materials transport) resulting in potential soil erosion and off-site transport of sediment via air or runoff to receiving marine waterways. This could impact water quality, such as increased turbidity, lowered dissolved oxygen levels and increased nutrients.

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
- 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 were assessed using dredge plume modelling (refer to Figure 17-2) which identified the following:

- The extent of the dredge plume (two milligrams per litre suspended sediment concentration) throughout the water column would be limited to a relatively small area, concentrated at the north eastern end of the dredging footprint near Balls Bay and around Balls Head
- The extent of the visible plume (suspended sediment content >20 milligram per litre) is expected to be very small, and would be contained in the dredging footprint next to the Sydney Harbour north cofferdam (WHT6)

- Suspended sediment released would be transported both in an upstream and to a greater extent downstream direction. Suspended sediment would also be transported into Balls Bay during dredging of the eastern part of the dredge footprint
- For half the duration (ie 50 per cent) of proposed dredging activities, the increases in suspended sediment concentrations are expected to be low (ie less than one milligram per litre), even within the dredging footprint
- The dredge plume extents are expected to be greater in the bottom layer than at the surface of the water, as shown in the example of the 95th percentile
- For a short duration (ie less than one per cent of the time), increases in suspended sediment concentrations above five milligram per litre are expected to occur in the area adjacent to the Coal Loader Wharf
- The sensitivity of dredging impacts to wind is likely to be limited to brief periods at selected locations in the off-channel bays (eg Balls Bay), due to weaker tidal currents and shallower bathymetry.

The results indicate that the dredging program would not have a significant impact on marine water quality. The dredging and construction activities for the project are likely to cause localised increases in suspended sediment concentrations but due to the rapid dispersion in Sydney Harbour is not likely to result in significant water quality impacts. Monitoring during the dredging activities would provide data to assess the compliance of the activities with this assessment.

Along with the use of shallow silt curtains around dredging activities, additional shallow silt curtains would be installed where appropriate to mitigate the potential impact to adjacent ecologically sensitive areas (eg seagrass beds).The use of deep draft silt curtains during dredging activities would not be possible, due to tidal currents and maritime traffic within Sydney Harbour.

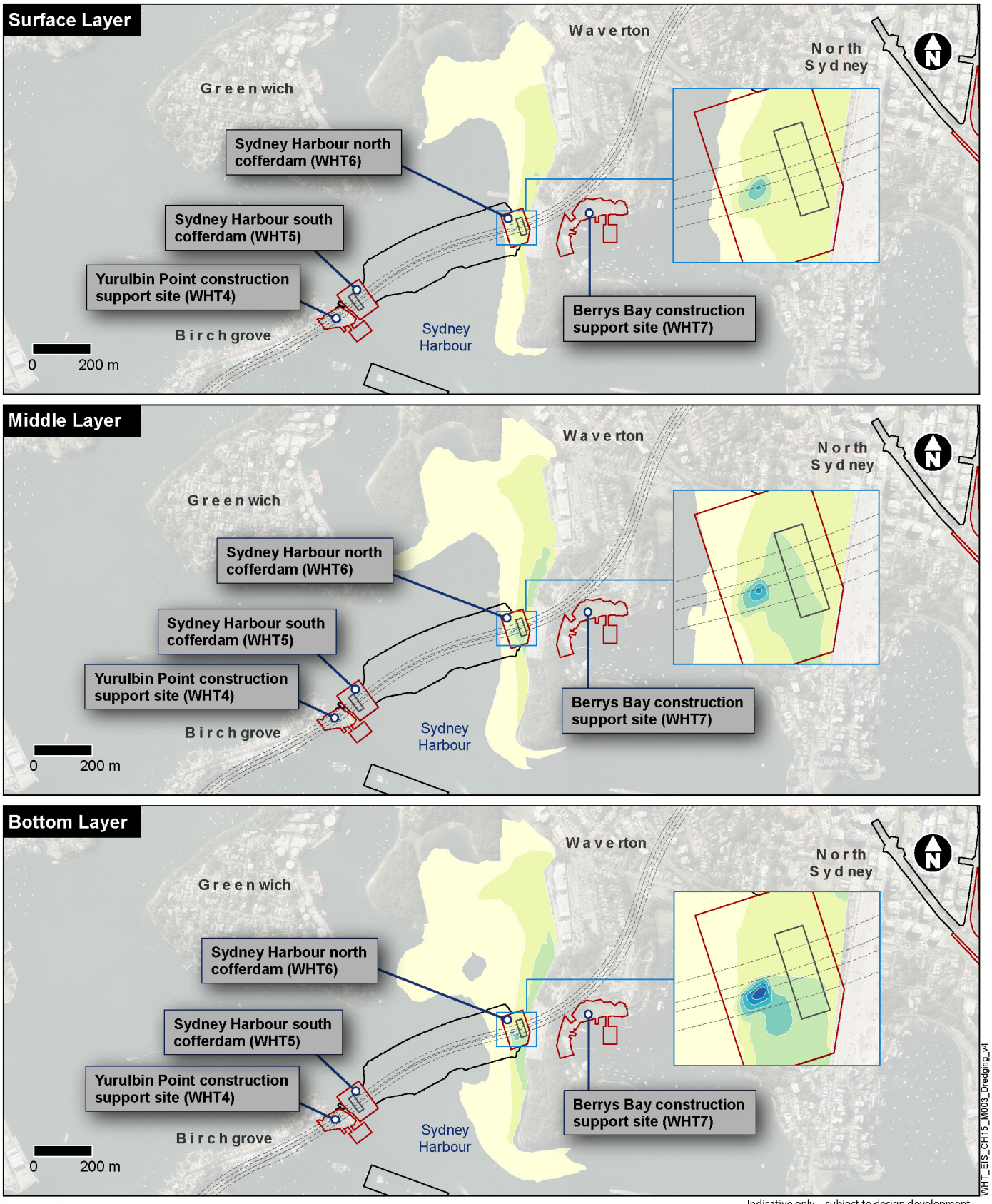


Figure 17-2 Dredge plume impacts within Sydney Harbour during dredging activities

Deposition of mobilised sediment

Modelling of sediment deposition on the bed of the harbour two weeks after the completion of dredging activities identified the following (refer to Figure 17-3):

- The majority of deposition would occur within and adjacent to the dredging footprint, concentrated at the north eastern end of the dredging footprint and along the shoreline adjacent to the Coal Loader Wharf, with sedimentation rates of just over one millimetre/day expected
- Lower levels of sedimentation are expected to occur within Balls Bay and the bays that line Sydney Harbour due to the lower tidal current speeds in these bays
- The highest rate of deposition is expected to occur during dredging activities in the sandy silty clay deposit adjacent to Balls Head
- Overall, the maximum and daily average deposition rates for the dredging within Balls Bay were less than the lowest thresholds noted in the literature.

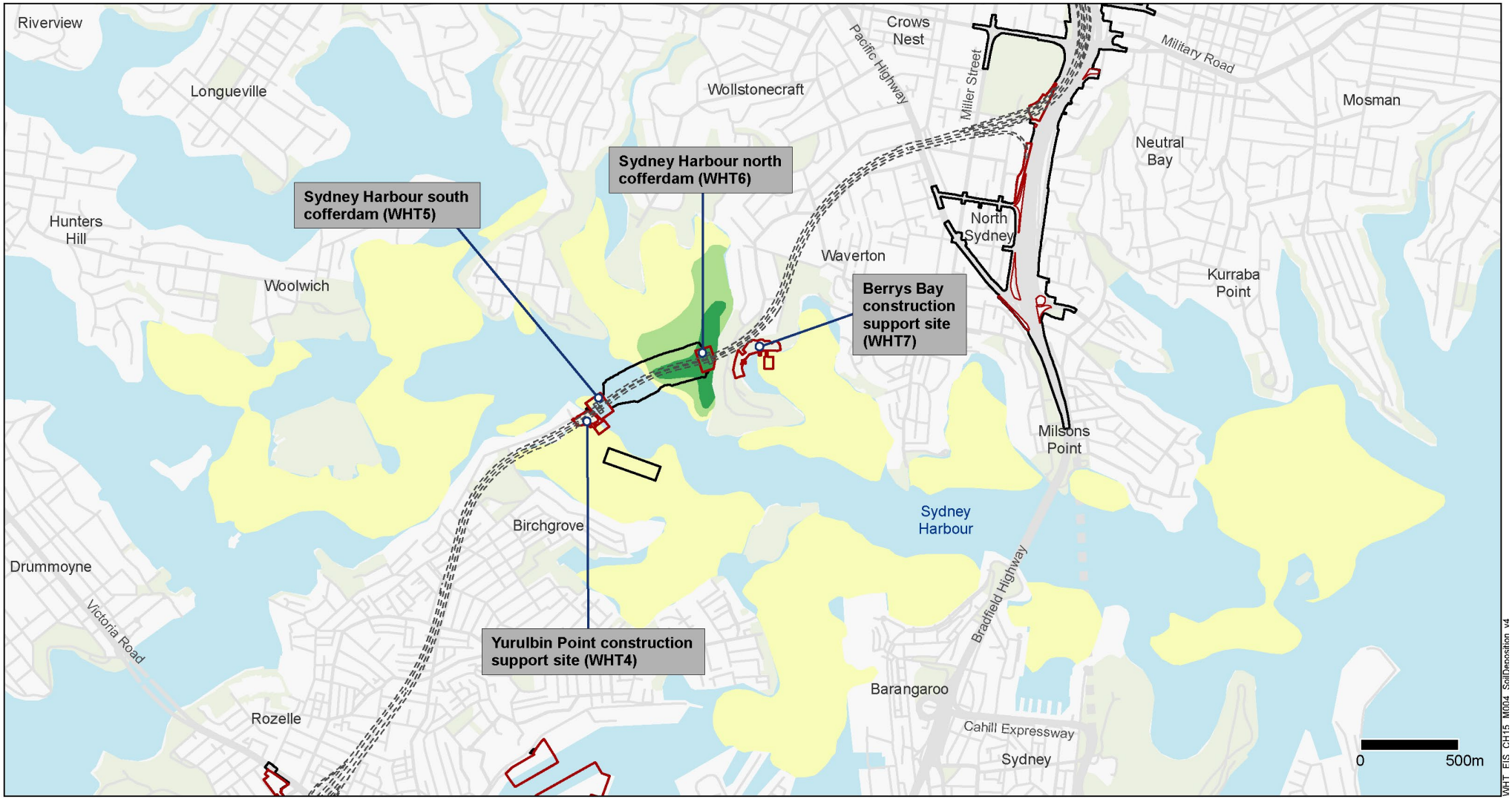
In summary, the effects of sedimentation as a result of dredging are expected to be minor. Short-term effects of turbidity and deposition would be similar to the effects following heavy rainfall events.

Mobilisation of contaminants

Sediment sampling carried out for the project within Sydney Harbour, White Bay and Berrys Bay identified levels of contaminants within the top 1.5 metre of sediments which would, if mobilised, exceed guideline criteria. Dredging and other construction activities within the 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 would be used to remove the top 1.5 metres of sediment. This would reduce the potential for release of contaminated sediments into the water (refer to Chapter 6 (Construction)). On this basis, it is unlikely that marine water quality would be substantially impacted.



Legend

Construction features

- Western Harbour Tunnel (tunnel section)
- Construction footprint
- Construction support site

Soil deposition depth

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

Figure 17-3 Sediment deposition two weeks after completion of dredging activities

Discharges, runoff, spills and leaks

Land based construction activities occurring immediately adjacent to marine waterbodies could potentially result in the release of sediment via air or runoff to receiving waterways. There is also potential for spills or leaks of fuels and/or oils from maintenance or re-fuelling of construction plant or equipment or vehicles incidents which could result in discharges to waterways. The discharge of treated water from onshore construction areas may also affect water quality in the marine waters.

These potential impacts would be effectively managed through the implementation of management controls and procedures such that there would be no major impacts on marine water quality.

17.4.3 Surface water quality

Surface activities

A summary of potential impacts to surface water quality as a result of surface works is provided in Table 17-12. Identified surface water quality impacts would be managed via standard erosion and sediment control management and mitigation measures for all work sites and surface works areas.

Table 17-12 Summary of potential construction impacts on surface water quality

Construction activities/ incidents	Potential impacts
Construction support sites	Establishment of construction support sites may result in erosion and mobilisation of exposed soils and open cuts by stormwater runoff and wind leading to sedimentation of waterways. Construction support sites may include activities that have the 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 unmitigated, direct impacts could 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: • Whites Creek

Construction activities/ incidents	Potential impacts
	• Willoughby Creek • Quarry Creek • Flat Rock Creek.
Stockpiling	Storage of earthwork materials, crushed rock, mulch and vegetation in stockpiles on construction support sites has the potential to impact water quality and impact the aquatic environment if not appropriately managed. Stockpiles within 500 metres of a waterway which could potentially present a risk to water quality, if unmitigated, would be located at: • Rozelle Rail Yards construction support site (WHT1) • Cammeray Golf Course construction support site (WHT10) and Warringah Freeway Upgrade and its construction support sites • Waltham Street construction support site (WHT11).
Demolition	Demolition works have the potential to disturb and/or spread sources of pollutants 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 downstream receiving waterways via the drainage network.
Contamination and acid sulfate soils	If unmitigated, disturbance of contaminated land or groundwater, or acid sulfate soils during construction could result in the mobilisation of contamination 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 for the areas of Lilyfield to Snails Bay and Balls Head to Crows Nest (refer to Appendix M (Technical Working Paper: Contamination)). There are isolated areas of high risk of potential acid sulfate soils being present at Rozelle Rail Yards and Birchgrove Park which could potentially affect Whites Creek if not managed appropriately.
Spills and leaks	If unmitigated, accidental spills or leaks could occur from spillage of diesel during refuelling, and leakage of hydraulic and lubricating oil from plant and equipment. Rinse water from plant washing and concrete slurries also have the potential to enter waterways if unmitigated.
Relocation of utilities	The relocation of utilities would involve soil disturbance as a result of trench excavation and under-boring. The disturbance of soil by machinery would increase the potential for soil erosion which has the potential to impact downstream water quality if not appropriately managed.
Installation of the communication cable	The trenching and underboring for the communication connection link between the Western Harbour Tunnel at Cammeray and the motorway control centre at Waltham Street, Artarmon would involve soil disturbance. If unmitigated, the disturbance of soil by machinery has the potential to increase soil erosion which has the potential to impact downstream water quality.

Construction activities/ incidents	Potential impacts
Vegetation removal	The removal of vegetation has the potential to increase the risk of erosion and sedimentation within the surrounding waterways if not properly managed. The majority of vegetation that would be removed would be located within the Warringah Freeway road reserve and the Cammeray Golf Course site. Additionally, a small area of vegetation would be removed from Yurulbin Park at Birchgrove. None of this vegetation is riparian or would impact bank stability.

Tunnelling activities

Sources of wastewater

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

- Groundwater ingress
- Rainfall runoff into tunnel portals and ventilation outlet tunnels
- Washdown runoff
- Heat and dust suppression water.

Most of this wastewater would be collected from groundwater seepage. 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.

The reuse of wastewater would be maximised during construction works (eg dust suppression). Despite this reuse, there is expected to be a surplus of wastewater, which would need to be treated 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. Site-specific trigger values would be developed during construction planning when setting the wastewater treatment plant discharge criteria to ensure that wastewater would be treated to a level that is representative of background concentrations of suitable reference sites or the ANZG (2018).

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 discharge points are presented in Table 17-13. The approximate duration of operation of construction wastewater treatment plants can be found in (Chapter 6 (Construction works)).

Table 17-13 Construction wastewater treatment plants

Plant location	Discharged quantity (kL/d)	Discharge location	Ultimate receiving waters
Rozelle Rail Yards construction support site (WHT1)	214	Local stormwater	Rozelle Bay

Plant location	Discharged quantity (kL/d)	Discharge location	Ultimate receiving waters
Victoria Road construction support site (WHT2)	413	Local stormwater	Iron Cove
Yurulbin Point construction support site (WHT4)	214	Snails Bay	Snails Bay
Berrys Bay construction support site (WHT7)	249	Berrys Bay	Berrys Bay
Cammeray Golf Course construction support site (WHT10)	196	Local stormwater	Willoughby Creek

The only discharge of treated water to freshwater would be from the Cammeray Golf Course wastewater treatment plant which would treat and discharge tunnel inflows to Willoughby Creek via the local stormwater system. Other wastewater treatment plants would discharge treated water into the harbour. The construction wastewater treatment plant at Cammeray Golf Course would treat wastewater generated from tunnelling activities to a standard suitable for discharge based on site specific trigger values to be developed during construction planning. Construction wastewater treatment trains would be designed to maintain or improve the water quality of the receiving ambient environment. As such, the impacts on the water quality of Willoughby Creek and ultimately Middle Harbour would be negligible.

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 management measures, pollutant loading to the receiving waterways is considered to be low compared to the existing pollutant loading from Whites Creek, Willoughby Creek, Quarry Creek and Flat Rock Creek catchments.

The project construction is therefore 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:

- Mobilised sediment which could build up in the streams if not appropriately managed
- Impervious surfaces created by the project, leading to increases in the volume and rate of runoff, which could cause erosion within the instream channel
- Subsidence below watercourses, potentially impacting on channel bed and bank conditions.

The Cammeray Golf Course wastewater treatment plant would discharge into Willoughby Creek via the local stormwater network at a cumulative and continuous average rate of about 0.002 kilolitres per second for 3.5 years. There would be also a period of about six months when the wastewater treatment plants at the Cammeray Golf Course construction support site (WHT10) and Beaches Link and Gore Hill Freeway Connection project Cammeray Golf Course construction support site (BL1) would discharge concurrently into Willoughby Creek at a continuous average rate of about 0.004 kilolitres per second (that is, four litres per second).

This cumulative flow is considered low when compared to creek flows experienced for the 50 per cent annual exceedance probability (12.8 kilolitres per second). Annual exceedance probability is the likelihood of occurrence of a flood of given size or larger occurring in any one year and is expressed as a percentage.

Cammeray Golf Course wastewater treatment plant discharges into Willoughby Creek are not anticipated to change the creek geomorphology as the creek channel is a modified concrete and rock channel that handles greater flows during frequent flood events. The susceptibility of the waterway 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 discharges anticipated compared to existing flows.

If unmitigated, 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 could include Willoughby Creek, Quarry Creek, Flat Rock Creek and along drainage lines flowing into the harbour. Potential for watercourse geomorphology impacts would be mitigated through environmental management measures outlined in Section 17.6.

17.4.5 Water balance, environmental water availability and flows

Water balance for the construction of the project

The expected water balance for the project construction, based on average groundwater inflows, and the estimated treated discharge quantities are shown in Table 17-14. Non-potable water uses would include roadheader supply, dust suppression, plant wash-down and rock bolting.
Some demand activities are consumptive such as water used in the offices which would be discharged to 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 17-13.

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 17-14 Construction water balance

Activity[1]	Total water demand (kL/d)	Consumptive use (kL/d)	Groundwater inflows[3] (kL/d)	Harvested rainwater (kL/d)	Treated water reused (kL/d)	Sydney water supply (kL/d)	Discharge quantity (kL/d)
Warringah Freeway Upgrade	109	109	0	0	0	109	0
Tunnelling[2]							
Rozelle Rail Yards (WHT1)	39	39	243	1	30	9	214
Victoria Road (WHT2)	460	39	168	1	177	283	413
White Bay (WHT3)	75	75	0	0	0	75	0
Yurulbin Point (WHT4)	228	17	94	1	92	136	214
Berrys Bay (WHT7)	241	30	144	1	107	134	249
Cammeray Golf Course (WHT10)	159	15	135	1	84	75	196
Waltham Street (WHT11)	16	16	0	0	0	16	0
Total	**1327**	**340**	**783**	**5**	**490**	**837**	**1286**

Note 1: Water demand and use estimates for Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6) construction support sites are included in White Bay (WHT3) construction support site.

Note 2: Incorporates all nine Warringah Freeway Upgrade construction support sites plus Berry Street North (WHT8) and Ridge Street north (WHT9) construction support sites.

Note 3: Groundwater inflow estimates have been apportioned based on the tunnel drainage design to provide an indicative estimate of likely inflow volumes that would be pumped to each construction wastewater treatment plant.

Water availability and flows

Water extraction from surface water is not proposed during construction of the project. However, surface environmental water availability and flows have the potential to be reduced as a result of groundwater drawdown during construction of the project.

The assessment of groundwater impacts for the project indicate that the maximum groundwater baseflow reductions at Whites Creek and Willoughby Creek would be negligible, with a less than one percent total flow reduction. Quarry Creek and Flat Rock Creek are not within the groundwater drawdown area of influence of the project and would not be impacted.

North Sydney Council stormwater harvesting scheme

The existing storage dam at Cammeray Golf Course would be relocated as part of the project during construction and reinstated indicatively within the north-western end of the golf course. The reinstatement of the storage dam would only occur once the Western Harbour Tunnel and Beaches Link program of works at the Warringah Freeway are completed, due to land availability. During that period of time, North Sydney Council would no longer be able to harvest stormwater runoff to irrigate areas such as the Cammeray Golf Course and other open space areas that form part of the scheme.

Transport for NSW would continue to consult with North Sydney Council to identify opportunities that provide a permanent solution earlier in the program that is reasonable and feasible. During periods in which the storage dam is not operational, Transport for NSW would come to an arrangement with North Sydney Council concerning the increased demand on other water sources.

17.4.6 Residual impacts on water quality and hydrodynamics 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 17.3.7 and Section 17.3.8 is expected be low provided the proposed management measures are implemented, maintained and monitored.

Construction activities are not expected to result in a significant change to the sediment dynamics in the vicinity of the Sydney Harbour crossing.

17.5 Assessment of potential operational impacts

17.5.1 Hydrodynamic environment of Sydney Harbour

The bed of Sydney Harbour at the proposed immersed tube tunnel would be returned to about the same level as it was prior to works commencing. Therefore, no hydrodynamic impacts to Sydney Harbour are expected during operation of project.

17.5.2 Marine water quality

When operational, the hydrodynamic environment of Sydney Harbour would be restored to existing conditions. No impacts to marine water quality would be expected.

17.5.3 Surface water quality

Surface water runoff

During the 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 Whites Creek and Willoughby 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.

At Rozelle, the surface water from the Western Harbour Tunnel portals and the road connecting the Western Harbour Tunnel with the Rozelle Interchange would be collected by the tunnel drainage system. It would not change the quality of Whites Creek or Rozelle Bay.

At the upgraded Warringah Freeway, stormwater discharge pollutant loads from impervious surfaces would be comparable to existing conditions. No additional surface water quality impacts are predicted.

Tunnel drainage and treatment

The tunnels would include drainage infrastructure to capture groundwater and stormwater ingress, spills, maintenance wastewater, fire suppressant deluge and other potential water sources. The water captured would be treated at the Rozelle operational wastewater treatment plant.

Tunnel wastewater treatment

Water intercepted by the tunnel drainage systems would be collected at a sump and pumped to the project wastewater treatment plant at the Rozelle Interchange. Following treatment, the water would then be discharged into drainage infrastructure constructed as part of the M4-M5 Link and ultimately into Rozelle Bay via the local stormwater system at a flow rate of about 0.006 kilolitres per second (that is, six litres per second).

The Rozelle Interchange wastewater treatment plant would be designed to meet specific discharge criteria as per ANZG (2018) 95 per cent species protection levels; ANZG (2018) 99 per cent protection levels for contaminants that bioaccumulate and the NHMRC (2008b) recreational guidelines water quality criteria for iron.

Impacts on NSW water quality objectives during operation

During operation, the project would treat tunnel inflows and road tunnel runoff at the Rozelle wastewater treatment plant. The plant would be designed to treat key indicators of concern to a level that is consistent with the ANZECC/ARMCANZ (2000) water quality guidelines and the NHMRC (2008b) recreational water quality guidelines.

Runoff from the surface connection and portals at Rozelle that is not collected by the tunnel drainage system would use the M4-M5 Link proposed water quality treatment devices. Runoff from the surface connection at Rozelle is unlikely to reduce the water quality of Whites Creek.

Runoff from the upgraded Warringah Freeway would not change exports of annual pollutant loads with no decrease in the water quality of Willoughby Creek or Quarry Creek.

The overall impacts to ambient water quality are likely to be negligible. Therefore, the project is considered to have a negligible influence on goals to achieve the WQOs for NSW waterways.

17.5.4 Impacts to the local stormwater system

Treated water from the Rozelle Rail Yards wastewater treatment plant would discharge into the local stormwater system at a flow rate of about 0.006 kilolitres per second (that is, six litres per second). This discharge rate is unlikely to have a material impact on the local stormwater system.

17.5.5 Impacts on geomorphology

Given that the additional discharge of water from the project would be via the existing stormwater network, the potential impacts to the geomorphology of watercourses are considered negligible. Similarly, Rozelle Rail Yards wastewater treatment plant discharges would be received into Rozelle Bay with negligible impacts to Whites Creek geomorphology.

Cumulative long-term surface settlement from tunnelling works and groundwater drawdown is expected to be nil or very minor at creeks intersected at depth or in proximity to the tunnel including Whites Creek, Willoughby Creek, Quarry Creek and Flat Rock Creek. 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.

17.5.6 Water balance, environmental water availability and flows

Water balance for the operation of the project

Operation of the project has the potential to alter the water balance of surface and groundwater systems. The permanent wastewater treatment plant at Rozelle would treat all groundwater inflows during operation of the project. Any non-potable water demand during operational of the project would be sourced from this facility. The operational stage water balance is shown in Table 17-15.

Table 17-15 Operational water balance

Wastewater treatment plant location	Water demand		Average groundwater inflows (kL/d)	Treated groundwater reused (kL/d)	Water make-up from other sources (kL/d)	Discharged quantity (kL/d)
	Washdown (kL/d)	Deluge Testing (kL/d)				
Rozelle Rail Yards	1	5	510	6	-	504

Water availability and flows

Water extraction from waterways is not proposed during operation of the project. There are not expected to be any impacts to the flow within Whites Creek as all discharges from the operational wastewater treatment plant would be discharged to Rozelle Bay via the stormwater network.

Groundwater drawdown is expected to be negligible and unlikely to impact creek flows. Similarly, the risk of creek flow losses from bed cracking has been identified as negligible.

North Sydney Council stormwater harvesting scheme

A new dam would be provided at the operational stage of the project indicatively within the north-western end of the golf course. The new dam would have a stormwater harvesting yield comparable to the existing one. The operational stage of the project would not impact the operation and volume of water harvested for the North Sydney Council stormwater harvesting scheme.

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) guidelines (refer to Section 17.1.3), and spill controls and water quality monitoring would be implemented to manage operational impacts on ambient water quality within the receiving waterways.

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 17.3.7 and Section 17.3.8 is expected 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 17-16. No specific measures are required for hydrodynamics given the methodology to be implemented during construction activities in Sydney Harbour (refer to Chapter 6 (Construction work)) and the minimal hydrodynamic impacts expected as a result of the project. Similarly, no hydrodynamic impacts are expected during operation of the project as the tunnels would be located beneath the bed of the harbour.

Table 17-16 Environmental management measures for water quality impacts

Ref	Phase	Impact	Environmental management measure	Location
WQ1	Construction	Erosion and sedimentation	Erosion and sediment 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 by both Transport for NSW and the Contractor for the duration of construction of the project to provide advice regarding erosion and sediment control including review of Erosion and Sediment Control Plans (ESCPs).	WHT/WFU

Ref	Phase	Impact	Environmental management measure	Location
WQ2	Construction	Spills and leakages	Emergency spill procedures will be developed to avoid and manage accidental spillages of fuels, chemicals or fluids during construction.	WHT/WFU
WQ3	Construction	Wastewater discharge	Construction wastewater treatment plants will be designed to treat wastewater generated from tunnel groundwater ingress, rainfall runoff in tunnel portals, heat and dust suppression water and washdown runoff generated during construction. Site-specific trigger values will be developed during construction planning to set the wastewater treatment plant discharge criteria ensuring wastewater will be treated to a level that is representative of background concentrations of a suitable reference site or the ANZECC/ARMCANZ (2018) guidelines.	WHT/WFU
WQ4	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 M4-M5 Link and Beaches Link and Gore Hill Freeway Connection projects. The program will be developed in consultation with the Environment Protection Authority, Department of Planning, Industry and Environment (Regions, Agriculture and Resources), Department of Planning, Industry and Environment (Water), and relevant councils. Sampling locations and monitoring methodology will be in accordance with the *Guideline for Construction Water Quality Monitoring* (RTA 2003b). Each monitoring/discharge point will have a specific concentration of pollutant that cannot be exceeded at the discharge point. Should any of the site-specific trigger values be exceeded, a management response will be triggered. This response will be documented within the construction freshwater quality monitoring program.	WHT/WFU

Ref	Phase	Impact	Environmental management measure	Location
WQ5	Construction	Local stormwater system capacity	Further design development will confirm the local stormwater system capacity to receive construction wastewater treatment plant inflows. In the event that 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 construction support site.	WHT
WQ6	Construction	Dredge plumes	Ongoing monitoring of dredge plumes will be carried out 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 that may ultimately result in the cessation of dredging for a period sufficient to remove the stress.	WHT
WQ7	Construction	Watercourse geomorphology	Construction drainage and discharge outlet infrastructure will direct flows downstream to minimise alterations and erosion of watercourse bed and banks. Energy dissipation and erosion scour protection will be implemented as appropriate. Construction work activities within or next to the watercourses and drainage lines will be minimised as much as feasibly possible to minimise disturbance of sediments in or near the waterway.	WHT/WFU
WQ8	Design and post-construction	North Sydney Council stormwater harvesting scheme	Reasonable and feasible opportunities to provide an interim or permanent solution for the relocation of the existing storage dam at Cammeray Golf Course earlier in program will be identified in consultation with North Sydney Council during detailed construction planning. During periods when the storage dam is no longer operational, Transport for NSW will come to an arrangement with North Sydney Council concerning the period in which the storage dam is no longer operational for the increased demand on other water sources.	WHT

Ref	Phase	Impact	Environmental management measure	Location
WQ9	Design and operation	Wastewater discharge	The permanent wastewater treatment plant at Rozelle will be designed to treat wastewater generated from tunnel groundwater ingress and rainfall runoff in tunnel portals. The level of treatment provided will consider the characteristics of the receiving environment (Rozelle Bay). Discharge from WWTP during the operation of the project will be required to meet specific discharge criteria as per ANZG (2018) 95% species protection levels; ANZG (2018) 99% protection levels for contaminants that bioaccumulate and the NHMRC (2008b) recreational guidelines water quality criteria for iron. These criteria will be defined during the construction planning phase to assist in determining wastewater treatment plant discharge criteria and ensure neutral or beneficial impacts to water quality of Rozelle Bay. Should any of the criteria be exceeded, a management response will be triggered. The management response will be documented within the Water Quality Monitoring Program.	WHT
WQ10	Design and operation	Local stormwater system capacity	The capacity for the local stormwater system to receive operational wastewater treatment plant inflows will be confirmed during further design development. In the event that 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 at the Rozelle Rail Yards.	WHT
WQ11	Operation	Operational monitoring	Operational monitoring will be carried out in line with the *Guideline for Construction Phase Water Quality Monitoring* (RTA 2003b) to: a) Assess and manage impacts on the receiving waters as the sites stabilise b) Assist in deciding when the site has stabilised c) Identify water quality conditions after development d) Identify appropriate measures to improve water quality performance. As a minimum, monthly monitoring will be	WHT/WFU

Ref	Phase	Impact	Environmental management measure	Location
			carried out for the first year of operation. Should any of the discharge criteria be exceeded, a management response will be triggered. The management response will be documented within the operational water quality monitoring program.	

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

Chapter 18

Flooding

January 2020

18 Flooding

This chapter outlines the potential flooding impacts associated with the project. 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.

The proposed environmental management measures relevant 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; and c. Hydraulic categorisation (floodways and flood storage areas).	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).
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** of this chapter 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 during construction and operation respectively thereafter.
a. How the tunnel entries and cut-and-cover sections of the tunnels would be protected from flooding during construction works;	**Section 18.5.2** summarises the findings of the assessed flood risk at the 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.
b. Any detrimental increases in the potential flood affectation of the project infrastructure and other properties, assets and infrastructure;	**Section 18.5** and **Section 18.6** of this chapter present the findings of an assessment of the potential impacts on flood behaviour during the construction and operational phases of the project, respectively.

Secretary's requirement	Where addressed in EIS
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% AEP flood. **Section 18.5.2** includes discussion on the potential flood hazard at proposed 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** of this chapter 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. **Section 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** present the findings of an assessment of the corresponding 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 State Emergency Services and Council;	**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. **Section 18.8** includes a recommendation for the incorporation of flood emergency management measures into the relevant environmental management document (construction and operation) of the project.

Secretary's requirement	Where addressed in EIS
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.
3. The assessment should take into consideration any flood studies undertaken by local government councils, as available.	**Appendix R** (Technical working paper: Flooding) contains details of previous flood studies that were considered as part of the present investigation.
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 rainfall intensity of flood producing rainfall events due to climate change.	**Section 18.6.2** of this chapter provides an assessment of the impact the project would have on flood behaviour under future climate change conditions.

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 ten 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 (PMP) 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 regards 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, with a sensitivity analysis of the recently released ARR 2019 edition
  - *Australian Disaster Resilience Handbook 7: Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia* (AIDR) 2017 edition
- State level:
  - *Floodplain Development Manual* (FDM) 2005
  - *Guideline on Development Controls on Low Risk Flood Areas* 2007
  - *Environmental Planning and Assessment Act* 1979
  - *Floodplain Risk Management Guidelines: Practical Considerations of Climate Change 2007*
- Local level:
  - Leichhardt Local Environment Plan (LEP) 2013
  - Willoughby LEP 2012
  - North Sydney Flood Study (WMAwater, 2016).

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 catchments that are crossed by the project
- Update of the existing flood models where required to more accurately define flooding and drainage behaviour in the vicinity of the project
- Preparation of exhibits showing flood behaviour under present day conditions for design floods with AEPs of 10%, 1%, 0.5% and 0.2%, as well as PMF
- Assessment of the potential flood risks during construction and the operational features of the project
- Assessment of the potential impact the project would have on flood behaviour while under construction and during operational conditions
- Assessment of the impact future climate change would have on flood behaviour under 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
- An application of the ARR 1987 methodology (and recently released 2019 ARR sensitivity analysis) to the design flood estimation.

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).

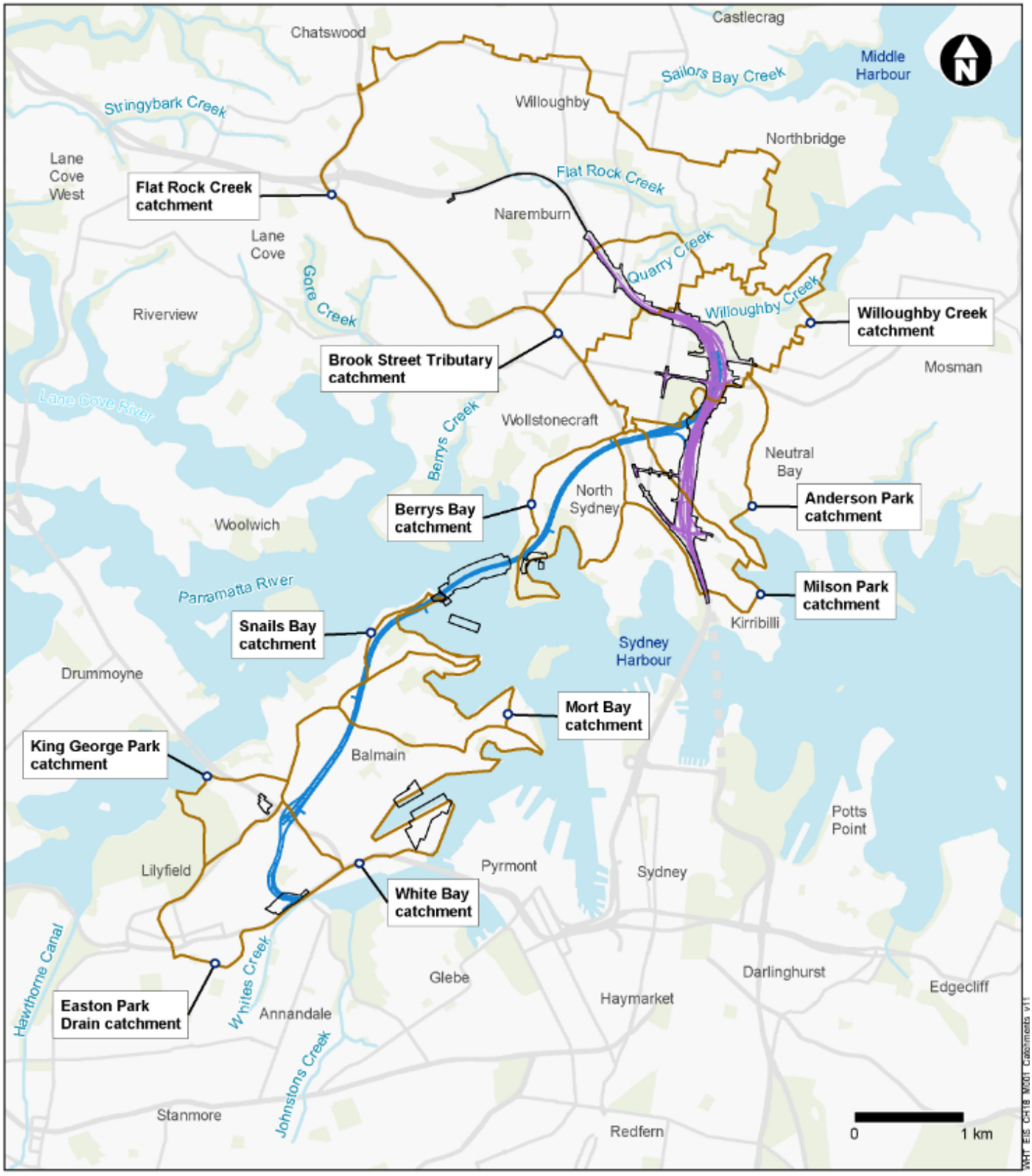
18.4 Existing environment

18.4.1 Overview

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

- Easton Park Drain
- King George Park
- White Bay
- Snails Bay
- Berrys Bay
- Milson Park
- Anderson Park
- Willoughby Creek
- Flat Rock Creek
- Brook Street Tributary (a sub-catchment of Flat Rock Creek).

Flat Rock Creek, Brook Street Tributary and Willoughby Creek drain to Middle Harbour, while the remainder of the catchments drain to Sydney Harbour. 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.



Legend

Operational features
- Western Harbour Tunnel
- Warringah Freeway Upgrade

Construction features
- Construction footprint

Catchments and waterways
- Catchement boundary
- Waterways

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 description

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.

Easton Park Drain

The Easton Park Drain runs in an easterly direction from Easton Park in Rozelle and has a total catchment area of about 1.18 square kilometres (118 hectares) where it discharges into Rozelle Bay. The catchment is located within the Inner West local government area and includes the suburbs of Rozelle and Lilyfield.

A series of drainage systems comprising pipe and box culvert sections control runoff from the catchment converge at the Rozelle Rail Yards where they discharge into a vegetated channel that has recently been constructed as part of the M4-M5 Link project. The vegetated channel runs for about 600 metres before discharging into a box culvert that runs under City West Link and into Rozelle Bay.

The Rozelle Rail Yards construction support site (WHT1) is proposed to be located along the north-western side of the aforementioned vegetated channel that runs through the Rozelle Rail Yards.

King George Park

The King George Park catchment drains in a north-westerly direction, extending from Darling Street in Rozelle to King George Park, and has a total catchment area of about 0.43 square kilometres (43 hectares). The catchment is located within the Inner West local government area and includes the suburbs of Rozelle and Lilyfield.

The eastern portion of the catchment, where the Victoria Road construction support site (WHT2) is proposed to be located, mainly comprises medium density residential development, as well as commercial development along the main arterial roads of Darling Street and Victoria Road.

Runoff from the eastern portion of the catchment is controlled by a series of piped drainage systems that connect into a trunk drainage line that runs along the western side of King George Park and discharges into Iron Cove Bay.

White Bay

The White Bay catchment drains in a south-easterly direction, extending from Darling Street in Rozelle to White Bay, and has a total catchment of about 1.61 square kilometres (161 hectares).

The catchment is located within the Inner West local government area and includes the suburbs of Rozelle and Balmain.

The White Bay construction support site (WHT3) is proposed to be located along the northern and southern sides of the bay, about 200 metres east of the main trunk drainage line that controls runoff from the catchment.

Snails Bay

The Snails Bay catchment drains in a north-easterly direction, extending from Spring Street in Birchgrove to Snails Bay, and has a total catchment area of about 0.23 square kilometres (23 hectares). The catchment is located within the Inner West local government area and includes the suburb of Birchgrove.

The Yurulbin Point construction support site (WHT4) is proposed to be located at the northern end of the catchment within Yurulbin Park.

Berrys Bay

The Berrys Bay catchment drains in a southerly direction, extending from McHatton Street in North Sydney to Berrys Bay, and has a total catchment area of about 0.8 square kilometres (80 hectares). The catchment is located within the North Sydney local government area and includes the suburbs of Waverton, North Sydney and McMahons Point.

The western portion of the catchment, where the Berrys Bay construction support site (WHT7) is proposed to be located, comprises residential development and open space. A 525 millimetre diameter piped drainage line controls runoff from the residential area along Balls Head Road and discharges into Berrys Bay to the west of Carradah Park.

Milson Park

The Milson Park catchment drains in a south-easterly direction, extending from West Street in North Sydney to Milson Park, and has a total catchment area of about 0.63 square kilometres (63 hectares). The catchment is located within the North Sydney local government area and includes the suburbs of North Sydney and Kirribilli.

The Warringah Freeway runs north-south through the middle reach of the catchment. The upper portion of the catchment to the west of the freeway mainly comprises the North Sydney central business district, while the lower portion of the catchment to the east of the freeway mainly comprises medium to high density residential development, as well as commercial development within Kirribilli Village.

The main trunk drainage line controlling runoff from the catchment ranges in size from a 1500 millimetre wide by 1200 millimetre high box culvert where it runs under Mount Street west of Walker Street, to a three metre wide channel where it runs along the northern side of Milson Park and discharges into Careening Cove. The trunk drainage line crosses Warringah Freeway between Mount Street and High Street as a 1500 to 1900 millimetre by 1200 millimetre high box culvert.

Anderson Park

The Anderson Park catchment drains in a southerly direction, extending from Military Road in Neutral Bay to Anderson Park, and has a total catchment area of about 0.89 square kilometres (89 hectares). The catchment is located within the North Sydney local government area and includes the suburbs of North Sydney and Neutral Bay.

The Warringah Freeway runs north-south through the western portion of the catchment, which predominantly comprises medium density residential development with areas of higher density residential and commercial development also present along Military Road and the area to the west

of the Warringah Freeway. Areas of open space include Forsyth Park, Anderson Park and the eastern portion of St Leonards Park.

The main trunk drainage line controlling runoff from the catchment ranges in size from a 1500 millimetre diameter pipe where it runs under Forsyth Park to a four metre wide channel where it runs along the western side of Anderson Park and discharges into Neutral Bay Harbour.

The western portion of the catchment is drained by a series of piped drainage systems that cross the Warringah Freeway and discharge into the aforementioned trunk drainage line that runs through Forsyth Park and Anderson Park. The largest of these piped drainage systems comprises a 1200 millimetre diameter pipe where it crosses the Warringah Freeway to the south of Hampden Street.

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 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 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 it 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.

Brook Street Tributary

The Brook Street Tributary runs in a north-easterly direction from Chandos Street in St Leonards and has a catchment area of about 0.9 square kilometres (90 hectares) where it joins the main arm of Flat Rock Creek (see Technical working paper: Flooding for more information). About 75 per cent of the Brook Street Tributary catchment lies in the North Sydney local government area, while the remainder is located in the Willoughby local government area.

The existing trunk drainage line controlling runoff from the catchment ranges in size from a 1200 millimetre diameter pipe at Chandos Street to a single 1350 millimetre diameter pipe where it discharges to an open channel near the intersection of Marks Street and Quarry Street. A number of minor lateral drainage lines discharge to the trunk drainage system along its length.

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 North Shore railway 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 North Shore railway 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 downstream of the North Shore railway line culvert to Willoughby Road was constructed in the 1930s 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.

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 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 280 metres to the east of Flat Rock Drive.

18.4.3 Catchment areas and drainage characteristics

Provided below is a brief description of the patterns of both mainstream flooding and major overland flow in respect to present day (ie pre project) conditions within areas in the vicinity of construction and/or operational components of the project. Reference is also made in the following discussion of the proposed construction support sites, further details of which are outlined in Chapter 6 (Construction work).

The patterns of mainstream flooding and major overland flow are classified using Annual Exceedance Probability and Probable Maximum Flood which, as outlined in Section 18.1.1 above, are defined as follows:

- Annual Exceedance Probability (AEP) –
  - 10% AEP – there is a ten 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 result of the optimum combination of the available moisture in the atmosphere and the efficiency of the storm mechanism in regards to rainfall production.

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 that the discussion below only considers those flooding patterns in catchment areas for which impacts are predicted. As such, AEP and PMF flood impacts are not reported for all catchment areas.

Figure 18-2 to Figure 18-7 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 Figure 4.2 to 4.4 in Appendix R (Technical working paper: Flooding)).

Easton Park Drain

A channel has recently been constructed as part of the M4-M5 Link project that runs in an easterly direction along the southern side of Rozelle Rail Yards and discharges into Rozelle Bay via a culvert crossing at City West Link. While the channel has been designed to convey the 1% AEP flow from the catchment to the west of the Rozelle Rail Yards, a series of ill-defined overland flow paths are shown to also occur through the northern portion of the rail yards due to flow that surcharges the drainage system in Lilyfield Road. Flooding in the vicinity of the proposed Rozelle Rail Yards construction support site (WHT1) is a low hazard nature and is classified as flood fringe for storm events up to 1% AEP in intensity.

King George Park

Overland flow in the vicinity of the proposed Victoria Road construction support site (WHT2) is shown to be largely confined to the roadways of Victoria Road and Waterloo Street for all events up to the PMF. Flooding within the vicinity of the Victoria Road construction support site (WHT2) is principally of a low hazard nature, with floodway areas confined to the road reserve of Victoria Avenue for storm events up to 1% AEP in intensity.

White Bay

The White Bay construction support site (WHT3) would be located on foreshore land that is located above the PMF level due to elevated storm tides.

Snails Bay

While the area of Yurulbin Park where the Yurulbin Point construction support site (WHT4) is proposed to be located is not impacted by mainstream flooding or major overland flow, the area would be affected by local catchment runoff of a low hazard nature from the residential area to its west.

Berrys Bay

A series of ill-defined overland flow paths are shown to occur through the southern portion of Carradah Park where the Berrys Bay construction support site (WHT7) is proposed to be located. This overland flow is due to runoff from the residential area bounded by Balls Head Road and Larkin Street. Depths of flow through Carradah Park are typically less than 0.3 metres during a 1% AEP event. Flooding in this area is classified as low hazard flood fringe for storms up to 1% AEP in intensity.

Milson Park

Up to 1% AEP

An overland flow path is shown to occur due to surcharge of the drainage system in Mount Street and Walker Street during a 10% AEP event. Overland flow collects at the sag in Arthur Street between Mount Street and the Pacific Highway, where it surcharges onto the northbound carriageways of the Warringah Freeway. The northern section of Arthur Street near its intersections with Mount Street operates as a high hazard floodway during a 1% AEP storm event.

Flow that discharges onto the Warringah Freeway from Arthur Street and at St Leonards Park combines with local catchment runoff and pond at the sags in the northbound and southbound carriageways that are located to the north of the High Street overbridge (hereafter referred to and identified as ‘the southern Warringah Freeway sag’).

Surcharge of the existing trunk drainage line which runs from the southern side of the High Street southbound on ramp to the Cahill Expressway to Careening Bay causes flooding in a number of

residential unit block and terrace-type developments during storms as frequent as 10% AEP. It also causes flooding of the James Milson Village (Retirement and Residential Care) development which is located on Clark Street in North Sydney. Areas within the village that are impacted by flow which surcharges the trunk drainage line include existing basement car parking and below-ground storage facilities.

During a 1% AEP storm event, several low and high hazard floodway areas would develop along the section of the Warringah Freeway which runs through the Milson Park catchment, while a flood storage area would form at the location of the southern Warringah Freeway sag. Two flood storage areas would also develop beneath the elevated section of the Cahill Expressway west of Broughton Street during a storm of this intensity.

PMF

Flow that discharges onto Warringah Freeway from Arthur Street, Hampden Street and St Leonards Park would combine with local catchment runoff and pond at the sags in the northbound carriageways to a maximum depth of over two metres. The depth of ponding at this location is sufficient to overlap the adjacent concrete barriers where floodwater would enter the tunnel portals to the Sydney Harbour Tunnel[1].

Anderson Park

Up to 1% AEP

Flow would surcharge onto the Warringah Freeway from St Leonards Park where it runs in a southerly direction along the northbound and southbound carriageways at depths that are typically less than 0.2 metres during a 1% AEP event.

Overland flow that surcharges the drainage system between McLaren Street and Ridge Street would pond at the sag that is located on the western side of the Berry Street on ramp to the Warringah Freeway to a maximum depth of 1.7 metres during a 10% AEP event, increasing to 2.4 metres during a 1% AEP event. The level of ponding during a 1% AEP event is about four metres below the adjacent level of the northbound on-ramp from Berry Street.

Similar to the Milson Park catchment, several low and high hazard floodway areas would develop along the section of the Warringah Freeway which runs through the Anderson Park catchment during a 1% AEP storm event. A high and low hazard flood storage area would also develop immediately to the west of the Berry Street on ramp to the Warringah Freeway during a storm of this intensity.

PMF

Flow that discharges onto the Warringah Freeway from St Leonards Park runs in a southerly direction along the northbound and southbound carriageways at a maximum depth of about 0.4 metres.

Overland flow from McLaren Street and Walker Street that collects at the sag located on the western side of the Berry Street on ramp to the Warringah Freeway would pond to a maximum depth of about five metres, which is sufficient to cause floodwaters to surcharge onto the Warringah Freeway.

[1] Unlike the current project, the flood immunity requirement for the Sydney Harbour Tunnel was to prevent the ingress of floodwater to the tunnel system for storm events up to 1% AEP in intensity.

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 in the vicinity of 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 people 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 would also 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 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 runs 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.

Brook Street Tributary

Up to 1% AEP

Flow surcharges the sag in Atchison Street to the west of Willoughby Road during a 10% AEP event where it discharges in a north-easterly direction along Chandos Street and Wheatleigh Street to the underpass of the Gore Hill Freeway at Brook Street. From the Brook Street underpass overland flow continues along Palmer Street and Hamilton Lane and discharges into Flat Rock Creek to the north of Hamilton Reserve. Depths of overland flow immediately to the north and south of the Gore Hill Freeway are greater than one metre in a 1% AEP event, which is sufficient to result in hazardous flooding conditions to persons and property.

While a low and high hazard floodway would form along the valley of the catchment during a 1% AEP storm event, flooding along the section of the Warringah Freeway which runs through the Brook Street Tributary catchment is generally classified as low hazard flood fringe. The notable exception is a low and high hazard floodway area which would form along the southbound Brook Street on ramp to the freeway during a storm of this intensity.

PMF

Depths of flow would be greater than one metre along the full length of the overland flow path that runs along Brook Street Tributary between Atchison Street and Flat Rock Creek.

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 1 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 that are 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 travels 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 collects 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 that are located between Herbert Street and the North Shore railway line also contributes to overland flow travelling east along the eastbound carriageway of the Gore Hill Freeway.

Flooding along the Gore Hill Freeway is of a low hazard nature, with floodway areas forming along the edge of several of the carriageways during a 1% AEP storm event.

PMF

The main carriageways and various 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.

The section of Gore Hill Freeway between Reserve Road and the North Shore railway 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 North Shore railway line are controlled by the rail underpass, which constricts overland flow travelling along the Gore Hill Freeway.

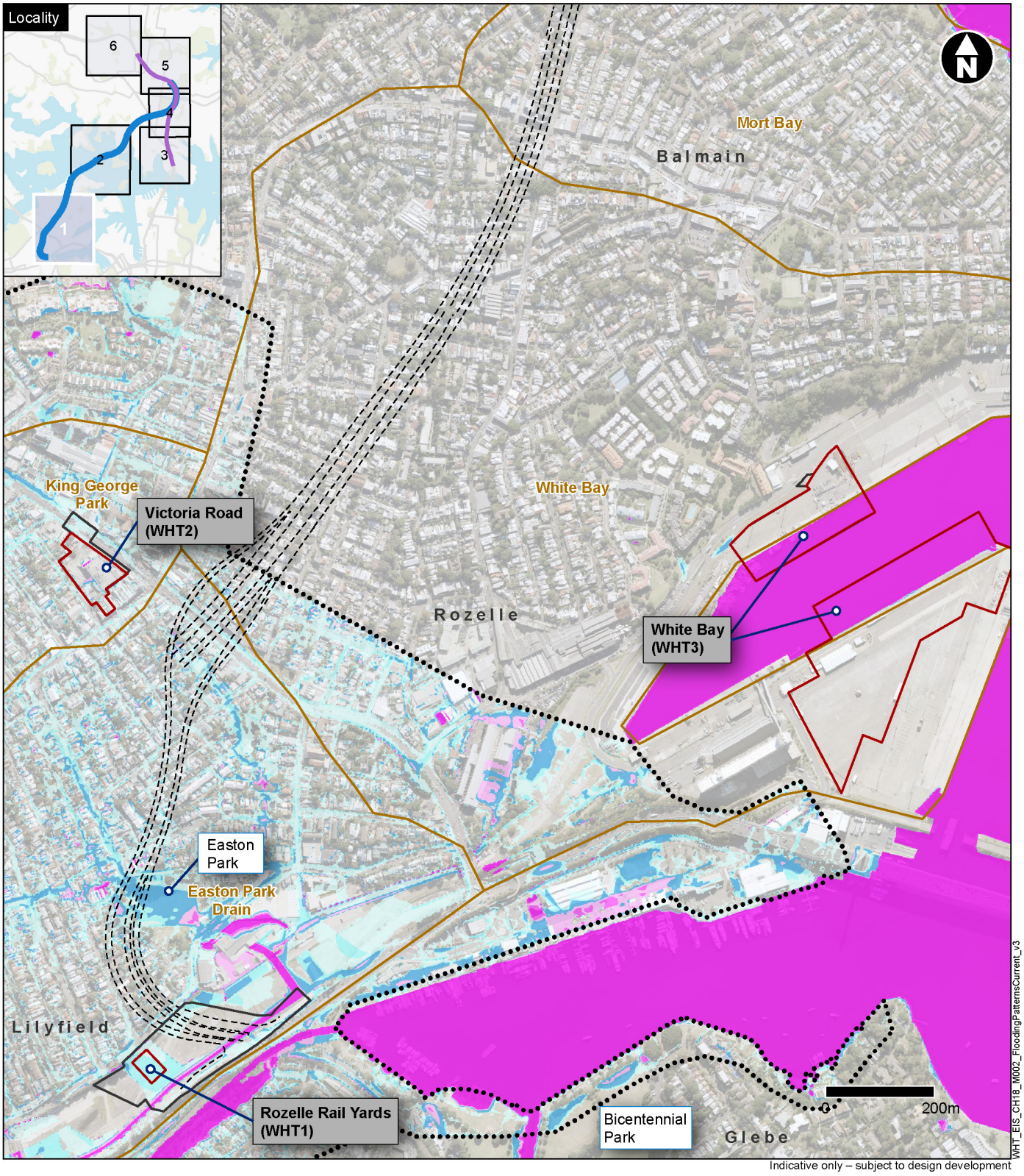
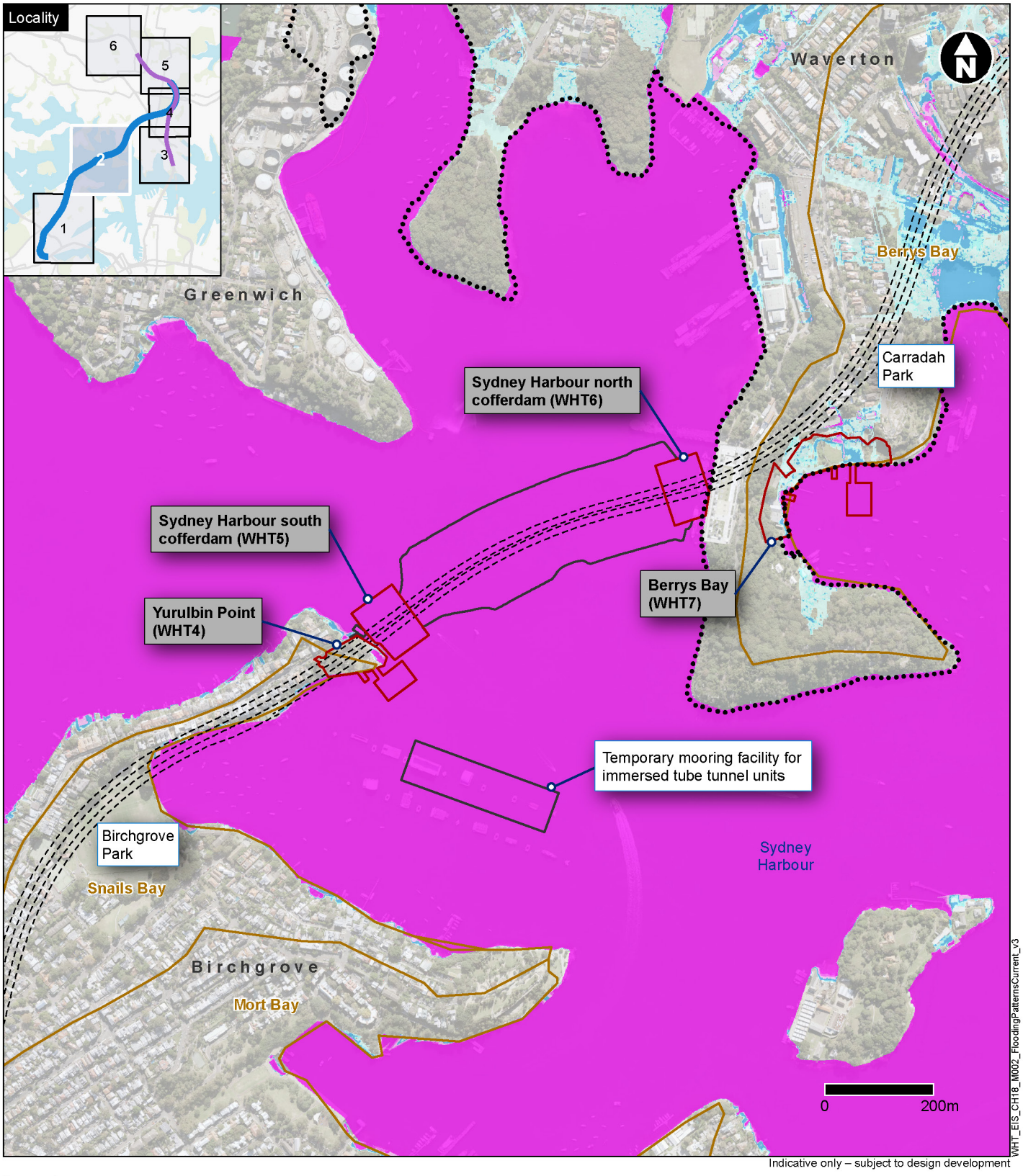


Figure 18-2 Flood behaviour under present day conditions – 1% AEP event (Rozelle) (map 1)



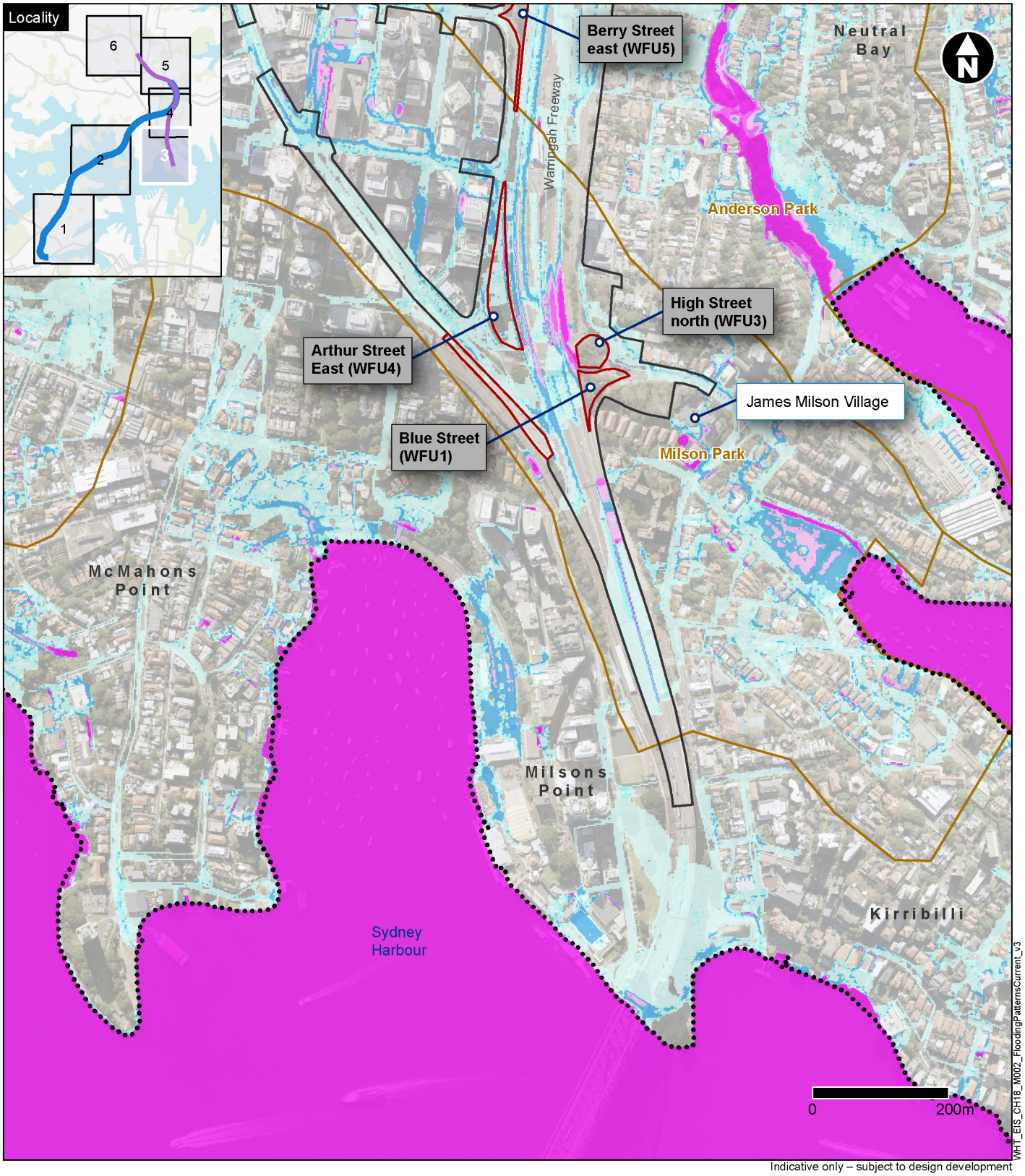
Legend

- Limit of main stream flooding and major overland flow mapping
- Tunnel section
- Construction footprint
- Construction support site
- Catchment boundary

Indicative depth of inundation (m)

- <0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- >0.7

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



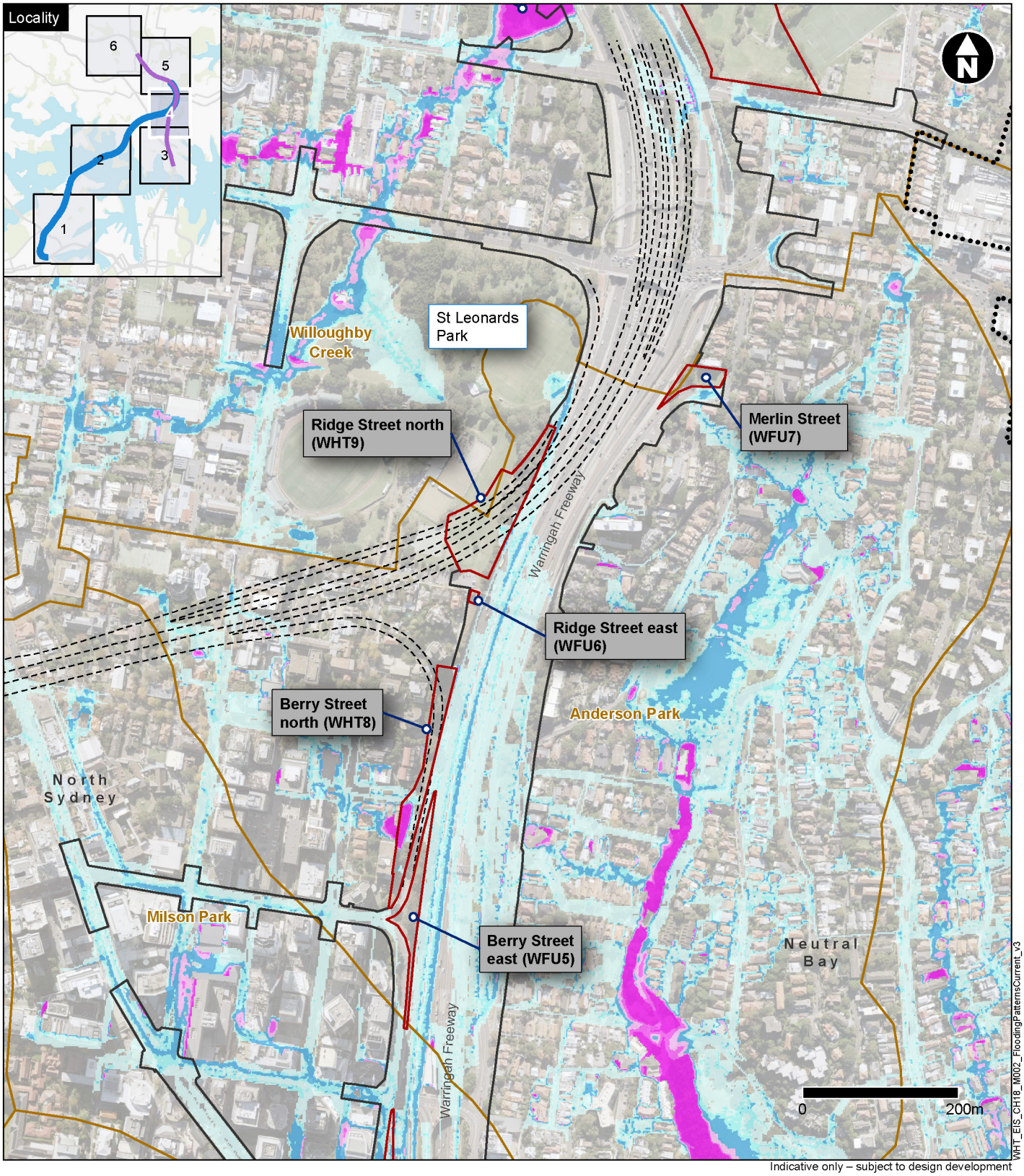
Legend

- Limit of main stream flooding and major overland flow mapping
- Tunnel section
- Construction footprint
- Construction support site
- Catchment boundary

Indicative depth of inundation (m)

- <0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- >0.7

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



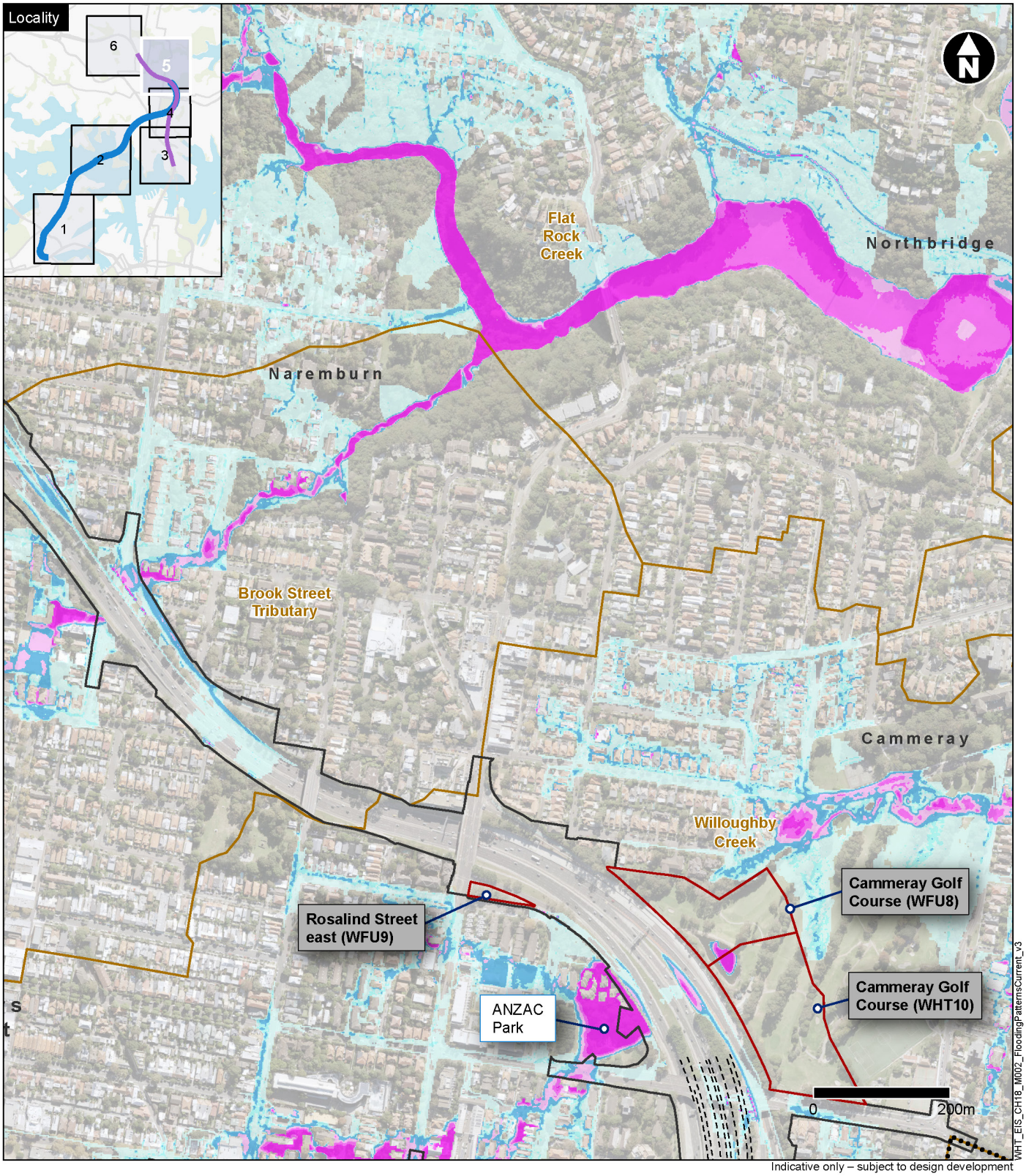
Legend

- Limit of main stream flooding and major overland flow mapping
- Tunnel section
- Construction footprint
- Construction support site
- Catchment boundary

Indicative depth of inundation (m)

- <0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- >0.7

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



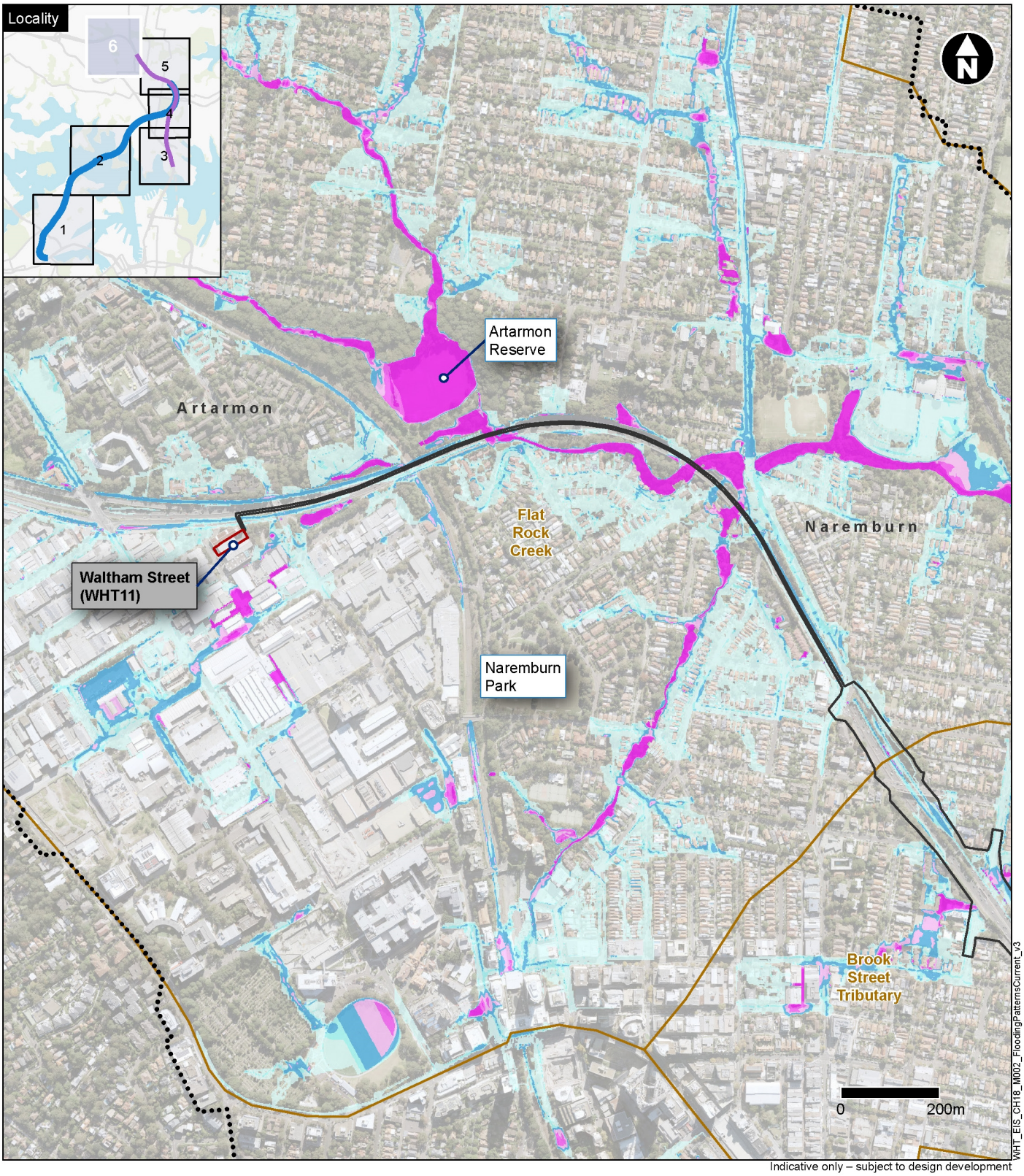
Legend

- Limit of main stream flooding and major overland flow mapping
- Tunnel section
- Construction footprint
- Construction support site
- Catchment boundary

Indicative depth of inundation (m)

- <0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- >0.7

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



Legend

- Limit of main stream flooding and major overland flow mapping
- Tunnel section
- Construction footprint
- Construction support site
- Catchment boundary

Indicative depth of inundation (m)

- <0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- >0.7

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

18.5 Assessment of potential construction impacts

This section provides an assessment of the flood risk at the proposed construction support sites which would be associated with the construction of the Western Harbour Tunnel and Warringah Freeway Upgrade project. Details of the proposed 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 increase flooding conditions when compared to both present day and operational conditions. This is because 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 are summarised in Table 18-2.

While the majority of the 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 the Berry Street north (WHT8) and Cammeray Golf Course (WFU8) construction support sites. 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.

While the findings of the assessment provide an indication of the potential impacts of construction activities on flood behaviour, further investigation would be carried out during detailed design as layouts and staging diagrams are further developed. 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.

Tunnel construction

The key activities associated with tunnel construction are carried out from the Western Harbour Tunnel construction support sites, including:

- Tunnel excavation
- Cut and cover structures.

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

Spoil management and stockpile areas

The construction of the project would generate a significant amount of spoil which would 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.

Stockpiling of spoil material is proposed at all construction support sites with the exception of Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6). While the majority of these sites are affected by flooding to varying degrees (refer to Table 18-2), 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 construction support sites, the main area of surface earthworks is associated with the Warringah Freeway Upgrade project.

The nature of the flooding that could be experienced within the project surface works footprint during the construction of the Warringah Freeway Upgrade project would generally be shallow and of a short duration. The exception to this would be the major ponding areas that are located adjacent to ANZAC Park in the Willoughby Creek catchment and the Sydney Harbour Tunnel portals in the Anderson Park catchment. Figures 4.2, 4.3 and 4.4 of Appendix R (Technical working paper: Flooding) show the indicative extent and depth of inundation over the extent of project surface works footprint under present day (ie pre-project) conditions.

The inundation of the surface earthworks by floodwater has the potential to cause scour of disturbed surfaces and transport sediment and construction materials into the receiving waterways. It would therefore 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 the Warringah Freeway Upgrade project, the construction of which would be managed from the Blue Street (WFU1), High Street south (WFU2), High Street north (WFU3), Ridge Street east (WFU6), Merlin Street (WFU7) and Cammeray Golf Course (WFU8) construction support sites.

Proposed bridge works at both the High Street and Mount Street overpasses of the Warringah Freeway could be impacted by floodwater during storms that result in the surcharge of the existing stormwater drainage system which controls surface runoff in the Milson Park catchment.

Works associated with the proposed demolition of the existing Ridge Street shared user bridge and the construction of the upgraded Ridge Street shared user bridge could be impacted by relatively shallow overland flow which occurs during stormwater which result in the surcharge of the existing drainage system of the Warringah Freeway where it runs through the Anderson Park catchment.

The proposed bridge works around the Falcon Street overpass of the Warringah Freeway are not at risk of being flooded during construction.

The proposed bridge works adjacent to Cammeray Golf Course would be subject to flooding during very rare and extreme flood events when the noise wall which runs along the western side of the Warringah Freeway would be overtopped.

18.5.2 Potential flood risk at construction support sites

Without the implementation of appropriate management measures, the inundation of the 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 measures such as site sheds, stockpiles, noise walls and flood protection walls, which in turn could increase flooding conditions in existing development located outside the construction footprint.

Table 18-2 provides a summary of the proposed activities, as well as the assessed flood risk at the construction support sites that are associated with the construction of the Western Harbour Tunnel and Warringah Freeway Upgrade projects, respectively. Figure 5.1 of Appendix R (Technical working paper: Flooding) shows the extent to which floods of varying magnitude affect each construction support site, while Figure 5.2 shows the indicative depth and extent of inundation in their vicinity for floods with AEPs of 10% and 1%. Figure 5.3 of Appendix R (Technical working paper: Flooding) shows the provisional flood hazard and preliminary hydraulic categorisation of the floodplain in the vicinity of each construction support site for a 1% AEP flood event. Further details of each construction support site and its associated facilities and activities is provided in Chapter 6 (Construction work) of the environmental impact statement. 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 activities at proposed construction support sites

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
Western Harbour Tunnel									
Rozelle Rail Yards (WHT1)	Easton Park Drain	✓	✓			✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • Floodwater surcharges the southern kerb line of Lilyfield Road where it discharges through the construction support site during storms more frequent than 10% AEP, albeit at relatively shallow depths • Overland flow discharging through the Rozelle Rail Yards construction support site (WHT1) during storms up to 1% AEP in intensity is classified as low hazard flood fringe.	• Activities within the confines of the Rozelle Rail Yards construction support site (WHT1) have the potential to alter patterns of overland flow in this area.

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
Victoria Road (WHT2)	King George Park	✓	✓	✓		✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • The construction support site is subject to relatively shallow overland flow which originates from the rear of several properties that are located along Darling Street • Overland flow discharging through the Victoria Road construction support site (WHT2) during storms up to 1% AEP in intensity is classified as low hazard flood fringe.	• Activities along the southern boundary of the Victoria Road construction support site (WHT2) have the potential to obstruct the passage of overland flow which discharges from the rear of the adjacent properties in Darling Street.
White Bay (WHT3)	White Bay	✓	✓	✓				• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • Flooding of the White Bay construction support site	• Activities within the confines of the White Bay construction support site (WHT3) would not have an impact on water levels in Sydney Harbour.

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
								(WHT3) is principally limited to elevated water levels in Sydney Harbour • Wave action due to coincident high winds could increase flooding conditions at the construction support site during periods of elevated water levels in Sydney Harbour.	
Yurulbin Point (WHT4)	Snails Bay	✓	✓	✓		✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • Inundation of the Yurulbin Point construction support site (WHT4) is principally limited to elevated water levels in Sydney Harbour • Wave action due to coincident high winds could increase flooding conditions at the	• Activities within the confines of the Yurulbin Point construction support (WHT4) site would not have an impact on water levels in Sydney Harbour.

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
								construction support site during periods of elevated water levels in Sydney Harbour.	
Sydney Harbour south cofferdam (WHT5)	-			✓		✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • Inundation of the Sydney Harbour south cofferdam (WHT5) is principally limited to elevated water levels in Sydney Harbour • Wave action due to coincident high winds could increase flooding conditions at the construction support site during periods of elevated water levels in Sydney Harbour.	• Activities within the confines of the Sydney Harbour south cofferdam (WHT5) would not have an impact on water levels in Sydney Harbour.
Sydney Harbour north	-			✓		✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R	• Activities within the confines of the Sydney Harbour north cofferdam

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
cofferdam (WHT6)								(Technical working paper: Flooding) • Flooding of the Sydney Harbour north cofferdam (WHT6) is principally limited to elevated water levels in Sydney Harbour • Wave action due to coincident high winds could increase flooding conditions at the construction support site during periods of elevated water levels in Sydney Harbour.	(WHT6)would not have an impact on water levels in Sydney Harbour.
Berrys Bay (WHT7)	Berrys Bay	✓	✓	✓		✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • While flooding of the Berrys Bay construction support site (WHT7) principally occurs as a result of flow which	• Activities within the confines of the Berrys Bay construction support site (WHT7) would not have an impact on water levels in Sydney Harbour.

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
								surcharges the existing stormwater drainage system to its north, its subject to flooding as a result of elevated water levels in Sydney Harbour • Wave action due to coincident high winds could also increase flooding conditions at the construction support site during periods of elevated water levels in Sydney Harbour • Overland flow discharging through the Berrys Bay construction support site (WHT7) during storms up to 1% AEP in intensity is classified as low hazard flood fringe.	
Berry Street north (WHT8)	Anderson Park	✓	✓		✓	✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper:	• Construction activities within the confines of the Berry Street north construction support site (WHT8) have

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
								Flooding) • Flooding of the Berry Street north construction support site (WHT8) occurs during storms which result in the surcharge of the existing stormwater drainage system which control surface runoff to its west • Overland flow would pond on the western side of the Berry Street on ramp to the Western Harbour Tunnel to depths greater than 1 metre during storms more frequent than 10% AEP • Overland flow discharging through the Berry Street north construction support site (WHT8) during storms up to 1% AEP in intensity is generally classified as low hazard flood fringe, although a high and low	the potential to increase the depth of ponding on the western side of the Berry Street on ramp to the Western Harbour Tunnel which would increase flooding conditions in existing residential development • Changes in the level of the Berry Street on ramp to the Western Harbour Tunnel have the potential to increase flooding conditions in existing development that is located to its west, as well as in the vicinity of the existing Sydney Harbour Tunnel portals.

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
								hazard flood storage area would form on the western side of the Berry Street on ramp to the Warringah Freeway during storms that surcharge the existing stormwater drainage system.	
Ridge Street north (WHT9)	Anderson Park	✓	✓		✓		✓	• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • The construction support site 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 Ridge Street north construction support site (WHT9) during storms up to 1% AEP in intensity	• The provision of hard stand areas within the confines of the Ridge Street north construction support site (WHT9) would increase the runoff potential of the area, which in turn would increase the rate at which flow discharges onto the Warringah Freeway • Runoff discharging from St Leonards Park has the potential to impact excavation for the adjacent cut and cover, and tough sections of the Western Harbour Tunnel northbound off ramp.

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
								is classed as low hazard flood fringe.	
Cammeray Golf Course (WHT10)	Willoughby Creek	✓	✓	✓	✓	✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • The Cammeray Golf Course construction support site (WHT10) would be subject to very shallow sheet flow during heavy rainfall events, principally due to runoff generated from within its extent (*Note that it is assumed that the existing golf course dam would be filled as part of the construction of the Western Harbour Tunnel and Warringah Freeway Upgrade projects*) • Overland flow discharging through the construction	• 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 (WHT10) has the potential to increase 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 (WHT10) have the potential to obstruct flow which surcharges the Warringah Freeway during a PMF, thereby increasing flooding conditions in existing development that is located on the western side of the freeway • Floodwater originating from ANZAC

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
								support site 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 (WHT10) at depths exceeding 0.5 metres.	Park as well as from within Warringah Freeway corridor has the potential to impact tunnel works that are proposed adjacent to Cammeray Golf Course • The staging of the works associated with the replacement of the major trunk drainage line which crosses the Warringah Freeway from ANZAC Park to the Cammeray Golf Course has the potential to increase flooding behaviour in existing residential development that is located on the western (upstream) side of the road corridor.
Waltham Street (WHT11)	Flat Rock Creek	✓	✓			✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • The Waltham Street construction support site (WHT11) is subject to relatively shallow overland flow along its eastern boundary in a PMF event.	• Activities within the confines of the Waltham Street construction support site (WHT11) would not impact flood behaviour.

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
Warringah Freeway Upgrade									
Blue Street (WFU1)	Milson Park	✓	✓			✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • The Blue Street construction support site (WFU1) is not subject to flooding.	• Activities within the confines of the Blue Street construction support site (WFU1) would not impact flood behaviour.
High Street south (WFU2)	Milson Park	✓	✓			✓	✓	• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • The High Street south construction support site (WFU2) is not subject to flooding.	• Activities within the confines of the High Street south construction support site (WFU2) would not impact flood behaviour.

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
High Street north (WFU3)	Milson Park	✓	✓			✓	✓	• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • The High Street north construction support site (WFU3) is not subject to flooding.	• Activities within the confines of the High Street north construction support site (WFU3) would not impact flood behaviour.
Arthur Street east (WFU4)	Milson Park	✓	✓			✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • Flooding of the Arthur Street east construction support site (WFU4) occurs during storms which result in the surcharge of the existing stormwater drainage system which control surface runoff to its west • Two low hazard floodway areas would develop	• Activities within the confines of the Arthur Street east construction support site (WFU4) have the potential to obstruct overland flow which surcharges the eastern kerb line of Arthur Street. Obstructions to the passage of overland flow through the Arthur Street east construction support site (WFU4) have the potential to increase the depth of inundation on Arthur Street and along the frontage of several commercial properties that located on its western side.

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
								through the Arthur Street east construction support site (WFU4) during storm events which surcharge the existing stormwater drainage system.	
Berry Street east (WFU5)	Anderson Park	✓	✓			✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • The Berry Street east construction support site (WFU5) would be subject to relatively shallow overland flow at its northern and southern ends during storms which result in the surcharge of the existing stormwater drainage system which control surface runoff to its west. • Overland flow discharging through the Berry Street	• The provision of hard stand areas within the confines of the Berry Street east construction support site (WFU5) would increase the runoff potential of the area, which in turn would increase the rate at which flow discharges onto the Warringah Freeway.

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
								east construction support site (WFU5) during storms up to 1% AEP in intensity is classed as low hazard flood fringe.	
Ridge Street east (WFU6)	Anderson Park	✓	✓			✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • The Ridge Street east construction support site (WFU6) is not subject to flooding.	• Activities within the confines of the Ridge Street east construction support site (WFU6) would not impact flood behaviour.
Merlin Street (WFU7)	Anderson Park	✓	✓			✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • The Merlin Street construction support site (WFU7) is not subject to flooding.	• Activities within the confines of the Merlin Street construction support site (WFU7) would not impact flood behaviour.

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
Cammeray Golf Course (WFU8)	Anderson Park	✓	✓			✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • The Cammeray Golf Course construction support site (WFU8) would be subject to very shallow sheet flow during heavy rainfall events, principally due to runoff generated from within its extent (Note that it is assumed that the existing golf course dam would be filled as part of the construction of the Western Harbour Tunnel and Warringah Freeway Upgrade projects). • Overland flow discharging through the Cammeray Golf Course construction support site (WFU8) during storms up to 1% AEP in intensity is classified as	• 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 supports site (WFU8) has the potential to increase flooding conditions in existing residential development that is located along Warringa Road, Falls Street, Cammeray Road, and Grafton Street • Floodwater originating from ANZAC Park as well as from within the Warringah Freeway corridor has the potential to impact tunnel works that are proposed adjacent to Cammeray Golf Course.

Construction support site	Catchment	Site facilities[1]	Spoil management[1]	Tunnel launch support[1]	Cut-and-cover structures[1]	Surface earthworks[1]	Bridge structures[1]	Description of existing flood behaviour	Potential impacts of construction activities on flood behaviour
								low hazard flood fringe • During a PMF event, floodwater would surcharge the Warringah Freeway where it would discharge through the construction support site at depths exceeding 0.5 metres.	
Rosalind Street east (WFU9)	Anderson Park	✓	✓			✓		• Refer to Figures 5.1, 5.2 and 5.3 of Appendix R (Technical working paper: Flooding) • The Rosalind Street east construction support site (WFU9) is not subject to flooding.	• Activities within the confines of the Rosalind Street east construction support site (WFU9) would not impact flood behaviour.

[1] 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 if appropriate management measures are not incorporated into its design. 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 the assessment of 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.

The assessment outlined below only deals with areas to the north of Sydney Harbour where the proposed tunnel portal, bridge and surface road works have the potential to impact flooding behaviour (ie the scope of permanent works to the south of Sydney Harbour is limited to subsurface works as the tunnel portal and initial tunnelling at Rozelle Rail Yards would be carried out within the scope of the adjacent M4-M5 Link project).

18.6.1 Potential flood risk to the project

Tunnel portals

A series of flood walls have been incorporated into the design of the project in the vicinity of the tunnel portals which would prevent the ingress of floodwater to the Western Harbour Tunnel for events up to the PMF. The existing stormwater drainage system has also been upgraded so as to divert local catchment runoff around the proposed trough structures.

Road and pedestrian bridges

The road and pedestrian bridges that are proposed over the Warringah Freeway at High Street, Mount Street, Ridge Street and Falcon Street, as well as the proposed bridge over the southbound lane at Miller Street, are all high level structures that would only be subject to relatively shallow sheet flow during storms which surcharge the pavement drainage system.

Provision has been incorporated in the design of the proposed bridge over the southbound lane at Miller Street for floodwater to discharge unobstructed across the Warringah Freeway for events up to the PMF (Figure 6.3 (Sheet 4) of Appendix R (Technical working paper: Flooding)).

Surface road works

The majority of the Warringah Freeway would be subject to relatively shallow inundation during storms up to 1% AEP in intensity. Major ponding would occur across the northbound and southbound lanes at the location of the southern Warringah Freeway sag during storms more frequent than 10% AEP (Figure 6.4 (Sheet 2) of Appendix R (Technical working paper: Flooding)). Constraints imposed by the capacity of the existing stormwater drainage system downstream of the road corridor would likely mean that ponding at the location of the southern Warringah Freeway sag could not be prevented from occurring during storms up to 1% AEP in intensity.

Further north, 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 (Figure 6.5 (Sheet 4) 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.

Motorway facilities

Finished ground levels would be raised above the level of the PMF at the location of the motorway facility that would be constructed on the northern side of the Warringah Freeway adjacent to Cammeray Park.

Motorway control centre

The motorway control centre that is proposed on Waltham Street in the Flat Rock Creek catchment is located on land which generally lies above the level of the PMF. Provision has been 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 shown in Figure 18-8 to Figure 18-11. Changes in flood depth as a result of the project in the 1% AEP event are shown in Figure 18-12 to Figure 18-15. 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 situated north of Sydney Harbour.

External to the road corridor

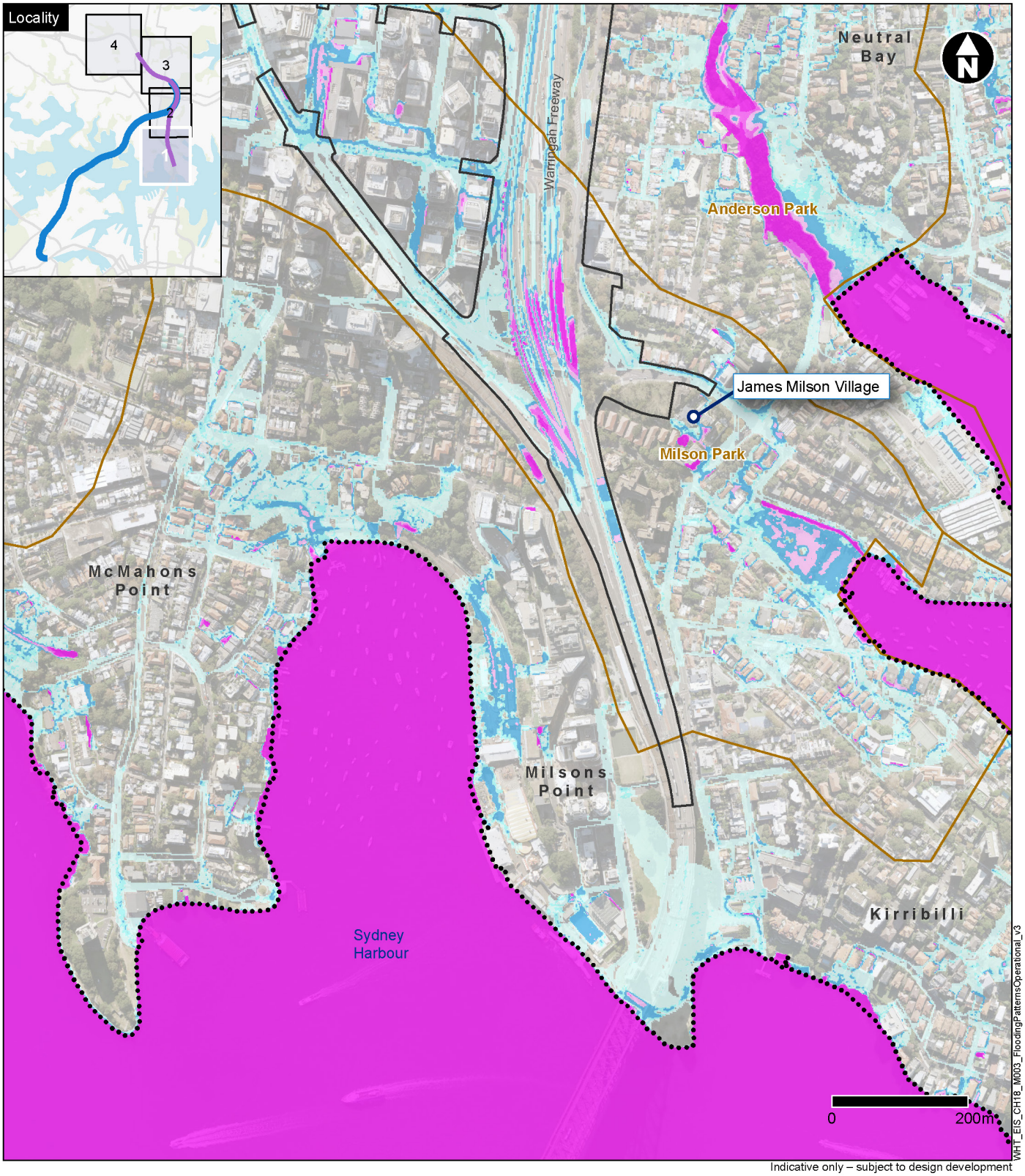
The project would generally result in a neutral or beneficial effect on flood behaviour external to the road corridor for storm events up to 1% AEP in intensity with the following exceptions:

- On the eastern side of the road corridor along the trunk drainage line which runs from the southern Warringah Freeway sag to Careening Cove in North Sydney and Kirribilli. Peak flood levels would be increased by up to 75 millimetres in the James Milson Village (Retirement and Residential Care) development, located on Clark Street in North Sydney, which would already be flooded during storms up to 1% AEP in intensity. Areas within the village which would be affected by the project include existing basement car parking and below-ground storage facilities. Increases of up to 16 millimetres would occur along the rear of several residential terraces that are located along Hipwood Street in Kirribilli
- On the eastern side of the Warringah Freeway corridor adjacent to an existing channel which is located at the eastern end of Nook Avenue in Neutral Bay. Peak flood levels would be increased by up to 55 millimetres in four at-grade garages that are connected to a three-storey residential unit block type development located on the northern side of Nook Avenue, which would already be flooded during storms up to 1% AEP in intensity. Similar increases in peak flood levels would also be experienced on the southern side of Nook Avenue within an already flooded allotment that has been subdivided for residential purposes
- Immediately downstream of the stormwater detention and reuse basin that is proposed on the northern side of the Warringah Freeway in the Willoughby Creek catchment. Flood modelling carried out as part of the present investigation showed that the basin would surcharge during a 1% AEP. However, the flood waters would be contained within the existing Cammeray Golf Course.

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 increase flow velocities in the following locations:

- East of the Warringah Freeway along the trunk drainage line that runs from the southern Warringah Freeway sag to Careening Bay in the Milson Park catchment. Flow velocities in existing development, including the James Milson Village (Retirement and Residential Care) development would be increased by up to 0.9 m/s, which could cause scour of unsealed areas that are located along the flow path
- Along a short reach of the existing channel which is located at the eastern end of Nook Avenue in the Anderson Park catchment. Flow velocities in the channel would be increased by up to about 0.2 m/s, which would not increase scour potential within the existing watercourse
- The flow path which would form downstream of the stormwater detention and reuse basin that is proposed on the northern side of the Warringah Freeway in the Willoughby Creek catchment would reach a maximum of about 1.5 m/s.



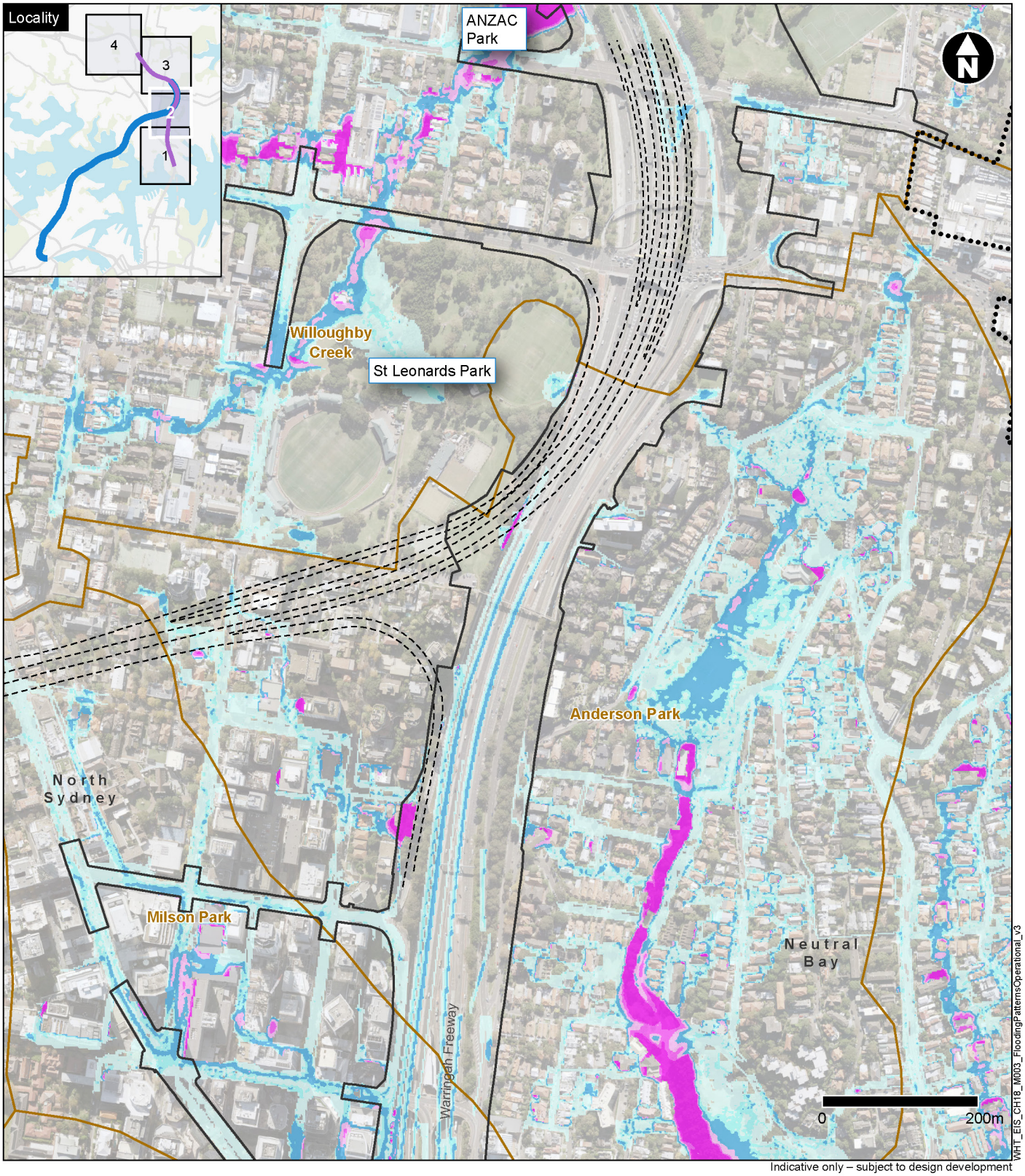
Legend

- Limit of main stream flooding and major overland flow mapping
- Tunnel section
- Construction footprint
- Catchment boundary

Indicative depth of inundation (m)

- <0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- >0.7

Figure 18-8 Flood behaviour under operational conditions – 1% AEP event (North Sydney, south) (map 1)



Legend

- Limit of main stream flooding and major overland flow mapping
- Tunnel section
- Construction footprint
- Catchment boundary

Indicative depth of inundation (m)

- <0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- >0.7

Figure 18-9 Flood behaviour under operational conditions – 1% AEP event (North Sydney, north) (map 2)

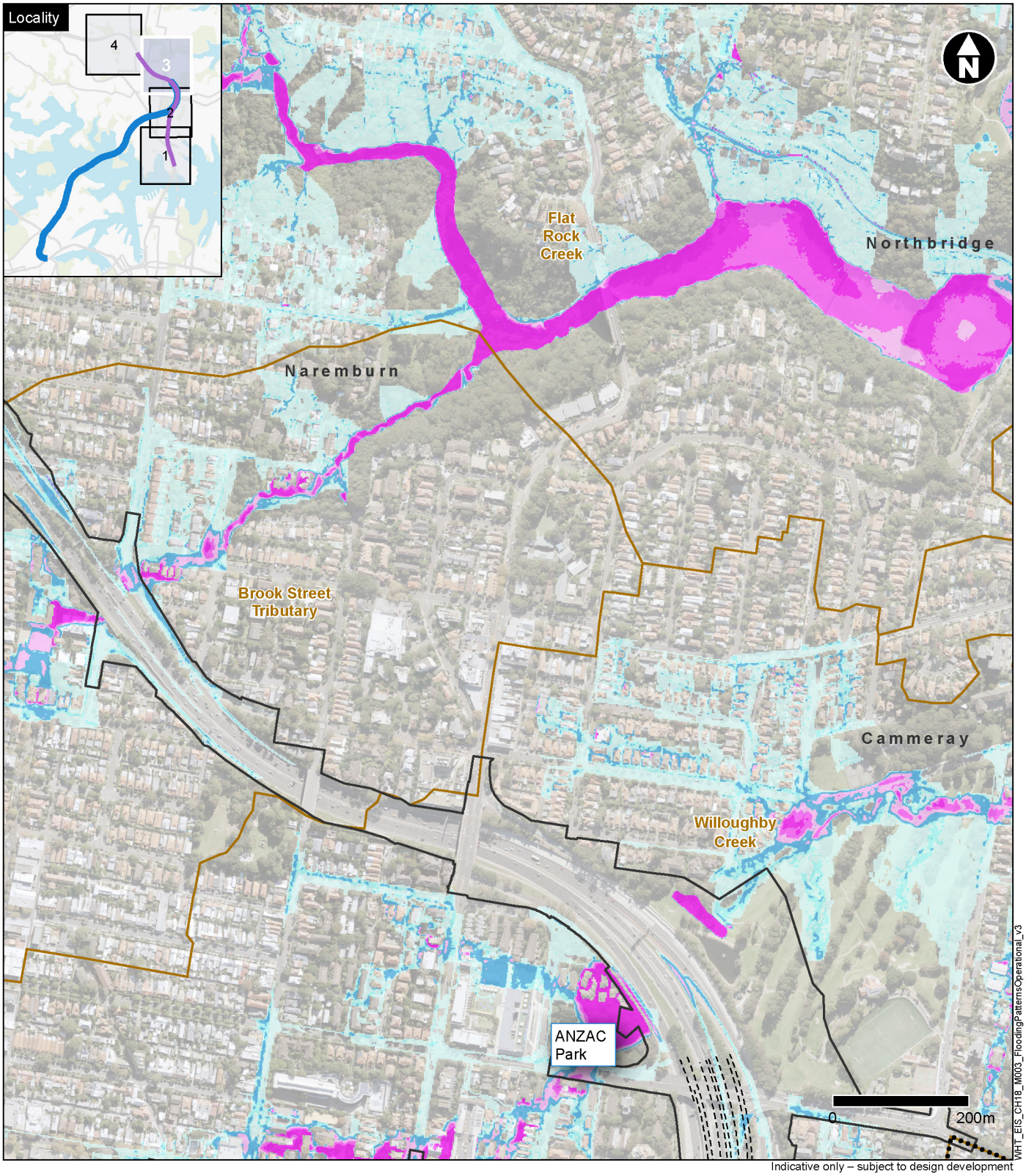
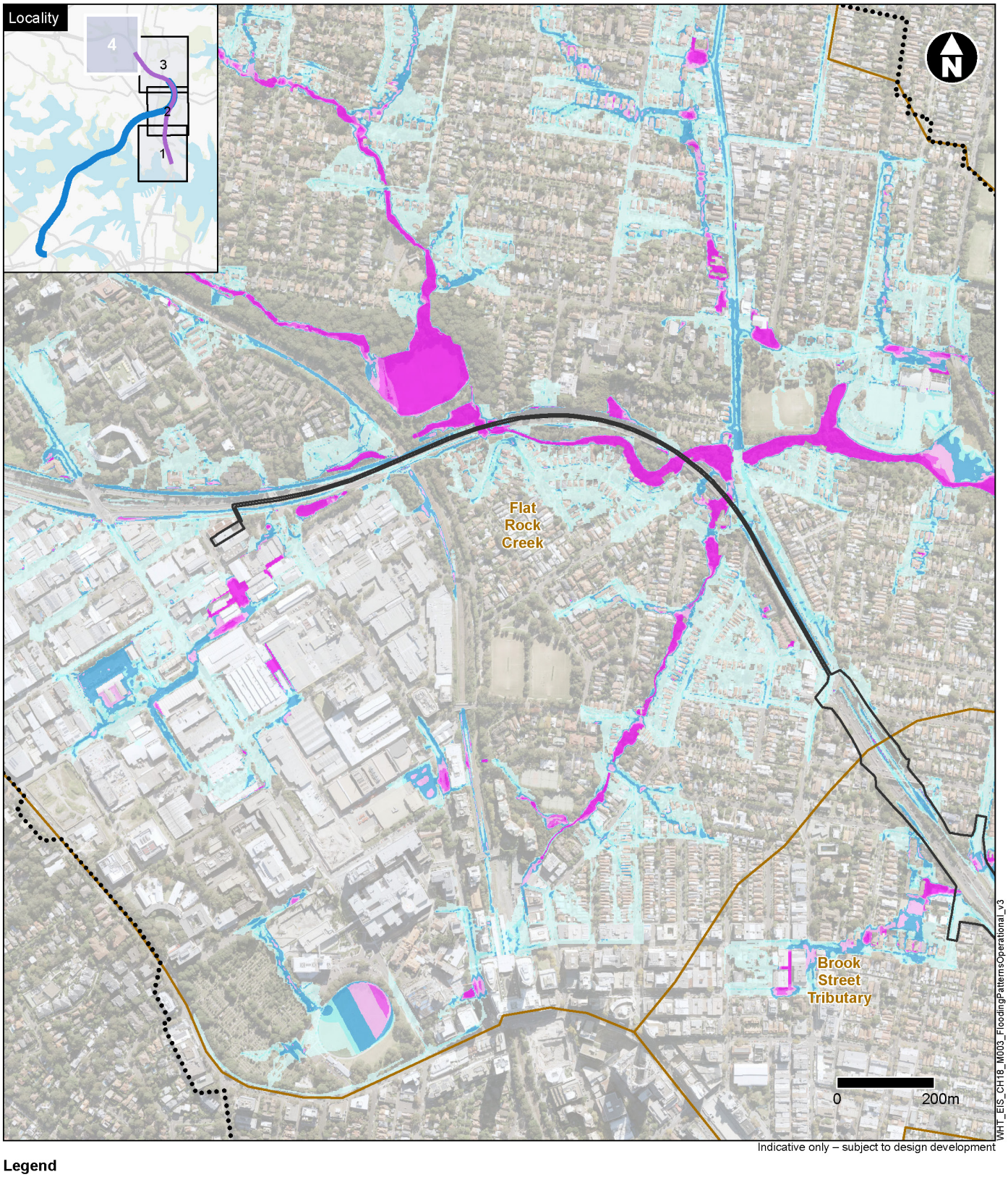


Figure 18-10 Flood behaviour under operational conditions – 1% AEP event (Cammeray) (map 3)



Legend

- Limit of main stream flooding and major overland flow mapping
- Tunnel section
- Construction footprint
- Catchment boundary

Indicative depth of inundation (m)

- <0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- >0.7

Figure 18-11 Flood behaviour under operational conditions – 1% AEP event (St Leonards/Artarmon) (map 4)

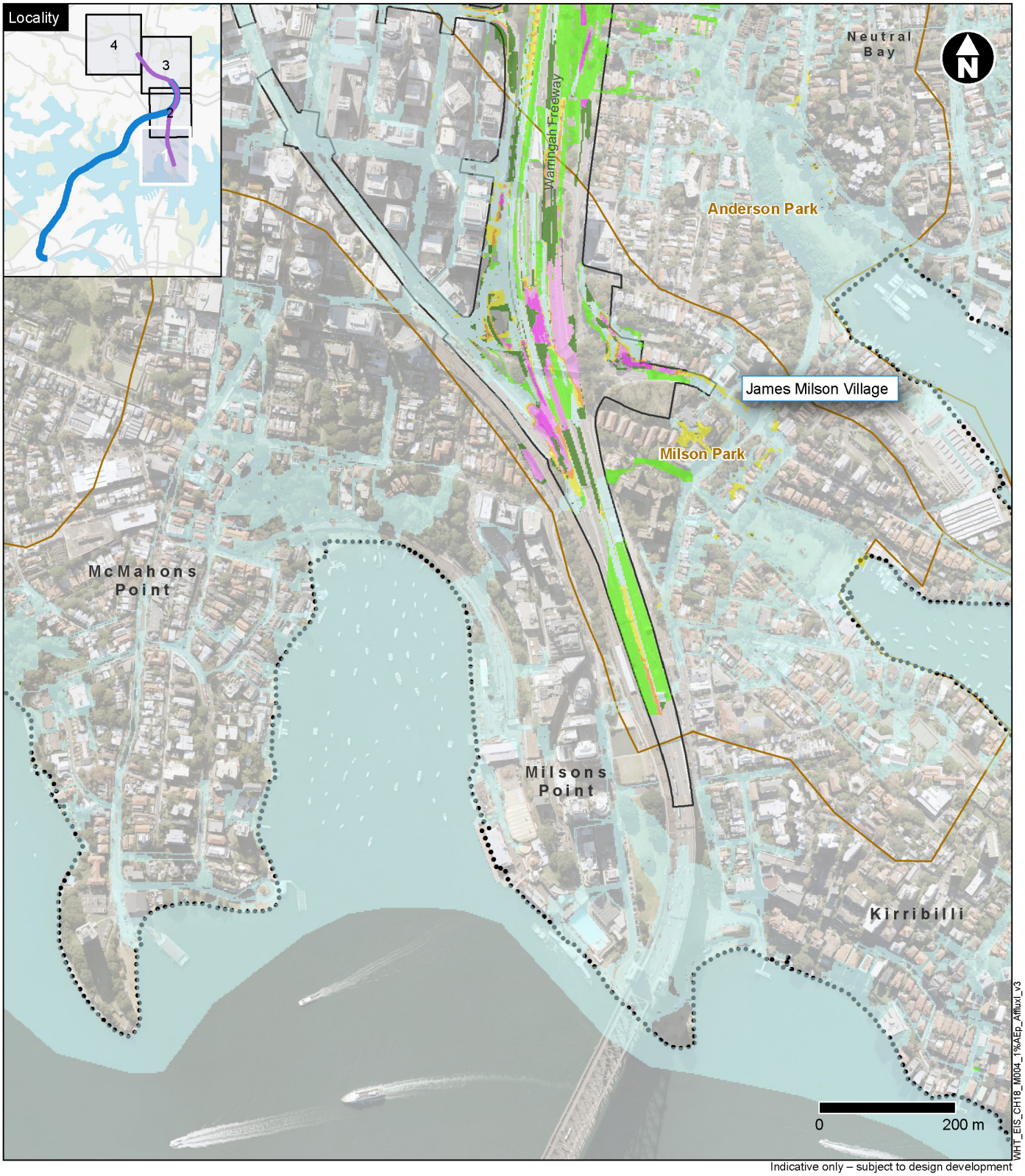
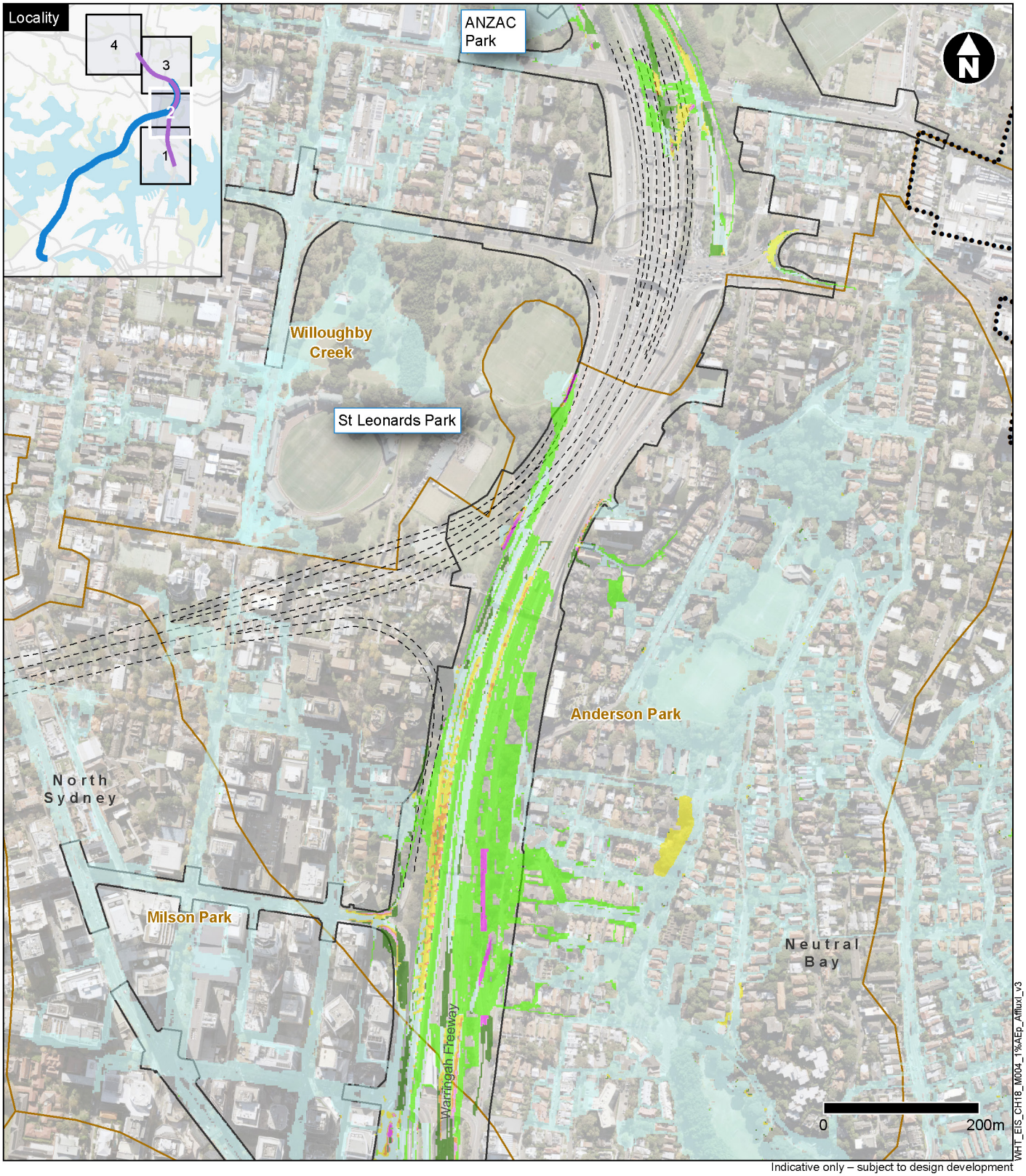


Figure 18-12 Change in flood depth under operational conditions – 1% AEP event (North Sydney, south) (map 1)



Legend

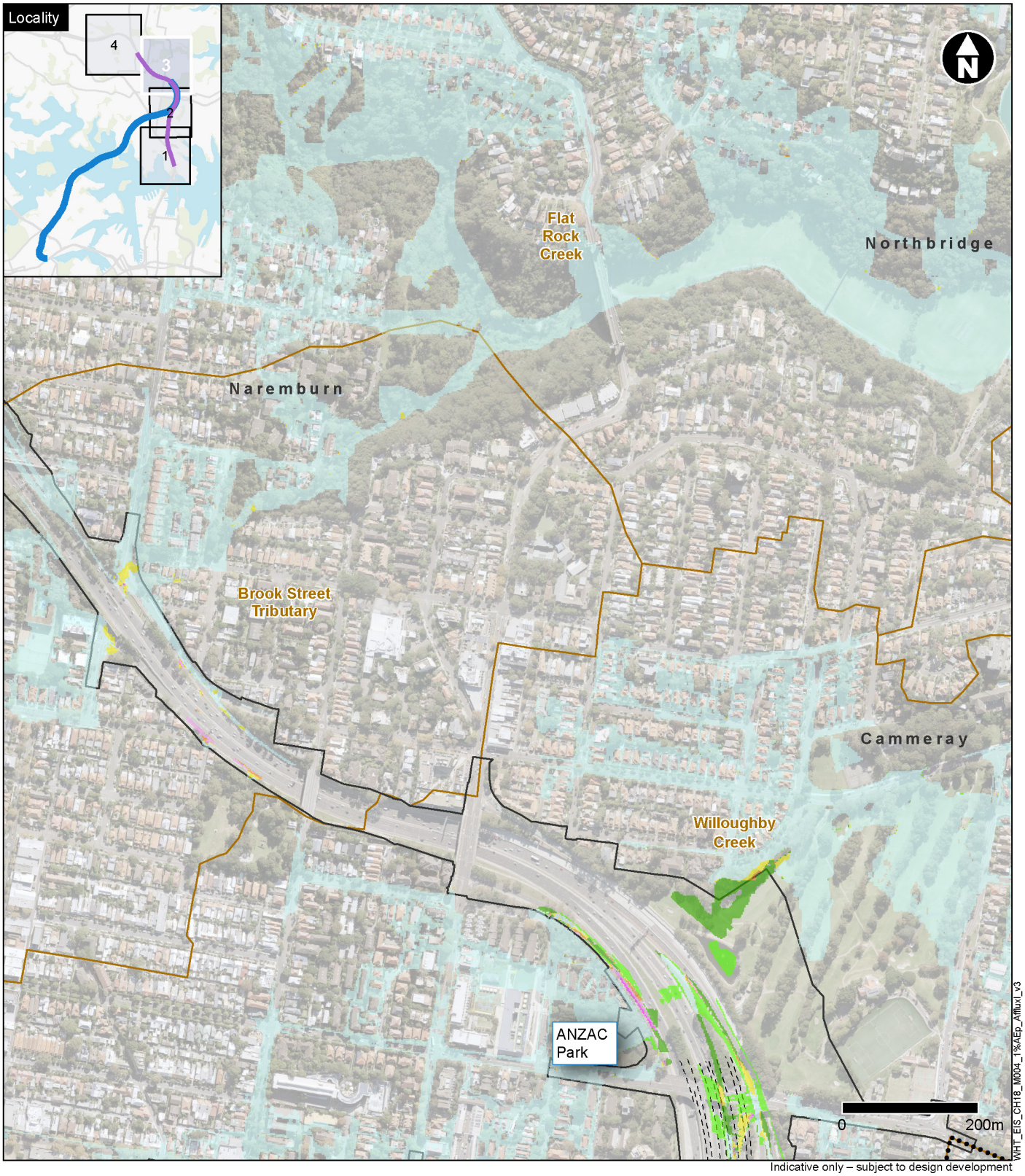
- Limit of main stream flooding and major overland flow mapping
- Tunnel section
- Construction footprint
- Catchment boundary

Change in flood depth (m)

- <0
- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.5
- > 0.50

- Land rendered flood free as a result of change
- Additional area of land flooded as a result of change

Figure 18-13 Change in flood depth under operational conditions – 1% AEP event (North Sydney, north) (map 2)



Legend

- Limit of main stream flooding and major overland flow mapping
- Tunnel section
- Construction footprint
- Catchment boundary

Change in flood depth (m)

- <0
- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.5
- > 0.50

- Land rendered flood free as a result of change
- Additional area of land flooded as a result of change

Figure 18-14 Change in flood depth under operational conditions – 1% AEP event (Cammeray) (map 3)

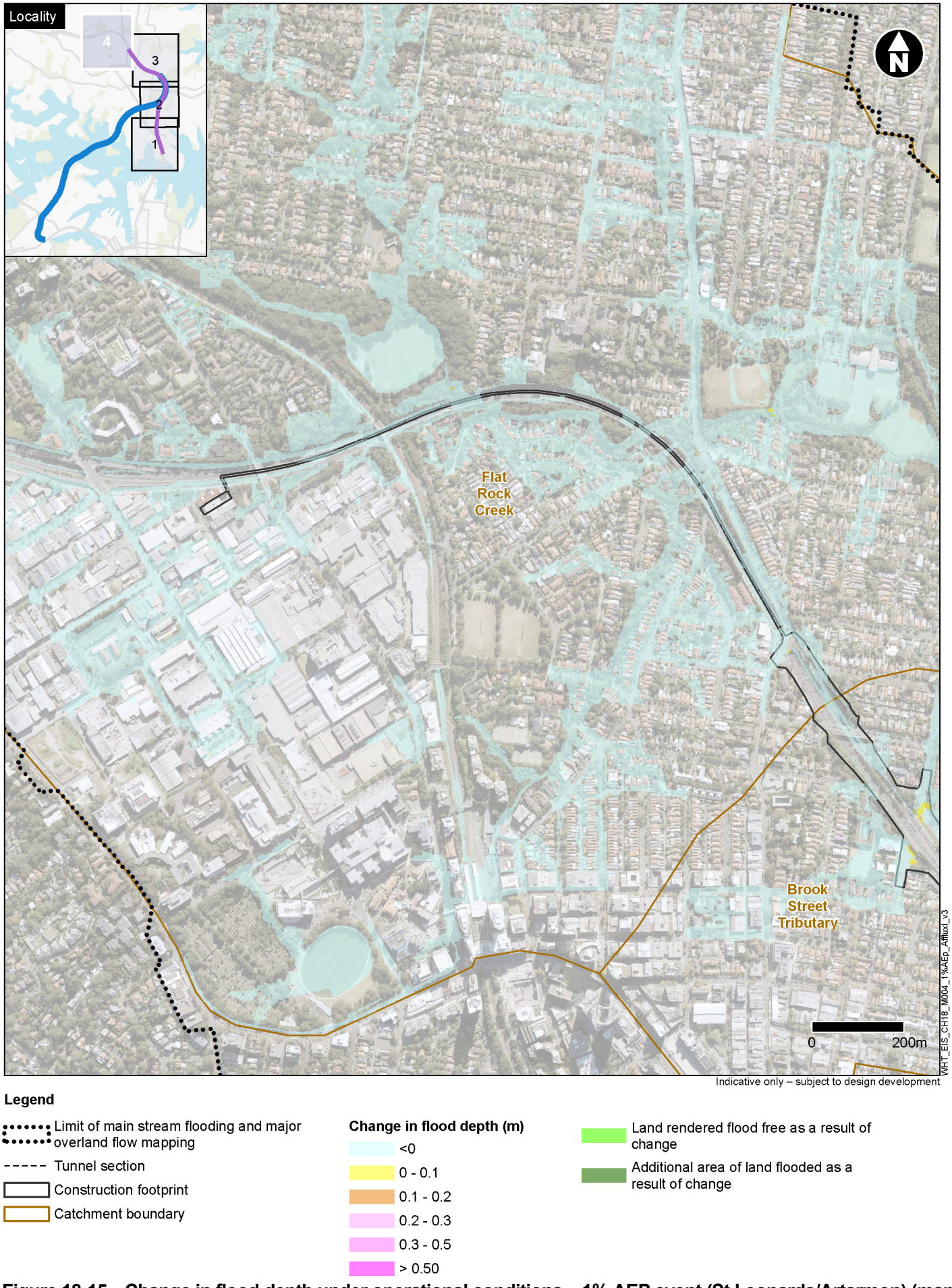


Figure 18-15 Change in flood depth under operational conditions – 1% AEP event (St Leonards/Artarmon) (map 4)

Internal to the road corridor

Internal to the road corridor the project would increase flooding in several of the northbound and southbound lanes of the Warringah Freeway south of the Ridge Street pedestrian bridge principally due to the channelising effect of the proposed Type-F safety barriers along the alignment. While depths of ponding at the location of the southern Warringah Freeway sag would generally be increased by the project, the project would not increase the rate at which overland flow discharges to the Sydney Harbour Tunnel portals for storm events up to 1% AEP in intensity. While floodwater currently enters the Sydney Harbour Tunnel via its portals during a PMF event, the increased depth of ponding at the location of the southern Warringah Freeway would result in an increase in the rate and volume of floodwater discharging to the tunnel system during an extreme flood event.

Flow velocities would be increased by up to one and two m/s along the Pacific Highway and Warringah Freeway, respectively, as a result of changes in road levels and the provision of Type-F safety barriers along the alignment which have the effect of channelising the flow.

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

While clause 6.3 of Willoughby Local Environmental Plan 2012 titled 'Flood planning' outlines Willoughby Council's objectives in regards to development of land that lies at or below the flood planning level, the North Sydney Local Environmental Plan 2013 does not contain a similar clause.

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, subject to the provision of appropriate mitigation measures, 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 Willoughby Local Environmental Plan 2012 would apply.

While no floodplain risk management studies or plans have been prepared for the catchments through which the project runs, the findings of the assessment presented in Section 18.6.2 show that the project would have only a small change on peak flood levels and flow velocities external to the Warringah Freeway corridor.

NSW State Emergency Service maintains local units that are located on Balls Head Drive, Waverton and Station Street, Naremburn, both of which are located remote from the project and its flood related impacts.

Provided the flood mitigation measures as set out in Section 18.8 are incorporated into the design of the project, then it would not increase the flood hazard in existing development for all events up to the PMF. It would also not have an adverse impact on NSW State Emergency Service's emergency response arrangements.

18.6.4 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 associated with future climate change are principally limited to the southern Warringah Freeway sag. For example, depths of ponding at the southern Warringah Freeway sag would be increased by 280 millimetres and 260 millimetres for the scenarios where the intensity of a 1% AEP storm event are increased by 10 per cent and 30 per cent, respectively.

During a 1% AEP flood event, flood levels would be increased by up to 0.9 metres along the western side of the entry ramp to the Western Harbour Tunnel and the Berry Street on ramp to the Warringah Freeway, however, peak flood levels would not overtop the proposed flood wall at this location. Similarly, while peak 1% AEP flood levels would be increased by up to 0.9 metres in ANZAC Park, they would not be high enough to overtop the proposed flood walls which would border the proposed tunnel portals.

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

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 two assessed climate change scenarios.

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

The mechanism and geometric 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 this 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 C1) of Appendix R (Technical working paper: Flooding) shows the impact a partial blockage of the local stormwater drainage system would have on peak 1% AEP flood levels in the vicinity of the proposed tunnel portals, bridges and surface road works. The assessment showed that a partial blockage of the local stormwater drainage system has the potential to increase flooding conditions at the location of the southern Warringah Freeway sag. For example, depths of ponding at the southern Warringah Freeway sag would be increased by up to 40 millimetres in a 1% AEP storm event.

While peak 1% AEP flood levels would be increased by about 1.2 metres along the western side of the on ramp from Berry Street to the Western Harbour Tunnel and Warringah Freeway, they would not be high enough to overtop the flood wall that is proposed at this location. Similarly, while peak 1% AEP flood levels would be increased by about 1.4 metres in ANZAC Park, they would not be high enough to overtop the proposed flood walls which would border the proposed tunnel portals.

18.6.6 Application of ARR 2019 to Design Flood Estimation

The ARR (Australian Rainfall and Runoff) 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 and both it and the hydraulic model 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 each.

Based on the above finding, 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 projects in its vicinity. 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

M4-M5 Link project

Flood behaviour under post WestConnex M4-M5 Link conditions has been used as the basis for assessing the flood risk during the construction of the project. Operationally, any impacts south of Sydney Harbour have not been considered in this assessment.

Beaches Link and Gore Hill Freeway Connection

The proposed Beaches Link and Gore Hill Freeway Connection project would involve the construction of the following:

- Tunnel, trough and cut-and-cover structures within the Warringah Freeway at Cammeray
- Motorway facilities on the northern side of the freeway adjacent to Cammeray Park
- Tunnel, trough, cut-and-cover and bridge structures, as well as surface road works within the road reserve of the Gore Hill Freeway at Artarmon.

The construction of the tunnel, trough and cut-and-cover structures within the Warringah Freeway at Cammeray would not impact flood behaviour for storm events up to 1% AEP in intensity (ie because the construction area is not impacted by flooding during storms up to this intensity).

Construction of the Beaches Link and Gore Hill Freeway Connection project would not impact flood behaviour in the immediate vicinity of the Western Harbour Tunnel motorway control centre that is located on Waltham Street.

Other projects

There are no other proposed 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 further 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

Ref	Phase	Impact	Environmental management measure	Location
F1	Design	Impact of the project on flood behaviour	Impact of the project on flood behaviour during construction and 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. A floor level survey will be carried out in affected areas to determine whether the project would increase flood damage in adjacent development (i.e. in properties where there is a potential for increases in peak flood levels for storms of up to 1% AEP in intensity). The design of the project will incorporate measures that are aimed at mitigating the impact of the project on flood behaviour in properties where existing buildings would experience above-floor inundation under present day conditions during storms of up to 1% AEP in intensity.	WHT/WFU
F2	Design	Flooding on the Warringah Freeway	Where feasible and reasonable, the hydraulic capacity of the existing transverse drainage of the Warringah Freeway will be designed to comply with relevant guidelines and standards.	WFU
F3	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	WHT
F4	Construction		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	WHT

Ref	Phase	Impact	Environmental management measure	Location
			the project works.	
F5	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 1% 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 that would impact flooding conditions in adjacent development.	WHT/WFU
F6	Construction	Flood impacts to construction sites	Site facilities will be located outside high flood hazard areas based on a 1% AEP flood.	WHT/WFU
F7	Construction and operation	Impact of flooding on the project	Flood emergency management measures for construction and operation of the project will be incorporated into relevant environmental and/or safety management documentation.	WHT/WFU

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